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IAHR—PIANC
SYMPOSIUM
RIVER & ICE

PROCEEDINGS

in eleven volumes

of

3 of 4

BUDAPEST 1974 HUNGARY

1 IAHR-PIANC SYMPOSIUM RIVER & ICE

PROCEEDI~NGS

in eleven volumes

Volume of General Information and Postprints

IAHR/PIANC

IAHR/PIANC

International Association for Hydraulic Research

SECTIONS FOR FLUVIAL HYDRAULICS AND FOR ICE PROBLEMS

Permanent International Association of Navigation Congresses

SECTION OF INLAND NAVIGATION

INTERNATIONAL SYMPOSIUM ON RIVER AND ICE

Budapest 1974 Hungary

PROCEEDINGS

in eleven volumes

Prepared for the press by

Dr. Ottó Haszpra D.Sc.

in co-operation with

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Felelős kiadó: Dr. Stelczer Károly

VÍZDOK

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INTERNATIONAL SYMPOSIUM
ON
RIVER AND ICE

Budapest, January 15 to 17, 1974, Hungary

Organized jointly by the

SECTIONS FOR FLUVIAL HYDRAULICS AND FOR ICE PROBLEMS,

International Association for Hydraulic Research
and the

SECTION FOR INLAND NAVIGATION,

Permanent International Association of Navigation Congresses

. under the auspices of the

HUNGARIAN ACADEMY OF SCIENCES

and the

NATIONAL WATER AUTHORITY OF HUNGARY

IAHR/PIANC IAHR/PIANC
International Association for Hydraulic Research
SECTIONS FOR FLUVIAL HYDRAULICS AND FOR ICE PROBLEMS

Permanent International Association of Navigation Congresses
SECTION OF INLAND NAVIGATION
INTERNATIONAL SYMPOSIUM ON RIVER AND ICE

Budapest 1974 Hungary

Volume of General Information and Postprints

This volume and the ten Preprints volumes contain all important information on and all lectures, papers and discussions presented at the Symposium River and Ice according to the List of Contents on pp. XI—XV.

PREFACE

On the invitation of the Presidents of the Hungarian Academy of Sciences and of the National Water Authority of Hungary, respectively, a Symposium on the theme of "Hydraulic Research on Rivers and on Ice with Special Regard to Navigation" was held in Budapest from the 15th to 17th January, 1974. The Symposium was organized jointly by the Sections of Fluvial Hydraulics and of Ice Problems, International Association for Hydraulic Research (IAHR) and by the Section of Inland Navigation, Permanent International Association of Navigation Congresses (PIANC).

It is the first time that these two internationally respected associations jointly arranged a meeting on an important sphere of scientific problems. We, the hosts, felt very much honoured that this meeting was held in our country and that it was participated by a great number of distinguished professionals, in spite of the narrow theme chosen.

As the hosts had hoped, this symposium proved to be a remarkable success from two points of view. As for science and profession, the 41 contributions and the discussion presented results of high scientific and practical value. And as for co-operation between professionals of different branches of science on international level, this Symposium demonstrated that such joint ventures could offer an excellent opportunity for achieving compromise between often inconsistent human needs, as it was pointed out by Prof. Harold Jan Schoemaker in his lecture and by Prof. Imre Dégen, Prof. Taizo Hayashi, and Prof. Henri Vandervelden in their toasts at the final banquet of the Symposium.

In the name of the local committees, the Sponsoring, the Scientific, and perhaps first of all the Organizing Committee, I must express my sincere thanks for that really intensive and helpful guidance, assistance and co-operation by which the Secretariats of both Associations made it possible for us to achieve such a success as this Symposium has turned out to be.

Budapest, 30th September, 1974

József Vincze

Vice-President
National Water Authority of Hungary

Chairman, Local Sponsoring Committee
IAHR/PIANC Symposium on River and Ice

GENERAL INFORMATIONS

L I S T O F C O N T E N T S

of the eleven Proceedings volumes

of the Symposium on River and Ice

I. Titles of the volumes

1. General Information and Postprints (this volume)
2. I.Dégen: Water Management Aspects of Flood- and Ice Control in Hungary. Formal Address
3. Ö.Starosolszky: General Lecture on Subject A. Relationships of Fluvial and Ice Hydraulics
4. Contributions to Subject A
5. M.Kozák: General Lecture on Subject B. Interrelations between River Training, River Canalization, Low-Head Water Power Development and Navigation with Special Regard to Ice Control
6. Contributions to Subject B
7. I.Mátrai: General Lecture on Subject C. Effects of Runoff Regulation
8. Contributions to Subject C
9. H.Simmler: Some Aspects of the Ice Formation in River Reservoirs (C8)
10. J.Szenti: On the Activity of the Lower Danube Valley District Water Authority in the Baja Study Tour Region.

    River Regulation, Channel Marking Service and Ice Control along the Lower Danube River Section (Between River Stations 1560 and 1433 km)
11. L.Honfi: Hungarian Icebreaker Fleet

II. Detailed contents of volumes 1, 4, 6 and 8

Page

8. Contributions to Subject C,

Effects of Runoff Regulations

THE SYMPOSIUM ON RIVER AND ICE

held on 14 through 18 January, 1974
in Budapest, Hungary

The Sections for Fluvial Hydraulics and for Ice Problems of the International Association for Hydraulic Research (IAHR), in co-operation with the Section for Inland Navigation of the Permanent International Association of Navigation Congresses (PIANC) held an International Symposium in Budapest on "Hydraulic Research on Rivers and Ice with Special Regard to Navigation" under the auspices of the Hungarian Academy of Sciences (MTA) and the National Water Authority of Hungary (OVH).

Prof. Imre Dégen, Secretary of State and President of OVH, was the Honorary Chairman of the Symposium and the Chairman of the International Honorary Committee. The preparation of the Symposium was directed by a Local Sponsoring Committee (Chairman: Mr. József Vincze, Vice-President, OVH; Secretary: Prof. Dr. Ede Kertai CSc., Head, Department of Water Management, OVH) and by a Local Scientific Committee (Chairman: Prof. Dr. John L. Bogárdi, Member of MTA, Budapest University of Technology; Secretary: Prof. Dr. Ödön Starosolszky CSc., Deputy Head, Department of Water Management, OVH), furthermore by a Local Organizing Committee (Chairman: Dr. Károly Stelczer CSc., Director of the Research Institute for Water Resources Development, VITUKI; Secretary: Dr. Zoltán G. Hankó, Head, Department of Hydromechanics, VITUKI). The Symposium material was prepared for publication in form of preprints and postprints by Dr. Ottó Haszpra D.Sc., Scientific Consultant, VITUKI.

The Subjects of the Symposium covered the hydraulic aspects of the following fields:

- river regulation and flood control, river canalization and water power development, etc.;
- ice phenomena of natural, trained and canalized rivers;
- inland navigation.

At the sessions of the Symposium the papers submitted on the following subjects were discussed:

A) Relationships of fluvial and ice hydraulics

The effects of the flow conditions on the ice formation, drift, cover development, jamming and break-up with special regard to multipurpose river training and navigation.

B) Interrelations between river training, river canalization, low head water power development and navigation with special regard to ice control

River training works for improving ice flow conditions, interrelations between river morphology and ice regime. Strategy of ice breaking for ice flood prevention on rivers, melting from upstream, considering meteorological forecasting. Problems connected with ice phenomena on canalized rivers of small slope including effects of runoff or peak river power plants. Effect of natural and artificial effluents, including cooling water, on the ice regime of rivers. Ice regime of trained or canalized rivers with respect to navigation.

C) Effects of runoff regulation

Effects of runoff regulation, on water, ice and bed regimes, in upstream and downstream reaches of rivers, caused by natural or man made reservoirs with special regard to navigation.

41 papers were submitted as a total. 38 papers were grouped and published as preprints according to the subjects as follows: Subject A) - 13; Subject B) - 17; Subject C) - 8. 3 other papers arrived too late and were published in the Postprint volume.

From 18 countries 160 experts participated in the Symposium.

The events and results of the Symposium - without the intention of completeness - may be summarized as follows.

On 14 January, 1974 the participants of the Symposium were welcomed and registered, furthermore scientific and informative material was distributed.

In the morning of 15 January at the opening session Prof.Dr. John L.Bogárdi, Academician and President of the Commission for Scientific Water Management of MTA, addressed the participants on behalf of the hosts, namely of the Hungarian Academy of Sciences (MTA) and of the National Water Authority of Hungary (OVH); and delivered a formal opening speech. On behalf of the organizing international associations Prof.Dr.Taizo Hayashi (Japan), President of IAHR, and Prof.Henry Vandervelden (Belgium), Secretary General of PIANC, welcomed the Symposium. Furthermore Dr.György Pekete, Director of the International Danube Commission's Secretariat addressed the participants of the Symposium and Prof. Kiril Zvorykin (USSR) conveyed the best wishes of Dr.Mikhail Skladnev, President of the Soviet National Committee for IAHR.

The opening session was followed by a festive session at which Prof.Imre Dégen, Secretary of State, welcomed the participants of the Symposium by a formal address conveyed on behalf of the Hungarian Government, furthermore performed a festive lecture on "Water Management Aspects of Flood and Ice Control in Hungary". Following the lecture a film was presented, informing about some events of the major floods and the development of the methods and means of fighting against floods in this country between the 20's of this century and the present days.

In the afternoon of 15 January Prof.István Mátrai held a general lecture on subject C). After the lecture the submitted papers were introduced by the authors calling the attention to the main points and final conclusions. The session was closed by a general discussion.

In the evening Prof.Dr.György Csanádi, Academician and President of the Branch of Civil Engineering Sciences of MTA, Minister of Transport and Post of the Hungarian People's Republic, gave a reception, marking the opening of the Symposium, on behalf of the Hungarian Academy of Sciences (MTA)*.

On 16 January the sessions on subject B) were introduced by a general lecture of Prof.Dr.Miklós Kozák. Because of the illness of Prof.Kozák the lecture was conveyed by Dr.Miklós Szalay. The lecture was followed by the introduction of the papers and the afternoon session was closed by a general discussion on subject B). In the evening the Symposium members participated in the theatre performance of "Wedding Feast of Ecser" by the Hungarian State Folk-Ensemble.

On 17 January the general lecture on subject A) was performed by Prof.Dr.Ödön Starosolszky. The introduction of the papers was followed and the afternoon session was closed by a general discussion.

At the closing session of the Symposium Prof.Ir.Harold J. Schoemaker performed a lecture on "Past Experiences and Future Trends in Development of Co-operation between International Associations Dealing with Water". The scientific and professional results of the Symposium were summarized by Prof.Dr.John L. Bogárdi. The Symposium was formally closed by Prof.Henry Vandervelden.

In the evening Prof.Imre Dégen, Secretary of State, gave a dinner in honour of the Symposium participants, on behalf of the National Water Authority of Hungary (OVH). His toast emphasized the advantage, necessity and importance of the international co-operation in both governmental organizations and non-governmental associations or institutions, furthermore it commemorated with compliments the initiative of the IAHR concerning the co-operation between the international associations dealing with water. In their replies Prof.Dr.Taizo Hayashi, President of IAHR and Prof.Henry Vandervelden, Secretary General of PIANC, besides appreciating the success and results of the Symposium and emphasizing the usefulness of the international co-operation, expressed their hope that the experiences of the Budapest Symposium would stimulate also other organizers to call for similar joint ventures.

In the mornings of 16 and 17 January the Symposium participants had the opportunity to visit the Hydraulic Laboratory of the Institute for Water Management and Hydraulic Engineering at the Budapest University of Technology (BME-VVI) and that of the Research Institute for Water Resources Development (VITUKI), respectively.

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* Surely all the participants will be shocked by the sorrowful news that just in the time of preparing this volume Professor Csanádi died unexpectedly, causing a great loss to the scientific life of Hungary.

On 18 January, in a one-day study tour, the Symposium participants got acquainted with the Hungarian Icebreaker Flotilla which held a demonstration with 11 units on the Danube in the Baja region. The demonstration was directed by Mr. János Szenti, Director of the Lower Danube Valley District Water Authority. The usefulness of the Flotilla was proved by the demonstration in spite of the Danube having no ice cover. After the demonstration Mr. Ferenc Kincses, President of the City Council of Baja, received the guests, then on the activity of the Lower Danube Valley District Water Authority Mr. János Szenti and on the Hungarian Icebreaker Flotilla Mr. Lászlo Honfi, Director of the River Regulation and Gravel Dredging Co., respectively, delivered lectures.

The accompanying persons of the Symposium members participated in social and recreational programmes.

The results of the Symposium may be summarized around two ideas:

- With respect to forming the way of thinking, it must be regarded very important that experts, investigating the same phenomena from the view-points of different social-economic goals, could exchange their ideas concerning fluvial and ice hydraulics, and navigation. The joint venture summoning experts of various disciplines offered an excellent opportunity for achieving compromise between inconsistent human needs.

- It follows from the foregoing that the scientific and professional outcome of this joint venture contributed, in a wider light, to the solution of some problems in the control of the aquatic environment of mankind.

Budapest, February, 1974.

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* The Local Organizing Committee announces with the deepest regret that Mr.Till, who fulfilled so conscientiously the highly responsible tasks of financial managing the Symposium, unexpectedly died in the time of editing this volume.

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SUBJECTS OF THE SYMPOSIUM

Subject A) RELATIONSHIPS OF FLUVIAL AND ICE HYDRAULICS

The effects of the flow conditions on the ice formation, drift, cover development, jamming and break-up with special regard to multipurpose river training and navigation.

Subject B) INTERRELATIONS BETWEEN RIVER TRAINING, RIVER CANALIZATION, LOW HEAD WATER POWER DEVELOPMENT AND NAVIGATION WITH SPECIAL REGARD TO ICE CONTROL

River training works for improving ice flow conditions, interrelation between river morphology and ice regime. Strategy of ice breaking for ice flood prevention on rivers, melting from upstream, considering meteorological forecasting. Problems connected with ice phenomena on canalized rivers of small slope including effects of runoff or peak river power plants. Effect of natural and artificial effluents, including cooling water,on the ice regime of rivers. Ice regime of trained or canalized rivers with respect to navigation.

Subject C) EFFECTS OF RUNOFF REGULATION

Effects of runoff regulation, on water, ice and bed regimes, in upstream and downstream reaches of rivers, caused by natural or man made reservoirs with special regard to navigation.

PROGRAMME OF THE SYMPOSIUM

Participants' Programme

Monday, January 14, 1974

10,00 - 20,00 - Welcome of Symposium Members
- Registration of participants

Tuesday, January 15

8,00 - 18,00 - Registration of participants
9,30 - 10,15 - Opening session
10,15 - 10,45 - Break
10,45 - 12,00 - Festive session
"Water Management Aspects of Flood- and Ice Control in Hungary"
Invited speaker Prof.I.Dégen,
Honorary Chairman of the Symposium.

Cinema performance on the same subject
12,00 - 14,00 - Break
14,00 - 14,45 - General lecture on Subject C.
Invited speaker Prof.I.Mátrai,
Member, Local Scientific Committee
14,45 - 15,15 - Introduction of papers on Subject C by the authors.Discussion
15,15 - 15,45 - Break
15,45 - 16,30 - Introduction of papers on Subject C by the authors (continued). Discussion
16,30 - 18,00 - Discussion (Subject C)
20,00 - 22,00 - General reception offered by the Hungarian Academy of Sciences

Wednesday, January 16

9,00 - 9,45 - General lecture on Subject B.
Invited speaker Prof.Dr.M.Kozák*,
Member, Local Scientific Committee
9,45 - 10,15 - Introduction of papers on Subject B by the authors.Discussion
10,15 - 10,45 - Break
10,45 - 12,00 - Introduction of papers on Subject B by the authors (continued).Discussion
12,00 - 14,00 - Break
14,00 - 15,15 - Introduction of papers on Subject B by the authors (continued).Discussion
15,15 - 15,45 - Break
15,45 - 18,00 - Discussion (Subject B).

* Substituted by Dr.M.Szalay

9,00 - 12,00 -	Alternative programme Technical visits to Hydraulic Laboratories at the - Institute for Water Management and Hydraulic Engineering, Budapest University of Technology (BME) and - Research Institute for Water Resources Development (VITUKI)
20,00 - 22,00 -	Theatre performance "Wedding Feast of Ecser" by the Hungarian State Folk-ensemble

Thursday, January 17

9,00 - 9,45 -	General lecture on Subject A Invited speaker Dr.Ö.Starosolszky, Secretary, Local Scientific Committee
9,45 - 10,15 -	Introduction of papers on Subject A by the authors. Discussion
10,15 - 10,45 -	Break
10,45 - 12,00 -	Introduction of papers on Subject A by the authors (continued). Discussion
12,00 - 14,00 -	Break
14,00 - 14,30 -	Introduction of papers on Subject A by the authors (continued). Discussion
14,30 - 16,00 -	Discussion (Subject A).
16,00 - 16,30 -	Break
16,30 - 17,30 -	Closing session "Conclusions Gained on the General Lectures, Papers and Discussions; Current and Future Trends of Hydraulic Research on Rivers and Ice with Special Regard to Navigation". Invited speaker Prof.Dr.J.L.Bogárdi, Chairman, Local Scientific Committee "Past Experiences with Future Horizons for Co--operation between International Associations Dealing with Water." Invited speaker Prof.H.J. Schoemaker, Member, International Honorary Committee
9,00 - 12,00 -	Alternative programme Technical visits to Hydraulic Laboratories at the - Institute for Water Management and Hydraulic Engineering, Budapest University of Technology (BME) and - Research Institute for Water Resources Development (VITUKI)
19,30 - 22,30 -	Banquet offered by the National Water Authority of Hungary

Friday, January 18

7,00 - Departure from Budapest for Baja
- Introduction of the Hungarian Icebreaker Flotilla on the Danube in the Baja region
- Lunch
- Introduction of the activity of the Lower Danube Valley District Water Authority in the fields of flood control, river training, ice problems and navigation at the Baja City Hall.

Host Mr F.Kincses, President, Baja Municipal Council.

Invited speakers Mr J.Szenti and Mr L.Honfi, Members, Local Sponsoring Committee

21,00 - Arrival in Budapest

Ladies' Programme

Tuesday, January 15, 1974

9,30 - 11,30 - Visit to the Castle Hill in Budapest
11,30 - 14,30 - Break
14,30 - 17,30 - Visit to the Buda Royal Castle Museum
20,00 - 22,00 - General Reception offered by the Hungarian Academy of Sciences

Wednesday, January 16

9,30 - 11,30 - Excursion to the Buda Hills, refreshment at the Hotel Vörös Csillag
11,30 - 14,30 - Break
14,30 - 17,30 - Cooking show at Hotel Budapest
20,00 - 22,00 - Theatre performance "Wedding Feast of Ecser" by the Hungarian State Folkensemble

Thursday, January 17

9,30 - 11,30 - Visit to the National Gallery, Budapest
11,30 - 14,30 - Break
14,30 - 17,30 - Walk in the downtown area of Budapest
19,30 - 22,30 - Banquet offered by the National Water Authority of Hungary

Friday, January 18

- Common programme with the participants'

POSTPRINTS

On the following pages the material of the session discussions is reproduced on the basis of tape recordings and submitted written notes. In some cases when the tape recording was interrupted and also the discusser did not submit any written material, this interruption is marked by (......). The reader and the discussers concerned are asked to pardon kindly the organizers for this deficiency. These postprints contain some papers, too, which attained the local Organizing Committee too late to be included into the Preprints volumes. They are found at the end of the related Session discussions.

Tape recordings have been put down by Dr.Pál Magyar.

OPENING SESSION

9:30 a.m. January 15, 1974

J.L.Bogárdi, Chairman
I.Dégen, G.Pekete, T.Hayashi,
H.J.Schoemaker and
H.Vandervelden, Members

J.L.Bogárdi, Chairman:

Ladies and Gentlemen!
Distinguished Participants of the Symposium on River and Ice,
Dear Guests,

On behalf of the Hungarian Academy of Sciences and of the National Water Authority I have the pleasure to welcome you in Budapest at the Opening Session of the Symposium on River and Ice, organized jointly by the International Association for Hydraulic Research and by the Permanent International Association of Navigation Congresses. Personally I myself, as citizen of the host country, feel very much honoured by your interest which is demonstrated by the large number of the audience.

It is my pleasure to greet first His Excellency Professor Dégen, Secretary of State, President of the National Water Authority who is representing the Hungarian People's Republic. I gladly greet with respect Professor Taizo Hayashi, President of IAHR, Professor Harold Schoemaker, Secretary-Treasurer of IAHR and Professor Henry Vandervelden, Secretary General of PIANC representing the sponsoring international associations of this Symposium. Finally allow me to greet also Dr.György Fekete,Director of the Secretariat for the International Danube Commission and the members of the International Honorary Committee as well as all council members of both international associations who have been able to participate in this Symposium. Last but not least allow me to greet also you, Ladies and Gentlemen, our dear guests, participants of the Symposium on River and Ice with Special Regard to Navigation.

Ladies and Gentlemen,

I am convinced that this joint venture of these two famous and well known international organizations will prove to be an important step in the co-operation and co-ordination between the various non-governmental international organizations dealing with water in various aspects and working in various disciplines.

I should also like to hope that this three day Symposium will have successful results not only from the point of view of science and engineering but also in better understanding among the peoples of various nations and so it is not hopeless to predict that - earlier or later - peace will govern all over the world. I wish so, I hope so.

Ladies and Gentlemen,

I wish you a successful work in the Symposium, a pleasant stay in Budapest and with these thoughts in my mind allow me to declare the Symposium opened. Thank you.

Now, may I invite Prof.Hayashi, President of the IAHR to take the floor and to address us. Prof.Hayashi!

T.Hayashi: Thank you Mr. Chairman!

Mr.President, of the National Water Authority of Hungary, Mr.Chairman, Distinguished Guests, Members of the Symposium on River and Ice, Ladies and Gentlemen!

It is my privilege to greet you on behalf of the International Association for Hydraulic Research which I represent here, First of all, I should like to express our deep gratitude to our hosts - The Hungarian Academy of Sciences and The National Water Authority of Hungary - for their gracious invitation, and the Symposium committees for the great effort which they have made for the preparation of this Symposium. The arrangements as evidenced thus far are outstanding.

It is very gratifying that this Symposium is organized jointly by the Sections for Fluvial Hydraulics and for Ice Problems of the International Association for Hydraulic Research and the Section for Inland Navigation of the Permanent International Association of Navigation Congresses.

Since I think that some of you may not know so well about the IAHR as about the PIANC, let me give a brief explanation of the aims and activities of the IAHR and also our old and close relations with the PIANC.

The IAHR was stablished in 1935 as the IAHSR - The International Association for Hydraulic Structures Research - with the purpose of international co-operation of the engineers and scientists interested in hydraulic research.

And this took place on the occasion of the 16th Congress of PIANC held in Brussels, in which 66 participants specialized in hydraulic research felt necessary to make a forum for their own specialization. Later, its name was changed to the present name, International Association for Hydraulic Research by deleting the word "Structures" and the objectives of the Association were stated as "to stimulate and promote hydraulic research, both basic and applied, in all aspects". The IAHR is an association of individuals and of groups of individuals, and it has now some 1960 individual members and some 260 corporate members from 81 different countries of the world. A recent concern of the IAHR is fluid mechanics in the problems of water environment, and the Association conducted its last two congresses on the general themes relevant to water environment. Its next congress, i.e.the 16th Congress, which will be held in Sao Paolo in summer next year, will also be conducted on a general theme pertaining to the water sciences useful to the management of the water environment. Keeping physics and technology as its base of competence, the IAHR is eager to have co-operation with other international associations interested in water problems. With respect to river mechanics, the IAHR had the great pleasure of organizing a symposium jointly with the International Association of Hydrological Sciences about a year ago in Bangkok. And today we are very happy to be able to organize this symposium jointly with PIANC. I am convinced that many fruitful results will be derived from the exchange of information and knowledge between the members who get together with different techniques and through different approaches. And I hope we shall be able to hold meetings like this between our Associations from now on.

I am speaking on behalf of the IAHR and in this context may I express my hope that hydraulic research may have great inspirations from the collegues who expect useful results of our work.

Mr.Chairman, I thank you very much for the opportunity given to me to address at the opening session of this Symposium which you and your committee have laboured.

Chairman: We are very grateful for the warm greetings extended to the Symposium by Prof.Hayashi, President of the IAHR. Thank you.

May I now invite Prof.Vandervelden, Secretary General of PIANC to take the floor.

H.W.J.Vandervelden: Mr.Chairman! His Excellency Prof. Dégen, Secretary of State, Ladies and Gentlemen!

It was with great pleasure that the Permanent International Commission of the Permanent International Association of Navigation Congresses, on behalf of which I have the honour of addressing this assembly, accepted to sponsor this Symposium jointly with the International Association of Hydraulic Research.

Speaking for the President of PIANC, Professor G.Willems,unfortunately unable to be with us today, it is my privilege to congratulate the organizers for their initiative to hold this Symposium on "River and Ice" under the auspices of the Hungarian Academy of Sciences and of the National Water Authority of Hungary and to wish them every success in this undertaking. However, with personalities such as Professor Dégen, Secretary of State, President of the National Water Authority of Hungary and Professor Dr.Bogárdi, Chair of Hydraulic Structures, Budapest University of Technology, among the leading officials of this Symposium - this success is guaranteed beforehand.

For the last ten years or so PIANC has endeavoured to stimulate closer collaboration between technical international organizations pursuing kindred objects. The first signs of such collaboration came to light on the occasion of our 20th Congress,held in Baltimore, USA, in 1961. It took a more concrete form at our 21st Congress (Stockholm, 1965), when so-called "sister" associations were asked to furnish technical papers on subjects of the official program and were invited to send an observer to the Congress itself. This practice has been continued with satisfactory results at subsequent congresses.

This collaboration is not confined to our congresses which, as you know, only take place every fourth year. We have also applied this principle to our international Study Commissions.

These are set up to examine topical problems requiring more time than the few hours available at a Congress.

A few sister associations are generally invited to cooperate in the work of these Commissions in order to concentrate efforts and thus obtain the best possible results.

In this connection I would like to pay tribute to Professor Schoemaker of the Delft University of Technology, the devoted Secretary General of the International Association of Hydraulic Research, who took the initiative to contact me over a year ago regarding the sponsorship of this Symposium. He knew very well that his suggestion would be echoed favourably, since he was aware of PIANC's longstanding wish for collaboration and avoidance of duplication.

I might add here that more recently, Professor Schoemaker has initiated collaboration in yet another field of activity: that of water resources development. The aim is to form a group of water-oriented international non-governmental organizations who would strengthen their cooperation in all technical problems deriving from the use of water in order to avoid both the dispersal of efforts and the overlapping of activities. A meeting of four such organizations was held in Istanbul last September. They decided, inter alia, to set up a central body (or President Council) composed of delegations of each participating organization.

As far as PIANC is concerned, its governing body, the Permanent International Commission, has not yet been acquainted with this new proposed collaboration; there is, however, no doubt that it will be favourably accepted at the next General Assembly, in June.

On behalf of the Permanent International Association of Navigation Congresses I express most sincere wishes for a fruitful and in every way successful Symposium. May the discussions be beneficial to all the participants and may further progress be achieved in the field of scientific research, thus contributing to improve the welfare of mankind.

Chairman: We have been deeply impressed by the kind friendly words of Prof.Vandervelden, which testified the thorough understanding of the problems to be discussed. Thank you Prof. Vandervelden!

Now I should like to invite Dr.Fekete, Director of the Secretariat for the International Danube Commission, to take the floor.

Gy.Fekete: Mr.Chairman! Honourable Secretary of State! Ladies and Gentlemen!

First of all let me greet you not only on my part but also on behalf of the Danube Commission on the occasion of the beginning of this Symposium.

For us, the representatives of the Danube Commission, it is a great honour to participate in the work of such a high-level scientific plenum.

Scientists coming from all parts of the world have gathered here to discuss the important problems connected with the relationships of fluvial and ice hydraulics and the effects of runoff regulation with special regard to navigation. These problems have much in common with the tasks of the Danube Commission.

As it is known, the sphere of activity of the Commission covers particularly the establishing of the plans of the basic works on the Danube as well as the coordination of the hydrometeorological service on the Danube for navigation purposes.

It is, of course, impossible to solve these problems without scientific fundamental basis, but the main task is to sum up the results of scientific research in the pertinent field.

Danubian countries performed important work within the frames of the Danube Commission. The Commission has established the basic plans.

To this end the Commission adopted recommendations concerning the establishment of a uniform method for the determination of the navigation and regulation level on the Danube, it has also elaborated and adopted recommendations on the establishment of the parameters of the navigable channel, of hydrotechnical and other structures. The Commission edited two voluminous publications, as report, on the ice regime of the Danube.

The record on the shallows is published annually. The longitudinal river profile for the stretch of the Danube from Ulm to Sulina, i.e. over that falling into the competency of the Commission, was published.

In order, to coordinate the activity of the hydrometeorological stations of the Danube countries, the commission adopted recommendations relating to the co-ordination of the hydrometeorological services on the Danube, which contain in particular the description of unified methods of the observation and processing of data. In order to unify the data relating to runoff along the entire length of the Danube, the Commission adopted recommendations as regards the necessary measures to be taken for making the data of the discharge percise. Hydrological Yearbooks are published regularly,and besides this, at ten year intervals hydrological reference books concerning the Danube are edited.

The Commission synthesizes the experiences obtained by the riparian countries as regards hydrological forecasts and is engaged in studying the possibilities of their improvement.

Ladies and Gentlemen,

I am convinced that the results of this Symposium will contribute even more to the efficient realization of practical works aiming at meeting the demands of navigation.

In conclusion, may I assure you that we shall follow the preceedings of the present symposium with the greatest attention and shall do our best to utilize as much as possible the results to be obtained for the benefit of ensuring an even more efficient navigation on the Danube.

I wish every success in the work of the Symposium.

Thank you for your attention. Thank you very much, Mr.Chairman!

And now may I give to you the Great Medal of the Danube Commission which was issued at the 25th anniversary last year.

I would ask our Chairman, Prof.Bogárdi to accept from me in the name of the Secretariat of the Danube Commission the Great Medal of the Danube Commission. Thank you!

Chairman: Thank you. And I should like to thank my friend, Director Fekete for his address which we highly appreciated. And of course, many thanks for this nice present. And now I should like to call to the floor Professor Zvorykin, to read the message of Professor Skladnev who unfortunately is not able to participate in our Symposium. Prof.Zvorykin!

K.A.Zvorykin: Mr.Chairman! Ladies and Gentlemen!

President of the Soviet Committee of IAHR Prof.Skladnev unfortunately cannot be present at our Symposium. Let me read the brief message of Prof.Skladnev.

"Mr.Chairman! Dear Colleagues, Ladies and Gentlemen!
On behalf of the IAHR Soviet National Committee and myself I have the pleasure of welcoming the participants of the Symposium on River and Ice.

I am glad that the final decision of arranging this Symposium and its current subjects was taken at the 2nd International Ice Symposium held in Leningrad in 1972.

Our Hungarian Colleagues took advantage of the experience of Soviet scientists in organizing this Symposium. I wish most cordially to all participants of the Symposium River and Ice a great success in this "cold" but very important and interesting branch of science.

Unfortunately, winter ice conditions prevented some of my colleagues from coming to the Symposium. But I trust their co-workers who are present here will excellently cope with the duties entrusted. I wish you every success in your activities.

M.Skladnev, President of the IAHR Soviet National Commitee".

Chairman: Thank you Professor Zvorykin! And may I ask you to extend our best regards to Professor Skladnev. We regret very much that he is not able to participate.

Ladies and Gentlemen, now we shall have a break and the Festive Session will be opened at 10:45. Thank you.

F E S T I V E   S E S S I O N

10.45 a.m. January 15, 1974

T.Hayashi, Chairman,
J.L.Bogárdi, G.Fekete,
H.J.Schoemaker and
H.Vandervelden, Members
I.Dégen, Invited Speaker

(The opening address of Prof.I.Dégen, Secretary of State, is published in the 1st preprints volume.)

SESSION ON SUBJECT A

Relationships on Fluvial and Ice Hydraulics

9:00 a.m. January 17, 1974

L.A.Zolotov, Chairman
W.Lászlóffy, Co-Chairman
Ö.Starosolszky, Invited Speaker

L.A.Zolotov, Chairman: Ladies and Gentlemen! I am Zolotov from USSR. I declare opened the first session on Subject A. The main theme of our session is "Relationships of Fluvial and Ice Hydraulics". Today we will discuss the effects of the flow conditions on the ice formation, drift, cover development, jamming and break-up with special regard to multipurpose river training and navigation. I would like to introduce my co-chairman Dr.Woldemár Lászlóffy. Professor Lászlóffy is scientific adviser of the Hydraulic Documentation and Information Centre, and Professor Dr. Ödön Starosolszky who is our invited speaker.
Dr.Starosolszky, I ask you to present your report.

Ö.Starosolszky: Thank you Mr.Chairmen! Ladies and Gentlemen!
Distinguished Participants of the Symposium on River and Ice!
I feel very much honoured that I have the privilage to deliver a general lecture concerning interrelations between fluvial and ice hydraulics. In my general lecture concerning mainly ice hydraulics I wish to summarize the recent results, to give a general view of the state of art on the investigations of ice phenomena, to visualize the future problems to be solved and finally to put the papers submitted in our Symposium to Subject A in a common framework.

Prof.Dégen in his introductory lecture has emphasized that ice conditions are controlled fundamentally by the combination of channel morphology and climatic conditions. And further these conditions can be controlled by human interference, fundamentally by river regulation structures. These two statements fundamentally underline the clese interrelation between fluvial and ice hydraulics. From these the following conclusions can be arrived at:

1. No adequate information on ice hydraulics can be obtained without information on channel morphology and fluvial hydraulics these latter representing boundary conditions to ice phenomena.

2. No ice control measures can be devised unless the hydraulics of ice and river are totally understood.

These conclusions may appear logical and in my lecture I thought it to be important to emphasize them specially.

The foundation of modern fluvial hydraulics was around the middle of the last century by famous French hydraulicians. Accurate observations and the use of models have reached nowadays far enough to predict the flow of water in streambeds with a fair degree of reliability. Provided that the initial and boundary conditions are known. In alluvial channels where these boundary conditions are subject to variations the solutions considered otherwise accurate appear approximations only. Concerning the complete description of sediment transport and the influence thereof on the channel and in term of the flow itself the present methods however advanced they may appear contain a number of uncertainties. It is for this reason that fluvial hydraulics in spite of the exact mathematical models remains a rather empirical science and the majority of engineers engaged in this field leaves reliance rather on actual field experiments than on the application of advanced theories.

This statement may be discussed. And I hope that my distinguished friend Dr.deVries, Secretary of the Fluvial Committee will discuss in this respect. Ice hydraulics which deals with the travel of ice and thus with kinetic ice phenomena has not yet attained this stage. Certain physical similarities have been recognized between the movement of ice and sediment but the development of a scientific approach based on the mechanics of fluids and of solid bodies and does not exlusively on experiences associated on the activities and events of the international associations on hydraulic research. Several congresses and seminars contribute greatly to this development as a result of which we can speak of ice hydraulics at all. It is logical that advances in river hydraulics promote the evolution of ice hydraulics as well. A brief review should illustrate this statement.

In the field of fluvial hydraulics a considerable development has taken place in recent years. Let me refer only to a few of them. The differential equations describing unsteady heat-flow phenomena became accessible to solution, although mostly with an approximative character only, with the help of advanced computational techniques and high speed computers. At the same time it was experienced that the volume and accuracy of basic data available failed to meet the requirements of advanced computer techniques.

Another conclusion: advances in computation techniques offer the possibility for more accurately analyzing the effects of human interference (reservoirs, dams, river barrages, diversions, discharges etc.) on flow and regime conditions in natural alluvial channels. Although the advancement was not as spectacular than in the former case, nevertheless it opened the way for describing more accurately than before three-dimensional flow phenomena, the importance of secondary currents in the highly non--uniform river channels, that was fully appreciated yet allowance for them could be made just as in the case of frictional resistance at the cost of rather crude approximations and simplifications only. Development in instrumentation, especially the introduction of flow direction meters, can be regarded as new tools in this respect. In the observation of pulsation and of different attached phenomena the introduction of laser-techniques and advanced recording related have resulted in considerable improvements especially where no more than the macro effects of the process that means the complete evolution of mixing was of interest. The scientific advancement in fluvial hydraulics was followed with a slight phase-shift by knowledge on ice phenomena. Where the relative scarcity and expansive nature of observation techniques presented considerable difficulties and obstacles as a consequence thereof there is still alot of parameters for the theoretical solutions and it is virtually impossible to check theoretical results against field observation data. In fact, the unsteady variation of flow is mostly accompanied by unsteady ice--motion. Of course, a phenomenon in ice movement may be unsteady even if the flow itself is steady since the formation and melting of ice are themselves unsteady phenomena. Concerning the effects of hydrotechnical structures on ice phenomena additional variables must be introduced or certain simplifying assumptions lose their validity.

Concerning the influence of three-dimensional flow conditions on ice phenomena the relationships available are again of a qualitative character only. In that the pattern of the streamlines on the surface are virtually traced by following the movement of the ice floes that flow usually on the surface. Nevertheless, ice drift would be more reliable to forecast if information were available on three-dimensional velocity distribution. Better understanding on pulsation and diffusion phenomena would permit the more exact description of cooling and freezing processes as well as of the movement of flush and frazil ice. In this domain appears the possibility of transplanting the results of research conducted on account of pollution control, turbulence and this possibility should be utilized. This seems to afford the only means for estimating the impact cooling water discharges on the ice regime in rivers. Which problems have been mentioned yesterday and before yesterday many times. The few examples are believed to demonstrate the necessity of a parallel development in fluvial and ice hydraulics. The practical benefits of theoretical advancement may accrue among others to navigation. This can be illustrated by the following examples.

As a consequence of the growing number of cooling water discharges the thermal pollution in the recipients and thus the average temperature of water in them is also increased, especially in industrially developed countries. In the winter season this rise in temperature has an influence on ice formation and consequently on the length of the navigation season. Ice formation may be restricted to much shorter periods of the year. But it may also extend to much longer periods. The length of the river reach affected is of fundamental importance. The question is obviously of economic interest; the ice is removed from a longer distance. The appearance of ice on longer reaches may make the removal of the presumably thin ice cover over the intermediate reaches by ice breakers economically attractive. Advances in the theory of unsteady flow and ice movement may lead to a program of runoff control whereby navigation can be prolonged for an extended period. Besides releasing relatively warmer water from reservoirs reference is made here to the possibility of breaking up the ice cover by artificial flood-waves especially before the advent of melting when conditions otherwise are favourable.

After this introduction let me summarize the main problems of ice hydraulics.

(The main part of Dr.Starosolszky's lecture has been published in the 2nd Preprints volume.)

Ladies and Gentlemen! Before finishing my lecture I want to emphasize the complex character of future research. Relationships of general validity cannot be expected unless fundamental relations of natural sciences are adopted as a starting basis. Local observations must be extended to simultaneous measurements of all relevant factors involved. More studies should be performed on the basis of fundamental relations and on conditions corresponding to local observations. The mathematical models formulated can be solved under various initial and boundary conditions. The validity of the relationships assumed is verified by field observations. Therefore organized research activity is required in which earlier observation data are used in combination with accurate observations performed in their majority with the help of new advanced methods and equipment from which some have been introduced yesterday.

Finally let me express my hope that this complex way of investigation may be performed in a framework of an international cooperation. Thank you very much for your kind attention!

Chairman: Thank you very much, Dr.Starosolszky, for your very interesting report. Now we shall discuss the papers.

There are 13 papers connected to Subject A. Now all these papers are open to discussion. Let me begin our discussion with Paper A2. "The Mechanics of River Ice Jams" by Dr.Kennedy and Dr.Uzuner. Dr.Kennedy, you are welcome.

J.F.Kennedy: Thank you, Mr.Chairman! The work I am going to report today is serving as a subject to the doctoral thesis of one of our graduate students, Mr.Uzuner, my co-author. His Master's paper resulted in a work on ice and it was presented in our last conference in Leningrad. And now he is continuing his work on this subject. His home is Turkey so I predict he will be a leading authority on ice problems when he returns home.

The subject of ice jams is a very complex one involving - as it does - most of the aspects that enter into river ice problems, including the hydraulics of the flow under ice, strength of the ice, transport of the ice and the production and melting of ice. This is perhaps that makes ice jams the very interesting and troublesome problem that they are.

If I could have the lights down please! And turn to the slides. Thank you!

Let me begin by noting that ice jams have attanded artistic attention during past years as we see this in the painting by Monet called "Breaking of the Ice". However, when one looks at a real ice jam it loses some of its artistic attractiveness and becomes a somewhat more frightening phenomenon. This is a photograph made by the Corps of Engineers from the 196· ice-jam in the vicinity of Quab City between Iowa and Illinois. The flood produced by this ice jam was one of the greatest experienced in recent years in the Upper-Mississippi River and produced tremendous damage. When one looks more closely to the surface of an ice-jam - as you can see - you find a real mess. I think if one wants to do theoretical work on ice-jams perhaps you should never go out and look at an ice-jam. You become so discouraged that you might give up right at that time. I am always also a little startled and puzzled by the amount of junk and trash accumulated on ice-jams. You will find barrels, old doors of cars, all matter of trash and I just do not understand where does this come from? But it seems invariably to be present. This again is the ice accumulation on the Mississippi River in Iowa and Illinois. When one is faced with a difficult natural phenomenon it is always a good idea to look at it in the laboratory and we have done this in the laboratory flume at Iowa using simple paraffin blocks that show some of the characteristics of ice jams. This is a photograph made through the side glass wall of a flume with the flow from left to right. The features of the ice accumulation show general thickening from the upstream end. The ice apparently thickens until its strength at any point is great enough to support the load supply from the upstream end. These loads will be discussed in more detail later but consist of the impact of the flow and ice against the upstream end, the shear stress on the bottom of the ice cover, the component of the weight in the direction of the flow that is the gravity exerted on the ice and on the water that it contains. One also frequently observes in this modelized jams at least the phenomenon that Dr.Starosolszky spoke of, that is the transport of the individual particles on the underside of the ice cover. Eventually though, one does achieve a more or less equilibrium thickness at some distance downstream from the leading end of the ice jam and at this point the forces exerted on a unit length of the ice jam, that is the weight of the ice and the water it contains - plus the shear stress on the bottom -, are just balanced by the shear exerted on the ice jam by the walls of the flume or by the banks of a river. That is to say, the net resisting force due to the normal stress in the jam is constant because of the uniform thickness.

Let us now look at a still more idealized situation and start to consider the framework to the analysis that will be developed. Now today I am going to describe an analysis that is somewhat different from the one presented in the preprints. The preprint was prepared almost a year ago and since that time we have made considerable additional progress so I will describe to you the present status of this research. It is still continuing but nearing completion.

The flow approaches the upstream end of the ice jam and because of the presence of the ice jam there is of course an increase in the water surface, that is the additional resistance offered by the presence of the ice cover causes the flow to deepen. Consequently, one has upstream of the ice jam the formation of a backwater region. Now, with the arrival of more ice to the upstream end the ice cover will propagate the upstream direction, that is the leading edge will move upstream. The notation used in the slide, I believe, is international due to Dr.Starosolszky's terms. The equilibrium thickness and the equilibrium depth of flow under the ice are noted by t_e and h_e, respectively. t_x and h_x are the thickness and depth of flow upstream from the point where the jam achieved its equilibrium conditions. Now just to give a general overview, Uzuner has succeeded now in solving the unsteady ice-jam accumulation problem for the situation in which the equilibrium conditions have been reached at some downstream point. And then one can grab the problem by simply to make a change in the coordinates, you look at the problem in a moving coordinate system. And the results of the analysis are the profiles giving the ice thickness and also the distribution of depth upstream from the ice jam, as well as the rate at which the ice jam is propagating in the upstream direction. Let us now look at some of the forces involved in achieving the equilibrium. As always in a problem of this sort we do not have much to work with Newton's laws and the equations of kinematics or continuity. So the basis for the analysis - as far as the ice is concerned - is the static equilibrium of an element taken from the ice cover. Now keep in mind, that in this analysis we will treat the force balance in the ice cover as static, but we will treat the unsteady dynamic equations of the water flow under the ice. Now what are the forces acting on the elementary control volume that we see. This is a parallel pipehead section cut from the ice jam and extending over the whole depth. You can see the water surface noted by these small nabla and the forces acting are the following:

First of all there is the weight of the ice and the water it contains in the direction of flow. That is to say the stream will be slightly inclined and consequently there will be a weight component along the stream. There is the normal stress σ_x, acting on the upstream end and the balance will be made by the normal stress on the downstream end plus the additional normal force along the length on the side of the ice jam. And if you extend the size you will find the banks of the stream eventually. There are the shear stresses τ_{xy} acting. Finally at the bottom of the ice cover there is the shear stress exerted by the turbulent flow of water beneath the stream. You might also note the coordinates used - the most important one being X in the downstream direction. Now before we can begin to solve the problem you obtain the thickness T as a function of length along the stream. We must first express the stresses σ_x and τ_{xy} somehow in terms of the thickness. This is a particularly puzzling problem, one which we will consider later. But I want to refer now to the lower figure just to set the background of what you will see later. In a fragmented ice cover the normal - I should say the vertical normal stress $\sigma_{\bar{z}}$ is distributed in the triangular form that you see illustrated. Now this is the effective interparticle stress between the ice fragments. And of course it reaches a maximum at the water line. Being the buoyancy of the particles below the water surface supports the weights of the particles above. And we have in expressing τ_{xy}, we have related their failure values or maximum values to this applied normal stress $\sigma_{\bar{z}}$ and have used the average value of it. Stated in other way we can say that the maximum value of the normal shear stress σ_x is proportional to the mean value $\sigma_{\bar{z}}$. Similarly, the maximum or failure value of τ_{xy} is equal to a cohesive intercept or constant cohesion plus a constant times $\sigma_{\bar{z}}$. The motivation for doing this stems from the fact that the whole ensemble of flowing ice is less constrained in the vertical direction than in the other directions. Any failure due to application of stream ice forces or shear forces can be releaved by expansion and the consequent relative motion of the ice fragments, an expansion in the Z direction.

Well, let me now simply summarize the equations that enter into the problem. And I won't go into the details of the solution. First of all there is the force equilibrium of the ice cover which is - I told you before - considered as static. That simply says the change along the length of the normal forces plus the change caused by the shear stress minus the shear stress applied by the flow is equal to the weight of the ice. As we just discussed, the longitudinal normal stress σ_x is assumed to be proportional to the average vertical stress $\bar{\sigma}_z$ resulting in Eq.2. And this follows directly from the hydrostatic relations. Similarly, the shear stress τ_{xy} is expressed as - first of all it is assumed to be, or shown to be - linearly distributed across the channel. It is clear - I think - that the shear stress τ_{xy} must be zero in the channel's centerline and then it is distributed linearly across the channel and to show this you make an analysis very similar to that you might show that the shear stress in an open channel flow or uniform pipe-flow is linearly distributed. But the maximum shear stress itself τ_{xy} is taken to be equal to a cohesive intercept (......) dynamical boundary conditions simply says that at the leading edge of the ice cover σ_x times t that is the strength of the ice cover must be equal to the force supplied by the momentum of the oncoming ice blocks. And notice that we are now in effect using a moving coordinate system because v_s surface velocity of the ice particles is increased by the amount of v_w which is the velocity with which the upstream into the ice cover is progressing. And finally from simple kinematics one can derive Eq.9 which gives a velocity with which the ice cover moves. Well, one takes this system of equations not too bad to solve you rapidly can get an equation for just t from $\frac{\partial t}{\partial x}$ which arises in Eq.6. can be expressed from Eq.1. with the other quantities and you get a system of equations which are readily solved. Now, the integration proceeds from the downstream end that is from the point where we have equilibrium conditions or some other specified values for t_e and h in the upstream direction. Now one can also derive straight away expressions for the equilibrium thickness simply by dropping the $\frac{\partial}{\partial x}$ terms in the force equation for the ice and in the momentum equation for the fluid and you get the bar expressions for t_e and h_e. Now when you start to integrate the equations you run into some mathematical difficulties for the case of equilibrium conditions. These are circumvented by taking second derivatives making substitution and then it is very straight forward to solve.

Now the results: I want to give you here some typical examples. This is the normalized thickness of the ice jam from the upstream end versus distance along the ice jam. And of course this is a function of the primaries which arise in the equation, notably the slope of the stream, friction factor for the underside of the ice cover, and the porosity.

Given a strength one can calculate from the equations quite easily and one can also solve for the unsteady case, how fast the ice jam is propagating upstream, how fast the flood wave is moving upstream, this is all programmed now by the results being generated.

Now let me turn to this question of evaluating these stress coefficients. We have undertaken some subsidiary research program in which we are attempting to determine the normal and shear strength of fragmented ice covers. This work was being done in the low temperature room of the University of Iowa and we are using this ice force facility which I mentioned yesterday. And in these experiments we place fragmented ice of roughly controlled dimensions, this is surface (.....) ice in the tank to the desired thickness. The shiny sheet what you see which is mounted on the motorized carriage is then moved into the ice jam to compress it until it fails. The plate is mounted on a dynamometer and you get out of this a record of displacement and force. And these experiments have been made with different sizes of ice, different ice thicknesses and different carriage speeds. The first set of results showed the dependence of this quantity k_x normal strength coefficient on the carriage velocity. And you see that the strength of the ice is also strongly dependent on the carriage velocity. These velocities vary from about 0.01 cm/s to 0.1 cm/s. And this is one of the most difficult aspects. The second aspect that is difficult is the fact that for a given speed there is such wide variability of k_x. And this is illustrated in the slide that shows the results for the constant velocity noted here. Now, we see that even for the constant velocity for different ice sizes there is a special case for k_x and we think that this is due to an unadequacy in our analytical framework for k_x or is due instead to just the fact that for the same conditions k_x varies widely. We have made similar experiments to evaluate the shear strength which represented in this case by f_o - a shear force and you can see the strong dependence on the velocity, with the normalized velocity on the horizontal scale but with much less scatter and there is this intriguing relation that the normalized shear strength seems to - times the normalized velocity is practically constant.

But the fact that the strength coefficient depends so strong on the ice is certainly a troublesome feature.

This is for the program how it now stands; I believe the general analytical framework for the ice jam is relative complete but the remaining work to be finished is quantification of this strength coefficients of the ice. Which are of central importance to the formulation of ice jam mechanics. Thank you!

Chairman: Thank you Dr.Kennedy! Are there any questions or comments? Concerning Dr.Kennedy's report?

G.Rouvé: My name is Rouvé from the University of Aachen,Germany and I want to ask Mr.Kennedy whether the shear stress is not a function of time? If you placed your prefabricated ice blocks in the flume and you start moving the carriage with the dynamometer I would expect that it depends very much on time. I would like to know if you obtained some experiences in this respect?

J.F.Kennedy: Yes, this is quite right. As the ice is sitting in an undisturbed way for a time this cohesive term becomes predominant one. And for ice at very low velocities the cohesion is much-much greater than the granular friction. Whereas when the ice is disturbed and then you move it fast the cohesion term is practically zero. But I think this velocity dependence is connected with this cohesion. If you are loading the ice very slowly first of all the individual particles are being pressed together and secondly they have time to stick together. And I think this is the origin of this velocity dependence. But you are quite right. After the ice sets even a short time the initially fragmented cover becomes more the matrix of or post medium ice, it is no longer fragmented ice.

A.P.Larsen: I am Larsen from Sweden. You have developed an equation of ice cover thickness varying with distance downstream and you get t as a constant over the width of the channel. Now the shear stress is increasing from zero at the centerline of the channel to a maximum at the banks. So one would expect the equilibrium ice thickness to increase towards the banks.

Dr.Kennedy would you please elaborate a little this.
Thank you!

J.F.Kennedy: One must distinguish in this case between the shear stress being experienced by the ice at any point, the actual shear stress in the cover and the failure shear stress. And according to this model failure shear stress occurs at the banks. That is the maximum value that can occur. And this is this maximum or failure value of shear stress or shear strength that is related to the thickness. And then the shear strength is reducing from this value across the channel to become zero at the centerline. So this makes the distinction between the shear stress at any point and the shear strength of the ice. Did I make this clear?

Chairman: Thank you Dr.Kennedy. Now I declare a break about one half of an hour. The second part of our session will start at 11 sharp. Thank you!

Chairman: Let us continue our discussion. Let me introduce Dr.Starosolszky that time not as a general reporter but as the author of paper A1. "General Trends of River Ice Research".

Ö.Starosolszky: Thank you Mr.Chairman! I have to apologize in disturbing you again.

Economic life in the countries situated under cold and moderate climates is fundamentally influenced especially in winter by the conditions in rivers. It was this economic necessity which prompted the inhabitants of these countries to devote scientific and engineering attention to the phenomena related to ice. The knowledge afforded on ice by the natural sciences and the engineering-technical measures following therefrom, have in general resulted in consequences of economic interest. This is the main basis that we in Hungary have had a quite a long traditional way on research activities on ice.

The main achievements in Hungary made thus far can be summarized as follows. In Hungarian hydraulic engineering practice ice conditions primarily on the Danube and to a lesser extent on the Tisza River are of major interest. The fundamental work of data collection has been performed in the last 30 years. First of all Prof.Lászlóffy whom we are having today as co-chairman and Dr.Horváth whose publications in international professional literature disseminated the Hungarian results in hydrology of ice must be mentioned. Some of these papers may be visualized in a small exhibition in the buffet-hall. In the course of this analytical work they arrived to a number of conclusions and have determined relationships with meteorological conditions of great practical interest. More recently Dr.Csoma and Dr.Zsuffa have considered similar problems by applying advanced mathematical statistics to them. Experiences concerning the ice cover formation during the past years have been collected primarily for the Danube in the framework of the COMECON. This was made mainly by Mr.Knézy, a practical engineer of the district water authority. The work performed by ice breaker vessels has been analyzed by Mr.Bognár. On that time he was the director of the Lower Danubian District Water Authority which will be visited by you to-morrow. Ice phenomena in the vicinity of structures has been studied by Mr.Somody and Mr.Baka with special regard on the ice control at the first river barrage on the Tisza River.

The thrust and other effects exerted by ice have been dealt with in detail by Dr.Török. These publications have been published - sorry to say - mainly in Hungarian in the periodical "Vizügyi Közlemények" (Hydraulic Engineering), during the last decade. The relevant professional foreign literature has been reviewed in a comprehensive report by me in which the thermal budget of water courses, the hydraulics of sediments, of ice movement, ice pressure and the protection of structures from ice have been discussed. An interesting contribution to the knowledge of the behaviour of the ice cover and on the influence of structures has been made recently by Mr.Zsilák. Results from his work will be demonstrated by Dr.Hankó here somewhat later.

Practical information available on ice control has been summarized by several authors, whose work was coordinated and edited by Dr.Sipos in a comprehensive manual. Let me show you this. You will find it in your briefcase. Sorry to say that it is in Hungarian but it has, as I remember, English, French, German and Russian summaries.

In order to disseminate up-to-date information to engineers engaged with ice problems in practice, the text of lectures delivered at a training course in the winter of 1972/73 was published by the National Water Authority. This comprehensive review of the Hungarian practice in ice-control has been published quite recently, some days before and I hope that all of you have received it. In response to practical requirements and considering first of all the conditions prevailing in Hungary research subjects may have been suggested and the list of these suggestions can be found in my paper.

What I wish to emphasize is that different methods are needed for studying ice phenomena. And especially in Hungary. Because Hungary is a small country we don't have enough brain-forces to study everything. Therefore I wish to inform you about our efforts in this respect in the future.

In some of the subjects it is considered advisable to review the present state of knowledge in a preliminary paper founded on available experience and on the relevant literature. In this respect we are very glad having this symposium here in Hungary and having the possibility to collect different data from different countries and to exchange experiences of leading personalities in ice hydraulics and ice control.

In the case of some subjects it is not desirable to go into further details. In some problems field observations are believed necessary because all phenomena are affected by different climatological conditions and we have to take into consideration the special Hungarian conditions.

Finally, a third group of subjects appears to require beyond field observations, investigations either in the field or in the laboratory, the results of which would permit conclusions to be drawn for particular locations.Our research has to deal with this special subject.

The manifold character of the subjects listed in my general lecture suggests logically to conduct research work on the basis of organized international cooperation, organized primarily by the IAHR Committee on Ice Problems. Therefore we would welcome more intensive work in the framework of this organization. I would like to inform you that yesterday at the lunch break we had small meeting for the members of the Committee on Ice Problems and we decided some measures, some advancement in the work of our Committee. Only one thing that I wish to emphasize. Because we want to speak in a common language we need a good terminology. During the last years a comprehensive terminology has been prepared by the National Committee of the USSR in Russian language and the English version was made by the Canadian group. We would prefer to enlarge this work to as many languages as possible. Therefore we want to recruit some voluntary people who will be able to prepare other versions. Especially we would prefer a German version, of course a French version and some others. The only one I can report that the Scandinavian version, maybe the Swedish one, was accepted by Prof.Larsen and of course we Hungarians have to offer the opportunity to prepare a Hungarian version even though the Hungarian language is not an international one. This is considered necessary in order to perform research work with the required intensity and the hope of a designed research of general validity. We hope that in the coming years our Committee on ice problems will be able to make more contact with other committees of our association as this e.g. is our Fluvial Committee and perhaps with other groups or committees of other international associations, e.g. the Committee on Snow and Ice of IASH. We hope that the international cooperation will be a good basis of the improvement of the knowledge on ice in the near future. Thank you very much for your kind attention!

Chairman: Are there any comments or questions? Please.

G.Tsang: Gee Tsang from Canada. It is my personal opinion and also the informal opinion of some of my superiors in Canada. We consider in an area like ice and hydraulics, which is well known to you that a lot has to be done and on a national scale, if you want to do the things separately it will take a long time to do it. Seeing that how much effort has been done in the frames of the IHD and the International Geophysical Year, a similar international effort should be sought by IAHR to study ice-hydraulics problems. Last time personally I was in Bern on our last meeting and I was right happy to see the number of scientific papers coming out from that meeting, probably about 4 or 5 times the number of papers here we have for this symposium. And also IGY is a good example, a global geophysical cooperation and therefore and based on that - this also is my personal opinion - we should consider IAHR to go into the possibility to have a similar kind of cooperation. Thank you!

Chairman: Thank you very much! Any comments?

Then we shall go to the next paper A3. "Kinematics of Flow Under Ice Cover" by Dr.Zhidkikh, Sinotin and Guenkin. I now invite Prof.Zvorykin who will present the paper.

K.A.Zvorykin: My name is Zvorykin, I am from Leningrad. Mr.Chairman, Ladies and Gentlemen! I want to make a short addition to paper A3 because the authors are unfortunately absent. They are my Soviet colleagues.

Among various problems of ice hydraulics those of kinematic structure of plane pressure turbulent flows are of particular interest. The experimental results presented enjoy many practical applications in such leading branches of economy as hydropower engineering, water transport, water supply, etc. However, the problem of calculation of flow kinematics under ice cover has not yet been solved adequately partly due to lack of perfect design methods and partly due to some difficulties in choosing initial data, and particularly ice cover roughness coefficients,

To simplify calculations formulae some investigators (Levi, Grishanin,etc.) proceeded from equations of the semi-empirical theory of boundary layer. In terms of this theory the kinematic characteristics of flows under ice cover are governed only by the ratio of the ice cover roughness coefficient to roughness coefficient of the river bottom.

In the paper submitted to the Symposium the authors employed equations of motion, in which molecular viscosity is replaced by eddy viscosity. The coefficient of turbulent exchange is assumed to vary stepwise at the depth of maximum velocity and is calculated by the Prandtl-Kármán formula. As a result, relationships have been obtained for the basic features of the kinematics of flow, viz.: flow velocity, water discharge, the position of the maximum velocity plane and turbulent exchange coefficients.

It should be emphasized that the kinematic characteristics of flows covered with ice depend on the absolute values of roughness of the ice cover and the river bottom, rather than on their ratio, which is in full agreement with experimental results presented in the paper.

Similar effect of boundary resistances on the internal structure of certain system has been known long ago in a number of sciences, for example in the theory of heat transfer.

In due time the under-surface of the ice cover alters (becomes smoother). In other words, the ice cover as well as the river bottom may be considered as an erodible surface. However, in contrast to the river bottom, the erosion of the ice cover results from thermal rather than the mechanical effect of the flow.

The above independence of the kinematic structure of flow on the roughness of boundary surfaces enables one to assume that in flows under ice cover occurs mutual adjustment of the ice cover and the river bottom roughnesses.

Further quantitative study of this phenomenon is required. Besides, laboratory and field investigations should be carried out to estimate roughness coefficients of the ice cover.

Thank you very much!

Chairman: Thank you very much, Professor Zvorykin. Any questions?

H.D.Olbrisch: My name is Olbrisch, from the University of Aachen.

The method of calculation is developed here by regarding the vertical strips in the middle of the cross-section.

And by defining a curve that will describe the velocity distribution as it is shown in Fig.1 and Fig.2 in this paper, you will find the maximum value of the velocity given by the height h_1. Regarding such a vertical stripe not in the middle of the cross-section but in the outer part of the cross-section especially near to the banks and if the banks are very steep or may be vertical the question now is, how the height h_1 has to be determined in those outer parts of the cross-section where the side influence of the banks is effective.

Chairman: Thank you very much. Professor Zvorykin? Do you want to answer?

K.A.Zvorykin: That was made by the authors and not by me. I presented only an addition to what they had to say. In general I think the remark is good and we have to find the solution for the problem presented in the comment of Mr.Olbrisch.

Do you want something else or are you satisfied? If you want to have an answer to your question, please write to the authors. I will submit your paper and they will answer your problem directly. Are you satisfied?

H.D.Olbrisch: Thank you, Professor Zvorykin!

Chairman: Our next paper is A4. "An Approach to Evaluating the Instability of Longitudinal River-Bed Variations", by Dr. Komura. Unfortunately, Dr.Komura is not present at our symposium.

Is anybody commenting on his paper? Or submit this report? No. Unfortunately we cannot discuss this report because the author is not here. The state of things is with report A5, "Some Observations of Fluvial and Ice Hydraulics in the Cold Climate", by Dr.Li. The author is also not here. Is there anybody who can tell us something on this report?

Next paper A6, "A Few Problems of Ice Motion Which Covers a Major Part of the Water Surface, Termed Saturated Motion" by Dr. Zsilák. Dr.Hankó, I invite you to present this report.

Z.G.Hankó: Allow me please, to convey some additional information to you for Mr.Zsilák, who is the author of this paper.

Saturated ice motion is a passage of ice with hardly any free surface of water between the individual ice floes, so that the water is moving along with the ice. Between the individual floes, running ice and the embankments a powerful interaction is being developed. The relationships presented in the paper can be evaluated starting from two differential equations. The first of these is the Newton equation of motion and the second the equation of continuity.

If the thrust between the ice drifts equals zero, the ice motion is termed congestion-free motion. If this is not the case, it is referred to as congested motion. In the case of congestion-free motion the resistance of flow can be related to ice velocity, and in the case of congested flow, when thrust is existing between the ice drifts, the flow resistance can be approximated as a linear function of the thrust.

For a permanent, rectilinear, uniform and congestion-free flow it may be derived that the relative slip of ice velocity decreases with the increase of water velocity - as it is shown in the paper. Contraversely, in the case of a permanent, rectilinear, uniform but congested motion two recent results must be mentioned.

The first may be called as the range of influence. It indicates the length over which an influence decreases down to its e-th fraction, in which e refers to the base of the natural logarithm. The range of action may suitably serve for characterizing the ice conditions of a river.

And secondly: using the relationships described in the paper a possibility is given as determining the thrust distribution developing within the following body of ice.

The slide shows two thrust distributions. The solid line refers to a case with a characteristic flow velocity of 2 m/s and the broken line to one of 1 m/s. On the vertical axis you can see the stress in Mp/m2. ℓ_2 refers to the length of the backwater curve, while ℓ_1 is the length of the ice drift upstream from the end of the backwater. On the right side of the horizontal axis is the barrage. The maximum values of the thrust appears within the range of the backwater limit and decreases towards the barrage at first rapidly, then at a modest rate.

Stress distribution shows a similar pattern also with a standing ice cover. This circumstance explains why ice jams develop with the creation of ice cover. The ice drift coming from the upper river reach forms an ice cover of a loose consistence within the reach at the beginning. As soon as the upper end of the ice cover attains the backwater limit, respectively passes beyond it, the ice cover in the reach will be exposed to an ever increasing stress. Individual floes occurring in this period may be ascribed to the compression of the ice cover undergoing an ever increasing stress, and likewise to an unsuitable support on the river banks. The force originating from the decrease of the stress must be taken up by the banks. If the reaction force of the banks is insufficient, the ice cover becomes congested with one individual floe over the other and will thicken until the equilibrium is reached. Thank you very much!

Chairman: Thank you very much Dr.Hankó! Are there any comments concerning report A6? Or are there additional materials? No comments, no question. Our next report is A 13 by Dr.Bulatov. I invite Dr.Onipchenko to present this paper. You are welcome, Dr.Onipchenko.

G.Onipchenko: I am Onipchenko from USSR. Mr.Chairman! Ladies and Gentlemen! Let me greet you on behalf of Mr.Bulatov and present his paper "River Debacle as a Function of Stream Hydraulic Regime and Melting Ice Cover Strength".

The presented relationships are derived on the basis of many years of observation data of the USSR rivers. Computations on concrete conditions closely agreed with the prototype data. We can use this method consequently for the short period forecast of river debacle. In this case the main acting force is taken as a function of the ice cover lower surface causing destructive stress in the ice cover. Physical model of interaction forces permit to consider wind effects in case of flow velocity is equal to zero. This model of the debacle process is assumed to develop the method of short range forecast of the debacle for all rivers of the USSR. In this respect this model of the debacle process is universal. For specific rivers and points, however, the knowledge of local conditions is needed. E.g. concerning the Central Asian rivers flowing from the South to the North one has to take into account the inflow of heat contained in waters from the upper, non-frozen parts of the river. Additional knowledge of heat brought by water is needed for rivers flowing out of lakes and water basins. For some rivers it is necessary to accurately know an increase in water discharge under debacle and for some others more accurate knowledge of heat inflow to ice cover, etc.

However, according to the mentioned peculiarities all rivers can be divided into groups for which it is possible to develop typical methods of debacle forecast that is such which are suitable with small changes not for one river but for a whole group of rivers. At present, typical methods of debacle forecast are being developed in the Hydrometeorological Centre of the USSR.

Calculation of thickness and melting ice cover strength found an independent application for developing forecasts of water level height under ice blockings in rivers including also forecast of optimum time for ice-breakers to come into operation with the purpose of opening transit navigation.

Thank you!

Chairman: Thank you very much Dr.Onipchenko. Any question or comments? No. Our next paper is A7. "Variation of Discharge with Cross-Sections with Ice Cover" by Prof.Rouvé, Olbrisch, and Stottmeister. I invite Dr.Olbrisch to present this report.

H.D.Olbrisch: Mr.Chairman! Ladies and Gentlemen!

This paper does not include new results of ice research but the aim of this work was to find a new method for the calculation of discharge under an ice cover in comparison to the discharge of the same cross-section without an ice cover.

Regarding some of the formulas which I will show in the next picture, the composite roughness has to be calculated in this way. These formulas have some restrictions. These restrictions are described in the paper. Using modern computer techniques it is possible to vary input data - as it is shown here- and to vary the data in a very wide range. For this purpose a lot of cross-sections of different shape and size have been investigated, cross--sections of natural form as well as cross-sections of regular form as to be found in man-made channels. The roughness of each cross-section was used not only for the whole profile but also for parts of the cross-section dividing them into vertical stripes. Using then dimensionless equations for the roughness and the discharge or the reduction of the discharge - as it is shown here - all resulting points of a particular cross-section lie on one curve that is defined by the ratio of $\frac{P_1}{P}$ as this is shown in this picture.

But this curve is not only valid for one cross-section but also for all cross-sections with the same value of $\frac{P_1}{P}$.

Some points are to be found here according to the formula of Krishnamurthy and these points are situated in the above part and here in the lower part quite away from the main part of this curve where the other points are situated right close together, according to the other formulas. This may cause some problems - of which I will talk about later -. In logarithmic system you can derive a very simple method - as an example is shown here - to determine the reduction of the discharge. This example - and it may be represented by this cross-section - shall show which variations can be done in the developed program because all of the shown variables can be changed for instance to simulate the influence changing with time or with a growing ice cover or changing roughness, variation of the cross-section, etc. In this method of calculation one problem may arise. If we calculate the discharge of any cross-section that can be done by calculating the discharges of all parts of the cross-sections - as I have mentioned - and if this results sum up to the whole discharge over the cross-section we cannot find the same value as in the first calculation of the profile and the whole amount of discharge.

This picture will give you an idea of the reason for this problem. Namely, by finding mathematical curves describing the velocity distribution under an ice cover. This will be pointed out in a study being under work and it will be reported later. Thank you very much!

Chairman: Thank you very much Mr.Olbrisch. Dr.Larsen,please!

A.P.Larsen: Mr.Chairman, I have a few slides to present. Mr.Chairman, Larsen from the University of Lund Sweden. I would like to correct a statement in the paper by Rouvé at al.regarding my paper "Hydraulic Roughness of Ice-Covers". Its reference number is 3 in paper A7.

The authors state that "The computations seem to have been based on the assumption that both the roughness coefficients for the channel bottom and the ice-cover are equal.

This is not the case as it would readily appear from Fig.4. of the paper. Fig.4 is a diagram giving the composite roughness coefficient as a function of the ratio of roughness coefficients of two boundaries with different roughnesses.

So here, in slide 1, you see the composite roughness on the vertical scale divided by the rougher of the two boundaries and the abscissas are ratios of roughness of the smoother boundary to the rougher boundary. Now the rougher boundary could be the upper one, the ice cover in this case, or the rougher boundary can be the lower one. It is a matter of putting the indices right.

It seems appropriate to comment a little further on the theory behind this diagram, particularly since these comments also pertain to paper A3 by Dr.Zhidkikh et al.

Any of the formulas cited in the paper A7, i.e. formulas by Horton, Einstein. Lotter, Pavlovski, etc. are based on one of the following assumptions:

1. The mean velocity of each of the sub-areas is equal to the mean velocity of the whole area.
2. The resistance to flow of the whole area is equal to the sum of the resistances of the sub-areas.
3. The total discharge of the cross-section equals the sum of the discharges of the sub-areas.

These are underlining assumptions on which these formulae all are based.

The common procedure of these assumptions is the sub-division of the cross-sectional area. In order to derive a correct description of the physical behaviour, the sub-areas should be chosen in such a way that the flow within each area is governed by the type of roughness characteristic to the wetted perimeter assigned to that area.

The authors get results that differ depending on which formula they use. Particularly, the result indicated in Fig.2 of the authors' paper, which shows an increase of discharge with ice cover - an impossible result, as stated by the authors - but it seems to be compatible with Ven Te Chow's statement in his Open Channel Flow Book that some of the formulas result in negative friction factors.

A method of subdivision based on the assumption that the velocity distribution follows the logarithmic law for fully developed turbulence has been described in a paper "Head Losses Caused by an Ice Cover on Open Channels", Journal of the Boston Society of Civil Engineers, January, 1959, and I think a brief summary of this method outlined there I should give you now here.

What we see here in the next slide is a two-dimensional flow, a bottom where the roughness is described in this case by a Manning-factor. At the time when I developed these formulas I was more engineering oriented, now as I am more involved in research I would better use Darcy's friction factor. The upper boundary has a different roughness described by a Manning coefficient n_1. Now the velocity distribution within the two layers is described by the Prandtl logarithmic distribution law which for a rough turbulent flow states that the velocity is the function of the distance to the wall. Then using the equations for continuity the condition that the shear is zero when the two profiles join - in other words where the velocity is maximum - and using the condition that the flow is uniform - so that the slope of the energy line is the same - you can derive two equations, one of which gives you the ratio between y_1 to y_2 (the depth of the upper and lower layers) and also you get an equation relating the composite roughness to this ratio of depth. Now, the equation from the composite roughness which you see down to the left of the slide can be expressed in the ratio of y_1 to y_2 exclusively, so therefore this indicates that the composite roughness is a function only of this ratio. And this is the basis of my diagram which you saw on the first slide.

Now, there is a restriction to this. And that is: although the composite roughness is a function only of the ratio y_1/y_2 this ratio is a function of the total depth. And that is the reason for the limitation which you saw on my slide No.1. So that graph is limited in terms of depth if you need it for a high accuracy or for a depth less than 1 m.

And there is a question which was brought up by one of my German friends here: what happens at a slope?

Well, the velocity at a certain point - according to the Prandtl-distribution - is a function of the perpendicular distance to wall so the error we commit if the slope is not too steep is cos times the depth compare to the depth itself.And this error is very small. If you have a vertical wall of course you would have to look at it in a different way but the slope shown on the slide here is 1:2 which is a common slope in nature and in artificial channels.

I show here a slide on velocity distribution in a power-canal in Sweden with an ice cover. One feature is the thickening of the ice cover towards the banks. In the central part of the cross section the thickness is very small and then it increases towards the banks. Now, this ice cover is developed pretty much in the same way as ice develops on a lake. So it is not a cover produced by fractured ice. You see that the maximum velocity is found pretty close to the mid-depth. Thank you very much!

<u>Chairman:</u> Thank you very much Dr.Larsen. Who is the next speaker? Dr.Rouvé, please.

G.Rouvé: Mr.Chairman! Thank you very much, Mr.Larsen, for your comments. I think your remarks with the first slide was a misunderstanding due to the shortage of space in the articles. We refer to your paper a sentence ahead and the next sentence where we speak about the common roughness of ice surface and the bottom surface is not directly connected to the sentence ahead but I feel that it is quite important also at the bottom. Roughness is not unique over the whole width as the surface roughness is not common for the whole width. On your last slide you had the larger ice thicknesses at the borders where we certainly should have larger roughnesses. I feel that could be the result of the extension of this paper which we hoped to be ready today but due to some unexpected difficulties we could not finish up this paper. The main aim is now to get by adjusting an alfa value - if I could see the last slide please - and this value is either directly connected with the value in the paper of the Russian colleagues or connected to your value y_2 - with other words(....) which divides the upper and the lower influence of the roughness - we hope that we can get the same discharge as calculated by a common friction coefficient.

Now, we would be very grateful if you, Dr.Larsen, or somebody else could give us data because we expect as soon as this alfa value as a function of roughness and water depth is found we cannot only calculate the discharge knowing the ice cover or knowing the roughness of the ice cover but also - and that would I feel be much more interesting - if you know the discharge you can calculate the roughness of the ice cover.

Thank you very much!

Chairman: Thank you very much, Dr.Rouvé. Dr.Larsen. Please, Sir. You want to answer?

A.P.Larsen: Well, I just want to show you some results of actual measurements. Measurements made in the channel of which I showed the velocity distribution in the last slide. Here we made measurements in summer time to establish roughness of the bottom. And have measured 8 different discharges, shown here as points along the lower curve. The upper curve is based on 4 measurements for 4 different discharges in winter time when the channel was covered with ice. During these 4 measurements some 340 vertical sections were measured with current meters and the ice roughness was computed based on velocity profiles.

And then in terms of the Manning coefficient we found that the Manning n was 0.0192 for the ice cover. Then we computed the composite roughness based on the formula I just show you and found that the composite roughness was 0.027 and then we computed the composite roughness based on direct measurements of head loss and f and exactly the same results in between the limits of accuracy which was a difference in the third decimal. From this slide you see that the increase in head-loss is approximately 60 % with the ice cover. Now this whole research was undertaken in order to obtain some data because at that time we were designing a much longer canal in Sweden where the head-losses were quite important for the power-plants. And we used this approach and predicted that the losses in this channel would be about 100%

higher with an ice cover. The canal has since been constructed and measurements have been made and it has been found that for one part of the channel the increase in head-loss is 120 %, for the other part - the two parts are round 3,5 km each - we found an increase of 80-90 %. So these are the figures we can produce from Sweden today. We hope to do some more measurements and produce some other results soon. Thank you very much!

Chairman: Thank you very much Dr.Larsen! Dr.Rouvé, are you satisfied? If you do not answer, thank you very much.

G.Rouvé: It is surprising and I could not think about it that the Symposium on River and Ice may have such hot discussions. It is difficult for me to believe the remarks on Ven Te Chow's negative roughness and that the value could be larger than one. At the moment I do not see any possibility. On the other hand your increase of energy loss is certainly - you take the energy loss for the ice-free flow as 100 % - is not it? When you speak about increase? All right, yes, thank you very much.

Chairman: Thank you, Mr.Rouvé. Well, Ladies and Gentlemen, with this we conclude our morning session. Our discussions will be continued afternoon, before the closing session. Our second session or afternoon session will start at half past two.

Thank you very much, for your kind attention.

S E S S I O N O N S U B J E C T A (Continued)

2:30 p.m. January 17, 1974

C.F.Pimenta, Chairman
E.Kertai, Co-Chairman
Ö.Starosolszky, Invited Speaker

C.F.Pimenta, Chairman: Ladies and Gentlemen! We go to continue the presentation and discussion of papers on Subject A that we have started this morning. I am Professor Pimenta from the Technical School of the São Paolo University, Brasil. I am also director of the Technological Center, Water Hydraulics and Electrical Department of the Secretariat of Work and Public Services of São Paolo State of the Federative Republic of Brasil.

Professor Dr.Kertai is co-chairman, who is the Secretary of the Local Sponsoring Committee and also Head of the Department of Water Management of the National Water Authority and Professor of Hydraulics at the Technical University of Budapest.

Sometimes I will ask him to help me because my English is very little. My second language is French.

This morning we arrived to paper A8 and now we go to continue. Let us see paper A9. I ask for the author of this paper. Please, Mr.Thomas, would you introduce it? Is there someone to introduce this paper? Then the next paper is A10. I ask for the author of this paper to introduce it. Mr.Majewski?

W.Majewski: Mr.Chairman! Ladies and Gentlemen! The paper I am going to present has the aim to develop a method for calculating water temperature along the St.Lawrence River and to give a forecast or say, what result will be of certain methods proposed to increase the length of the navigation period or at least to keep it icefree in the whole winter.

The first slide shows here the longitudinal section of the Great Lakes and The St.Lawrence River and the section of the river which was under investigation. It begins just from Lake Ontario and contains several hydraulic structures. This section is about 260 miles long which is appr. 400 km. The whole section is shown from Lake Ontario, you see the point zero which was taken as a reference point at Kingston and then we go downstream through Montreal and this section was under investigation.

The section at the St.Lawrence is quite complicated here because it includes a river channel which is a true channel and then you can see farther some enlargements of the river, Lake St.Francis, Lake St.Louis and Lake St.Peter. All these have to be taken into account when we have started with this study.

The schematic river section looks like on this picture;

Above the horizontal line this shows the St.Lawrence River, the meteorological stations along the St.Lawrence River and below the points for the measurement of water temperature. The measurements of water temperature and ice service were started about two years ago for this study when it was initiated. The discharge of the St.Lawrence River is very steady. This is due to the influence of Lake Ontario which is a big reservoir not only from a hydraulic point of view but also from a thermal point of view. It is a very steady thermal stability. Then there is a dam about 62 miles from the lake which can control the discharge of the St.Lawrence River and then we have two power stations. The average discharge is 210 000 cfs and this is equivalent to 5950 m3/s. I am using here two systems of unit because actually this study was carried out in English units and most of the people here - I think - are accostumed to the metric system. Along this section it was investigated only one bigger inflow that is the Ottawa River with the discharge of 1130 m3/s which was actually taken into account in this study. We had here six meteorological stations which give us all meteorological parameters and we had also six points for water temperature which were nearly in the same places at the meteorological stations. Investigating the values of meteorological parameters along this river section we came to the conclusion that at the meteorological station of Montreal we get practically an average value for the whole section and therefore we used these values for our study. Here you have the run of air and water temperatures in Montreal which are shown as t_a and t_w and also the temperature at Kingston that is in the point zero. Now, the first point which we have to do is the evaluation of the heat transfer coefficient. And we did it for several months before freezing and in the fall and winter through October, November, December, January and February. To calculate heat transfer coefficients the following parameters were taken into account: evaporation, conduction, radiation, back-radiation and precipitation in the form of snow. They were calculated in BTU/ft^2 day and in Fahrenheit degrees which you see on the vertical axis and on the horizontal we see the difference between water and air temperature. The system developed for the calculation of water temperature was as follows: we divided the whole river section in sub-sections of the length of two miles, equivalent to 3.2 km. For each of these cross-sections we had the values of discharge which was practically constant changing only in one point at the inflow of the Ottawa River, then we had to calculate the cross sections, then average velocities, then the time for passage of water particles between the two cross-sections taking into account the length and the average velocity and then we calculated time, the cumulative time of passage. The formula which was developed for this calculation is given in the proceedings. I only want to emphasize here the point where we had to interpolate the air temperature for a given point. So we assume that the water particle is moving between two meteorological stations along the river and the time passes by, so we interpolated the air temperature according to time and distance between two stations.

First of all we had to make the verification of our model. From about two-three years of field measurements we took several periods of air and water temperatures in October, November, December, January, February and we calculated exactly what temperatures we obtained from our method. Of course, when I show you one of my examples on the picture on the top, you can see that we calculated the continuous line and then you can see the dots which show the points obtained from field measurements. Of course this is one of our best fits - usually given for verification. Some of our checks were not so good than this one. And then we wanted to find out what was the discrepancy of the measured and calculated temperatures and then we came to the conclusion that the result was the information on ice. Which was not taken in our system into account. That means the heat diffusion has here an important role. The other line on the graph above is the cumulative value of time which means the passage of water particles from point zero to the end of our investigated point - about 16 days. Now the picture below shows the air temperature interpolated and you also can see the discharge which is constant over the whole section. With the only change where the Ottawa River comes into the St.Lawrence.

Now, we in our study took three methods of improving our situation, the thermal situation of St.Lawrence. One was the so--called regimented channel, which means that some of the areas of St.Lawrence we could exclude from the flow by closing them by dams or by other hydraulic structures. Of course this could be done at places where it was possible from an engineering point of view. And the result of this thing was that we increased the flow velocity and also we decreased the water surface so we acted in a double way, we lowered the heat transfer to the atmosphere and we shortened the time at which water particles have flown from point zero to the end of our section. Some of these places are shown here on the picture and you can see the reduction of the water surface. Of course in our calculations we had to introduce new cross sections of smaller values. Now, the calculations of water temperatures in the St.Lawrence River we did for natural conditions and for partly regimented channel.

Here also you can see the influence of the second method which was proposed that means the increase of discharge. Because as I told before, at the beginning of the river section there is a dam which controls the flow and then there is a possibility to increase the discharge in certain limits. But we wanted to see what influence that will have on the extension of the period without ice or simply on water temperature. And on the picture above you can see that starting with a temperature at Kingston from 40 °F for different discharges the distance when the water temperature reaches the point of zero or the freezing point. And also you can see the influence of the initial temperature - 2°F at the beginning at Kingston - with practically quite a big difference in water temperature from the St.Lawrence River. Now the picture below shows the influence of the regimented channel - confining the river in a limited channel - and here you can compare these two lines with the picture on the top 210 and 300 000 cfs and you see the length until the water temperature reaches the point of zero.

Of course we came here to the conclusion that neither the regimented channel nor the increase of discharge can solve the problem.

The third method which was taken into account was the addition of waste heat from thermal or nuclear power-plants. What we here present is that heat addition increases the water temperature from the picture with 12 times 0.5 °F from 12 power stations with the capacity of 3600 MW. This was calculated on the basis that the efficiency of a power station is about 40 %, the discharge was 210 000 cfs and we used here the heat transfer coefficient 95 BTU/ft^2 day which is appr. equal to 466 Cal/m^2 day and given in centigrades. The first line above shows the run of the water temperature for natural conditions without heat addition and the line with steps shows the addition of heat and you can see that the whole section under investigation can be kept ice--free. The other solution here on the picture down shows the heat addition with partly regimented channel and you can see that even here starting with a temperature from Lake Ontario with 36 °F, that is 2.2 °C, the addition of heat at a rate of 10 times 0.5 °F leaves the whole section without ice. So this study actually gave the idea what can be done by using one of these three methods and this is the final conclusion, that the only solution which could give a good result is simply heat addition. Of course I am not discussing the feasibility of this solution and other disadvantages which may arise from having open water surfaces in a very cold climate which can have very far reaching effects, but this of course was not discussed in my study.

Thank you!

Chairman: Thank you Mr.Majewski! Mr.Günneberg would you like to make a comment?

F.Günneberg: I have three remarks on Mr.Majewski's paper.

1. The heat transfer coefficients in Fig.1 show quite a plausible dependence on water temperature, in that they are lowest in February, when water temperatures are lowest, though the average wind speeds play an important role, too. The dependence of the heat transfer coefficient on the difference t_w-t_a seems to be wrong. In addition to the turbulent exchange caused by wind there is an exchange caused by buoyant lifting of air elements that were heated when in contact with the warm water surface. This buoyancy effect rises with the temperature difference t_w-t_a.

KUHN (Physikalisch-meteorologische Überlegungen zur Nutzung von Gewässern für Kühlzwecke. Archiv Met.Geoph.Biokl.Ser.A. 21, S.95-122, 1972) finds the rise of heat transfer coefficient to be 3 %/deg.

2. The total heat transfer coefficient may rise, when ice formation begins. The ice formation modifies the heat exchange processes in two ways: a) The floating ice isolates the river thermally. The surface temperature of the loose collars of ice floes is close to the air temperature, the difference $t_{ice}-t_{air}$ is small, and so is the heat exchange. The inner parts of ice floes are closer to the water temperature, depending on the thickness and age of the floes, and the heat exchange is greater here. So when the ice coverage be 30 %, the thermal isolation may be 10 to 20 % only.

b) The ice structures protruding over the water surface enhance heat exchange in two ways: I. The surface is roughened, so that the wind stumbles over the obstacles. Thus the lowest centimetres of air are more intensely mixed, and the warmed skin of air in contact with the water is more rapidly replaced by cold air. II. The proximity of very cold collars of ice floes and warm open water gives rise to an intense buoyant exchange of air, bringing more cold air into sensible contact with the water surface.

The question now is, whether the intensification of heat exchange as described in b) will be compensated by the isolation described in a). The magnitude of effects depends on the form and coverage of ice and on the meteorological conditions. Possibly up[to a certain coverage the heat transfer is considerably enhanced.

3. The equilibrium temperature during an ice period may be about -10 deg. centigrade (air temperature -12 deg.). Adequately spaced power stations may keep the water temperature 10 deg. higher. If now the weather changes and the equilibrium temperature rises to 0 deg., the power stations will raise the water temperature to +8 deg. (the heat exchange coefficient rises too). In Western Germany water qualities are such that biologists strongly disapprove so high heatings up. So the power stations should have two cooling systems, once-through-cooling for the ice periods and cooling-towers for the remainder of the year. This on the other hand is unprofitable for the electricity producers.

Thank you!

Chairman: Mr.Majewski, would you like to reply?

W.Majewski: Actually, there were three points which I should answer.

1. Changes of heat transfer coefficient with increasing difference between air and water temperature.

This relation was based on the average monthly meteorological parameters using formulas adopted by other authors.The study was not specially concerned with changes of heat transfer coefficient and later average values were taken into account for calculation of water temperatures.

2. Influence of ice on heat transfer coefficient.

This was not specially investigated and in some cases of verification I only mentiond that the discrepancy between calculated and observed water temperatures might be influenced by the ice formation, i.e. the heat of fusion.

3. The influence of heat discharge into river.

This study did not concern with summer period and therefore I cannot give a precise answer. I quite agree that this problem should be also investigated for summer time from the point of view of environment. Thank you!

Chairman: Does somebody else make a question on this paper? OK. The next paper is A 11, "Entrainment of Ice Blocks - Secondary Influences" by Dr.Ashton. Please!

G.Ashton: Thank you, Mr.Chairman! Ladies and Gentlemen!

My name is George Ashton, I am from the Cold Regions Lab in Hanover, New-Hampshire. I would add my qualification because some of the data which I will show today came out from The University of Iowa. It was actually obtained when I was there and at that time I was perplexed by one part of it and I was not able to figure out what the solution was at that time; later I did and at the time Professor Kennedy, his student Uzuner and myself have communicated on it. I think we are closer to the agreement than when we started the problem.

The problem is a very fundamental one which deals with the similitary of the entrainment of a floating block or in a particular case of a given specific gravity ice. Historically, there is a certain development that deserves some recounting.

Some time in the late 50's (......) proposed that a criterion for ice jamming would be the Froude number. A conventional Froude number based on the depth of flow. This idea was subsequently extended and some support given to it by the studies of Pariset and Hausser and later of Michel. On one form or another of the entrainment of a single block.

May I have the first slide?

Before we go on I think it is worth pointing out that the very first thing that happens when an ice block comes down the river that it strikes the leading edge of something. Ordinarily it is an ice cover, it may be another obstacle such as a floating bridge or even various sorts of weirs.

Now, going into the problem: you have the thickness of the block, you have the length of the block, you have the depth of the flow a main velocity of the flow and that - as this will be talked later - is related by straight forward continuity relationship to the velocity that would be average under the block.

Finally, you have the density of the water and the density of the block which in the case of a solid piece of ice is well established but in the case of a cohesive frazil flock it is not so well defined, and may be much closer to that of the water itself. And finally another term is gravity that will affect the problem considerably. Now, this is the problem that Pariset and Hausser worked at and they concluded that the entrainment - that is the condition under which the velocity or depth conditions force the block to submerge or go under the cover or to stay floating in its original arriving position - was given by a Froude number, in their case a densimetric Froude number which they first defined with the length parameter of the thickness. They did not say that this was equivalent to a certain constant which comes out of the argument they used and then they put a multiplier k on it. And this was used by a number of authors. And this was explained in a number of ways.

Pariset and Hausser recognized that in the simplest case the phenomenon is equal with a simple submergence while the block remains in a horizontal position. And to get the relationship they got you simply balance the velocity pressure differences against the buoyancy of the block when it is in a horizontal position.

And all that you require is complete submergence before instability occurs.

They recognized that this did not always occur. That often the block turned. This would be indicated by this angle α which becomes nearly π after a while. In most cases it does this. However, they reported that the effect of this was to cause this coefficient to vary this k value from approximately 2/3, which was associated with rather cubic shape blocks to 1.3 with the very thin blocks. In other words, very thin blocks are more stable than are the very thick blocks.

This is where things were standing for some time.

Reported in 1972 but began in 1970 Mr.Uzuner working under the direction of Prof.Kennedy did a lot of detailed analysis on this problem, very detailed analysis. It was numerical and included the effects of the angle and integrated the pressure forces that would occur. The results of this study gave a great amount of data. By very carefully done experiments. And by the permission of Dr.Kennedy these data are available and they are very impressive in their scope because they cover a number of specific gravities - besides that of ice - ranging from appr. 0.5 to up very near that of ice. They also cover a wide range of thickness over height of flow of appr. 1/10 of the flow depth to 8/10 which becomes to be very meaningless. And these data as they presented them were very successfully used in prediction methods. However, it was predicted individually by the separate specific gravities. The top curve is the data for specific gravity of about appr. 0.5, the next one for 0.67 and then finally this is the one with specific gravity of 0.87 which is near ice.They then unified these data - they recognized that these could be unified better than to have separate plots and so they could use it as a prediction scheme. The whole thing resulted in a moment coefficient both as a function of the specific gravity of density and as a function of the thickness - length ratio.

At this point I started looking at the data and particularly at the analysis and I found it very good but also I found it very complicated. So I prepared a simpler analysis even by leaving out some details so that we would not have to go through this complicated analysis every time. And I simply did a moment equilibrium on that. I said that the weight of the block points downward, the buoyancy force acts upward, it rotates such that the point of instability occurs when the upstream leading edge of the block is at the stagnation water level. And then finally you have a pressure term which simply can be derived as a one-dimensional energy relationship and it might be more complicated when you go in extreme cases such as a deep flow and you certainly have a pressure difference there but it is local.

From these we go straight forward to a simple expression but with no indication what the ratio thickness over length would give. This presentation is a bit biased in my favour. We would go back to Kennedy's and Uzuner's presentation for a moment. The result of this is that you may plot the data of Kennedy and Uzuner on a densimetric thickness Froude number plot, this is the thickness over depth ratio. This is one plot if you study it carefully. The next two plots have identical ordinates and abscissas but data of three different specific gravities. There are some data here represented by these particular symbols which are the ones that tend right above the line. The straight line is equivalent to the Pariset and Hausser line with k = 1. The other two lines are variations in the assumptions that you make of the depth at which the rotation occurs. I won't go in the details of those - as you can see it is not too much difference in the results and certainly the scatter of the data causes some differences.

Now if you take all these three plots of data and superimpose you see that they lie in a band that is shown by these vertical lines. And it lies quite close to this very simple solution that comes out from a simple moment equilibrium analysis. However, those few points which I showed you are outside of this envelope and are associated with very thin blocks. Otherwise there is a small effect of thickness over length or thickness ratio but not very much. One set of data suggested that perhaps if you come very close to the density of water or as you become very thin in the block either in terms of thickness over length or thickness over depth of flow that perhaps they not behave the same way.

And accordingly, myself and a man working with me did some experiments with very thin blocks. And we found essentially no difference. Which leaves this one data set unexplained. At least at the moment. We did find one thing that was of interest and that is that we did not get any difference in the critical velocity depending on whether the block was initially at rest and the velocity of flow speeded it up until the instability occured. We found no difference in the behaviour in that case and in the case in which a block was floated on the water upstream and came down and turned under.

I might further add, and this is not in the paper that the fact that the initial block is entrained, as is given by this relationship of the data in the lower line, does not necessarily mean that you cannot form a stabil cover. We found that at velocities intermittent between this line and this top line that the blocks underturned and stucked. In a fashion that we could measure that the Pariset - Hausser criterion with k = 1 was correct. So we are now here you have instability ocourred but the way it occurs results in a secondary mode in forming a new cover with the thickness that it should have for that velocity. Now, hopefully you can be convinced that the regional depth Froude number is incorrect and the thickness Froude number is the correct one. All that you need is to multiply that left ordinate by the equare of the thickness - length ratio and recover yourself with the same data to a densimetric depth Froude number and you see that the data line is in the similar band and you see the conventional plot of the data.

Now, what I want to conclude from this (......) in
A peculiar way to do the analysis. In my analysis, Kennedy's analysis and in the previous analysis the critical assumption was the (......) when the top leading edge became submerged. This not necessarily has meant that the entire block was submerged. And you may write down the flow-equations aligned for other reactions and further constrains in a classic stability manner but they become not handlable and I chose not to solve them. There was very low effect found of the thickness over length - ratio, anyhow one must stress uncertainty with very thin blocks in very deep water depth. Finally, I wish to apologize for not to be close to the subject but I wanted to show a picture of winter naviga-

tion as it occurs very close to my home, and very close to Dr. Kennedy's laboratory and rather in the middle of the United States in February, two years ago. I thank you if you found it interesting. In this case a private company decided that it wanted to deliver a cargo of phosphate in winter, when no ships were operating and navigation had ceased. I think you will find this different to other transportation systems in many places. Barges are 200 feet long, there are six of them here, it is too wide and they are pushed by one tug-boat of 3000 HP. We were successful in breaking 9-12 in unbroken ice, unbroken before we got there; after we got there, there was a course of broken ice for the next boat and we also found that there were a lot of other boats moving cargo up as soon as the path has been cleared. The reason I say this is because we had times when navigation was difficult in the ice. We were laterally stopped. And the ability of these tug-boats simply to run ahead as an ice-breaker was quite notable and it occurred in many cases that we had no problem at all in clearing the path and in going back in taking the barges on. And I think the total length percentage of the reach where there was difficulty was only in the order of a few percents. This is a very attractive way to operate in the ice. Still another prospective before I quit, I will show you a view from the front of the barge. I want to point out only one striking thing; that the breakage of ice on the first pass through the cover extended about 2 inches aside of the barge. It left a very clean track. However, the next passage left a very wide track because the by-way that the diverging way-pattern originating at the bow will at some distance outfirm the barge. Subsequently the entire track or path will full with broken ice. That was I wanted to say to you and I would be happy to answer any question. Thank you.

Chairman: Thank you Mr.Ashton. The next paper is A 12. Mr. Degtyarev, please.

V.Degtyarev: Mr.Chairman! Ladies and Gentlemen! Let me introduce myself. My name is Degtyarev, I am professor of Novosibirsk Institute of Water Transport. I shall read the report by Balanin and Borodkin professors of Leningrad Institute of Water Transport. They are absent from the symposium* ......

Thank you!

Chairman: Thank you Mr.Degtyarev! Is there any question about paper A 11 by Mr.Ashton? Mr.Kennedy, please.

J.F.Kennedy: I am Kennedy from the United States. I think Ashton's contribution of showing how this rather converse relation developed by him and myself can be simplified is worthwhile, and you are willing to accept this degree of approximation, which is very adequate in most cases. You do not need to consider the links effect. It is interesting also to consider how the links effect enters and either for the vertical sub-

* The text is published in the volume "Contributions to Subject A".

mergence mode of sinking or the underturning mode of sinking which have been analyzed by earlier investigators in Canada and also by myself and Ashton - in either case the links effects enter as a result of the rather massive flow-field around the upstream end, due to flow separation and reduced pressure region and so on. Now, using Uzuner's analytical model you have one additional tool which you can use to take account of this effect of low pressure around the upstream end. It may not be too important, as Ashton's results indicated it apparently does not go into the larger values, in which case you can use a single relation in terms of the densimetric Froude number. One other comment concerns this no-spill condition, which also Ashton mentioned and that is that this is another rather artificial device which we used as a substitute for the correct and complete analysis which we should do. As he mentioned that was found rather difficult. I recently tried to begin too to undertake to ascertain, I used both the moment and the vertical force equilibrium when underturning or sinking has occured and I discovered only that I had not becoming smarter than I was two years ago as I could get a reasonable close function this time neither.

Chairman: Mr.Ashton, would you like to reply?

G.Ashton: I do not make a reply but I want to comment some observations of Mr.Kennedy. One is that there is still a question about the very thin blocks. We found some very difficult problems on the real numbers, on what really happened. The very thin blocks in the order of 2/3 cm thick seem to behave differently. That is it takes a higher velocity to entrain them as this is predicted by the other data. And so there is a question there, this is a rather important question, many of the ice-floes that come down are very thin relative to their length. Even thinner than those weirs, and they may come down with their thickness 0.02 relative to their length. So it is still an open question, there is quite a lot of room that it may be possible to do a limited analysis, just let limit yourself to very small values of t/L ratio and perhaps to consider Kennedy's analysis to look over parts of it. Thank you.

Chairman: Any question about paper A 12? Mr.Kennedy,please.

J.F.Kennedy: Just one short observation on this interesting scheme that has been proposed. I have observed in flying over the Mississippi River and the Missouri River in the United States that there is a point where side-jet discharge of a power-plant along the river came in. The heated water of these rivers makes usually its own rather narrow way like a channel. Ice covers almost entirely the river except only the very site of the discharges. And I think one might be well advised - he who is going to pursue this scheme - to seek designs which would undertake to maintain the stratification, to keep the heated water at the surface and then rather be content by the ice channel which makes itself. And I think this way you are quite right to protect the main body of the river from the temperature-rising effect.

Chairman: Mr.Degtyarev! Would you like to reply?

Chairman: Now, we start discussion about Subject A.

Mr.Tsang please, you like to comment?

G.Tsang: First of all, I wanted to make my comment this morning but since I am now here I would like to say something about this morning's paper about the discharge variation between a river with and without ice-cover. The author Dr.Rouvé has shown in his paper a curve which shows the ratio of too many coefficients, the ratio of n_1/n, as a function of discharge ratio. Last year I had a recirculating flume and I just wanted to see what happens if I have an ice cover outside under natural conditions. I have a motor driving the water going around and around, I leave the flume outside and then I observed what happens. First, of course, the ice cover was formed. Without ice cover the head difference was about 1 mm or so. And when the ice cover was formed, this head increased. The flume was a glass-flume so I could observe how the air was trapped underneath the ice cover. And you can see the air bubbles gradually going down underneath the ice cover. In fact, it seems the trapped air has quite an influence on the underside roughness of the ice cover also. And then we continued the experiment, and in the experiment the power input was tested. The input power lead to the motor was constant, but however, we found the velocity gradually increased especially when you have frazile ice, and this frazile ice was formed in the size of 2-2 1/2 cm. It then stuck to the bottom, which was gravel in uniform sizes, and also stuck to the top. And when this thing happened the resistance increased by a factor of an other order of magnitude and I think this is extremely important, and probably a lot of ice will be overloaden due to this under natural conditions.

Talking about the comment on this morning paper, the author professor has talked about the sediment transport effect of frazile ice. We have a research site in a river in Ontario, in Canada and in a straight section we have picked samples in four cross-sections throughout the whole winter. And then we found, that when frazile ice is formed and a secondary current in the river induces a double-vortex, this takes the frazile to the middle and so in the middle you have an island, more or less an island made up with frazile and all this in a river of the width of 50-60 metres. Now we went to the....... River which was 500--800 m wide - very wide river- and we observed that the secondary current transported the frazile ice again in the middle. Now when frazile ice goes in the middle, this accumulates there, and I tried to trace whether it goes down with the current. And we have noticed the frazile accumulation in the first section, gradually increasing in the second section but it never reached the third and fourth section. I think it just went by melting and by eroding away. All this information was gathered in Canada by the Water Survey of Canada, when we took measurements of ice during winter discharge, making holes in the ice to be able to measure also the discharge. And sometimes, when we see a frazile pack always almost in the middle going right to the bottom and on the two edges all is clear and when then we take a measurement in the clear water planes and we go also upstream not far away, to a place which has no frazile ice and take another discharge measurement, they are about 40 %. Why is that? Frazile ice becomes sometimes a porous material. You have water passing through. Sometimes the frazile would behave like a sediment carried away by the water, but sometimes it will baheve like a porous material usually as it has been accumulated at a certain place after some time. We call this tracing effect, when ice is accumulated like a sand pack. Small channels are developed in this case in the ice through which water may pass through. I think this would be a very interesting thing, to study further. And probably this would rise a question to you in your future work. Thank you.

Chairman: Somebody else to make a comment? No? I do.

In my country, in Brasil, we have no ice problem, except to find enough ice to keep our whisky cold. But we have another problem that is very similar to that of ice covers and ice jams in rivers. In some of our rivers an aquatic plant called "aguape" grows. This plant has its roots in the river bed, and is connected to the main floating part by a long stem. During floods the increase in stage causes the floating part of the plant to rise, and the stems are broken. The plants then float downstream until they reach a bridge, or some other obstacle, where they accumulate. They then form a "green cover" on the stream that is very similar in its behavior to an ice cover. These "green covers" may become several feet in thickness and may cause large increases in the water stage.

This plant produces a beautiful flower, and many tourists are tempted to take samples home to plant in their own gardens. However, this is a very dangerous practice, because these plants spread and grow very fast, and can soon infest the river of the new location - bringing a Brazilian problem to the site.

For example, the Nile River has recently this problem, as the result of thoughtless tourists.

I would like to take this opportunity on behalf of my government to invite the participants of this Symposium to come to São Paulo to attend the 16th Congress of the IAHR which will be held in July 1975. The exact dates are July 27-August 1. I look foreward to see you in Brasil. Mr.Starosolszky, would you like to summarize the results of this session? Thank you.

Ö.Starosolszky: Thank you,Mr.Chairman, giving me the privilege to make a summary about the results of our morning and afternoon discussions. Of course, may I emphasize, this is very usual in engineering practice, when we do not have a proper and accurate method to solve the problem to use some approximations. Now I feel somewhat, that I shall use only an approximative method for making a summary on this subject. We had many interesting discussions and papers concerning different problems of ice-hydraulics and interrelations between fluvial and ice hydraulics. As we recognized immediately now, from the discussion of Prof.Pimenta,there are similarities all around the world where our knowledge concerning ice may be used. Let me mention e.g. that there is a very big similarity between the motion of timber on a river, that means logs on a river and ice. And our knowledge concerning the ice-hydraulics may be used in other different subjects. I have here four points, as the main tasks for future research. Let me refer to them.

First, the observations concerning ice phenomena may be judged as rather poor, when we want to use some mathematical modeling on ice formation, ice drift in ice jamming. As a consequence of this statement, we need an improvement of the observation methods including instrumentation. And of the subjects of observation as well. For solving the different problems, based on different mathematical models - some of these have been introduced - we need quite a lot climatological data. Because the ice regime is depending on the atmospheric conditions and the World Meteorological Organization has the responsibility on problems of operative hydrology, it may be proposed to find some contacts with this governmental organization. The WMO, as a governmental international agency may ensure the unified methods of observation. What we need when we want to make some comparison concerning the observations and the results on different rivers of the world.

The second conclusion maybe as follows: the cooperation in the field of ice-formation, ice-floes and the breakup would be encouraged in all countries situated in a common catchment. The information system may be based on telereporting or telemetering. I think an example in the Danube Basin would serve as a good example of such an international cooperation. This would be a useful tool making preventive measures against ice damages.

The third conclusion: parameters concerning ice properties have to be investigated more intensively in order to obtain data which we need when using ice hydraulics for forecasting of ice phenomena. Investigations on cohesion, strength and of other mechanical properties of ice would be especially welcome because of the proper values we need when using different hydraulic computations concerning ice problems.

The fourth and the last one which was many times discussed: the thermal power stations and the connected outlets of cooling waters may change the ice regime of the rivers. Therefore, a special care has to be taken on the observations in this respect, and take into consideration their effects on winter-navigation. I think, that today's morning and afternoon sessions have been good contributions to coordinate future research and for a better understanding of ice-phenomena. Thank you very much.

Chairman: I close this session with many thanks to the authors, many thanks to the general reporter Mr.Starosolszky, many thanks to our Cochairman Mr.Kertai and many thanks to all participants of this symposium. And many thanks to the Organizing Committees and excuse-me for my very bad English.

(On the next pages two late papers on topics belonging to Subject A are published, and also an Addition to Paper A-3)

ADDITION

TO PAPER A-3 "KINEMATICS OF FLOW UNDER ICE COVER"

by ZHIDKIKH V.M., SINOTIN V.I., GENKIN Z.A.

submitted by K.Zvorykin

Among various problems of ice hydraulics those of kinematic structure of plane pressure turbulent flows are of particular interest. The experimental results presented enjoy many practical applications in such leading branches of economy as hydropower engineering, water transport, water supply, etc. However,the problem of calculation of flow kinematics under ice cover has not been yet solved adequately partly due to lack of perfect design methods and partly due to some difficulties in choosing initial data, and particularly ice cover roughness coefficients.

To simplify calculation formulae some investigators (I.I. Levi, K.V.Grishanin et al.) proceeded from equations of the semi-empirical theory of boundary layer. In terms of this theory the kinematic characteristics of flows under ice cover are governed only by ratio of the ice cover roughness coefficient to the river bottom one.

In the paper submitted to the Symposium the authors employed equations of motion, in which molecular viscosity is replaced by eddy viscosity. The coefficient of turbulent exchange is assumed to vary stepwise at the depth of maximum velocity and is calculated by the Prandtl-Kármán formula. As a result, relationships have been obtained for the basic features of kinematics of flow, viz.: flow velocity, water discharge, the position of the maximum velocity plane and turbulent exchange coefficients.

It should be emphasized that the kinematic characteristics of flows covered with ice depend on the absolute values of roughness of the ice cover and the river bottom rather than on their ratio, which is in full agreement with experimental results presented in the paper.

Similar effect of boundary resistances on the internal structure of certain system has long been known in a number of sciences, for example, in the theory of heat transfer.

In due time the under-surface of the ice cover alters (becomes smoother). In other words, the ice cover as well as the river bottom may be considered as "erodible" surfaces. However, in contrast to the river bottom, the "erosion" of the ice cover results from thermal rather than mechanical effect of the flow.

The above dependence of the kinematic structure of flow on the roughness of boundary surfaces enables one to assume that in flows under ice cover occurs mutual "adjustment" of the ice cover and the river bottom roughnesses.

Further quantitative study of this phenomenon is required. Besides, laboratory and field investigations should be carried out to estimate roughness coefficients of the ice cover.

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ANALYSIS OF CONDITIONS FOR SNOW ICE FORMATION AND ESTIMATION OF ITS THICKNESS

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ABSTRACT

The present paper deals with the conditions of snow ice formation: overloading of the ice cover and the appearance of cracks and openings in the ice through which the snow is flooded by water. The paper contains formulae for computing distances between thermal cracks and determining the critical values of water level fluctuations causing the formation of ice cracks near the shore.

The process of snow ice formation is divided into two phases: the flooding of the snow-ice cover and freezing of water-saturated snow. The author suggests formulae for the estimation of the flooding depth and area. The paper presents the estimated data on the depth of flooding and the thickness of the frozen snow saturated with water.

It is shown that the intensive snow ice formation occurs in the regions of man's activities facilitating ice cover flooding water level fluctuations in the upper and lower pools of hydroelectric plants, ice-breaking and exploding, thermal openings in ice at the site of industrial waste discharges, ice holes made by fishermen, etc.

Rivers, lakes and reservoirs of the USSR, especially of the north-west, are often subject to the formation of snow ice due to the freezing of water-saturated snow on the surface of ice cover. In some water bodies the formation of snow ice is equal, sometimes even dominating, factor of the increase ice cover thickness: its portion in the total "gross" ice thickness is 50% and more.

The main and obligatory condition of snow ice thickness increase is thick snow cover formation on the ice, which causes ice overloading, i.e. snow weight is greater than the lifting capacity of the floating ice cover:

$$h_s \rho_s > h_i (1-\rho_i) \qquad (1)$$

where h_s and ρ_s - depth and density of the snow cover;
h_i and ρ_i - depth and density of the ice cover.

The second condition of snow ice formation, which is no less important, is the occurrence of cracks and openings in the

Derugin

ice cover which discharge water to the ice surface. The main factors of ice crack formation are as follows:

(1) thermal deformation of the ice cover;

(2) water level fluctuations;

(3) man's economic activities;

Thermal deformations result in two types of cracks: shallow fracturing and deep splits. The shallow fracturing is conditioned by sharp daily changes in the air temperature and is characteristic for snowless periods. Shallow cracks penetrate only the upper layer of ice cover, thus being non-responsible for water leaking out into the ice cover. Deep cracks are formed in case of stable fall or rise of temperature: they are wedge-shaped and come through the whole ice cover. Deep wedge-shaped cracks are explained by the deformation of the ice cover that tends to bending as the result of thermal compression or expansion of upper layers, the sizes of the lower layer remaining unchanged. As a first approximation it may be assumed that the surface of a thermally bant ice cover has a slightly curved cylindrical form which makes it possible to consider the interaction of forces taking a beam with a rectangular cross-section as an example. The following equation will be true for a bent freely floating ice beam:

$$P'x_1 + P''x_2 = \frac{h_i^2}{6}\sigma_t \qquad (2)$$

where the left part presents the sum of bending moments of forces (P' is the load at the place of the beam rise; P'' is the force acting at the place of the beam lowering; x_1, x_2 is the

Derugin

distance between fulcra and the beam centre), while the right part presents the balancing internal tension (σ_t is the tensile force at the beam surface; h_i is the ice beam thickness).

From the hydrostatic balance conditions of the cambered floating ice beam and geometric relationships we obtain the values P' , P'' , x_1 , x_2 , deriving the following equation after substituting these values in (2):

$$\sigma_t = \frac{L^4 \gamma_w}{4.1 R h_i^2} \tag{3}$$

where L is the half length of the beam (distance between cracks), γ_w is specific gravity water; $R = \frac{h_i}{\alpha \Delta t}$ is the radius of the beam curvature (α is the thermal coefficient of the beam linear expansion, Δt is the change in the beam surface temperature).

The formation of cracks is probably connected with the fact that tensile forces at the ice cover surface reach their critical values, i.e. $\sigma_t > \sigma$ (σ is the temporary resistance of ice to tension). Formula (3) makes it possible to determine the shortest distance between the through cracks (L) for specified σ, R and h_i .

The water level fluctuations cause the formation of bank cracks. The critical value of lèvel fluctuations (ΔH) for the known ice thickness (h_i) at which the fracture of a floe takes place, may be computed by formula

$$\Delta H = 2.8 \sqrt{h_i} \tag{4}$$

Formula (4) was obtained in accordance with the theoretical research made by B.V. Proskuryakov and V.P. Berdennikov.

Derugin

Water also comes out to the ice surface through cracks and holes formed as the result of man's economic activities such as water level fluctuations in upper and lower pools of hydroelectric power stations, ice holes cut by fishermen, air-holes in zones of active warm industrial water discharging, construction of bridges and roads on ice, etc.

The process of snow ice formation is divided into two qualitatively different and strictly successive stages:

(1) Submersion of snow-ice cover by water;

(2) Congealing of water saturated snow.

At the first stage of snow ice formation process it is necessary to determine the depth of snow submersion and sizes of submersion zone. When water freely comes out to the ice cover surface, the submersion takes place till the hydrostatic equilibrium is established, i.e.:

$$P_1 + P_2 + P_{a.b.} = P_3 + P_4 \tag{5}$$

where P_1 is the lifting force of submerged ice; P_2 is that of submerged snow; P_3 is the weight of snow above the submersion level; P_4 is the weight of capillary water ascending above the submersion level; $P_{a.b.}$ is the elevating power of air bubbles in submerged snow.

After substitution of values $P_1, P_2, P_3, P_4, P_{a.b.}$ in (5) and transformations made, the following equation for computing the submerged snow depth (h_{sub}) is obtained.

$$h_{sub} = \frac{h_i \rho_i - 0{,}084 h_i + \alpha_c h_c}{1.092 \rho_i + A} \tag{6}$$

where h_c is the capillary rise of water in snow; ρ_i and ρ_c are the densities of ice and snow, respectively; α_c is the average

Derugin

water content in 1 cm^3 of the capillary fringe; A is the lifting capacity air bubbles in 1 cm^3 of submerged snow. Values d_c and A have been determined experimentally: d_c = 0.44 g/cm^2 (when h_c equals 2 cm to 10 cm), A = 0.03 g/cm^3.

If the submersion depth computed by (16) is more than the snow depth $h_{\text{д}}$ (which is senseless), then it should be assumed that $h = h_{\text{д}}$. The submersion is accompanied by snow settling caused by decreasing mechanical strenght of wetted ice crystals. The settling coefficient of wetted snow, being the ratio between the depth of wetted snow layer and the depth of this layer before wetting, varies within 0.6 - 0.8 depending on snow density and some other factors.

Applied to 17 cases of snow ice formation at Klyazma Reservoir when water was more easily going out to ice surface during winters of 1956-59, formula (6) gave a + 2cm deviation (1.3 cm for absolute values) as compared with the observed depth, the sign taken into account.

A free submersion of snow ice cover takes place only when the air temperature is about $0^{\circ}C$ which does not last long in winter. At low temperatures the submersion level does not always reach its possible limit since the cracks through which water goes out to ice are blocked by ice reefs or completely frozen. That is why the velocity of water expansion over ice under snow is of great importance in submersion process.

The formula for computing the submersion zone has been obtained on considering the equation of water motion in the

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horizontal capillary:

$$\frac{d}{d\tau}\left(M\mathrm{v}\right)=P \tag{7}$$

where M is the mass of moving water, V is velocity, P is driving force, τ is time.

Water flowing through a capillary is affected by the following forces: hydraulic head P_H, hydraulic resistance P_η and suction force of wetting liquid P_Δ.

Introducting values P_H, P_η and P_Δ into (7), we obtain the following differential equation:

$$\frac{d}{d\tau}\left(\ell\frac{d\ell}{d\tau}\right)+\frac{8\eta}{\rho_w r_c^2}\ell\frac{d\ell}{d\tau}+g\left(H+h_c\right)=0 \tag{8}$$

which is solved as follows:

$$\ell=r_c\sqrt{\frac{\rho_w g(H+h_c)}{4\eta}\left(\tau+\frac{\rho_w r_c^2}{8\eta}e^{-\frac{8\eta}{\rho_w r_c^2}}-\frac{\rho_w r_c^2}{8\eta}\right.} \tag{9}$$

where η is water viscosity coefficient, ρ_w is water density, g is gravity acceleration, r_c is capillary radius, ℓ is the distance passed, H is hydraulic head.

Results of computing by (9) correspond quite satisfactorily to the data of experiments and observations.

The dependences considered do not take into account the thermal conditions that obviously influence the velocity of water motion through snow and submersion depth. Strictly saying, these dependences are only applicable when the

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temperature is about $0^{\circ}C$ or a little below.

The data obtained from experiments and theoretical research enable to make several gradations of thermal conditions and corresponding velocities of water expansion through snow for an approximate estimation of the process of snow-ice cover submersion.

1. At the air temperature of $0^{\circ}C$ to $-3^{\circ}C$ the motion of submersion front may be computed by (9). However, the front will not move slower as it remotes the original source of water appearance at the ice surface since the front movement is usually followed by appearance of new sources close to it. Under these conditions the submersion front moves at the distance of 20-40 m a day.
2. At the air temperature of $-3^{\circ}C$ to $-10^{\circ}C$ the submersion front passes a 6-10 m distance a day.
3. The air temperature being $-10^{\circ}C - 20^{\circ}C$, the front covers a 4-6 m distance a day.
4. At the temperature below $-20^{\circ}C$ the submersion of snow by water and formation of snow ice do not practically occur.

The second phase of snow ice formation process is the freezing of water saturated snow. When computing the freezing of water-and-snow mixture at the ice cover surface, it is necessary to take into account some peculiarities that distinguish this process from an analogous process, i.e. the pure water freezing.

Derugin

1. The water-and-snow mixture has a solid phase (ice); consequently, in the process of freezing 1 cm^3 of the mixture will liberate less heat than that of pure water.
2. Heat conductivity of a frozen mixture layer is smaller than that of pure water since it contains a considerable number of air bubbles.
3. Heat flux coming to the lower surface of the ice cover does not influence the mixture freezing.

O.Devik's simplified formula of ice thickness has been applied to compute freezing of water saturated snow.

Taking into account the above peculiarities, the formula will look as follows:

$$h_{si} = -\frac{\lambda_{si}}{\lambda_s} h_s + \sqrt{\left(\overset{\circ}{h}_{si} + \frac{\lambda_{si}}{\lambda_s}\right)^2 + \frac{2\lambda_{si}}{\tau(\rho_{si} - \rho_s)} \int t_s \, d\tau} \qquad (10)$$

where h_{si} is the depth of a frozen layer of water-and-snow mixture (snow ice); $\overset{o}{h}$ is the original thickness of snow ice; λ_{si} and λ_s are heat conductivities of snow ice and snow, respectively; ρ_{si} and ρ_s are densities of snow ice and snow, respectively; is heat of ice formation; t_s is the average temperature at snow surface for selected time interval; τ is time.

Verified computations using (10), the results of which are presented in Table I, satisfactorily correspond to the data of observations made at the Krasavitsa Lake (Leningrad district):

Derugin

Table I

P e r i o d	Snow ice thickness, cm	
	designed	observed
20.Jan.-1.Feb.1955	4.5	5-6
8-10 Feb.,1955	2	2-3
10-21 Feb.,1955	13	15-16
20-31 Dec.,1955	13	11-12

Water-saturated snow usually freezes rapidly, but sometimes (after abundant snowfall or at pre-spring period) the freezing is prolonged. In these cases it is expedient to compute freezing or to examine the ice cover thoroughly, since the unfrozen snow slush considerably deteriorates the working conditions of passages and sharply changes the character of ice break in spring.

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SECTIONS FOR FLUVIAL HYDRAULICS AND FOR ICE PROBLEMS
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SECTION OF INLAND NAVIGATION
INTERNATIONAL SYMPOSIUM ON RIVER AND ICE
Budapest 1974 Hungary

HYDROMETEOROLOGICAL CONDITIONS OF SPRING ICE JAM FORMATION ON THE DNIESTER RIVER AND FORECAST OF MAXIMUM ICE JAM HEIGHTS

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ABSTRACT

The paper deals with the process of the Dniester breaking-up and ice jam formation in spring. The accepted breaking-up process model is used as the basis for determining the main factors of spring ice jam formation responsible for jam dimensions at different years.

These factors include flood flow, ice cover strength and thickness of ice jam accumulations in winter. The relationship obtained enabled to develop the forecast of maximum ice jam heights for several points on the Dniester-river. The forecast is based on computing the ice strength from meteorological data and flood flow from observational data obtained at river head and some tributaries.

The breaking-up of the Dniester-river is followed by ice jam formation on the stretch between the town of Galitch and Dubossary Reservoir. By the scale and frequency of ice jam events the Dniester exceeds even northern rivers. The floods caused by ice jam overflow the populated areas in the river valley and bring forth much damage. That is why much attention is paid to studying the Dniester spring ice jam in order to develop preventive measures and methods of forecasting.

The Dniester originates in the north-eastern Carpathians at the altitude of 760 m. The river stretch from its source to Galitch presents a mountain river type. Within the greatest part of the stretch liable to ice jam the Dniester flows through a narrow valley with steep slopes and poorly developed floodplain. The average gradient varies within 0.1-0.5 ‰ , but at numerous shallows it falls considerably. The climate of middle Dniester is rather unstable. In winter the thaw periods frequently occur causing a repeated formation of ice cover. Sometimes the ice thickness reaches 50-60 cm.

The Dniester breaking-up starts at the river head and goes on downstream which makes possible ice jam formation despite the southern situation of its basin. Ice jam events are also determined by the morphology of river bed and valley. Numerous bed obstacles such as alluvial cones, islands,channel constractions and abrupt bends hamper the downstream transport of ice and form the centres of jam piling-up. The Dniester

Chizhov-Buzin

stretch from Galitch to Dubossary counts 36 places liable to ice jam formation.

The Dniester is also characterized by winter ice jam events formed as the result of the river breaking-up in winter. These winter ice jams affected further by cold form the frozen ice accumulations with the depth of 1-3 m. These accumulations do not cause dangerous level rises, but considerably hinder the ice drift during spring breaking-up forming sizeable ice jams at many river points (Fig.1).The spring breaking-up accompanied by ice jam events takes place during February-March period or the first half of April.

The jam formation is a very complex process, depending on many factors. The factors permanent in time include those determining the conditions of ice transport on different river stretches, while the factors varying in time are presented by hydrometeorological peculiarities of breaking-up. Among the variable factors the flood intensity, freezing conditions, ice thickness and others are usually taken into account. However it is rarely possible to obtain satisfactory dependences between ice gorge thickness and one of the above factors.

When studying the Dniester ice gorges it has turned expedient to schematize the breaking-up process for making clear the factors that determine spring ice jam formation under particular conditions.

Generally the breaking-up of rivers occurs as the result of interaction between thermal and mechanical factors.

The thermal factor causes ice melting and its strength weakening, i.e. it determines the degree of ice cover stability. The mechanical factor is the sum of forces affecting the ice cover destruction, hummocking of ice floes and their transport along the river.

As a criterion of ice cover stability may serve the value of its integral strength:

$$\Omega = \int_h^0 f(\sigma)\,dh \tag{1}$$

where h is the ice cover thickness, σ is the temporary resistance of ice to compression, flexing or cutting. For the analysis of river breaking-up process the flexing resistance is preferable as the most stable characteristic usually determined in field investigations.

In spring the ice cover transverse strength becomes equalized, therefore parameter σh may be assumed with a reliable accuracy as an integral characteristic of ice cover strength and its potential resistance, that numerically expresses the thermal factor.

The main force affecting the ice cover is the pull force of the stream.

$$\tau = \gamma R J = \gamma \frac{V^2}{C^2} \tag{2}$$

where γ is the water volume weight; R is the hydraulic radius, J is the water surface gradient, V is stream velocity and C is Chezy's coefficient. In a first approximation for a particular river stretch the mechanical

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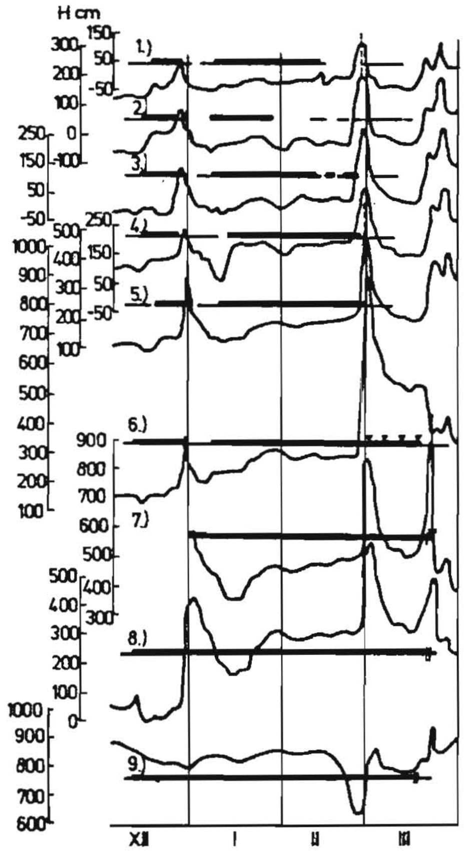

Fig.1. The combined graph of the Dniester-river stages, 1967-68.
1 - Galitch; 2 - Nizhny; 3 - Zaleschiki; 4 - Zhvanets; 5 - Mogilev-Podolsky; 6 - Soroki; 7 - Grushka; 8 - Kamenka; 9 - Rybnitsa.

factor is the function of water discharge or level.

The comparison of schedule graphs of the ice cover strength and those of water fluctuations (Fig.2) gives a good presentation of hydrometeorological conditions, under which the sizeable ice jams are formed on the Dniester. All years with spring ice jam events on the Dniester differ from each other by meteorological peculiarities. At the beginning of spring flood development an intensive rise in temperature frequently accompanied by rainfalls causes an intensive snow melt, thus determining the flood wave formation. At this period the ice cover strength is intensively weakened. If such weather regime does not change until the flood has passed the mid-river stretch, the ice strength to this moment is so lessened that no considerable ice jam is formed even if the ice cover thickness is great. The breaking-up like that above took place in 1950 and 1956. But when during the flood formation period the rise in air temperature is followed by its fall, the weakening of ice strength ceases or is even restored due to freezing. The situation comes when the great values of discharges are combined with those of ice cover strength. These were the causes for an intensive ice jam formations in 1953, 1954, 1965, 1968 and 1969.

The breaking-up process judging by observational data on the Dniester river develops as follows.

The temperature rise period initiates the process of ice cover weakening and water level rise. Shore leads appear

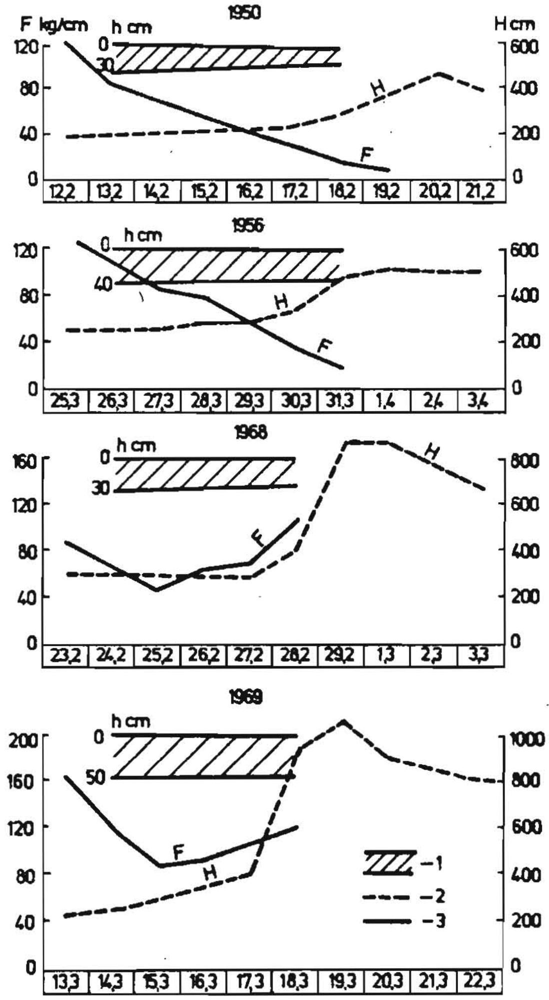

Fig. 2. Schedule graphs of water stages (2), ice strength (3) and ice cover thickness (1) The Dniester-river at the town of Soroki.

and ice tears off the banks. Stream forces cause the tensions in the ice cover that concentrate at the sites of ice cover contact with the banks. At this time the ice cover is subject at different sites to compression, expansion and flexure. The initial stage of breaking-up is predominated by tensile and bending stresses depending on the stream velocity, the length of the stretch where ice is torn off the banks, channel width and meandering. At the places where these tensions exceed the temporary resistance of ice, the ice cover is destructed and ice starts to move; the cover becomes disintegrated. The first breaks in the ice cover appear at the channel bends. The condition of the breaking-up beginning for a definite stretch may be expressed as follows:

$$\sigma h \leq f(H) \tag{3}$$

For some points on the Dniester satisfactory dependences have been obtained (correlation coefficient 0.83 - 0.90) between the stage immediately before the beginning of ice drift and the ice cover strength as expressed by the linear equation:

$$H_{br} = a_0 + a_1 \sigma h + a_2 H_{ew} \tag{4}$$

where H_{br} is the breaking-up level; H_{ew} is low water level in winter, which is a characteristic for autumn-winter ice jam events at the stretch; a_0, a_1, a_2 are constant values.

The first ice motion makes the ice cover break into

Chizhov-Buzin

pieces, thus starting the second stage of ice breaking-up. The compression tensions concentrating at the places of ice contacts with the banks are predominant at this period. The increase in discharges starts the destruction of ice fields, hummocks and channel dams. At the same time the ice drift begins on some stretches. As many cofferdams are broken, large ice masses pile-up above some centres causing hummocks and formation of multilayered ice conglomerations.

It follows from the above scheme of ice jam formation that the thickness of ice accumulation of the ice jam is determined by the sum of forces developing at the motion of ice masses, i.e. stream forces pulling ice masses; gravity force component, hydrostatic head of water; inertial forces and resistance forces on account of internal friction between ice floes and friction against banks. All these forces depend mainly on the stream velocity and discharges. It may be thus conceived that the ice cover thickness (H_3) of the ice jam or level (ΔH_3) of an additional rise on account of the stream cross section narrowed by the ice jam accumulation is the function of discharge during the spring ice jam formation (Q_3) :

$$\Delta H_3 = f(Q_3) \tag{5}$$

If maximum discharge of the flood wave is assumed as the argument, then (5) should be put as follows:

$$\Delta H_3 \leq f(Q_{max}) \tag{6}$$

Chizhov-Buzin

wherein the symbol $\leqslant$ means that some additional condition is required for ice jam formation with the accumulation thickness that may be created by the wave maximum discharge. During ice jam formation in the zone of channel damming there arise strong compressive tensions owing to the head of ice masses liable to hummocks. If the tension in the ice jam centre exceeds the temporary resistance of ice to compression, the ice jam will be destructed at the stage of its formation. The stability of ice jam centre is determined by parameters of a particular channel stretch and by ice cover potential strength (σh). Ice jam formation and its stability is also greatly affected by residual winter jams. The value of this factor may be characterized by winter low water level (H_{ew}).

Hence, the condition for ice jam formation is put as follows:

$$\Delta H_3 = f(Q_3) \leq f(\sigma h, H_{ew}) \qquad (7)$$

This dependence for some points of the Dniester has been realized in the form of the linear polynomial:

$$\Delta H_3 = a_0 + a_1 \sigma h + a_2 H_{ew} \qquad (8)$$

Ice jam rise (ΔH_3) for 26 year observational period has been determined by the combined graphs of stages,

Chizhov-Buzin

parameter σ_h has been computed by S.N. Bulatov's methods /1/.

These dependences enabled to develop the method for a short-term forecast of maximum ice jam levels for towns of Mogilev-Podolsky and Soroki.

Computations required for forecasting include:

- computation, 2-5 days in advance, of flood discharges and water levels that could take place in case of no ice jam and ice cover, by their relationship with the source waters and those of several tributaries;
- computation of ice cover strength by meteorological data.

By checking it was established that computation of σ_h for 2-4 days in advance proved impossible due to inaccuracies of the meteorological forecast. More satisfactory results have been obtained using the values of ice cover strength on the day of forecasting, i.e. 2-3 days before the flood passage.

It should be noted that the realization of the method of forecasting maximum levels caused by ice jam has been favoured by a great number of ice jam forming places closely situated to the points under study. The longest distances between them enable to consider ice jams on these stretches as having their permanent places of formation.

Fig. 4 presents the graphs of relationship between actual maximum ice jam levels (H_{max}) and those computed by developed methods (H'_{max}).

Results of forecast quality assessment are given in the table below.

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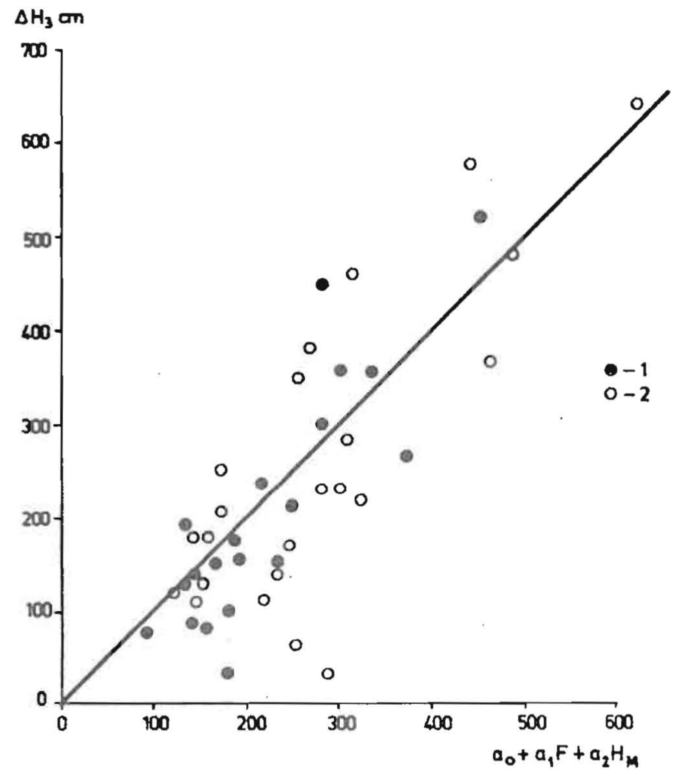

Fig 3. Dependence of water level rise caused by ice jam on the ice cover strength (F) during breaking-up period; and winter low water level.
1 - town of Mogilev-Podoīsky;
2 - town of Soroki.

Table

Point	Number of serial terms by which dependences have been obtained	Correlation coefficient	Mean square root deviation from the standard σ_H cm	Mean square root error of checking forecasts, $\bar{S}$ cm	$\frac{\bar{S}}{\sigma_H}$	Days in advance	Mean square root deviation of level change for advance period $\sigma_{\Delta H}$	$\frac{\bar{S}}{\sigma_{\Delta H}}$
Megilev-Pedelsky	28	0.90	182	78	0.43	2	155	0.51
Soroki	27	0.92	241	94	0.39	3	195	0.48

Forecast is made as follows. When air temperatures become positive the daily values of ice cover strength and ice thickness are computed by nomograms compiled for the Dniester; and when the water levels at the river head begin to rise, discharges and free-from-ice-jam levels are computed 2 or 3 days in advance. The breaking-up level and the date are determined by the dependence (4). For this date and subsequent days maximum water levels are predicted.

The relationship between Q_{max} and σh is used to determine the character of breaking-up. In case of the ice jam breaking-up the maximum level is computed by the following dependence:

$$H'_{max} = a_0 + a_1 Gh + a_2 H_{en} \quad a_3 Q_{max} \tag{9}$$

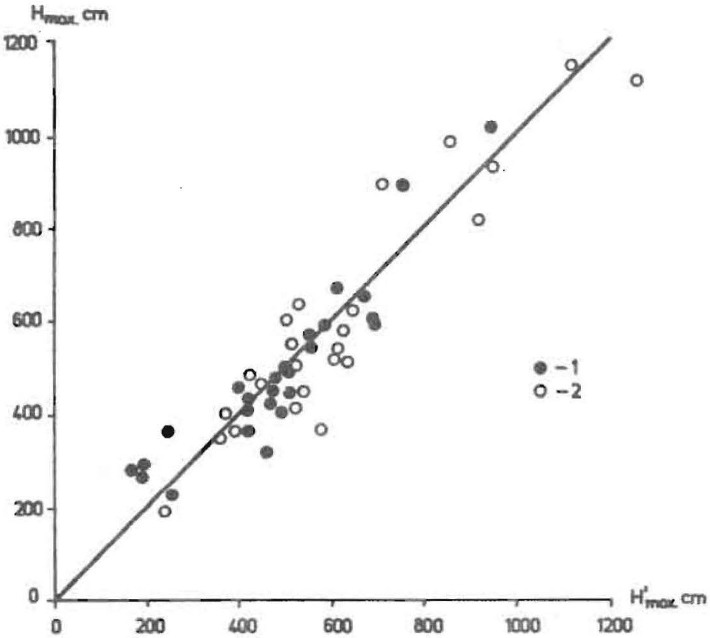

Fig.4. Relations between maximum observed (H_{max}) and predicted (H'_{max}) water levels

1 - the Dniester-river at Mogilev-Podolsky
2 - the Dniester-river at Soroki.

In case of free-from-ice-jam breaking-up the maximum level is computed according to Q_{max}. If the flood is incapable of breaking the ice cover, the maximum level is computed by the dependence:

$$H'_{max} = H_{ew} \left(a_0 + a_1 \Delta Q \right) \tag{10}$$

where is the discharge increment since water level begins to rise.

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S E S S I O N O N S U B J E C T B

Interrelations between River Training, River Canalization, Low Head Water Power Development, and Navigation with Special Regard to Ice Control

9:00 a.m. January 16, 1974

Ch.K.Hurst, Chairman
L.Rákóczi, Co-chairman
M.Kozák, Invited Speaker
(substituted by M.Szalay)

Ch.K.Hurst, Chairman: My name is Charles Hurst, I am a chief engineer of the Department of Public Works in Canada, I will be acting as chairman for this morning session. The associate chairman is Mr.Rákóczi; I find that we both are colleagues in the sense that we attended the same university although in different times. And we have had a few reminiscences about the geographical part of Canada which we both are familiar with. Professor Szalay is substituting for Professor Kozák who is unavoidably ill and is not available with us today. The same rules of procedure will apply as yesterday. I hope that anybody who wishes to participate will fill in the proper form and I also hope that we will have a little more discussion today than we had yesterday.

This seminar - as you know - is a combination of two major associations: one which is basically an association concerned with operating and building problems and the other one with solving some of the problems represented by the other association.So that rather than have two parallel courses of presentation of papers I hope that we will have today some cross-fertilization.

Now, if I can ask Professor Szalay to make a summary of the papers and introduce the subject.

M.Szalay: Mr.Chairman, Honourable Guests, Ladies and Gentlemen!

Before making my general report I would like to ask for excuse because probably I shall speak also about problems or raise questions already discussed yesterday in topic C, but this is due to the fact that we have many things in common and there are many overlappings in them. And in order to avoid your reproaches I ask for your pardon*......

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* The text of the lecture appeared in the separate volume of General Lecture on Subject B by M.Kozák.

Ladies and Gentlemen, I arrived to the end of the general report and I thank very much for your kind attention.

Chairman: I think the questions raised at the end of Mr.Szalay's report are very pertinent and I think to these it should be given further consideration. I would add one additional one, through which we came across in the last couple of years and that is the effect of ice control on environmental factors. You may say: Well, how can that affect the environment? Let me give you the example.

During the wintertime the flow of Lake Erie through the Niagara River is affected to a considerable extent by an ice boom which has been placed across the total length of the river to hold back the ice in its natural state. As a result, some people claim that the ice has been retained in the lake for a considerable time afterwards, thus affecting the climate in the particular area adjacent to the lake. And they have caused some considerable distress amongst the engineers who are responsible for this and nobody really knows what the answer is. Now, some research work has been carried out, but I would like to raise this question with you to include those who were listed: how do we know the effects on the environment of the activities that we undertake while managing ice.

Now we come to the first paper, paper B1, which is to be discussed by Prof.Degtyarev of the Soviet Union.

Prof.Degtyarev?

V.Degtyarev: Mr.Chairman! Ladies and Gentlemen! Let me read the report of M.I.Zhidkikh, senior engineer of the Leningrad Institute of Water Transport, because the author of this report is absent from this symposium[x]......

Thank you very much.

Chairman: Thank you. Are there any questions that anybody liked to ask? I think I have a question here from Mr.Günnenberg.

F.Günnenberg: Mr.President! Gentlemen! I have two remarks to make.

In the German Federal Republic barrages are protected against pressure from ice sheets by air bubbling. The river water is fully mixed and is at the freezing point down to the ground, so that no heat can be transported by the water thus pumped up. Nevertheless a gap in the ice sheet can be held open. The water, between emerging to the surface and vanishing again under the ice sheet, is exposed to the cold atmosphere for less than two seconds. I presume, that this space of time is not sufficient to allow for an efficient under cooling of that water. Thus the velocity of growth of the ice sheet towards the gap is essentially zero.

To effect this, we need about 10 times more air per second and metre than the installations described in the paper presented.

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[x] The text of this lecture appeared in the separate volume of Contributions to Subject B by M.I.Zhidkikh.

The compressors consume about 300 Watts per metre of length of the construction protected. 400 Watts would be sufficient to compensate for the heat extracted from the water surface of a one metre wide gap by the cold atmosphere. So I would raise the question, as to whether it might be easier to install a cheap heating device instead of an expension air bubbling system.

Thank you!

Chairman: Are there any remarks? Would you care to comment on that?

G.Ashton: My name is George Ashton from the Cold Regions Research and Engineering Laboratory in Hanover, USA.

The discusser has raised the interesting question concerning whether the power expended in a pneumatic installation could be better used by direct heat application to melt the ice. In some cases this may very well be true, particularly if a negligible thermal reserve is available, as is often the case in river installations. In other cases, however, the energy transported and delivered by a pneumatic installation far exceeds the energy input. It should also be pointed out that in extended installations, such as used to suppress ice in navigation channels, there is often a danger of prematurely exhausting the thermal reserve.Very much needed are temperature measurements with good resolution, of the order of 0,01 °C, since very small water temperature differences may often accomplish significant ice suppression if sufficient volume of water is moved.

Chairman: Thank you! Kennedy from the United States!

J.F.Kennedy: I would like to back up the point made up by our German colleague concerning the use of these bubblers in rivers where generally the temperature stratification is very small or zero, there is simply the same temperature from top to bottom, and in these cases the bubblers work by not transporting heat to the surface but by bringing in a continuous supply of ice-free water to the surface. And it passes over the surface before the ice crystals conglomerate and makes more ice. Consequently, I question the applicability of the heat transfer calculation to the situation. Because this is not a question of cooling the water to the freezing point but rather a question of convecting the crystals past the open area before they can form an ice sheet. Secondly, in this case, I think, one should keep in mind that the bubbler-system is likely to increase the overall iceproduction in a region because you are maintaining a reasonable open water for having more heat transfer with the atmosphere and then in this case one must compare the amount of energy input through the bubbler system, and include the transfer from the air to the water, with the increased open surface area and hence to greater possibility for heat transfer to the area. So, you may supress ice formation locally but cause more overall ice production. Finally, as concerns the energy efficiency of such systems, I question whether a pneumatic system is in general the most efficient.Certainly, it is perhaps more convenient that you must provide just one energy source and then distribute the air. However, we must recall what these systems are doing. They are in effect acting as pumps. Which are bringing water from one level convecting past the surface. Now, an air-rise pump is a very inefficient pump. And I think, in general, a more efficient system involves direct pumping of the water. After all, in order to compress air to the pressure near under the water you must do a rather large amount of work on it. And all of that energy is lost then when the air escapes from the surface. Whereas, simply to bring water from one elevation to another within the same body of water will cause that you work only against the small amount of potential energy difference due to stratification and that is very-very small but you must end against the friction of any piping that might be required. But you do not have to put the energy into the fluid which is lost as you do in the case of air which is released from the water due to a lower pressure. Thank you!

Chairman: Thank you Dr.Kennedy! Are there any other comments? Most of these comments relate to the question of the protection of hydraulic structures. I wonder if there is any work done on the possibility of using this type of whether it is pumps or whether it is pneumatic systems or maintenance an ice-free channel. I know that the National Research Council in Canada has carried out some experiments a few years ago on bubbler systems in the Arctic, they were successful in two other cases in keeping ice away from structures, but this was based on heat transfer. In the third case there was no heat at all in the water and there was no ability there to maintain an ice-free operation. Well, are there further comments on this particular paper? May we move to paper No.B2? Which was prepared by our Rumanian colleagues. I gather that there are no people here from Rumania, is there anybody available to present that paper? Or is there anybody who wishes to make any comments on it?

S.Petković: Mr.Chairman! Ladies and Gentlemen! My discussion is connected to paper B2. I am sorry that the authors are absent.

The problem of ice control in the backwater zone can not be solved by ice breakers only, as it is mentioned in the paper B2. The ice regime has to be controlled simultaneously by the action of ice breakers and overflowing the dam, in order to increase the slope and flow velocity in reservoir.

As it is well known, the river damming specially aggravates the ice regime in the upstream zone of backwater. In the concrete case of Iron Gate reservoir, the large populated and industrial areas are situated in this zone. On a basis of this, it could be concluded that the protection of these populated areas is more important than the energy losses, caused by overflowing the dam. Thus, in this case and all similar cases, the only method of ice control consists in correlated action of ice breakers and decreasing of water levels in reservoir by overflowing.
Thank you!

Chairman: Is there anybody who wishes to comment on the past comments? Then can we proceed to the discussion of paper B3. I understand that Professor Zvorykin is to discuss that paper. And after this paper we will have our break. So, Professor Zvorykin!

K.A.Zvorykin: I am Zvorykin, USSR.

Mr.Chairman! Ladies and Gentlemen! I have a short addition to paper B3 "On Forecasting and Control of Ice Conditions in Shiplifts" that is presented by my Soviet colleagues Dr.Pekhovitch and Dr.Shatalina who unfortunately are not present.

Investigation of the ice regime in shiplifts is essential for the selection of the optimum service conditions. Comparison of the three types of service conditions reveals that the amount of growing ice is the minimum when the shiplift chamber is either drained and exposed to the ambient air, or submerged in and filled with water (the second type of operating conditions). Such "dry" hauling of ships is conducive to ice production over the chamber walls through cold accumulation in steel (the regenerative ice formation scheme).

The currently adopted technique of hauling of ships in a water-filled chamber has certain disadvantages from the viewpoint of winter operation. In this case ice production is attributable to simultaneous regeneration of cold in the chamber walls and recuperation of cold when the chamber is exposed to the ambient air, which results both in the increase of the chamber weight owing to icing of the outer chamber wall surface, and in the decrease of its cross-section.

The structural features of the shiplift chamber have a considerable effect on the character of ice formation. When calculating freezing-over of actual engineering structures it should be borne in mind that stiffening ribs induce local ice accretion up to 50 %.

In calculations of ice thickness account must be taken of the wall thermal resistance R_{τ} including the effect of stiffening ribs

$$R_{\tau} = R_{o} - \frac{1 - Bi}{\alpha}$$

where R_o is the thermal resistance of the wall, with the effect of stiffening ribs neglected;

Bi is the dimensionless parameter considering the effect of stiffening ribs and depending on the shape, dimensions and spacing of the ribs;

α is the heat-transfer coefficient from the ribbed wall surface of the shiplift chamber.

In regions with strong winds prevailing icing of the chamber may be also due to spraying of water over the walls and wave action. The experiments conducted by the authors demonstrated that the ice production rate for ice growing in thin layers over the chamber walls may be very high as compared to that when the input of cold is effected at the expense of heat conduction.

Thank you!

Chairman: Thank you, Dr.Zvorykin! Are there any further comments on this paper? Possibly we could break for - I would say - a half an hour, which seems long enough. And could reconvene here at a quarter to 11, please.

Chairman: I have been asked to change the order of presentation. Mr.Szenti who is the author of paper B16 would not be available for discussions this afternoon so has asked if we would allow him to participate this morning. And if there are no objections I would now like to ask Mr. Szenti to take the podium to present his paper.

J.Szenti: Mr.Chairman! Ladies and Gentlemen!

The presence of ice caused significant floods on the lower reaches of the Hungarian section of the Danube River, on a reach about 100 km long upstream from the Yugoslavian border, moreover, in 1956 a catastrophic flood occurred. After the latter, when in the district of the town of Baja more than 20 levee failures occurred on both sides of the river and the levees were overtopped on long sections more km long, active flood protection based on ice-breaking methods has been conducted by the Hungarian Water Management Service. The ice-breaker fleet has been created in the past decade. The direction of the ice-breaker fleet is a rather complicated task requiring the development of available information. In order to operate the fleet in the most efficient way it is indispensable to know the amount of the floating ice, e.g. the numerical parameters of the process in concern. Taking into consideration these facts, new kinds of ice observations have been introduced in 1971. Instead of the visual observation of the river's ice cover photogrammetric observations carried out from elevated points have been introduced. Ice thickness is measured from ice breakers properly. Besides introducing objective instruments of observation the way of measuring was established in order to obtain statistical samples. Ice thickness is determined by 30 observations per day while the ice cover is observed by ten daily photos at each of five stations. The velocity distribution of the moving ice can also be determined by knowing the intervals between taking the pictures and analyzing the same. From the basic values obtained in this way the most important parameters of the ice regime - the ice yield defined in a quite analogous way - can be determined either in squ.metres per second or cu.metres per second. Data are supplied together with their mathematical-statistical parameters. In possession of these data the process of development of standing ice can be forecasted with high reliability. In this way, the character and time table of the ice-breakers' operation can be defined. Details of calculating the ice yield are contained in the paper. It is not intended to demonstrate how the observations are carried out and the data processed. Namely, participants of this symposium will have opportunity on Friday to see the ice-breaker fleet as well as to be acquainted with the methods of measuring and processing. The automatic, electronic instrument calculating the ice cover from electric data of a television monitor will also be shown. This highly precise instrument will be developed in the way that it should also produce yield data without any calculations by hand. Should anybody of the participants be interested in the details of this process, we are glad to supply this information during the study-tour to Baja on Friday. Thank you very much for your attention!

Chairman: Thank you Mr.Szenti. Does anybody have any questions that they liked to ask or any comments they wished to make? Well, then thank you very much! We look foreward on seeing you on Friday. Now, we will return to our schedule and paper B4 - I think, if my information is correct, Dr.Sokolov is to speak on this.

I.N.Sokolov: Mr.Chairman! Ladies and Gentlemen!

I want to give some additional information on paper B4.

Some additional data on the ice conditions in the Yenisei River downstream from the Krasnoyarsk Dam are presented.

Winter water temperatures in the Krasnoyarsk Reservoir reaching 100 m depth near the dam are relatively high. While water temperature in the upper layer under the ice cover is near zero, in the bottom layers it reaches 3.4 to 4 °C. In winter the water temperature immediately downstream from the dam is about 2 °C. The temperature of the water discharged through the bottom outlets is higher than that of the water discharged through the turbines, since the bottom outlets are located at an elevation 50 m lower than the turbine intakes. The higher located turbine intakes select cold water from the upper layers of the reservoir while the bottom outlets draw warm water from the deep water layers.

In January through March the temperature of the water discharged from the bottom outlets was 2.32 to 2.50 °C, while for the same period the temperature of the water discharged through the turbines (draft tubes) was 2.14 to 1.63 °C.

The temperature difference of the discharged water through the turbines and the bottom outlets in January was 0.18 °C, and by the end of the winter it amounted to 0.87 °C. With increased discharges this temperature difference decreases, because in this case the water is drawn into the turbine intakes from the entire water body.

Early in winter during the first year of the plant operation there was an ice-free area over 200 km long downstream of the dam. Late in January, when air temperatures dropped very low, the polynia reduced to 67 km and then, as the weather grew warmer, it became again larger. During spring thaws in March the polynia increased rapidly. Thank you!

Chairman: Thank you! Are there any comments on this paper? Mr.Tsang?

G.Tsang: I am G.Tsang from the Canada Center for Inland Waters.

It is good to release comparatively warm water from a reservoir to increase the length of the ice-free stretch downstream from the reservoir. However, this increase in discharge will increase the thickness of the ice cover further downstream. Field investigation in Canada (report in a paper by Tsang and Zsues at the IHD Symposium in Banff, Canada, in Sept.1972) showed that as winter sets in and the rate of discharge subsides, an ice cover will form and slowly sag with the water level. During this period, the growth of the ice cover is slow and it thickens only 5-6 cm in two weeks or so. This is because ice is a bad heat conductor. With a snow cover further on the top, the loss of heat from the ice cover can be greatly reduced. However, if there is an increase in discharge, especially when the rate of discharge increase is sufficiently rapid so the ice cover instead of floating with the water surface and deforming plastically, it will crack and water will come up from underneath and floods the then concave ice surface. Once exposed to the cold air the water and the melted snow will quickly freeze and increase the thickness of the ice cover. For the same ambient temperature, we found from our experiment that the ice cover can increase 10-15 cm in about two days. In fact, flooding and freezing is a major factor in the growth of a river ice cover and it is greatly affected by the stage hydrograph.The strength of the ice cover formed by flooding and freezing is also higher than the ice cover grown by the freezing of the melted snow only because of the reduction of gaps in the ice. Therefore it presents more problem for ice breaking,etc. Based on the above, it is of my opinion that we must take the downstream ice thickening into account and plan very carefully in any scheme of extending the ice-free stretch by increasing the discharge from a reservoir. Thank you.

Chairman: Thank you! Mr.Sokolov, would you like to comment? O.K. Oh,my colleague would like to put a question.

M.Szalay: In this paper and also I think in other papers allusion has been made to the fact that it is desirable to withdraw water from the deeper layers where the temperature is rather high than it is near the surface. I myself do not see what measures can be taken to fulfil such a requirement if one has to conduct water through the turbines. In the case of weirs of course there is a possibility to open it at the bottom or on the top. But in case of turbines I would like to know how this goal can be achieved? Thank you!

Chairman: Is there anybody to answer Mr.Szalay's question? Dr.Kennedy?

J.F.Kennedy: Thank you! Concerning the question raised by Dr.Szalay I would find out that at a new, rather large dam in the United States, the Oregol (?) Dam, which is part of the California water project, they have installed a very extensive and expensive release device which makes it possible for them to take water from different levels in order to get the desired temperature downstream required for the fish. In this case, I think,it is not a question of releasing water through the turbines but just to withdraw from downstream release. In general, one does not have too much latitude in specifying the depth of intake except that fortunately the dam is at the deepest part of the reservoir usually so you can I suppose to make some sort of tower-intake withdrawal very close to the bottom. I would like to raise another question though related to Dr.Sokolov's presentation and to address it to our Soviet colleagues in general. In your paper you present an equation for calculation of the length L of the ice-free reach. And this involves the introduction of S, the heat transfer. I would like to ask if there are available any publications describing the Soviet practice for calculation of this heat exchange rate. This is a problem of very great interest to many of us and we would like to learn more about the details involved in the Soviet practice for the calculation of heat transfer from water bodies to the atmosphere.

I am interested in general and I would like to ask if any monograph has been prepared in the Soviet Union on this question.

Many Soviet writers prepare very nice monographs on particular questions. So my question is, whether a monograph of this type or extended work describing Soviet practice has been prepared?

Chairman: I presume that this question will be taken under the advisement of Dr.Kennedy. Are there any other comments? With respect to this paper? If not, can we move to paper No.5. Professor Doležal? Is he here? Is somebody here to discuss paper B5 - "Transverse Flow in the Upper Approach of a Sluice Chamber Closely Joined to a Weir"? Well, in the absence of any to discuss this maybe we can pass on to paper B6. Dr.Kontur, are you willing to comment?

Gy.Kontur: Concerning the ice condition over the Hungarian stretch of the Danube the gage-records of the Budapest Gaging-station are available for the last almost 150 years. According to this, 22 % of the highest floods were caused by ice. It is however more illustrative to investigate the causes of the 23 highest peak stages within the period. According to the data, in 15 cases, that is in more than 60 %, the reason was found to be ice.

The last great ice-flood running down the Danube in 1956 caused many breaches over the stretch downstream Budapest. Owing to ice jams the river-stage surpassed the hitherto observed highest icefree stage by 300 centimetres. On the other hand, downstream the jam the hitherto observed lowest water stage has been attained at the river gage Vukovár (1333 km), it was by 98 cm lower as compared with the recorded lowest ice-free water stage. This phenomenon can be highly disadvantageous from the point of intake works.

Hungary has fortunately a strong and efficient water management organization. It is due to this that following the disastrous flood in 1956 a forceful ice-breaker fleet could be created within a few years, which could cope not only with the ice jams over the Hungarian but also over the Yugoslavian Danube stretch. It should be added, however, for the sake of historical fidelity that cold winters like these of 1956 or 1940 have not occurred ever since.

The objective of my contribution is to investigate what favourable aspects could be considered in the future in ice formation over the Danube. Owing to industrialization of the country cooling water demand is steadily increasing. The higher temperature of the return flow may be responsible for the fact that the temperature of the Danube water between Budapest and Mohács is by 1 to 1.5 °C higher. This value will markedly increase at putting into operation of the thermal power stations.

The cooling water demand of a 4000 MW power station is 200 to 210 m3/sec which is a quarter of the Danube low water discharge. The temperature of the return flow is higher by 10 centigrades. Only a single such power station requires round 18 million m^3 water a day. This thermal quantity is theoretically sufficient for the melting of 2 million tons of ice but even with an efficiency of 25 to 30 % it is able to melt 500 to 600 thousand tons of ice. The efficiency can be increased by leading the cooling water through the turbines of a hydroelectric power plant.

This is also good for the oxygen increase of the water. Therefore, I suggest this method be established also on the Danube River.

According to my recommendation, the Danube Barrage projected at Fajsz should be placed and constructed at the thermal power station at Paks which would improve the cooling water diversion. Also the backwater dammed up over about 100 km would make navigation more favourable, improve the ice conditions of the river and of several intake works, so among others, the realization of the shortest Danube-Tisza Canal.

The complex utilization of a Danube Barrage will be advantageous from the economic aspect but owing to the multitude of our water management tasks could only be realized, in my opinion, if the investment costs can be charged against future generation.

One of the possible means could be the selling of the annual energy of about 600-700 million of kW hours to be produced and otherwise lost at about 1 Ft/kW hour consumer price and to spend the sums so incured to commodity export to the reimbursement of capital and interest rates to the creditors. Thank you and excuse me that I disturbed you!

Chairman: Thank you Dr.Kontur! Does anybody wish to make any comments on this particular paper? In that case paper B7 on the investigations on the Interrelation between Riverbed Configuration and Ice-Drifting by Mr.Mantuano - I do not think he is here - does anybody wish to comment on that paper? I understand, this was written in French. Anybody who wish to make comments on it?

The next paper, I also understand the author is not here. B8 - Regularities of the River Bed by Means of Canalization. He will not be here. Does anybody wish to comment on this paper? Fine. The authors of the next two papers are not here either and unless somebody has some comments on them we get passed to B11. Does anybody wish to comment on ... Yes.

J.A.Maza Alvarez: I want to make two comments to the formula presented by Prof.Chee in his paper B10. That formula has No.7 on page 76 of the proceedings. First if we consider a constant depth with maximum scour around an abutment at low velocities it is a function of that velocity. But after certain limit this scour remains more or less fixed and is independent, of velocity. So it is not possible to extrapolate this formula beyond the limits described in the paper. Second, the maximum depth around an abutment depends on the shape of the wall of the abutment, e.g. if the slope is 3:1 the scour is more or less 50 % less than the scour used for an abutment with vertical walls. So the formula is useful only for the shape that Professor Chee has proven. And for the same reason it is not useful for practical uses. Thank you!

Chairman: Paper B11, Mr.Matoušek?

V.Matoušek: Mr.Chairman! Ladies and Gentlemen! Our rivers with frazil production cause often difficulties around structures. In the impounding reservoir from which the water is taken the frazil accumulates clogging the inflow to the intaking equipment. Due to our insufficient knowledge on the winter regime in the rivers the intake equipment is often insuitable and the necessary measures for ensuring winter operation have to be taken only additionally. This was necessary in the case of the pumping station in the river Ohre. The pumping station is situated in a river stretch with intensive frazil formation. The impounding reservoir is completely filled with frazil. The proposed protective measure oonsists in catching the frazil in front of the pumping station of the reservoir. The impoundment of the water was achieved by constructing the reservoir dams having fixed weirs.

(Slides projected.)

The first dam is located 3.5 km upstream of the pumping-station. The new coffer-dam was built by placing stones on the bottom of the river. At the place of the fish-weirs the coffer dam is extended into the shape of the old river.

The coffer-dam was built in one layer using boulder-material. The dam surface was finished with small stones to permit the transport of lorries.

So is the dam after its completion.

From this picture it is evident that the dam does not interfere with the landscape but rather improves it. The second coffer-dam is placed 40 km upstream of the pumping station.Its shape is shown on this slide. It was built in the same way as the first one.

This slide shows the dam after its completion. The picture illustrates the situation before the freezing of the water surface. At the bank one can see surface ice, in the middle floes, and the surface became frozen the following day when the bank ice has split and the frazil could not pass through and behind it the frazil started to accumulate. The frazil accumulation is shown on the next slide. The purpose of protective measures was an operation of four winter seasons and to fill in its function. The constructed dams hold back the frazil and the pumping station operation proceeded without any difficulty. The experiences gained up to the present show that the first weir is usually suitably placed. The channel here is wide with moderate bottom slope.Even with a significant height of the dam a large capacity of the reservoir was achieved. The low velocity of the water in the reservoir leads to the formation of an ice cover in the first days of the period of ice appearance on the river. The placing of the second dam is far less favourable. The river bed here is narrow and to obtain a low water velocity in the reservoir the dam must be high. With high dams it is difficult to ensure their stability. The slope does not allow a greater extension of frazil accumulation upstream. The first dam with approximately the same construction costs exhibited a much greater effect. For the performance of this reservoir the placing of the dam is of paramount importance. The advantages of this solution are low investment costs and the possibility of an easy and rapid construction. However, it is only a temporary solution. The experiences gained and the measurements are to be used in the design of the definite solution as well as in the design of other structures. Thank you for your kind attention!

Chairman: Thank you! Are there any comments or questions on this? Dr.Tsang would you take the microphone please?

G.Tsang: Frazil is formed in waters of high turbulence, whether the turbulence is from the surface waves in case of a lake or from the fast flow in case of a river. Once frazil is formed, it tends to float to the surface. However, the turbulence in the water brings the frazil back to lower layers until a state of equilibrium is reached. It has been observed in Canada in Lake Erie that with high winds, frazil can be found at a depth of more than 10 m. The water drawn in by a City water treatment plant at a depth of 10 m has been clogged by frazil several times. A way to reduce frazil concentration at a lower layer is to reduce the turbulence level, by which the frazil can float to the surface. The level of turbulence can be reduced by reducing the flow velocity. This, in fact, is the method of frazil control by the present paper. Understanding the above, I would say that the weir reported by the paper will work if there is no wind and if the velocity of flow prior to the building of the weir is not too high. However, in windy days or on days with high discharge rate, I wonder whether the weir still works. Therefore I would like to know the operational experiences from the authors. Thank you!

Chairman: Would you like to answer, Mr.Matoušek?

V.Matoušek: As an answer, some data are given in my paper and we did not finish all work in this problem, we did not finish our report.

Chairman: It seems to me that we are proceeding in a rather rapid rate and I hoped that we will have more discussion in this morning. Paper B12. Is the author here of that paper to discuss it? Is Dr.Doležal here? No? There are some, I believe Mr.Lawrie from Canada has some slides which would be very interesting. I do not know how long it would take for you to project them?Could they be put on now? I think these are very interesting slides and I thought we could do those before lunch.

Ch.J.Lawrie: Yes, Mr.Chairman, you have got me a little bit unprepared here, taking me by surprise.

Ladies and Gentlemen! A have a number of slides of the conditions on the St.Lawrence River showing some of the problems we are encountered at us. And some of the methods we used to control the ice problems. Incidently, I have with me a copy of a report that I did prepare some time ago on these control measures and I am pleased to send a copy anybody who wish to have them. Just leave your address and name with me and I will send you a copy of that report. Today I would like to talk about but only one section of the St.Lawrence which you know streches between Lake Ontario and the Atlantic Ocean. A distance of about almost 2000 miles. I want to concentrate only on one small section. A 60 mile long section between Montreal and Quebec City. This is a section where we encounter most of the problems. The section below Quebec City is open to navigation all year round. Ships do get escort from our ice-breakers and we have no problem really in reaching the port Quebec. We have quite a number of problems between Quebec City and Montreal which require extensive use of ice--breakers and ice booms and other measures to control the ice. Upstream of Montreal in the section known as the St.Lawrence Seaway this is closed for the winter season. Normally it closes about the mid of December and is opened again in April following year. There are a number of people here from the St.Lawrence Sea-way Corporation who wish to comment on that particular section later on. I am going to approach this in three different aspects. The first set of slides will depict some of the ice conditions we experience on the St.Lawrence River, on the second set of slides we will see some of the ice breaking activities and thirdly we will look at some of the other measures we use for controlling ice, specifically the use of ice flumes and ice control structures.

This is a general location map! And the area, the sector I am going to talk about is red between Montreal and Quebec City.

This is a picture of the situation in Montreal Harbour some years ago, you can see the considerable amount of packing and shelling of ice, very difficult ice breaking conditions. This is what Montreal looks like in an open season. This is the bridge where the river narrows at Quebec. Here the river is deep appr. 50 metres as opposed to an average depth of 10 metres in the navigation channel, but it is very narrow, only about 800 metres wide. It is a tidal section and the tidal range is of the order of 6 metres. The problem here is that we can only break ice in high tide, when we can get rid of the ice more easily. These are representative pictures showing the navigation channel maintained by ice breakers in the reach from Montreal to Quebec which is about 50-60 mile downstream of Montreal. This is the situation which developed in the winter of 1968. When we had a very serious jam in the narrows at Quebec. At the bridge. This is the same bridge you have seen where the river is very narrow. We had a very serious jam there and the jam reached very quickly Montreal. And it took until the end of January to free the way for navigation. That is the channel through one of the lake sections of the river. Very narrow, and you can see there in the right-hand corner where the ice keeps breaking off and just below there is a narrow section where these big pieces of ice break off from the jam in the river. I shall speak about this a little bit later.

That is much the same picture. Here you can see on the right-hand side the ice booms we have installed there. This is Quebec City with fairly heavy ice cover in the harbour, you can see the open stretches in the river downstream in the background.

This is the terminal of the Golden Eagle Oil Co. in Quebec, this is just across the river from Quebec City. We do get tankers bringing oil up to Quebec during the winter time.

The same picture. The Oil Terminal. Here is one of the Canadian Pacific Containerships with the ferry crossing in the foreground.

Here is one of our ice-breakers, this is the Mcloud Rogers (?) attacking the ice jam just above Quebec.

This is the ice-breaker working at Montreal. These are one of our helicopters and we have again the Mcloud Rogers in the background. You see it is a quite of considerable amount of ice packing there.And in very severe conditions the ice is packing down to almost the complete depth of the river 10 metres in places and one of the problems has been in the past to maintain a channel in this particular reach of the river to prevent flooding of the low lying areas. And up to some years ago this was a regular operation of the ice-breaking fleet. More recently, we have recognized the need for ships to move into Montreal during the winter season and we do assist all ships. When they get tied up in the ice.

Here is a very distinct situation where we had a very severe push or shelf on the ice cover. And also it coincided with a very heavy snow-storm. This makes ice-breaking particularly difficult because of the frictional effects of the snow.

That is an ice-breaker which develops about 13 000 SHP.There is a system of ice-breaking where we use the heavier ice-breaking to these ships and following we use the smaller ones on both sides of the channel.

You see here again the Mcloud Rogers followed by two smaller ones.

Now I have to talk about the ice control structures that we used control ice-conditions. This is just above Montreal. You may be familiar with EXPO 67 site and at that time there was quite a lot of apprehension about the construction of this site. And the narrowing of the river channels - the flood situation would be worse when that was completed. And to prevent this we built an ice control structure above the site. The flow is from this direction. And the problem here is that there is a 7 mile stretch of river which is virtually an ice manufacturing machine and produces lot of frazil ice and together with the broken sheet ice coming from Lake St.Louis this would tend to jam in the harbour as you saw from one of our first slides and flooded this area.The principle of placing an ice control structure here is to assist and promoting earlier ice cover in the basin and allowing the frazil and broken ice to come down and be stored under that cover for most of the winter. Therefore, preventing this ice from moving into the harbour and creating an ice jam.

This is a picture of the (......) Rapids to which I referred. There is a tipical winter situation with the ice-control structure and the (......) Basin and the ice-control structure behind. You noticed that very little ice comes out below the ice control structure. On the low part of the picture you see the (......) Channel.

That is a general view of the structure, incidentally it is but 821 m in the length. These openings, there are I think about 81 of them and they are closed by steelbox-girder type of booms, that is a very sophisticated type of ice boom. These booms are about 1.8 m by 1.2 m in section and they are approximately 26 m in the length.

These are dropped during winter across the structure to form this ice cover.

Here is one shown here, this big thing on the left.

These are dropped in by the two traveling cranes here, especially adopted to pick them up, move them out and put them on the appropriate site. And then they float up and down on the water.

These guides are heated so that they do not freeze in any position.

This is just a picture of the ice coming down and flowing against the pier. Ice thickness we get is normally, say, about 30 cm or so. This is what happens when we get a large ice-floe which comes down and strikes the structure.These stop-logs are just knocked out completely away from the structure and the structure seems to be really damaged. So we have to be very careful in placing these logs that they are not exposed to a severe attack from the large floes coming down from the basin. Which can happen if there is a change in weather condition or perhaps a change in the water level situation.

This is taking some ice thickness measurements in the basin just above the structure and you can see they are also taking some velocity measurements.

Now, we come to the use of ice booms and this is a sort of arrangement to show you how these work. Large logs are connected by chains or strong steel cable which is ankered in intervals of about 500 feet.

This is so designed that when placed in a section where the velocity does not exceed about 2 feet per second that will retain to form an ice cover. If the velocity exceeds this then the flow tends to exceed the boom until such a condition has been stabilized again that the velocities are reduced and the booms come up and it helps to form the cover. You see that some of these logs are damaged; they are just about 10 m in length.

That is a tipical formation of a boom and most of the ice has gone. This is a situation in March when the break-up has already started. You see the fact that the boom has. One of the main purposes of the boom in this particular section of the river is to help to retain the ice cover on either side of the navigation channel. Our experience has been that ships navigating through this section, there is a tendency to generate waves by the ships for the ice cover to be broken up in large masses.These float down into narrow sections of the river and very quickly create an ice jam.

Here you have some of the larger pieces that have been broken up and are being retained by the boom.

Here is a picture of a flooded artificial island. This is another means that we have used to try to stabilize the ice cover. We placed those islands in fairly strategic localities to try to form an anker for the ice sheet.

And where possible and where it is strategically advisable we place our navigation aids on there. These are in relation to Lake St.Peter which I mentioned before, widening out the stretch of the river below Montreal into a lake section which is about 20 miles long, 8 miles wide, relatively shallow, only about 3 m in depth in average, with a channel depth of 10 metres.

These are very exposed and we got the same sort of problem that Dr.Tsang has mentioned in Lake Simcoe when you get the ice riding up on these structures. And we have protected those with fairly heavy rock rip-rap.

This is a general picture of the same island. That is all.

I hope this gave you a very rough idea of what we have tried to do in the St.Lawrence River and I would be very pleased to hand these out if you wished to get a copy.

Chairman: I think it would take a couple of minutes until anybody wanted to make or put any kind of question on this.But we are very close to our clock and I think there is an announcement that has to be made. Do you want it right now?

Ö.Starosolszky: Ladies and Gentlemen! The participants who are interested to get a preprint of the lecture of Prof. Dégen from yesterday are requested to get it at the information desk. The second announcement is that the Ladies and Gentlemen who are interested to attend the evening performance of the Hungarian Folks Ensemble or Dancing Ensemble are requested to collect the small paper, not the invitation but the paper, concerning thie performance. In the same way at the information desk. Thank you!

Chairman: Now the meeting is adjourned until 2 o'clock.

2:00 p.m. January 16, 1974

J.A.Maza Alvarez, Chairman
K.Stelczer, Co-Chairman
M.Kozák, Invited Speaker
(substituted by M.Szalay)

J.A.Maza Alvarez, Chairman: Ladies and Gentlemen! We continue the discussions of papers on Subject B.

Let me introduce myself. I am Antonio Maza Alvarez, professor of the National University of Mexico and Head of the Experimental Engineering Department of the Ministry of Hydraulic Resources.

My co-chairman is Dr.Stelczer, he is the chairman of the local organization committee of this symposium and director of the Research Institute for Water Resources Development (VITUKI). Unfortunately I do not know anything about ice problems, in Mexico we do not have, the only that I know about that is to eat ice creams. But fortunately all of you do know a lot about such problems and I hope that most of you will explain us your experiences in your practical work that you have done in mathematical models. First I would call again for some papers which have not been presented this morning.

Let us begin with B5 "Transverse Flow in the Upper Approach of a Sluice Chamber Closely Joined to a Weir", by Prof. Doležal. I suppose that he is in Budapest. Is Prof.Doležal here?
Or Skalicka?
Also I wanted to call for paper B12. I supposed that Prof. Doležal was here. It is a pity that he is not.

Well, then we start with the presentation of paper B13 "Studies on the Extension of Winter Navigation in the St. Lawrence River", made by René Ramseier and David Dickins.

D.Dickins: Mr.Chairman, Ladies and Gentlemen!

The St.Lawrence Seaway is closed for Navigation from mid December to about April 1. However, technical improvements like ice flushing systems, heating of the gates and ice diversion channels made possible a significant season extension from 234 days in 1960 to 260 days in 1970. The best hope for further extension to the season lies in improved methods of combatting ice formation at the beginning of the season coupled with an improvement in breakup date forecasting to enable optimum use of any navigation day.

This first slide is a very general view of the geography of the Eastern Canadian coast and you see the Seaway here from the gulf of the St.Lawrence River to the lake of Ontario.

The section, in which our Department is interested in our studies implies the Montreal - Lake Ontario section of the river and covers a distance of some 293 km.

The next slide is our detailed view of this section. There are here three segments. The first segment starts at Montreal and ends here while the upper segment goes up to lake Ontario in the upper left corner.

With the ultimate goal of constructing a model we wanted to predict ice conditions in the Montreal - Lake Ontario Section of the Seaway. The Department of the Environment is collecting data in the field over a period of 45 winters. At present remote sensing is combined with detailed ground measurements to provide the necessary information. However, all thickness and distribution measurements will be made by remote sensing by the coming next two years.

Initially in 1972 and 1973 false colour infra-red aerial photographies were taken about the area. This was combined by the preparation of a map showing ice type distribution based on interpretation of the photographies with the aid of visual ground observations and sampling.

This slide is not a false colour infra-red image, it is just a usual aerial photograph showing the very dynamic movement of the ice at the Lake Ontario entrance with dominant South-westerly winds blowing the ice from the edge of the lake into the St.Lawrence River. You can see floes here passing by the light-house here at left in the corner.

To provide a flexible aerial system, well independent of the surface snow-cover we intended to use a combination of side-looking airborne radar and passive microwave radiometry. In order to develop this system we prepared maps of ice type distributions throughout the winter.

In 1974 a unit operating on a frequency of 9 gigaherz will be flown between Montreal and Lake Ontario by helicopter recording once a week ice thickness continuously. This will be supplemented later by ground measurement at 50 points after the flight.

This shows the installation of the radar unit last winter. You can see the antenna on this small vehicle we used to check ice thickness. This was just a prototype model of the radar. The actual airborne packages are undergoing different trials at the moment.

This slide shows a typical radar trace with a large peak at the ice surface and a smaller peak at the ice-water interface. Relative magnitudes of the peaks depend on the change of the dielectric coefficient going between the two different media. In this case the change is most marked going from ice to water with a coefficient varying from 3 to 16 in water. Knowing the dielectric properties of the ice sheet and radar frequency the distance between these peaks can be easily calibrated in terms of ice thickness. Here in this case, thickness on this plot is 24.5 cm. The error is going to be ± 1 cm for thicknesses varying between 15 cm and several metres. There is a very strong effect of the reflectivity of the surface. So, consequently, this radar equipment cannot tolerate very wet surface conditions. It is necessary to have dry ice surfaces. It is not sensitive to the snow cover. Up to several inches of snow it can be used easily and in fact at a snow thickness of 6 inches you can see a third peak which actually is due to the snow thickness and not to the ice.The snow in no way hinders your ability to measure the ice thickness.

Detailed thickness measurements have been made at a daily basis at several sites in St.Lawrence to provide an example of typical growths patterns, evident in the area of static ice formation. And this next slide shows the three distinct growth phases that seem to appear in many areas of the section we are interested in. There is a primary layer around the zero point if you look at the upper plot. The Y axis is in terms of ice thickness and the X axis is in time plotted here in days. The superimposed ice in the form of snow-ice or snow-frazil-slush is plotted positive and the secondary ice in the form of calender ice and frazil is plotted negative. The calender ice seems to maintain here about a constant thickness throughout the winter stabilizing in a matter of two or three weeks. The final phase is characterized by a very rapid melt by flowing warm water into the river from the lake of Ontario. The higher latitude combined with low current velocities in the canal cause severe ice problems in the area of Montreal. Lake Ontario is the heat-source for maintaining water temperatures about freezing in this section of the Seaway and consequently the first stabil cover will form three weeks earlier at Montreal than at the Lake Ontario entrance.

This next slide shows the general pattern of decreasing secondary ice thickness with distance upstream. Lake Ontario is on the righthand-side of the plot and Montreal taken on the plot as zero km is on the left side. Again the Y axis is plotted as thickness. With superimposed ice positive and secondary ice as negative. In this case the dotted line is simply a total ice thickness summing both the superimposed and secondary ice. This we call a mid winter condition in February in the river.

Any study of the ice regime in this section of the Seaway must take into account dramatic variations in the weather patterns from the year to next. In 1973 the ice cover broke up prematurely one month earlier than in the previous year. This was caused by the combination of extremely high temperatures and relatively low thicknesses developing during the winter. And these water temperatures as it can be seen from the next slide from the 1973 curve rises dramatically one month earlier than it has in the previous year. The vertical scale goes from zero to 0.6 °C. The minimum water temperature which remains almost the whole winter is seen here to be less than 0.1. The rise previous to breakup is sharp and very sudden. The numbers on the top of the graph are combinations of different years' temperatures and snowfalls. In 1974 a continuous and much more detailed profile observation will be conducted in various depths on a 24 hour basis. This will be extended to discharge measurements at the entrance and the outlet of the system.

This project combined with our field studies in the St.Lawrence will also operate an air bubbler located in shallow water in this case about 3 or 4 metres. Ice sheet profiling with sonar will be performed also.

The ice conditions in 1974 were extremely low. You can see this from this picture. Some of the projects associated with field trials have been hindered by this fact. And also coming up in 1974 was a new air-conditioned vehicle as an icebreaking potential.

I have mentioned our objectives in improving our breakup forecasts in St.Lawrence. And equally important to us is the use of the St.Lawrence flush water system, to test remote sensing techniques potentially enabling us to provide with close to real time information about ice. Such a service will have its primary operation advantage not only in St.Lawrence but in the ever increasing shipping of the Arctic waters. Thank you!

Chairman: Thank you very much! You want to make any comments or put questions in connection with this paper? We will then continue with paper B14. But before doing that let us hear the contribution of Mr.James Hays and George Lykowski who want to present their views on the navigation problem of the St. Lawrence River.

J.E.Hays: Mr.Chairman! Ladies and Gentlemen! We thought to be appropriate this time to submit our views to the subject by a paper we prepared too late to appear in your proceedings. However, we have some copies with us and want to give some information on our findings. It is connected with the St.Lawrence - - Great Lakes Seaway Navigation Season Extension Program, in the United States. The Winter Navigation Program is comprised of a Demonstration Program and a Survey Study to determine the practicability and feasibility of means of extending the navigation season of the Great Lakes and the St.Lawrence Seaway. Features of this demonstration program include ship voyages that extend beyond the normal navigation season. Observation and surveillance of ice conditions and ice forces, environmental and ecological investigations, ice control facilities in each the navigation and ice breaking and the coordinated collection and dissemination of information to shippers which include weather and ice conditions. The survey study is designed to collect environmental and engineering impacts of extending the navigation season in the entire Great Lakes- St.Lawrence System. The paper that we have before the symposium limits itself to the St.Marie's River which is the connecting link between the Northest lake, Lake Superior and those below. Ice conditions here are severe. And they virtually involve every problem that ice can cause on this stretch. The paper reports on several selected problems in winter navigation and on the means and methods undertaking to overcome these problems. The merits and shortcomings of the field operations are discussed in a limited technical evaluation presented. The specific activities that we have described in this paper are island transportation, for those islands that we had in the center of the navigation channel of the system, soil erosion damage, soil structure damage, attributable to the extension of winter navigation season. Air bubblers in an open river channel and lock operations are also discussed. For those of you, who are interested in these I have some papers with me before printing of the material will be achieved.

Please, see me after this session and I will be pleased to provide you with a copy of it. I also have a short section of a film we made last winter as a part of the demonstration program. It was made to observe the effects that navigation causes on ice cover in the St.Marie's River. Just below the locks. This film was shot at a rate of one picture frame every two minutes. It shows how the ice cover forms and how it is broken and moves with navigation. The area in the lower right corner of the picture as you can note, will stay relatively free of ice due to the fact that it is the tail-race of a power plant.

Note on the right the relatively open area that remains there as the tail-race of the power plant. The ships pass through rather rapidly. You note the move that occurs after a vessel has passed through.

This is only a short segment of five days out of a film that covered the entire navigation season. I only selected this to show you what the type of data is that we are observing here in connection with the extension of the navigation season. In the rear of the hall I will place copies of a brochure that describes our demonstration program. And you are invited to take a copy with you. In addition to that my colleague in the presentation of the paper, Mr.Lykowski, would cover another very interesting aspect of our demonstration program. And he will describe that to you now.

Chairman: Thank you very much, Mr.Hays, for your picture and your comment. Someone of you wants to comment this paper and the description?

G.S.Lykowski: Mr.Dickins discussed the problem of navigations in his paper on the St.Lawrence Seaway. Then talked about side looking radar and its application to providing information for environmental purposes and for shipping purposes. I want to enlarge that a little bit. Our concern is with the St.Lawrence Seaway in the American section and also with our Great Lakes.The St.Marie's River is in the Great Lakes and, as Hays mentioned, the problem is there severe; if we can solve them we can possibly open up the Great Lakes.

The St.Marie's River incidentally is the connection between the uppermost lake and the lakes below. That narrow band of water contains locks, there is a drop of 22 feet between the two lakes and the ice jams up in these areas. The Great Lakes coastal areas have been described as the Fourth Coastline of the United States. Each year commercial vessels carry some 200 million tons of United States commercial traffic on the Great Lakes - St.Lawrence Seaway System. Nearly all of this traffic moves in the period between April and mid-December. System operations are suspended in the remainder portion of the year. Thus the fourth coast-line is not used about four months of the year. Millions of tons of iron ore are stockpiled toward the end of each shipping season to provide adequate supplies toward the winter months. Similarly, large volumes of grain are stored in elevators to await the spring opening of navigation because the inability to move the foreharvest due to close of navigation. High valued cargo reloaded to and from the Great Lakes' ports. The maximum ice cover on the Great Lakes shown in this figure for the Lake Superior deters from using the lake and all its facilities throughout the year. The other lakes below it do not freeze over completely but in severe winters they look almost like this. And in this kind of situation nothing moves. This has been recognized at some time as an extremely inefficient use of man power as well as the natural resources of the region. The study that Mr.Hays mentioned is a combined effort involving twelve federal agencies to assess the situation and to determine the feasibility to extend navigation into the unused portion of the year. An important aspect of this problem is providing all available information concerning the distribution of ice type, the thickness on the lakes on an almost daily basis. In other words in a real time operation where information is obtained and is passed out to the shippers. I have a couple of slides taken from satellites. Unfortunately there is no projector that could handle these because on this they are too small to be seen. I hope that eventually we will be doing this rather by stallites than by aircrafts. In the pictures that I have here taken from the satellite from an altitude of 570 miles and covering an area of 40 000 sq. miles on the ground.The picture just here in my hands is amazing because such a large area as the Great Lakes is seen on it without cloud cover. And particularly in winter. And this was one of the very few images that came from the satellite that showed all the Great Lakes clearly. We have adapted this system in an aircraft. And in this system we would use side looking airborne radar just to briefly describe it: a pulse of microwave energy momentarily illuminates the ground and receives the reflection and it is electronically processed and displayed on a cathode ray or TV tube.

The image of this tube exposes a film and creates an all--weather image on the film. I think you can see this much better if I show you a movie as I am talking, that develops such a film as we are watching it.

Flying such a system from a satellite altitude has not yet been achieved. It has been in use for a decade in military aircrafts. Our use of such a system on Lake Erie on a cloud covered day is shown to you as we develop it on the screen. In spite of the cloud cover this image covers a distance of about 300 miles, was made in a single flight over Lake Erie and the extent of the ice cover is clearly shown in the complete view. The two colour images in the upper part of the screen show how the various ice types look to the eye. The boundary in Lake Erie is the Canadian shore. The lower boundary in the lake is the American shore.Open water areas appear as black in this image and cities around the lake are brought out in green. The ice types occur in many forms. Some of the ice is pushed to the shore, other ice is smooth and dark. Each type represents more or less difficulty in vessel traffic and can be so designated. Imagery from such a system could be instrumental such as indicated. This can be used by shippers who would now with less difficulty and greater safety extend the shipping activities late into the season.

This was an experimental situation last year. This year we have contracted with an Army unit to fly over the Great Lakes' forests. We are providing to the shippers - there are some 19 companies - sailing in the extended season here. We are providing to them the type of imagery you saw here. A side looking radar photo is also enclosed, further an interpreted chart which defines the ice, its location, thickness and provided to them on a very rapid turnaround basis. The photos are processed immediately on the ground, the charts are prepared simultaneously and the charts are sent then out to the shippers by telephone-wires or on radio telephone and receiving units on the ships, get them almost at the time when the film is dry. So as they proceed into new areas they at least have a chart of the ice situation. We hope to make this system permanent, we have very very high hopes that it will be quite useful and valuable. The shipping interests are delighted, they are willing to invest a certain amount of equipment they may need to receive the data and we hope that this will be a step forward in providing all weather ice information. Thank you!

Chairman: Thank you very much. Questions to this paper? Any comments to do?

(......)

G.S.Lykowski: Now we do have this information from satellites. Problem is the cloud cover. And I have been able to show you the slides, I had a very clear picture of all of Lake Erie. And what was unusual about it, that there was a clear picture with no interference from clouds. But the problem is that clouds do cover the lakes and while we have the picture we have to take them as they come.

Chairman: Any other comment? We will continue with paper B14. It is on "Ice Cutting Operations in River Ice Control" and will be presented by Prof.Sokolov.

I.N.Sokolov: Mr.Chairman! Ladies and Gentlemen! I want to give some addition to paper B14, Ice Cutting Operations in River Ice Control by Korenkov, Morosov and Aleinikov.

At individual reaches of rivers and reservoirs prevention of ice jamming and trouble-free passage of ice may be effectively achieved by ice cutting combined with some other measures, such as blackening of ice cover surface or rapid drawdown of a reservoir.

Blackening can be performed by the type LFM milling machine used for ice cutting. For this purpose special removable 0.8 or 1.6 t hopper containing coal dust is to be mounted on the machine. Dust is scattered with the propeller located in the hopper. The rate and trajectory of coal dust can be controlled. Theoretically it seems possible both to combine ice cutting with surface blackening and to alterate dusted strips with ice-cutting routes. However, field observations are needed on the subject.

Experiments were carried out on ice cutting with subsequent rapid drawdown of a reservoir aimed at ensuring an earlier breakup. Under certain conditions a rapid drawdown on the reservoir with ice cover cut by slots was found to result in the displacement of ice fields. It is essential that ice-cutting operations be performed as close as possible to the downstream edge of the ice cover. An empirical relationship was established between the flow velocity at which the ice fields start to move, the river width within the reach treated by the ice cutting machine, the thickness of the ice cover and its bending resistance.

It is apparent that further field and laboratory investigations are required. Thank you!

Chairman: Thank you very much! Any questions on this paper? Or any comment? We will continue now with paper B15, "Use of Acoustic Emission in Forecasting Ice Breakup and Ice Jams"by Prof. Hansgud. I suppose he is not here. I only want to put a question to the General Reporter, whether he is here or not? I also want to know why this paper was not mentioned in the general report? And also are there any comments on this paper?

M.Szalay: When I took over my duty from Prof.Kozák I had no opportunity to revise his report. And it escaped my attention that he has not mentioned this paper. So I have to excuse on his behalf. Thank you.

Chairman: Any comment on this paper?

Well, the last paper that we have this afternoon is B17, "Long Range Forecast of Ice-Effects on the Middle Currents of the Danube River" by Professor Bálint. Is he here? No?

Well, in this way we have finished all the papers that were presented this day and now the general discussion is opened!
I want to repeat again some of the questions that the General Reporter presented in his paper. In that way it will be easier to discuss these.

First one: Are the recognized principles of river regulation applicable in all respects to winter ice conditions?

I think the third one is also important: what is the influence of geothermal radiation on the temperature of the water stored?

The fourth one: are the technical advantages of icebreaking and blasting fully exploited? How can these be improved? I think a lot of you can tell something about this.

Five: are the physical processes of ice formation,the physical processes of pure ice and such containing chemicals completely explored?

Which are the rules of contamination?

Six: are adequate observation data on ice available?Some of you can tell us about the equipments used to obtain data.Some of you are making this kind of work.

Seven: is sufficient information available on the rheological durability behaviour of saturated reinforced concrete structures exposed to freezing in winter?

Eight: quite a lot of experiments are conducted in ice laboratories. Some of you who work in ice laboratories could tell us what experiments are carried out there?

Nine: are there still "secrets", fundamental phenomena related to ice, what is the roughness on the underside of the ice cover?

Ten: How could discharge records be kept on a river flowing under a solid ice cover?

Some of you have something to ask or to answer to all these? Professor Kennedy, please!

J.F.Kennedy: Kennedy from the United States. First I have two questions for the authors of this afternoon. First, a point that I have missed in Dr.Dickins' presentation concerning the thickness measurements. As I understand these measurements were made by a radar mounted on this air-cushion vehicle. That will give you the two peaks. What is the maximum height the radar can be positioned above the water, above the ice surface to give you the two distinct peaks?

D.F.Dickins: I am not directly involved in setting of the actual electronics but as I know the system is presently designed to use it for 100 feet. The tolerance allowed is $\pm$ 20 feet. This is quite reasonable for a pilot flying to maintain this altitude. The altitude is in relation to the wavelengths. So a stepwise difference in altitude may allowable, maybe 150 feet or so. What I know that they fly at present at an altitude close to 100 feet and with 80 knots. Well, I have mentioned that actually from a few cms to a thickness of several metres can be measured and we checked these in lab tests with the help of an antenna -horn suspended several feet above the tank and we have taken very detailed actual physical measurements with heated wires through the surface comparing these with the radar measurements and we did that on a series of 15 to 20 plots. And the error of $\pm$ 1 cm is quite reasonable.

J.F.Kennedy: I also have a question with Dr.Sokolov's presentation. Concerning this ice cutting device. I did not understand from the paper exactly the type of the cutting device.What is the cutting instrument? Is it a milling machine in the classical type or a vertical cylinder? My idea with the milling machine, I do not know how it could be used for cutting? Or do we have the wrong translation to be a "milling" machine? Is this the same type that has been proposed for use in the States? George? It has been a considerable interest in the use of these devices in the States.

G.S.Lykowski: I don't know how to answer that but in the United States very much announces are in papers about various forms of cutting devices examined, primarily using the results from mechanical experiments on what sort of cutting devices should be used for ice? There are those with the vertical axes that are simply milling going towards their goal and there are what maybe termed wheel devices that cut very much as a saw with the axes of rotation transverse to the direction of motion.These have various details regarding their teeth and what is efficient. Their difficulty is with clearing the slot. The Soviet Union according to my knowledge has used various devices to weaken the ice cover previous to breakup. The impression I had by the paper presented by Sokolov was that it was a vertical device. To the question, my impression was that it was one of the disk devices, the disk in the plain of the direction of the movement. So still I am very unclear and I liked to throw the question out again. And also I wonder whether Larry Schultz can adding anything to this. Since he is working with ARCTEC and they are presently developing a prototype ice-cutter for the Coast-Guard.

L.A.Schultz: With regard to ice cutting, ARCTEC, incorporated has been engaged by the R&D branch of the U.S. Coast Guard to develop a Mechanical Ice Cutter for application in shallow waters, such as rivers, where the Coast Guard's conventional icebreakers cannot operate because of draft limitations. The Mechanical Ice Cutter (MIC) consists of a shallow draft hull fitted with three arms extending forward. Each arm supports a circular saw which rotates at high speed as the craft moves forward. The saws then cut two adjacent strips out of the ice cover. These are subsequently deflected downward as they pass under the hull and fail in bending. The hull is fitted with skegs designed to direct the segmented ice strips under the adjacent undisturbed ice cover. The MIC therefore leaves a completely clear open water channel through the ice cover. In contrast, conventional ice breakers leave the remaining broken ice pieces floating in the channel, resulting in the expenditure of large amounts of power from following ships in order to push the broken ice pieces along ahead of the ship. The circular saws were developed through testing conducted at the ARCTEC Ice Model Basin in Savage, Maryland, USA., and scaled prototype testing was conducted in river ice by ARCTEC personnel last winter. The results of these tests were very encouraging, indicating that in comparison to conventional ice breakers. The MIC could realize significant power savings in the range of ice thickness and speed of interest for U.S. river applications. We anticipate the initiation of the detailed design and construction of a full-sized prototype MIC vessel in the near future, and look forward to presenting further developments at the next symposium.

Thank you.

Chairman: Prof.Kennedy, you want to continue?

J.F.Kennedy: Our chairman invited people to speak on the subject of current active research in the labs. So with your permission I would like to give you a brief description of the overview of the ice research currently under way at the University of Iowa. And then I would suggest the chairman to invite other people likewise to describe the ice research that currently being persued in their organizations. The ice program at the University of Iowa is now in about its fifth year. At the start of this program we built a facility to study the hydraulic aspects of the ice. A recirculation refrigerated flume. Since that time we have also installed in our temperature controlled room an ice force facility. For investigation of various aspects of the strength of ice. And the structural characteristics of ice. Finally we now are also involved in a fair amount of field work on ice on the Mississippi and Missouri Rivers. Turning over to specific programs at this moment I would enumerate the following:

The first is concerned with the mechanics of formation of ice ripples. The first paper on this subject from the Iowa Research Program was given in Reykjavik in 1970 and our interest in the problem arouse largely from the publication of Dr.Larsen some years before. It seems that water flowing under an ice cover, under certain conditions creates ripples in the interface between the liquid water and the ice. These ripples are very similar to the geometrical characteristics and the kinematical behaviour to ripples formed in sand on the bottom of a stream. The first thesis conducted on this subject in Iowa was Dr.Ashton's, who is here, who succeeded in clarifying the physics that are responsible for the instability of each of the formation of ripples.Upon his graduation another student, now Dr.Shu, undertook the analysis and veryfying experiments for random ice ripples.Dr.Ashton's thesis was confined to simple sinus ripples but they are only sinusoidal by some idealization so in Shu's thesis the ripples are created as a random wave and characterized by the spectrum of the displacement of the surface from the mean. Shu was able to develop a theory which predicts surprisingly well the evolution with time of the spectrum of the ripples. He was also able from the developing spectra to determine the phase shift between the local heat transfer rate and the local boundary displacements.The second project is one about which you hear tomorrow sponsored by the Corps of Engineers and is concerned about the mechanics of ice jams. We currently have one doctoral thesis nearing completion which is concerned with construction of an overall mathematical model of an ice jam. I leave further description to this for tomorrow. However, there arises in the mathematical modeling of ice jams a need to know the strength characteristics of floating fragmented ice. The shear strength and the normal strength.So we have had other theses concerned with the termination of these strengths. It turned out to be a very difficult problem. Because strength is so very dependent on the velocity.

Yet another problem is concerned with he ice supression on rivers by large discharges. This work was initiated by the Corps of Engineers and is snow sponsored by the Cornwalls-Edison Co. This is a combination theoretical, laboratory and field project. In the laboratory Mr. (....) and his student have developed a generalized numerical predictor for the length of ice free reaches downstream from a power plant. I believe this can be viewed as an extension or refinement of the earlier work published from Krell (?) by Weeks (?) and co-workers. The undertaking got some laboratory verification of this work in a control temperature flume with particular interest focussed on the stream edge of the ice cover where some very interesting heat transfer phenomena occurred. Finally they are seeking the verification of the model - as I told yesterday - on the Mississippi River downstream from the Quab City's plant, this is a nuclear plant on the Mississippi.

In the area of ice strength most of the works are conducted by Dr.Schwartz. This was also mentioned yesterday. He has one student, Mr. (.....), he is just completing his doctoral thesis on ice forces on vertical piles. The work is just now being initiated on inclined piles. This work is being done in our ice force facility which is a tank which is some 3 feet wide 30 feet long and about 3 feet deep. We freeze a stationary ice cover in this tank and by means of crystal seeding or nuclear seeding we are able to control the crystal size in the ice. The pile, the model pile is then moved through the stationary ice cover. It is mounted on a modulized carriage through a dynamometry which is interfaced directly with an electronic computer which gives us the time history of the force variation. Their work has been concerned with the generalized predictors for the forces exerted on vertical piles in the case of freshwater ice. Concurrently with this Dr.Wu (?) who works with Dr.Schwartz is pursuing an analytical investigation the goal of which is derivation of fracture criteria for ice. It seems that there is no general agreement on what the logical fracture criterion is for such materials in general (concrete may also be considered here). Dr.Wu's specielities in the area of elasticity and plasticity is to verify the results that Schwartz was getting.

I might mention one aspect of their results which I think is particularly noteworthy and that is the following: when a vertical pile moves into an ice sheet the first failure is invariably only just ahead of the pile. The ice sheet forms a horizontal crack that extends some distance ahead of the pile. In the case of a thicker ice there will be two cracks. The first failure is a separation across the crystals and then after the ice fails in fracture. And Dr.Schwartz working with people pursuing theoretical investigations at CRREL has observed that this is also the situation in their large scale test. So the compression loading, the failure is in tension in this relatively unconstrained vertical direction. Our future activities in this direction - I think - will go on also to higher velocity loadings with the goal of confine or examine the dynamic effects.

One more study I should mention is concerned with not ice specifically but with heated plunge discharged into cold water. For the Commonwealth Edison Co. in conjunction with their designed plant on Lake Michigan we are conducting a study on heated ploons released near the lake bottom during the winter. The plunge is some 20 °F warmer than the receiving water, which is at the freezing point. The heated plunge starts to rise being eluded along its trajectory until its temperature reaches the 4 °C maximum density point. And thereafter it sinks again. And spreads over the lake bottom forming a blanket of relatively warm water. In this shallow shore region of Lake Michigan the lake is relatively well mixed and one has been concerned what this warmer water would do to the creatures that live on the bottom, during the winter.

Finally we have as a general aspect of our studies related to engineering always this question of modeling. This is particularly relevant to the case of modeling of ice forces around structures and modeling of ice jams, and we are trying to develop guidelines to help people who design the models in the interpretation of model results. Thank you!

Chairman: Someone wants to comment on this? On facilities in ice laboratories?

G.Ashton: My name is Ashton from the Cold Regions Research and Engineering Laboratory and generally I say that is CRREL and in general I have to explain what it is.

Essentially it is a laboratory which deals with nearly every area of engineering that relates to the cold regions. If our administrators are looking for funds a cold region is then defined as a place that is colder than 32 °F one day of the year. That takes care of almost the whole United States but we do have a wide and diverse program that deals with everything from wastewater management through mobility of vehicles in snow and ice conditions till what we would classify as civil works, in very loose terms "ice hydraulics". This term describes fairly well my particular area.

I would like to do now to simply run through a list which is drawn up to show some of our activities at CRREL. The various levels of activity I will describe very briefly and those who are interested in any particular subject I would request them to see me and perhaps I can them put in better communication with the particular researcher that is involved.

We have had several discussions on bubbler systems or as we do refer to these in this part of the world "pneumatic installations". There are two subjects, two part of that problem attacked in our laboratory. One is an experimental program by Dr.Chou-Yen which is measuring the heat transfer coefficient at the top of a axisymmetric or point-source bubbler system. That is not as yet published but he has a rather comprehensive set of data on a rather small scale, but it seems to be consistent in itself over several ranges of the parameters.

Myself I have been angaged in trying to simplify the designing procedure beginning with the pipe-size, discharge rate and depth. With the hope that analytically I would be able to predict the extent of supression of ice by a given bubbler system in a given thermo regime. I might add that there are a number of uncertainties that have been uncovered; perhaps the most notable one is the question of the recirculation imposed by the bubbler system. As Prof.Kennedy pointed out, we discharge 4°C water in zero degree water the jet plunges. The question that comes up then is if you are raising water via bubbler action and certainly the point is here the bubble will raise it, so the bubbles escape to the atmosphere, at that point the water is - if it is indeed warmer than the ice that you hope it will be the case to accomplish melting - it is more dense than the surrounding water and it should have the tendency to plunge. On the other hand, the common temperatures that we deal with in bubbler systems are very close to zero degree till we may be at the verge where the inertial effects of this jet may be more important than this tendency to plunge. This is an area that needs investigation. It has also become clear that in designing a bubbler syssem for a given installation one must look at the seasonal variation of ice production or the changing of the environment. To determine realistically what you will accomplish with that, it is very difficult to pick an average condition and then apply a steady-state analysis to that.

Let me get away from my work and describe the work of others. There is considerable work going on the Arctic pack-ice.The work is not so much hydraulic in its character in the moment though certainly the driving forces are hydraulic or at least they are dynamic and we are concerned with the movement,drift and behaviour of the Arctic pack-ice. So far we have accomplished the ability to provide a rather clear picture of ridge statistics.The frequency of occurrence, the height distribution that you would expect on a statistical basis and other features give us a rather clearer picture of the Arctic pack-ice we have had up till previous few years. This has been done as part of the Arctic Icy Dynamics Joint Experiment. Dr.Hibblers (?) and Mr.Mark and Aply (?) have been most active in this together with Dr.Weeks (?). As you noticed Dr.Weeks' name appears a lot of times here. I may add before I go on that Dr.Weeks is involved in all of these things in the role as a chief scientist of the laboratory. We sometimes complain that he is not involved in our individual subjects but he is involved nearly in all of these subjects.

As a marginal note, Dr.Weeks and recently myself have been involved in the exploring the concept - which is not a new task - of towing tabular ice bergs from the vicinity of the Antarctic ice shells to places on the Southern Hemisphere. The initial calculations show that we can do this on a cost comparable to the present cost of supplying water to the deserts in Chile or to the deserts of Western Australia. There is a great deal of work that has to be done in this field. Namely if once you deliver an ice berg what do you do with it? But clearly the feasibility of the delivery cost is we feel that has been well shown. Presently we are extending that particular work to determine the nonsteady stress forces that result from the evolution of the shape of the tabular bergs as they are towed. The problem is far from trivial since you must tow them fast enough to overcome the existing currents and winds, you must overcome the Coriolis force difficulties and finally hopefully you must show up with some ice when you arrive.

There has been continuing work in crystallography of ice and it has been primarily related to Arctic and Antarctic type of ice either from the Greenland sheet or from the Antarctic Cap. I quit a lot of sea-ice work. This is now directed increasingly towards river and lake ice. In this Dr.Tony (....) is working primarily. It is interesting that on lake ice we get rather large single crystals. Those people there are interested in using ice not for its own sake but for the sake of understanding such things as crystallography and metallography. For this single crystals are desirable because they can avoid then the problems of boundaries.

In the area of snow mechanics, but directly related to hydrology, Dr.Samuel Coalback (?) is now succeeded in predicting the evolution of the melt-water wave that passes through a snow-pack. Such phenomena begin with the energy input at the top surface he can predict-what you may term from hydrologic sense - the time of lag at which the water appears at the bottom of the snow-pack and its time distribution. He is presently extending that work to handle the case of ice layering where you have layers. The interesting result is that most ice layers are not very impermeable except for a very short time. An ice layer was impermeable only at the beginning of the melt and very quickly it becomes transparent in a permeability sense and lets the flow directly through. The next problem when you get to the bottom of the snow pack is how will it flow out. This again a permeability problem in porous media. And that he is also treating. He is also working in the field both alone and jointly with researchers from the University of Washington and from Canadian groups.

We have for some time been engaged in a cooperative program with the Danish primarily and with some others to do deep core drilling in both Antarctic and Greenland. This is on a very fundamental nature, on a year-year basis, it seems rather unuseful but on a long term basis it gives a great deal of insight into things that are such as our climate. The question for instance of increasing particular pollution in the air in changing our climate can be examined in looking at past cases of many thousands of years ago, the result of volcanic activity and see what happened to the climate after such a volcanic activity when things are much more polluted over a period of years, compared to that what we have achieved until now by our human efforts, though we come slowly very close to that. These core examinations go back to look at the formation of ice in the ice age, etc. There are many other things which may look to you rather philosophical but certainly give you ideas about climate trends and extreme ranges and such on a world-wide basis.

There is a continuing ice force work which is of similar nature to that Prof.Kennedy reported, perhaps in a larger scale, but larger scale has disadvantages of accomplishing fewer experiments in the same time. This is a complimentary effort of their in which ice piles of various configuration, shapes,pointed, inclined have been pushed through the ice or the ice pushed against the pile, to determine the ice force measurements. This work is under the direction of Dr. (.....) and Mr.Frankenstein and it is continuing.

We shortly will do a very small investigation which will concern on things that are now very popular in the States and these are the different kinds of arching of broken ice across an opening. There has been Russian work particularly on this subject; we hope to explore it ourselves a bit and hope that we can come up with relationships that would enable us to tell not only whether ice will arch across an opening such as an opening in an ice boom that allow navigation but also what are the effects of passing a vessel through that arched cover. Temporarily or locally distroying the arch. How it will reform itself and how it will develop after reformation.

Finally there is a work right now that is still going on to settle the question - and I am afraid that it will never be settled - of the mechanism in rates of brine drainage in see ice. As most of you know the brine in sea ice follows a rather strange way and behaves unlikely to freshwater ice. Understanding the rate of this brine drainage is a very useful thing in the understanding of Arctic pack ice.

Theory goes ahead nearly for ever, and I find in my own laboratory that I am never up-to-date in nearly everything that is going on and it is quite an effort simply to keep up. I tried to simply sample those subjects which touch on the theme of this symposium and the disciplines involved here. If you have any particular question feel free to find me, contact me, ask me; often all I can do is to bear your name to the man that does the work and who would then correspond with you. Thank you!

Chairman: Dr.Larsen, would you like to comment on your work, what you are doing in Sweden?

A.P.Larsen: Mr.Chairman, Ladies and Gentlemen! I am not going to report on laboratory work in Sweden but rather going to make comments on point Nr.3 of Dr.Kozák's general lecture: "What is the influence of geothermal radiation on the temperature of water stored?" In a pond e.g.

It is felt that heat transfer between the pond or river bottom and the water body is of considerable importance in affecting ice formation and development. Data obtained in the framework of the IHD program for a small lake in Sweden (lake Velen) show that the heat budget of the bottom sediments amounts to about 30 % of the heat budget of the body of water. Thus the amount of heat stored in the sediments during the summer and released during the winter is considerable.

It is known that the temperature amplitude of sediments decreases with lake depth which is a consequence of deeper lakes generally being more strongly stratified. However, since river water is almost homothermal river sediments are exposed to higher temperatures than lake sediments in a lake of similar depth. Therefore heat storage under rivers could be of greater significanse, relatively speaking, than under lakes.

A very important aspect of the heat transfer process is the phase shift between heat transfer and temperature. Some Swedish data indicate a delay time of some 4 to 6 weeks.

Since heat available in the water is significant in terms of ice cover development - including features affecting hydraulic roughness - it seems important that the mechanism of heat transfer be further explored.

A source of heat supply which under certain conditions may be of significance is the flow of groundwater into the river. It seems that this aspect has received very little attention.

Well, these were my comments to point No.3 and I want to make or show you some slides, actually those slides to which Dr. Kennedy referred to in his talk, showing the features of the underside of a solid ice cover on two Swedish power canals. So, could I have the first slide, please?

This is a power canal at the end of a river reach which is about 18 km long. At the downstresm end the river is canalized and the depth here is about 11 metres, the width is 65-75 metres. In the early January of 1960 we cut off with a chain-saw some ice floes about 3 m long and about 30-40 cm wide and turned them upside down. And we were very surprised to find that the cover was rippened on the other side. And this was perpendicular to the flow.

This is a close-up, you see the bank is put on as a reference; the amplitude of these roughnesses was max. 5 cm.

This slide shows a floe that was sawn out in the direction perpendicular to the flow. And here we see that although the floe is not smooth by any means this wavy pattern does not show up in this direction.

This is a section of about 6 km long of the River Dalälven in Sweden, a reach which has a power-station at the upstream end and another at the downstream end. And this floe is cut close to the downstream end. The depth here was about 4 m. The flow was two dimensional, maximum velocities of 0.65 m/s and zero velocity in the nighttime. We see here that these rippels are formed and the wavelength was considerably shorter also the amplitude was somewhat less.

Next slide! Yes, it likes very much like dunes. The common feature in the mechanism of development can be discovered in these things. Also I had but I think it is not included here a slide showing drifting snow where we see exactly the same type of pattern. And we have seen that in some of the photographs shown here today.

Well, in order to find out something about the development of the ripples, one floe that was completely smooth on the exposed side was turned around and was exposed to the flow of the canal - I think it was 18 days - and then it was turned around again. And this is what you see here. This floe was 3 weeks ago completely flat and after about 3 weeks this pattern has developed. Now this I would not say more about, because Prof.Kennedy and Dr.Ashton have explored this aspects and came along on a long way to understand this phenomenon.
Thank you very much.

Chairman: Yes, please!

L.A.Schultz: I do not think any researcher can turn down the opportunity to talk about his laboratory. So I may mention again, my name is Larry Schultz, associated with ARCTEC which is a private company in the US, for those of you who are not familiar with our company: it is a consulting engineering firm, specialized in cold region engineering and even architecture and we are engaged in theoretical work, modeling, simulations, model tests and full scale work. We have a model test basin which has been in operation now for three years and we conduct resistance tests of shifts in ice and measuring of ice forces on offshore structures. And we have a little brochure which describes our laboratory and some of the work we have done. If anyone of you is interested to have one of these I would be delighted to give you one, after this session. In the area of theoretical and math models and simulations we have had in the past engaged in very practical applications of math models to power plants. In particular power plants for ice-breaking vessels. We have done a mathematical simulation of the dynamic effect on the entire power trend. Currently we are engaged with the St.Lawrence Seaway Corp. and we are modeling the Seaway and looking for constrains in winter navigation. And we are well along on this project and perhaps Mr. Wilson - if you are interested - will brief you a little further on that. Ultimately we hope to end up with a benefit-cost analysis for all of the constrains that would apply to the Seaway so that we can make an outstanding quality evaluation of the various constrains in this system. In the area of ship model testing the ice forces on structures and powering on such ships is fairly well established because the laboratory procedures go on and this is what we have here in this small brochure. In addition to this we are just recently considering a program to develop design criteria on structures mounted on ice near open water. In other words, we have an ice sheet with open water and we want to build a structure- the question is how determine the levels in order to avoid damages. This is a strictly applied project and we got some good results on it. We have another test program which we are about to begin: one involving an ARCTEC surface effect vehicle which we are working on for the US Navy. We are studying the speed and power requirements of this vehicle as it transverses ice.Some of you may be familiar with the surface vehicle. When we look at the speed curves, the power characteristic curves of the vehicle, there is much problem how the power as the speed increases, the power required increases up to a point and this is described as being the point at which the vessel climbes up to the top of its own bellway if you want to think about it in this way. As the vessel moves along it generates a bellway in the water and at some critical speed you can get over that and you get a reduced power requirement for an increase in speed. The question is whether this also happen when the vehicle moves on ice. We will be starting that program within the next two months in our model basin in Columbia, Maryland. Finally, we have full scale tests on the Tanker of Manhattan and on the Coast Guard projects. Concurrently we have several people on the Great Lakes who are waiting for a full scale test for an air-bubbler system. A system mounted on a ship. They have been up on the Lakes for about two weeks now and the test will be running through February. Initial response just before I left was very promising. They were seemingly somewhere in the neighbourhood of 5 to 15 % power reductions when this air bubbler system was in operation. As far as the future is concerned, the company is concurrently constructing new laboratory facilities; our present model basin is 50 feet long by 8 feet wide and 5 feet deep. We have constructed a new model basin which is 100 ft long, 12 ft wide, and 6 ft deep. The basin itself is completed but is not in operation as of now.

We hope to have it operational near the end of the summer. Some time in August. Also in this laboratory we provided for a 100 ft long, 12 ft wide refrigerated circulating water flume and we also hope get into some hydraulic modeling, we have an area in the laboratory for that, which we will use not for saline ice but for freshwater ice in the hydraulic area. The synthetic material that has been developed by Professor Michel at the Laval University in Quebec, Ontario, Canada. So if you would like some information on that I would be eager to supply to you that. Are there any question?

Thank you!

Chairman: Are there any other comments? Well, before to finish, Mr.Hurst is going to make some comments on the papers discussed.

C.K.Hurst: Mr.Chairman, Ladies and Gentlemen! I must apologize for not being fairly prepared for this comment because I did not read the papers before I arrived and had really no chance to read them in the detail that they would have deserved.

The summary of the papers presented in section B, given by Professor Miklós Szalay provided a comprehensive analysis of the various items covered under the leading "Interrelations Among River Training, River Canalization, Low Head Water Power Development and Navigation with Special Regard to Ice Control".

Discussion of this subject by the members of the symposium covered many items but for the main part referred to three points.

1. The experience of the Soviet Union in use of Pneumatic Installation had been successful particularly where the difference in temperature between the lower and upper levels was in the order of 1 degree centigrade. Experience in Germany suggests that bubbler systems can be effective even when there is no temperature differential. The possibility of using a pump to circulate water instead of by bubbles was suggested. Most of the experience has been for the protection of hydraulic structures however there are several installations in existence and proposed in Canada for the maintenance of navigation channels by use of bubbler systems, existing installation is 2500 feet and its proposed installation is 3 miles in length. Further study appears to be required to determine whether bubbler systems can be effective where there is no heat transfer.

2. The possibility of transferring adverse effects of ice formation from one place to another by control activity was pointed out by Yugoslavia where the ice control activities related to the canyon at the Iron Gate on the Danube in Rumania may adversely effect low plain areas in Yugoslavia. It was also mentioned that the ice boom placed across the outlet of the Lake Erie in North America to reduce damage to shore property and power developments on the Niagara River was blamed for climatic changes in the area. This possibility of ice control activities must receive careful consideration.

3. Discussion brought out new survey techniques. The Hungarian method of determining size and velocity of ice formation by photographic means utilizing one observation post at a high level. Canadian use of radar for determining ice thickness was considered promissing. The United States use of side scanning radar from high flying aircraft and possible use of satellite observations and photography provides up-to-date ice situation reports to assist navigation in the Great Lakes of North America.

Other points considered were the conflicts that may arise in rivers used for multipurposes, power, navigation and flood control, and the possibility of ice control for one purpose having an adverse effect on others.

Use of water taken from various levels of a reservoir where the heat content is higher to control or eliminate ice downstream was an interesting problem. In some large reservoirs in the United States water can be taken from various levels to provide proper temperature for fish development downstream. It was suggested that this technology could also apply for ice control. Swedish experience indicates that up to 30 % of the heat budget of small lakes is provided by teothermal radiation from lake bottom. This phenomenon is worthy of further investigation. Discussion also covered ice cutting techniques developed in the USSR and use of this type of operation in flood prevention on the Lideau River in Ottawa, Canada. Mention was also made of early work done by Dr. Barnes on the lower St.Lawrence using the spreading of lampblack on ice surfaces to speed ice melting and also thermite bombs for ice elimination.

A recent study of the feasibility of constructing a marine terminal at Herschel Island in the Canadian Arctic provides interesting mathematical model study of ice management techniques required for Arctic conditions if a navigation channel is to be available all year around for supertankers. This study can be obtained from the Department of Public Works of Canada in Ottawa. Interesting films were shown by Mr C.Lawrie of Canada on ice breaking activities in the St.Lawrence, by Mr G.Lykowski,Col.Hays of the United States on ice formation in the Saint Marie's River. Dr.Larsen of Sweden showed interesting pictures of the effect of flow on the underside of an ice surface and the ripple pattern.

These were my comments, Mr.Chairman! Thank you very much.

Chairman: Thank you very much for your co-operation! I have an announcement for you! About the Theatre performance this evening. Departure of coaches from Hotel Budapest will take place at 7:30 p.m. About the study tour to Baja on January 18, the departure of coaches from Hotel Budapest will take place at 7:00 a.m. The departure of the special train from rail No.1 in the main hall of the Eastern Railway Station will take place at 7:30 a.m. Approximately, at 8:00 p.m. we will arrive to Budapest. Breakfast and dinner will be served on the train, snacks and beverages instead of lunch will be served at the City Hall. Before ending I want to thank the work of Professor Szalay, our general reporter this morning and also of Professor Hurst for his comments that he made.

And for all of you, thank you very much for your attention.

SESSION ON SUBJECT C

Effects of Runoff Regulation

2:00 p.m. January 15, 1974

J.F.Kennedy, Chairman
Z.G.Hankó, Co-Chairman
I.Mátrai, Invited Speaker

J.F.Kennedy, Chairman: Good afternoon, Gentlemen! And welcome to the first technical session of the Symposium on River and Ice! This session is entitled "Effects of Runoff Regulation".

My name is John Kennedy, and I am a Professor at the University of Iowa in the United States. My co-chairman this afternoon for this technical session is Mr.Hankó, seated on my right, who is chief of the Department of Hydromechanics at the VITUKI Hydraulic Laboratory here in Budapest, and also a member of the Organizing Committee.

Before we turn to the technical subject of this afternoon's session I would like to call your attention to certain administrative matters which will help the smooth flow of the sessions and of the discussions. In the briefcases which were given to you at registration you will find among other things two types of forms. One of these is entitled "Registration for Discussion" and if you want to discuss a paper you are asked to fill out this form and give it to some member of the staff or member of the Organizing Committee before the beginning of the session. Then later after the discussion you are asked to fill out the other type of form giving your name, the paper which you discussed and a short abstract of your discussion. This is your opportunity to write down what you wish you had said instead of what you have really said. I hope, however, that the use of these forms, which are very important for the Organizing Committee for the purposes for getting a written report of the discussions later, will not inhibit or reduce the amount of open discussion from the floor. The reason for we have symposia is for people to come together and to exchange ideas. So if you have something you want to say, please do not refrain from saying it simply because you have not filled out the form. That always can be done later. So, do not let the paperwork inhibit the free flow of ideas.

Our first general lecturer is Professor I.Mátrai, who is Deputy-Director of the Investment Agency for Hydraulic Structures of the State Water Authority and also Professor in hydraulic engineering of the Technical University of Budapest. Professor Mátrai will introduce theme C of this Symposium "Effects of Runoff Regulation" by a general lecture of the same title.I take a great deal of pleasure in presenting to you Professor Mátrai!

I.Mátrai: Mr.Chairman! Ladies and Gentlemen![x]......

I am at the end of my lecture. Thank you very much for your kind attention!

Chairman: Thank you very much, Professor Mátrai, for your concise yet very comprehensive overview of the effects of man's intervention on the regimen of rivers. I was particularly impressed by the skillful way in which you interrelated and wrapped together the presentations included in the papers which we will hear later in this afternoon in your surveying lecture.

We are now ready to take up the presentation of the individual papers by the authors. And I propose to take them not in just the order they have been listed on page 13 of the Bulletin to accommodate the schedule of some of our Soviet colleagues. I am going to call first for the presentation of paper No.C3 "River Channel Transformation Downstream from Hydro-Electric Plants" by Wekslar, Donenberg and Skladnev, from the B.E.Vedeneev All-Union Research Institute. The paper will be presented by Professor Zvorykin also from the Vedeneev All-Union Research Institute on behalf of his colleagues. Now I would call on Prof.Zvorykin.

K.A.Zvorykin: Mr.Chairman, Gentlemen! I have a short addition to the paper C3.

A number of additional aspects of the river channel transformation, apart from those described in our paper, is discussed in publications by Soviet scientists. One of them is the decrease in the stability of channel bars due to diurnal release waves running across the river deposit zone. According to N.I.Makkaveev, I.R.Rozovsky and V.A.Bazilevich, who comprehensively studied this phenomenon downstream from several dams this is induced by an intensified movement of sand bars under unsteady flow conditions. As a rule, to provide a navigable waterway in such river channels it is necessary to increase the volume of dredging.

Some Soviet investigators (P.A.Lisovsky, N.I.Makkaveev, A.K. Pyazoke, A.V.Serebryakov) suggest that rapid accretion of bars formed at the node of confluence of a regulated river and an unregulated tributary is caused by delayed and lowered peak flood in the principal river.

Steepening of the open surface slope observed within the mouth reach of the tributary is accompanied by increase in flow velocities and solid discharges in the tributary, with solids depositing on the bars within the node of confluence of the principal river with the tributary.

Of great interest are investigations by A.V.Serebryakov of the effect of changes in the thermal regime of a river due to creation of a large reservoir not only on its ice regime but also on sediment transportation. In particular, A.V.Serevryakov established that at lower water temperatures the scouring capacity of the flow decreases while its carrying capacity increases. Thus

[x] Prof.Mátrai's lecture has appeared as a separate volume of General Lecture on Subject C.

lower temperatures of water registered downstream from large reservoirs (as compared to unregulated rivers) during the spring and summer periods, i.e. during the periods of most intensive channel modifications, contribute considerably to the total stability of bed forms. The phenomenon is more pronounced on rivers flowing in channels composed of sand with large amount of particles less than 0.6 mm. While predicting river channel transformations downstream from hydropower plants under design the above considerations should be kept in mind together with the data presented in the paper. Thank you!

<u>Chairman:</u> Are there any questions on this paper? This whole question on the effects of temperature on bedforms is one of the really intriguing aspects of sediment transport. The fact that over certain ranges of temperature a change of only a few degrees can cause the whole character of the riverbed to change from a dune-covered one to a flat one and hence alter the entire sediment transporting characteristic of the river is really one of the most difficult aspects of sediment transportation engineers. It is interesting to see that this has been studied out of a case of temperature regulation by reservoirs. Are there any questions?

Well, you will have further opportunity during the general discussion session. I propose now that we adjourn for our break and resume again on schedule after 30 minutes that would be at 15:15 p.m. So that won't be exactly the schedule given on page 15 but let us have a 30 minute break and then reconvene for the consideration of the rest of the papers. Now may I ask you during the break, please, to fill out these forms which I mentioned to you at the beginning of the session. I also propose for the balance of the afternoon session, that we will proceed in the following way: After the presentation of each paper we will call for questions and discussion of that particular paper and then at the close of the afternoon session we will have a period for renewed discussion for all of the papers and of the entire subject. It appears from the information now available to me that not all of the authors are present this afternoon, two are missing, that will give us some added time for discussion of the individual papers as we proceed. So, if you would adjourn for our break we could cenvene at say, 20 minutes after three. Thank you!

<u>Chairman:</u> Again with a small administrative matter.

I have two announcements. First of all concerning the folk-dance performance to-morrow evening "Wedding Feast of Ecser" which is on your program. May I ask you to pick up your invitations at the information desk. This was not included in your material which you received at registration. But please, pick them up at the information desk. Similarly, the written version of Professor Dégen's lecture what you heared this morning is available at the information desk. And you are invited to pick them up, also.

Now, I trust that during the break you had the opportunity to fill out the often mentioned forms so if you will see that they are given to one of the young men standing around to bring them up to the podium.

Let us turn now to the continuation of the presentation of the technical papers. It is my understanding that Mr.Kray, author of paper C1 is not here. Is that correct? Or is he present? Or is there someone who will present the paper for him? Well, Mr. Kray gets another item in his publication list but we do not get to hear him. Likewise, I understand Mr.Liby, author of paper C2, is not here. Is that correct? Or is there someone to present the paper for him? We heared paper C3 just before the break. And we are now to go to paper C4. "Effect of Runoff Control on Ice Regime of Rivers and Terms of Navigation". By K.J.Rossinsky and A.A.Kondratskaya. Now it is my understanding that neither of these authors is present but that the paper will be presented by Dr. Onipchenko. Dr.Onipchenko, would you come foreward please?

G.Onipchenko: Mr.Chairman! Ladies and Gentlemen!

Authors, Mr.Rossinsky K.I. and Kondratskaya A.A. suggested the paper on the influence of run-off control on river ice regime.

From the analysis of ice regimes at dammed and natural rivers the authors made the following conclusions:

Water storage reservoirs entails considerable changes in the terms (time) of complete freezing and ice break-up. The reservoir freezing comes later than on rivers freezing under natural conditions, especially subjected to the action of winds.

In large storages the ice usually melts on the spot.

The terms of melting can be forecasted by the ice regime of large lakes located nearby.

If the river flows from the South to the North the lag of reservoir break-up can entail ice-jams in its headwaters where ice drifting has already begun.

The river run-off by the cascades of hydroelectric projects permits to eliminate the formation of ice-jams in the reservoir headwaters.

On rivers flowing from the North to the South the reservoirs break up before ice drifting under the effect of the sun radiation, wind and temperatures above zero.

Transit navigation is determined by the term of reservoir break-up, therefore the authors suggest to use icebreakers as the most effective means of prolongation of navigation.

In downstream pools of hydraulic power stations a river stretch free from ice (polynia) is formed, the length of which can be controlled by means of smooth change of water releases from the upper reservoir.

The investigation of thermal balance of water mass in downstream pools of hydroelectric projects makes it possible for authors to suggest formulas of determination of polynia length and the velocity of movement of its ice edge due to meteorological conditions and water discharge regimes. This method was used during the construction of Ust Ilim hydroelectric project on the river Angara for fighting against ice gorges in the area of construction. The polynia was maintained 350 km in length up to the spring by water releases from the Bratsk reservoir. This accelerated and facilitated the conditions of ice breaking in spring.

It is necessary to avoid sharp change of the discharge which leads to ice breaking and winter ice drifting. Thank you.

Chairman: Are there any questions which you want to address to Mr.Onipchenko? Concerning this paper? If not, let us continue then to paper C5, which is authored by two colleagues from a neighbouring country, Mr.J.Szolgay and Mme A.Stančiková, from the Water Institute of Bratislava. I believe the paper will be presented in Hungarian so those of you who do not understand Hungarian should put on your translation head-phones.

Mrs.A.Stančiková: Dear Colleagues, I try to tell you what we have done concerning a new barrage just being designed on the Czechoslovak section of the Danube. The designers asked the researchers what the ice conditions will be under the new circumstances. We have tried some calculation methods. First we calculated the appearance of the first ice on the basis of statistical analysis. Then the thermic balance was applied, finally the synoptic situation forecast. The statistical method gives only a first information. It has not yet been possible to put everything, climatological, hydrological and morphological data, influencing the ice conditions into the calculations. The synoptic method has not yet been elaborated to such a degree that the calculations could be considered accurate. We liked most the thermical balance method overtaken from a Soviet researcher, Shulyakovskiy. First of all we calculated the first appearance of ice on the Austrian Danube stretch, begun from 1927 when the Kachlet Barrage was already in operation. The calculation embraced the period to 1964, when the Danube had ice in 29 winters. These 29 winters are taken as 100 per cent and in 84 per cent the ice appeared at the barrage 1 to 40 days earlier. In 14 per cent the first ice on the Danube appears just on the same day when at the barrage the first real ice was observed. The essence is, the 62 per cent of the calculations is good. On the basis of this we calculated the appearance dates of the first ice for the Czechoslovak Danube section at the barrage and informed the designers about the expectable ice conditions. Thank you.

Chairman: Questions? Comments? Now we will continue with the papers and leave the general discussion until all papers have been presented. Our next presentation comes from Canada. Dr.Gee Tsang is in the Hydraulic Division of the Canadian Center for Inland Waters. His paper is entitled: "Ice Piling on Lakeshores; with Special References to the Occurrences on Lake Simcoe in the Spring of 1973".

G.Tsang: Thank you, Mr.President! Ladies and Gentlemen!

The paper deals with ice piling. In fact, only the ice piling of lake Simcoe was used as an example, but what has been found should be general. The story of this study is this: early this year we had ice piling in lake Simcoe and so people made a lot of noise. Because people around the lake have built many cottages. In Canada when people are so rich that they can build cottages they usually make a quite big noise. And so my boss said, O.K. go out and make some study. So I went out and made a study about it, and that is what I have found so far as it is reported in the paper. I found that ice piling can cause quite bit of damage. Especially for houses close to the lakeshores, and the main reason of ice piling is not by strong winds as many people believe - by the same reason as in icy regions in the arctic area - but by the change of direction of the wind from the onshore direction to the offshore direction, and the speed of the wind can be quite low for one instance, and we found that ice piling may occur under a wind of less than 6.75 m/s. This decimal number comes from converting the units because as you know we use British units so now we are supposed to convert to the metric units, and so this is roughly about 12 or 16 miles/hour.

And I had an ice piling about 30 feet or 9 metres. And that was the highest. And we also found that won't occur if temperature is about 0 °C because at that time the ice sticks together and the friction becomes high and so they won't pile. Based on this observation, I have made some numerical analysis on it and come out with a couple of formulae to predict the heights of an ice pile, the size of the ice floe and the base angle and also predict the time required for an ice pile to occur and also the width of the water gap that has to be available for ice to pile. The findings were confirmed by a few observations, at least by the data we have. On continuing this project this year in the coming spring continued observation will be done on a weather station that has been newly established at the lake-shore at one location where last year we had a big ice pile, and we also plan to put some current meters close to the shore as soon as I go back from this meeting in Canada and we also try to take the soundings and so this probably will answer the question of Prof. Hankó on the slope effects of the bottom on ice piling. And also to have a survey of the shape of the ice that is what affects the shape and the size of the ice floes. We are going to put, to draw big signs with a dye on the floes and on the ice cover and then we take up with an aeroplane and take pictures before and after the ice pile and so take a measurement to see how piling occurs and hopefully we will have some more data to come out which may lead to further improvement of the analytical treatment of the problem. In fact, I after reading my paper on the plane with which I came over, I have read another paper by a Hungarian scientist, Mr.Györke, and it seems we have had the same problem. And so I am quite happy to see that the scientists all over the world see water problems in the same way. Thank you!

<u>Chairman:</u> Thank you Dr.Tsang! Are there any question to the addressed concerning this paper? Yes, Dr.Ashton of the United States. I think to be translated you have to come to the microphone.

<u>G.Ashton:</u> The observation of the author that overriding occured a high percentage of the occurrences and that undersliding occurred in but a small per cent of the cases observed is most intriguing, particularly since piling was not observed to progress in the latter case. This gives rise to two questions. First, what behavior resulted after initial undersliding, and second, would it be reasonable to utilize some form of protective struct-

ure to encourage undersliding as a means of local protection against ice piling?

G.Tsang: The question may be answered in this way: Now when you have two pieces of ice the upwind piece will ride under and when this hits the first piece of ice it can only go down and cannot come up. And if it is going down - because in that area usually is a quite low temperature - so likely it will stop there and therefore the next one to come, it has to slide for a much longer distance. So it has not sufficient momentum then go up. This is how I have seen it. There is another phenomenon "rafting" which really is a buckling. And to the problem that you have more overrunning than underrunning it is due to the wave form. The wave usually gradually increases and you have an abrupt coming down and so I think you will have a better chance of coming on the top of it. And I think really if you can come up with some method how undersliding occurs it would be a good idea. You can it try out. And in fact for the method, for one of the methods I proposed, it would be nice to try out.

Chairman: Any questions? Dr.Starosolszky?

Ö.Starosolszky: Thank you Mr.Chairman! May I rise the question concerning the forces erected by the piling of the ice. Are you intending to measure the forces and if yes what type of instrumentation do you want to use? And simultaneously may I have a slight comment concerning the piling of the ice on Lake Balaton? As you know Lake Balaton is the largest lake in Central--Europe located in the middle of Transdanubia in Hungary. Its length is about 77 km and the width about 8-10 km. On this lake Prof.Cholnoky at the end of the last century has measured ice pilings on the shores. The results of his measurements have been published in a book about the beginning of this century. And these results are supporting the results which have been discussed by you. And on Lake Balaton we have quite a big problem with the dilatation of the ice cover. This dilatation is caused by the temperature variations of the ice cover especially in the days when we have quite heavy changes of temperature. E.g. in the morning or in the night. And the main troubles - according to our opinion - are caused by this dilatation and not only because of the wind. Thank you very much!

G.Tsang: To answer the first question concerning the measurement of the forces my answer is, I am afraid, no. The reason is because simply we in Canada do not have many people and support to do the job. In fact, many times I have found I am doing things singlehanded and this is quite difficult. And I am glad to know that I have some support from observations from this lake in Hungary. Which seems to me a little smaller than lake Simcoe but of comparable size. Talking about the temperature effect, I think there has been quite a few papers published about the temperature effect on ice cover, I think one is by a Canadian by the name of Milne and he has found that when the ice cover is subject to a temperature change it affects only the top 5 cm, which will be affected by the temperature. Because of this if you have a crack in there it tends to increase. And you have a high thermal stress in there. And if you have a stress concentration now you need a little wind to make some wave underneath and that would probably the main cause I think for breaking the ice. First you have a wind energy and that goes into the wave and water and then you have a wave change and this energy goes in the ice cover and from the fluctuation, from the vibration, the kinetic energy of wave changes has to go somewhere and it goes into breaking the ice cover. This is the way I see it.

Chairman: Other questions? I may raise a question in connection with the analysis, with the introduction of a friction coefficient. A constant friction coefficient. Do you know that much work has been done to measure the friction coefficient in stuck ice under dynamic conditions?

G.Tsang: I tried to find some material and I could not, because nobody so far has gone out to measure the friction of ice under natural conditions. And by the way, something has come up to my mind. In my paper I used a numerical method to integrate this distance and then I found out this which can be done also analytically.

Chairman: I think that in due time it likely will be found that this friction coefficient is very velocity dependent. And this is what we are finding more commonly in shear strengths and compressive strengths (.....) fragmenting ice. It is really very velocity dependent that makes the problem even more difficult. One other comment. I have concerns to temperature distribution in ice floes. The top centimetres being affected I think this is a very loose generalization that one cannot bank on too much, because it certainly will depend first of all on the rate of temperature change and of course also on the magnitude of it. There was some more published in the United States in the past year by two investigators in which they integrate non-steady heat flow equation for ice-floes taking into account the temperature dependence of the thermal diffusivity that is the conductivity of the ice and also the effects of salinity. So it is now time to make a generalized graph to take predictions about the temperature variations within the ice. Other questions? Comments? Thank you very much, Dr.Tsang. The seventh paper and the last one listed or scheduled for today is a contribution from VITUKI by Mr.O.Győrke under the title: "Ice Problems in Lakes and in Large Headwater Reservoirs on Canalized Rivers". And this paper follows properly after the last one. Mr.Győrke, please!

O.Győrke: Mr.Chairman! Ladies and Gentlemen!

I am dealing in my paper with ice problems in lakes and in large impoundment reservoirs in canalized rivers. In periods with strong winds and at locations where the width of the exposed water surface attains or exceeds a certain extent wind generated waves and currents will occur in the water body. If there are, in addition, floating ice floes on the water surface these are set into movement and carried downwind. In such cases the movement of ice floes is controlled by the resultant of currents due to gravity and wind action further by the movement imparted to the ice floes by wind. Where the ice free fetch is long, the wind-generated currents and wind imparted movement of the ice floes govern fundamentally the direction of movement and the velocity of floating ice floes. If the flow strikes an obstacle, solid ice or structures they accumulate and the resulting jam remains stationary or continues to move. This jam formation is always accompanied by energy transformation. This phenomenon occurs regularly in Hungary on Lake Balaton and to a much lesser extent on the Danube also, at locations where the flood bed in the direction of the wind is wide enough. In the wide backwater impoundments of canalized rivers and in storage reservoirs wind generated ice movement and jamming must always be anticipated. The conditions for the occurrence of this phenomenon and the possibilities for averting the damage can be investigated by a dynamic analysis of the ice movement.

I tried here to put into equation the forces acting in this phenomenon, see Eq.1. in my paper, and to evaluate the kinetic energy carried by the moving ice. See Eq.2.

But for using these two equations, in computations some quantities, which are also enumerated in my paper, must be determined. At the time, when we did not have valuable data for these terms I estimate that for practical purposes the critical extreme values are probably of interest. Reasonable estimates may play an important role here. To assist in these estimates attention is called to certain trends.

a) The size and the destructive power of the forming jam are controlled eventually by the mass and velocity of the striking ice.

b) The dimensions and destructive power of the ice jam are greater if large coherent floes strike the obstacle. The large floes tend to become pushed over each other at the obstacle, but break up mostly near the top.

c) The destructive effect of jamming can be reduced by promoting the possibility of deformation work taking place during breaking into pieces.

In order to prevent and avert damages due to jamming, further to promote winter operation of reservoirs the following considerations should be remembered:

1. Before designing the bank protections and structures, further before selecting the locations for harbours and ice sluices the following information is to be collected for a particular area:

- Periods with running ice.
- The direction of strong winds likely to occur during this period.
- On the basis of the foregoing, the shore sections exposed to ice jamming should be selected.

2. Harbours should be situated wherever possible along the windward shore.

3. Ice release sluices are effective along the lee shores where the broken floes are accumulated.

4. Damages to the shores due to ice jamming can be averted by having the jam be formed farther away from the shore, or by preventing its formation at all. The following alternatives should be considered here:

- if it is compatible with reservoir operation, the level

should be lowered, causing the ice to stop and jam before the bank slope, as in Hungary,
- at constant water level interception and jamming should be promoted by structures situated before the banks and deflecting the ice upward,
- causing the ice in the vicinity of the shore to settle on the bottom.

5. The levees enclosing impoundment reservoirs should be constructed with a wide crest.

6. Methods for ice breaking which would lead to the development of wide ice-free water surfaces and thus long fetches should be avoided.

Thank you for your attention!

Chairman: Thank you Mr.Győrke! There is at least one prepared discussion of this paper that of Mr. Brachtl of Czechoslovakia. Please Mr.Brachtl would you please come to the floor?

I.Brachtl: Mr.Chairman! Ladies and Gentlemen!

Mr.Győrke spoke about the damages due to ice jamming in Hungary. I would like to inform you about the possibility to prevent such damages used at some smaller rivers in Czechoslovakia*......

Thank you!

Chairman: Thank you very much to Dr.Brachtl this very interesting presentation and decription of an intruiging means of ice control. It is always a good idea to keep the ice where it makes the least damage. Now, are there any further questions on or of the discussion on paper C7? Are there questions?

Would anybody like to address any questions to Dr.Brachtl concerning the ice control structures he just described? Tsang?

G.Tsang: In Canada and in the United States ice control is often achieved by using ice booms. And as I noticed from Dr. Brachtl's paper the results obtained by these structures are very good. And I wonder, I would like to know more from the comparison between the structure which was developed in Czechoslovakia and the ice boom which has been widely used in North-America.

Chairman: Mr.Brachtl, would you like to reply this?

I.Brachtl: It is quite difficult to reply because my English is not on the level that I could speak fluently but we have no experience with ice booms which are used in Canada, I know some experiences obtained from St.Lawrence River and around Niagara Falls but in this case you saw on one of these pictures two profiles we have proposed for an ice control structure. And for the first time we made only one of them, that made of steel piles. In other cases we wanted to check the influence of swimming booms in some cases in combination with driven piles but one problem

* The text of Dr.Brachtl's discussion as a lately arrived paper is put at the end of this session report!

was for the spring flood. We are not quite sure that we will have time enough to put the swimming booms away. And in the lower region there is a bridge.The piles of the bridge are not far enough and there was a danger that the swimming booms will clog the bridge profile and will cause a great damage in this case. And therefore, we constructed at the first site and the first site is very good for the moment. If the conditions will not change and the amount of ice willnot be too much for this structure everything is good. Otherwise, we will check the possibility to construct another one in one of the profiles which you have seen on the pictures.

Chairman: Further observations on ice control structures, Mr.Hurst?

Ch.K.Hurst: Concerning the difference between the ice boom which we have in the North-American practice and the ice structure which was here discussed - the ice boom which is used close to the Niagara Falls is to encourage the formation of ice in the beginning of the year. So, you maintain the ice there and the ice cover to prevent it from flowing down the river. Whereas, the other structure - I presume - is used to break up the ice and hold it in the flood periods.

Chairman: Dr.Starosolszky?

Ö.Starosolszky: Thank you Mr.Chairman! Let me address a question to Dr.Brachtl. I would be interested about the design method of this piling. Did you take into consideration some special loadings erected from the ice. That means, I would be interested about designing of the opening between the front piles and simultaneously the loads but you have to take into consideration when designing the stability of the special form of the piles. Thank you!

I.Brachtl: In dimensioning of the structure we took the basic hydrologic data about the water level in winter period, it means lowest and the highest. In the last case in a section where peaking occured twice a day. Or three times a day. And therefore, the top of the ice control structure is a little beneath of the water level of the peaking. The opening between the structure is chosen after the dimensions of the flows we expected to come from the upper reach of the river. They are a little greater than the flows coming. It is supposed that the steel piles will form a crystallization of ice forming and that also ice will grow from these piles on the sides. And the coming floes will clog. We do not like to clog all the structure and in the period of peaking the ice cover moves upwards. And in this time it is necessary to have enough place between the ice cover and the bed in the profile for the discharge of the water to flow. And during peaking so the ice cover forms and forms upwards, straight upwards, so the river is protected from heat loss. And during winter, the whole quantity of ice is much smaller than without such a structure. You asked me about the loads. It is quite a difficult question. In preparing such a structure we do not know the height of the ice jam. So we only suppose that it will be the same as the height of the ice control structure and we chose such an inclination of the piles that other ice that will come will flow over the structure. It will be pushed over the structure.

Chairman: May I ask how that inclination was determined?

I.Brachtl: To tell you the truth, it was determined only by a feeling or guess. We observed several bridges, several bank formations and afterwards we have chosen the inclination and it seems to be all right in this case. It is working.

Chairman: Are there other questions or contributions on this subject?

Ch.K.Hurst (?): It seems to me that this kind of structure and the ice boom both have been in many respects a common function. Now the question is which could be used on a section which is navigable and must be moved in some ways.

Chairman: There is one more contribution which is not listed in your program. The paper was included as a separate in the material which you received at registration.

That is the paper from Dr.Simmler on some aspects of ice formation in river reservoirs. Is Dr.Simmler here? Or is a representative of him here? To read the paper?

If not, I would open the floor to the general discussion of all of the papers and of the subject as a whole. Dr.Starosolszky?

Ö.Starosolszky: Thank you Mr.Chairman! If you do not find too funny that I want to discuss with my distinguished colleage Prof.Mátrai on this floor, I may rise the question concerning the problem of the model tests of the ice runs. Prof.Mátrai has a statement in his general lecture on p.7 in Section 3 in the second sentence: "The model tests commonly adopted for estimating flow conditions yield little information on ice-run conditions." This is the question very frequently discussed among engineers who are devoted to the practical problems while working in practice and among researchers working in laboratories. According to our opinion it would be very difficult to make model tests, real model tests concerning the ice formation on the rivers. Because in this case we need special thermal labs which are very rare all around in the world. But when we are dealing with ice run conditions, according to our opinion, there are phenomena which may be modelled, which may be tested quite well. Let me emphasize that when we have a real sheet-flow and in the case of ice-run we have a real twodimensional problem on the surface of the river and when we are not too much interested in three-dimensional flow in the river itself we can prepare a model-test where the similarity may be ensured. Taking into consideration only the surface-pattern. And in this case when we are interested only in the ice-run conditions and not interested in the stoppage of ice-jamming the model tests may be used. Of course, if Prof.Mátrai will not agree with me may I ask him to discuss with me. Thank you very much!

I.Mátrai: I like to give my idea about this model-test. It would be better in Hungarian because my English is not perfect but I will try. My idea was that the perfect model testing is always a problem. But my idea was first of all that when the ice is moving, this two-dimensional motion can find a good material to make the ice floes - you can calculate the weight of the floating possibilities - and I think this is correct. But if the ice is moving in real life this has a strength of 22-20 kg/cm^2 and when ice is breaking this is even greater and this is the real problem. When the ice is moving and breaking we cannot do it in model tests and first of all when ice is jammed we cannot do it in model tests. That was my idea for the perfection a little of this problem but I do not know how to do it. Thank you.

Chairman: Yes, please. Mr.Győrke!

O.Győrke: As for the model tests. To model anything with perfect similarity is impossible. We are modelling in our problems phenomena in which there are different processes, some of them interesting for us. The ice problem is one of them. There are different processes:

- the process of ice formation is a thermal process. It can be modelled but the modeling is very complicated it is not easy to follow the floating ice piece as a solid on the water.
- When the ice is treated as a solid matter, floating on water and is not necessery to take into account the inner force, the rigidity of the ice, it can be modelled in a fluvial model only as a matter which is floating and the similarity depends only on current velocities and the mass of floating pieces.
- But if the phenomena depend on the rigidity of the ice also, - the ice jam is an example - where kinetic energy conversion takes place then the modelling process is other, one must take into consideration the inner properties of the ice material. Any modeling method has its rules and it must be decided always what process is decisive in this phenomenon, and model this process. Thank you!

Chairman: Thank you, Dr.Győrke! I would ask if there is a reply to this problem concerning modeling?

I.Mátrai: Thank you for the possibility of replying! I think you have underlined my opinion and there are lots of problems to solve in this field. Thank you very much!

Chairman: Thank you, Prof.Mátrai! I would tend to support this view also. At the laboratory where I work we are directing continuous attention to the question of modeling ice phenomena. First of all the question of modeling ice forces on structures. This work has been conducted by my colleague Dr.Schwartz, who is a visitor from Hannover. He has found that he can give quite good model-prototype correspondence in the case of ice forces on vertical structures. If he uses fresh water ice, provided sufficient attention is given making the ice crystals small enough and provided further that one uses an appropriate reference strength. That is say, the compressive strength under closed conditions.Or under simple compression tests. However, in the case of forces on inclined structures where bending becomes important, then it is necessary also to use reduced strength ice, say salt water ice. Now in the questions concerning the kinematics and dynamics of ice, such as the formation of ice-jams I think if you are interested in just the kinematic aspects of the ice movement then one can get pretty good or at least useful information using some form of artificial ice - we are all aware of the various types that have been tried. However, if one was going to try to model the dynamical aspects also that is to say the thickness and rate of accumulation in an ice-jam then - I believe - one is likely going to have to use some actual ice or at least some reasonable reproduction of ice because the limited data available indicating the strength, the compressing strength of the fragmented ice ensemble and the shear strength, are so dependent on the rate of deformation, it seems to me that it is going to be very difficult to find an artificial material that would model this. Of course, we have these modeling limitations and there are many other problems too in the case of all but the simplest problems and I suspect that in the case for modeling sediment transport problems, modeling ice problems continue to be at least partially an art for some years to come. Are there other questions or comments from the participants? If not, you allow me to attempt to summarize shortly and perhaps in an oversimplified way my view of the afternoon's proceedings and after I am finished I will ask once again if people would like to disagree of what I would say or amplify what I say or make some other questions.

It seems to me that the problems that have been discussed this afternoon can be reduced at least to four general categories. First of all is the continuing question of ice production, or the thermal balance of streams. It is interesting to speculate about what the future might bring on this subject. And I am reminded by a joke I heard at the first ice symposium in Reykjavik some in 1970 - I am sorry I cannot recall who told the joke - but it had to do with ice control in general and it said that the best ways to handle ice problems was to just avoid ice and in this regard we should learn the lesson from the Volkswagen, with its air-cooled motor. By simply eliminating water from the cooling system and using air they have avoided the freezing problem. So, in a Volkswagen the motor does not freeze only the people freeze. And certainly this is a good thing to avoid a certain problem. I think that if the environmental standards are more reasonably interpreted we might be in the position on major rivers of the world to avoid many ice problems and preventing ice formation. In the United States - if I may allowed to recount one experience - we now have a second year operation of a large thermal diffusor-pipe on the Mississippi River. Just west of Chicago. At the point was the average discharge of the river about 30 000 cfs. A 1600 MW powerplant discharges 2270 cfs of water into the river, practically in ideal fashion it is disturbed across the river and roughly mixed with the river flow through diffusor-pipes. During the last winter, which was a rather mild winter and so far this winter the ice for some distance downstream from the diffusor-pipe has been in effect eliminated. There is still the problem of ice coming from upstream especially when there is a wind from North to South. But the problem of large scale ice accumulation from this reach have been eliminated. And what is perhaps more important and interesting is the fact that the biologists who are conducting intensive studies on this reach of the Mississippi River report no measurable effects at all on the fish population, on fish sizes, not only the fish but the whole structure of life in the river seems to be unaffected. So, one can look foreward perhaps to the day on large riverways where we would do a series of nuclear plants which would use the river water for cooling during winter and thereby supress the ice and during the summer we would likely use other cooling methods such as cooling--towers. So, perhaps one of our ice problems will go away but there will continnously be here the problem of ice production and this is the first category of problems that I discuss today, that is the thermal regimes of river, the problems of estimating the heat transfer from the floes to the atmosphere. The techniques that we presently use in the United States in general take account at least in an approximate way of the various components of the heat transfer: radiation, conduction, etc. And then put these together in a generally linearized and somewhat synthesized formulas, e.g. there is the (......) equation that expresses that heat transfer in terms of the difference of the water temperature and the equilibrium temperature. And recently Macagno put forth another linearized method. These tend to be quite good provided that the meteorologic data are good, so we are more and more dependent on weather forecasting.

The second general problem concerns stress, strain,strength relations.

In any problem, when we have to manage ice once it is formed, we found strength relations. And in any problem connected with ice once it has been formed, we need knowledge about the strength of ice and I refer not only to ice sheets or uninrupted or I should say integral ice covers but perhaps equally important fragmented ice.I think this is going to be a very difficult problem, during many years to come.Because the solid mechanics people who are working on questions of strengths of the simplest case you can imagine - that is to say on simple ice under one dimensional compression - are finding very difficult problems arising in attempting to formulate critera. It is difficult (.......)

This company was authorized to put his plant into operation only after agreed to operate the diffusor-pipes for 40 months. During these 40 months they are constructing a spray-canal system, which would be a canal 2 1/2 miles long 700 feet wide and equipped with 1200 nozzles to spray the water in the air for cooling. This is what we call a back-feeding job. The cooling system is put in after the plant is built. And, of course, it is hard to get the best match or agreement between the cooling system and the rest of the plant. Only the life of the project, the cost of the cooling system plus the cost of the power it takes to operate this alternate cooling system, which makes 5 % of the power generated by the plant plus the reduced power output because of lower efficiency - that is higher back-pressure - will cost to the power company between 80-100 million dollars on a power plant that only cost 200 million dollars to build. That was the last case that they would obliged to build it. Now, we have the power crisis, and there is some question whether we would operate it at all. Because the roughly 60 MW that takes to run the cooling system is in very great demand now elsewhere in the system. So you can see the swings of preference and how explicit they have been in the United States. The swings caused by the environmentalists even if you present data to show that you are not hurting the environment.

Is this an answer to your question? Are there other questions?

Observations, Discussions?

If there are no further questions, I will conclude as I began on some administrative details.

First of all, I would call your attention to the reception this evening at 8 p.m. in the Hotel Budapest. I believe all of the visitors know where is the Hotel Budapest, so it will be very convenient for you. I also would like to direct your attention to pp.16-17 to the alternate morning programs that are available tomorrow on Wednesday and on Thursday, if you wish to visit these laboratories would you please sign up at the information desk. You noticed that there are accommodations for only a limited number of visitors on each of these tours, so would you please sign at the information desk.

Well, I would like to thank you very much, Ladies and Gentlemen, for your attention this afternoon, thanks to the authors that presented papers and to our general lecturer, Professor Mátrai, for his excellent presentation. Finally I like to thank my co-chairman Dr.Z.Hankó for participating on the podium and I declare this session to be ended. Thank you!

As addition to the material of Subject C, on the following pages Dr.Brachtl's paper is printed.

IAHR/PIANC IAHR/PIANC
International Association for Hydraulic Research
SECTIONS FOR FLUVIAL HYDRAULICS AND FOR ICE PROBLEMS

Permanent International Association of Navigation Congresses
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INTERNATIONAL SYMPOSIUM ON RIVER AND ICE

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ICE CONTROL STRUCTURES ON SLOVAK RIVERS

Ivo Brachtl, Dipl.Ing. C.Sc.
Water Research Institute, Bratislava, Czechoslovakia

ABSTRACT

Ice and frazil accumulation during ice run or due to peaking operations in the hydropower plants can result in ice jamming and jeopardizing of the adjacent areas.

One of the methods how to protect the respective region is to construct ice control structures. The ice control structures make possible to retain the moving ice and frazil on the chosen site, where no greater economic damage can arise.

During the frost period ice and frazil formation occur on Slovak rivers. In the course of thawing or temporary flow increase the ice mass sets out to move and freezes up again in some of the lower river reaches. Thus the ice jams may be formed jeopardizing the adjacent areas with floods.

After the completion of a water scheme or a whole cascade of water schemes a basic alteration of winter river regime is induced. This change can be seen most expressively within the area of the backwater end and in the section downstream of the water scheme. Especially during the peaking operation the discharge wave entrains the drift ice, border ice and frazil, deposited in the empty river channel. After the termination of the peaking this ice mass will deposit either in favourable sites of the river channel or at the backwater end of the next water scheme. There it freezes-up forming a solid barrier and causing a considerable water stage increase, often with resulting ice-flood.

We have been facing similar problem already in the course of the construction of the water scheme, when for the diverting of water there is only available a reduced channel or the structure dimensioned for the diversion of the normal discharge in the respective period of construction. The jamming of this structure or of the reduced channel would cause the flooding of the construction site, damages on the structures under construction and delay in completion of the water scheme.

One of the way how to prevent the abovementioned difficulties is to trap the advancing ice and frazil in a location where the prospective occurence of an ice jam and inundation will have no economic effects or - in an extreme case - smaller effects than without any external intervention.

The advancing ice and frazil can be held back by the so called ice control structure. For this purpose we use in our country simple wooden or steel protection piles. The ice control structure should be installed in the river cross-section where the inundation is of such a capacity as to be sufficient for retaining ice and frazil as well as for the diversion of the flood flow in the case of clogging of the ice control structure with timber during summer floods. Ice control structure operates more efficiently when installed in a section having a smaller river channel slope, or at the downstream end of this section.

Within the period of the construction of the Domaša water scheme on the Ondava River the water was discharged through two tunnels. If one of them would be clogged with ice floes during ice run or with timber during spring floods the construction site would be flooded and the earth dam under construction would be damaged. Therefore, the protection of the construction site by means of ice control structures was recommended. These were made as simple driven wooden piles, placed close to the bridge profile, about two kilometres upstream of the construction site. This profile has been chosen for a wide leftside inundation confined in the lower part by a high road embankment leading to the bridge. The designed system of ice control structures has been adopted since 1964 and proved to be successful in the course of the water scheme construction during the ice run as well as during the summer floods.

The construction of the water scheme Ružín on the Hornád River has changed substantially also the winter regime of the Hnilec River, flowing into the reservoir. As to protect the village Jaklovce - situated at the entrance of the Hnilec River into the reservoir - from annually occuring ice jams, we have designed its protection using the ice control structure. The height of the respective elements of the structure and their spacing within the cross-section were designed so as to allow the water to run off through the central part over the ice control structure on one hand, and round the ice jam on the other hand, if this would be too high /Fig. 1/.

It was recommended to construct the ice control structure in this case as a system of metal tripodes anchored in concrete blocks. The ice control structure has proved to be efficient during the 7-year operation.

A part of the town Žilina is situated at the backwater end of the reservoir Hričov. The winter regime of the Váh River in the reach between the hydraulic power plant Lipovec and the Hričov reservoir is influenced by the peaking operation of the hydropower plant Lipovec. During the breaks between peaking some reaches of the stream freeze-up and in the reaches with a greater slope frazil occurs. In the course of peaking this ice and frazil are transported towards the backwater end of the Hričov reservoir where they deposit and clog the channel. Thus the adjacent part of Žilina is endangered by ice jamming.

As to protect the town from flood the ice control structure was proposed to be constructed in the reach of the Váh River upstream of the town. The ice control structure consists of 61 steel piles sunk in holes Ø 200 mm, filled with concrete /Fig.2/. The height of the ice control structure was chosen so, that in case of the clogging of the whole profile with ice and frazil in the winter period or with timber in the summer the inundation profile would be adequate for conveying the flood wave /Fig. 3/. The ice control structure has been in operation since 1970 and has proved to be adequate and efficient.

With respect to the good experience obtained with the operation of the ice control structures we intend to recommend and design them also for the protection of other jeopardized sections of Slovak rivers.

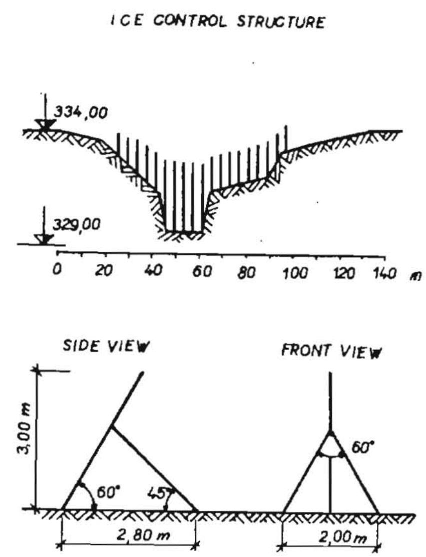


FIG. 1 ICE CONTROL STRUCTURE ON THE HNILEC RIVER

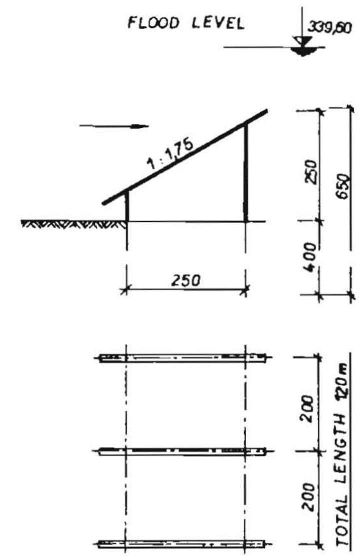
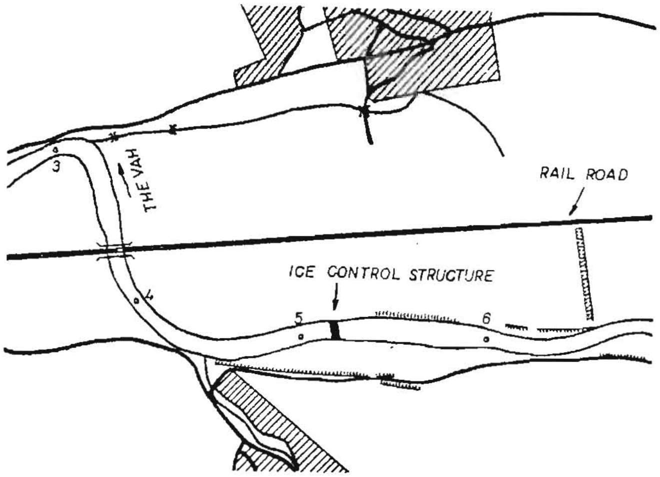


FIG. 2 DETAIL OF THE ICE CONTROL STRUCTURE ON THE VÁH RIVER



ICE CONTROL STRUCTURE
FRONT VIEW

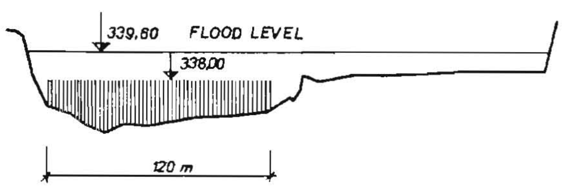


FIG. 3 LAY-OUT AND SCHEME OF THE ICE CONTROL STRUCTURE ON THE VÁH RIVER

CLOSING SESSION

16:30 p.m. January 17, 1974

H.Vandervelden, Chairman
I.Dégen, G.Fekete, T.Hayashi, Members
J.L.Bogárdi and
H.J.Schoemaker, Invited Speakers

H.Vandervelden, Chairman: His Excellency Prof.Dégen, Ladies and Gentlemen!

After three days of intensive work we come to the conclusion of our symposium.

Several eminent experts and experienced engineers took part in the lively discussions and it is my pleasure to give the floor to Prof.Dr.John Bogárdi, chairman of the Scientific Committee of the symposium who will summarize for you the gained results and conclusions and formulate some proposals which arose out of the discussions.

J.L. Bogárdi: Mr.Chairman, Ladies and Gentlemen!*......

Chairman: Thank you very much, Prof.Bogárdi, for this remarkable summary of the whole work of our symposium. I would, on behalf of all the participants, express our sincere thanks for the work you have done. This summary gives us not only an actual situation of the research work as indicated in the preprints of the papers but contains at the same time a program of the work to be done in the next future to improve our knowledge on "River and Ice". The proceedings of this symposium together with the preprints will be available in the next future. In the "Journal of Hydraulic Research " and in the PIANC Bulletin our associations will inform you and their members where they can obtain these volumes.

Now, I would like to introduce to you Mr.Ashton who represents the Organizing Committee of the next symposium on ice and I give him the floor.

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* The text of Professor Bogárdi's lecture follows on pp.159-164.

G.Ashton: Thank you, Mr.Chairman. On behalf of the Organizing Committee of the International Association for Hydraulic Research, International Symposium on Ice Problems I wish to invite the attendees of this symposium to attend a symposium on ice problems at Hannover, New Hampshire, in the USA from 18 to 21 August 1975. The symposium will be sponsored by the Cold Regions Engineering Research Laboratory and the meetings will be held on the campus of Dartmund College. The theme of this symposium will include extended season navigation of inland waterways, ice-jam control, effects of sea-ice on marine structures. Shortly, there will be a second circular distributed. Many of you should have received the circular much like this one which I have a few copies left. There is not any here I have it down at the desk, you may write there if you have not received one. Also, I have the membership attendance of this symposium and will be able to send out the circulars to those addresses. There also will be a study-tour after the symposium. It definitely will include the St.Lawrence Seaway, of which we have heard quite a lot here today. And, of course, there will be a Ladies' Program for the accompanying wives. Thank you.

Chairman: Thank you very much, Mr.Ashton. Ladies and Gentlemen, in my opening address to the symposium I paid tribute to Prof.Schoemaker, the devoted secretary of the IAHR as a fervent promoter of the collaboration between water-oriented international non-governmental organizations, who would strengthen their co--operation in problems deriving from the use of water. As this problem becomes more and more urgent Prof.Schoemaker has been asked to speak us about his opinion concerning this subject and it was titled: "Past Experiences with Future Horizons for Co--operation between International Organizations Dealing with Water." Prof.Schoemaker!

H.J.Schoemaker: Mr.Chairman, Your Excellency, Ladies and Gentlemen*........

Chairman: Ladies and Gentlemen! Let me allow to congratulate Prof.Schoemaker for his most remarkable views concerning co-operation between international associations. This aim is certainly not easy to reach but I am convinced together with Prof.Schoemaker that within a few years this collaboration will be a necessity if the associations want to keep their functions safe. Contacts between the different governing bodies of international associations certainly make this co-operation possible. Maybe this symposium was a first step in the good direction.

His Excellency Prof.Dégen, Prof.Bogárdi, Ladies and Gentlemen!

On the behalf of the International Association of Hydraulic Research and of PIANC and on behalf of all participants of this symposium I would like to congratulate His Excellency Prof.Dégen,

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* The text of Prof.Schoemaker's lecture is printed on pp.165-169

chairman of the symposium and Prof.Dr.Bogárdi representative of the Hungarian Academy of Sciences, to the Sponsoring Committee, to the Scientific Committee and the Organizing Committee for the complete success of this international event. This certainly demonstrates how valuable was to grant sponsorship for this gathering of experts on ice and rivers. The discussions in which many experts and engineers took part in the spirit of mutual understanding have brought to light much valuable information. This is yet another proof of the great value and fruitful results of an exchange of ideas on international level. Lastly, I would like to pay tribute to the traditional hospitality of our Hungarian hosts, expressed by the most heartly reception Thursday night given by His Excellency Minister Csanádi and the most enjoyable theatre show of yesterday night and would ask you to join me in giving a warm applause to our hosts.

And this must close our Symposium on River and Ice.

Thank you very much!

International Association for Hydraulic Research
SECTIONS FOR FLUVIAL HYDRAULICS AND FOR ICE PROBLEMS

Permanent International Association of Navigation Congresses
SECTION OF INLAND NAVIGATION

INTERNATIONAL SYMPOSIUM ON RIVER AND ICE

Budapest 1974 Hungary

CONCLUSIONS GAINED ON THE GENERAL LECTURES, PAPERS AND DISCUSSIONS; CURRENT AND FUTURE TRENDS OF HYDRAULIC RESEARCH ON RIVERS AND ICE WITH SPECIAL REGARD TO NAVIGATION

J.L. Bogárdi

Member of the Hungarian Academy of Sciences
Prof., Chair of Hydraulic Structures,
Budapest University of Technology,
Budapest, Hungary

At the end of the "River and Ice" Symposium, which - and it is my firm conviction - has been a very successful one and contributed much to our knowledge on fluvial ice problems, - let me add a few remarks about the present status and future trends of ice research.

At first, concluding from the presentation of the general lectures, papers and the discussions, it can be stated that the 41 papers presented on the Symposium cover a wide field of fluvial ice research and reflects very well the modern trends of it. Grouping the papers rather arbitrarily, we can see that 8 of them are dealing with the hydraulics of ice jams and ice covers, 5 papers analyze the interrelations between river-bed morphology and ice jam formation, 12 authors present experiences regarding ice effects on various hydraulic structures and reservoirs, 3 papers are dealing with the natural, respectively with the artificially influenced thermal balance of water courses, 7 papers with the forecasting of ice phenomena, 2 papers with defensive measures against ice, 1 paper with the problem of bridge openings and piers built on rivers with ice floes, 2 papers with ice protection of lake shores, finally, 1 paper is surveying the general trends in river ice research.

Undoubtedly, this grouping of papers is not without shortcomings, especially because several of them are connected and, what is more, overlapping each other to some extent. In spite of this, it can be seen, that the hydraulics of ice jams and ice covers as well as the ice effects on hydraulic structures and reservoirs are especially tempting for the researchers.

Both research fields are really very important from practical point of view and the related ice phenomena can be observed relatively easily, or in the absence of field data, laboratory experiments can be carried out.

Unfortunately, only the appearence of ice, the formation of border ice, ice covers and jams, the accumulation of ice sheets, the break-up of the covers and the disappearence of ice are the most easily and reliably observable ice phenomena and only the water and air temperatures, as well as the ice thickness are more or less conveniently and regularly measurable. Even such seemingly simple task as the assessment of percentage of water surface covered by flowing ice constitutes a rather subjectively solvable problem. Photographic methods from the top of high structures are promising, however, such structures cannot be found or built on every site where observations are required.

Measurement of temperature, flow velocity and suspended sediment concentration, especially their distribution in a cross-section of the river is hindered or even made impossible by increasing intensity of ice floe. Such measurements can be safely carried out but through a standing ice cover, i.e.during a specified part of the ice regime only. However, intensive ice transport under the ice cover can prevent us from measuring regularly through leaks made in the ice cover, though systematic observations often would be necessary e.g. for the evaluation of changes of vertical flow velocity profile due to changing roughness conditions.

The observation of the bottom roughness of an ice cover or hanging dam and that of its variation in time can be made also on suitable standing ice covers. Detailed field investigations on heat transfer phenomena at the water-ice interface and through the ice cover, as well as on the circumstances of break-up could also be carried out in such places.

Regarding the fact that in many papers presented on the Symposium and in the General Lectures repeatedly appeares the demand for collecting more detailed and reliable field observation data concerning various ice parameters, I would suggest to all participants to promote the start or improvement of the systematic ice data collection in their home countries. In a similarly complex and to the ice regime related field, namely in river-bed morphology successful data collecting and measuring programs have been started in Hungary on various selected experimental river reaches, mainly for improving river training methods and techniques. I think in countries under climates with regular fluvial ice regimes, it would be suitable to select river reaches known of their permanent ice problems, jam development, etc. and establish there special experimental stations with staff and equipment capable to observe and measure the above mentioned parameters.

During the ice-free seasons, detailed bed surveys should be carried out, thus supplementing the ice observations. It is highly desirable that a staff or recording gauge should be operated on or near the experimental river reach with a longer observation period in order to obtain a reliable rating curve corresponding to the ice-free regime.

Provided the necessary instruments will be developed, the permanent staff on such experimental stations could carry out observations on slush ice formation and movement, on bottom ice formation, on the correlation between suspended sediment concentration of the flow and frazil ice formation, determination of winter rating-curves by flow measurements under ice cover made by traditional or tracer injection methods, etc. Regular observations with a limited scope had already begun in Hungary five years ago at the River Training Experimental Station on the Rába river. Here daily water and air temperature measurements are carried out and the thickness of ice cover is determined repeatedly. However, this river is not navigable and no ice-jam is formed on the experimental river reach. There is no winter observation program at all on our other experimental river reaches, mainly because they are situated in remote unpopulated areas.

Partly to overcome this difficulty, partly to deepen our knowledge about ice effects connected with river canalization, the headquarters of ice experimental stations suitably can be chosen in the vicinity of river barrages. In this case, observations not only on the river, but also on the reservoir and on steel and reinforced concrete structures exposed to ice action can be made. The main problems for this kind of investigation are included in the General Lecture on subject B, thus, it is not necessary to repeat them here.

We have to admit, however, that even a well staffed and equipped ice experimental station cannot accomplish all research task demanded by the solution of theoretical and practical problems. A broad field of research is open to speculative work, to the analysis of field data and to laboratory experiments.

There are not too many ice laboratories in the world. I want to mention here only the Soviet and the Norwegian laboratories and the open-air experiments of Canadian researchers. From the contributions to our present Symposium we have learned about the American field observations, flume tests made with ice and about Canadian flume experiments where the ice cover has been simulated by plastic sheets. Laboratory flume tests are, therefore, not restricted to special cooled environments and this might increase the number of such experiments in the future.

Here I would like to mention that during the recent decade, ice floe experiments had successfully been carried out on two river barrage models and on the model of a cooling water outlet channel of a thermal power plant in Hungary. In one case the artificial ice sheets have been made of plastic foam sheets loaded by a cement layer, in the other of gauze pieces soaked in melted paraffin, then hardened. The formation of ice jams by piling up of the floating sheets could be very well simulated by the latter material.

As for the laboratory flume tests, I would suggest to continue the riverbed erosion studies around bridge piers and spur dykes under simulated ice cover. Another desirable investigation would be to clear up the effect of ice cover on the threshold of bed-load movement. Such experiments would help solving some problems of river training, since a solid ice cover can result in unexpected bed deformations even in cross-sections correctly dimensioned for flow and sediment conveyance, but disregarding ice.

Regular river-bed surveys and bed-morphology studies before and after erecting training works on stretches with frequent ice-jam formation are necessary for evaluation of effectiveness of engineering measures. Therefore, it is advisable to use the selected ice experimental river reaches as river training experimental reaches, too. Here has to be emphasized the significance of the sometimes neglected flood-plain regulation. The main objective of this is the clearing the vegetation in strips of various widths on each or one bank of the river and keep them vegetation-free. This clear strips make also the runoff of ice-free floods easier, but their main role is to prevent the dangerously large-scale constriction of the composite cross-section available for passing ice floods.

Equally important is the comparison of river training and/or flood-plain regulation measures with active ice protection methods, e.g. ice-cutting or breaking. This comparison should be made from both economical and technical viewpoints, worked out as detailed as possible. It seems advisable to carry out such calculations also for the combined application of bed-morphological improvements and active protection measures.

Since both the very interesting ice-cutting and the traditional ice-breaking methods can really effectively applied only if the blocks of the artificially broken ice cover can be transported away by the streamflow, these operations have to be co-ordinated with the release of water from the reservoirs.In the case of non-canalized rivers, the role of hydrometeorological forecasting is very important, because the start of ice cutting/breaking manoeuvres often can be correctly set only based on reliable flood forecasting.

I think we should continue research in order to improve our knowledge and experience in both mentioned fields, i.e. influencing the natural break-up of ice covers by artificial flood-wave generation in canalized rivers and imroving the present forecasting methods by simultaneously involving thermal and flow regime data in the mathematical statistical calculations. We have seen during the Symposium interesting results of speculative and field research on freezing-in and break-up of rivers. These papers are encouraging because they show that this problem has been and will be dealt with by several researchers in different countries.

Special problems arise in the case of rivers fed by great lakes, especially when the river is an international navigation route, as the St.Lawrence River. Here the thermal budget studies combined with up-to-date airborne remote sensing of ice thickness seem very promising to predict break-up time.

The effect of waste heat from power stations and industrial plants is getting increasing significance especially in highly industrialized countries. With the careful selection of sites for new plants, surprisingly long river reaches can be kept ice-free for the navigation, or at least the navigation period can be remarkably extended. The presented Canadian and Soviet examples demonstrate that the research has already advanced beyond the first steps in this field. With the progress of industrialization and with the increasing number of nuclear power plants, even the smaller countries might soon use these experiences and add their own contributions to it.

No papers have been presented on the Symposium about the measurement of ice pressures on bridge piers or on hydraulic structures. A couple of publications on the initial results,collected for example by Gamayunov in the Soviet Union and by Sanden and Neill in Canada, show that the first efforts have already been made in this important but rather difficult field of practical research. At the Soviet experiments, a steel shield was strapped to the outside of a railway bridge pier nose. The forces exerted on the shield by flowing ice blocks were taken up by hydraulic cells connected to a manometer. During an ice-run when ice of 30-40 cm thickness passed through the bridge at a velocity of 1 m/sec, the maximum force indicated was found 9,500 kp per 1 m width of the pier, corresponding to a pressure of 2.7 kp/cm^2. In Canada, the authors have measured the ice pressure right after break-up by a more complicated method and observed a peak pressure of 7 kp/cm^2. The forces were found oscillating by 5-6 cycles/ /sec.

The oscillating nature of ice forces is not significant in the case of a stiff bridge pier, however, can be important at hydraulic steel structures, therefore similar measurements in the future would be desirable. Besides, the above mentioned field experiments can be regarded as first steps only and much more data would be required to draw such conclusions which could be used for the possible alterations of present design code requirements concerning ice pressure on structures.

Another practical ice problem on which some research have already been made and some experience gained is the acceleration of ice melting by spraying the surface with dark grains. About 15 years ago, laboratory and field methodological studies have been conducted also in Hungary, testing different materials for this purpose. The main conclusion of the experiment was that the mixture of soot and sand gave the best results, because the soot remarkably decreased the albedo of the ice surface and the sand accelerated the breaking-up process by submerging more and more deeper into the freshly molten tiny holes of the ice body. I have to mention that no large-scale application of artificial ice melting has been carried out in Hungary. The fact that no paper has been presented here disclosing more recent results gained by this method or criticizing it, seems to indicate that no research or application is under way nowadays in this field.

Hoping that also this aspect of shortening ice cover periods will not be neglected in the future, I want to mention that new materials and technologies in river training also might require new research methods. For example, application of wire net boxes and mattresses filled with crushed rocks for bank protection is getting increasingly popular because they are economical and make mechanization of work possible. It will be the task of the near future, to investigate the counteractions between ice and this form of bank protection with special regard to its resistance against frost and mechanical actions of ice blocks drifting along the bank.

Papers dealing with piling-up of ice on lake shores are remarkable, mainly because they arise the interest of researchers inclined to disregard this phenomenon while tackling river ice problems. Stability of flood protecting dykes, bordering wide flood plains as well as man-made reservoirs, however, show very similar ice jam situations as lakes. Therefore, there is an undisputable necessity for increasing our research activity in the future in this field, too. Along the shore of the Kisköre reservoir on the Tisza River for example, as soon as the planned water level will be attained, we will face bank and levee protection problems. At first, the experiences gained on Lake Balaton and on other Hungarian lakes can be used,e.g. milder levee slopes and the application of protective reed strips,however,systematic field observations and studies will be needed to the optimum solution of local ice jamming problems.

Investigations on control of ice drift and on the piling-up process can also suitably be included into the program of an experimental river reach provided it is properly selected for observing various ice phenomena. The organized work at such experimental stations is, without doubt, a team task.The tendency, that even before establishing such highly specified ice-experimental stations, research on ice problems is calling more and more for the combined effort of specialists of different fields, is reflected by the fact that 17 of the total 41 papers presented on this Symposium have two or more authors. Furthermore, the professions of the authors show that experts from meteorology to acoustics and from fluvial hydrology to photogrammetry take part in ice research. This wide co-operation is not only necessary and fortunate, but also inevitable in order to solve the various very complex problems connected with ice.

Ladies and Gentlemen!

In the foregoing I tried to review briefly the fields of ice research which were mostly represented in our Symposium and to point to the problems which have not been dealt with at all or not in a number commensurate with their importance.Obviously, not all the ice problems are equally important in the home countries of the participants of the Symposium. The main emphasis, however has been laid on improving navigation conditions in rivers by shortening the periods with standing ice cover and by avoiding the possible damages due to ice floes, jams and generally to freezing. Nevertheless, it does not mean that ice-flood protection can not be equally or even more important in given cases.

Organized research, based on teams working at experimental stations and laboratories unquestionably promises quicker solutions of most urgent ice problems which have been clearly shown in the papers, general lectures and discussions. Besides, the close co-operation of scientists from different special fields and the application of up-to-date technical achievements in the investigations is encouraging in respect of getting better understanding of the basic physical processes involved. This scientific co-operation must not remain within the borders of any country, it must be international, not only in the presentation of results on international congresses but also in the practical research work. The IAHR, through its Section for and Committee on Ice Problems could help in various forms to fulfil this requirement.

Finally, I would like to acknowledge the excellent work of all the authors who presented here the results of their investigations, of the participants of the discussions, as well as of the members of the local sponsoring, scientific and organizing committees of this Symposium. I am especially thankful to the General Lecturers and to the secretary of the Organizing Committee for their efforts to make this Symposium a really successful one.

Now I should like to wish you a very good time for the rest of your stay in Hungary and a useful and interesting study tour on the Danube River to-morrow.

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International Association for Hydraulic Research
SECTIONS FOR FLUVIAL HYDRAULICS AND FOR ICE PROBLEMS

Permanent International Association of Navigation Congresses
SECTION OF INLAND NAVIGATION

INTERNATIONAL SYMPOSIUM ON RIVER AND ICE

Budapest 1974 Hungary

PAST EXPERIENCES WITH FUTURE HORIZONS FOR CO-OPERATION BETWEEN INTERNATIONAL ASSOCIATIONS DEALING WITH WATER

H.J.Schoemaker

Professor, Secretary of IAHR,
Delft Hydraulics Laboratory, The Netherlands

I. The subject of the final talk of this interesting symposium has been announced to you as the title above.

This subject has not been chosen to say simply good-bye to you, to wish you a happy return to your home and your work. I will try to say more, to invite you to think with me about the role we play and about the philosophy underlaying our work.

Let me be more specific. The title of my talk is somewhat too general; I like to confine myself to the water-oriented associations; that is more than enough for the time being.

My attempt to be philosophical is not due to a relatively advanced age, but it is based on real past experiences and it is perhaps the best way to give an impressionistic view of what can be or should be the development in the future.

We in the IAHR are most happy that we have found our parents in PIANC willing to undertake this symposium with us as a joint venture made possible thanks to the efforts of our respective Hungarian members.

The subject is one of advanced specializations; there are not many scientists interested in ice, as it appears in our water environment; giving many engineering problems, this time focussed on river navigation, and flood protection. It is simply logical that the engineers and researchers in navigation, river dynamics and physics of ice come together. In our two associations we did find the components for this interesting synthesis appearing in this symposium.

I must confess that this systhesis was an experiment and showed a by myself unforeseen incompleteness: our friends of the hydrological sciences, in particular those occupying themselves with ice could have perhaps participated. On the other hand, the symposium was perhaps too much engineering to be of great mutual interest. This symposium is the second experiment; a year ago we had one in Bangkok, that time together with the hydrologists on morphology of rivers.

I confess that the two experiments made me optimistic for the future in co-operation between specialists in water.

What I like to submit you starting out from the results of our second experiment, we are closing today, is an outlook on the future, beginning in the past, based on the needs of the human community and the duties of our profession.

II. The past I shall not review beginning in the remote history of our predecessors who left their traces in remarkable works: nor shall I occupy myself with the science of water in our part of the world for example Heron of Alexandria or Archimedes of Syracuse.

The reason, why I nevertheless mention history that we can learn from it the human behaviour of scientists and engineers. We see, that science and technique (we have at our disposal today) has been created by men of great diversity in background and approach of problems. We see mathematicians fascinated by the mechanics of continua and engineers attracted by the art of mathematical abstraction on one side and practical people with creative imagination sometimes with hardly any theoretical background, on the other side.

Nowadays it is not otherwise; what is new and in full development is that we have now a communication between the researchers of great diversity in character and attitude.

From the history of the nineteenth century we see that two extremes did little know of each other, or at least did not understand each other. Mathematicians creating nice descriptions of flow of idealized fluids which did not exist and engineers facing problems for which no mathematics was designed.

At the end of the nineteenth century hesitatingly a bridge was erected between the two. Aerodynamics, stimulated by the beginning of aeronautics, immediately started from the shore of theory; hydraulic engineering started building the bridge from the shore of practice with long tradition, a tradition which was based on experience and with hampering, sclerotic elements in it.

The need for more intensive communication, that between the very top scientists by correspondence lead to the creation of international organizations.

A nice example is PIANC from the engineers' side, facing water transport problems, which was established in 1885. In those days, transport was the main problem in the strongly expanding industrial world.

On the side of applied mathematics and mechanics we know IUTAM, established in 1924.

In these two organizations you are still in two completely different worlds in spite of the fact that both were established as forums of applied sciences.

The construction of the bridge continued and it is interesting to notice that the traditionally bounded hydraulic engineers made various attempts.

In 1925 PIANC had its first well shaped water child, the ICOLD at first in the parental house and now in its own existence and making its own career.

Ten years later the second water child was born. As happens more in families, this child was adventurous and sought its own ways, abandoning the traditions of its parental house. It has left the house imeediately after its birth, it was the IAHR in 1935. Quite independently and more or less provoked by circumstances far outside of the Western world a fourth engineering water-oriented organization was established; the youngest in the family, the ICID.

The historical review is not complete for hydraulic engineering. We are working in an environment which was traditionally an object of research of geologists and the object of fascinating descriptions by geographers and geodeticians or geometrists (in the true sense of the name). Also those scientists wanted their own society and the IUGG was established. I do not know when this was, I know only that this association has a remarkable past and a long tradition.

Whether it is in the character of pure science or not, I do not know, but this family has a great number of children, all still closely connected to their parental house, all keeping the respectable family traditions and the regular family reunions, - in our language "congresses" - which usually are colourful events. Volcanologists, deep-sea oceanographers, arctic explorers, meteorologists then tell you about their adventures, fascinating and exciting for us engineers.

This family opens for us the world in which we, as engineers, want to find places where we can live in safety; but as engineers, who have the task to create liveable circumstances, the observations of these discoverers are only introductions; we must always complete these with our own methods.

III. Up till now I gave only an impressionistic review of some of the distinguished and oldest families of interest for the hydraulic engineer. There are, however, many more, younger than we are, and the present circumstances are very fertile for the establishment of new families - in our language "associations". Our growing interest for our environment leads scientists and engineers to form centres of research and associations devoted to special aspects in the sciences related to the details of this environment. Moreover, the existing old groups create space in their traditional approach for the environment-oriented presentation of their work.

In addition, the international governmental organizations are creating branches for tackling the environmental problems too. Here I come to the present situation and I confine myself to the water environment - we are interested in - for living, working, recreation, for activities of transport, missing as resource for our ever growing demand and as an origin for danger against which we must protect ourselves.

We see two extremes in our consideration of the problems. One is traditionally the deepening of our knowledge of dynamics and processes we observe, the other has its roots in the past but is only recently recognized as scientifical tool in its own merit. It is presented under many different names not very lucid in the significance. The consideration of water circulation in nature as a totality; an integrated view of it by means of all sorts of models of systems, models which should reproduce what is actually happening, with all seemingly random variations.

This scientific tool is mainly a mathematical discipline and none of the many families I mentioned can claim it as a special piece of inheritence. This tool came into development in management, in which jobs and positions are many times occupied by engineers too. In general, I dare to say, that engineers have a good background as managers, or planners, just because they are, by education, familiar with the tools and with the components, which are to be integrated in coherent units.

Let me to complete the picture. One of the great advantages in being able to think in systems or environments is that we are aware where we stand and that we see the function, goals and the effects of our research.

In our association we see many members devoted to their work and fascinated by the problems they have to solve. The new look on systems and management, on concerted action is felt as intrusion in privacy, as a disagreeable and objectionable constraint and a limitation in freedom of science.

However, there is a generation of leaders who sense clearly the function and goals of science and its application to the problems caused by the spoiled environment in many places of the world, problems with numerous facets which have to be put together in concerted action. There is also a younger generation which asks about reasons why the efforts are required gaining skill in scientific research; they want motivation.

Let us go in less detail, let us consider the groupings of scientists and engineers - the associations.

We notice everywhere the consciousness of our responsibility for the environment. The responsibility we have in our position as scientists, experts, practical engineers. We see more and more our role in the context of a totality, we want to manage properly.

With evolution in knowledge, in our consciousness as background we see an evolution in the policy of the international associations in the choice of the themes of discussions and in the recommended scientific considerations. This happens, of course, with the respective specialities as a starting point and always aims this speciality in a wider context.

And here begins the concern for co-operation between many scientific disciplines. In water management a great diversity of physical, mathematical, mechanical disciplines come together. It is unavoidable that in this evolution everybody has the look at disciplines at the borders of his own, has a general knowledge about the role his speciality plays; a role as component of a system.

It is unavoidable that systems of these components are an object of research. It is unavoidable that we, as engineers, experts, scientists, playing with these systems, deal with the financial and social components, components not of physical nature. Here we are in the present situation. In the different associations there is a growing concern about their function and the human community, in the governmental authorities an attention for management in increasing size of units of water resources,in many cases beyond the national frontiers.

We confine ourselves today to the professional associations, to the activities for the near future. We see a remarkable parallel in the views of the respective Councils on the necessity of integration in science. We are aware that the many specialities cannot exist for their own sake.

What is needed now is communication between the associations. We should promote that in the different groupings real specialization on items developed elsewhere is available when needed,that achievements of research is accessible for practical engineering and in the reverse way, that problems arising could be directed to the places where they can be solved.

Now I come to the future. I am not a fortune teller so that I can express only my hope that we expand the co-operation of which this symposium is an example. There are a few facts which must be taken into account for developing our policy. These facts are the following:

Each association has its tradition and its own style of communication. Each association has definitely a well established reason of existence.

Both facts we have to respect mutually.

The third fact is that every discipline has two aspects, the basic scientific background, theory, methods and means on one side and its function and goals on the other side.

From this starting point an agreement for co-operation has been recently achieved as first between IAHS, ICID and IAHR. Then ICOLD joined and de facto PIANC joined too during this symposium. Formal acceptance of this agreement will undoubtedly come soon.

Now the future and here ends my written note for this talk I wanted to give to you. I do not dare to write it down, but what can we expect from the future?

Let me give some speculation, we hope that the agreement which has been achieved in Istanbul will help us to establish The International Council for Water-Oriented Associations (ICWA).That we can have directly from this Council a system of communication between the individual ssociations and perhaps in the somewhat remote future also to harmonize the items, the subjects for the different congresses and to develop what we have started now as an experiment, the holding of symposia on limited number of scientists coming together, because congress in general has a great attendance, many members coming together but it is more or less a forum for exchange. When you want to have a real deepening of a high specialized subject, smaller groups should be formed;that we should promote in the future. Possibly a Presidential Council can also be formed by this agreement which we have is mind. Let me thank for our Hungarian hosts for this highly interesting experiment, a successful experiment, which ends today.

2

IAHR—PIANC

SYMPOSIUM

RIVER & ICE

I. DÉGEN

WATER MANAGEMENT ASPECTS OF FLOOD- AND ICE CONTROL IN HUNGARY

FORMAL ADDRESS

Preprints

BUDAPEST 1974 HUNGARY

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Budapest 1974 Hungary

FORMAL ADDRESS

WATER MANAGEMENT ASPECTS OF FLOOD AND ICE CONTROL IN HUNGARY

PROF. I. DÉGEN
Secretary of State,
President, Hungarian National Water Authority

Mr Chairman,
Distinguished participants of the Symposium,
Dear Guests,
Ladies and Gentlemen!

I am greatly honoured by the opportunity of presenting to you in this formal address a comprehensive picture about water management in Hungary, emphasizing especially the problems related most intimately to river ice, namely flood control, river regulation and fighting ice-jam floods.

It is my privilege to extend at the outset, on behalf of the Government of the Hungarian People's Republic and the government agency of Hungarian water administration, the National Water Authority, the hearty welcome thereof to you, our esteemed guests from abroad, as well as to all participants of the symposium. It is especially pleasing to welcome the joint conference of two renowned international scientific societies, whe have selected for the first time Hungary for such an event.

I have the honour of welcoming the President of the International Association for Hydraulic Research, Professor Hayashi, its General Secretary, Professor Shoemaker, as well as the General Secretary of the Permanent International Association of Navigation Congressus, Professor Vandervelden.

Its should be emphasized by way of introduction already that the incessant struggle for and against water has played a decisive role in the economic and social development of this country. As a consequence of the geographical situation and of the prevailing meteorological conditions, ice phenomena in the winter season have frequently caused grave difficulties along the rivers and canals, affecting life in the towns and villages situated in the flood plains, as well as industrial and agricultural production there.

During your brief stay in Hungary we aim to make you acquainted with the development of water management in Hungary, with the measures taken in the interest thereof, with the results attained, as well as with the major water management objectives.

The subjects of the symposium, namely the perfection of measures for preventing ice-jam floods and for extending the navigation period in winter, are of considerable interest in this country and this is one of the reasons for welcoming warmly the scientists from 16 countries.

In the present lecture I intend to present a brief general review of water management in Hungary and subsequently to deal more in detail with flood control and river regulation, in their relations to the ice regime. The methods of controlling the adverse effects of ice will be discussed together with the experiences gained with them. Of course, it is not my purpose to go into the details of these problems and all I intend is to direct attention to the aspects thereof particular to Hungary and to some novel advances made here in this field. I expect the symposium will greatly contribute to the solution of such problems.

1. GENERAL DESCRIPTION OF WATER MANAGEMENT IN HUNGARY

Hungary is situated in the catchment area of the Danube and occupies the deepest part of the Carpathian Basin. The territory of the country is 93 thousand square kilometres of predominantly plain-land character. No more than 0,8% of the territory reaches higher than 500 m and only 32% is above 200 m altitude. The plains occupy two-thirds of the territory. The climate is dominated by three influences, namely Atlantic, Mediterranean and Continental of which the latter tends to predominate. The winters are cold (temperatures of —30 Centigrades are on record) and the summers hot, with temperatures often above +30 Centigrades and with frequent draughts. The three major rivers of the water system, namely the Danube, the Tisza and the Dráva rivers originate abroad, the latter two being tributaries of the Danube to which they discharge beyond the territory of the country. The major tributaries of the three major streams originate also without exception in the surrounding countries.

In the first half of the 19th Century one-quarter of the country, namely 2.3 million hectares, was covered by swamps, which were inundated regularly by the floods originating in the upstream parts of the Carpathian Basin. Agricultural and industrial production, the development of towns and villages in these areas were made possible by the reclamation and regulation works started in the second half of the last century.

The western and northern parts of the country are hilly in character and here the surface runoff is collected and conveyed to the major recipients by a network of minor water courses. Plains cover the overwhelming part of the country, where the excess runoff is collected by an extensive network of artificial drainage canals and lifted into the recipients by pumping stations.

The perspective plan of water management has recently been approved by the government, defining thus for long years to come the development of water management in Hungary.

The most important problems awaiting to be solved by water management in this country are as follows:

1. Meeting effectively the rapidly growing water demands of the population, of industry and of agriculture.

2. Minimizing, and where economically feasible preventing completely, the damages due to inundation by floods and excess runoff, to which round 50% of the territory is exposed. Efforts are made to apply the combination of appropriate engineering measures to develop the control structures for maximum safety against summer floods and ice-jam floods alike.

3. Protection of the human environment by controlling one of the most servious drawbacks of advancement, namely water pollution.

The second group of these problems will be emphasized in the present lecture, remembering always that under the complex approach to water management the utilization of water and controlling the potential damages thereby are considered as closely interrelated objectives. In this manner complex runoff control in major regions may provide radical solutions to each of the three groups of problems mentioned. In connection with the subjects of the symposium it may be of interest to mention that ice presents serious problems in virtually all branches of water management in Hungary. Controlling ice-jam floods and extending the navigation season in winter are the most important ones in this respect and are thus closely related to the main subjects of the symposium.

In solving the problems due to ice in water management, the results of several branches of science must be utilized, including besides hydrology and hydraulics meteorology, thermo-dynamics, soil mechanics, but naturally economic and sociological studies are also essential. Hydrology and water management in Hungary are based on traditions and have controlled the development of society over the history. The evolution of the national economy, together with the growing intensity of engineering, scientific and economic international relations in recent decades has greatly promoted the development of water management by refreshing the flow of knowledge and information.

The development of water management in Hungary has been promoted also by the favourable pattern of administration. Water being of fundamental influence on socio-economic evolution and as a natural asset, forming the common property of society it was warranted to create a unified organization for channeling most appropriately material and intellectual resources for the guidance of water management.

The Hungarian National Water Authority as a central government agency is responsible for comprehensive, planned guidance, coordination and implementation in solving the fundamental water problems. Centralization is nevertheless not an absolute one, since all industrial and agricultural sectors must be concerned with water management, with water production and with controlling water damages, but the responsibility for guidance and coordination is vested with the National Water Authority.

2. FLOOD CONTROL

Owing to the plain-land character of the country, one-quarter of its territory is exposed to inundations by flood waters in the rivers. In this territory 50% of the population is accomodated and a significant proportion of the national property is concentrated. The flood control development which has taken place in the last century was of fundamental significance, in that it created the backbone of the flood control system in the country, namely the system of main flood levees the length of which has surpassed 4200 km by now (Fig. 1).

Over long decades these levees have been raised, strenghtened successively, using a variety of soil materials and construction technologies. Consequently, they are far from uniform, the properties of the subsoil vary from section to section making it impossible to accurately predict their behaviour. Efforts are being made at developing the levee system to safely withstand 1% probability floods, but over some sections protecting valuable property in major towns and industrial settlements the levees are required to afford protection against the 200 year or even 1000 year flood as well.

Up to recent decades flood control efforts were confined mainly to the strengthening of existing levees, to the elimination of uncertainties resulting from the variety of contruction methods and to the improvement of the weakest links. Besides the constructional methods, other engineering solutions are studied and flood control systems are improved by the most appropriate combination thereof. For example, in some areas plain-land storage reservoirs and floodways have been provided. The possibility of constructing jointly with the surrounding countries mountain reservoirs to reduce flood peaks is contemplated. Efforts are being made to reduce flood damages by economic controls, by influencing settlement patterns so that the method of flood plain zoning is also taken into consideration.

It is generally appreciated that the evolution of agriculture and industry, as well as urbanization tend to result generally in higher flood stages, since the accumulation of water is accelerated by human interference into runoff conditions (Fig. 2). Aside from the irregularities, ageing, and deterioration of earth levees and from the growing value of property in the flood plains this is an important factor warranting the perfection of flood control system.

The history of floods in Hungary will not be detailed here. It should be noted however, that floods occur on the average every second year on one of our rivers, requiring practically permanent preparedness and considerable expenditures in materials and labour.

Owing to its topography, morphology and climate ice jam floods occur frequently in Hungary. Such floods may be especially disastrous on the Danube, where the last ice jam flood in 1956 has exceeded by 2 to 2.5 metres the highest ice-free flood stage on record.

In the interest of successful flood control, detailed studies have been devoted to the hydrology of conditions causing flood exposure to the levees, to the behaviour of the levees under such exposure, further to the initial and boundary conditions which govern in their combination the extent of flood safety. It was found necessary further to extend the concept of the flood levee to include, besides the earth embankment proper, also the terrain and subsoil before, behind and under it to distances up to which the resistance of the earth embankment is influenced by these. The foundation of the levee must not be treated simply as that of a building or structure having a solid base and frame, nor as an earth structure, whose interior structure is not exposed to the dynamically variable effect of water.

There is ample experience available showing that on great plain-land streams, such as the Danube and the Tisza River, as well as the tributaries exposed to their backwater, flood stages may last for several days, or even several weeks. Consequently height is not the only factor controlling the safety of levees, in that besides overtopping other dangerous phenomena, such as boiling, slope slumping, saturation, etc., frequently invoke the danger of breaches. These phenomena are greatly influenced by the duration of the flood, i.e., by the time factor. Consequently, when considering flood exposure the peak flood stage, or flood discharge must be examined in combination with the parameters related to the duration of the flood wave. This parameter is referred to as flood exposure, defined as the area of the flood hydrograph above the toe of the levee and expressed in metre, day units.

Great importance is attributed to the investigations aimed at eliminating the effect of uncertainties stemming from short hydrological records. The objective random character of Nature is inaccurately described, especially in the range of great floods, by the flood probabilities estimated on the basis of 30 to 40 years long observation records. A method is being developed for minimizing the magnitude of the flood loss due to this error by adding a margin of development.

Besides the studies on flood hydrology, our recent efforts have been directed increasingly towards the hydro- and soil mechanical, as well as colloid-chemical processes taking place in the interior of flood levees.

It has become clear at the same time that these phenomena must not be considered alone, but in various combinations and in their complicated interrelations.

During the construction of levees it is frequently experienced that no trace can be found where the subsoil would be perfect as far as both stability and underseepage are concerned. Over considerable lengths of levee in Hungary floods are always accompanied by boiling as a consequence of adverse subsoil stratification in random distribution. Owing to the successive development of the levees the distribution of soil-physical parameters within the levee body is also a random one. Explorations have revealed the frequent occurrence of extremely loose and pervious layers even within levee cross-sections where the bulk of the soil is otherwise of average density and permeability. Consequently, the statistical analysis which was formerly confined to the flood hydrograph had to be extended to cover also the soil-physical parameters affecting the resistance of the levees. The degree of protection offered by the levee system is treated as a probability of failure and for this purpose it was found necessary to extend the methods of reliability theory to earth structures.

A further difficulty arose from the fact, that the majority of flood levees had been built of cohesive soils in which prolonged saturation results in a failure mechanism differring from that commonly assumed in soil mechanics. For explaining these phenomena an approach through colloid chemistry was necessary. During the extreme flood of 1970 on the Tisza River slumping and sliding of the air-side slope was observed in a number of cross-sections, which were not experienced previously and which endangered the stability of the levees. In several places the cohesive soil of otherwise adequate shear strength has become fluid as a consequence of saturation.

These phenomena were traced back to two different processes, namely to the ageing of the levee material and to chemical decomposition. The first of these processes is a rather slow alteration and as a consequence thereof the most important properties of the soil such as its shear strength and imperviousness decrease gradually over the years. This is due to the aggregation of soil particles and the reduction in density owing to repeated cycles of drying and wetting, to the influence of humic acids and to the hardness of river water which tend to change the electrolyte concentration in the soil. The second process results in a loss of the crystalline structure and in the development of an amorphous layer on the particle surfaces. Prompted by these experiences it was found necessary to regard soil as a specific building material in hydrotechnical construction. The results of these investigations are applicable, naturally, not only to flood levees but to all earth structures exposed to water.

The most important engineering properties of soils as construction materials can be described in terms of the following four factors:

1. The magnitude of the specific surface of particles present in the soil.
2. The extent of aggregation of soil particles.
3. The mineral composition of soil particles.
4. The crystalline or amorphous character of the individual soil particles.

This approach differs radically from that commonly adopted in soil mechanics and neither the tests used for determining the above four properties, belong to those conventionally applied. The formerly unexplained phenomena in flood levees can be interpreted by regarding the soil as a colloid-disperse system. The properties of such systems, such as shear strength and permeability as well as the variations thereof in time depend on the state of the system. The advances in this field are believed to be of considerable interest, although a number of questions remain still unanswered. The studies on the physico-chemial mechanism of these processes has thus far failed to produce a method by which the extent of ageing could be predicted reliably over the entire service life, about 40 to 50 years, of the structure. Nor could an exact relationship be developed between the hydrological characteristics, such as peak stage and duration of the flood, and the loss of shear strength in the soil system. Nevertheless testing methods have been developed and introduced by which the aforementioned state parameters of the soil can be determined in a relatively simple manner. These advances are believed to be of considerable importance.

In view of the subjects dealt with at this symposium it is deemed necesarry to emphasize that ice jam floods may cause in the levees dangerous phenomena other than those mentioned before. Temperature conditions during ice jam floods are frequently such to cause the external crust of the levees to thaw. The combination of flood explosure and thawing was found to cause levees of granular soils to slump, while those of cohesive material to become liquid. These phenomena can also be explained in terms of the colloidal soil properties. The water present in granular soils is in fact of Newtonian structure in that it moves in a gravitational field along the gradient. The increase in volume at freezing reduces density especially in the case of two-phase seepage, while subsequent thawing tends to restore the original soil density. This is accompanied by a movement and rearrangement of the soil particles and may be accompanied by slumping. Owing to the smaller pore sizes and large specific surfaces in cohesive soils the structure of water is altered by the electrostatic field surrounding the soil particles. A fact of considerable importance during ice jam floods is that such structured water has a freezing point well below that of normal water. Thus if the cohesive soil of the levee is satured by this water and this has frozen over the winter within the levee, the soil may start thawing at temperatures below the freezing point and soil liquefaction and loss of shear strength may occur within a short time, practically without transition. Seepage phenomena are thus further complicated during ice jam floods, the resistance of the levee being substantially affected by the season of the year and the air temperature conditions under which flood exposure occurred.

Information on levee saturation is most important for those concerned with flood control. Continuous and accurate exploration of the levee and of the subsoil is, however, important not only for effective flood fighting but also for the improvement of the flood levees. At times of low water, but also during floods the conventional methods of soil exploration are too slow to cope with the problem, owing partly to the large volume of work involved, on the other to the novel methods of testing. For this reason nuclear and geoelectric methods are applied extensively which are capable of yielding without the help of samples information on the most important soil physical parameters along and within the cross-section of the levees.

The objective is to locate the weak sections of the levee during summer and ice jam floods alike and to apply methods of reinforcement by which the desired resistance can be attained at lowest cost. A wide array of methods is now available to the engineer to improve the resistance of levees to the desired extent. Adherence to a standard cross-section over long levee sections is no more acceptable, but the methods and designs must be differentiated according to the actual values of the factors affecting resistance. Impervious blankets, diaphragm cutoff walls, asphaltic lining, interception canals or wells may all prove effective, but in the majority of cases these must be applied in combination. Complex solutions appeal thus desirable involving combined levee cross-sections the incorporation of drains, intercepting canals or sealing blankets, watertight cores plastic foils or bituminous layers in order to minimize the effect of seepage.

Flood levees along the rivers continue to form the backbone of the flood control system in Hungary, nevertheless all potential engineering solutions are considered in selecting the most economical solution. Where possible, flood stages and discharges are reduced by storage, floodways are used to by-pass dangerous locations and especially for preventing ice-jam floods its is considered essential to adopt the appropriate river regulation measures by which the formation of ice jams and the development of extreme flood stages can be avoided.

3. RIVER REGULATION

The total length of rivers in Hungary is 2820 km, of which 600 km have been completely regulated, 620 km partly regulated by now, while no major regulation work is needed over 920 km. As a result of the regulation works performed thus far the conditions for the passage of flow, ice and sediment have been improved and the danger of ice-jam and normal floods has been reduced, though not to the desirable extent.

The depths over crossings and navigation conditions in general were also favourably affected by river regulation. The total length of waterways suited for large vessels is 1560 km in Hungary. The channel marking service continuously surveys and marks the channel over a length of round 1000 km. The length of waterways classified into categories III and IV, i.e., accessible to vessels of 650 to 1500 tons capacity, is 750 km.

Regulation of rivers in Hungary and the principles of regulation have evolved by a long process to their present standard. Early, sporadic regulation attempts were followed already at the beginning of the 18th century by comprehensive regulation plans. Nevertheless, more than a century had passed untill these comprehensive regulation works were started and the classic regulation principles were evolved, prompted by regularly recurring floods, of which the ice jam flood on the Danube in 1838 and the summer flood on the Tisza River in 1845 caused especially heavy damages.

The ice jam flood of 1838 has clearly demonstrated the fact that the disastrous consequences of such floods cannot be prevented by flood levees alone. Pál Vásárhelyi, the eminent Hungarian hydraulic engineer was the first to study in 1842 the causes of ice jam floods, concluding that the formation of jams must be traced back, besides weather conditions, to the morphology and channel geometry of the rivers. It was also Pál Vásárhelyi who prepared in 1846 the general plans for the regulation of the Tisza River. Relying on experiences gained during previous floods he succeeded is solving the tasks of river regulation by adopting a uniform approach. His primary objectives were flood control, the accelerated passage of flood waves by an improvement geometry for the mean-water channel and for the flood bed related thereto. The mean-water channel of improved morphology resulted not only in the accelerated passage of flow, but also in improved ice-passage conditions, moreover navigation also benefited therefrom. This serves to demonstrate that river regulation is indeed a multi-purpose activity. Flood control, channel regulation and the improvement of navigation conditions are closely interrelated. Concerning the importance, or urgency of regulation in particular cases, flood control, bank stabilization, or navigation may assume priority and any of these may be the dominant, or prompting factor, but it is never advisable to separate the works performed for different purposes, or to execute these without regard to their manifold interrelations.

This principle has been observed in all other regulation works as well. Thus for instance, in regulating the Hungarian Upper Danube section, the primary objective was the improvement of navigation, while over the central section the promotion of ice passage and the protection of the flood plains on the left-hand side of the Danube, especially of the capital, were the main considerations. In both cases the same measures proved necessary in the interest of navigation and flood control alike.

Regulation of the 120 km long Iron Gate rapids on the lower Hungarian Danube was extremely successful. This outstanding achievement has served up to the commissioning of the Iron-Gate Dam, essentially up to these days navigation on the Danube and has made the river navigable also for seagoing vessels.

The classic principles of regulation were very modern at their time and the fundamentals thereof have retained their validity to our days. Advances in water management have presented, however, new requirements for river regulation. The idea of river canalization was raised at the beginning of this century already. Canalization to meet at the same time the requirements of modern water management and organically related thereto has been made urgent in modern times by the diversity of water uses. It is for this reason that the objectives of river regulation reflect today not only the passive functions of water management, but are closely coordinated with the general objectives of water management and the national economy, as well as with the water management schemes of the neighbouring countries.

The convertional methods of regulation are in many instances no more sufficient for attaining these objectives and this has focussed attention on the canalization of rivers. Following the construction of weirs on minor rivers, the complete canalization of the Tisza River is under way with two of the five contemplated barrages completed already. In the perspective plans the canalization of the Danube and the Dráva River, further the construction of the Danube-Tisza canal are envisaged. The development of the waterway network is warranted also by the completion of the Danube—Main—Rhine canal scheduled for 1980.

Advanced water management has thus expanded the sphere, the scope and methods of river regulation acitivities requiring a control of discharges in space and time, in accordance with the needs of water management, but even under the new conditions the unobstructed passage of ice and sediment as well as of floods must be guaranteed.

The expansion of the scope of river regulation, the improved efficiency of future regulation has made studies on the effects of former regulation works and the evaluation of the results attained imperative. The tracing in time of the effect of individual regulation measures on channel development, on the flow and ice regime amounted practically to experiments in the field. From these studies it was positively concluded that each river represents a system tending to establish dynamic equilibrium, where a change in any factor of influence, i.e. independent variable, entails necessarily a corresponding change in the other factors. The objective of river regulation is, to influence this dynamic system to meet the objectives of water management by creating new boundary conditions with the help of regulation structures.

All attempts at formulating a deterministic or stochastic model of this system, in which all factors are included, have failed thus far. The mathematical models describing the complex mechanism of river development still involved a number of physical, hydrological, hydraulic and morphological relationships. For this reason theoretical assumptions must frequently be supported by physical model tests, while their validity must be checked and verified by field observations. The importance of observations in the field is emphasized by the fact that the resulting effect of the trend towards a dynamic equilibrium is reflected in channel development and this gave added impetus to morphological studies.

In the studies related to morphology and to the regulation plans associated with flood control it is essential to obtain information on curvatures and geometry of the channel including the flood bed as well. During the past ten years advanced hydrographic monographs have been prepared on all rivers in Hungary which contain besides the maps, profiles and geometrical dimensions, historical data on the geology, development and regulation of each river, together with the main hydrographic and hydrological information.

Earlier hydrographic surveys and the new hydrographic monographs provide the basic data for the morphological studies. In the course thereof a method has been developed for the parametric description of bend development, and relations were determined between bend development and the parameter values. These relations have been used succesfully in preparing general river regulation plans.

Information on the morphological parameters has offered the possibility of determining relations between the ice regime and the morphological characteristics. Mathematical relations are now available for describing the interrelations between river slope, the characteristic parameters of the bends, the geometric dimensions of the channel and the ice regime. The morphological parameters have made forecasts possible on the density of ice drifts and on the development of a solid cover. These relations permit us to identify the river sections which are critical for the passage of ice.

In both morphological studies and in river hydraulics the application of the energy equations represents a new approach. The results of regular observations along experimental reaches provided the data for estimating the energy needed for overcoming channel resistance, for transporting sediment and for moving the material involved in channel rearrangement. The results attained are of considerable interest, in that they afford for the first time numerical values on the capacity of rivers, which can be used to advantage in river regulation provided that the boundary conditions are controlled appropriately by corresponding structures.

The domain of river regulation research was highlighted by a few morphological studies only, since experiences gained over more than a century have demonstrated positively the most effective method for improving ice regime to consist in the modification of morphology. To be effective, this work must be extended to the entire river section which forms a natural entity, to the low- and meanwater, as well as flood bed in particular. The ice regime in rivers is however, controlled by the combination of two factors, namely weather and channel morphology. Since there is no human interference available at present to modify the former, the danger of ice-jam floods continues to exist even if regulation works are performed to perfection. Under adverse wheather conditions ice jams can always be expected to form. For this reason the other methods of ice control must also be perfected.

4. ICE CONTROL

Ice conditions on rivers, the formation and melting of ice depend essentially on the thermal balance, which in turn is controlled in accordance with the laws of thermodynamics by the prevailing weather conditions, as well as by the hydraulic and mophological conditions of a particular body of water. Whereas the ice phenomena taking place in artificial systems can be described in a manner verified by experiments with the help of the relationships of engineering thermodynamics, it has proved impossible to apply extensively these exact methods to practical problems arising in connection with natural channels, owing primarily to the uncertainty of initial and boundary conditions, further to the lack of observation data available for such purposes. Nevertheless, great importance must be attributed to the efforts and initiatives for clearing the problems associated with the formation, movement and packing of river ice hydraulics, which have become apparent during the recent years and which are reflected in several interesting papers submitted to the present Symposium. Observations in Nature afford the foundations for theoretical investigations, too. Regular observations on the ice regime of rivers in Hungary were started at the beginning of the past century. The dates of beginning ice drift, of the build-up of a solid cover, of breakup and disappearance of drifting ice have been adopted for describing ice conditions. According to experience gained over many years, freezing on rivers started on the average around the 20th December, but a solid ice cover has built up as early as the middle of November already. Drifting ice was observed on the average to disappear by the end of February, but the solid ice cover prevailed in some years up to the beginning of April. Ice tends to appear in general on the minor watercourses. In recent years advanced methods and techniques of mathematical statistics, which are becoming increasingly popular in hydrology, have been applied to the large volume of observation data in studying ice phenomena. The results permit the magnitudes and dates of ice phenomena of different probabilities to be estimated, moreover from these results certain regularities in the ice phenomena on major streams could be detected.

These statistical analyses will be illustrated by a few examples related to the Danube and the Tisza rivers. The frequency of ice drifts and packing, further the duration of ice-days and of the solid ice cover are shown in Fig. 3 resolved according to probabilities along the successive sections of the Danube. The same characteristics have been plotted for the Tisza River in Fig. 4. The occurrence of both drifting and solid ice is associated with higher probabilities on the Tisza River than on the Danube, nevertheless ice jams and consequent floods are more liable to develop on the Danube.

The frequency of days with a solid ice cover tends to increase downstream along the Danube from 20 to 60%, whereas it is virtually constant at about 80% along the Tisza River.

The duration of 1% probability of a solid ice cover over the Hungarian section of the Danube is 100 days, whereas it is 120 days on the Tisza River.

The probability distribution curves for the river sections farthest to the South in Hungary, namely for Mohács on the Danube and for Szeged on the Tisza River are shown in Figs. 5 and 6, respectively.

As a comparison will reveal, the low discharges in the Tisza River respond more readily to variations in weather, so that ice appears at an early date and remains for extended periods of time on the river of an extremely flat slope. At the same time, the embedding process resulting from river regulation has created favourable conditions for the breakup and removal of ice. The flow is confined to the relatively large mean-water channel, which is thus capable of conveying even major flood waves breaking up more readily the ice cover.

The radical differences in the ice regimes on the Danube and the Tisza River, the two major streams in Hungary, demonstrate positively the dominating influence of weather on ice conditions.

Over the catschment area of the Danube one of the three principal air-mass movements predominates. Mild air masses of high moisture content are conveyed by the Atlantic air streams from the West, by the Mediterranean air streams from the South, whilst cold and dry air masses are transported from the interior of the continent by easterly winds. Whenever the cold, continental air masses cause drifting ice to appear on the river and subsequently the building up of a solid cover, and melting in the spring is caused by Atlantic air masses so that the resulting flood wave arrives from the West, the ice masses drifting downstream on the wave strike a solid, hard-frozen ice cover and cold air masses along the central section of the Danube. Unter such conditions ice jams are very likely to develop. If, however, the warm air masses arrive from the Mediterranean and reach first the lower- and central sections of the Danube, the subsequent flood wave from the upstream section finds no difficulty in breaking up and removing the weakened ice cover on the river. According to statistical data in 75% of the years the spring thaw arrives from the West and since a solid ice cover is formed in 40 out of every 100 years, meteorological conditions favour the formation of ice jams at 3 to 4 years intervals. This situation, related to the so-called temperature inversion may be especially dangerous, as demonstrated by the ice-jam flood of 1956.

The Tisza River takes its course through a region under a colder climate in winter, primary ice drifts appear at an earlier date and owing to the flat slope the ice cover is built up earlier. Mild air masses in spring arrive first over the lower sections of the river, regardless whether of Mediterranean-, or Atlantic origin.

As a consequence thereof, by the time the flood wave triggered by snowmelt or rainfalls in the Carpathians arrives at the upstream edge of the solid ice cover, the ice there is usually weak, readily lifted and broken up enabling it thus to pass safely downstream.

It is of interest to note that owing to lack of funds the flood bed between the levees provided at the time of regulation is generally narrow along the minor rivers, yet even along some sections of the Danube and the Tisza River. Consequently any ice jam may cause the stages to rise to the critical height.

Ice-jam floods are especially dangerous, since they are impossible to predict, there are no known methods for estimating stages, so that they are difficult to control and flood fighting efforts are questionable in their success.

On canalized rivers conditions differ radically from those under natural conditions. Experience has shown the volume of ice on canalized rivers to be essentially the same than before canalization.

Upstream of isolated barrages ice jams are likely to form around the end of the backwater reach, and more intensive ice control at an ice cover of extended duration must in general be anticipated in the vicinity of the weir. In the tailwater, on the other hand, the beneficial effect of the upstream ice cover causes ice to appear for very short periods only. On a completely canalized river section this beneficial effect is even more pronounced and the ice cover building up from a downstream barrage extends but seldom to the tailwater of the next upstream.

Natural conditions have thus far prevented us from gaining much first-hand experience with large river barrages and we expect to hear more on these problems at the Symposium, attended by participants from several countries, where long-year experiences have been gathered on the operation of barrage systems in winter.

Ice phenomena, ice formation and the consequences thereof affect, however, not only the fluvial water management problems, but also the operation of multi-purpose water projects, the services of which are needed in the winter period as well.

Excess surface waters are drained from over 40% of the territory of Hungary. These waters result in their bulk from precipitation accumulated in the form of snow and ice during the winter. The meltage waters accumulate and flow towards the open drainage canals, where they are conveyed in channels blocked more or less by snow and ice. Ice may be deposited on the structures (weirs, sluices) controlling the flow in them, the flow cross-section may be restricted and operation made difficult thereby, so that the conveying capacity of the drainage system is greatly reduced. The pumping stations may on occasion be forced to operate intermittently the flow in the approach canals being reduced by ice to below the capacity of the pumps.

The situation is quite similar at intakes and diversions, especially in the case of supply systems drawing on open channels and storage reservoirs and delivering the water to the population, to industry, or to fish-ponds. Ice freezing on the structures and control organs by become a source of considerable operational difficulties particularly at drinking-water reservoirs.

Research into the related ice phenomena and the elaboration of methods of prevention are tasks to be accomplished in the future. Concerning ice control at structures and in canal reaches the potential applications of say aeration and air-bubble curtains must be explored.

In designing water management projects in Hungary, and in countries with climates resembling ours, allowance must be made for ice phenomena liable to occur during winter operation.

The problems to be studied in the near future include the influence of relatively large volumes of cooling water discharged into the recipients on the ice conditions in them. The volume of cooling waters is likely to increase all over the country, but especially along the Danube. The potential oecological damages of thermal pollution must be compared with the probable beneficial effects thereof on ice formation.

The fundamental measures of controlling ice-jam floods or at least of minimizing the dangers thereof must necessarily consist of removing the channel-morphological causes thereof by river regulation. During the ice-jam floods still occurring these may be completed effectively by appropiately applied methods of ice breaking.

During the recent decades considerable damages were caused by the ice-jam floods of 1940, 1941 and 1956 on the Danube. Owing primarily to the danger of repeated ice-jam floods on the Danube, but also on minor rivers, the continuous development and improvement of ice control imposes an important responsibility on the Hungarian Water Service.

Highly organized, efficient observations and reporting are essential prerequisites of ice control and of averting the demages of ice-jam floods.

Ice control forms an organic part of the flood control system in Hungary. Under bilateral agreements the neighbouring countries supply information on ice conditions over the river sections beyond the boundaries of the country for use in controlling and fighting ice-jam floods.

Experience has shown terrestrial observations, however carefully made, to yield data of limited accuracy only. For this reason aerial inspection and reconnaissance was found essential in critical periods. Reliable information on ice conditions can be gained from the interpretation and evaluation of aerial photographs. Thermal remote sensing and other photographic-optical methods should therefore be introduced and adopted for general use.

The aircrafts of the water service are used for regular reconnaissance flights in the winter ice period and transmit reports when necessary during flight already over the VHF network of the water service.

The observation results are reported to the competent authorities, who decide on the appropriate ice control measures, such as ice breaking, or blasting to be taken. On large and medium streams ice breaker vessels proved more effective.

Until not long ago we were virtually uncapable of averting ice-jam floods, but the methods developed during the past 20 to 25 years for dispersing the ice, such as ice breakers and blasting methods have proved effective, yet they still do not afford by far the desired safety and reliability of ice control. It may be of interest to present a slightly more detailed account of the experiences gained in the application of icebreaker vessels and ice blasting.

The icebreaker fleet on the Danube and the Tisza River comprises at present 11 units of 600 to 1440 HP, 9 units of 300 HP and 3 units of 170 HP engine capacity, i.e., altogether 23 units.

Under the Hungarian-Yugoslav water agreement Hungarian icebreaker vessels operate (5 this year) also over the Yugoslav part (border to Vukovár, R.Sts. 1433 to 1333 km) of the Danube section of common interest.

The usual method adopted for icebreaking abroad consists of tackling the downstream end of the ice cover at the beginning of melting with a relatively large number of units. Consequently these operate only before the beginning of, and during, secondary ice drifting. In the vicinity of estuaries to the sea the possibilities for the application of this method are favourable. On several rivers in Hungary, especially on the Danube, other methods must be adopted. Different methods may be found appropriate even within this country, depending on particular weather and morphological conditions, and on the ice regime controlled by these.

On the Danube the icebreakers operate already in the period of primary (freezing) ice drifting. Ice is removed first from the buttresses causing severe channel contractions and building up from ice floes arrested at the edge of sand bars over the familiar overdeveloped sections which can be regulated but successively. In each period of ice drift the passes are repeated three to four times. The aim of destroying continuously the buttresses is to reduce the arrested ice masses and to pass an as large as possible an ice mass below the mouth of the Dráva River contributing to the flow in the Danube, further to delay (and in milder winters to prevent) the formation of a solid ice cover and finally to minimize the danger of jamming in the period of secondary ice drifting.

On the Danube the icebreaking vessels operate also in the solid ice cover. In the 150 to 200 m wide low-water channel a 30 to 40 m wide corridor is broken and maintained until the ice starts to melt. The corridor does not follow accurately the main current line, but is cut along the centerline in the transition sections (counterflexure), while in the apex of bends it is cut along the sand bar at the convex side. In this way the thin part of the ice cover is separated from the large ice mass of the buttresses adhering to the sand bar, eliminating the initial arching resistance of the ice to the start of drifting. Moreover, the ice fields built up over shorter sections are closed to a coherent cover to prevent slush ice from forming in the exposed water surfaces. Once melting has started the ice breakers cut up successively along the corridor the ice masses of buttresses and jams without the hazard of renewed congealing.

When the first signs of secondary drifting are observed the fleets of icebreakers start breaking up the cover along the 227 km long Danube section of common Hungarian-Yugoslav interest, proceeding upstream in sections.

On the Tisza River the icebreaking vessels operate commonly along the backwater reaches upstream of the Tiszalök and Kisköre Barrages, as well as farther upstream over a river section of round 100 km aggregate length. At the start of thawing the ice is broken over a 1.5 km long section above the barrages and the ice floes are passed downstream by lowering the tilting leafs of the weirs. Subsequently a 20 to 30 m wide corridor is cut in the headwater for a distance of 20 km over the section where the backwater and meandering has resulted in large ice deposits. Hereafter the entire ice cover is removed proceeding upstream. The ice cover is broken up and kept moving as long as dense drifting continues.

The cutting and maintenance of a corridor at the start of thawing proved effective on the medium-size tributaries as well. In narrow bridge openings the ice cover is completely broken up. In the period of secondary drifting the jamming ice is broken up mainly at the bridges and other critical sections using small vessels in cooperation with ice blasting patrols.

Although the fleet of icebreaking vessels is operated over the entire length of the ice period on the Danube, in winters of greater than average severity 4 to 8 m thick jams form regularly at primary drifting, which the icebreakers are uncapable of penetrating. These were destroyed by blasting and since the fleet of icebreakers was commissioned no jam developed in the period of secondary drifting, which the vessels could not remove. Over the sections of the Tisza River where the icebreakers operate blasting must be resorted to but exceptionally, while the blasting patrols operate regularly along the sections higher upstream.

Conventional charges, such as powdered or pelletized explosives, placed, or dropped on the ice surface act within a short time, but their introduction under the ice calls for lengthy operations. Blasting ice holes by placing several charges repeatedly on the same spot is also a lengthy and uncertain procedure.

For making hole drilling and blasting faster and more effective a series of ice perforator and blasting charges was developed.

The ice perforators are cumulative in their effect, the conventional charges containing from 0.4 to 5 kg of explosive.

The ice perforators are capable of blasting a hole through covers, or jams of 1 to 8 m thickness, the hole blasted being 0.6 to 2.0 m in diameter at the top and 0.4 to 1.2 m at the bottom. The holes are filled with ice. The number of holes blast is governed by that of charges which it is desired to fire in a field simultaneously, or in a delayed order.

The most effective type of charge used for ice blasting may be termed, depending on application, an ice mine.

The charges contain 45, 35, 20, 10, 5 and 2 kg of explosive (paxite) in cylinders with a conical keel at the bottom. The total weight of the charges ranges from 72 to 3 kg, the length of the cylinders from 90 to 22 while their diameter from 31 to 10 cm.

The ice is broken up in sections, starting from the downstream end. In a wide ice cover, or in a jam a corridor is blasted around the main current line. The blasting holes are arranged according to a definite pattern.

For several sections liable to ice jam formation on both the Danube and the Tisza River ice blasting plans have been elaborated for several potential situations.

The experiences gained in ice control have been compiled in the Ice Control Manual, which contains general guidelines and methods for those participating in the operations.

In the domain of ice control the Hungarian water organization has attained the results reviewed in the foregoing and dealt with in several papers submitted to the Symposium, further in the Ice Control Manual mentioned before. Still a number of problems remains to be solved, of which the following are deemed to be of special interest:

It has become increasingly clear that instead of the former isolated solutions, coordinated, comprehensive plans must be elaborated for realizing the inherently interrelated water management objectives, which are important prerequisites of economic-social evolution. Cooperation extending to the entire catchment of the Tisza River and the combination of the efforts of all interested C.M.E.A. countries open wide possibilities for solving flood control problems in an advanced, economic manner, the benefits of which must be exploited in ice control as well. On the Danube all countries along the river must be included in an international organization like the C.M.E.A., or ECE — assisted by the valuable activities of the Danube Commission — for finding a solution to the common problems. The united waterway system created by the completion of the Danube—Main—Rhine Canal will call with added emphasis for the canalization of the river, the extension of the navigation season and the implementation of more effective ice control measures. These important problems cannot be solved, unless observations are intensified and research is conducted by international cooperation, in order to advance ice control on scientific, engineering and economic foundations.

CONCLUSIONS

I have endeavoured to present a comprehensive picture about the situation and problems of water management in Hungary, with the main emphasis on flood control, and river regulation, accentuating the ice regime on the rivers in Hungary and the methods of ice control. To complete the picture a film will be projected immediately after this lecture, the methods and equipment are displayed in the exhibition here, reference is made to the papers submitted by the members of the Hungarian Water Service and a study tour is organized on the Danube.

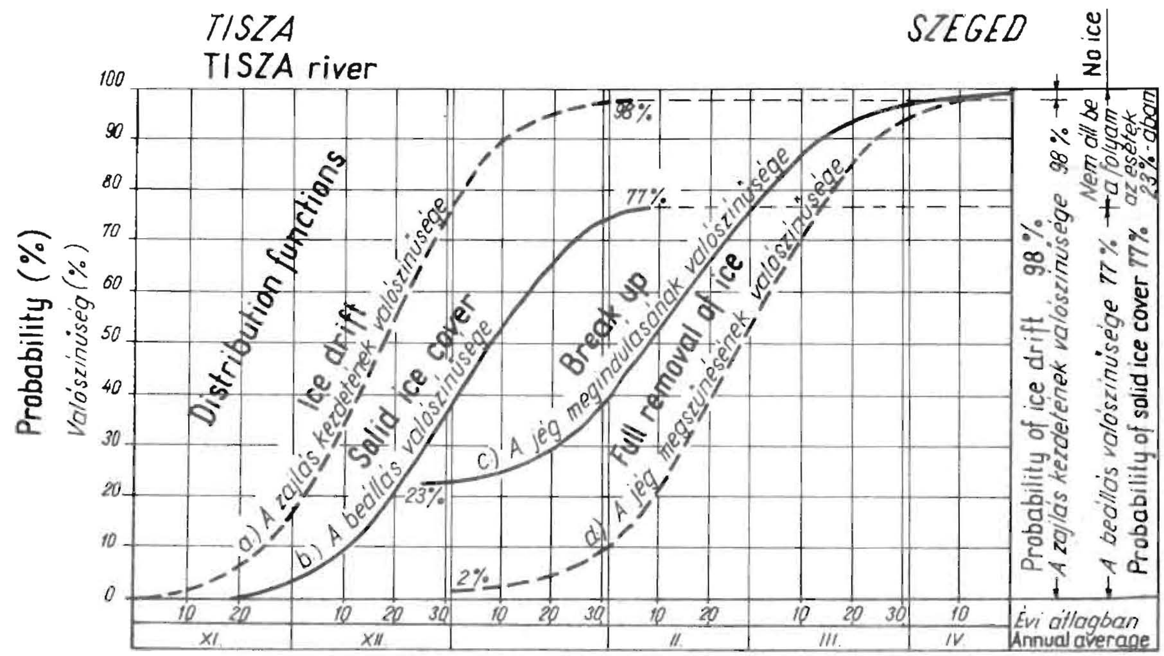
In conclusion it should be pointed out that extended, coordinated research considering scientific, engineering and economic aspects alike is still needed before the experiences available can be generalized, a better understanding of ice phenomena is obtained, the damages can be prevented and ice phenomena can be controlled reliably.

We expect that the comparison and synthesis of research conducted under different climates and on different continents will yield valuable results. The unprecendented opportunities of international exchange of experience may make science indeed accessible to mankind, provided that the vast potential of international cooperation is fully exploited.

With these ideas in mind, successful work in reviewing comprehensively the present knowledge on iver ice phenomena, in exploring the problems awaiting to be solved and in staking out the main trends of future research.

Mr Chairman, Distinguished General Secretaries,

On the occasion of the joint venture of the two renowned international societies I should be allowed to express my sincere hope that you, as well as the societies of which you are officers continue proceeding on this path of international cooperation, contributing thus to the realization of the most ambitious objectives of mankind.



6. ábra. Jégjelenségek valószinüsége
Fig. 6. Distribution functions of ice phenomena

3

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SYMPOSIUM

RIVER & ICE

Ö. Starosolszky

General Lecture on Subject A

RELATIONSHIPS OF FLUVIAL AND ICE HYDRAULICS

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General Lecture on Subject A

RELATIONSHIPS OF FLUVIAL AND ICE HYDRAULICS

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ABSTRACT

The fundamental processes of cooling, ice formation, ice movement, ice cover formation and break up are reviewed together with the relevant theories and recent advances in research. The close interrelations between fluvial- and ice hydraulics are emphasised. The problems of which a better understanding is considered desirable are listed and finally the papers received are grouped accordingly.

SOMMAIRE

Le rapport donne un aperçu des proces fondamentaux du refroidissement, de la formation et du mouvement de glace, de la formation de couche de glace et de la débacle, en traitant les théories importantes et les progrès récents des recherches aussi. Les interrelations étroites entre l'hydraulique fluviale et l'hydraulique glaciale sont mises en évidence. Des problèmes dont une raisonnable compréhension est désirable sont enumerés puis les études presentées sont groupées en conséquence.

River ice is a phenomenon of Nature which must be reckoned with over large areas of the Earth, over periods of varying length each year. As far as ice formation is concerned, the watercourses may be classified as follows:

- rivers with ice runs, or covered with solid ice for short periods, or in some years only,
- rivers with ice runs and covered with solid ice for short periods, but regularly each winter,
- rivers covered each winter with solid ice for extended periods, and
- rivers permanently covered with ice.

The importance of the phenomena to be considered varies consequently from river to river, the economic significance of the problem and thus the intellectual-material resources devoted to the relevant engineering solutions are controlled fundamentally by the number of ice-run days, or the length of the period of the ice cover. There are, however, certain fundamental problems - related to Subjects 2 and 3 on the agenda - which receive virtually uniform interest by the professionals dealing with ice.

These problems may be listed as follows:

- the cooling process preceding ice formation,
- the formation of ice,
- the movement of ice in the watercourse and on the surface,
- formation of the ice-cover,
- the adverse phenomena associated with icecover formation,
- the breakup of the ice-cover and the start of ice runs,
- the interrelations between the flow carrying the ice and the ice itself (velocity distribution, energy losses, etc.).

In some countries all these phenomena are intimately related to diverse human activities so that owing to these interferences it is virtually impossible to arrive at conclusions on the natural conditions. Such interferences are for instance river regulation, river canalisation or cooling water discharges. These human interferences may be beneficial or adverse so that it is essential to make allowances for these, especially where the problem is to predict the effect of a particular activity on future ice conditions.

1. The cooling process

Ice is likely to form whenever the temperature of water in a stream drops to below the freezing point. Under natural conditions this is preceded by the cooling of the atmosphere resulting in intensive heat losses across the water surface. In the majority of watercourses this process extends to the entire cross sectional area, that is the entire water mass is affected by the heat exchange. The process is influenced, obviously,by the flow conditions in the air- and water space, the intensity of heat exchange being governed by these.

The micro phenomena involved in the process are not fully understood, owing to technical problems of measurement. Between the flowing water and the moving (or stationary) air masses dynamic- and temperature boundary layers exist.

The intensity of heat exchange is controlled by the gradients prevailing in the boundary layers, in that heat exchange is very intensive at high gradients while quite moderate at low gradient values. In a stationary air layer a moving boundary layer is created at the air-water interface owing to the shear stresses transmitted from the water flowing below it. As a consequence of evaporation the vapour content in the air layer in direct contact with water is high and thus its heat conducting properties will differ from those of the air layers overlying it. These are the boundary layer problems which make the determination of the heat transfer coefficient, and consequently the positive description of the cooling process rather difficult.

The cooling process occurs usually under atmospheric conditions that are far from constant so that the temperature- and occasionally kinetic conditions within the air space must be considered variable during the cooling period. Accordingly the cooling process must be considered variable with time. Since the river bed itself is variable, its heat dissipation properties are similarly variable, as a consequence of which the ensuing process is variable along the watercourse. The problem may be rendered even more difficult if differences in atmospheric conditions prevail over longer river sections even at the same instant. It will be appreciated from the foregoing that the cooling process is an unsteady, variable phenomenon into which a certain periodicity is introduced by diurnal periodic fluctuations of the atmosphere. Higher temperature during the day and cold nights cause thus diurnal, secondary, periodic variations in the cooling trend line. The combinations of several factors controls the typical cooling record (Fig.1).

The highly complex phenomenon must be drastically simplified in the interest of formulating a computation model. The simplifying assumptions introduced are usually as follows:

- over a certain period of time and river section a constant value is assumed for the rate of change in temperature,

- the influence of diurnal changes in atmospheric temperature is eliminated by introducing the daily mean temperature into the computations,

- the three-dimensional phenomenon is reduced to a two-dimensional one at the water surface, or even to a single- dimensional one.

An attempt has been made in Fig.2 to illustrate actual conditions while in Fig.3 the more common simplifying assumptions.

It should be realised that the combination of a similarly great number of simplifications may under adverse conditions result in misleading conclusions. For this reason it would be very important to examine both theoretically and by practical applications the accuracy of the approximating methods, which are still rather complicated to apply in practice. Such studies should yield actual data on the validity of diverse simplifying assumptions.

The process of cooling may be strongly influenced by human interferences, primarily discharges, and especially those of cooling water. These are extremely difficult to take into consideration numerically, particularly over the section where mixing is incomplete, the process year being necessarily a three-dimensional one. Even the length over which complete mixing takes place is very difficult to determine so that certain simplifications must be introduced to solve this complex problem.The process of mixing in the watercourse is of considerable influence on cooling and vice versa, since high temperature differences are conducive to more intensive mixing. This interference is often strong enough to be of interest, resulting in the necessity to formulate a separate cooling model for the river section affected.

Heat losses across the surface play invariably a fundamental role in any model of the cooling process. In practical computations this heat loss is taken proportionate to the difference of air and water temperatures, the factor of proportionality being assumed to equal the heat transfer coefficient which in turn depends on the hydrological- meteorological characteristics prevailing at the water surface. In view of the fundamental importance of the heat transfer coefficient in the cooling process it is deplorable, that no exact method is available for its determination. Unfortunately, the data and results published thus far apply mostly to particular locations and are not suited for generalisation.

2. Ice formation

The formation of ice is in principle possible once the temperature of water has dropped below the freezing point. This is usually the case in standing bodies of water so that surface ice begins to form along the banks where the velocity is negligible and where, owing to laminar conditions, the water is not exposed to turbulent heat exchange.

The rate at which the thickness of this riparian ice increases is controlled by heat exchange across the ice cover.

Different conditions prevail in turbulent flow where certain overcooling is a prerequisite of iceformation. The phenomenon of overcooling is due to the temperature boundary layer. At air temperatures below the freezing point a boundary layer must develop in the top water layer whenever the water temperature has approached (or attained) the freezing point.The temperature in this boundary layer depends on the ambient air temperature but is invariably below the freezing point. Owing to turbulence the water particles travel in this overcooled layer for periods of varying length and become thus overcooled. Hereafter they are carried again by turbulence to different points of the cross section, as a consequence of which the entire water volume becomes overcooled. It is logidal to assume that within this overcooled water volume the temperature of all water molecules is not uniform, nevertheless the mean temperature as a resultant temperature of all molecules is lower than the freezing point. A typical time-record of overcooling has been demonstrated by T.Carstens, who derived therefrom the record of iceformation as well.

Of the factors affecting overcooling, or the formation of frazil ice, the sediment concentration of water, the rate of cooling and the intensity of turbulence are generally recognised.

As a crude approximation a formula has been derived for the rate of frazile ice formation in terms of heat loss from the water surface. The volume of frazile ice formed is accordingly regarded proportionate to the air temperature. This experience is supported by some observations. At the same time, there is other evidence to indicate that this relationship is not a linear one, but exponential in character.

In mathematical form

$$\frac{Q}{Q_o} = 1 - e^{\lambda \frac{\Delta T}{\Delta t}}$$

where $\Delta T/ \Delta t$ is the rate of cooling, λ depends on the type of heat transfer and Q_c is the rate of frazile ice formation without cooling (i.e. pertaining to steady temperature conditions). Although scattered data on frazil ice formation are available for some major streams, the importance of the problem would warrant more detailed field observations on this fundamental phenomenon.

The particles of frazile ice coagulate to form needles,flocs loose clumps or clouds and floating up to the surface tend to form slush ice and eventually small ice floes. Together with the ice separating from the banks and rising from the bottom they freeze into floating ice floes the magnitude and area of which are typical for the ice conditions on a particular watercourse.

3. The movement of frazile ice in the watercourse

Frazil ice appears in a variety of forms and shapes in the watercourse, but its specific weight is always lower than that of water. It is thus subject to a buoyant force so that is rises shortly after its formation to the surface, or would remain there if formed at the surface.

As to any finely dispersed substance in turbulent flow, the relationships of turbulent diffusion are likely to apply also to frazil ice. It is not clear however, how far the loose masses or clouds may be regarded as finely dispersed, discrete masses, moreover rather little is known about the dimensions and shape of frazil ice particles. Consequently, although the theory of suspended sediment transport appears applicable in principle to slush and frazil ice as well, the rate at which this ice rises in water is subject to rather crude approximations however important its influence on the phenomenon may be.

In any effort to obtain a better understanding on the distribution of frazile ice within the cross section or on its rising length in the stream the following factors must be clear:

- the rising velocity of frazil ice,
- the similarity of movement of isolated particles and agglomerations.

In analogy to the theory of suspended sediment transport the percentages proportion of floating frazil ice depends basically on the parameter

$$z = \frac{C}{0{,}4\sqrt{g}} \quad \frac{w}{v} ,$$

where C is the velocity coefficient of Chézy, w is the rising velocity and v is the velocity of flow in the stream. If $z \to \infty$ the phenomenon may be regarded laminar, whereas for $z \to 0$ the phenomenon departs increasingly from laminar conditions indicating a reduced settling tendency of the frazile ice.

No quantitative relationships of general character are available on other forms of appearence of frazile ice, e.g. bottom ice and no such relations are expected in the near future. It is thus felt necessary to concentrate efforts on theoretical statements of general validity.

4. The movement of ice on the surface

The ice floes, or the ice cover composed of floes, move together with the stream. The velocity of movement is influenced by the proportion of the surface covered by ice, which varies as a function of channel width. In contractions the ice is concentrated and the velocity of movement is reduced. As a consequence thereof even a standing ice cover may develop. On the other hand, isolated ice-floes are carried depending also on the direction and velocity of wind, mostly at a velocity more or less identical with the surface velocity of water.

The movement of ice-floes at the surface is described by the simplified continuity equation and is characterised in simple cases by the percentage area covered. Beyond the condition of "free movement" the kinetic energy transmitted to the ice from water is dissipated by friction along the banks and between the individual floes and then the dynamic equation of ice movement must also be introduced into the relation.

5. Formation of the ice cover

The hydraulics of ice cover formation (Table I) have been formulated in Canada, where a fundamental distinction has been made, as will be recalled, between wide and narrow streams.

This approach is characterized by the effort towards exact hydraulic description of the phenomenon. Nevertheless, the unavoudable simplifying assumptions may entail certain inaccuracies and the methods cannot be applied, unless specific parameters of the ice cover are known. In many instances these characteristics are impossible to determine. The assumption of numerical values for these may introduce errors exceeding in magnitude even those due to the simplifying assumptions.

The method has been derived for straight, prizmatic channels of uniform slope and roughness in which the rate of streamflow is constant. Accordingly the expressions derived appear applicable to regular wide canals rather then to alluvial channels. Actually the running ice is arrested at contractions, in bends and at islands, moreover the forces exerted on the banks are extremely difficult to estimate.

There is ample experimental evidence for the assumption that the critical velocity of the front of the ice cover at the surface is described by an expression of the form

$$v_{kr} = k \sqrt{2g \frac{\rho - \rho'}{\rho} h}$$

This would imply that the thickness of the ice cover i.e. the thickness of the arriving ice floes is the dominant factor. The magnitude of the factor k depends on the dimension and shape of the floes. The scatter of experimental data is due to secondary factors which are neglected in the formula.

Considerable importance is attributed by Michel also to the porosity of the ice cover.

Pariset and Hausser have defined wide streams as such, where maximum pressure in the ice cover occurs at a certain distance below the upstream edge, rather than at the upstream edge of the cover. The applicability of their method is limited by the circumstance that some of the parameters must be derived from the field observations. These parameters include the cohesion of ice to the banks and the coefficient of ice friction. Whereas the friction of ice on ice may be assumed for the coefficient of the friction, little empirical data are available on the magnitude of cohesion. It is for this reason that in practical applications of the method cohesion is neglected in the interest of safety.

The main advantage of the exact hydraulic methods is that they can be applied even in the absence of observation data, provided we succeed in estimating fairly closely the parameters involved in the expressions. It thus follows that for various streams in the World it would be desirable to determine the parameter values from data collected, or to be collected on the ice cover. This appears to offer the only way for developing a method which is indeed generally applicable.

Observations on wide streams seem to support the conclusions which may be termed qualitative and which can be arrived at from the expressions derived.

One of the fundamental cases of ice cover development, namely increase in thickness, is when the ice floes arriving from upstream are carried under the ice cover at the upstream end and get stuck there, since the ice carrying capacity is inadequate.

The ice transporting capacity is usually derived by analogy to bed-load transportation and the critical ice discharge, which is still just capable of being passed, is estimated in this manner. For the computation the formulae of Einstein, Meyer-Peter and Ning-Chien are applied. The fundamental difficulty in this method is that the shape of the bed load particles is poorly comparable to that of the ice floes and consequently the relation $\Phi = f(\psi)$ derived theoretically and verified experimentally for bed load is applicable to ice floes with crude approximation only.

The application of the method presumes further the knowledge of the velocity coefficient as well, or of the slope of the energy line. Difficulties are encountered in the assumption of both, as will be pointed out in Section 6.

The ice ripples developing on the underside of the ice cover, for which striking examples have been presented in recent times by several investigators, are subject to changes with time, so that the velocity coefficient itself is liable to vary considerably. An increased number of observation data on this phenomenon would improve materially the reliability of assumed values.

6. Flow under the ice cover

It has been pointed out repeatedly in the foregoing that the ice cover acts to reduce the conveying capacity of the river bed. Rating curves observed in winter with ice on the surface, were found in several countries to differ considerably from their summer counterparts.

The conveying capacity of the channel decreases perceptibly as the surface area is covered to any considerable extent by floating ice floes. In other words the stages pertaining to the same streamflow become higher. The formation of a solid ice cover, on the other hand, brings abour radical changes. Any rough estimate should suffice to reveal that even if the loss in the flow cross-section is ignored, the friction taking place at the interface of the water and the ice will cause alone a 20 to 30 % reduction in the streamflow rate. This is visualized best by imagining the distorted velocity profile in the cross-section, the development of a double boundary layer. In the closed cross-section under the ice cover the magnitude of the maximum velocity is reduced and its location is displaced to greater depths in the cross-section from the vicinity of the surface. Irregular ice deposits give then rise to highly irregular velocity distributions, as a consequence of which the three-dimensional character of flow is usually enhanced, giving thus rise to additional head losses.

Velocity observations under the ice cover, the number of which is no more negligible, support conclusively this phenomenon. Assuming two-dimensional conditions to prevail, several theories have been suggested, but no attempt has thus far been made to take three-dimensional flow into consideration.

Unsteady flow under the ice cover is liable to set the cover into some kind of motion, e.g. flood waves often break up and carry downstream the cover. Downstream of weirs and dams this method may be successful in breaking up and removing the ice cover. The discharge required for breaking up the ice cover can be estimated by methods outlined in Section 5. However, the ice phenomena caused by unsteady flow can be predicted in broad outlines and with local character only. No forecasting method of general validity can be developed therefrom, unless a new theoretical model is conceived, for the practical application of which the parameters are determined on the basis of regular field observations.

7. Problems in fluvial- and ice hydraulics

The solutions and problems outlined in the foregoing demonstrate positively the close interrelations between fluvial- and ice hydraulics and that in ice hydraulics several solutions have been borrowed, especially in connection with the movement of ice, from fluvial hydraulics.

The future problems likely to arise in ice hydraulics raise a number of problems in fluvial hydraulics as well. An attempt will be made here to review those believed to be the most essential ones.

- For describing cooling conditions in alluvial channels it is necessary to have sufficiently accurate information available on the magnitude of the turbulent dispersion coefficient, or the turbulent diffusion coefficients. The determination of generally recognized diffusion-dispersion coefficients describing positively the phenomenon of mixing and thus also the temperature conditions in streams is thus generally desirable in ice hydraulics as well.

- The phenomenon of ice formation is greatly influenced by the sediment discharge in the stream as well as by the quality (crystal system) of the sediment. More accurate and reliable data are, however, required on the magnitude of this influence.

- Heat exchange across the water surface in streams is affected by the temperature boundary layer, which in turn, is influenced by the boundary layer of movement. Ice accretion on the underside of the cover and the change in velocity distribution are also related to the boundary layer.

- The heat generated by friction is one of the important sources of heat in the water mass moving under the ice cover. At the same time, no accurate data are available on the influence of bottom ice, and in general any ice cover on the channel surface, on the magnitude of the friction coefficient of the bed perimeter. Friction values for the underside of the ice cover are easier to obtain.

- For describing the movement phenomena of frazil ice more accurate information would be desirable on the dispersion coefficient mentioned before, for a particular stream with- and without an ice cover. This is believed to materially affect the phenomenon of settling out.

- The transportation of ice floes, just as that of bed load is a process in which energy is normally consumed. The collisions between ice floes is one of the causes of energy consumption.This is why it is necessary to explore the energy losses taking place in watercourses, in order to obtain a better understanding of the processes preceding the formation of a stationary, solid ice cover.

- For describing the precesses resulting in the arrest and jamming of ice flows it is necessary to determine friction- and cohesion coefficients.

- The movement of solid ice under the ice cover cannot be described, unless parameters representing the shape of ice floes and the possibility for more accurately estimating the ice conveying capacity are determined. In this respect it may be possible to use the accepted bed load transport analogy.

- It seems desirable to develop expressions describing more accurately the critical stability conditions of the ice cover and the effects of unsteady flow on stability, together with the relevant parameters.

- Methods are needed by which the effects of diverse human interferences on the phenomena of ice formation, ice movement, cover formation, breakup, etc. can be estimated more exactly. (These problems are dealt with more in detail under Subjects 2 and 3 of the symposium.)

8. The papers submitted to the symposium

The papers submitted on Subject 1 have contributed to the solution of the aforementioned problems. The authors will find opportunity to present their papers individually, so that no more than a common framework is deemed desirable for them.

General problems are discussed in two papers (A1, A5), one paper is on colling phenomena (A10), while artificial thermal effects are considered in one (A12). Two papers are devoted to flow and water conveyance under the ice cover (A7, A10). In three interesting papers (A2, A6, A11) the problems of ice cover- and ice jam formation are approached. The phenomenon of breakup is discussed the paper A13. The dimensioning of bridge spans caussing no ice jamming is analysed in the paper A8. Thus the number of papers dealing with ice problems is 11.

In two papers the problems of ice hydraulics are not mentioned directly, one being devoted to bottom changes along the stream (A4), the other to hydraulic problems at the crossing of rivers and navigable canals. Both problems are of fundamental importance for navigation.

The papers on ice hydraulic include thus a rather wide domain and reflect well the research work conducted in this field all over the world.

Hydraulic conditions of ice cover formation

Moving ice cover — *Stable ice cover*

Wide channel, $\alpha > 0$

Moving ice cover	Stable ice cover
$Q > \beta H^2 C \sqrt{B}$	$Q < \beta H^2 C \sqrt{B}$
$\dfrac{Q^2}{BC^2H^4} > Y$	$\dfrac{Q^2}{BC^2H^4} < Y$

$$\alpha = \frac{B}{2k_1 \tan\phi}\left(f_2 + f_3\right) - \frac{\tau h}{k_1 \tan\phi} - f_1$$

$$Y = \frac{\mu\left(1 - \frac{\varrho'}{\varrho}\right)\frac{\varrho'}{\varrho}\left(\frac{h}{H}\right)^2\left(1 - \frac{\varrho'}{\varrho}\frac{h}{H}\right)}{1 + \frac{\varrho'}{\varrho}\frac{h}{H}}, \qquad \beta = \sqrt{Y_{max}}$$

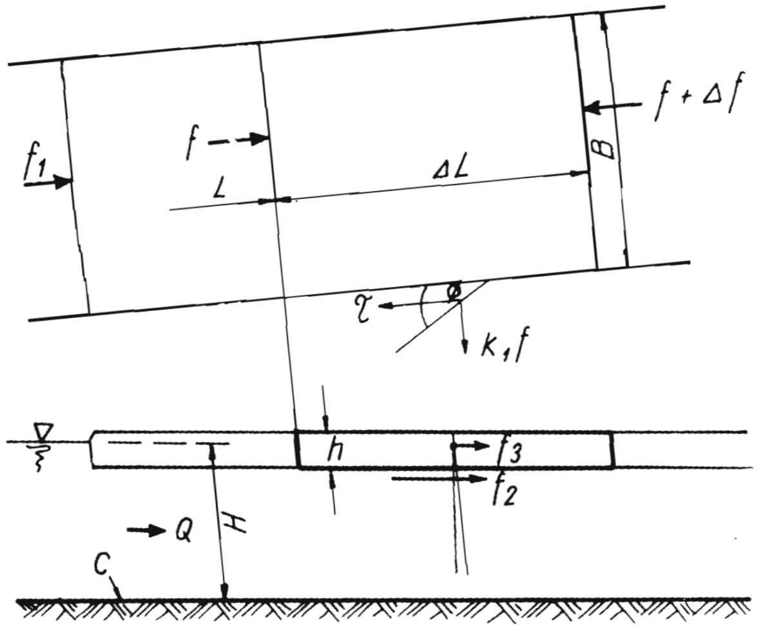
Narrow channel, $\alpha < 0$

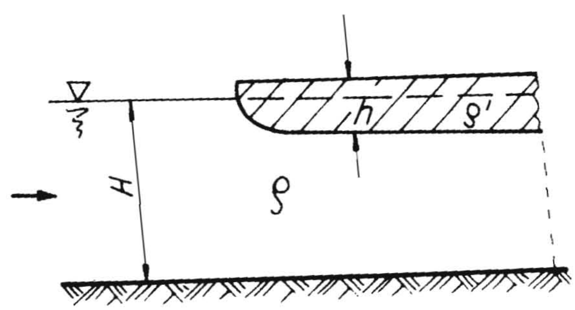
Moving ice cover	Stable ice cover
$\dfrac{v}{\sqrt{2gH}} > 0{,}109$	$\dfrac{v}{\sqrt{2gH}} < 0{,}109$
$\dfrac{h}{H} > 0{,}33$	$\dfrac{h}{H} < 0{,}33$
$\dfrac{v}{\sqrt{2gH}} > y$	$\dfrac{v}{\sqrt{2gH}} < y$

$q_i < q_{i\,cr}$	$q_i > q_{i\,cr}$
Ice floats downstream	*Ice accumulates*

$$y = \sqrt{\frac{\varrho - \varrho'}{\varrho} \cdot \frac{h}{H}\left(1 - \frac{h}{H}\right)}$$

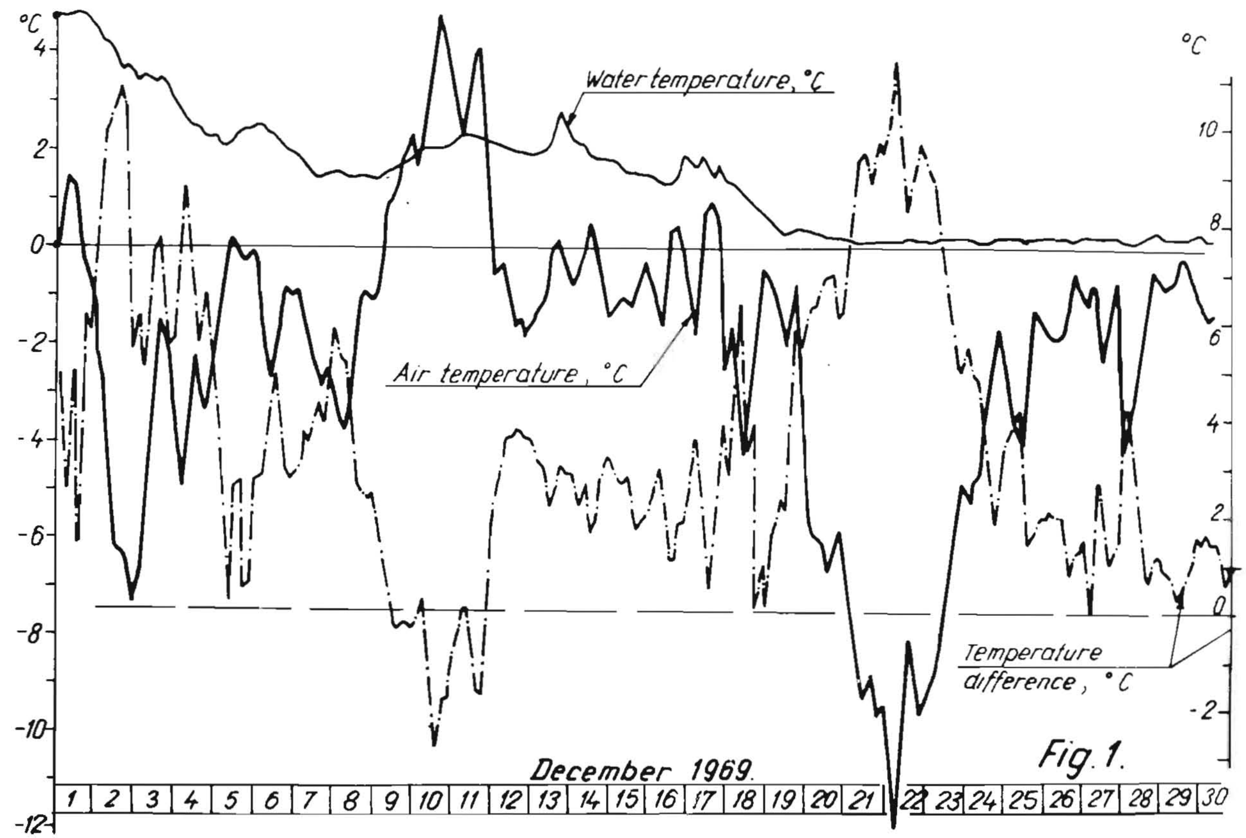
Table I.





Symbols in the Table I.

Starosolszky



°C
4
2
0
-2
-4
-6
-8
-10
-12
°C
10
8
6
4
2
0
-2
Water temperature, °C
Air temperature, °C
Temperature difference, °C
December 1969.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

Fig. 1.

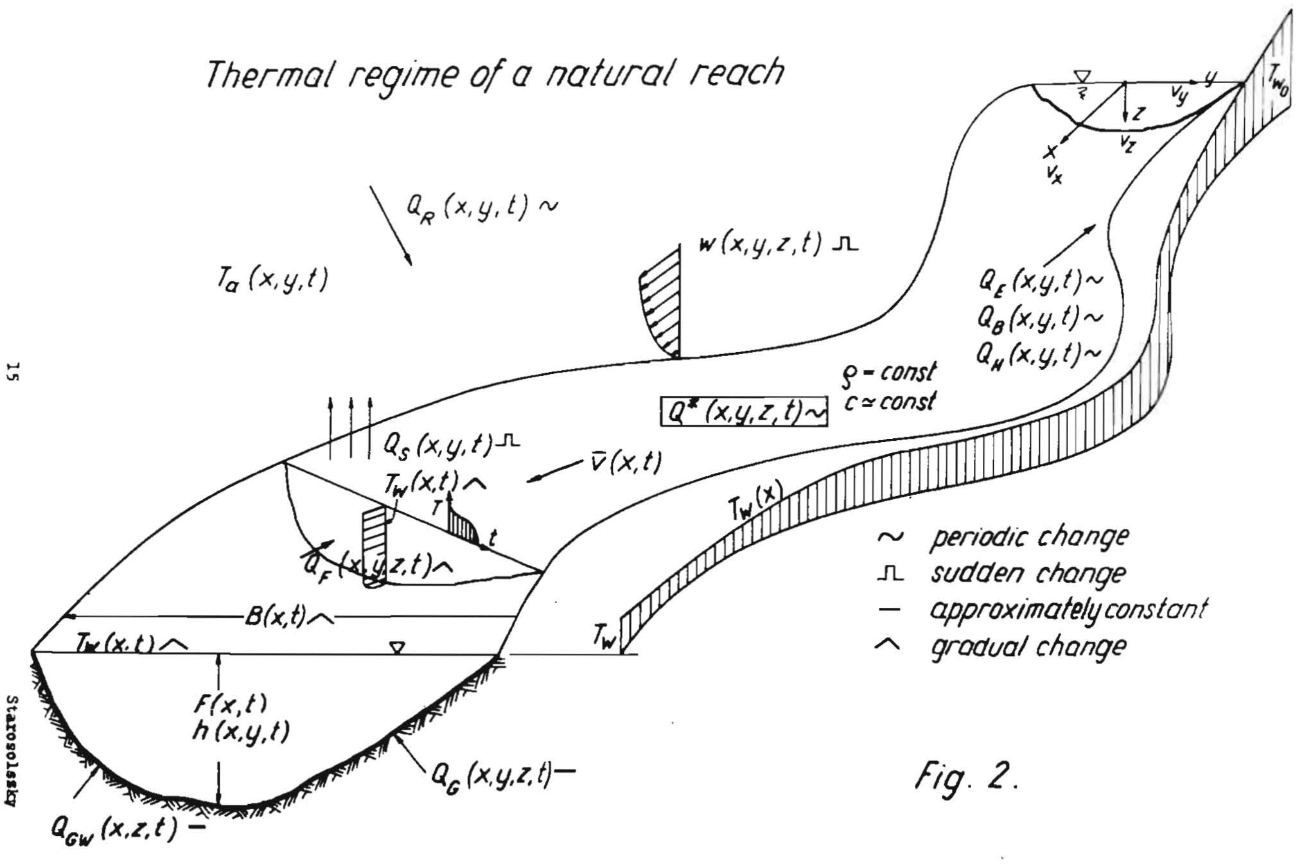

Thermal regime of a natural reach
$Q_R(x,y,t) \sim$
$T_a(x,y,t)$
$w(x,y,z,t)$ ⎍
$Q_E(x,y,t) \sim$
$Q_B(x,y,t) \sim$
$Q_H(x,y,t) \sim$
ϱ - const
$c \simeq$ const
$\boxed{Q^*(x,y,z,t) \sim}$
$Q_S(x,y,t)$ ⎍
$\bar{v}(x,t)$
$T_W(x,t) \wedge$
T
t
$Q_F(x,y,z,t) \wedge$
$T_W(x)$
T_W
T_{W_0}
$B(x,t) \wedge$
$T_W(x,t) \wedge$
$F(x,t)$
$h(x,y,t)$
$Q_G(x,y,z,t)$ —
$Q_{GW}(x,z,t)$ —
x
y
z
v_x
v_y
v_z
$\sim$ periodic change
⎍ sudden change
— approximately constant
$\wedge$ gradual change

Fig. 2.

Thermal regime of an idealized reach

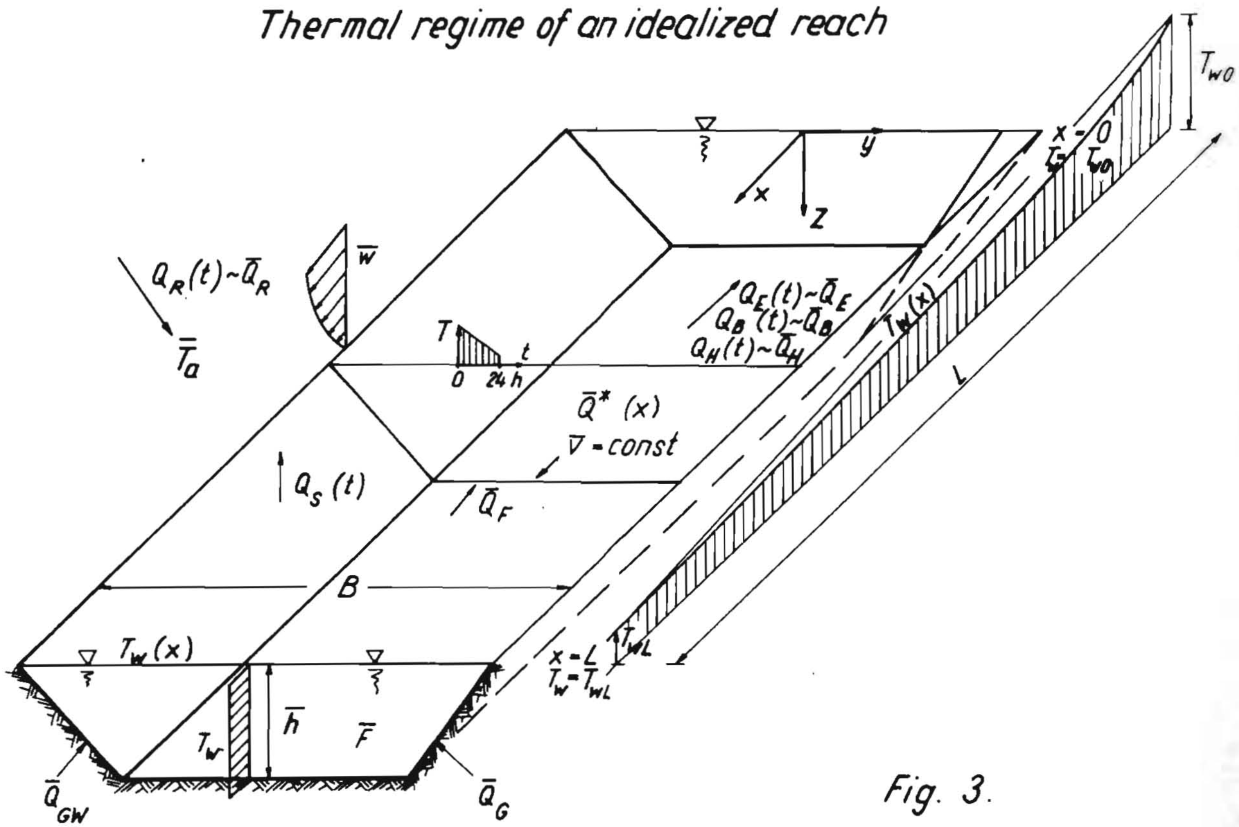


Fig. 3.

IAHR—PIANC 4

SYMPOSIUM

RIVER & ICE

Contributions to Subject A

RELATIONSHIPS OF
FLUVIAL AND ICE HYDRAULICS

Preprints

BUDAPEST 1974 HUNGARY

Economic life in the countries situated under cold and moderate climates is fundamentally influenced, especially in winter, by the ice conditions in rivers. It was this economic necessity which prompted the inhabitants of these countries to devote scientific and engineering attention to the phenomena related to ice. The knowledge afforded on ice by the natural sciences and the engineering-technical measures following therefrom, have in general resulted in consequences of economic interest.

In recent decades the volume and efficiency of information retrieval has multiplied, and international exchange of experience has gained in intensity.

Whereas simple observations and the statistical processing of the data obtained thereby have yielded results of mostly local significance, the application of model studies alone does not always permit the development of generalized conclusions. Relationships of general validity cannot be expected unless

- fundamental relations of natural science are adopted as a starting basis,
- local observations are extended to the simultaneous measurement of all relevant factors involved,
- model studies are performed on the basis of the fundamental relations and under conditions corresponding to local observations,
- the physical- mathematical models formulated can be solved under various initial and boundary counditions, and
- the validity of the relationships assumed, is verified by field observations.

To comply with the above conditions organized-coordinated research activity is required in which earlier observation data are used in combination with accurate observations performed in their majority with the help of new, advanced instruments and equipment.

The main problems in research can be outlined as follows:

Determination of a relationship of general validity suited for describing the formation of ice on the basis of observations on factors related to the development of river ice, as well as on laboratory experiments.

Determination of relationships between the morphological and hydraulic characteristics of the bed affecting the movement of ice and the formation of a solid ice cover, in the interest of predicting the formation of ice jams and of adopting the most appropriate preventive measures.

Studies on the effectiveness of measures aimed at preventing the formation of ice jams, and improvement of the effectiveness of ice jam control.

Rivers under cold and moderate climates are covered by solid or floating ice over a considerable part of the winter period. Aversion of the damages potentially caused by river ice is largely the responsibility of fluvial and hydraulic engineering and any improvement in these activities calls for a thorough understanding of the phenomena related to the formation and movement of ice. Of the variety of potential preventive measures available, the most appropriate one can be selected on the basis of engineering and economic considerations, relying on the results of detailed investigations.

The process of ice formation is controlled by the heat budget which must be studied in relation to the conditions prevailing at the surface of water courses. Studies on temperature variations may yield information on the special conditions under which an ice cover is formed, and which govern the stability of the ice cover. The thermal balance in rivers may evolve in a manner favouring the formation of slush-ice which may contribute materially to the thickness of the ice cover. On the other hand, the ice cover once formed will necessarily affect the temperature conditions in the river. All these fundamental phenomena - influenced by the ice arriving from above, and by the conditions of turbulent diffusion in the river - will necessarily affect the forecasts on ice conditions which are of great interest concerning both the formation and break-up of the ice cover over short and long time ranges alike. All these phenomena are greatly influenced by the hydrological (regime) conditions prevailing in the river.

The movement and distribution of ice in the river bed are governed by certain specific laws of hydraulics. The presence of ice is of considerable influence on stages, on the distribution of velocities and on the discharge in rivers. Thorough knowledge on this flow retarding effect is important, on the one hand concerning discharge statistics in winter, on the other hand for determining the design flood stages. A clear understanding of the physical conditions controlling the stability of the ice cover is desirable in order to decide on the method by which it can be controlled most effectively. The formation of ice jams depends on specific physical conditions, the understanding of which permits measures to be taken to reduce the hazard of ice jam floods. The break-up of ice jams is also induced by a change in the hydraulic parameters and a more detailed exploration of the relevant factors is expected to promote the artificial break-up of dangerous jams. The banks, as well as the structures situated in the bed or on the banks are exposed to pressures of considerable magnitude due to the moving and standing ice cover, the exact determination of which is of great interest to the designers.

The detailed analysis of the work performed by ice breaker vessels applied for averting the hazard of ice jam formation may lead to conclusions resulting in higher efficiency. The potential methods of destroying ice jams include the breaking, the blasting and melting of ice, but there is a need on the one hand for improving, on the other for comparing these methods.Over river sections where ice jams are liable to form, it is advisable to take appropriate preventive measures in ice-free periods by influencing artificially the channel morphology and the hydraulic conditions. Once the hydraulics of ice jam formation have been cleared as mentioned before the corresponding control structures must be evolved and the preventive measures determined for various river sections.

From the research objectives and their justification the complexity of the problem will be readily appreciated. Successful research in this broad field becomes thus extremely difficult especially in small countries, although the practical application of such results would be of peramount significance. For this reason organized or spontaneous international cooperation and the as fast as possible exchange of experiences would be essential. In view of the intellectual and material (financial) capacities available a certain international allocation of tasks is also considered desirable, the beginnings of which have been observable during the past years in this field as well.

The main achievments arrived at in Hungary thus far, may be summarized as follows:

In Hungarian hydraulic engineering practice, ice conditions primarily on the Danube and to a lesser extent on the Tisza-river were of major interest. The fundamental work of data collection, analysis and description has been performed first of all by W.Lászlóffy [1] and S.Horváth [2], whose publications in the international professional literature have disseminated the Hungarian results on the hydrology of ice. In the course of this analitical work they have arrived at a number of important conclusions and have determined relationships with meteorological conditions of great practical interest. More recently J.Csoma [3] and I. Zsuffa have considered similar problems by applying advanced mathematical statistics to them.

Experiences concerning ice cover formation during the past years have been collected primarily for the Danube by L.Knézy [4]. The work performed by the ice breaker vessels has been analysed by Gy.Bognár [5]. Ice phenomena in the vicinity of structures and the necessary preventive measures have been studied by I.Somody [6] and S.Baka [7].

The thrust and other effects exerted by ice, have been dealt with in detail by L.Török [8].

The relevant professional foreign literature has been reviewed in a comprehensive paper by Ö.Starosolszky [9] in which the thermal budget of water courses, the hydraulics of ice movement, ice pressure as well as the protection of structures from ice effects have been discussed. An interesting contribution to the knowledge on the behaviour of the ice cover and on the influence of structures has been mady by E.Zsilák [10].

Practical information available on ice control has been summarized by several authors, whose work was coordinated and edited by B.Sipos in a comprehensive manual [11].

In order to disseminate up-to-date information to engineers engaged with the ice problems in practice, the text of lectures delivered at a training course in winter 1972/73 was published by the National Water Authority.

In response to practical requirements and considering first of all the conditions prevailing in Hungary the following research subjects may be suggested:

1. Studies on the formation of river ice

1.1 The thermal budget of water courses in the range of freezing and the formation of a solid ice cover
1.2 Determination of temperature changes in water courses
1.3 The quantitative description of slush ice formation
1.4 Effect of the ice cover on temperature changes
1.5 Forecasting problems related to ice

2. Studies on the movement of river ice and on the formation of an ice cover

2.1 Laws governing the movement of slush ice
2.2 Laws governing the movement of ice floes
2.3 The effect of ice run and of the ice cover on stages, velocity distribution and discharge
2.4 Stability criteria of the ice cover
2.5 Criteria of ice jam formation
2.6 Criteria governing the break-up of ice jams
2.7 Estimation of the magnitude of ice thrust on hydrotechnical structures

3. Control and aversion of danger situations due to ice

3.1 Evaluation of the performance of ice breaker vessels in preventing ice jam formation
3.2 Improvement of methods for promoting the break up of ice jams: Ice breaking
Ice blasting
Ice melting
3.3 Engineering measures for river sections where ice jams are liable to form (general guide lines)
3.4 Program for organizational, equipment development, etc. measures for averting icedamages
3.5 Technico-economic comparison of ice breaking and preventive river regulation measures

Methods of research

In some of the subjects it is considered advisable to review the present state of knowledge in a preliminary paper founded on available experience and on the relevant literature (3.3).

In the case of some subjects it is not considered desirable to go into greater detail (2.7).

In some problems field observations are beleived necessary (1.1), (1.2), (1.4), (2.1), (2.3) and in the future the collection of experiences as well as the processing of data should be made institutional (3.1), (3.2).

Finally, a third group of subjects appears to require beyond field observations, investigations either in the field (3.3) or in the laboratory (2.2, 2.4, 2.5, 2.6), the results of which would permit conclusions to be drawn for particular locations (3.3).

The manifold character of the subjects listed in the foregoing suggests logically the idea to conduct research work on these on the basis of organized international cooperation, organized primarily by the IAHR Committee on Ice Problems.This is considered necessary in order to perform research work with the required intensity, with the hope of the desired results of general validity.

This is the idea which I could suggest as a starting basis for discussions.

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SECTION OF INLAND NAVIGATION
INTERNATIONAL SYMPOSIUM ON RIVER AND ICE
Budapest 1974 Hungary

THE MECHANICS OF RIVER ICE JAMS

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ABSTRACT

An analytical model is formulated for a two-dimensional jam of fragmented ice on a stream flowing in a uniform channel. Predictions of thickness of ice accumulation, streamwise normal stress, lateral normal stress, and shear stress are made. The governing differential equation is derived on the basis of the force equilibrium of an elemental control volume taken from a fragmented ice cover. Hypotheses are introduced concerning the nature of the force interaction between ice fragments and the resulting differential equation is integrated under two different assumptions concerning the nature of shear stress applied to the bottom of the cover by the stream flow. Finally, some laboratory data on the mechanical strength properties of fragmented floating ice covers are summarized.

SOMMAIRE

Un cadre analytique a été formulé afin de prédire les distributions d'épaisseurs d'accumulation, la force normale et la tension dans le sens du courant, la tension normale latérale et la tension tranchante, dans un blocage bi-dimentionnel de glace fragmentée sur un courant s'écoulant dans un canal uniforme. L'équation différentielle qui régit le phénomene a été dérivée en analysant l'équilibre des forces agissant sur un volume de contrôle élémentaire pris sur la couche de glace fragmentée. Des hypothèses ont été introduites concernant la nature de la force d'interaction entre les fragments de glace puis l'équation différentielle résultante a été intégrée sous deux suppositions différentes concernant la nature de la tension tranchante appliquée à la partie inférieure de la couche par le courant. Finalement, le sommaire de quelques données de laboratoire sur les propriétés de la résistance mécanique des couches de glace flottante fragmentée a été présenté.

I. Introduction

This paper is concerned with the development of an analytical model of a two-dimensional jam of fragmented ice on a stream flowing in a uniform channel. Predictions for the thickness of ice accumulation, streamwise normal stress, lateral normal stress, and shear stress are made. The governing differential equation is based on the streamwise force equilibrium of an elemental control volume taken from the fragmented cover. After introduction of hypotheses concerning the nature of the force interaction between ice fragments, the differential equation is integrated under two different assumptions concerning the nature of the shear stress applied to the bottom of the cover by the stream flow.

II. Force Equilibrium of an Ice Cover

Consider a rectangular plan-form control volume as depicted in Fig. 1, including the full thickness, t, of a fargmented ice cover. The external streamwise (x-direction) forces acting on the control volume may be summarized as follows:

a. The shear force, F_{S1}, applied to the bottom of the element by the flowing water:

$$F_{S1} = \tau_o \, dx \, dy \tag{1}$$

b. The shear force, F_{S2}, due to the gradient across the stream (in the y-direction) of the shear stress τ_{xy}:

$$F_{S2} = t \frac{\partial \tau_{xy}}{\partial y} dx \, dy \tag{2}$$

Note that t is treated as constant across the channel (i.e., independent of y).

c. The normal force, F_n, resulting from the gradient of σ_x in the streamwise direction:

$$F_n = - \frac{d}{dx} (\sigma_x t) \, dx \, dy \tag{3}$$

It should be noted that τ_{xy} and σ_x are the average values of the stresses over the thickness, t.

d. The component of the weight of the control volume in the x-direction is:

$$F_w = [t(1-p)(\rho'/\rho) + t(\rho'/\rho)p] \, \rho' g \sin\theta \, dx \, dy \tag{4}$$

where p is the porosity of the cover, ρ and ρ' are the densities of the solid and liquid phases, respectively, g is gravitational acceleration, and θ is the slope of the stream. It has been assumed that the ice cover is supported at the level of hydrostatic equilibrium. For conditions of static equilibrium, the sum of the forces given by Eqs. (1), (2), (3), and (4) must be zero, which results in:

$$\frac{d}{dx} (\sigma_x t) - t \frac{\partial}{\partial y} \tau_{xy} - \tau_o = t\rho' g \sin\theta \tag{5}$$

III. Effective-stress Relations for Fragmented Ice Covers

The fragmented ice cover will be treated as a continuum, and certain principles of noncohesive soil mechanics will be assumed to be applicable. In particular the failure values of σ_x, σ_y, and τ_{xy} will be assumed to vary linearly with the average value of the normal stress in the z-direction, $\bar{\sigma}_z$, which is produced by the weight of the fragments and is given by

$$\bar{\sigma}_z = (1/2)t\ (1-\rho'/\rho)\ (1-p)\ \rho' g \cos\theta = \gamma_e\ t \tag{6}$$

where

$$\gamma_e = (1/2)\ (1-\rho'/\rho)\ (1-p)\ \rho' g \cos\theta \tag{7}$$

is an equivalent unit weight of the cover. The linear relations between the σ_x, σ_y and $\bar{\sigma}_z$ can be written as

$$\sigma_x = k_x\ \bar{\sigma}_z \tag{8}$$

and

$$\sigma_y = k_y\ \bar{\sigma}_z \tag{9}$$

The stress ratios k_x and k_y can vary between two limits known as the Rankine active and passive values. On the basis of Mohr-Coulomb failure law, the shear stress at failure, $(\tau_{xy})_M$, may be written

$$(\tau_{xy})_M = C_i + \sigma_y \tan\phi \tag{10}$$

where C_i is the cohesion intercept and ϕ is the friction angle and is related to the passive stress coefficient by

$$k_p = (1+\sin\phi)/(1-\sin\phi) \tag{11}$$

Finally it should be pointed out that in the case of a straight prismatic channel, in which τ_o is distributed uniformly across the stream, τ_{xy} varies linearly in the y direction:

$$\tau_{xy} = -(2y/B)(\tau_{xy})_M \tag{12}$$

where B is the channel width and $(\tau_{xy})_M$ is the maximum shear stress, at the banks, and is given by Eq. (10).

Substitution of Eq. (6) into Eqs. (8) and (9) yields the normal stresses expressed in terms of the ice thickness. Combining Eqs. (10), (12), and (9), a similar expression for shear stress is obtained. Substitution of the stresses into the equilibrium equation, Eq. (5), and normalizing by setting $x_o = X/H$ and $t_o = t/H$ yields

$$t_o \frac{dt_o}{dx_o} = a + bt_o + ct_o^2 \tag{13}$$

where

$$a = \tau_o/(2k_x\gamma_e H) \tag{14}$$

$$b = (\gamma' g S_o - 2C_i/B)/(2k_x\gamma_e) \tag{15}$$

and

$$c = -(k_y/k_x)(H/B)\tan\phi \tag{16}$$

IV. Calculation of Ice Thickness Profiles

The presence of an ice cover on a stream increases the resistance to flow by lengthening the wetted perimeter of the flow section. As a result, the flow tends to deepen, and part of the discharge may then flow outside the main channel in the overbank areas. Determination of the fraction of the discharge that continues to flow beneath the ice cover is not a straightforward matter, and requires consideration of the hydrodynamic roughness of the ice cover, channel geometry, overbank topography, etc. For continuation of the present analysis, two limiting cases will be considered: constant discharge, and constant energy gradient.

A. Constant Discharge Model. Here it is assumed that the discharge under the ice cover is constant along the channel. In terms of the Darcy-Weisbach friction factor, the shear stress exerted on the cover is

$$\tau_o = (f/8)\,\rho V_u^2 \tag{17}$$

where V_u is the mean velocity at any station. The velocity V_u may be related to the velocity upstream from the cover, V, by the continuity relation, with the result

$$V_u = VH/(H - t\rho'/\rho) \tag{18}$$

where H is the depth upstream from the leading edge of the cover and t is the thickness of the cover. Substituting Eq. (18) into Eq. (17) and Eq. (17) into Eq. (14) yields

$$a = \mathbb{F}^2 f\gamma/(16k_x\gamma_e)(1 - (\rho'/\rho)t_o)^2 \tag{19}$$

where $\mathbb{F} = V/\sqrt{gh}$ is the Froude number of approach free surface flow and $\gamma = \rho g$. Equation 13 with the quantity a given by Eq. (19) is a first-order non-linear ordinary differential equation and can be solved by using fourth-order Runge-Kutta method with the leading edge condition $t_o = 0$ at $x_o = 0$. A typical set of profiles for this case is presented in Fig. 2.

It can happen that the ice cover thickens sufficiently that for each segment of the cover contained between any two planes normal to the stream axis, the shear forces exerted by the banks on the ice are adequate to balance the streamwise component of the weight of the cover and the shear drag exerted on it by the flow. In this case $\frac{dt_o}{dx_o}$ is zero in Eq. (13), which then reduces to a fourth-order polynomial in t_o. This equation can be solved numerically, to obtain the equilibrium thickness, t_e, for known values of $\mathbb{F}$, H, B, k_x and k_y.

B. Constant Energy Gradient Model. If the hydraulic gradient of the flow, rather than the discharge remains constant and if it is assumed that the channel is wide and the shear stress is equally divided between the channel bed and the underside of the ice cover, then the hydraulic radius, R, of the flow section is

$$R = h/2 = [H-(\rho'/\rho)t]/2 \tag{20}$$

The expression for the shear stress then may be written

$$\tau_o = \rho g\, R \sin\theta = (1/2)\,\rho g[H - (\rho'/\rho)t] \sin\theta \tag{21}$$

A procedure suggested by Carey [1] can also be used to calculate the hydraulic radius of the portion of the flow section for which the streamwise garvity force is balanced by the shear stress on the cover, and therefrom τ_o. Introducing Eq. (21) into Eq. (14) leads to

$$t_o \frac{dt_o}{dx_o} = a' + b't_o + c't_o^{\,2} \qquad (22)$$

where

$$a' = \frac{1}{4}\frac{\gamma}{\gamma_e}\frac{\sin\theta}{k_x};\; b' = \frac{1}{2k_x\gamma_e}\left(\frac{\gamma' S_o}{2} - \frac{2C_i}{B}\right);\; c' = -\frac{k_y}{k_x}\frac{H}{B}\tan\theta \qquad (23)$$

Integrating Eq. (22) with the boundary conditions $t_o = 0$ at $x_o = 0$ yields

$$x_o = \frac{1}{2c'}\ln\left(\frac{a' + b't_o + c't_o}{a'}\right) - \frac{b'}{2c'\sqrt{-q}}\ln\frac{(2c't_o + b' - \sqrt{-q})}{(2c't_o + b' + \sqrt{-q})}\frac{(b' + \sqrt{-q})}{(b' - \sqrt{-q})} \qquad (24)$$

where $q = 4a'c' - b'^2$, which is always negative. Profiles calculated from Eq. (24) are shown in Fig. 3. The equilibrium value of t_o, denoted by t_e, is obtained by deleting the derivative term from Eq. (22) and solving the resulting quadratic euqation; this yields

$$t_e = (-b' - \sqrt{b'^2 - 4a'c'})/2c' \qquad (25)$$

V. Experimental Determination of Mechanical Properties of Floating Ice.

For the quantification of the stress coefficients, k_x and k_y, defined by Eqs. (8) and (9), two types of experiments were conducted in the Institute's Ice Force Facility (see Fig. 4), and one-foot wide glass-walled flume.

The tests for k_x were run in the Ice Force Facility by compressing a fragmented ice cover,with a rigid plate mounted on the motor driven carriage through a dynamometer equipped with a strain-gage force transducer (Fig. 4). The force applied to the plate by the ice cover was recorded by the dynograph while the carriage was in motion. In these tests it was observed that the force applied to the cover increased gradually until failure was reached. The failure point was utilized in the calculations to determine k_x. Considerable variation in the results was observed between nominally identical experiments, presumably due to variations in the ice-fragment contacts which in turn were due to different arrangement of ice particles. Each experiment was repeated ten or more times and the average failure force was used in the calculations.

The force exerted on the plate can be written

$$F = \sigma_x t_c W \qquad (26)$$

where σ_x is the streamwise stress as defined by Eq. (8), W is the width of the tank, and t_c and p are the thickness and porosity, respectively, of the fragmented cover. Substituting Eqs. (8) and (6) into Eq. (26) and solving for k_x yields

$$k_x = F/0.5\rho' g\,(1 - \rho'/\rho)(1 - p)t_c^2 W \qquad (27)$$

The results of the experiments are presented in Fig. 5, where d_e is given by

$$d_e = \frac{\bar{b}}{\bar{d}} \left(\frac{\bar{b} + \bar{d}}{2} \right) \tag{28}$$

where $\bar{d}$ and $\bar{b}$ are, respectively, the average of the longest plan dimension and the one perpendicular to it. The symbols in Fig. 4 are summarized in Table 1.

$\frac{L}{t_c}$	p	symbol	t_i	Block Size $\bar{b}$ (in)	Block Size $\bar{d}$
10	0.485	○	0.75	4.47	6.28
20	0.485	⊖	0.75	4.47	6.28
30	0.485	●	0.75	4.47	6.28
20	0.478	▽	1.00	5.88	8.10
30	0.478	▼	1.00	5.88	8.10
40	0.478	⩡	1.00	5.88	8.10

For determination of the lateral stress coefficient, k_y, shear experiments similar to the direct shear tests used in soil mechanics were conducted in the one-foot wide glass wall flume, except that they were made with floating materials (with specific gravities close to that of ice) contained between a horizontally moving shear apparatus. The force required to shear a fragmented cover, with the cohesion intercept $C_i = 0$, can be written

$$T = \tau_{xy}\, t_c\, L_s \tag{29}$$

where τ_{xy} is the shear stress as defined by Eq. (10), L_s is the length of cover, and t_c and p are the thickness and the porosity of the material, respectively. Substituting Eqs. (6) and (9) into Eq. (10) and then into Eq. (29) and dividing by W_s^2 yields

$$F_s = \frac{T}{\rho' g L_s W_s^2} = k_y \tan\phi \left[\frac{1}{2}\left(1 - \frac{\rho'}{\rho}\right)(1-p)\right] \left(\frac{t_c}{W}\right)^2 \tag{30}$$

where W_s is the width of the flume. Letting

$$\eta = k_y \tan\phi, \text{ and } t_s = \left[\frac{1}{2}\left(1 - \frac{\rho'}{\rho}\right)(1-p)\right]^{\frac{1}{2}} \frac{t_c}{W_s} \tag{31}$$

in Eq. (30) results in

$$F_s = \eta\, t_s^{\,2} \tag{32}$$

The results of the experiments and the best fit parabolas to the data points are presented in Fig. 6.

VI. Concluding Remarks

The research program which produced the results reported herein still is in progress at the time (1973) of this writing, and it remains to be seen if the principal results, notably the relations for the strength of the ice cover in compression and in shear, Eqs. (27) and (32), and the predictions of the streamwise distribution of ice thickness, typical examples of which are given in Figs. 2 and 3, prove to be reliable. If these results are verified for uniform channels, the next logical step would appear to be application of this type of analysis to meandering channels.

A complete analysis of an ice jam in a river must include consideration of the whole flow-ice-river channel system. Specifically, for a fixed quantity of ice coming to rest in a channel to form a jam, one should calculate the added resistance it will offer to the flow, the corresponding rise in the water surface and the overbank flow this produces, the thickness distribution of the ice, and the interaction among these. This would involve, no doubt, calculation of the evaluation of the ice jam with time using a computer based simulation of the jamming process. The analysis developed herein would appear to provide one of the key components of such a simulation.

Acknowledgments

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VII. References

1. Carey, K.L., 1966, "Observed Configuration and Computed Roughness of the Underside of River Ice, St. Croix River, Wisconsin," *U.S. Geological Survey, Prof. Paper 550-R,* pp. B192-B198.

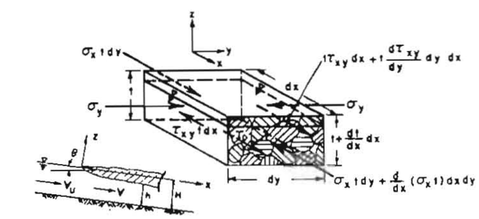

Figure 1. Definition sketch for analysis
Figure explicatrice

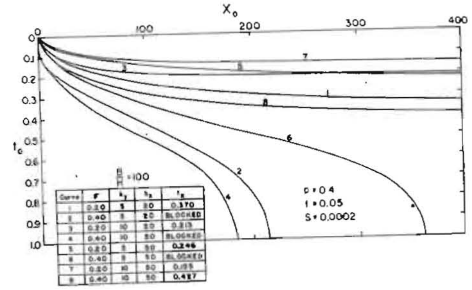

Figure 2. Normalized ice thickness profiles for constant discharge case
Profiles normalizés dépaisseurs de glace pour le cas de debit constant

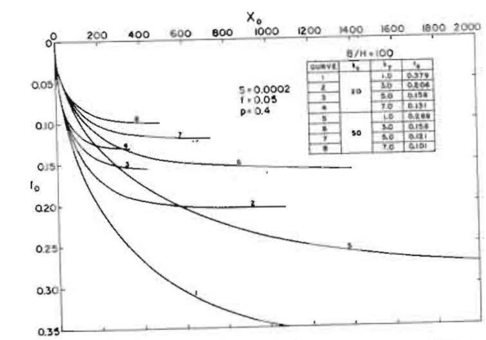

Figure 3. Normalized ice thickness profiles for constant energy gradient case
Profiles normalizés dépaisseurs de glace pour le cas de gradient dénergie constant

Figure 4. Photo of apparatus used in k_x experiments
Photografie de l'appareil usé dens les expériences de k_x

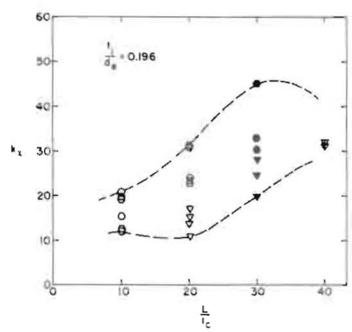

Figure 5. Typical results of compression tests
Résultats typiques des essais de compression

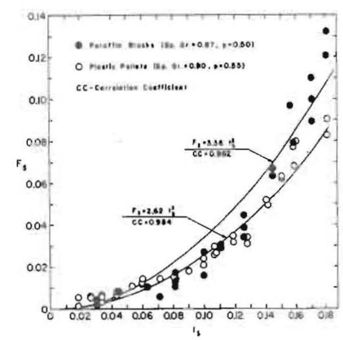

Figure 6. Summary of shear force tests
Résumé des essais de force tranchante

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KINEMATICS OF FLOW UNDER THE ICE COVER

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ABSTRACT

Presented are experimental and theoretical research findings on the kinematics of flow under the ice cover. Formulae are derived to determine flow velocities, discharge, the position of the maximum velocity plane, and eddy diffusivity of momentum. The kinematic parameters of the flow appear to be governed by the absolute values of ice cover and bottom roughness, and not by their ratio as it was supposed earlier.

SOMMAIRE

Le rapport traite les résultats des recherches experimentales et théoriques sur le régime cinématique des écoulements sous la couverture de glace. Sont données les formules de calcul des vitesses d'écoulement, du débit, de la position du plan de la vitesse maximale, ainsi que des coefficients d'échange turbulente. On souligne que les caractéristiques cinématiques des écoulements sous glace dépendent des valeurs absolues de la rugosité de la couverture de glace et du fond, et non pas de leur relation, comme on a supposé auparavant.

As distinct from open channel flow, the flow under the ice cover possesses an additional boundary (i.e. ice) with a roughness differing from that of the rest of the wetted perimeter. Besides, the presence of the ice cover creates closed surface conditions. Similar flow conditions occur in pipes and flumes with roughness varying along the perimeter.

The vertical velocity profile is asymmetrical (Fig. 1). In case an autumn ice run precedes the formation of the ice cover, the roughness of the underside of the ice cover exceeds that of the bottom, and the plane of maximum velocities (h_1) is shifted downward from the centre of the vertical. Provided no ice run takes place before the final freeze-up, the underside of the ice cover is relatively smooth, then the velocity maximum moves into the upper portion of the flow. With the ice thickness increasing, the ice cover roughness diminishes, hence h_1 is liable to move upwards during the winter.

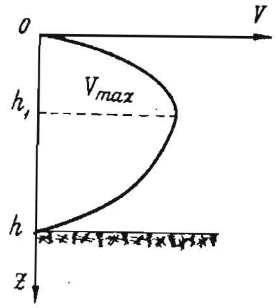

Fig. 1. Diagram of flow velocities distribution under the ice cover

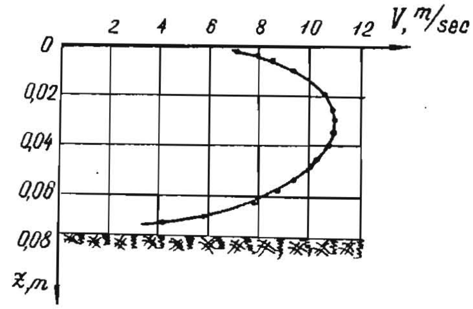

Fig. 2. Experimental profile of flow velocities (h = 7.6 cm; $\mathcal{Y}$ = 1.54; n_1 = 0.0117; n_2 = 0.0181)

N.N. Pavlovsky [1931] was one of the first investigators to study the kinematics of flow under the ice cover. Proceeding from the principle of the maximum discharge capacity of the channel, he derived formulae to evaluate the average velocities and the flow rate. Pavlovsky suggested Chezy's well-known equation for use in routine computations in engineering practice after incorporating into it the average roughness coefficient ($\bar{n}$) dependent on the ratio between the ice cover and bottom roughness.

A similar approach to the problem of flow under the ice cover is to be found in the work of G.K. Lotter [1938, 1941], A.A. Sabaneev [1948], I.D. Denisenko [1963], V.B. Dul'nev [1962] et al.

In the above studies the water body is assumed to be divided vertically into two zones. There appears to be a marked difference of opinion as to the proper location of the boundary between them. Some authors, viz. Pavlovsky, Lotter, Dul'nev et al. consider that the cross-section should be divided proportionally to the parts of the wetted perimeter, others, namely, P.N. Belokon' [1940], I.M. Konovalov [1952], U.S. Ros' [1965] assert that it should coincide with the plane of maximum velocities. Hydraulic calculations of each zone are based on Chezy's equation which was originally derived for the case of a uniform free surface flow obeying the quadratic law.

I.I. Levi [1948] and K.V. Grishanin - F.A. Spetsov [1968] applied the well-known equations of the semi-empirical theory of the boundary layer to compute the flow under the ice cover. The vertical distribution of averaged velocities was found to conform to the logarithmic law.

M.Ya. Gil'denblat evolved a four-layer model for the flow under the ice cover by dividing each zone into a wall region and the main stream. A velocity profile may be plotted on the basis of the expression for linear distribution across the depth of shearing stresses due to friction, the eddy diffusivity of momentum being assumed to vary linearly in the wall regions, while that in the main stream was taken to be constant.

Without analysing in detail the relationships employed in the calculations one should emphasize that in many cases they yield markedly discrepant results. Common to all the studies listed above is the division of the flow under the ice cover into two independent zones whose kinematic conditions are affected only by the surface adjacent to them. In other words, when the absolute values of ice cover and bottom roughness differ, but the ratio between them is the same, the flow velocities and the other kinematic parameters should be equal. However this conclusion is not born out by the data from a special laboratory test program outlined below.

The experimental rig consists of a wind flume 400 cm long, 43.5 cm wide, and 8 cm high with bottom and roof made of glass and wooden walls. The air supplied to the contraction is ejected by a fan after passing through the flume. The contraction and the first 50 cm of the flume are equipped with deflectors ensuring a uniform velocity distribution across the width of the flume. The effect of the flume walls was noticeable up to no more than 5 cm from each wall. Flow velocities were measured by a Pitot-static airspeed tube; piezometers were mounted in the walls of the flume to obtain the piezometric slope line.

Tests were conducted at 6 different roughness values for the upper and lower glass surfaces, as well as for surfaces formed of sand and gravel with grain diameters of 0.5, 1.5, 3.5, 5.5, and 14 mm. 30 tests were run with various surface linings and 6 with identical ones.

The latter permitted to evaluate the boundary roughness coefficients: for glass n is 0.0089, for grain sizes of 0.5 mm, 1.5 mm, 3.5 mm, 5.5 mm and 14 mm n is 0.0117, 0.0137, 0.0153, 0.0118 and 0.0222, respectively.

Of vital importance in processing experimental findings is the choice of the computing origin for the absolute roughness and the depth of the flow.

There appears to be a wide divergence in the opinions of individual investigators concerning the problem. Thus according to M.M. Ovchinnikov [1965] the average height of the roughness elements on the bottom, Δ, is $0.645d$, where d is the mean grain diameter, after A.N. Rakhmanov 1968 Δ is $0.672\,d$; V.N. Goncharov 1962 and S.Ya. Muchnik 19 accepted $\Delta = (0.5 \div 0.7)\,d$.

In our calculations Δ is equal $0.5\,d$. In determining the plane of reference for depth (the so-called hydraulic bottom) one should bear in mind that with a flow passing over a rough bottom, vortex zones are formed between the roughness elements where the motion of water becomes mainly rotational. Hence the plain of reference should be located somewhat lower than the peaks of the roughness elements. Some researchers selected a plane of reference $(0.05 \div 0.12)\,d$ below the peaks of the roughness elements. The problem stands in need of further elucidation. It should be noted, however, that calculation of flow in rough channels remains valid irrespective of the position of the plane of reference, when chosen within reasonable limits, relative to the peaks of the roughness elements. Afterwards all the hydraulic flow parameters are to be referred to the chosen depth reference plane. Herein in reducing the experimental data the position of the reference plane was assumed to be $0.25\,d$ below the peaks of the roughness elements. The tests indicated that the discrepancy between the roughness coefficients evaluated with the depth reference plane either at $0.26\,d$ or at $0.05\,d$ below the peaks of the roughness elements amounted only to 4.5% for gravel with grain size of 14 mm, while for grains with d = 5.5 mm it is, practically, absent. Hence the depth of the flow was determined during the tests as:

$$h = H + 0.5\,(r_1 + r_2) \qquad (1)$$

where H is the spacing between the roughness elements; r_1 and r_2 are radii of the roughness elements at the roof and at bottom, respectively.

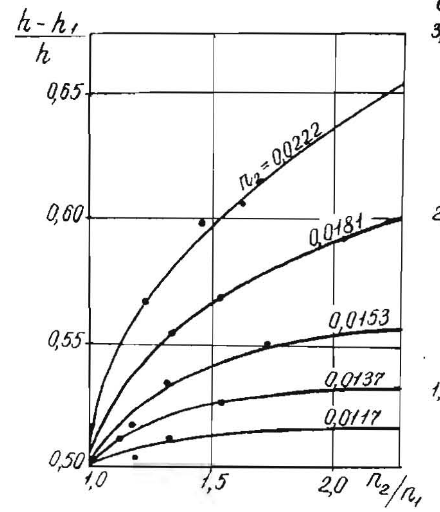

Fig. 3. Position of maximum velocity point

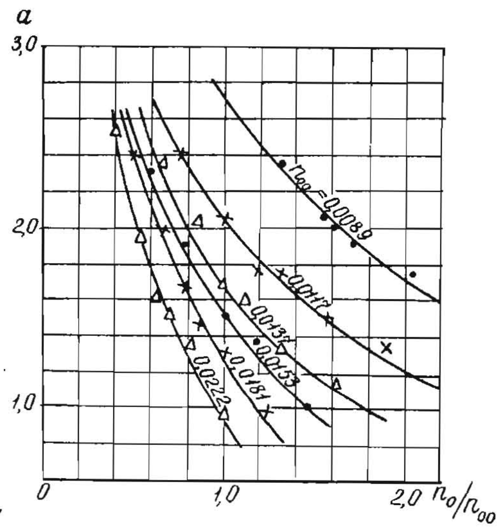

Fig. 4. Relation $a_i = f(n_1, n_2)$

Vertical velocity profiles for two test runs are shown in Fig. 2 and the point of maximum velocity in Fig. 3. The kinematic parameters of flow between boundaries described by different roughness coefficients are seen to depend solely on the absolute values of roughness and not on the ratio between the surface and bottom roughness. Though contradicting the results obtained by other researchers, the conclusion is far from being unexpected. A similar effect of boundary conditions on the regime within certain systems has been recorded in a number of fields of science. E.g. the theory of heat transfer recognizes that the thermal regime of a body is governed by the absolute values of surface heat transfer coefficients, but not by their ratio.

Let us pass on to the analysis of the kinematics of flows under the ice cover. Let the origin of coordinates be placed on the ice cover surface and the normal x -axis is directed downward. Assuming the motion to be uniform and steady, the equations for the upper ($x \leq h_1$), and lower ($x \geq h_1$) zones of the flow may be written as

$$A_i \frac{d^2 v_i}{d x^2} + g \rho J = 0 \qquad (2)$$

Here i is 1 and 2 (the values with subscript 1 referring to the upper flow zone, and those with subscript 2 to the lower one);

v_i is mean velocity;

$\mathcal{A}_i$ is the eddy diffusivity of momentum (viscosity);

$\mathcal{Y}$ is the slope;

g is gravity acceleration;

ρ is density of water.

The solid boundary conditions may be described by

$$v_1 \Big|_{z=0} = L_1 \frac{d v_1}{d z}\Big|_{z=0}, \qquad (3)$$

$$v_2 \Big|_{z=h} = L_2 \frac{d v_2}{d z}\Big|_{z=h} \qquad (4)$$

The L_i are given as

$$L_1 = a_1 h_1 \quad and \quad L_2 = a_2 (h - h_1). \qquad (5)$$

where a_i is an empirical value defined below from experimental data.

In the $z = h_1$, plane the following conditions must be satisfied

$$\frac{d v_1}{d z}\Big|_{z=h_1} = \frac{d v_2}{d z}\Big|_{z=h_2} = 0. \qquad (6)$$

$$v_1 \Big|_{z=h_1} = v_2 \Big|_{z=h_1} \qquad (7)$$

$\mathcal{A}_i$ in Eq(2) represents the mean value of the turbulent exchange coefficient within each region, i.e.

$$\mathcal{A}_1 = \frac{1}{h_1}\int_0^{h_1} \mathcal{A}_1(z)\,dz \quad and \quad \mathcal{A}_2 = \frac{1}{h-h_1}\int_{h_1}^{h} \mathcal{A}_2(z)\,dz. \qquad (8)$$

The Prandtl-Karman formula which is extensively used for the solution of various problems of fluid-mechanics is applied to determine

$$\mathcal{A} = \frac{(|dv/dz|)^3}{(|d^2v/dz^2|)^2}, \qquad (9)$$

It should be pointed out that a similar approach can be found in the work of V.M. Makkaveev [1940] , A.V. Karaushev [1961].

However the results obtained stand in need of further refinement on the ground that the $\mathcal{A}$ coefficient was assumed constant across the depth and was computed from the expression $\mathcal{A} = \frac{\gamma q}{2 m C_2}$ derived for free surface flow where γ is the specific weight of water; q is the water discharge; C_2 is the Chezy coefficient for the bottom; $m = 22.3\ m^{0.5}/sec$. Besides, the values of a were established by Basaine's empirical formula for vertical velocity distribution in free surface flows.

By integrating Eq.(2) including the conditions of Eqs (3)-(7) as well as (8) and (9) after some transformations the following relationships can be obtained for flow velocities, the position of maximum velocity and coefficients of turbulent exchange:

$$v_1 = \frac{g\rho\mathcal{Y}}{\mathcal{A}_1}\left[z\left(h_1 - \frac{z}{2}\right) + L_1 h_1 \right]; \qquad (10)$$

$$v_2 = \frac{g\rho\mathcal{Y}}{\mathcal{A}_2}\left[z\left(h_1 - \frac{z}{2}\right) - h_1\left(h_1 - \frac{h}{2}\right) + L_2(h - h_1) \right]; \qquad (11)$$

$$h_1 = \frac{-[L_1 + \kappa(h - L_2)] \pm \sqrt{[L_1 + \kappa(h - L_2)]^2 + (1-\kappa)\kappa h(h + 2L_2)}}{1 - \kappa} \tag{12}$$

$$\mathcal{A}_1 = 0{,}4\rho\varkappa h_1 \sqrt{gJh_1}\,; \tag{13}$$

$$\mathcal{A}_2 = 0{,}4\rho\varkappa(h - h_1)\sqrt{gJ(h - h_1)}\,; \tag{14}$$

$$\kappa = \frac{\mathcal{A}_1}{\mathcal{A}_2} = \left(\frac{h}{h - h_1}\right)^{3/2}. \tag{15}$$

Introducing the symbols

$$\eta = \frac{x}{h}\,; \quad \eta_0 = \frac{h_1}{h}\,; \quad V_0 = \sqrt{gJh}\,; \quad \mathcal{A}_0 = \rho h V_0\,; \tag{16}$$

then

$$\tilde{V}_i = \frac{V_i}{V_0} = \frac{1}{0{,}8\varkappa\eta_0\sqrt{\eta_0}}\left[\eta(2\eta_0 - \eta) + 2a_i\eta_0^2\right]; \tag{17}$$

$$\tilde{\mathcal{A}}_i = \frac{\mathcal{A}_i}{\mathcal{A}} = 0{,}4\varkappa\eta_0\sqrt{\eta_0}\,; \tag{18}$$

$$\kappa = \left(\frac{\eta_0}{1 - \eta_0}\right)^{3/2}. \tag{19}$$

$\eta' = 1 - \frac{x}{h}$ and $\eta_0' = 1 - \frac{h_1}{h}$ must be substituted in Eqs (17) and (18) for η and η_0 when computing V_2 and $\mathcal{A}_2$.

From a simultaneous solution to Eqs (12) and (15) the position of the maximum velocity is

$$\eta_0 = \frac{1}{b^2 + 1}\,, \tag{20}$$

in which

$$b = \frac{2a_1 + 1}{2a_2 + 1}. \tag{21}$$

The water discharge relation is

$$\tilde{q} = \frac{q}{V_0 h} = \int_0^{\eta_0} \tilde{V}_1\, d\eta + \int_{\eta_0}^{1} \tilde{V}_2\, d\eta = \frac{1}{0{,}4\varkappa}\left(\frac{a_1 + \frac{1}{3}}{\sqrt{\eta_0}} + \frac{a_2 + \frac{1}{3}}{\sqrt{1 - \eta_0}}\right). \tag{22}$$

The laboratory findings described above may be used to estimate the a_i value incorporated into Eqs (17)-(22). a_i values are obtained by Eq (17) in which all the terms except a_1 and a_2 are found experimentally. In the calculation results presented (Fig. 4) the roughness coefficient of the boundary adjacent to the layer is designated by n_0, while n_{00} stands for the roughness coefficient of the opposite boundary. The data plotted in Fig. 4 are approximated by

$$a_i = \ln\left[870\, n_0^{-1,87}\left(\frac{n_0}{n_{00}}\right)^{-1,52}\right]. \tag{23}$$

Substituting Δ_i for n_i we have

$$a_i = \ln\left[9{,}5\,\Delta_{00}^{-0,312}\left(\frac{\Delta_0}{\Delta_{00}}\right)^{-0,255}\right]. \tag{24}$$

In Fig. 5 the a_i values obtained are represented as a function of the V_{*i} / V_{max} ratio, in which V_{*i} is the dynamic velocity of the upper and lower flow layers, respectively. The same figure shows the calculated values of a_i based on F.A. Spetsov's field observations. Experimental and field data appear to be in very good agreement. The relationship represented in Fig. 5 is described by

$$a_i = 0.054\left(\frac{V_{*i}}{V_{max}}\right)^{-1.3} . \qquad (25)$$

On condition that the values of n_i and Δ_i are known, Eqs (23) and (24) yield the values of a_i. In case n_i and Δ_i are unknown, a_i can be evaluated by Eq (25) provided h, and V_{max} are predetermined. The ratio V_{*i} / V_{max} may be defined as

$$\frac{V_{*i}}{V_{max}} = 3.15\, \bar{n}^{\,0.9}$$

based on the outlined experimental findings. Given the n_1 and n_2 values, $\bar{n}$ may be calculated, for instance, from Pavlovsky's formula.

The formulae (17) -(23) given above together with the relationships (23) -(25) permit to obtain a full solution to the problem of calculating the kinematics of flow under the ice cover.

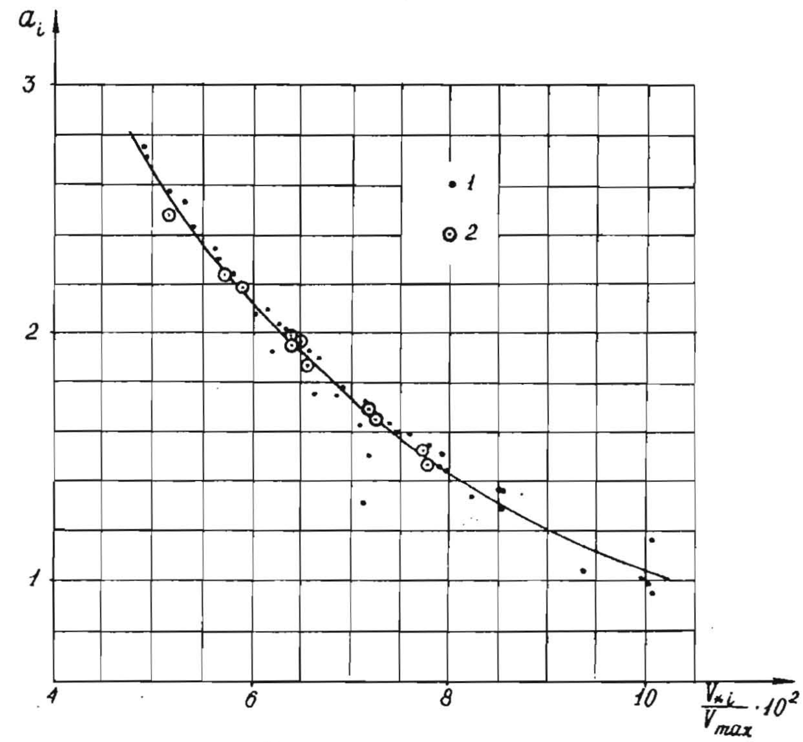

Fig. 5. Relation $a_i = \varphi\left(\frac{V_{*i}}{V_{max}}\right)$; (1 - experimental data; 2 - field data)

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AN APPROACH TO EVALUATING THE INSTABILITY OF LONGITUDINAL RIVER-BED VARIATIONS

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ABSTRACT

A procedure is presented for evaluating the instability of longitudinal river-bed variations. The rate of river-bed variation is obtained from the equation of continuity for sediment transport and a sediment transport formula. A numerical example is presented to illustrate the computation procedure and an evaluation of the instability of longitudinal river-bed variations.

SOMMAIRE

Une méthode est proposée pour l'évaluation de l'instabilité des variations du lit de rivière longitudinales. Le taux de variation du lit de rivière est obtenu par l'équation de continuité pour le sédiment et par une formule du sédiment. Un exemplaire numérique est presenté pour illustrer la méthode de computation et l'évaluation de l'instabilité des variations du lit de rivière longitudinales.

INTRODUCTION

Longitudinal river-bed variations are usually induced by runoff regulations of reservoir operations, and by inflows from tributaries and outflows to diversion channels. For inland river navigation, it is important to maintain the depth of flow in waterways. Therefore, it is considered that the stability of longitudinal river-bed variations is essential to river navigation. From this point of view, an approach to evaluating the instability of longitudinal river-bed variations is presented in this paper.

BASIC EQUATIONS FOR CALCULATING THE RATE OF RIVER-BED VARIATION

By taking the x-axis in the downstream direction along the river-bed, and letting Z be the river-bed elevation measured from a datum surface, then for the rectangular cross section of width B, the equation of continuity for sediment transport is

$$\frac{\partial Z}{\partial t} + \frac{1}{B(1-\lambda)} \frac{\partial (q_T B)}{\partial x} = \pm \frac{q_{io}}{B} \qquad (1)$$

in which t = time, λ = the porosity of the bed material, q_T = the rate of sediment transport including suspended sediment in volume of material per unit time and unit width, and q_{io} = the sediment inflow or sediment outflow per unit time and unit width (the sign + indicates the sediment inflow, and the sign - refers to the sediment outflow). From the above equation, the rate of river-bed variation, $\partial Z/\partial t$, can be expressed as

$$\frac{\partial Z}{\partial t} = - \frac{1}{(1-\lambda)} \frac{\partial q_T}{\partial x} - \frac{q_T}{B(1-\lambda)} \frac{\partial B}{\partial x} \pm \frac{1}{B} \frac{\partial Q_{io}}{\partial x} \qquad (2)$$

in which Q_{io} = the total sediment inflow per unit time or total sediment outflow per unit time, and $\partial Q_{io}/\partial x = q_{io}$.

As to the equation of sediment transport, the Sato-Kikkawa-Ashida formula[1)] is used:

$$\frac{q_B}{U_* d} = \frac{\phi(n)\ F(\tau_o/\tau_c)\ U_*^2}{[(\sigma/\rho) - 1]\ g\ d} \qquad (3a)$$

in which q_B = the rate of sediment transport(bed load) in volume of bed material per unit time and unit width; U_* = the friction velocity; d = the mean diameter of the bed material; g = the acceleration of gravity; σ and ρ = the densities of sediment particles and water, respectively; τ_o and τ_c = the shear stress and critical shear stress, respectively; $F(\tau_o/\tau_c)$ = a function of τ_o/τ_c as shown in Fig. 1; and $\phi(n)$ = a function of Manning's roughness coefficient n. The value of $\phi(n)$ can be obtained from the following equations:

$$\phi(n) = 0.623 \quad \text{for} \quad n \geq 0.025 \qquad (4a)$$

$$\phi(n) = 0.623(40n)^{-3.5} \quad \text{for} \quad n < 0.025 \qquad (4b)$$

From Eq. 3a, the rate of sediment transport is

$$q_B = \frac{\phi(n)\ F(\tau_o/\tau_c)\ U_*^3}{[(\sigma/\rho) - 1]g} \qquad (3b)$$

In this paper, the rate of sediment transport, q_B, is used instead of q_T (i. e. the suspended sediment is not included in the analysis of river-bed variations).

APPLICATION TO AN EXISTING RIVER

Description of River.— As a numerical example, the lower Tenryu River is used. The Tenryu River flows through Hamamatsu City, Shizuoka Prefecture, Japan, and flows into the Pacific Ocean. This river has a drainage area of 5095 square kilometers, and the length of the river is 213.7 kilometers. Mean river-bed slope in the lower Tenryu River is about 0.001. Fig. 2 shows the plan view of a study reach in the lower Tenryu River. Longitudinal river-bed profiles and the longitudinal variation of water surface width are shown in Figs. 3 and 4, respectively. Fig. 5 indicates the longitudinal distribution of mean grain size of the bed material.

Computed Results and Evaluation.— Taking $\Delta x = 200$ meters, and using Eqs. 2, 3b, 4a and 4b, the values of $\Delta Z/\Delta t$ at each section were computed for $Q = 4500$ m^3/sec, 7000 m^3/sec, and 11130 m^3/sec. Figs. 6, 7, and 8 show the longitudinal variations of $\Delta q_B/\Delta x$ for $Q = 4500$ m^3/sec, 7000 m^3/sec, and 11130 m^3/sec, respectively. The longitudinal variation of $\Delta B/\Delta x$ is also shown in Fig. 9. Final results on the longitudinal variations of $\Delta Z/\Delta t$ for $Q = 4500$ m^3/sec, 7000 m^3/sec and 11130 m^3/sec are shown in Figs. 10, 11, and 12, respectively. For comparison purpose, the longitudinal variations of the observed minimum river-bed elevation are shown in Fig. 13. Observations for the minimum river-bed elevation were conducted in 1960, 1962, 1964, 1966, and 1968 by the Hamamatsu Office of Construction Works, the Ministry of Construction, Japan. In Fig. 13, the reference year was taken in 1958. This figure was reproduced from the reference 2. From Figs. 10, 11, and 12, it can be seen that the longitudinal variation of $\Delta Z/\Delta t$ in a reach of 19 through 24 kilometers is very high. Accordingly, the river-bed in this reach(19 $\sim$ 24 kilometers from the river mouth) is considered to be unstable. By comparing Figs. 10 through 12 with Fig. 13, it was found that tendencies of aggradation-degradation are very similar. Therefore, the instability of longitudinal river-bed variations can be inferred from the figure of $\Delta Z/\Delta t$.

CONCLUSIONS

The conclusions obtained from this investigation are as follows:

(1) The instability of longitudinal river-bed variations, and aggradation-degradation tendencies can be inferred from the figures on the longitudinal variations of $\Delta Z/\Delta t$.

(2) For a reach which has a very high fluctuation of $\Delta Z/\Delta t$, the fluctuation range of $\Delta Z/\Delta t$ should be narrowed by river-course rectification works. Following this direction, a stable river-bed for river navigation would be obtained.

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2. "Report of River-Course Design of the Tenryu River," Hamamatsu Office of Construction Works, the Ministry of Construction, Hamamatsu City, Shizuoka Prefecture, Japan, March, 1971, 332 pp, (in Japanese).

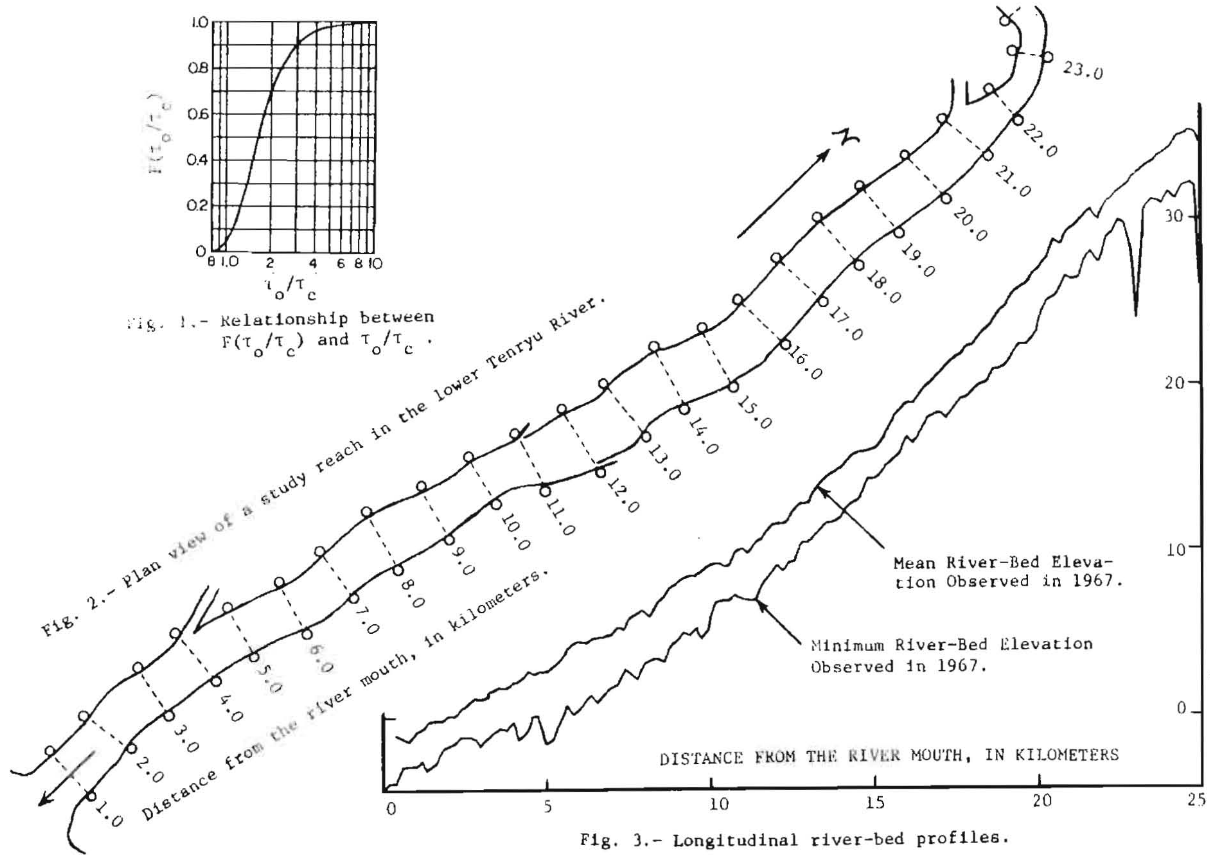

Fig. 1.- Relationship between $F(\tau_o/\tau_c)$ and τ_o/τ_c .

Fig. 2.- Plan view of a study reach in the lower Tenryu River.

Fig. 3.- Longitudinal river-bed profiles.

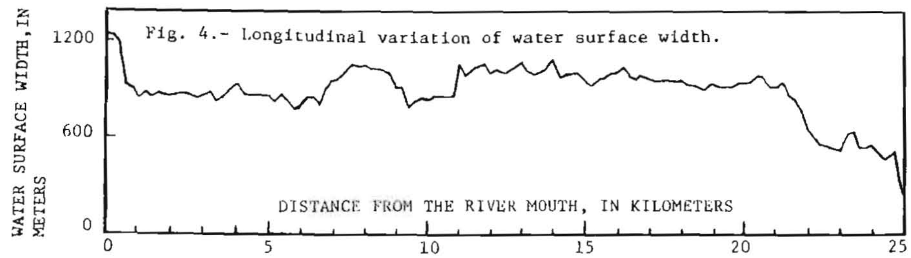

Fig. 4.- Longitudinal variation of water surface width.

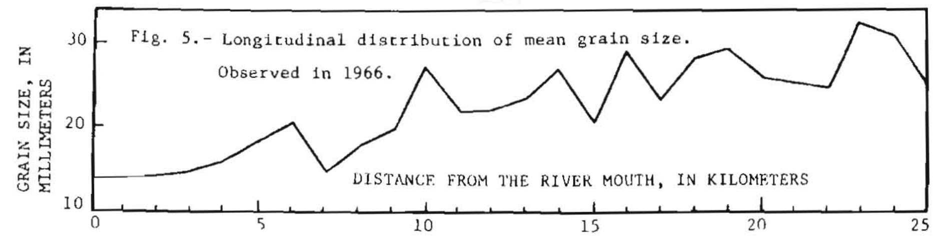

Fig. 5.- Longitudinal distribution of mean grain size.

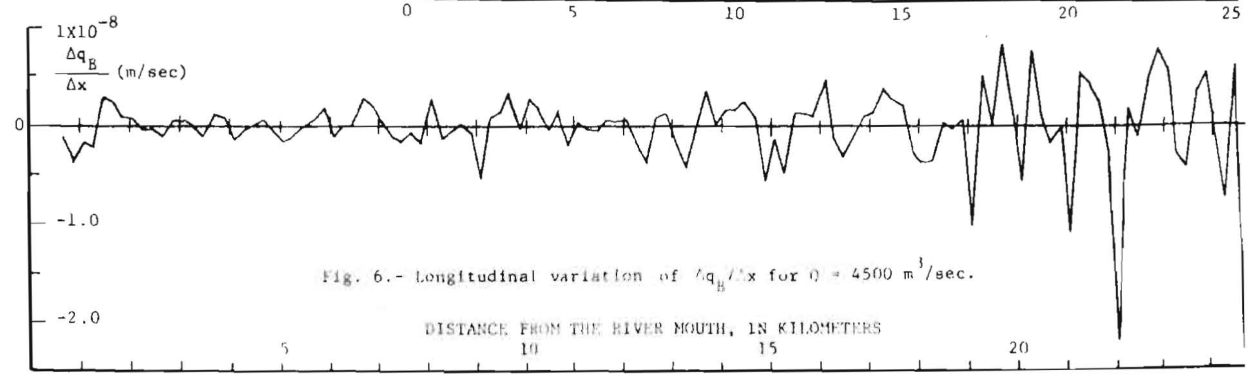

Fig. 6.- Longitudinal variation of $\Delta q_B/\Delta x$ for $Q = 4500\ m^3/sec$.

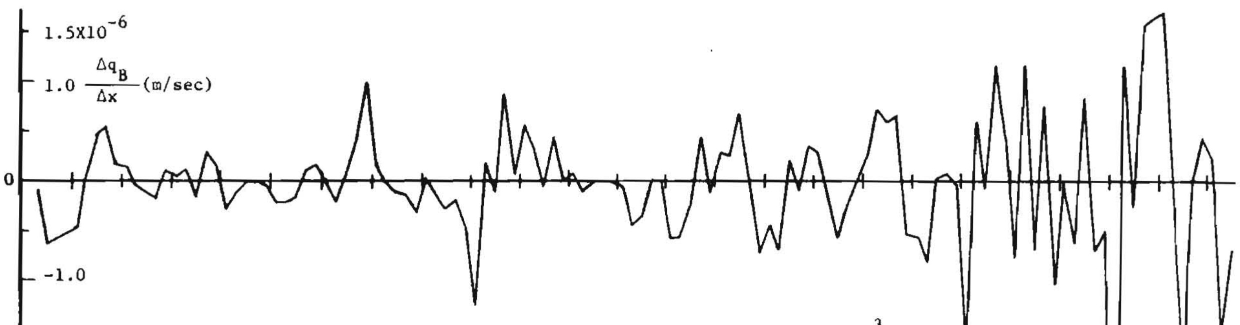

Fig. 8.- Longitudinal variation of $\Delta q_B/\Delta x$ for $Q = 11130\ m^3/sec$.

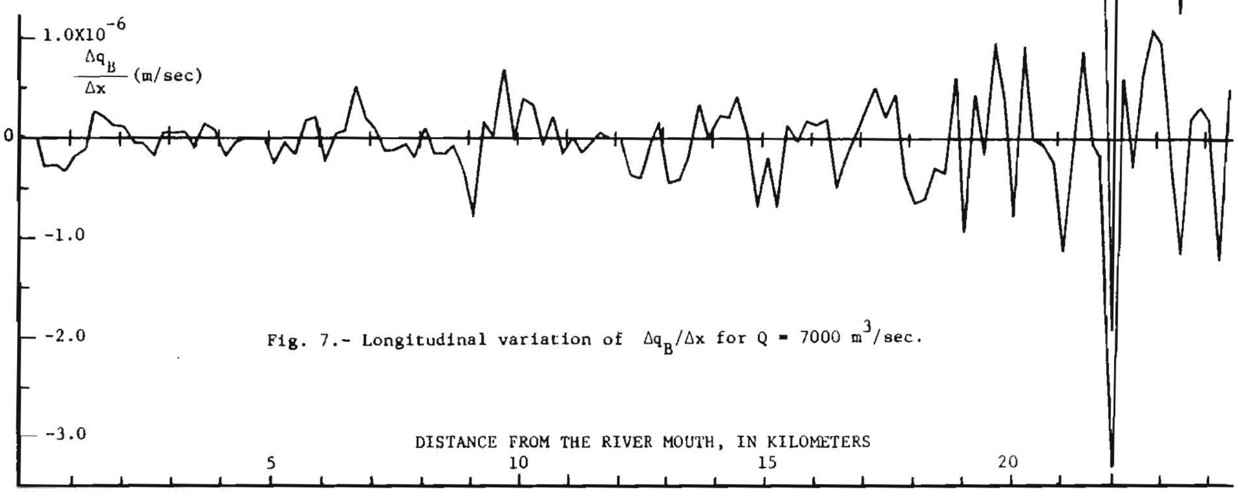

Fig. 7.- Longitudinal variation of $\Delta q_B/\Delta x$ for $Q = 7000\ m^3/sec$.

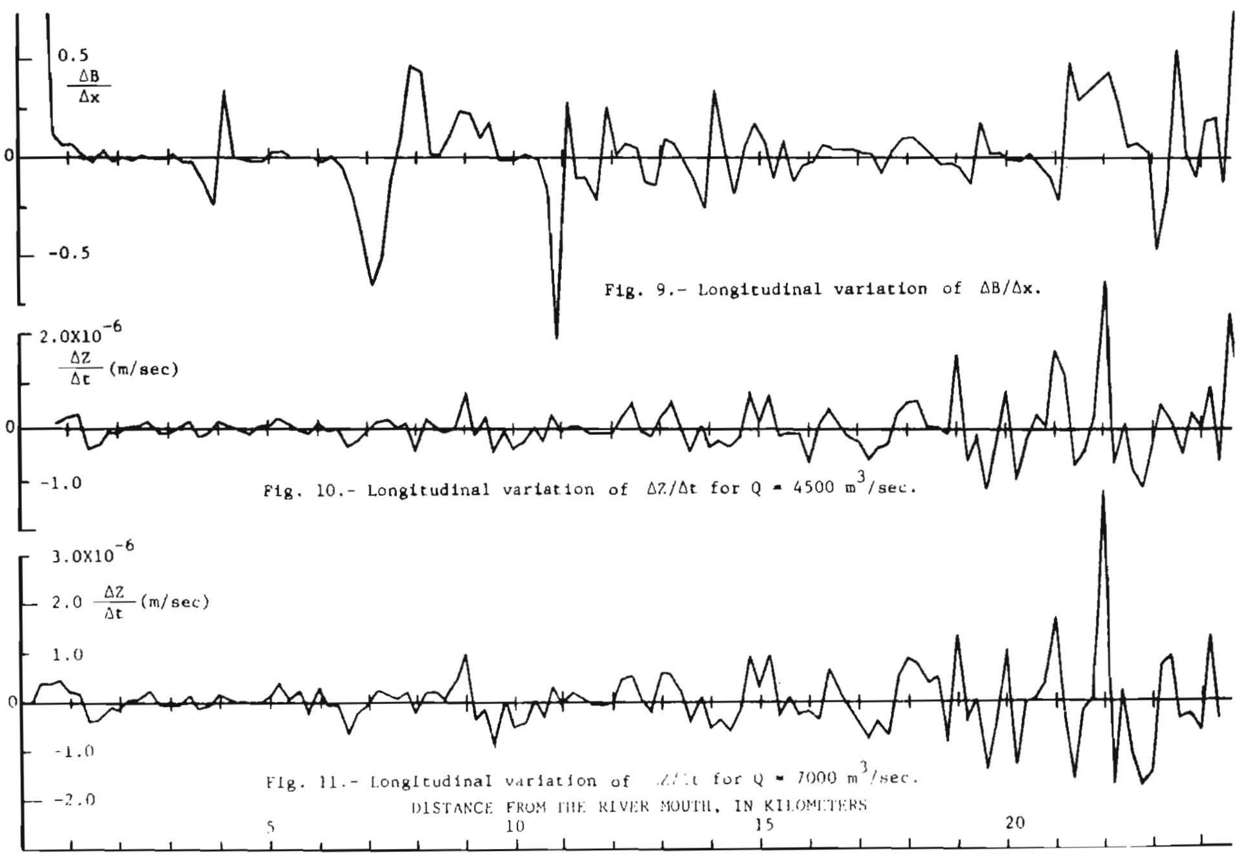

Fig. 9.- Longitudinal variation of $\Delta B/\Delta x$.

Fig. 10.- Longitudinal variation of $\Delta Z/\Delta t$ for Q = 4500 m^3/sec.

Fig. 11.- Longitudinal variation of $\Delta Z/\Delta t$ for Q = 7000 m^3/sec.

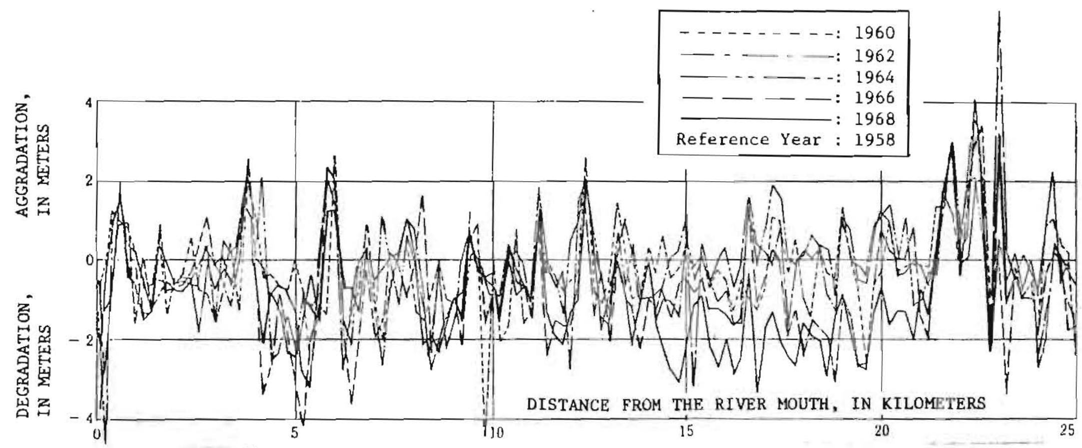

Fig. 13.- Longitudinal variations of observed minimum river-bed elevations. (Reproduced from the reference 2).

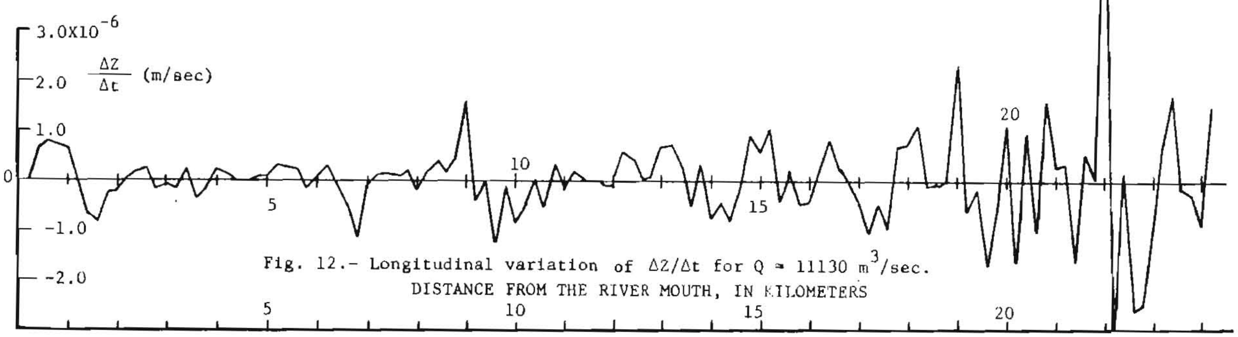

Fig. 12.- Longitudinal variation of $\Delta Z/\Delta t$ for $Q = 11130\ m^3/sec$.

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SOME OBSERVATIONS OF FLUVIAL AND ICE HYDRAULICS IN THE COLD CLIMATE

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ABSTRACT

It presents the author's observations on ice and glacier formation, co-existence of ice with water, ice floatation, ice-cover development and its effects, viscous flow of ice and glacier under stress, kinetic drifting of ice blocks and icebergs, their stability and jamming, keeping ice free at obstructions, and breaking ice for navigation.

SOMMAIRE

On présente des observations au sujet de la formation de la glace et des glaciers, de la co-existence de la glace avec l'eau, de l'émission de la glace, de la développement de l'abri de glace et ses effects, du flux visqueux de la glace et des glaciers sous la pression, de la portée cinétique des blocs de la glace et des icebergs, de leur stabilité et compressant, de tenir la glace libre aux obstructions, et de rompre la glace pour la navigation.

INTRODUCTION

Since the present age might be an interglacial age with a new ice age coming, as climate experts so auticipate, the timely importance of this Symposium can never be overemphasized. Even though another ice age may never come, an International Symposium on River and Ice has its significance particularly for hydraulic engineers perennially working in the cold climate, in the higher altitudes, and in the higher latitudes.

History has revealed that man first migrated from temperate zones to the tropics. As mineral resources become depleted in the lower latitudes, man is reversing its migration toward the poles for exploitation, encountering new problems different in degree and extent from those existing in the more-inhabited regions only cold in the winter. This adds to the justification of this Symposium.

As a hydraulician born, raised, educated, and practised in the cold climate, the writer has seen so much of river ice from his youth during the past seven decades that he would like to share his observations with this International Assembly.

In the domain of fluvial and ice hydraulics, there are many scientific and technological facets and noteworthy relationships. Because of space limitation, this paper can only deal with a few observations of the effects of flow conditions on ice formation, drift, cover developments, jamming, and break-up. These effects are, in turn, affected by man's efforts in improvement works for multipurpose river training and navigation.

OBSERVATIONS ON ICE AND GLACIER FORMATION

Ice Formation from Liquid Water

This section refers only to ice formed by the freezing of natural bodies of liquid water at temperatures below 0° Celsius (32° Fahrenheit) as in the lakes, rivers, canals, estuaries, and seas. The formation of ice in the form of snowflakes in the clouds by the freezing of water vapour will be referred to in the next section. Excluded herein are the formation of ice in the form of frost at ground level by the freezing of water vapour, and the formation of ice by the freezing of liquid water as hail, or as ice made through refrigeration, though the latter two consist of a compact aggregate of many crystals as ice in rivers in the cold climate.

The fact that ice formed in the natural bodies of water consists of a compact aggregate of many crystals is not ordinarily apparent, because ice crystals grown from liquid water do not develop crystal faces. The individual crystals can, however, be revealed by allowing the ice to begin to melt in bright sunshine. As the individual crystal grains are much more stable than their boundaries, the latter melt first, leaving the many crystals as separate pieces of ice.

It is also expedient to reveal the crystalline structure of ice by focussing the sun's rays inside a crystal. This causes the ice to melt internally, and a snowflake-shaped figure known as Tyndall (1820-1893) flower, filled with liquid water, is formed inside the crystal. The figure reveals the same hexagon symmetry as frost formed at ground level and snowflakes formed in the clouds.

Typical ice specimens have crystals about only 1 to 20 mm in size. When the crystals have grown larger by long-continued recrystallization, they may reach half a meter in diameter as in old glacier ice.

Snow Formation from Water Vapour as the Pre-State of Glacier

Snow is the pre-state of glacier, in the solid form of water. It is formed at temperatures below 0° Celsius (32° Fahrenheit) by the freezing of water vapour. It shows clearly the crystalline nature. Each snowflake is a single crystal of ice, and its hexagonal shape reveals the symmetry of the crystal. The shapes of snowflakes and also frost crystals, while conforming to hexagonal symmetry, show great variety such as needles, prisms, hollow columns, plates, simple stars, intricately branching stars, and combinations of all these. The crystal shape is dependent on temperature, and a change of only a few degrees can greatly alter the shape of an ice crystal growing from the vapour.

Glacier Ice Formation by Consolidation of Snow

Glacier ice forms by the consolidation of snow under the weight of successive layers, accumulating year after year. The snow crystals first transform into small rounded grains of ice by breakage of their delicate arms and evaporation of their sharp tips, forming a porous granular aggregate called firn.

By subsequent compaction and recrystallization, firn becomes glacier ice. The transition occurs when the pores, containing air trapped with the original snow, become sealed off from one another. Because the pores strongly reflect and scatter light, snow and glacier ice appear white, in contrast to pure, pore-free ice, which is transparent and colourless.

CO-EXISTENCE OF ICE AND FREEZING WATER

The latent heat of fusion for water is high compared to those of most substances. It requires 79.8 calories of heat to melt one gram of ice. Melting ice remains at a constant temperature of 0°C. In fact, the 0° on the Celsius scale is defined as the temperature of an "ice-water mixture" under air at atmospheric pressure. It is this phenomenon of co-existence that makes ice drift possible in rivers. It is the consumption of heat for ice to melt that makes ice a natural refrigerating agent or heat sink in the atmospheric environment in the spring. On the other hand, it is the liberation of large latent heat and the maintenance of 0° C in the early winter that makes the freezing water an effective buffer against severe cold.

FLOATATION OF ICE

For equal mass at 0° C, while water has a density of 0.9988 g cm^{-3}, ice has a density of only 0.917 g cm^{-3}. Therefore a mass of ice occupies 9% more volume than an equal mass of water. Not only is this responsible for the bursting of water pipes on freezing, but also for the fact that ice floats and drifts in water, with about one-ninth of its volume above the surface.

The decrease in density on freezing, though unusual among substances, is very important for life. Because of it, the seas, lakes, and rivers do not freeze solidly from top to bottom, but instead become protected from further freezing by the ice floating on top as an insulating layer.

As a result of the increase in volume on freezing, the melting point of ice decreases under pressure, by 0.0075° C per atmosphere of applied pressure. The low sliding friction of ice surfaces, as seen in ice skating and sledding can be attributed to the melting and consequent lubrication that occurs where the sliding object presses against the ice. The same is true for ice blocks sliding over icy surfaces as well as a glacier layer sliding over another layer. More of these phenomena are presented in the section on "Ice and Glacier Flow."

OBSERVATIONS ON ICE COVER DEVELOPMENT AND ITS EFFECTS

The condition of low-water flow through rivers in the winter season with slack current causing streams sluggish, coupled with low inflow due to snow precipitation and accumulation of snow in shaded areas, and frozen tributaries, contribute to the favorable factors for ice formation even in the main streams in the northern climate. In natural regimens with occasional shallow expanses of water, the almost non-flowing shallower portions will freeze first.

In the previous section, it was stated that natural bodies of flowing water do not freeze solidly from top to bottom, but become protected from further freezing by the ice floating on top as an insulating layer. This insulating top layer is commonly known as an ice cover. Once ice beginning to form, unless perturbed, continued cold temperatures below 0° C will first develop a thin cover, and this thin cover will grow thicker and thicker until a thermal equilibrium is reached and maintained at the underside of the cover.

Under the severe cold climate of northern Manchuria of China where the liberation of heat upon additional freezing is quickly lost through conduction, there are abundant cases in which the ice cover has continually grown to such great thickness and strength that railroad trains can be diverted to run on tracks laid over ice cover crossings while the bridges are subjected to repair.

The formation of ice cover over flowing water will be followed by the growth of ripples on the underside, and an increase in hydraulic roughness caused by the ripples and the thicker ice near the interface of the river with its banks where the current is much slower. For want of space, however, the biochemical oxygen demand (BOD) and oxygen depletion in ice-covered rivers will not be treated herein.

Ripple Formation on Underside of River Ice Covers

By cutting out large-size ice flats over flowing waters of rivers, canals, and other channels, and turning them upside down, one can examine the occurrence and properties of ice ripples that form on the underside of such ice covers. These ripples are affected by flow patterns, freeze-and-thaw cycles, heat transfer and thermal conductivity.

The local rate of freezing or melting at the ice-flow interface is related to the difference between the local heat transfer rates by conduction through the ice and turbulent transfer from the flow to the ice. The local heat flux to the interface from the flow may be expressed as a small perturbation expansion in terms of the steepness of the monochromatic interfacial wave, assuming the local heat flux to be shifted relative to the interface wave. Further analysis can yield a stability criterion and expressions for the amplification rate and celerity of the ripples.

Hydraulic Roughness of Ice Covers

In cold regions where rivers and canals are covered with ice, not only the ripple-like reliefs are developed on the underside but also the ice depth near the banks are several times thicker than that over the much swifter main stream part of the waterway. Their combined effects cause an increase in surface roughness coefficient and hydraulic roughness and consequently an increase in head losses considerably higher than those of smooth boundaries.

These features are caused by heat transferred from the bottom of the stream and heat loss by thermal conductivity through the ice cover. Observed ratios of wave height to wave length of the ripples do not exceed approximately 1/8 which is the approximate upper limit of wave index number of separation free flow over sinusoidal waviness. The overall hydraulic roughness will consist of a composite roughness coefficient as a function of ice-underside and channel-bed coefficients.

VERY VISCOUS FLOW OF ICE AND GLACIER UNDER STRESS

Despite being brittle and shattering like glass when struck with a hammer or pick, ice flows plastically under low stresses of long duration, or under high stresses when fracture is inhibited by pressure as at depth in very thick ice or glaciers.

The hexagonal layers of the ice crystal can glide past one another, much like pieces of paper sliding over one another. Such gliding occurs with the movement of crystal dislocations. It is in this manner that the flow of glacier ice takes place by the deformation of the individual crystals, whether be it at high latitudes or at high altitudes.

Since the different crystals, gliding in different directions, tend to interfere with one another, they impede the flow and force the crystals to bend. However, the bending does not become severe, because a process of recrystallization causes new, fresh crystals to grow continuously at the expense of old, deformed ones.

The flow of ice in bulk resembles somewhat like the flow of a very viscous liquid. With a viscosity for ice of about 10^{14} poise, the viscosity coefficient is not as constant as in liquids, but decreases rapidly with the increase of stress. This explains why the flow rate increases much more rapidly than in simple proportionality to the stress. This further explains why most of the deformation in glaciers is concentrated close to the bottom where the stresses are highest.

KINETIC DRIFTING OF ICE BLOCKS AND ICEBERGS

Ice pieces, blocks, and flats drift downstream in rivers. Icebergs drift in seas. Their difference only lies in the magnitude of the floating mass. At the upstream reach of large streams in higher latitudes or at higher altitudes, the flow of ice resembles that of a glacier.

In the spring, temperature rise coupled with warm rains and accentuated by torrential ice-and-snow-melt flows, the ice cover will partially melt, break up, and drift downstream. A floating mass of ice broken from the lower end of a frozen upstream drifts with the downward current until all melted.

An iceberg is a floating mass of ice broken from the end of a glacier or a polar ice sheet. Icebergs drift according to the direction of the sea currents, frequently from the polar regions to navigable waters. They are, therefore, occasionally encountered far beyond the polar regions.

It is when a glacier descends to the sea and is pushed outward into water of greater depth than the thickness of the ice that the ends are broken off and the detached masses float away as icebergs. Only one-ninth of the mass of ice is seen above water. Many icebergs are overturned, or tilted, as they set sail, as the result of the wave cutting and melting which disturb their equilibrium.

The disintegration of a polar ice sheet is even a simpler matter, as the ice is already floating. The ice sheet cracks at the end and the masses break off, accompanied by considerable violence, owing to the upward pressure of the water upon the lighter ice.

Icebergs, especially those of glacier origin, usually carry a load of debris which they gradually strew upon the sea floor. Glacial material found in dredgings shows that icebergs occasionally transport their load for a considerable distance.

STABILITY OF FLOATING ICE BLOCKS AND THEIR JAMMING

There are two obvious circumstances that may affect the stability of floating ice blocks: (a) when the buoyant blocks on a flowing stream are swept under a downstream floating cover; and (b) when floating blocks hit a natural bend or ledge, or a spur dike or groin, or bridge piers.

The critical condition of stability at which buoyant blocks are swept under a downstream floating cover can be inferred from a one-dimensional hydrodynamic analysis of the flow passing beneath the upstream end of a floating cover, and the force and moment equilibrium of the block. The condition of incipient submergence is reached when the block sinks and rotates until the stagnation water surface elevation equals that of the top upstream edge of the block.

When blocks of ice drift downstream, they will hit natural bend or ledge, or artificial spur dike or groin, or bridge piers. Upon impinging impact, they are rotated or broken into smaller pieces. Sometimes, large blocks of ice cannot flow through narrowly spaced bridge openings. Even the elongated ice blocks, though may be much narrower than a bridge opening, upon impact on a bridge pier, are rotated and hence cannot drift through.

Thus, ice jamming may occur at much narrower sections of a river or at the upstream side of narrowly spaced bridge openings. The jamming will start with big floating ice blocks, and then further aggravated by the accumulation of smaller ice blocks, piling up on the upstream side.

KEEPING ICE JAMS FREE AT BRIDGE OPENINGS

In cases of jamming on the upstream side of bridge piers, the piling up of ice can exert tremendous pressure on the substructures. Narrowly spaced high pile trestles carrying narrow roadways are especially prone to such jamming and its consequence of overturning. There were cases in which pile trestle bridges having given many years of satisfactory services were completely damaged to destruction.

In such instances, it is imperative to keep the upstream side always free of ice accumulation by having attendants to break the ice, working from a boat. The same precaution can be advantageously applied to the upstream side of dams to relieve the added lateral pressure due to ice expansion upon freezing.

ICE BREAKING AND ICEBREAKERS

To keep navigation open during the winter in seas, lakes, and large rivers in the cold regions, ice breaking operations have been resorted to for nearly a century by the use of icebreakers. They are especially designed vessels equipped to clear a path through ice in navigable waters. Generally, they have been designed to adapt their use to particular ice environment, such as the Arctic, the Baltic Sea, the Great Lakes, and the North China Seaports.

In order to perform their functions efficiently, the design of icebreakers usually requires to incorporate several features:

1. A high beam-to-length ratio to permit the icebreaker to cut a channel wide enough for a conventionally built ship to follow in the waters under consideration;
2. A high horsepower-displacement ratio to permit the icebreaker to make sustained progress in ice of varying thicknesses;
3. Using flare-shaped transverse sections to permit the icebreaker to lift when under ice pressure during operation, and to take advantage of the heavy rolling action (up to 40° to 50°, resulting from the use of flared sections) for ice breaking and for helping the vessel to free itself should it become stuck;
4. Heavy plating of the underwater body, combined with rugged framing to resist the crushing effects of ice breaking;
5. Providing a rugged rudder and propellers, and bow propellers in addition to those in the stern, to create turbulence in the water to assist the breaking action of the bow and to move broken ice out of the way;
6. Providing electric drive for propulsion to develop maximum power from a standing start; and
7. Providing large fuel capacities for icebreakers operating in polar or other regions where refueling facilities are lacking, or using nuclear-powered icebreakers.

CONCLUDING REMARKS

The above have been observed in the cold climate on sea lanes, on approaches to and in the harbours, on unregulated or untrained rivers, and on regulated navigable rivers and canals for flood discharges, navigation, and water conveyance.

In general, it is easier to keep deeper seaways (whether natural or dredged), with stronger currents and larger diurnal tides, open to navigation. In inland waterways, more pools exist with unregulated, untrained rivers, where the conditions are more favorable to the formation and development of ice cover. As a result of river training, straightening, and elimination of meanders, the slope becomes steeper, which adds to the velocity of ice drift and increases the chances of jamming at narrower sections even there be no bridge pier obstructions.

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A FEW PROBLEMS OF ICE MOTION WHICH COVERS A MAJOR PART OF THE WATER SURFACE, TERMED SATURATED MOTION

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ABSTRACT

Part of the problems concerning winter-time operation of low head barrages are related to ice motions covering a large water surface and are termed saturated motions. In this paper permanent, linear, uniform types of ice motions are being discussed in the first place. The results obtained point out a few features of ice motion and permit the examination of ice-run produced through backwater effect, as well as determining the pressure inside the flowing body of ice.

SOMMAIRE

1. Differential equations for saturated, linear, gradually varying ice motion

Saturated ice motion is a passage of ice with hardly any free surface of water between the individual ice blocks, so that the water is moving along with the ice. Between blocks, running ice and the banksides a powerful interaction is being developed. Writing down Newton's law for the ice running across a prism of an average width of B, thickness d and length dx, the following differential equation can be obtained:

$$\frac{1}{g}(Bd\gamma_i\,dx)\left(\frac{\partial v_2}{\partial x}v_2+\frac{\partial v_2}{\partial t}\right)=Bd\gamma_i\,i\,dx+sgn(v_1-v_2)\beta B(v_1-v_2)^2dx-$$
$$-P_r\,dx-Bd\frac{\partial p}{\partial x}dx\pm B\beta_w v_w^2\cos\xi\,dx \qquad 1.$$

Designations:

d / m /	Thickness of ice
g /m s^{-2}/	Acceleration of gravity
i	Grade
p /Mp m^{-2}/	Thrust
t / s /	Time
v_1/ m s^{-1} /	Mean section velocity of water
v_2/ m s^{-1} /	Mean section velocity of ice
v_w/ m s^{-1} /	Velocity of wind
B / m /	Average width of river
P_r /Mp m^{-1}/	Resisting force for a unit length
β /Mp s^2m^{-4}/	Velocity coefficient for friction between water and ice
β_w /M_p s^2m^{-4}/	Velocity coefficient for friction between ice and wind
γ_i /M_p m^{-3}/	Gravimetric density of ice

ξ /radian/ Angle included between the direction ice-run and that of wind

The direction of ice-run is the positive direction and for forces acting between the ice blocks thrust is to be considered positive. Entrainment between the blocks may be neglected.

From the aspect of dynamics consolidated ice motions can be divided into two groups. In the case $\frac{\partial p}{\partial x} = 0$, the ice motion is referred to as a motion free from congestion, if this is not the case, as jammed ice motion.

The law of the conservation of energy comes here to the foreground as a precondition of continuity which can be expressed, with density and thickness of ice being constant, by the following differential equation:

$$v_2\left(\frac{\partial n}{\partial x} + \frac{n}{B}\frac{\partial B}{\partial x}\right) + n\frac{\partial v_2}{\partial x} + \frac{\partial n}{\partial t} = 0 \qquad 2.$$

Designation: n surface cover.

2. Permanent, uniform and linear ice motion

In this case $\frac{\partial n}{\partial t} = 0$, and $\frac{\partial v_2}{\partial x} = 0$. Upon the precondition of consolidation, however, $\frac{\partial n}{\partial x} = 0$. Thus Equ. 2 will be reduced to the simple form of $v_2 \frac{n}{B}\frac{\partial B}{\partial x} = 0$, from which follows that B = const.

2.1 Ice motions free from congestion

A resisting force will result from percussions and friction occurring both inside the body of the ice and alongside the riverbanks. Both types of resistance may be brought into connection with the velocity of ice. Consequently, the resisting force for a unit length is described by a function $P_r = a_o + f/v_2/$ to which a suitable approximation exists through the quadratic polynome for ice velocity:

$P_r = a_o + a_1 v_2 + a_2 v_2^2$

From differential equation 1 the following relation may be deduced, with consideration of the polynome mentioned above:

$$\eta = \frac{v_2}{v_1} = \frac{2+\frac{\alpha_1}{v_1} - \sqrt{\left(2+\frac{\alpha_1}{v_1}\right)^2 - 4(1-\alpha)\left(1-\frac{\alpha_2}{v_1^2}\right)}}{2(1-\alpha)} \qquad 3.$$

where $\alpha = \frac{a_2}{B\beta}$; $\alpha_1 = \frac{a_1}{B\beta}$; $\alpha_2 = \frac{a_0}{B\beta} - \frac{d\,\delta_i}{\beta} \pm \frac{\beta_w}{\beta} v_w^2 \cos\xi$

further on $\lim\limits_{v_1 \to \infty} \frac{v_2}{v_1} = \frac{1}{1+\sqrt{\alpha}}$ 4.

It can be proved that the function $\eta = f/v_1/$ has no extreme value within the range of positive ice velocities, which means, that the relative retardation of ice diminishes with the increase of water velocity.

The value of α can reasonably be approximated through relation 4. E.g., in the case of $\eta = 0{,}95$ $\alpha = 0{,}0025$, and in the case of $\eta = 0{,}80$ $\alpha = 0{,}0625$. The approach for α_1 is a similar one, in that case it is suitable to proceed from the condition $\alpha_2 = 0$, resulting in $\alpha_1 \approx \left(\frac{1+\eta^2}{\eta} - 2\right) v_1$. For example, for $v_1 = 2{,}0$ and $\eta = 0{,}8$ the $\alpha_1 = 0{,}10$. Some functions $\eta = f/v_1/$ are shown in Fig 1.

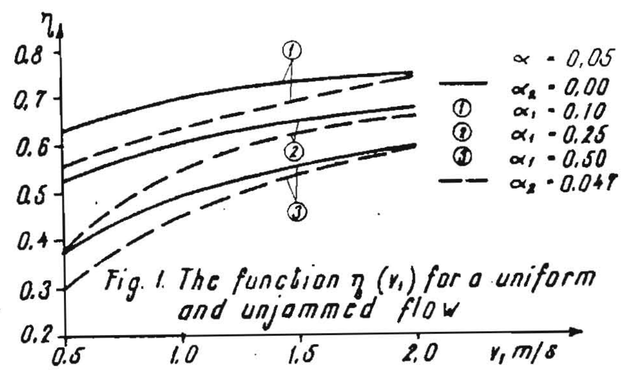


Fig. 1. The function $\eta(v_1)$ for a uniform and unjammed flow

2.2 Jammed ice motion

For this motion resistance may be brought into connection with thrust appearing between ice blocks, through the relation $P_r = a_o + f/a_{op}, v_2/p$ which can, in first approximation, be treated as a linear function of thrust. In that case differential equation 1 may be brought to the following form:

$$\frac{dp(x)}{dx} + \frac{f[dop(x), v_2]}{Bd} p(x) = A_o(x) + v_2 A_1(x) + v_2^2 A_2(x) \qquad 5.$$

where $A_o/x/$ ... etc, are functions which can be written on the basis of water velocity and river bed characteristics. Substituting $\omega /x_1 v_2/$ for $\frac{f[dop(x), v_2]}{Bd}$ and for the cases $x = 0$, $p = 0$, it will be

$$p = e^{-\int_0^x \omega(\xi, v_2) d\xi} \left[\int_0^x A_o(\xi) e^{\int_0^x \omega(\xi, v_2) d\xi} d\xi + v_2 \int_0^x A_1(\xi) e^{\int_0^x \omega(\xi, v_2) d\xi} d\xi + \right.$$
$$\left. + v_2^2 \int_0^x A_2(\xi) e^{\int_0^x \omega(\xi, v_2) d\xi} d\xi \right]$$

For the case $\omega /x_1 v_2/ = \text{const}$, it will be

$$p = \int_0^x A_o(\xi) e^{-\omega(x-\xi)} d\xi + v_2 \int_0^x A_1(\xi) e^{-\omega(x-\xi)} d\xi + v_2^2 \int_0^x A_2(\xi) e^{-\omega(x-\xi)} d\xi$$

with designations $A_o(\xi) + v_2 A_1(\xi) + v_2^2 A_2(\xi) = F(\xi, v_2)$

$$p = F(x, v_2) * e^{-\omega x}$$

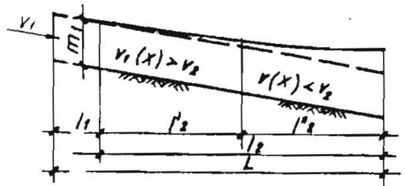
At the end of the jammed stretch $/x = L/$ the thrust is zero. In this case relation 6 will lead to the following equation:

$$0 = \int_0^L A_o(x) e^{-\omega(L-x)} dx + v_2 \int_0^L A_1(x) e^{-\omega(L-x)} dx + v_2^2 \int_0^L A_2(x) e^{-\omega(L-x)} dx \qquad 7.$$

As the forces which are being transferred from the water on to the ice or from the ice to the water are not independent of the sign of the difference existing between the velocities, the coefficients to v_2 cannot be calculated unless v_2 is known. In any particular case an additional equation can be written between v_1 and v_2. The Equ. 7 can be transformed in a way that v_2 can be defined. Such a problem usually leads to a transcendental equation to be solved.

2.3 Ice motion developing within the reach in the case of a linear variation of water velocity

The model is shown in Fig 2.



$$l_1 \leq x \leq L$$

$$v_{1x} = kv_1 + \frac{1-k}{l_2} v_1 (L-x)$$

Fig. 2 A model for examining the ice motion developing within the reach

Through the solution of Equ. 7 the following transcendental equation will be obtained:

$$-\frac{t_b'^2}{2} + t_b'(1+e^{-t_b'}) + 2e^{-t_b'} - \Delta = 0 \qquad 8.$$

where
$$\Delta = 1 + e^{-t_b}(t_b+1) - \frac{d\sigma i}{2\beta c^2 m_1}\left[\frac{k^3}{s^2} + \frac{3k^2}{s} + 6k + 6s - e^{-t_b}\frac{3}{s}(1+2s+2s^2)\right]$$

Designations:

c /$m^{1/2}$ s^{-1}/	The Chezy velocity factor
e	Basis of natural logarythm
k	Ratio of entrance to exist water velocity within the reach
l_1 / m /	Length of the river stretch upstream of the reach
l_2, l'_2, l''_2/m/	Stretches typical for the reach
m_1 / m /	Average water depth
$s = \frac{1-k}{t_b}$	Auxiliary value for calculations
$t_b = \omega l'_2$	Auxiliary value for calculations
$t'_b = \omega l''_2$	Auxiliary value for calculations
$\omega \simeq \frac{2\mu z}{B}$ /m^{-1}/	A characteristic constant for jammed ice motions

z – Proportionality factor between tangential stress and thrust;

μ – Quotient of longitudinal and lateral thrust

The quantities of Equ. 8 are non-dimensional. The equation is valid on the following conditions:

- $e^{-\omega L} = e^{-\omega l_1} e^{-\omega l_2} \ll e^{-\omega l_2}$ and obviously $e^{-\omega L} \ll e^{-\omega l_2'}$
- for determining the head only the friction between water and river bed should be involved,
- the relation should not include the third member of the resisting force, an examination of the role of thrust being the objective. Otherwise, the expression for D will be supplemented, when the constant member of the resisting force is being considered, by a member $\dfrac{a_0}{B\beta v_1^2}$

Equation 8 was solved applying the Newton method and using an IBM 1130 computer. The results are shown, in graphical performance, in Fig 3

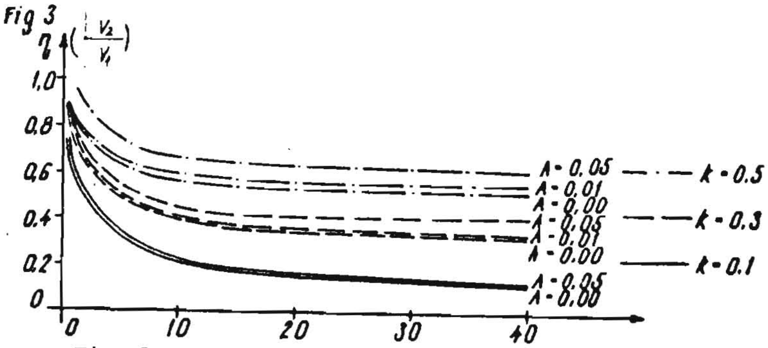


Fig. 3. Interrelation between η and ωl_2

3. Summary. Conclusions

The relations described above draw the attention, regardless that they concern a relatively narrow range of ice motion, to a few considerations of practical importance, namely:

- it is conspicuous from what was said in chapter 2.3 that the conditions of low head barrages a permanent operation would be inadequate to produce an ice-run under backwater effect. Over stretches with a higher water velocity the propellent force to be transferred to the ice will in greater part be used up by the friction originating from the pressure within the body of the ice. In order to produce an efficient ice-run a non-permanent operation should be carried out in which the ice is made to pass through with the water level being changed and the discharge being increased;

- for the case $\omega/_2 < 10$ the effect of the dimensions of the reach are strongly felt. The effect of these dimensions greatly decreases over the range of $10 \leq \omega/_2 \leq 20$ and, if $\omega/_2 > 20$, this effect will be a function of k;
- with an ice flow free from congestion the relative retardation of ice will decrease with the increase of water flow velocity, the rate of decrease not being generally directly proportional to the increase of water velocity.

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VARIATION OF DISCHARGE IN CROSS-SECTIONS WITH ICE-COVER

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ABSTRACT

The discharge in a profile of a natural or a man-made channel is reduced if the cross-section is covered by ice. The roughness of the cross-section may vary and differ from the roughness of the ice-cover, which can also change across the section.

Relations between nondimensional roughness and the reductions of discharges are found with known formulae for the composite roughness considering the MANNING formula. Simple relationships between the cross-section characteristics and the reduction of discharge are the result evaluated in a FORTRAN IV program running on a CD 6400, subroutines have been checked on a WANG 720 C.

SOMMAIRE

Si le profil d'un cours d'eau est formé par une couche de glace, le débit diminue. Dans ce cas la rugosité à la base est variable et differente de la rugosité de la couche de glace, qui elle-même peut varier le long du profil.

A l'aide de formules comme pour les rugosités composées et l'application de la formule de MANNING, on trouve des relations entre les valeurs de rugosité rendues sans dimensions et la diminution du débit. On obtient de cette manière une relation simple entre les données du profil et la diminution du débit. La relation est évaluée à l'aide d'un programme en FORTRAN IV sur ordinateur CD 6400 . Des parties du programme ont été vérifiées sur ordinateur WANG 720 C .

Introduction

Not much information has been given so far about the hydraulic losses and the reduced discharge capacity of a so-called open channel flow with ice-cover. Some efforts have been made in Sweden (3) to find a relation between the hydraulic losses and the ice-cover. The computations seem to have been based on the assumption that both, the roughness coefficients for the channel bottom as well as for the ice-cover, are equal.

This problem leads to a more general problem of relationship between fluvial and ice-hydraulics, namely to calculate the mean roughness or composite roughness for a cross-section in which the partial roughness varies from section to section around the wetted perimeter.

Many equations are known, but those cited in (1) as well as (2) are connected with different constraints.

Discussion of formulae

The discharge is calculated by the MANNING-formula. The influence of the variation of various members like slope, shape of cross-section, change of roughness along the wetted perimeter on the discharge is checked.

The composite roughness is determined according to (1) with the simplifications mentioned therein:

Horton, Einstein: $$n = \left[\frac{\sum_{i=1}^{N} (P_i n_i^{1,5})}{P}\right]^{2/3}$$, Lotter: $$n = \frac{P\,R^{5/3}}{\sum_{i=1}^{N}\left(\frac{P_i R_i^{5/3}}{n_i}\right)}$$

Pavlovskii, Mühlhofer, Einstein, Banks: $$n = \left[\frac{\sum_{i=1}^{N} (P_i n_i^{2})}{P}\right]^{1/2}$$

For particular flat cross-sections (2) finds: $$\ln n = \frac{\sum_{i=1}^{N} P_i d_i^{3/2} \ln(n_i)}{P_i d_i^{3/2}}$$

The same author recommends for wide shallow cross-sections: $$\ln n = \frac{\sum_{i=1}^{N} P_i \ln(n_i)}{P}$$

Aim of this Paper

The main aim of this paper is to develop a computer program for a solution with a general validity without the constraints and overcoming some of the basic assumptions previously necessary. The program is written under the same assumption as in developing the above formulae that the cross-section is divided into N-parts. The members of each part are the hydraulic radius R_i, the wetted perimeter P_i, the mean velocity v_i and the roughness n_i. Any shape of cross-section is described by the x_i, y_i coordinates. The program can not only be used for regular man-made channels but also for irregular, natural cross-sections. Data varying across the section are: roughness n_{1i} of the channel, roughness n_{2i} of the ice-cover, waterdepth d_i, thickness of the ice-cover t_i.

The composite roughness is calculated with the help of the mentioned formulae using the roughness of the channel and the ice-cover. The total discharge Q_1 of a cross-section without cover and the total discharge Q under the ice-cover are computed introducing the composite roughness-coefficients calculated from those different formulae. Apart from these computations the partial discharge of the N-parts of a cross-section is calculated and summed up resulting in Q_N. Depending on the formula used a larger or smaller difference between Q_1 and Q_{N1} and Q and Q_N is found.

The difference depends on the assumed partial roughness of bottom and cover. The difference between the mean calculation of the discharge Q and the sum of the partial discharges Q_N is a result of the assumptions necessary during the derivation of the formula for the composite roughness. Only the expression of LOTTER delivers equal results.

But there is another difficulty if the LOTTER expression and formula (2) are used. The corresponding water depth in a cross-section with ice-cover is different from the real depth. The depth d under the cover has to be divided into two parts (after 4) namely

$$d_{io} = \alpha . d_i \quad \text{and} \quad d_{iu} = (1 - \alpha) d_i \qquad (\alpha < 1) \; ,$$

the first part belonging to the ice-cover, the second to the bottom. The partition of the two areas is done through the maximum velocity following a logarithmic velocity distribution (Fig.1)

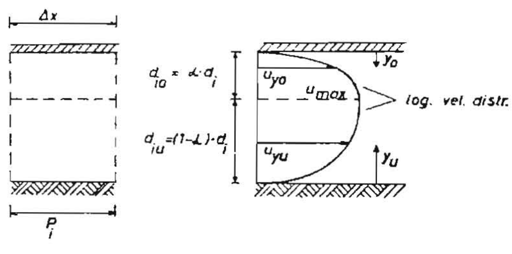


Fig. 1

This computation will also give different results for the total discharge and the sum of the partial discharges. A separate paper will be published soon where a method will be explained to calculate exact α-values.

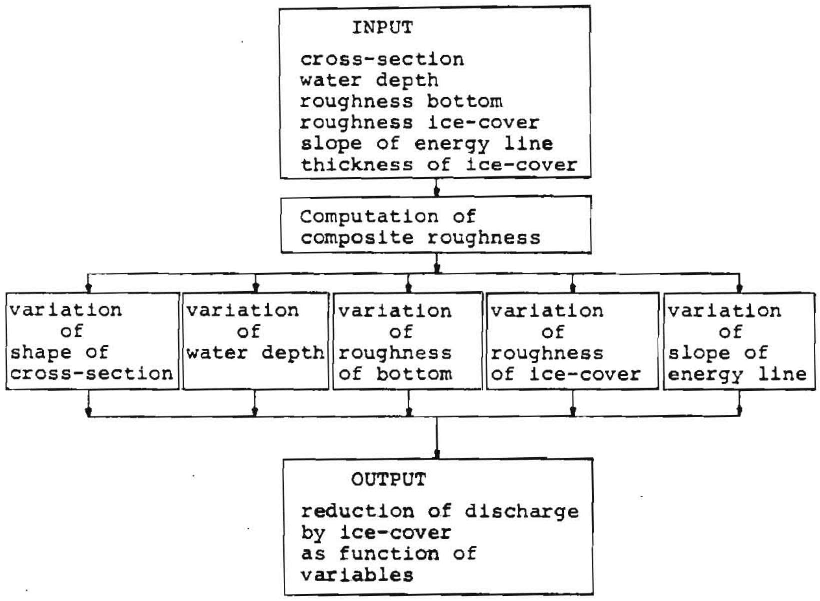
In the following only the total discharge Q and Q_1 respectively is considered. In a nondimensional form the reduced discharge capacity is a function of cross-section characteristics and roughness-values.

Method of Computation

In the calculation used here some of the simplified assumptions are no longer necessary. The limitation can be abandoned that the hydraulic radius and the wetted perimeters of ice-cover and channel are the same in all particular parts. The further condition that $R = R_1/2$ is not longer necessary to calculate Q from Q_1.

In parts of the cross-section with small water depth covering the embankment and forelands a higher roughness can be used in the computation. By variations of the water depth the influence of a downwards growing ice-cover on the discharge can be simulated also in the case, that the roughness changes with the time.
If the underside of the ice-cover is not horizontal in the profile a thickness growing from the deeper portion of the channel to the banks can be introduced into the computation.

The variation of the profile can also be examined in its effect on the discharge in an ice-covered channel.



Results

The calculation shows that the nondimensional discharge can be represented by a function of the variables.

The relation of the composite roughness n calculated by the different formulae of the channel with ice-cover to the composite roughness n_1 without ice-cover is shown above the relation of the corresponding discharges Q and Q_1 .

The result is a functional connection of the form

$$\frac{n}{n_1} = \frac{Q_1}{Q} \cdot (\frac{P_1}{P})^{2/3}$$

The equation is valid independent of the formula used, the curve depends only on the shape of the cross-section given by the characteristic value P_1/P .

For one cross-section the curve is shown in Fig. 2 .

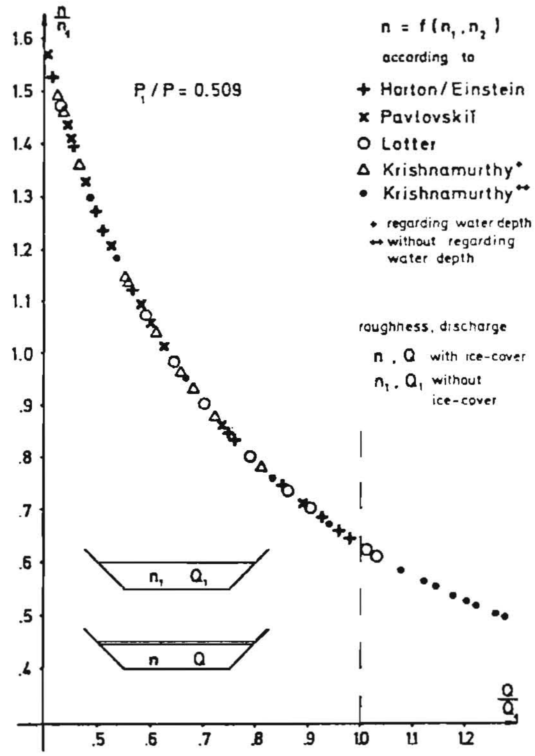


Fig. 2

Fig. 2 shows that some values $Q/Q_1>1$ have been received. That would mean that the discharge with ice-cover is larger than without, what is physically not possible. The range of application of (2) has to be limited in case of ice-covered cross-sections. The values resulting from LOTTER above $Q/Q_1 = 1.0$ are only received for extreme roughness conditions very rarely possible in nature. In bilogarithmic coordinates the curves of Fig.2 prove to be straight lines. The values of all formulae are represented by parallel straight lines depending only on P_1/P - values (Fig.3).

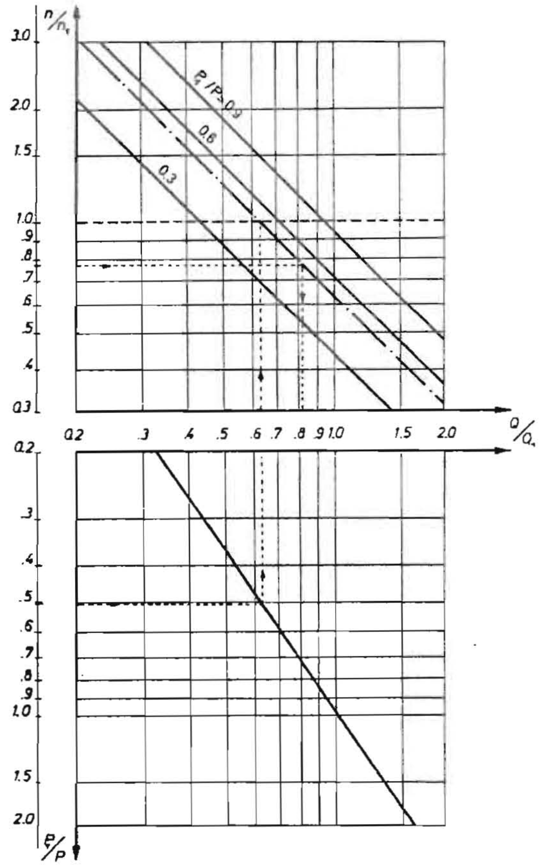


Fig. 3

The parallel straight lines of the mathematical form

$$\ln(n/n_1) = \frac{2}{3} \cdot \ln(P_1/P) - \ln(Q/Q_1)$$

cut the horizontal $n/n_1 = 1.0$ in points whose positions depend on P_1/P.

If one enters the lower part of Fig.3 with the known cross-section value P_1/P and transfers via the reflection line into upper part up to the horizontal $n/n_1 = 1.0$, the point is to be found through which the straight line corresponding to the given P_1/P runs, so that the line can be drawn parallel to the others.

Starting from the calculated ratio n/n_1 in the upper part of Fig.3 with help of the now known line depending on P_1/P the wanted value Q/Q_1 giving the nondimensional reduced discharge is to be found.

In dependence of the roughness ratio n/n_1 and the roughness of the cover the discharge may find a reduction up to 20 % and more.

It was observed that in the mean Q/Q_1 reduces as the width increases and the composition of section becomes more multiple. The reduction Q/Q_1 is small in a wide range of channel width. Varying the assumed roughness-values for one cross-section, the results of Q/Q_1 computed after the several formulae differ.

PAVLOVSKII delivers the largest, LOTTER the smallest, HORTON a mean value of the reduction. The standard deviation of the results in connection with an equal variation of roughness can be a measure for the sensitiveness of the methods of calculation. Regarding the changes of input-data of roughness it is to be shown that the standard deviation of the results after PAVLOVSKII is low, after LOTTER high and after HORTON a mean value.

In calculating after (2) the problem seems to lie in the laying down of the water depth at the ice-covered channel, this problem does not arise in the calculation of the composite roughness in an iceless channel.

The results show clearly the necessity of measurements in nature to obtain comparable data for the calculation methods used.

The slope is set up to be constant in one process of calculation but it can be varied for the research of cross-sections succeeding in the direction of flow. The results give a general view of the discharge decrease along the channel.

Example

The computation is made for a cross-section given in Fig.4 . The input-data for this example are:

x_i, y_i coordinates of the cross-section
water depth d
thickness of ice-cover t
roughness-values for the bottom n_1
roughness-values for the ice-cover n_2
slope of energy-line $I_e = 0.001$

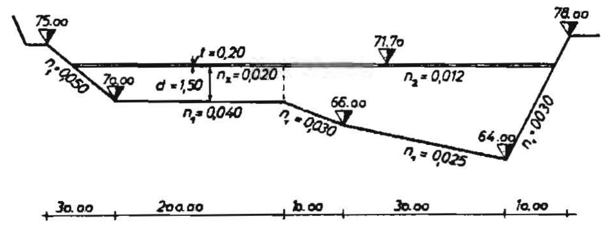


Fig. 4

The output-data are:

1) cross-section characteristics

$$P_1/P = 252{,}18 \;/\; 499{,}03 = 0{,}505$$

2) friction factors for the composite roughnesses and discharges according to the several formulae

	n/n_1	Q/Q_1
HORTON / EINSTEIN	0,771	0,822
PAVLOVSKII	0,792	0,801
LOTTER	0,755	0,840
KRISHNAMURTHY (with d_1)	0,704	0,901
KRISHNAMURTHY (without d_1)	0,871	0,728

The method of using the diagramm Fig.3 is shown with the values of HORTON/EINSTEIN as an example.

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CONDITIONS OF THE ICE PASSAGE THROUGH BRIDGE OPENINGS FREE OF JAMS ON SIBERIAN RIVERS.

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Summary

The spring ice run on most great Siberian rivers proceeds impetiously and with ice blocking.For the most rapid opening of navigation it is necessary to ensure the ice movement free of obstructions through bridge openings, thus eliminating every possibility for ice fields to stop long at piers.

A method for estimating minimum dimensions valid for bridge spans is developed in this paper which takes into account the principal factors of phenomena, in particular central surface velocity of the streamflow, the ice floe dimensions and their strength, as well as the size and form of bridge piers. A method developed by the author is used in the USSR for projecting of railway and high-way bridges.

Certain particularities of the ice passage through the bridge openings.

In projection of river crossings used for navigation and floating the relatively small blocking of streamflow is fixed and there-by the dimension of the backwater level at the bridge is comparatively small. Therefore the ice passing proceeds always without breaking up of ice floes on the falling surface curve. It is attributed to the greater strength of ice fields as compared with the ice discharged from the reservoir after long retaining in the upper reaches.

At the beginning of spring ice run the great ice fields approached at the bridge piers and being partially destroyed in the zone of contact, they are often stopped. With the rise of water level the stream-flow velocity is increased, the linkage of stopped ice floes with the banks is weakned and the groups of ice fields begin to move affecting the bridge piers.

It is assumed that even in construction of the bridge at the rectilinear part of the riverbed there is an active length of that filled with crushed ice which have to be taken into consideration. Located up stream the ice fields already do not affect the bridge piers. There is a picture similar to that which is taken into account to estimate the ground pressure on the tunnel casing.

If kinetic energy of group of ice fields filling the active length of the river part has been enough to destroy the ice floes at the bridge piers, so is provided for ice passage through bridge openings free of jams.

At one of the greatest bridge in Siberia we have observed (1) the succeful work of the great bridge spans / 100 m/ during ice passing and formation of local ice jam at the abutment span with dimensions 15 - 20 m.

Thus, the ice passing through bridge openings is connected essentially with the dimensions of span, the form and the pier dimensions(inclined cutting edges and piers with sharp vertical edges faciliate to destroy the ice cover), the strength of ice movement velocity of ice fields.

Character of interaction of ice cover and bridge piers.

When the ice field impact the pier having vertical cutting edge, there is to be observed a partial entry of the pier in the ice accompanied by a considerable deformation, shearing and formation of crack of ice. The resistance of ice cover against impact of the pier involves influence of local crumpling increasing the ice strength at the breaking up 2,5 times. In connection with the breaking up of the ice edge the perimeter of cutting edge of the pier touches the ice usually only at portion (0,5–0,8) of its length.

The influence of the form of the pier in plane is to involve the factor diminishing for more edged formation of the cutting edge of the bridge pier. The variation of the ice strength during spring ice run reported from different climatic zones of the USSR may be determined by the calculating formula of climatic factor which changes from 0,75 to 2,25 (2).

It should be noted that the process of cuting of ice cover changes in time therefore the bridge pier is affected by alternatig pressure and is vibrating, what also Canadian and German scientists wrote about.

The detailed investigations of this problem, carried out in the USSR are shown in the standards which are valid for our country (2). Using the normative recommendations may be determined both the impact ice pressure against the pier /P ton/, and specific dynamic pressure of ice per 1 sq.m. of the contact area of the pier /width b_0/ with the ice floe having thickness / h /. It is evident that the specific dynamic pressure of ice is given by

$$K = \frac{P}{b_0 h} \quad ton/sq.m \qquad /1/$$

When the ice field impacts the pier having inclined cutting edge, it is destroyed by its bending. The vertical pressure component can lead to the breaking up of the ice cover at some distance from contact zone, usually equal to 3-6 thickness of ice cover. At first advancing cracks form and then a circular crack is formed yielding a pecullar ice cantilever.

It stands to reason that the pressure force of ice on the bridge pier increases at first, then when the ice is broken up, it decreases almost to zero. Then the process is repeated cyclically.

The analysis of the literatura data as well as personal observations permit to determine, that the insufficient dimensions of the bridge span can lead to the formation of ice jam, rise of water level and ice floe impact on the bridge span structures. It may be the undercut of the bridge piers and their deformation.

Conditions of the ice-passage through bridge openings free of jams.

Consider a possible method for estimating minimum dimensoins valid for bridge span from conditions of the ice passage through bridge openings free of jams.

The river in width / B_o / is spanned with a bridge whose opening / $L = B_o$ / is devided into / n / equal spans, with dimensions/ ℓ /. The observations that had been conducted on the Siberian rivers permit to conclude that during the full ice run the dimensions of the most often occuring larger ice floes were from 1/20 to 1/8 of river width, with the ice floes having approximately the same width and length.

Assuming that the ice floes of such dimensions at the period of the full ice run move with velocity / V_1 /, contacting each other and representing a compact field with active length / L_o /, mass / M /. Its storage of kinetic energy may be estimated by

$$T = \frac{M V_1^2}{2} \qquad /2/$$

The investigations of the work of ice protection reservoir, carried out in the USSR by Latyshenkov (4) permitted to estimate that at $L > 3B_o$ of the further increase of the ice pressure on the reservoir is not to be observed, for the part of pressure is transmitted on the banks of water passage. Recently V.K.Troinin(3) analysed this problem and faund that the relation / $\frac{L_o}{B_o}$ / depends essentially on physical and mechanical properties of the crushed ice (angle of internal friction, adhesion), stream-flow velocity regimen, and for usual conditions in Siberia, it can reach the value equal to 3,9.

Taking into account the active length L_o in accordance with recommendations /1, 2 / equal to threefold of width of water passage and movement velocity of ice floes equal to 0,9 of surface current velocity / V_o / and with / ρ / designating the part of river water plane covered with ice, we find (fig.1)

$$T = \frac{\Omega h \gamma V_1^2}{2g} = \frac{B_o^2 h \rho V_o^2}{8,6} \quad (3)$$

The storage of kinetic energy of the crushed ice masses transmitted on one bridge pier, may be found equal to

$$T_1 = \frac{T}{n} = \frac{B_o^2 h \rho V_o^2}{8,6 n} \quad (4)$$

It is evident that the ice jam will not take place, when / T_1 / has been enough to destroy the ice floes at the bridge piers with length / l_1 /.

Designating with / H / the horisontal ice pressure component at the breaking up of ice field by the bridge pier , we obtain unconditional inequality

$$T_1 \geqslant H l_1 \quad (5)$$

Whose using may be found from (4) the relationships for limiting case

$$\lambda = \frac{B_o}{n} \geqslant \frac{8,6 H l_1}{h \rho V_o^2} \quad (6)$$

It is easy seen that the value / λ / is always a little more than the bridge span / l /, with the relationship valid for

$$l = \lambda \frac{n}{n+1} \quad (7)$$

Estimating the different values of the number of the bridge piers / n /from 4 to 10 can be obtained, that the relationship / λ /

changes from 0,80 to 0,91 and at an average may be taken equal to 0,85.

A minimum size valid for the bridge span may be found from the expressions (6,7)

$$\ell \geq \frac{7{,}3\,\kappa\, b_o\, \ell_1}{\rho\, V_o^2\, B_o} \qquad (8)$$

where κ is the specific dynamic pressure of the ice /ton/sq.mt/ arising with the crushing or breaking ice cover by the bridge pier.

The relationship (8) takes into account the velocity streamflow / V_o /, concentration of floating ice / ρ /, the ice floe dimensions / ℓ_1 /, as well as the ice strength, the size and the form pier in plane and in profile / κ / and thus it shows the effect of most essential factors. The formula (8) is shown in the normative documents (5).

It should be noted that from field observations for ice run on the Siberian rivers may be taken into account

concentration of floating ice $\rho = 0{,}66 - 0{,}85$

size of ice floes $\ell_1 = (0{,}05 - 0{,}12)\,B_o$

As is seen in figure 1 the relationship (8)is obtained for particular case, when the width of stream flow is equal to the bridge opening. With the construction of bridges the opening is designed often less than the width of streamflow /fig.2/. Using the method at the first approximation similar to considered above,may be obtained a more common relationship to be determined a minimum size valid for the bridge span from condition of the ice movement free of obstructions

$$\ell_1 \geq \frac{7{,}3\,\kappa\, b_o\, \ell_1\, f}{\rho\, V_o^2\, B_o} \qquad (9)$$

Here the parameter / f / may be determined by the formula depending upon the relationships of the width of streamflow (at site of river crossing during spring ice run) to the dimensions of the bridge span.

$$f = \frac{2}{z+1}; \quad z = \frac{B_o}{L}. \qquad (10)$$

The dimensions / f / for different / z / may be determined by the table :

z =	2,00	1,75	1,50	1,25	1,00
f =	0,66	0,71	0,80	0,89	1,00

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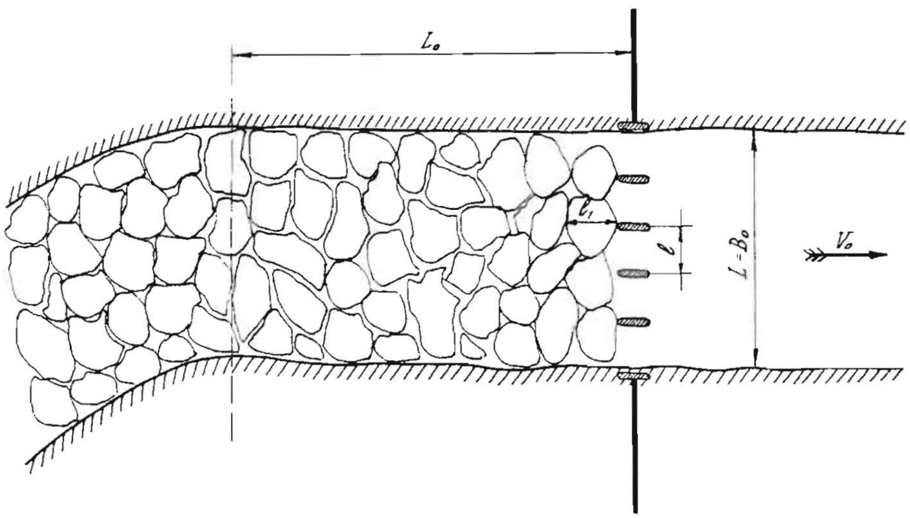
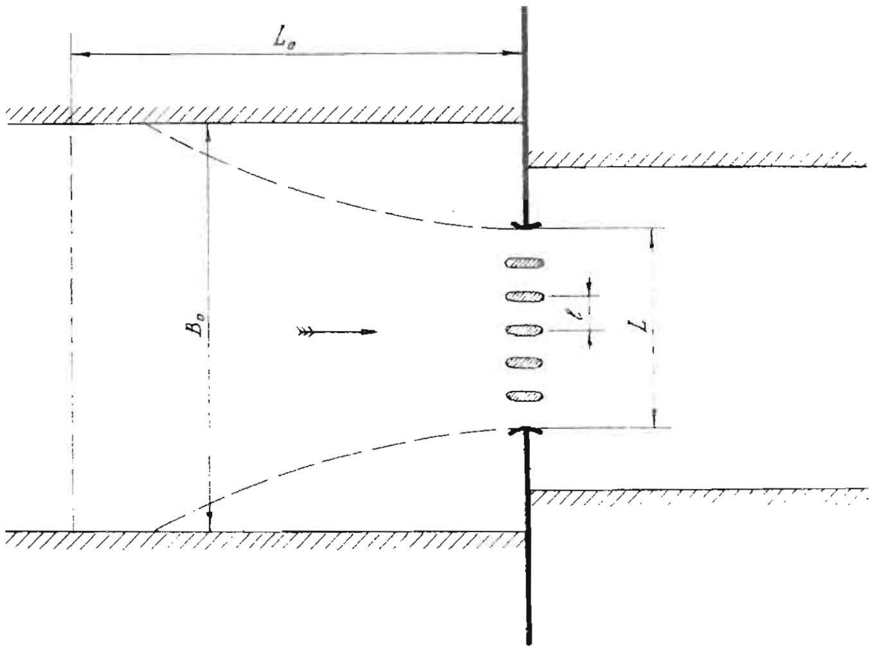


F i g. I

View of ice at bridge.



F i g. 2

Scheme of bridge.

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SOME HYDRAULIC AND NAVIGATIONAL CHARACTERISTICS OF CROSSINGS BETWEEN A RIVER AND NAVIGATION CANAL

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ABSTRACT

The substance of the hydraulic and navigational problem of a level crossing of a river with a navigation canal lies in the diametrically opposite requirements concerning the magnitude of river flow velocity at the crossing. In this connection several hydraulic phenomena, occuring at the crossing, which affect its navigation properties, are pointed out. Equations have been derived for the approximate calculation of the water volume exchange between the river and the mouth of the canal at the crossing.

SOMMAIRE

Le principe du problème hydraulique et de navigation du croisement à niveau de la rivière avec le canal de navigation consiste dans les exigeances diamétralement contraires présentées sur la vélocité de l´ecoulement fluvial dans le croisement. Dans ce contexte on a souligné quelques-uns des phénomènes hydrauliques existant sur un croisement qui influencent les qualités de navigation.

Les équations sont dérivées pour le calcul approximatif de l´échange du volume de l´eau entre l´écoulement sur le croisement et la tête du canal.

The substance of the hydraulic and navigation problem of crossing a river with a navigation canal lies in the diametrically opposite requirements for the magnitude of the river flow velocity at the crossing. From the point of view of bedload transport in the river, this velocity must be as high as possible in order to prevent the widening of the river flow and in turn the settling of the bedload. On the other hand, to permit vessels including tow and large pusher trains to meet safely at the crossing and to turn from the canal into the river and vice versa, it is desirable for the riverflow velocity to be as low as possible.

Due to these contradictional requirements, hydraulic phenomena may be encountered at the crossing which affect negatively its navigation properties. Some of them are to be mentioned here.

Since there is no left and right river bank at the crossing, a regular oscillation of the river flow occurs from one canal mouth to the other due to the geometrical assymetry of the riverbed and due to the obstacles to the watermass movement (narrowing of the navigation canal behind its mouth, sluice chamber) on both canal branches (Fig. 1).

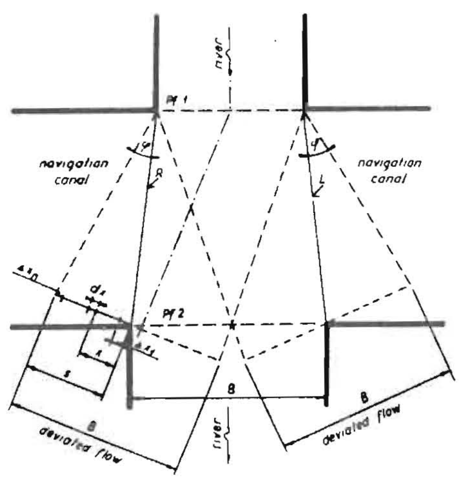

Fig 1

This oscillation results in the exchange of water between the river and the canal mouth which supports the siltation of the entrance to the two canal branches by suspended sediments carried by the river, causes unstationarity of the discharge below the crrossing and affects adversely the trajectories of ships crossing the river.

Water Exchange between the River and Navigation Canal Mouth. The siltation rate in the canal mouth depends on the magnitude of the water volume exchanged between the river and the canal mouth. If this exchange is small, only a small discharge water quantity carrying bedload enters the mouths of the two canal branches from the river and hence only little bedload settles in the mouth. When the discharge exchange is greater, the quantity of bedload settled in the mouths will be naturally also greater so that it can even create a navigation hindrance. For this reason we are interested in the calculation of at least the approximate discharge quantity which enters each mouth in one oscillation period of the river flow. Let us derive equations for this calculation.

For the derivation of these equations we start from simplifying assumptions:

1. The water leaves the oscillating watercourse (Fig. 1) only through its outflow profile 2; actually it will flow out also through the lateral surfaces L and R; through these surfaces the water will also reenter the river from the mouth.
2. The water velocity in profile 2 is constant in all points of this profile and equals the profile velocity U_2.
3. The deviation velocity of the water flow into the canal basin and its return velocity to its initial position is equal when the deviation angles of the flow is the same.

First, let us derive the equation which is suitable for the calculation of the discharge quantity which enters the mouth, when from direct measurements the time dependance of the deviation magnitude s of the flow is known:

$$x = f(t) \tag{1}$$

In time $t_1 = \Delta t$, the flow deviates from its initial position in the direction into the basin by segment Δx_1 (Fig. 1). In the same time interval the water quantity

$$Q_1 = \Delta Q_1 = \Delta x_1 \, H \, U \, \Delta t \tag{2}$$

passes through the surface $\Delta F_1 = \Delta x_1 \, H$. In time $t_2 = t_1 + \Delta t = 2 \Delta t$, the flow deviates from the initial position by

$\Delta x_1 + \Delta x_2$, whereby through segment Δx_1 the discharge quantity $2 Q_1 = 2 \Delta Q_1$ passes in time t_2 and through segment Δx_2 passes $\Delta Q_2 = \Delta x_2 H U \Delta t$ in time Δt.
The total discharge quantity passing through the deviated flow in time $t_2 = 2 \Delta t$ amounts then to

$$Q_2 = H U \Delta t (2 \Delta x_1 + \Delta x_2). \quad (3)$$

Adding all partial discharge quantities entering the basin in time $t_s = n \Delta t = \frac{T}{4}$ through the partial segments Δx_1 to Δx_n, we receive for the corresponding discharge quantity $Q_{1/4}$

$$Q_{1/4} = H U \Delta t \left[n \Delta x_1 + (n-1) \Delta x_2 + \dots + \Delta x_{n-1} + \Delta x_n \right]. \quad (4)$$

In Eqs (1) and (4) n = the number of intervals into which time t_s is divided, t_s = time after which the flow deviates from the initial position to the position of maximum deviation s, T = oscillation period.

Let us now derive an equation for $Q_{1/4}$ assuming that function f in Eq. (1) is given by the law of simple harmonic movement according to which

$$x = s \sin \frac{t_x}{t_s} \frac{\pi}{2} \quad (5)$$

where t_x is the time necessary for the flow deviation to reach value x. Through the element of the area dF_x of the outflow profile, the water passes into the basin during the time

$$\Delta t_x = t_s - t_x \quad (6)$$

after which the river flow deviation is greater than that given by length x. For t_x we get from Eq. (5)

$$\Delta t_x = \frac{2 t_s}{\pi} \arcsin \frac{x}{s} \quad (7)$$

Introducing Eq. (7) into Eq. (6)

$$\Delta t_x = t_s \left(1 - \frac{2}{\pi} \arcsin \frac{x}{s}\right). \quad (8)$$

The discharge quantity passing through $dF_x = dx\, H$ in time Δt_x is $dQ = H U \Delta t_x\, dx$ and expressing Δt_x in the last expression by Eq. (8),

$$dQ = H U t_s \left(1 - \frac{2}{\pi} \arcsin \frac{x}{s}\right) dx. \quad (9)$$

The total discharge quantity $Q_{1/4}$ discharged in time t_s with a river flow deviation from its original position from $x = 0$ to its maximum deviation $x = s$, is

$$Q_{1/4} = H U t_s \int_0^s \left(1 - \frac{2}{\pi} \arcsin \frac{x}{s}\right) dx \quad (10)$$

and by integrating we obtain

$$Q_{1/4} = \frac{2}{\;} H\, U_s\, t_s \tag{11}$$

From the third assumption it follows that for a discharge quantity $Q_{1/2}$, which enters one basin in half an oscillation period (and thus even in a whole oscillation period), the following relation $Q_{1/2} = 2\, Q_{1/4}$ holds true.

If the number of the water flow oscillation is n in 1 hour, the quantity of water flowing into the basin of one canal branch is $Q_{1\ hr} = n\, Q_{1/2}$.

The discharge quantity entering the basin in time T/2 cannot be stored in the basin permanently. This quantity flows from the basin into the riverbed during the second half of the oscillation, i. e. during the time, when the water of the deviated flow enters the oposite basin. It is evident that the flow of water from the basin into the river channel is not uniform so that the discharge per second in the riverbed below the crossing during the oscillation period fluctuates and is not equally distributed over the riverbed width.

Effect of Flow Conditions at the Crossing on the Trajectories of Ships. The safety of the crossing of the river by ships sailing in the canal and the safety of their mutual encounter at the crossing depends in the first place on the flow conditions at the crossing, since these conditions determine the trajectory width B of the ships crossing the river (Fig. 2). Let us consider some of the factors affecting this width.

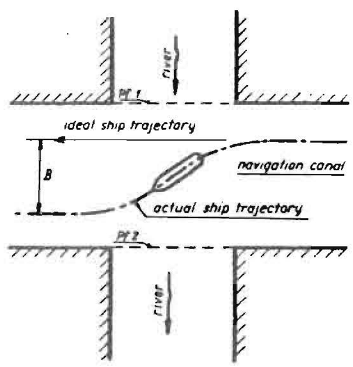

Fig. 2

a) At the given ship velocity and way of manoeuring ath the crossing, the width B of the ship trajectory is greatly affected by the profile velocity U_1 of the river in profile 1. The hydrodynamical resistance R of the submerged part of the ship-hull surrounded by turbulent flow having a velocity U_1, is

$$R_1 = \frac{1}{2} c_1 \varrho U_1^2 S \tag{12}$$

where c_1 = coefficient of the total ship-hull resistance, ϱ = water density, S = section through the ship-hull perpendicullarly to the direction of the water flowing round it. If the flow velocity in profile 1 is changed from U_1 to U_2, the resistance of the submerged part of the ship is, under otherwise identical conditions:

$$R_2 = \frac{1}{2} c_2 \varrho U_2^2 S. \tag{13}$$

With the turbulent flow surrounding the ship-hull, $c_1 \approx c_2$ so that the relation between force R_2 and R_1 is given by

$$R_2 \approx R_1 \left(\frac{U_2}{U_1}\right)^2 . \tag{14}$$

Since the trajectory width B is proportional to the resistance R, we can write that $B_1 : R_1 = B_2 : R_2$, i. e.

$$B_2 \approx B_1 \frac{R_2}{R_1} = B_1 \left(\frac{U_2}{U_1}\right)^2 . \tag{15}$$

From this equation it can be seen that for $U_2 < U_1$ we obtain at the crossing a significant decrease of trajectory width B and in turn an increase in the safety for the crossing of the boat in the river.

b) The trajectories of the ships crossing the river are affected by the angle, which is enclosed by the deviated water flow and the ideal ship trajectory. If this angle is a sharp one and the movement of the crossing ship takes place in the direction to that side of the canal to which the flow is deviated, the ship´s velocity increases considerably. This greater velocity of the ship is the cause of the greater width B and thus also of the increased danger of collision of boats which meet at the crossing.

c) The crossing is the cause of singular energy losses in the river. For this reason, the river at the crossing has a greater surface gradient than would be the case, if it were not disturbed by the crossing. The increased longitudinal water surface slope, however, affects to a greater extent the trajectories of ships moving in the crossing. A ship sailing in the canal and crossing the river axis perpendicular to its longitudinal axis, is driven, by the component G $\sin\alpha$ of its weight, in the direction to the lower banks (G = ship weight, α = angle of water surface slope with the horizontal at the crossing). For this reason the sailing of ships through the crossing is safer when the ship crosses the river obliquely against the direction of its flow.

From the above and some other analyses it appears that the optimal shape of a navigation crossing is the one shown in Fig. 3. Its characteristic features are:

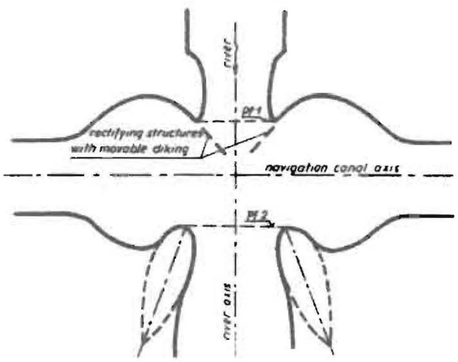

Fig 3

1. mutual perpendicularity of the river axis and the two canal branches;
2. symmetrical and parallel position of profile 1 to profile 2, i. e. the longitudinal axis of profile 1 and 2 are not shifted against each other in the ground plan;
3. circular widened mouths of the two canal branches (such mouths has the crossing of the river Lek with the Amsterodam-Rhine Canal /1/);
4. the banks of the inflow channel reach above profile 1 have a hydraulically suitable shape, used e. g. in rectifying structures of bridge profiles; the objective of this measure is to equalize the velocity profile of the water flow entering the crossing;
5. the approach edges of profile 2 and the adjoining banks of the riverbed have also a hydraulically suitable shape;
6. the navigation chambers on the canal are to be removed a much

as possible from the crossing (at least about 1 km).

Although these characteristics can improve the total hydraulics and navigational function of the crossing, they cannot solve the basic dilemma between the hydraulic requirements with regard to satisfactory bedload transport in the river and the navigation requirements demanding the lowest possible velocity of the river at the crossing. This dilemma may be alleviated by providing rectifying structures with movable tilting diking in the river inflow to the crossing, which permit to change the size of the discharge area of the inflow profile and thus also the flow velocity of the river in the crossing. This may be used with advantage for the passage of long towing and for flushing the rivebed in the crossing section to remove settled bedload (for increasing the velocity).

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A STUDY OF THE THERMAL BALANCE OF THE ST.LAWRENCE RIVER IN WINTER REGIME

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ABSTRACT

The purpose of this study was to develop a method for the calculation of temperatures in the St.Lawrencé River for natural conditions before freeze-up and the forcast of the possibility to keep river channel ice-free in winter-time.

The paper presents the analysis of hydrological, thermal and meteorological conditions for the investigated river section, calculation of heat transfer coefficient, and the development of the method for the calculation of river temperatures. Verification of the method was based on data from field measurements. Three ways of improving thermal conditions in the river were considered: increase of discharge, decrease of water surface by river training in the form of a regimented channel, and the utilization of waste heat from thermal or nuclear power plants.

SOMMAIRE

Les études presantées dans ce rapport avaient pour but l'élaboration de la méthode du calcul de la temperature d'eau dans les conditions naturelles avant la période du gel du fleuve, ainsi que de la progose de la possibilité d'entretien en l'hiver du lit du fleuve sans glace.

Dans le rapport on présente une analise des conditions hydrologiques, thermiques et météorologiques du tronçon étudié du fleuve, les calculs du coefficient d'échange de chaleur et une méthode de calcul de la temperature d'eau. Sur la base des données de mesures en nature on a verifié les calculs. On a resolu trois moyens d'amélioration des conditions thermiques en fleuve, c'est a dire par: l'augmentation du débit, la diminuation de la surface d'eau par la régulation du lit du fleuve, et par la chaleur rejetée des centrales thermiques ou nucleares.

1. INTRODUCTION.

The St.Lawrence River as a traditional navigation route was always of great importance to Canada. Considerable thought was given to the improvements of navigation and in particular to the possibility of maintaining it a year-round ice-free channel.Many proposals were advanced in the past to achieve this end. Barnes [1] studied the effectiveness of icebreakers and pointed out the possibility of utilizing the large heat content of Lake Ontario. Kerry [5] strongly advocated the use of heat reserve of Lake Ontario by channelling the river flow so that heat losses would be reduced. During 1951-3 Pruden et al [6] conducted thermodynamic studies to evaluate heat losses by theoretical and empirical formulae. In 1961 Hydraulics Section of the NRC initiated temperature measurements in the St.Lawrence River from Kingston to Port St.Francois. As a result of field observations Ince [4] found that because of thorough turbulent mixing, stratification and temperature gradients are destroyed. Close agreement between recorded and calculated water temperatures was obtained with the heat loss coefficient recommended for open water conditions by Joint Board of Engineers.

2. RIVER DISCHARGE.

Discharge in the St.Lawrence River from Kingston to Port St. Francois is very steady due to the influence of Lake Ontario and hydraulic structures which control the flow. The minimum and maximum discharge assumed for this study are 170 000 and 300 000 cfs respectively. These values were increased by 40 000 cfs for Ottawa River. The average discharge in the fall and early winter is 210 000 cfs increasing to 250 000 cfs after the inflow of Ottawa R.

3. THERMAL AND ICE CONDITIONS.

Hydraulics Section iniciated in 1961 water temperature measurements and ice surveys which were indispensable for the evaluation of thermal conditions. Permanent recording stations were established along the river section 256 miles long. For the present study, average daily water temperatures were used. During months of December and January ice surveys were made and maps of solid ice cover were outlined.

4. METEOROLOGICAL CONDITIONS.

The present study is based on average daily and monthly values of various meteorological variables. This was considered as sufficiently adequate for the comparison of alternative ways of keeping the river ice-free. The normal monthly air temperatures for November and December Table 1 do not differ very much for 6 stations along investigated river section. Therefore it was decided to use meteorological data for one station Montreal as representative of the whole river section, to calculate heat transfer coefficient. This data is listed in Table 2.

Table 1. Normal monthly air temperatures.

Location	Distance from Kingston	Air temperatures (^{o}F) November	Air temperatures (^{o}F) December
Kingston	0 miles	37,3	23,5
Brockville	48	37,2	22,6
Cornwall	104	33,6	20,1
Montreal	166	35,7	20,1
Sorel	226	33,4	16,9
Port St.Franciois	256	33,6	17,3
	Average	35,3	20,1

Table 2. Average meteorological data for Montreal.

Month	t_a	V	h	m	S	Q_{IR}	t_w	$t_w - t_a$
October	49	10,7	74	5,9	0,02	794	58	9
November	36	11,7	78	7,3	0,28	384	46	10
December	20	11,8	79	7,3	0,73	391	34	14
January	16	12,4	78	6,4	0,76	593	32	16
February	17	12,6	77	6,6	0,81	790	32	15

t_a -air temperature (^oF)
V -wind velocity (mph)
h -humidity (%)
m -cloudiness (tenths)
S - snowfall (in/day)
t_w - water temperature (^oF)
Q_{IR} - incoming radiation (BTU ft^2 day)

5. HEAT TRANSFER COEFFICIENT.

In order to calculate heat losses from the river it was necessary to formulate heat loss rate in a sufficiently simple form that can be integrated along the river reach during the time, a particle of water moves along the reach. The calculation of heat transfer coefficient was based on the amount of heat flow through river surface which is composed of the following contributing elements: evaporation, convection, incoming radiation, back radiation, and precipitation. The following formulas were used for calculation.

Evaporation, based on Mayer formula

$$Q_E = 1{,}92\lambda\,(1 - 0{,}1\ V)\,(e_w - e'_a) \qquad (\text{BTU/ft}^2\ \text{day}) \qquad (1)$$

λ - heat of evaporation (BTU/lb)
e_w - saturated vapour pressure at water temperature (in Hg)
e'_a - vapour pressure of water at given air temperature and relative humidity h (in Hg)

Incoming radiation was obtained from direct measurements.

Convection based on the Bowen ratio

$$Q_C = Q_E \cdot 0{,}0108 \cdot \frac{(t_w - t_a)}{(e_w - e'_a)} \qquad (\text{BTU/ft}^2\ \text{day}) \quad (2)$$

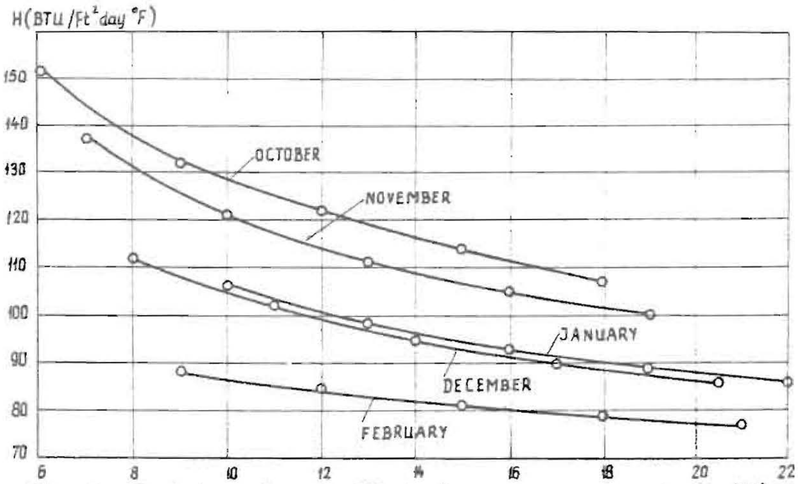

Fig. 1. Heat transfer coefficient.

Back radiation

$$Q_B = \sigma T_w^4 \left(1 - 0{,}09\ m\right)\left(1 - a_b - b_b \sqrt{e_a'}\right) \quad (\text{BTU/ft}^2\ \text{day}) \quad (3)$$

σ - Stefan Bolzman constant $\qquad a_b = 0{,}43$
T_w - water temperature (^{o}R) $\qquad b_b = 0{,}082$

Precipitation snow

$$Q_S = 0{,}52\ S\left[144 + (t_w - 32)\right] \qquad (\text{BTU/ft}^2\ \text{day}) \qquad (4)$$

The heat absorbed by precipitation falling into river is mainly due to snow because of the heat of fusion. Rainfall was excluded from the consideration because of its infrequency in this period and its small heat exchange with the river. Calculation of heat transfer coefficient was based on the average meteorological conditions given in Table 2. For each month 5 different air temperatures were assumed. The highest values of the coefficient were obtained for October and the lowest for February Fig.1. Average values for December and January 95 BTU ft^{2}day ^{o}F were very close to those suggested by the Joint Board of Engineers. It was decided to use the average value of the coefficient in further calculation.

6. DERIVATION OF THE FORMULA FOR CALCULATION OF WATER TEMPERATURES.

For the derivation of the formula the following simplifying assumptions were made. 1 The flow over the section of the river is steady and uniform, with uniform velocity over the whole cross-section. 2 Water temperature is uniform over the whole cross-section. 3 Heat flow through river bed, heat gain due to fluid friction, and heat flow due to ground water flow into or out of river are neglected.

Using the notation presented in Fig.2. the following heat balance eqation may be written:

$$Q\,\rho\,c\,t_w = Q\rho c\left(t_w + dt_w\right) + W\ H\ dx\left[\left(t_w + \tfrac{1}{2}\ dt_w\right) - t_a\right] \qquad (5)$$

ρ - water density $\qquad$ c - specific heat of water

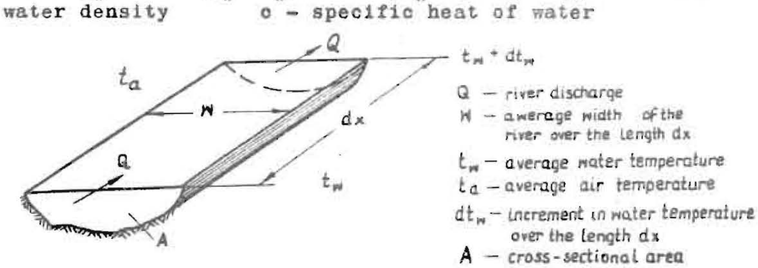

Fig. 2. Scheme for the calculation of water temperatures.

This equation may be simplified to:

$$Q\,\rho\,c\ dt_w = -W\ H\ dx\left(t_w - t_a\right) \qquad (6)$$

After integration we obtain

$$t_{w1} = \left(t_{wo} - t_a\right) e^{-K} + t_a \quad (7) \qquad K = \frac{H\ s}{Q\,\rho\,c} \quad (8)$$

s- water surface between cross-sections 0 and 1

7. PROGRAMME FOR THE COMPUTOR.

To calculate water temperatures along the St.Lawrence River, the section under study was devided into 2 miles sections for which surface areas S_i and cross-sectional areas A_i were calculated.

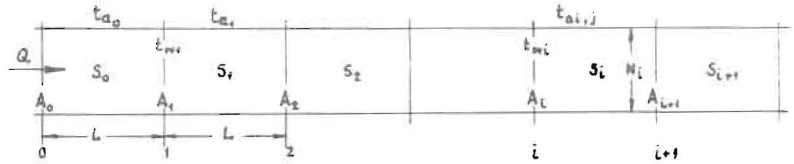

Fig. 3. Scheme for the numerical procedure.

The scheme presented in Fig.3 was used for numerical procedure. For these notation the formula for temperature calculation obtains the following form:

$$t_{w_{i+1}} = e^{-Ki}\left(t_{wi} - t_{a_{i,j}}\right) + t_{a_{i,j}} \qquad 9$$

j - is the time index

In order to evaluate air temperature for a particular cross-section it was necessary to interpolate it according to distance between two meteorological stations, and time of travel of water particle. The programme prepared for SDS-920 computor allowed for discharge and water temperature changes at each of the 2 miles sections. Average daily air temperatures were prowided in a tabular form for each of the six meteorological stations. Description of river included cross-sectionel areas and water surface areas between two cross-sections. Each calculation started with a definite initial water temperature t_w at cross-section 0 Kingston. Results of the calculations are presented as graphs made on a plotter connected to the computor. They include temperature curve, cumulative time curve, air temperature curve obtained from interpolation, and discharge curve.

8. COMPARISON OF CALCULATED AND OBSERVED WATER TEMPERATURES.

In order to check the method developed for calculation of water temperatures, several comparisons between measured and calculated water temperatures were made. Three of them for a definite periods of time are prsented in Fig.4. They were carried out for discharge 210 000 cfs, heat transfer coefficient 95 BTU/ft^2 day $^{\circ}$F definite initial water temperatures, and air temperatures taken from the records. The first two periods 11-27 Dec. 1964 and 1-17 Nov. 1965 gave very good agreement. This agreement for the period 1-17 Dec.1963 was not good. During that time temperatures of the air were well below normal which resulted in rapid ice formation. This reduces water surface exposed to heat transfer and also releases heat of fusion thus reducing cooling process. These factors were not taken into account during the calculation of heat transfer coefficient. Reduction of the coefficient to the value of 75 gave already more close results with observed water temperatures.

From these comparisons it may be concluded that the value of the coefficient 95 will give correct water temperatures before freeze-up. However when ice begins to form, discrepancies between calculated and measured values may be expected.

9. SOME METHODS FOR IMPROVING THERMAL CONDITIONS IN THE RIVER.

Three methods for improving thermal conditions in the river were taken into account in this study.

1. Partly regimented channel. Confining river channel to a smaller cross-section has two results: (a) decrease of water surface area reduces heat losses: (b) increase of flow velocities reduces the time during which a water particle travelling along the river is

exposed to heat losses. The channel will be restricted only in reaches where it is feasible from engineering poit of view.

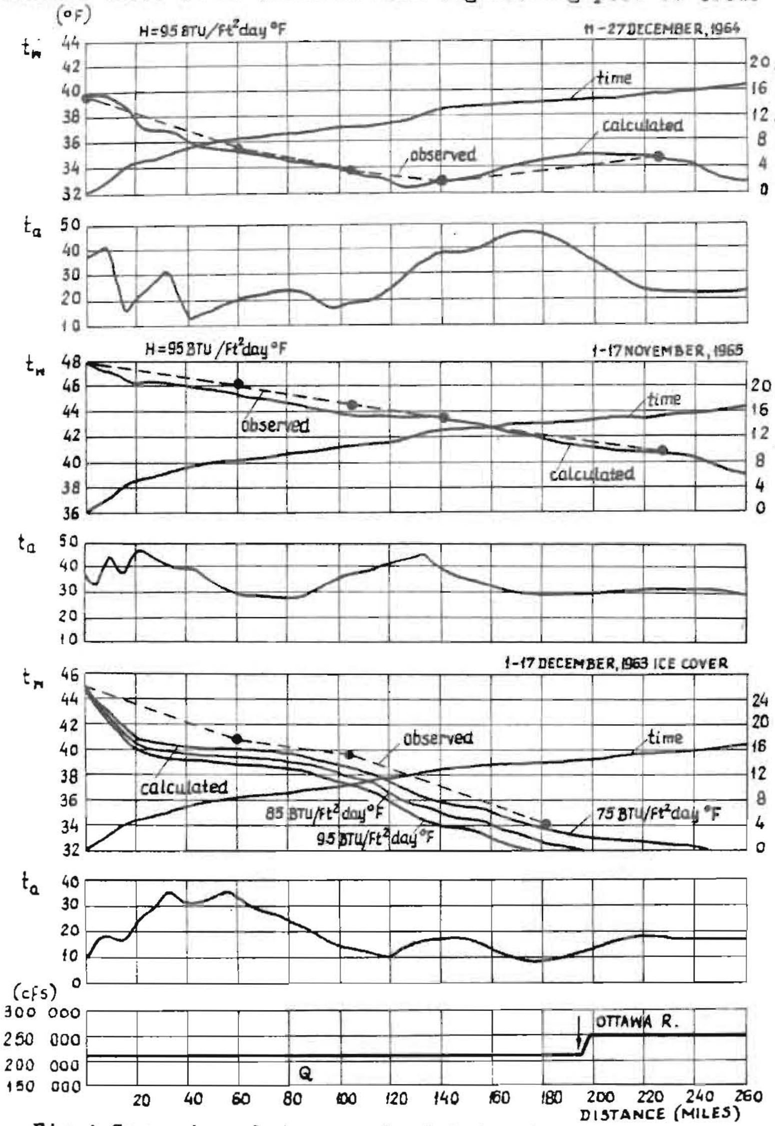

Fig.4 Comparison between calculated and measured water temperatures.

2. Increase of river discharge. It results in higher flow velocities, thus (assuming that surface areas and cross-sections remain unchanged) reducing the time of travel and hence heat loss. At the same time, initial heat input becomes larger.
3. Heat addition from thermal or nuclear power plants. At present in fossil fuel thermal power plant about 60% of the generated heat is rejected with cooling water [2]. For nuclear power plant this efficiency is even lower. For discharge of 210 000 cfs the increase of temperature of 1°F assuming thorough mixing is an equiwalent to a power station of the capacity of 7250 MW. Thus 6 increaments of 1°F give the total installed capacity of 43 500 MW, while 5 increaments of 1°F will result in capacity of 36 250.

Results of some investigated cases are presented in Fig. 5,6,7.

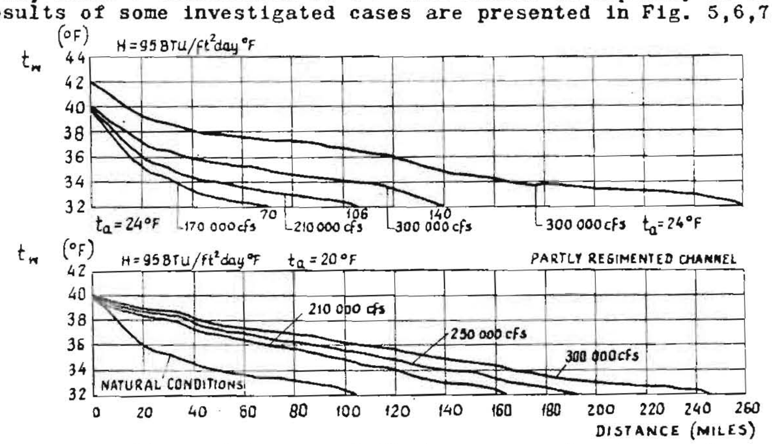

Fig. 5. Effect of increased discharge on water temperatures.

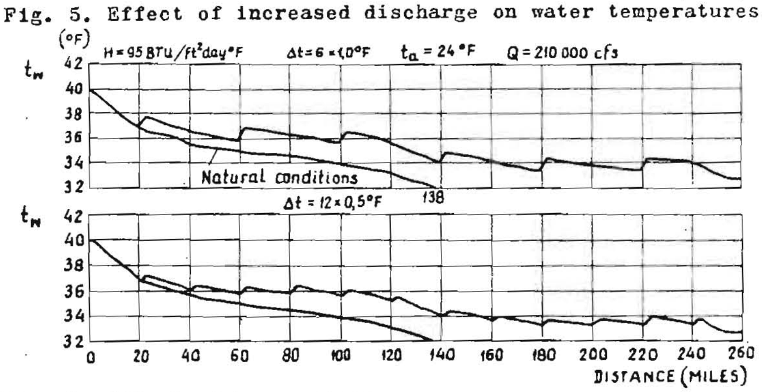

Fig. 6. Effect of heat addition on water temperatures of natural river.

10. CONCLUSIONS.

1. Using the outlined above method it was possible to calculate water temperatures along the St. Lawrence River for different boundary conditions.

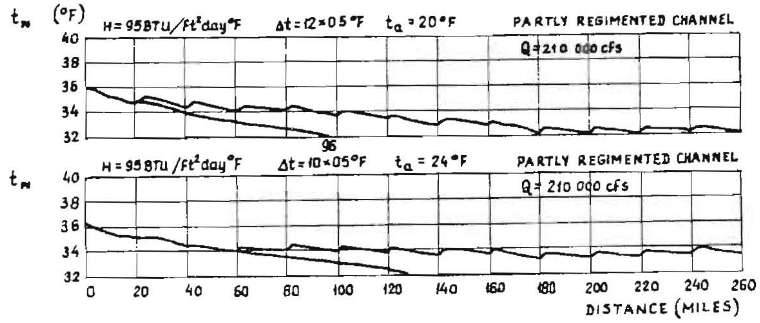

Fig. 7. Effect of heat addition on water temperatures of partly regimented channel

2. The heat transfer coefficient calculated on the basis of average meteorological conditions represents the cooling process quite accurately for the period before freeze-up. This was confirmed by comparisons of measured and calculated water temperatures. In case of ice formation the value of heat transfer coefficient should be reduced.
3. Three methods for improving thermal conditions were considered. Increase of natural river discharge, and partly regimented channel may be applied for the period when water temperatures in Kingston are still about 42°F and air temperatures do not drop significantly below 32°F. With lower air and water temperatures this method will not be sufficiently effective.

   Waste heat addition from power stations can provide an ice-free navigation channel over the whole winter. Total power capacity requirement is about 45 000 MW which may be installed in 12, 10 or 6 stations along the river. Regimented channel combined with waste heat addition gives very good results.

ACKNOWLEDGEMENTS.

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ENTRAINMENT OF ICE BLOCKS - SECONDARY INFLUENCES

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ABSTRACT

The conditions under which a floating fragment of ice is either entrained under the upstream edge of a downstream ice cover or accumulated upstream are examined in detail. The effects of the geometry of the leading edge and of the arriving fragments on the critical Froude number for entrainment are determined and provide criteria for modelling studies, and for the design of stable channels in river ice covers. The mathematical model considers both flow depth and thickness Froude effects as well as the thickness-length ratio of the blocks and the specific gravity. Combination of an equilibrium moment analysis with hydrodynamic relations enables explicit determination of the effects of t/L and t/H (t = thickness, H = flow depth, L = block length) on the critical Froude number ($F_t = V/[gt(1-\rho'/\rho)]^{1/2}$) for entrainment. Analytical results are compared to experimental results.

SOMMAIRE

INTRODUCTION

The processes of accumulation of floating ice under the action of river and lake currents are of considerable interest to those who must design structures to control ice movement. Understanding of the interactions between floating ice and the flowing water are also useful in the design and operation of vessels moving through ice fields, in the prediction of effects resulting from changes in the ice regime of rivers and lakes, and in the avoidance of ice problems. Herein the processes of entrainment and accumulation of floating ice fragments at an obstruction near the surface of the flow are examined and interpreted. The basic problem considered is the process of initial entrainment of a single ice fragment arriving from upstream.

Behavior of Individual Blocks

We examine first the behavior of an individual block which strikes an obstruction near the surface (see Figure 1). Two modes of entrainment, or submergence, have been identified in the laboratory and a third in field observations. The block may submerge without rotating or underturning and be swept under the cover while remaining in a more or less horizontal orientation; this mode is termed vertical submergence. The block may rotate about its downstream end, either about the lower edge or the upper edge depending upon the detailed geometry of the obstruction or the block, subsequently underturning and either passing downstream or stacking in an inclined position to form a thicker cover. Finally, the block may ride up over the obstruction.

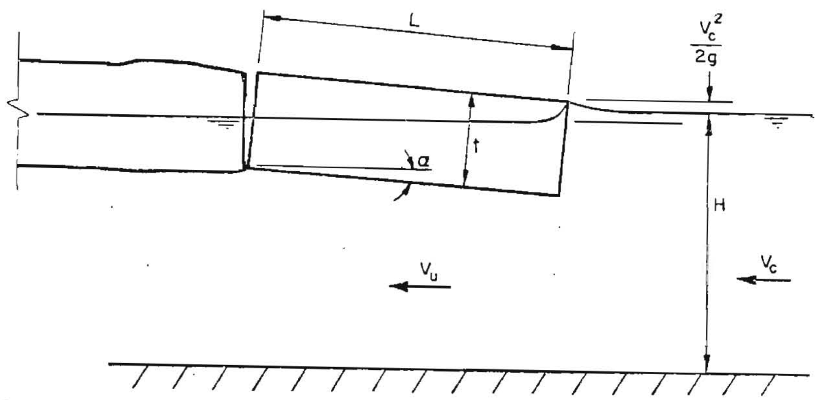

Figure 1 - Definition sketch

The condition for vertical submergence has been analyzed (Michel, 1971) by equating the pressure reduction due to the increased velocity beneath the floe to the force required to overcome the buoyancy of the floe. The analysis implies adoption of the so-called no-spill condition, i.e., that entrainment occurs when the stagnation water level exceeds the top edge of the floe. The resulting criterion for vertical submergence is

$$\frac{V_c}{[gt(1-\rho'/\rho)]^{1/2}} = \sqrt{2} \tag{1}$$

Michel (1971) also introduces a lift coefficient applied to the pressure reduction term which is dependent upon the form of the floe, and separately considers the porosity of the floe although the basis for the former is not clear and the latter may easily be included when calculating the floe density ρ'.

Most floes submerge by underturning, as pointed out by Pariset and Hausser (1959, 1961), Cartier (1959), and more recently by Uzuner and Kennedy (1972). The underturning usually occurs at a lower velocity than given by equation (1) and has been treated analytically by introducing a multiplier K on the right-hand-side of equation (1). Pariset and Hausser presented the stability criterion in terms of the average velocity under the block (V_u) in the form (see Figure 1),

$$\frac{V_u}{[gt(1-\rho'/\rho]^{1/2}} = K\sqrt{2} \tag{2}$$

and evaluated K in laboratory and field tests as a function of L/t and L/b (where b is the transverse plan dimension of the block). K was found to vary from 0.66 for cubic blocks to 1.3 for thin floes. An effect of t/H is implied in equation (2) since approximately

$$V_u = \frac{V_c}{1-\frac{t}{H}} \tag{3}$$

Uzuner and Kennedy (1972), using a moment equilibrium method, interpreted the results of single block experiments for a wide range of t/H, t/L, and ρ'/ρ ratios and empirically determined a moment coefficient presented as a function of ρ'/ρ and t/L. They found both short, thick (t/L >0.8) and long, thin (t/L <0.1) blocks to undergo vertical submergence while blocks with intermediate t/L underturned. When their moment coefficient is zero their analytical result is essentially the same as the criterion given by equation (2).

Recently Ashton (1973) presented a simplified moment equilibrium analysis and also invoked the no-spill condition as the criterion for incipient instability. Underturning was found to occur when

$$\frac{V_c}{[gt(1-\frac{\rho'}{\rho})]^{1/2}} = \frac{2(1-\frac{t}{H})}{[5-3(1-\frac{t}{H})^2]^{1/2}} \tag{4}$$

The envelope of experimental results of Uzuner and Kennedy (1972) are presented in Figure 2 together with equation (4) and, for reference purposes, equation (2) with K = 1. Equation (4) provides good fit to the data in the range of greatest practical importance $0 < t/H < 0.5$, and adequately accounts

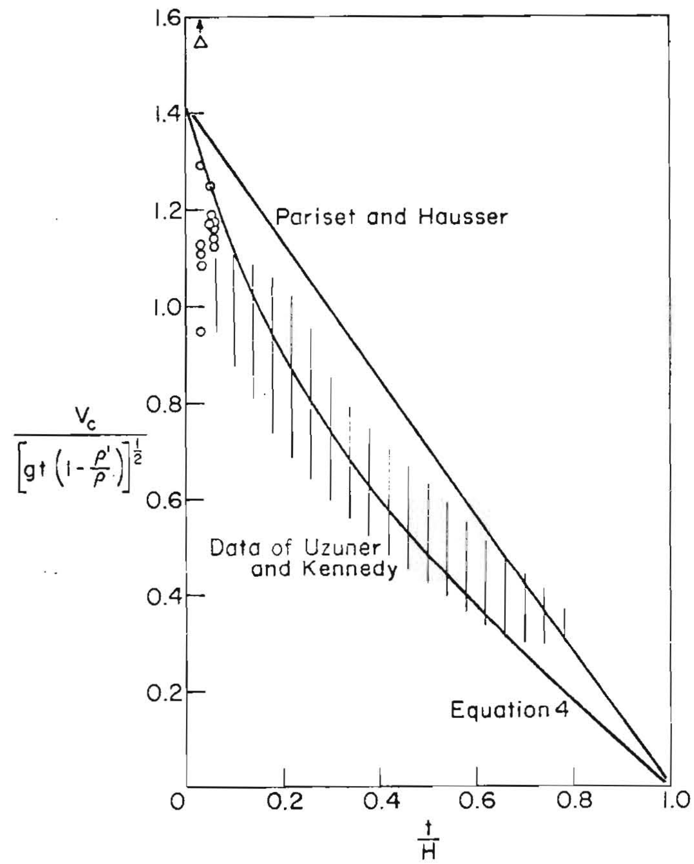

Figure 2 - Froude criterion based on block thickness

for the variation in ρ'/ρ over the experimental range 0.5 to 0.87. The data exhibit some effect of t/L (see Ashton, 1973), particularly at higher values of t/H. Within the limits of the scatter and the range of the data, equation (4) appears to provide a sound basis for design of models using materials of different densities to simulate the ice.

The same results may be presented in terms of a Froude number based on flow depth, again with a densimetric scaling parameter, by multiplying the left hand side of equation (4) by $(t/H)^{1/2}$. The corresponding plot of results is presented in Figure 3. For comparison the analytical result of Pariset and Hausser (1961) with K = 1 is also presented. Pariset and Hausser recognized the fact that K may be different than 1.0 but implied that K is

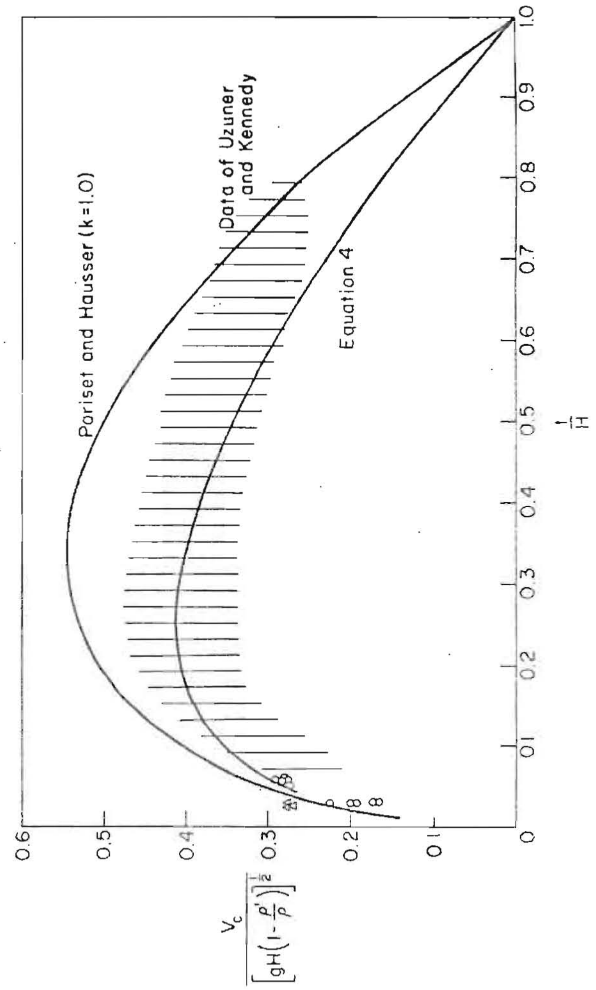

Figure 3 - Froude criterion based on flow depth

more a function of t/L than t/H. The extensive data of Uzuner and Kennedy suggest that K is not significantly affected by t/L, and in fact an empirical K may be replaced by the analytical prediction embodied in equation (4). In particular, comparison of equation (4) with equation (2) provides a means of evaluating the dependence of K on t/H, i.e.,

$$K = \left[\frac{2}{5-3\left(1-\frac{t}{H}\right)^2}\right]^{1/2} \qquad (5)$$

and K varies from 1.0 for $t/H = 0$ to 0.63 at $t/H \rightarrow 1.0$.

Equation (4) does not explain the observations of Pariset and Hausser (1961) of K values as high as 1.3 and similar values have been reported and observed by others (D. Foulds, personal communication), particularly for blocks with small t/L. It is also noted that there has been little experimental evidence presented for blocks with $t/L \rightarrow 0$.

In an effort to fill this gap in the existing data sets a series of rectangular blocks of small t/L ratio (< 0.1) were tested in a flume to determine if the existing relations for predicting underturning were valid for very small t/L and very small t/H. The blocks were of two thicknesses, with ρ'/ρ approximately 0.6. Two variations in the experimental procedure were used; in the first the block was released well upstream of a barrier shallowly submerged approximately one block thickness; in the second the block was initially against the barrier and the velocity was increased until underturning occurred. Little difference in behavior resulted between the two procedures. The results of these preliminary tests are presented in Figure 2 and Figure 3. Detailed examination of the data (see Table 1) shows a tendency for increasing K with decreasing t/L for the blocks which were 1.9 cm thick. Three series of tests with 0.67 cm thick blocks yielded K values considerably above the prediction (see Table 1) and suggest that there is a lower limit to the thickness at which the similitude relations developed earlier are applicable. Clearly more tests are needed if models are to utilize very thin blocks.

Acknowledgement is made to Darryl Calkins who aided considerably in performing the experiments. This work was supported by DA Project No. 4A062103A894, Engineering in Cold Environments.

TABLE 1

t (cm)	$\frac{\rho'}{\rho}$	$\frac{t}{H}$	$\frac{t}{L}$	$\frac{V_c}{[gt(1-\frac{\rho'}{\rho})]^{1/2}}$	K*	K**
1.9	0.57	0.052	0.122	1.19	0.89	0.93
"	"	"	0.083	1.25	0.93	"
"	"	0.060	0.106	1.17	0.88	0.85
"	"	"	0.053	1.14	0.86	"
"	"	"	0.040	1.17	0.88	"
"	"	"	0.032	1.15	0.86	"
"	"	"	0.026	1.17	0.88	"
"	"	"	0.021	1.17	0.88	"
"	"	0.031	0.106	0.95	0.69	0.92
"	"	"	0.053	0.99	0.72	"
"	"	"	0.040	1.08	0.79	"
"	"	"	0.032	1.11	0.81	"
"	"	"	0.026	1.13	0.82	"
"	"	"	0.021	1.29	0.94	"
0.67	0.56	0.027	0.045	1.69	1.23	0.93
"	0.060	"	0.029	1.65	1.20	"
"	0.64	"	0.022	1.70	1.23	"

* Defined by equation (2)

**Predicted by equation (5)

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THE DESIGNING OF PROLONGING NAVIGATION ON INLAND WATERWAYS WITH THE USAGE OF WASTE HEAT FROM INDUSTRIAL ENTERPRISES

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B.Borodkin - assistent professor of the Leningrad Water Transport Institute. USSR.

ABSTRACT

The paper deals with the conditions of rational use of spent water from industrial enterprises for prolonging navigation on inland waterways, as well as with the methods of thermal calculations, necessitated when designing these measures.

SOMMAIRE

Dans le rapport on examine les conditions de l'usage rationnel d'eau détendue des entreprises industrielles pour la navigation prolongée sur les voies d'eau intérieures, aussi qu'une méthode des calculs thermiques qui sont nécessaires au projet de ces mesures.

Nowadays the problem of prolonging navigation draws attention of experts in many countries of the world. It should be noted, however, that while the problems connected with providing the operation of navigable structures under negative temperatures may be considered mainly solved, navigation in mentioned conditions on both not canalized and canalized river sections, especially on navigable channels with limited cross-section still offers considerable difficulties. The use of ice-breakers and ship caravan convoying sharply increases the prime cost of shipping. Besides, the possibilities of such navigation on not canalized rivers and canals are rather limited as the ship route is strictly fixed and repeated ship passage causes such a cànsiderable increase of ice cover thickness that even an ice breaker is unable to overcome it. The suggestion to draw away ice beyond the verges of navigable route, when water course section is restricted, also proved non-perspective due to limited capacities for loose ice. In addition, under rather low temperatures, it may cause intensive frazilization on the open surface of water body, that complicates navigation conditions still more. The experiments carried out showed that even in reservoirs, where there are great opportunities to change routes, prolonging navigation by ice-breakers, that is maintaining regular navigation under rather severe climatic conditions, becomes not effective.

Along that, intensive construction of thermal power plants, condensation ones in particular, as well as atomic power stations requiring cooling ponds (which successfully might be navigable rivers, reservoirs and canals) are being carried out. But there arise complications caused by the fact that with unrestricted discharge of warm waters being cooled into a water body there comes danger of so called heat pollution affecting negatively the flora and fauna of a water body, Besides, effect for navigation, especially on water storage basins appears to be rather negligible owing to restricted volume of the lane, maintained de-iced.

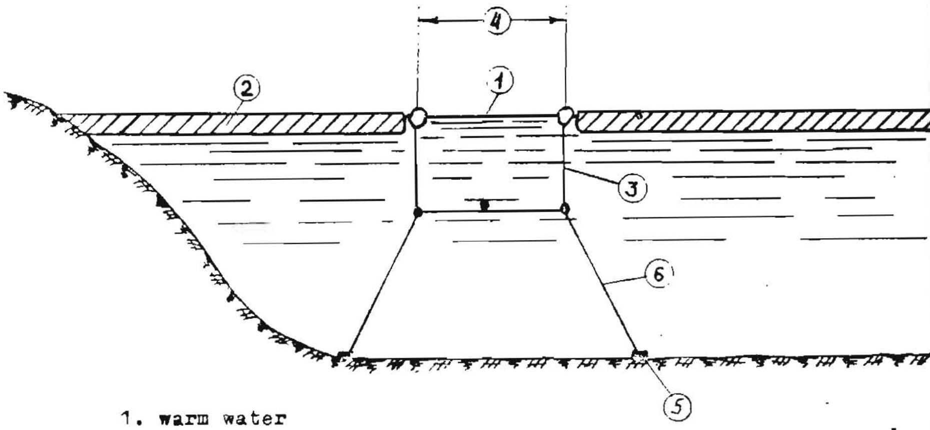
The problem may be solved provided the cooled water is fed into a water line of limited dimensions. Then only this restricted section of water body will be liable to heat pollution, while length of the lane will sharply increase due to slow heat transfer from restricted open surface. In warm seasons, when much greater water area is required to cool water at the same extent, there may be no restrictions and warm water will spread all over the water body. As, at that period the temperature of water in a water body doesn't greately differ from that of water discharged by power plants, the heat pollution effects will be considerably less.

The task, thus, is to find such constructive solution, which would meet the requirements, stated above.

We think rather prospective to protect the ship course by a synthetic film which may be either lowered throughout the whole water body depth as for instance in a channel (fig. 1a) or this film will comprise only a part of its water section which is expedient in rivers and especially in water storage basins (fig. 1b).

1. warm water
2. ice
3. film of synthetic materials
4. deiced navigable channel
5. anchor

Fig. 1a



1. warm water
2. ice
3. film of synthetic materials
4. deiced navigable channel
5. anchor
6. rope of synthetic materials.

Fig. 1b

The buoyancy of the device will be provided by air pipelines formed of the same film and placed at the surface. To protect the air pipelines from the damage caused by ships and ice, they may be provided with additional protective cover. Water supply from termal or atomic stations is carried out along the arm connected from below to the film protecting the ship course. Another arm that is connected up-stream provides the intake of cooled water. Power stations should be placed at distances providing necessary water cooling under winter temperatures. In summer successively discharging air from pipe sections beginning with those placed downstream, it is possible to increase the cooled water area and, thus, to provide all the necessary conditions for the cooling of discharged water.

The same means may be used for concentrating water discharged by hydro-power stations within the section of water course limited in width and for creating thus below hydro-power station, not wide but long lane necessary for navigation.

For steady motion with variable value of heat transfer from surface, stipulated by flow temperature change, considering meteorological conditions, flow depth and width as well as the incoming discharge being constant, we can obtain the following approximate dependency [I] to define distance x, at which temperature will change from its initial value τ_o to final one τ, i.e. the distance which should be betwee the stations:

$$x = \frac{c\gamma Q}{M} \ln \frac{M\tau_o + N}{M\tau + N}, \qquad (I)$$

where Q - flow discharge
γ - specific weight of water
c - heat capacity

The values of coefficients M and N may be written as follows:

$$M = \kappa B - 2h\kappa_1 + B\kappa_2$$

$$N = \kappa t_g B - EB + 2h\kappa_1\theta + B\kappa_2\theta',$$

where κ - coefficient depending on temperature in the heat transfer formula,
E - coefficient not depending on temperature in the heat transfer formular,
t_g - air temperature,
B - width of warm water,
h - the depth of stream,
κ_1 - coefficient of the total heat transfer from the water of flow to the water of a water body through the film,
κ_2 - coefficient of the total heat transfer from the water of flow to the water body bottom,
θ - temperature of water body considered unchangable,
θ' - temperature for water body considered unchangable.

For condensation power station of 1 mln. kwt capacity, assuming $\tau_o = 30°C$, $\tau = 20°C$, $Q = 60\,m^3/sek$, $t_g = -15°C$, $B = 30\,m$, $h = 5{,}0\,m$, $\theta = 0{,}2° = \theta'$, we obtain that distance x between the stations is equal to 100-

-120 km that makes the supposed solution of the problem quite practicable.

When to maintain the channel de-iced, water flowing into the lower pool of a hydro-power station (the temperature of which may vary with the time) is used to calculate average in section temperature of plane flow, the following heat balance equation [2] is used:

$$\frac{\partial \tau}{\partial x} v + \frac{\partial \tau}{\partial t} = A_o(\tau + B_o) , \qquad (2)$$

where t - time,

A_o and B_o - coefficients,

v - flow velocity,

General solution of equation (2) is as follows:

$$\tau = \left[\tau_o \varphi\left(t - \frac{x}{v}\right) + B_o\right] e^{\frac{A_o x}{v}} - B_o , \qquad (3)$$

where τ_o - water temperature in initial range when time equals 0,

$\varphi(t)$ - arbitrary function of time,

x - distance from initial range to the section considered.

Coefficient $A_o = \frac{K}{c\gamma h}$; $B_o = \frac{E - q_{rp}}{K}$,

where q_{rp} - heat transfer of the ground.

The analysis of dependencies given shows that when heating water in the initial range, water temperature in the channel downstream always decreases. When cooling water in the initial range, the character of temperature distribution all over the channel length is defined by the intensity of this cooling and by the value of heat transfer from unlimited surface. Depending on the correlation of the factors stated, water temperature along the flow can either increase or decrease.

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RIVER DEBACLE AS FUNCTION OF STREAM HYDRAULIC REGIME AND MELTING ICE COVER STRENGTH

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ABSTRACT

This paper describes a hydraulic model of the river debacle process including a decrease in the ice cover strength and an increment in water rates during spring melting.

The model permits to compute (and predict) the debacle time from the relationship of melting ice cover thickness and strength to the drawing force of a stream which is characterized by the hydraulic-morphometric parameters of a river reach.

SOMMAIRE

Le rapport décrit le modèle hydraulique du débâcle des fleuves qui tient compte la diminution de la solidité de la couverture de glace et l'accroissement des débits pendant la période de la fonte printanière.

Le modèle permet de calculer (et prévoir) le temps du débâcle d'après la relation de l'épaisseur et de la solidité de la couverture de glace en fusion avec la force entrainant du cours d'eau qui est caractérisée par les paramètres hydrauliques et morphométriques du tronçon d'une fleuve.

The calculation of river debacle time (so as to issue short-range forecasts of this phenomenon) is based on the model of the debacle process elaborated in the USSR Hydromet-centre. In this model the debacle moment is determined by the condition, in which

$$\varphi h \leq f(N) \tag{1}$$

In this condition φ - relative destructive stress equal to σ/σ_0 where σ - destructive stress for melting ice cover, σ_0 - the same for ice cover at 0° not subjected to melting; h - ice cover depth, N - water friction force at the ice cover lower surface.

The product φh characterizes the strength of ice cover as an engineering structure. In a simplest case, ice cover can be treated as a strip with thickness h and width b which is stretched (or contracted) by force N; then, according to the known relationship

$$\sigma = \frac{N}{bh}$$

Considering that b - the ice cover width for a given river prior to debacle remains practically constant, while $\sigma = \varphi\sigma_0$, the following may be written

$$\varphi h = \frac{N}{b\sigma_0} = aN$$

where a - some coefficient, only slightly variable for a particular river reach.

By the debacle moment this expression is converted into condition (1). This expression can also be reached by considering the work of ice cover for bending in the horizontal plane under the influence of friction forces at the reaches between the riverbed bends /3/.

During the melting period the value φh is computed from the meteorological data. The computation technique is described in /1, 2/.

At present the direct determination of the friction force N at the ice cover lower surface is difficult because the necessary information is insufficient. For example, it is not easy to determine the roughness coefficient at the ice cover lower surface, the current velocity at the debacle moment and other parameters determining the force N . Therefore, in practical computations the friction force is assumed to be an approximated function of the water level height (H) or its elevation (ΔH) over a certain horizon (for example, over the maximum winter level or minimum pre-flood level).

Then condition (1) will be written in the following way

$$\varphi h \leq f(H, \Delta H) \tag{2}$$

Having at hand a series of observed water level values for many years at the time of debacle and having computed the values of φh for the same series at the time of melting, it is of no difficulty to obtain an empirical relationship (2). And as an argument it will suffice to assume one of the values, i.e. H or ΔH .

Fig.1 shows relationship (2) for the North Dvina river near the village of Abramkovo. The water level rise ΔH_M over the maximum winter level was assumed as an argument.

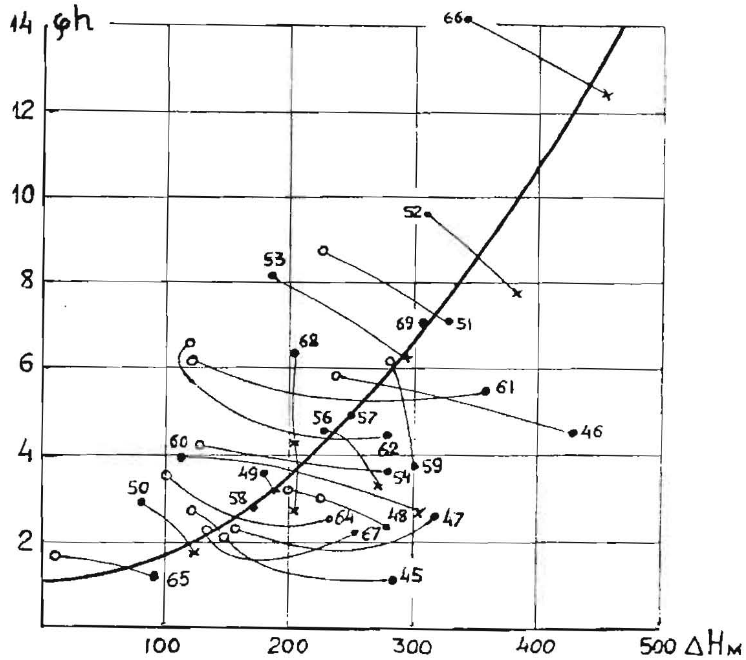

Figure 1

In the diagram dots were plotted which correspond to the day of debacle (black dots) and to the day on the eve of debacle (light dots). The curve was drawn with an intention that the light dots should fall to the left of it and the black ones - to the right. The relationship is approximated by the condition.

$$\varphi h \leq 1{,}2 + 0{,}6\left(\frac{\Delta H_M}{100}\right)^2. \tag{3}$$

When this condition is being fulfilled the black dots are either on the curve or to the right of it, i.e. debacle is taking place.

Similar relationships are inferred for many rivers of the USSR in different physiographic and climatic conditions. All those relationships are of high accuracy: in 96 percent of the cases the error in determining the debacle day does not exceed the limits of $\pm$ 2 days, and in 85 percent it is well within $\pm$ 1 day.

All the empirical relationships obtained are approximated with a quadratic parabola and have a structure similar to (3). A drawback of these relationships is that data are needed for many years to obtain them. Besides, to forecast water levels in the melting period is less convenient than, say, water discharges.

Therefore an attempt was made to express the friction force N through the rate of discharge (Q) and other parameters which could be determined.

Shezy is known to have taken the bed resistance as proportional to the average stream velocity squared, i.e.

$$\frac{\tau_0}{\gamma} = \xi v^2 = \frac{v^2}{C^2} \tag{4}$$

In this equation τ_0 - resistance per unit area of moistened bed surface, γ - water density, ξ - resistance coefficient depending on the bed roughness, on the size and shape of an effective cross-section equal to $1/C^2$, where C - Shezy coefficient; v - mean flow speed.

If the bed resistance and ice cover coefficients are assumed to be equal, then the resistance of ice cover with width b_Λ over length ℓ will be

$$N = \tau_0 b_\Lambda \ell = \gamma \frac{v^2}{C^2} b_\Lambda \ell \tag{5}$$

Length ℓ over which force N is generated, depends on the morphometric features of a bed and on its contour outlines; for a particular river reach it may be assumed as nearly constant. As was mentioned above, the ice cover width was also assumed as constant.

In expression (5) it is convenient to replace the flow speed with a ratio of water discharge to the cross-section area, i.e. to the product of the bed width (b_p) by the mean depth (h_{cp}). Integrating all the constants into one value "A" we will obtain.

$$N = A \frac{Q^2}{C^2 b^2 h_{cp}^2} \tag{6}$$

From equation (6) it is possible to omit values b , h_{cp} and C for a particular river reach, if their relation to Q is determined.

Thus, for a reach of the Oka river near the town of Kashira the relationships $h_{cp} = f(Q)$ and $b = f(Q)$ turned out to be linear, within the limits of the water discharge during debacle over many years.

Let us consider the relationship $C = f(Q)$

To determine this relationship a series of values of coefficient C was computed according to the Shezy formula on the basis of the measured values of v, i and h_{cp} . It was assumed meanwhile that roughness coefficients of the lower ice surface are close to those of the bed surface and hydraulic inclinations under the ice cover with equal filling of the bed are proportional to inclinations in an open bed.

The computed values of coefficients C also turned out to be linearly related to water rates Q .

Thus, the debacle condition assumes the form

$$\varphi h \leq f(Q^2) \tag{7}$$

However, this condition holds good only when $b_\Lambda = b_p$ But the ice cover width is seldom equal to the bed width because debacle as a rule takes place when the level is rising, i.e. under the conditions when the ice cover is separated from the banks by ever expanding flanges. Therefore it is worthwhile to introduce the ratio b_Λ / b_p into (7).

For the Oka river near the town of Kashira the debacle condition is approximated in the following way:

$$\varphi h \leq 2 + 50\left(1 - \frac{b_\Lambda}{b_p}\right)Q^2 \times 10^{-6} \tag{8}$$

This relationship is of high accuracy: among 30 test computations (i.e. for a 30-year series) in 16 cases (53%) the computational error is equal to 0, in 26 cases (87%) the error does not exceed ± 1 day, and in all 30 cases (100%) it does not go beyond the limits of ± 2 days. The RMS error is about 1 day, i.e. it corresponds to the conventional accuracy in debacle date determination at the gauging stations.

Relationship (8) has been tested within the following range of factor variations: $3 < \varphi h < 38$; $200 < Q < 2200$; $0,40 < B_A/B_P < 0,90$

Let us pay attention to the structure of expression (8).

In the right-hand side of this inequality one cannot fail to notice a free term equal to 2. It indicates that even at $Q = 0$, debacle will take place when the ice cover strength is characterized by the product φh and not equal to zero.

It was assumed above that the only force causing ice cover destruction, is the water friction force (N). But there is also a force of wind friction against the ice cover upper surface (N'). This force is small, on an average it is 10 times less than the water friction force /3/, but if the flow speed during debacle is small, the value φh also reaches minimum quantities (ice is melting on the spot), therefore the wind effect, i.e. the N' force, becomes appreciable, and that effect is (roughly) described by the free term.

Condition (8) is not universal, i.e. it is inapplicable to every river, but it fairly well describes the physical aspect of the debacle process. For this condition to become universal it is necessary to study the relationship between the numerical coefficients involved in it and the morphometric parameters of the river.

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5

IAHR—PIANC

SYMPOSIUM

RIVER & ICE

M. Kozák

General Lecture on Subject B

INTERRELATIONS BETWEEN RIVER TRAINING, RIVER CANALIZATION, LOW—HEAD WATER POWER DEVELOPMENT AND NAVIGATION WITH SPECIAL REGARD TO ICE CONTROL

Preprints

BUDAPEST 1974 HUNGARY

Introduction

The appearance of ice in rivers creates extraordinary and complicated flow conditions. Experience has shown ice carrying floods to be often the cause of disastrous inundations.

In the interest of using the available water resources in a more rational manner, attempts are made at the complex development of surface waters. Reservoirs are built in growing numbers, rivers are canalized, power generation and navigation are promoted. Inland navigation on the continental waterways is being developed at an increased rate, since this fits well into complex water projects.

Humán interference into the natural life of rivers is likely to result in new conditions in a number of respects, but especially in the ice regime. It is generally recognized that hydrological conditions in ice covered rivers are insufficiently understood even in their natural state. The ice phenomena over canalized river sections may be especially complicated and dangerous. At the same time the need for protecting human life and property calls for adequate safety and careful considerations in designing hydrotechnical structures. Nevertheless, considering numerous branches of technological development it must be admitted that our knowledge on the effects of ice is inadequate, or at least less than could be.

With these in mind the following subjects will be considered in the present brief paper:

- natural watercourses and ice,

- ice conditions over canalized river sections and in the vicinity of hydrotechnical structures on them, finally

- the means of ice breaking, operating experiences.

It is intended to mention only the major engineering problems in each sphere of subjects. The most important research topics will be summarized at the end of the lecture.

1. Relations between the morphology, meteorology, hydrology and ice conditions in rivers

Ice conditions in rivers are influenced by four major factors, namely meteorology, hydrology, morphology and the geographical location. The origine and melting of ice are a process of thermal household, controlled by weather, the hydraulic-thermal conditions and morphology of the fluid space.

The important of the four is meteorology, i.e., the variation of temperature. Experience has shown dangerous ice conditions to be created by adverse temperature variations along the length of the river, rather than by the mean sub-freezing temperature.

Thus e.g. on the Danube the spring flood coincides with cold air masses and high-strength ice. These factors favour the formation of ice jams. On the Tisza River, on the other hand, meteorological conditions are less adverse, so that the ice cover has become loose and weak by the time of the spring flood, so that it is readily removed.

The influence of hydrology and river regime is also of paramount importance for the development of ice conditions.The greater the fullness of the bed, the greater the purity of water and the more uniform the spacing of tributaries along the recipient, the more favourable conditions prevail for the safe breakup and travel of ice. Freezing starts usually on rivers which are situated under colder climates, and which carry a greater sediment load, yet as far as ice travel is concerned conditions are less favourable on rivers with no tributaries over long distances,discharging flood waves to breakup the ice cover. High sediment concentrations favour ice formation. This is supported by the fact that secondary ice formation is less ready to start, since the majority of sediment particles has settled under an earlier ice cover and thus the nuclei of crystallization are reduced in number.

Bed morphology plays an important role in the development of ice conditions. Owing to secondary currents in river bends the water is mixed over the entire depth, which plays a decisive role in ice formation.

Turbulence and secondary currents result in accelerated mixing, as a consequence of which the entire water mass is overcooled at a high rate. The factors promoting ice formation and retarding ice travel are as follows: shallow, deteriorated fords, sand bars, low depths, great surface widths, sharp and overdeveloped bends. Ice floes tend to become arrested and jammed at such locations, accelerating the development of a solid ice cover.Rapid cooling of the entire water mass is favoured by extended low stages in winter and the frozen regulation structures (groynes, training dikes, etc.) protruding above the water surface.

The geographical location, the direction of flow in rivers may fundamentally affect the ice conditions in them.In the northern hemisphere, the rivers flowing northward are more liable to form ice jams, since thawing occurs at a later date along the lower river reaches. Poor ice conditions may be detrimental to navigation, to the channel and may often cause disastrous ice floods.

Winter ice conditions on rivers can be improved and ice floods can be prevented by eliminating the adverse channel morphology by means of river regulation.

The principles of normal river regulation for ice-free conditions are familiar, with little research remaining to be done in this respect.

Differences in meteorological conditions may, however,cause wide differences in ice conditions on rivers. Identical curvature- and depth conditions may prove adequate under tropical climates but may be wholly inadequate e.g. in the northern hemisphere under cold climates.

The principles of river regulation are thus in need of further development with allowance for meteorological conditions. Additional observation data on ice phenomena are believed desirable for this purpose. Conflicting river regulation principles apply to ice-free and ice run conditions, in that for dynamic equilibrium sinuous river courses, whereas for unobstructed ice travel straight river sections would be desirable.

There is, however, empirical evidence indicating that on rivers with suitable morphological conditions winter ice causes in general no damages. This is emphasised also in the paper B8, reporting on river regulation experiences performed in the interest of averting ice damages. The river regulation measures proved successful and even the period of development of the new channel could be predicted.

It has been observed with interest that on a number of natural rivers in their original condition ice jams have never caused floods. True, these rivers are in dynamic equilibrium (The Dráva and Rába Rivers). The safe, rapid passage of ice carrying floods can be promoted effectively by clearing the flood bed. For the unobstructed passage of ice runs it is essential that the bottom of the flood bed should be uniform, free of ridges and other obstacles. Increased attention should be devoted to studies on the role of road embankments and bridge spans, further of the shape of the flood bed in the development of ice jams.

It is generally concluded that in the case of uncanalized rivers the passage of ice can be improved first of all by improving the morphological conditions, i.e., by river regulation. At cuts, the upstream end of abandoned beds must be closed since these favour the formation of ice jams. The origin and existence of ice is, however, closely related to the three-dimensional circulation and thermodynamic conditions in the interior of the flow field. Therefore, a more thorough exploration of the problem calls for the development of methods permitting the three-dimensional velocity- and temperature distribution to be computed in flow spaces subject to dynamic- and thermodynamic effects.

This subject is dealt with in the papers B1, B7, B8, B9, B13 and B16.

2. <u>Ice conditions and navigation on canalized rivers</u>

The canalization of rivers, i.e. the construction of a sequence of barrages causes fundamental changes in the morphology, regime and thermal household of rivers and thus in winter navigation conditions. The relevant operating experiences will be reviewed subsequently.

In the headwater:

- ice appears earlier, the solid ice cover is more readily formed and - depending on weir operation - broken up later than under natural conditions, resulting in poorer navigation conditions;

- the thermal household in the stored water volume is improved, therefore less ice per unit volume of water is formed (bottom-, frazil- and surface ice) but the ice cover is built up at a higher rate upstream;

- ice control in the reservoir is affected by navigation, power production, flood control and water resources management, ice from the reservoir is released preferably at times of floods only;

- in spring the solid ice cover recedes at the rate of round 5 km/day, but by increasing the peak discharge this may attain as much as 15 km/day.

Appreciable amounts of heat are accumulated in the water mass stored. The temperature of water increases together with the number of peak releases, i.e., with turbulence. E.g. the water temperature behind the Bratsk dam increased during the three winter months by $\Delta t = 1.7$ Centigrades (Paper B4).

Ice conditions in the tailwater depend also to a great extent on barrage operation. E.g. power stations producing peak power divert in winter water from the warmer layers of the reservoir and affect thus beneficially ice conditions in the tailwater.

In the tailwater of barrages:

- under the influence of variable hydraulic conditions the break-up and travel of the ice cover is accelerated;

- the number of ice-free days increases and thus the length of the navigation period is extended;

- the beneficial effects to winter navigation are proportionate to water temperature and to changes in discharge, in that the higher the intensity of the change, the more favourable the effect. (E.g. in the tailwater of the Novosibirsk hydroelectric station the upstream edge of the solid ice cover is removed even under winter conditions 26 km downstream of the power plant.);

- the length of the ice-free water surface in the tailwater depends greatly also on the water temperature in the reservoir. In spite of winter conditions the free reach may attain a length of 30 to 50 km;

- the influence of water temperature on the length of the ice free reach in the tailwater is much more favourable than that of colder, or warmer temperature conditions. (E.g. at a water temperature of + 1 Centigrade the length of the ice-free navigable reach in a "warmer" x winter was $\Delta x = 30$, whereas in a "colder" winter $\Delta x = 15$ to 20 km.);

- according to Soviet experience the length of the navigable, ice--free reach can be increased most effectively by increasing the peak discharge and by withdrawing water from the deeper (warmer) layers.

The boundary of the running ice and winter navigation conditions differ from river to river and from power plant to power plant under variable meteorological conditions.

Numerous efforts have already been made to study the changes in flow- and operating conditions caused by ice. Several investigators have concluded that similarity is impossible to ensure in numerous respects. The main reason for this is that river models are usually distorted and consequently it is especially the surface flow pattern and the centrifugal forces which are distorted in the model. Nevertheless, the efforts for studying ice phenomena in models are expected to bring interesting results. The papers on related topics are B2, B4, B8, B9, B10 and B12.

3. <u>Ice- and flow conditions in the vicinity of structures</u>

Running and solid ice, further temperatures below the freezing point and adverse meteorological conditions may create special conditions in the operation of structures as well. Winter temperature conditions must always be taken into consideration in designing structures and their appurtenant equipment and installations. The estimation of the effects of low winter temperatures is often very difficult, which makes field observations on the winter operation of structures all the more valuable.

Owing to their mass, shape and character of movement the ice floes have an extremely high erosion potential and the parts of structures exposed to the overfalling ice floes, namely the tailwater apron and downstream channel are exposed to this erosion. The structure of the weir and the tailwater apron must be dimensioned for these strong impacts. Depending on morphological conditions the downstream channel must be protected against these dynamic effects over a 5 to 20 km long section. The hydraulically correct design of the downstream part of the weir, of the downstream guidewalls is extremely important for ensuring winter navigation.

It is essential to understand the behaviour and rheological properties of saturated reinforced concrete units of hydrotechnical structures under winter conditions at, at freezing temperatures. The problem is of importance for the service life of the particular structural element, rather than for the momentary operation of the structure.

At fixed steel- and r.c. structures the common and successful methods of ice control include de-icing (ice removal), heating, air-bubble generation, circulation of warm air-water mixture and ice melting by flame throwers. Some papers contain reports on the successful application of the conventional methods of ice control. Recent experiments (B1) have also demonstrated the freezing-retarding effect of aeration in the fluid space. Field observations are claimed to support essentially the theoretical conclusions (c.f. table 1 in B1). It would be interesting to know how the author succeeded in ensuring similarity for the rising air bubbles.

The topic B3 is likely to command general interest, since it deals with freezing of water on steel structures having a large surface and exposed alternatingly to cold air and water. The study is based on reliable theoretical and experimental foundation. Hoists and movable structures are often exposed to the effect of ice freezing on them. It is essential to take such circumstances into consideration and to make adequate provisions for such contingencies.

As a consequence of surface ice, and especially of a solid ice cover, open channel flow is transformed into closed conduit flow. The underside of the ice floes at the surface may display ridges, by which friction head losses and turbulence are rapidly increased and velocity distribution is changed. Where such flow is still more constricted by piers, the possibility of scouring around the structure (bottom erosion) is increased. This problem is of particular interest under cold climates where the ice cover persists for long periods.

The author of paper B10 made an apparently successful attempt on the basis of laboratory experiments at estimating scouring around structures, under the ice cover. Fig.2, presented by the author, showing long-term structure changes in stationary ice, is of great interest.

Slush- and frazil ice may often cause inconveniences at diversions and intake structures. As remedial measures the methods which have already proved successful can be suggested, including the reduction of the number of crystallization nuclei (sediment) and promotion of the development of the surface ice cover (B11).

There is empirical evidence (B4) showing that the water issuing under gate leafs was warmer by $\Delta t = 1.2$ Centigrades than the water discharged by the turbines. In the interest of navigation, water should be withdrawn from the deepest possible layer.

Unfortunately little experience is available on the winter operation conditions of ship locks, ship lifts and navigable canals. It would be very interesting to hear such reports from the contributors. The relevant papers are B2, B3, B4, B5, B9, B10 and B11.

4. <u>Ice breaking and its strategy on rivers</u>

Adverse meteorological and hydrological conditions may occur on rivers with poor morphology but even in regulated channels, which may cause the development of dangerous ice conditions, such as jams, pile-ups, etc. Disastrous ice conditions may result from sudden and periodic changes in weather and in the hydrological situation which may coincide in a manner adverse to ice travel along the river course.

In such cases artificial interferences into the process of ice running are necessary to prevent, or minimize the distaster situation. The objective thereof is to promote and accelerate ice travel at the critical locations. Ice conditions are, however, controlled for other purposes as well. The measures and means of control depend on the goal to be attained and include ice breaking, blasting, hydraulic and thermal methods, etc.

Ice breaking by means of special vessels is widespread practice and is applied successfully. Ice breaker vessels are built in a number of types and designs (B6, B13, B14). The purposes are manifold, such as delaying or preventing the formation of a solid ice cover, ensuring the development of a uniform ice cover, maintaining a free corridor for navigation, destroying jams, keeping ice free surfaces in the vicinity of structures, accelerating breakup and travel at times of melting. The experiences gained with ice breaker vessels in both Hungary and abroad are favourable (B6, B13).

The new type of self-propelled ice cutting machine which operates on the ice surface as described in paper B14 seems to command special interest. In contrast to vessels, this propeller driven ice cutter can operate regardless of water depth under the ice cover and of weather conditions. It appears to be especially useful under climates with exptended cold spells. The machine is capable of cutting a round 200 m long, 5 cm wide cut per hour in a round 1.5 m thick ice cover. Applications and the main features of the technology are described in B14.

Ice blasting can be practiced at a safe distance from structures only. The primary application of explosives in the removal of jams, where ice breakers prove ineffective. The fundamental prerequisites for successful blasting are progress upstream, adequate depth (current line) for removing the scattered ice masses, sufficient explosives and the rapid mounting thereof, etc.

Local ice formation can be delayed, or minimized and ice can be removed effectively by hydraulic-, hydro- and aerodynamic-, further by thermal methods. An interesting example for the application of the hydraulic method is the plan for the reducing the ice thickness on the St.Lawrence river by pumping a greater discharge from the relatively warmer Lake Ontario.

According to one solution of the thermal method, the effect of solar radiation is enhanced by lending the ice a darker colour (using soot, or pulverized coal) and weakening thus the cover.The use of the method is limited to the vicinity of structures.

Electric heating of the critical parts of structures exposed to freezing is still an effective and automatic method of controlling ice. The ice frozen to steel structures has been removed successfully by flame throwers.

Ice control over large areas involving several countries can be solved, depending on geographical and boundary conditions, by international cooperation only.

5. Conclusions

It is intended to mention briefly the following topics in the conclusions: the approach based on sound theoretical and practical foundations proved successful thus far, problems and future research trends, further the prognostic approach.

The external factors controlling winter navigation conditions on natural watercourses are clearly understood. These are meteorology, hydrology, morphology and the geographical situation.

On canalized rivers navigation conditions become poorer in the headwater, but in the tailwater they can be improved considerably by a proper release schedule and by selecting suitable diversion sites. The possibility and reliability of winter navigation depend further to a great extent on the design of structures and the component parts thereof.

The period of winter navigation can be extended and ice floods prevented by the recognized methods of ice control (ice breaker- and cutter vessels, blasting). In the vicinity of structures hydraulic and thermal methods of control are also applicable, but in this respect many opportunities are believed to be still unused.

Problems

1. Are the recognized general principles of river regulation applicable in all respects to winter ice conditions as well?E.g. how should flood beds be regulated to promote the safe passage of ice runs?

2. The winter heat budget of river impoundments is known to have a favourable effect as regards ice formation.But, is the fluid exchange between water layers of different temperature,the direction thereof and the factors affecting it sufficiently understood? What is the potential role of these factors in ice formation?

3. What is the influence of geothermal radiation on the temperature of the water stored?

4. Are all the technical advantages of ice breaking and blasting fully exploited? How can these be improved? Is international cooperation adequate in this field?

5. Are the physical processes of ice formation, the physical processes of pure ice and such containing chemical substances completely explored?

6. Are adequate observation data on ice available? In what direction is it considered desirable to extend observation and introduce automatic methods?

7. Is sufficient information available on the rheological, durability behaviour of saturated reinforced concrete structures exposed to freezing in winter?

8. The number of ice laboratories, where ice phenomena can be studied thoroughly at temperatures well below the freezing point is small. What experiments are being conducted at these laboratories?

9. Are there still unexplored "secrets", fundamental phenomena related to ice, the better understanding and application of which would effectively contribute to ice control efforts? How "rough" is the underside of the ice cover on a river? How does it look? Has anybody a slide showing it?

10. How could discharge records be kept on a river flowing under a solid ice cover?

6

IAHR—PIANC

SYMPOSIUM

RIVER & ICE

Contributions to Subject B

INTERRILATIONS AMONG
RIVER TRAINING,
RIVER CANALIZATION,
LOW HEAD WATER
POWER DEVELOPMENT
AND NAVIGATION WITH SPECIAL
REGARD TO ICE CONTROL

Preprints

BUDAPEST 1974 HUNGARY

Anti-icing pneumatic systems provide one of the effective means ensuring a trouble-free operation of hydraulic structures in winter. The operating principle of these installations consists in supplying compressed air through perforated pipes and individual nozzles into the lower water layers of the reservoir.

As air bubbles ascend to the reservoir surface, they entrain warm bottom water which spreads over and prevents ice formation. Continuous currents of warm water provide a closed circulation loop.

In case of an insufficient amount of heat accumulated in the reservoir an artificial heating is effected through releasing preheated or waste water. Here again air is used to intensify the ascension of warm water to the surface.

The water currents around a pneumatic installation can be considered either as axisymmetrical or two-dimensional, depending on the installation design. To determine the required air rate and the size of an ice-free water surface it is necessary to study the kinematic and thermal regimes in the vicinity of an operating installation.

The complexity of the kinematics of water flow calls for its schematic presentation. The results of the laboratory and the prototype investigations carried out by the Leningrad Institute of Water Transport as well as other data available show that the entire circulation zone may be schematically divided into three regions: I - the region of an ascendant flow; II - the region of spreading; and III - the region of a return flow (Fig. 1).

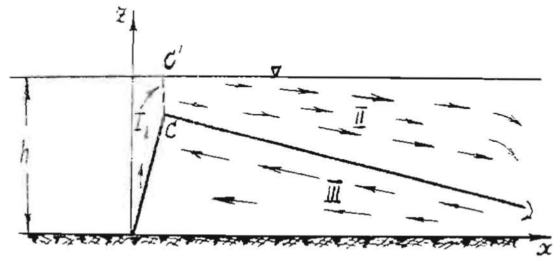


Fig.1. Scheme of currents in the active zone of a pneumatic anti-icing installation

For each of the three regions analytical relationships are obtained, permitting to evaluate the velocity field for both a two-dimensional and an axisymmetrical flows.

The flow velocities in the regions are given as functions of the air rate and the water depth. These relations are given in author's paper presented at the First Ice Symposium*.

* M.I. Zhidkikh "Calculation of flow velocity in the operative zone of pneumatic installations used for ice-fighting" - IAHR Ice Symposium, Reykjavik, 1970.

The thermal and hydraulic regimes in the operative zone of a pneumatic installation are closely connected and affect each other, the kinematics of the flow being the governing factor. Therefore, the problem may be simplified by considering the thermal regime in each individual region for a given hydraulic regime.

Since the contribution of each of these regions in the formation and maintenance of an ice-free water surface is different, the relevant calculation procedures are different too.

Let us first consider Region III. Region III is a certain accumulator of heat the amount of which determines the possibility of keeping water surface free from ice. This region serves as a source of heat for other circulation regions.

Pneumatic installations will be most effective with a large amount of heat available in the reservoir and the average temperature of water in Region III practically independent of time and close to that of the bottom water layer under natural conditions, $T_{III} = T_n$. The calculation procedure given herein is applicable just to the above-specified conditions.

In Region I heat flows from the bottom to the surface of the reservoir. In other words, Region I may be considered as a "heat conductor" whose performance is the more effective the less is its heat resistance. This region is characterized by a nearly complete absence of temperature gradients across the depth. The aim of the calculation is the evaluation of the water temperature averaged over volume, the approximate value being found from the heat balance equation:

$$T_I = T_{III} - \frac{\Sigma S \omega_I}{c_w \gamma_w Q_I} . \qquad (1)$$

Here Q_I and ω_I are the discharge of water and the cross-section area, respectively, as obtained from hydraulic calculations;

ΣS is the total heat transfer to the atmosphere, as estimated by the well-known formulae of A.P. Braslavski, M.I. Budyko et al.;

c_w and γ_w are the specific heat capacity and the volume weight of water, respectively;

W_m is the velocity along the axis (the plane of symmetry) of the upward flow;

h is the depth of the reservoir.

The values of Q_I and ω_I will be:

for a two-dimensional flow

$$Q_I = 0.25\, W_m h; \quad \omega_I = 0.42\, h;$$

for an axisymmetrical flow

$$Q_I = 0.04\, W_m h^2; \quad \omega_I = 0.54\, h^2.$$

Region II is mainly responsible for the processes of ice melting and heat exchange with the atmosphere. Here it is essential to know the water temperature variation along the flow.

The heat balance equation for steady-state thermal conditions in Region II will be written as

$$c_w \gamma_w\, d(Q_{II} T_{II}) - c_w \gamma_w\, dQ_{II} + \Sigma S\, d\omega_{II} = 0. \qquad (2)$$

Here Q_{II} and ω_{II} are the discharge of water and the area of the open water surface in Region II as obtained from hydraulic calculations;

W_m is the flow velocity at the open water surface.

M.I.Zhidkikh

The values of Q_{II} and ω_{II} will be:

for a two-dimensional flow

$$Q_{II} = 0.22\, W_m \sqrt{h}\,(0.64h + x);$$

$$d\omega_{II} = dx;$$

for an axisymmetrical flow

$$Q_{II} = 0.18\, W_m h r;$$

$$d\omega_{II} = 2\pi r dr.$$

Upon appropriate transformations of Eq.(2) we obtain:

for a two-dimensional flow

$$\frac{dT_{II}}{dx} + \frac{T_{II}}{2(0{,}64h+x)} + \frac{2B}{\sqrt{0{,}64h+x}} - \frac{T_{III}}{2(0{,}64h+x)} = 0; \qquad (3)$$

for an axisymmetrical flow

$$\frac{dT_{II}}{dr} + T_{II}\frac{dQ_{II}}{Q_{II}\,dr} - T_{III}\frac{dQ_{II}}{Q_{II}\,dr} + \frac{2\pi \Sigma S}{c_w \gamma_w Q_{II}} = 0. \qquad (4)$$

For obtaining calculation formulae it is necessary to integrate the above equations considering that at the initial section we have $T_{II} = T_I$. Solving of Eqs (3) and (4) yields the following expressions:

for a two-dimensional flow

$$T_{II} = T_{III} - B\,\frac{2x - 0{,}1h}{\sqrt{0{,}64h + x}};$$

$$B = \frac{\Sigma S}{0{,}22\, c_w \gamma_w W_m \sqrt{h}}; \qquad (5)$$

for an axisymmetrical flow

$$T_{II} = T_{III} - B\left(r - 0{,}34h + 0{,}22\frac{h^2}{r}\right); \qquad (6)$$

$$B = \frac{2\pi \Sigma S}{0{,}18\, c_w \gamma_w h W_m}.$$

These equations express spacial variations in water temperature and include the following basic factors: the ambient temperature, the heat transfer to the atmosphere, the velocity of the upward flow (and consequently, air rate) and the reservoir depth. The calculations based on the investigation results obtained in the Mezhdurechie harbour show a satisfactory agreement between the calculated and experimental data.

The water temperature along the ice edge, T_{edge} , is determined from the K.I. Rossinski formula based on the condition that the heat loss from the open water surface near the ice edge, ΣS , is compensated by the heat inflow from the water body, S_w , the surface temperature, T_{surf} , being equal to 0°C.

$$S_w = \alpha\,(T_{edge} - T_{surf}), \qquad (7)$$

where α is the heat-transfer coefficient;

$\alpha = 0.097\, U_{mean}$ $W/m^2 \cdot {}^{\circ}C$;

U_{mean} is the mean longitudinal flow velocity, m/day.

If the formulae obtained for the mean flow velocity (Region II) are substituted into the K.I. Rossinski relationship, then:

for a two-dimensional flow

$$U_{mean} = 0{,}42\, W_m \sqrt{\frac{h}{0{,}64h + x}}$$

and for an axisymmetrical flow

$$U_{mean} = 0.22\, W_m \frac{h}{1.1h + z},$$

then the expressions for the water temperature at the ice edge will be as follows:

for a two-dimensional flow

$$T_{edge} = \frac{\Sigma S}{0.83\, W_m} \sqrt{\frac{0.64\, h + x}{h}} \tag{8}$$

and for an axisymmetrical flow

$$T_{edge} = \frac{\Sigma S (h + z)}{0.43\, W_m\, h}. \tag{9}$$

The width of an open water surface formed in the ice cover due to the operation of a pneumatic installation can be determined through simultaneous solution of two pairs of equations, Eq.(5) and Eq.(8), Eq.(6) and Eq.(9).

For making practical calculations of an open water area less cumbersome, calculation graphs have been plotted for the cases of a two-dimensional and an axisymmetrical problem (Fig. 2) based on the solutions obtained.

From the above relationships it follows that for a given width of the open water surface the upward flow velocity along the axis (the plane of symmetry) and consequently the air rate can be determined and, vice versa, for a given air rate the width of the open water surface and hence the required spacing of pipes and nozzles can be found.

As seen from Table 1, calculation results fairly agree with experimental data.

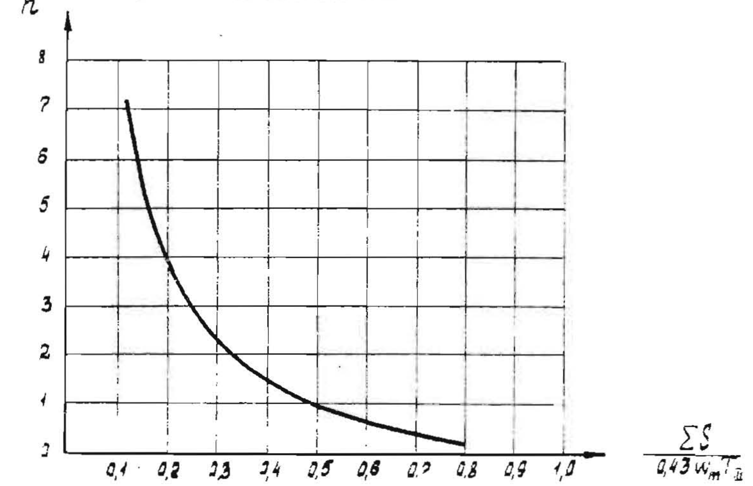
Table 1

Item No	Location of pneumatic installation	Air rate m^3/min *	Water temperature near bottom, °C	Width (diameter) of open water surface, m	
				Calculated	Experimental
1	Mezhdurechie harbour	0.008	0.46	2.5	3-5
2	Nizhne-Svirskaya Hydro Power Plant	0.010	0.50	0.9	0.5
3	Lembolovskoye Lake	0.006	4.0	10	5-7
4	Ust-Kamenogorskaya Hydro Power Plant	0.064	0.5 **)	3.5	3**)
5	Keokuk Dam on the Mississippi River	0.030	0.5	5.5	6

*) Air rates reduced to normal pressure for Items 1-4 (a two-dimensional flow) are given per one linear metre of piping and for Item 5 (an axisymmetrical flow) per nozzle.

**) Prior to commissioning of the Bukhtarminskaya Hydro Power Plant

a) a two-dimensional flow



b) an axisymmetrical flow

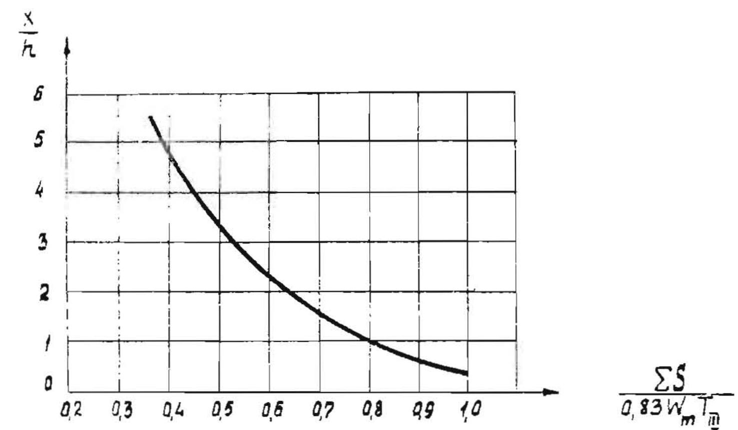


Fig. 2. Calculation graphs

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INTERNATIONAL SYMPOSIUM ON RIVER AND ICE

Budapest 1974 Hungary

[illegible]

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ABSTRACT

The paper comprises a synthesis of the problems concerning the operation ensurance of the Iron Gates hydroelectric and navigation system on the Danube in winter conditions, insisting on the following aspects :

- particular conditions of ice forming in natural conditions ;
- modifications in the ice forming and flow as a result of the Danube damming ;
- some conclusions after the first two exploitation years.

SOMMAIRE

L'étude comprend une synthèse des problèmes mis pour assurer le fonctionnement en régime d'hiver du system hydroelectrique et de navigation les Portes de Fer sur le Danube, insistant sur les aspects suivants :

- les conditions particuliaires de la formation de la glace en régime naturel ;
- les modifications dans la formation et l'écoulement de la glace comme résultat de la construction du barrage sur le Danube;
- quelques conclusions après les primières deux années d'exploitation.

The "Iron Gates" zone on the Danube separates the Carpathians of the Balkan mountains and is extended from Gura Văii (Km.D.943) to Moldova Nouă (Km.D.1o48).

This zone presents some hydrological particularities.

Owing to this fact one of the first reference gauges was set up on the Danube since 1838 at Orşova, then in 1854 at Drencova, in 1874 at Baziaş, in 1879 at Tr. Severin and in 1889 at Moldova Nouă.

From the morphologic point of view, the zone has some distinct characters in comparison with the rest of the river, as :

- steep slopes in the Km.D.943 zone ; Iuţi Km.D. 1o35; Greben Km.D.1ooo; Alibeg Km.D.1o35.
- sudden variations of the river bed width, particularly in the Sikolovaţ-Alibeg zone (Km.D.1o35-1o39) where from 2000 m it diminishes to 32o m and at the entrance into the Cazane gorges (Km.D.974) where it diminishes from 12oo m to 15o m.
- a great variation of the water depth which oscillates between 1 m on some sills (Iuţi) and 5o m (Cazane).

1. The ice regime in the conditions existing before the sector development

In winter this sector is characterized by the formation of large quantities of all forms of ice : surface, bottom and particularly interior ice (frazil) conditioned, by the regime of the air temperature and the fenomena of advanced water cooling ; the ice flow is often associated with the formation of some agglomerations and the river blocking ; usualy due to the ice arriving from the upstream course of the river and from the tributaries, particularly from Sava, The first blocking is usually produced at Cazane, and 2-3 days latter the blocking in the Alibeg-Sikolovaţ area is produced. In the zone the frost occurs also very seldom - 2 times within the period 19oo - 1962 - and in the rapids and underfluvial cliffs sector : Ada-Kaleh - Sip has never frozen; in this last sector the flow is so rapid and turbulent that the floating ice arrived from upstream is exposed to a crushing process.

On different characteristic zones of the Iron Gates sector the following are to be noted :

- The sector of the falls between Drencova and Svinița (Km.1o15 -995) with the series of channels cut in rocky sills: Cozla-Doica, Islaz-Tahtalia, Svinița doesn't usually freeze, and only in some very severe winters, the ice scheet from Cazane (km 974) is developing toward upstream

with a frequency which doesn't exceed 13 % - comprising partly also this area of rapids.

- In the alibeg-Sikolovat sector (Km.1o35-1o39) and Cazane entrance (Km 974) where the river bed has strong throttlings, the conditions of ice flow and ice sheet formation are so favourable that the probability of ice occuring in the sector is of 65 % , differing slightly from the probability of ice occuring in the whole sector which is of 75 % ; the average duration of the ice sheet is of 2o days/year in comparison with the 26 days period which is the average duration of the ice flow. In severe winters the ice sheet duration at Cazane increases sensibly, the maximum limit reaching 78 days in 1953/54. Other factors which favoured the ice blocking in Cazane or Alibeg are the following : low air and water temperatures (under - 1o°) and (under o.2°) respectively, downstream wind, ice floes on about 5o % of the river width and usualy at lowering levels.

The blocking produced at Cazane or Alibeg doesn't mentain the character of ice sheet, and the upstream ice increases the agglomeration generating large ice dams (see the photo) , obstructing strongly the flow section and determining important backwaters ; the ice dam thickness in this period may exceed 2 m above the water and over 5 m under the water, reaching here and there the river bed bottom.

The most serious flow perturbations due to the ice dams occur in the thaw period January - March, when the river discharges may vary between 2ooo and 13ooo m^3/s ; the thaw starts in the upper catchment area and particularly on the tributaries : Sava, Tisa sometimes Morava ; the high waters coming from upstream press the ice sheet from Alibeg partly weakened by the air temperature rise and produce its swelling and finally the ice sheet is detached from the banks and crushed. Afterwards the entrained ice floes reach Cazane in less than 24 hours after being previously crushed in the Stenka-Doica, Islaz, Svinița, Iuti falls. If the winter was not too severe the Cazane ice dam - under the pressure of the flood wave yields easily enough, 1 - 2 days after the starting of the Alibeg one ; in the severe and long winters the Cazane ice dam break is much delayed - about 3 - 5 days after the upstream one - and the water level behind the ice dam rises considerably causing large floodings, within this interval the ice floes resulted from the upstream ice dam are pu shed by the stream either under the Cazane ice dam or over it forming bigger and bigger ice agglomerations, and sometimes the whole mass of the ice dam is lifted upward without detaching it from the banks ; the ssizes reached by the ice dam are impressive :

- in March 1954 the overlaped ice had reached at the Cazane ice dam 12 m over the water level, its depth being impossible to be investigated,

- after the observations made in 1963 the ice dam in Cazane reached 5 m above the water level and 12 m here and there under the water.

But the larges flooding have been caused by the ice dam in 1941 - 42 the formation of which had begun at high

enough levels of the Danube (- 248 m at Orşova staff);§
in the thaw period (February 28-1942), a high flood brought by Sava river, being not able to flow under the Cazane ice dam has flooded the ice dam, lifted it and after 8 days has passed beyond the banks depositing 8 m high ice piles ; in the upstream area of the ice dam the water level has exeeeded by 5-6 m the highest levels known without ice.

2. Modifications of the ice regime after the Danube damming

For the development of the Danube hydroelectric potential and for the improvement of the navigation conditions in the sector by removing the obstacles shown in the first part, the two riparian states the S.R. of Romania and the F.S.R. of Yugoslavia, have realized together the Iron Gates hydroelectric and navigation system by damming the Danube at elevation 68 in the Km.D 943 zone.

The works have been completed in 1971.

The river damming modifices the factors which are conditioning the winter regime both upstream and downstream of the dam.

In the headwater the slopes and velocities are considerably reduced, and the main zone which presented remarkable particularities with regard to the ice formation and flow remain in the reservoir depth ; thus over the Cazane gorges the water depth increases by over 2o m, and over the Cozla-Doica, Islaz-Tahtalia, Sviniţa falls a still water mass over lo m thick is lain, eliminating all the conditions of ice formation in the interior and on the bottom ; at Alibeg the water mass thickness increases by about 8 m.

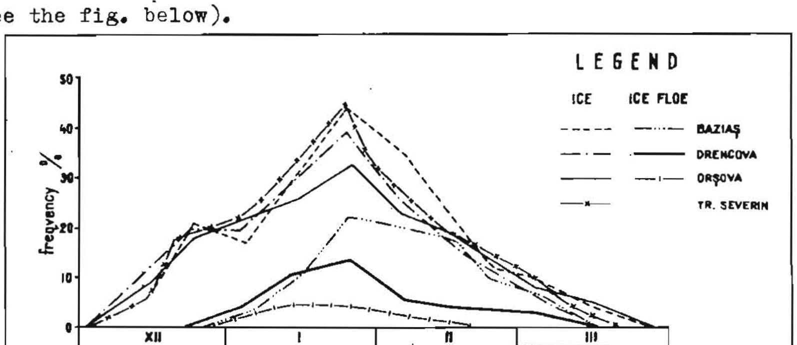
The reservoir levels are controlled by handling the gates on the spillway after a settled programme, in order to avoid to exceed the elevation 68 m ASL at Nera Km.D 1o75, at discharges lower than the installed ones and the achievement of natural levels at higher discharges.

In the same time with the increase of the headwater depth and cross sections, the flow velocities are substantially reduced and the superficial slopes become negligible, the maximum changes - with regard to the natural regime being shown in the following table :

regime	Greben (km. 999) natural	Greben (km. 999) dammed	Iuti (km.998) natural	Iuti (km.998) dammed	Sip (km.945) natural	Sip (km.945) dammed
Stream velocity m/s						
Q = 2ooo mc/s	> 3 m/s		3,1 m/s		4 m/s	
35oo mc/s	> 3 m/s	under	2 m/s		4,1 m/s	under
5ooo mc/s	3,3 m/s	o,5 m/s	"	o,45 m/s	4,2 m/s	o,2 m/s
8ooo mc/s	4,3 m/s		"		4,6 m/s	
Maximum velocities	4,8 m/s	o,7 m/s	3,1 m/s		5 m/s	o,3 m/s
(at averageQ)‰	2,4	∿ o	1,3o	∿ o	3,o7	∿ o
Slopes maximum	4,8					

The still regime of the reservoir determines the exclusive formation of the ice sheet and surface ice which is rapidly extending, freezing the river surface from the zone known in the past as "the Sector for the lower Danube falls and the Iron Gates", to the reservoir tail area - upstream of Nera -, the situation becoming more favourable for the ice flow with the possible blocking as ice dams.

Synthetizing the data from the 3 key stations in the sector Turnu Severin, Orşova, Drencova, within the period 19oo - 1961 (see the fig. below).



ice freqvency curves

it results that from the observation made during 61 years in 47 years the ice was present : if during the years with average characteristics the ice appears by the beginning of January and ends by 15 - 2o of February, there were very severe winters when the ice appeared at December 7 (as in 19o2 and 1925), and the latest date when the ice floes passed the section was March 25 (in 1929 and 194o) ; the ice dam has occured the earliest at December 16 (19o2) and has lasted, the latest, until March 18 (in 1954).

The maximum duration of the ice flow was recorded in 1953/54 and has lasted 9o days and of the ice dam in 1953/54 and has lasted 63 days. The ice flow is realy significant for the Danube discharges not exceeding 7 - 8ooo m3/s but the maximum frequency of the ice flow is correlated with 32oo - 35oo m3/s discharges ; similarly the ice sheet is seldom formed at discharges exceeding 5ooo m3/s the most frequently occuring at 18oo - 2ooo m3/s discharges.

The essential modifications concerning the morphology and the hydraulic parameters of the flow being derived from the achievement of the reservoir, are acting , as a matter of fact, in unchanged climatic conditions. The Carpathian Mountains which are neighbouring this sector, have a significant influence on the climatic conditions. The corering of the relatively still surface of the reservoir with an almost uniform ice layer requires a more reduced "frost quantity" , so that it will occur more often than in undeveloped conditions, being able to reach a probable frequency of 8o %, the ice sheet beginning and ending date will be unfavourably modified, increasing the whole duration in comparison with the natural situation.

A particular influence on the ice sheet in the neighbouring zones of the dam and especially on the ice sheet part in Cazane gorges, will likely exe t the large variation of the reservoir levels caused by the spring floods. At about 4ooo m3/s increases of the affluent discharges, the reservoir levels are lowered by about 1.5 - 2 m. Because of the level variation which may be usually produced, is to be expected not only the ice sheet detaching from the banks but also an advanced fisuration and even a break-up of the ice sheet.

In the reservoir tail sector where the backwater created by the reservoir is gradually vanishing, the flow velocities are modified in large limits ; as a result, favourable conditions appear for the ice agglomeration and ice dam formation.

Based on the two years observations since the commissioning of the Iron Gates hydroelectric and navigation system (1971-1973) when the winters were mild, only some qualitative conclusions may be drawn which in a considerable part corroborate the studies and consideration made concerning the ice regime modifications (tests on models, information from other power stations, etc.).

Thus during 1971 it was only a 5 days period in January when ice has flowed in the Bazias-Orsova Sector.

In 1972 a thin ice sheet was formed on the whole area.

Due to the throttling at Cazane and the ice floe supply from upstream the ice was stopped for a period of about 3o days (January - February).

As far as the tailwater is concerned, in natural conditions the sector in the downstream part of the dam site doesn't freeze because of the stream velocities still high enough ; in the very severe winters the ice sheet formed at Gruia Km. 851 was extended towards upstream reaching up to Turnu Severin.

The river works carried out in the power station tailwater and in the navigable channels towards the two locks have brought some modifications of the hydraulic regime; but the most important changes in comparison with the natural flow regime are due to the power station operation in peak load conditions which generates in the tailwater an unsteady movement felt on about 8o km downstream of the site ; the velocities and slopes in unstready motion are higher than in natural regime without influencing the navigation conditions.

The main in luence on the winter phenomena in the tailwater is exerted by the downstream delivery of some water quantities with positive temperature from the depth of the reservoir;

it is estimated - on the bases of the data from other developments presenting similitude concerning the tailwater - that on a 4o - 5o Km lenght of the tailwater the river will not freeze. As a matter of fact during the first operation years no frost phenomena were recorded in the downstream zone of the dam comprised between Km D 942 and 851.

3. The conditions of the new ice regime reflected in the studies and designs carried out for the Iron Gates hydroelectric and navigation system

The assurance of the exploitation in winter conditions of the navigation and power generation as well as the measures required have been established by the design of the Iron Gates Hydroelectric and Navigation System, drawn up jointly by ISPH-Bucarest and Energoprojekt-Belgrad.

In order to state the technical solutions of "The Iron Gates System" works tests on hydraulic models have been carried out.

Concerning the ice discharge from the reservoir over the spillway, the new conditions occuring after the damming have been revalued, considering that the maximum dimensions observed in the past for the ice floes detached from the Cazana ice dam will be unable to be repeated in the future, the ice discharging over the dam being able to occur in three conditions ;

- occasionally if water discharges are carried out in winter time,
- in planned way , when the ice dam breaking and the resulting ice discharging is performed,
- in the thawing periods when the ice flow may be concomitant with the high water on the Danube river.

In normal conditions the ice discharge is made over the hook gate by handling the valve; the hydrologie researches have shown that once every 1o years discharges higher than 85oo m3/s occur during the ice flow periods and for corresponding levels in the reservoir - under elevation 65,8o.-The ice of maximum thickness are unable to be discharged over the hook gates; for this situation it was necessary to be foreseen the very difficult conditions to discharge the ice by rising completly the gates (at Q = 85oo m3/s) with the level in the reservoir at elevation 53.8o.

Thus an 1o.6o m overflowing nappe is created, representing the base criterion for the overflowing profile tracing ; because of the specific discharge increase on the dissipator by 4o % over the maximum allowed value in normal conditions of flood discharge, it was necessary to solve in the laboratory the energy dissipation conditions and their correlation with the tailwater levels.

The winter regime on the reservoir will be influenced and controled in a certain extent by a constant action of the icebreakers existing on site.

The icebreakers will mostly act in the following main areas:

- on the first 2o Km upstream of the dam where the reservoir is 1 -1.5 Km wide the icebreaker action is efficient because the ice breaking may be correlated with ice floe pushing and leading in order to be discharged over the spillway ; as far as possible a free channel will be mentained through which are to be led the ice floes from the Cazane ice sheet and from the upstream part, which are ditaching either naturally or big means of the icebreakers.

- on the reservoir tail area where the natural stream together with the velocity and slope conditions of the reservoir will favour the ice floes agglomeration and the possible formation of ice dams ; here it should be provided a channel on which are to be led the ice arrived from upstream. This action will be concentrated in the sectors where the natural conditions will be more favourable for the ice floes blocking and ice sheet and possible ice dam formation.

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ON FORECASTING AND CONTROL OF ICE CONDITIONS IN SHIPLIFTS

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ABSTRACT

Factors governing the regime of ice formation in a shiplift chamber under different operating condition are considered. The process of icing is represented schematically according to the manner in which cold is supplied to the iced surface. A procedure is outlined for calculating the growth of the ice layer. Experimental findings are presented on the rate of icing of a shiplift model.

SOMMAIRE

Les auteurs analysent les conditions de la formation du régime de glace dans la chambre d'un ascenseur à bateaux aux régimes différents de son exploitation. Le processus de la formation de la glace est schématisé en fonction du caractère du transfert du "froid" aux surfaces gelées. Les méthodes de calcul d'accroissement de la glace sont décrites. On donne les résultats expérimentaux relatifs à la vitesse de l'accroissement de la glace sur le modèle d'un ascenseur.

In connection with the construction of a shiplift incorporated in the Krasnoyarsk power development, the first of its kind to be built in the U.S.S.R., researchers in the fields of ice thermal engineering and hydraulics are faced with a number of problems associated with its operation at low temperatures owing to the extension of the navigation period. Among the problems treated are the evaluation of the ice formation effect on the service properties of the structure, an allowance for the additional load exerted by the weight of the ice, et al. A technique is outlined herein for estimating the increase in the icing over the surface of the structure under various operating conditions. Experimental findings are adduced of a test program related to the calculation of the ice conditions in the Krasnoyarsk shiplift.

Formulation of the Problem

Two schemes of icing over of a solid surface are to be distinguished, both with the latent heat of ice formation removed through the lock wall rather than into the water (an ice layer is formed over the wall surface).

In the first case freezing and the input of cold are simultaneous and continuous. E.g. thus an ice layer grows over the upstream plating of navigation lock gates. A similar process takes place across the inner walls of a shiplift chamber filled with water. The cold is supplied by the ambient air through the walls of the ice-covered structure.

In the second case freezing occurs intermittently, i.e. the ice formation period is followed by one of cold accumulation etc. The process can be illustrated by the icing of canal slopes due to water level fluctuations and wave action, as well as by the icing of certain shiplift members which are periodically submerged in water.

Making use of conventional heat engineering terms, the first case may be designated as recuperative, and the second one as regenerative. Many investigators focused their research efforts on recuperative input of heat transferred through the wall towards the interface [R. 1-3] , while regenerative ice formation was considered mainly relative to icing of channel bank slopes as well as racks and gates of tidal power plants [R. 4, 5] .

We shall deal with three types of winter service conditions in a shiplift chamber, each being characterized by a corresponding temperature variation on the inner and outer chamber wall surfaces (Fig. 1).

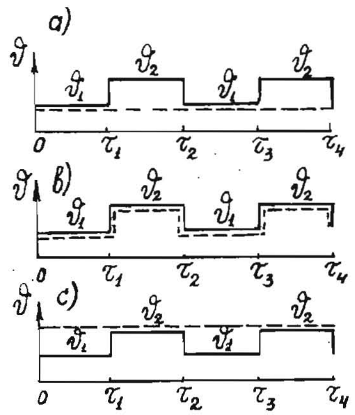


Fig. 1. Temperature variation over the outer —— and inner - - - shiplift chamber wall surfaces at three different operating conditions

The operational cycle is subdivided into periods when the chamber is surrounded by air in moving from the upstream pool downstream (τ_1), is in the water of the downstream pool, ($\tau_2 - \tau_1$), returns from the downstream into the upstream pool ($\tau_3 - \tau_2$) resides in the upstream pool ($\tau_4 - \tau_3$). The ambient air and water temperatures are ϑ_1 and ϑ_2 , respectively. The first and second regimes pertain to "dry" hauling of ships, with the chamber drained.

In the former (Fig. 1a) icing occurs over the outer surface of chamber walls during its residence time in water ($\tau_2 - \tau_1$ and $\tau_4 - \tau_3$) with regenerative and recuperative ice formation proceeding simultaneously. Regenerative icing takes place due to the cold accumulated by the chamber wall during the time τ_1 , with associated recuperative ice formation due to "cold" transfer through the wall, from the cold air inside the chamber to the water.

In the second case (Fig. 1b) flooding of the chamber is simultaneous with its entering the water of either the downstream or the upstream pools, with similar temperature conditions obtaining both on the outer and inner surfaces of the chamber walls. In such situations purely regenerative icing is induced by the accumulated "cold", with the ice layer growing at the same rate both on the inside and outside wall surfaces. The third type of conditions (Fig. 1c) is attendant to the motion of the flooded chamber. In the air (τ_1 and $\tau_3 - \tau_2$) ice is formed inside the chamber owing to recuperation. After, the submergence of the chamber regenerative icing outside and inside commences caused by the accumulated cold.

Calculation Procedures

The evaluation routine for the ice volume produced during each operational regime is as follows:

a) the "cold content" accumulated within the shiplift chamber wall is determined;
b) the heat flux from the cold wall surface into the water taking into account the boundary conditions is defined;
c) the ice thickness and the ice production rate are ascertained.

At water temperature equal 0°C the total "cold content" is consumed by ice production.

The calculations proceed from the following assumptions and conditions:

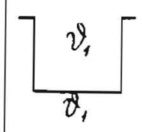
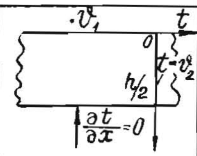
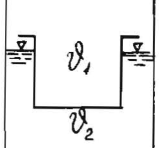
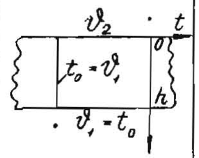
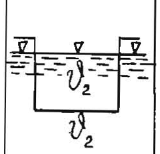
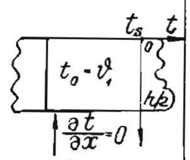
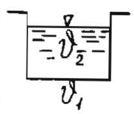
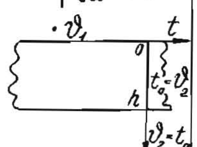
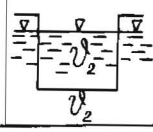
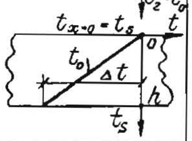
a) a plate of reduced (i.e. equivalent) thickness is substituted for the actual shiplift wall structure;
b) in each successive calculation the wall thickness includes the ice layer formed by the time.

The calculation schemes and analytical expressions to assess the average temperature included in the equation permitting to obtain the heat flux are presented in Table 1.

Problems N 1 and 2 correspond to the first operational situation (Fig.1a), the second (Fig.1b) is described by problems N 1 and 3, while the third is covered by problems N 4 and 5.

The regenerative ice production rate is governed by the accumulated "cold content" in the chamber walls. The latter value is included in the problem as the initial condition. The recuperative ice production rate is controlled by the boundary conditions of the problem. Subsidiary graphs R.6 are used to evaluate $\bar{\theta}_1, \bar{\theta}_2 \ldots . \bar{\theta}_5$. Figure 2 shows a subsidiary graph for problem N 1 illustrating the dimensionless average temperature as a function of the arguments $Bi = \frac{\alpha h}{\lambda}$ and $Fo = \frac{a \tau}{h^2}$.

Table 1

N of problem	Position of chamber	Filling of chamber with water	Physical scheme	Calculation scheme	Analytical solution
1	in air	drained			$\bar{t} = \vartheta_1 + \bar{\theta}_1 (t_0 - \vartheta_1)$
2	in water	drained			$\bar{t} = t_0 + \bar{\theta}_2 (\vartheta_2 - t_0)$
3	same	flooded			$\bar{t} = t_s + \bar{\theta}_3 (t_0 - t_s)$
4	in air	flooded			$\bar{t} = t_0 + \bar{\theta}_4 (\vartheta_1 - t_0)$
5	in water	flooded			$\bar{t} = t_s + \bar{\theta}_5 \Delta t$

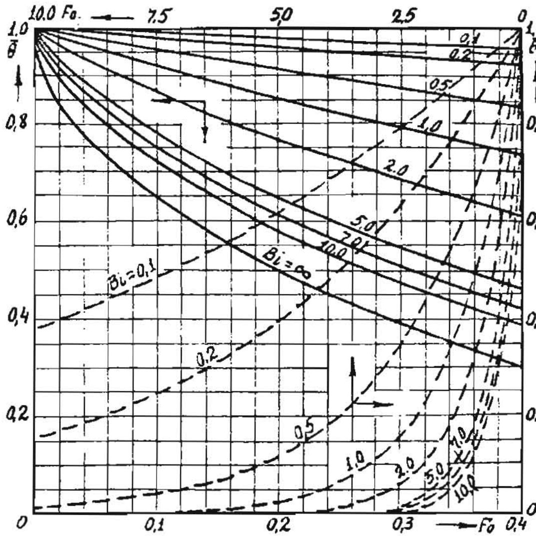


Fig. 2. Subsidiary graph for the evaluation of the average dimensionless temperature

Below a calculation example is given of the ice volume produced on the shiplift chamber wall surface under the second type of operational conditions (Fig. 1b)

with air temperature,	ϑ_1 = -20°C
up- and downstream water temperature,	ϑ_2 = 0°C
thickness of the steel wall,	h_o = 50 mm
coefficient of heat transfer from air to wall surface,	α = $14.6 \frac{\text{kcal}}{\text{m}^2\text{hr}^\circ\text{C}}$
residence time in pools,	0.5 hr
movement of chamber in air	1 hr

$$0 \leq \tau \leq \tau_1 \text{ (period of cold content accumulation)}$$

The calculation scheme of problem N 1 is made use of. Reduced wall thickness (with reference to heat content and the boundary condition of the third kind $Bi \leq 0.5$) are used in the computations.

$$h_{red} = h_0 \frac{c_0 \gamma_0}{c_i \gamma_i} = 50 \cdot 10^3 \frac{0.109 \cdot 7841}{0.5 \cdot 920} = 93 \cdot 10^{-3} \text{ m}$$

Accumulated "cold content" in the wall $Q = c_0 \gamma_0 h_0 \Delta \bar{t} = c_i \gamma_i h_{red} \Delta \bar{t}$

With $t_0 = \vartheta_2 = 0°C$; $\Delta \bar{t} = \bar{t}$.

From the solution to the problem we have $\bar{t} = \vartheta_1 + \bar{\theta}_1 (t_0 - \vartheta_1)$.

The arguments in defining $\bar{\theta}_1$, are

$$Bi = \frac{\alpha (h_{red}/2)}{\lambda} = \frac{14.6 \cdot 93 \cdot 10^{-3}}{2.02 \cdot 2} = 0.341$$

$$Fo = \frac{a \tau_1}{(h_{red}/2)^2} = \frac{4.35 \cdot 10^{-3} \cdot 1 \cdot 4}{93^2 \cdot 10^{-6}} = 2.02$$

The value of $\bar{\theta}_1$ is established from the graph in Fig. 2

$$\bar{\theta}_1 = 0.525$$

Hence $\bar{t} = 9.5^{\circ}C$, and $Q = 406 \frac{kcal}{m^2}$

$\tau_1 \leqslant \tau < \tau_2$ (period of regenerative icing on both sides of the chamber wall)

Employing the calculation routine of problem N 3 with the argument

$$Fo = \frac{a(\tau_2 - \tau_1)}{(h_{red}/2)^2}$$

$$h_{red} = h_o \sqrt{\frac{a_i}{a_o}} = 50 \cdot 10^{-3} \frac{4.35 \cdot 10^{-3}}{51 \cdot 10^{-3}} = 14.6 \cdot 10^{-3} \ m$$

$$Fo = \frac{4.35 \cdot 10^{-3} \cdot 0.54}{14.6^2 \cdot 10^{-6}} = 41$$

We obtain $Fo \gg 2$; $\bar{\theta}_3 = 0$, i.e. the whole "cold content" is consumed in ice production.

The total thickness of the ice layer formed will be

$$h_i = \frac{Q}{\rho \gamma_i} = \frac{406}{920 \cdot 80} = 5.5 \cdot 10^{-3} \ m$$

$\tau_2 \leqslant \tau < \tau_3$ (period of accumulation of "cold")

Taking advantage of the procedure employed in problem N 1 we have

$$h_{red} = 93.10^{-3} + 5.5 \cdot 10^{-3} = 98.5 \cdot 10^{-3} \ m.$$

The solution scheme being the same as for the first period $0 \leqslant \tau \leqslant \tau_1$.

Arguments: $Bi = \frac{\alpha(h_{red}/2)}{\lambda} = \frac{14.6 \cdot 98.2 \cdot 10^{-3}}{2.0 \cdot 2} = 0.36$

$$Fo = \frac{a(\tau_3 - \tau_2)}{(h_{red}/2)^2} = \frac{4.35 \cdot 10^{-3} \cdot 1 \cdot 4}{98.5 \cdot 10^{-6}} = 1.8$$

The value of $\bar{\theta}_1 = 56$ is found from the graph in Fig. 2.

$\bar{t} = -8.8^{\circ}C$; $Q = 376 \frac{kcal}{m^2}$

$\tau_3 \leqslant \tau \leqslant \tau_4$ (period of regenerative ice production on both sides of the chamber wall).

Following the calculation routine adopted in problem N 3

$$h_{red} = 14.6 \cdot 10^{-3} + 5.5 \cdot 10^{-3} = 20.1 \cdot 10^{-3} m$$

The argument $Fo = \frac{a(\tau_4 - \tau_3)}{(h_{red}/2)^2} = \frac{4.35 \cdot 10^{-3} \cdot 0.5 \cdot 4}{20.1^2 \cdot 10^{-6}} = 21.5$

The whole of the "cold content" is consumed in ice production

$$h_i = \frac{Q}{\rho \gamma_i} = \frac{376}{920 \cdot 80} = 5.1 \cdot 10^{-3} \ m.$$

A total of more than 10 mm of ice is produced during one cycle. Ice thickness will increase with the number of cycles. The additional load during one cycle will be 10 kg/m^2, which amounts to 60 tons for the total chamber surface.

Experimental studies

In connection with the design of the shiplift for the Krasnoyarsk hydroelectric development the Laboratory of River and Reservoir Winter Regime of the B.E. Vedeneev VNIIG carried out a research program on regenerative ice production, icing over of the shiplift chamber and running gear. Studied were: the ice production rate on pre-cooled plates submerged in water; icing of a model chamber and running gear; icing of the gear drive due to intermittent submersion in water.

1) Experiments on the determination of the ice growth rate were run by repeatedly dipping into the water steel and ice plates at temperatures ranging up to -25°C, the water temperatures varying between 0 ÷ 8°C.

The experimental findings are reduced to a dimensionless form

$$K = f(Fo, \ Bi \cdot \theta).$$

The analytical solution was obtained as $K = \bar{\theta}_1 - Bi\,\theta Fo$

where $\bar{\theta}_1$ (see Fig. 2), the temperature ratio parameter is $\bar{\theta}_1 = 1 - \frac{t_{i,\tau}}{t_{i,\tau}} = f(Fo)$

Comparison between experimental and calculated data brings out an identical pattern in both (Fig. 3).

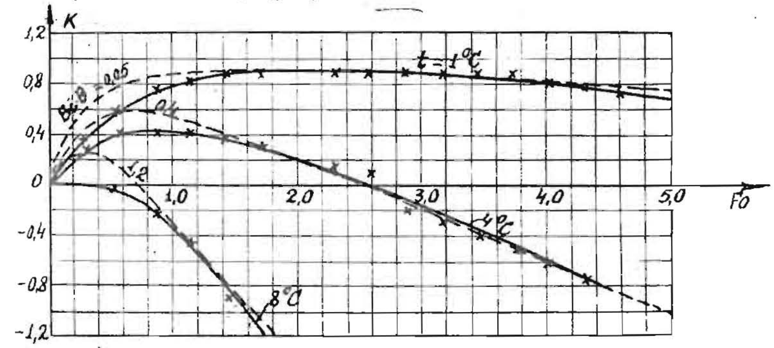


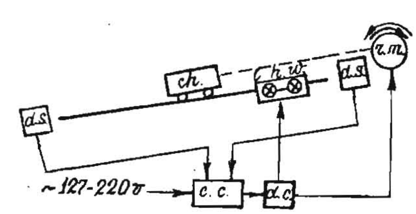
Fig. 3. Comparison of experimental and calculated data on freezing and melting of ice.

Hence the equations derived appear to be sufficiently reliable to be used in foretelling regeneration icing conditions.

2) Tests on the icing of the model chamber and running gear were conducted at:

length of the rails	9 m
slope	1:10
width of gauge	64 cm
velocity of chamber motion	0.36 m/sec
chamber dimensions	100x50x50 cm
time of residence in water	30 sec
time of residence in air	30 sec
length of a cycle (lifting, lowering)	110 sec
air temperature	-8°C
water temperature	0÷3°C

The block diagram of the experimental rig is depicted in Fig. 4.



ch. - chamber
c.c. - controlling computer
d.s. - directional switch
d.c. - directional contactor
r.m. - reversible motor
l.hw - lamp heaters of the wheels

Fig. 4. Block diagram of the experimental set up.

The tests permitted to obtain a correlation between ice thickness on the outer chamber wall and the number of cycles (Fig. 5), the rate of icing decreasing with the number of cycles.

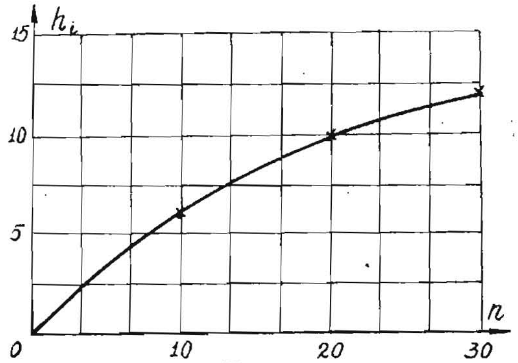


Fig. 5. Correlation between ice layer thickness over the chamber wall surface and the number of cycles (model)

Icing of running gear, freezing of wheels to the rails and such like phenomena were observed during the experiment. Especially difficult are the ice conditions along the water edge where icing of rails is frequently encountered, while floating ice blocks and accumulations of fragmented ice obstruct the movement along the rails.

The gain in weight of the bogie amounted to 20 kg in 30 cycles. At water temperatures in excess of 3°C the experimental set-up ran continuously without interruptions.

3) Operation of partially submerged gear drives subjected to icing was studied by means of a cylindrical horizontal single-reduction gear with a gearing modulus, m = 6.5. The test demonstrated that ice was formed at the roots of teeth. Icing of gear materially increased the shearing resistance

$$f_g = f_0 + \kappa h_i \qquad \frac{kg}{cm^2}$$

The proportionality factor, κ , may be assumed to be

at $\vartheta_1 \geq -5°C$ κ = 5.35

$\vartheta_1 < -5°C$ κ = 10.2

Choosing the rated capacity of gear in this situation, a coefficient making allowance for operating conditions should be introduced.

Conclusions

Theoretical calculations and experimental research into regenerative ice production testify that in situations where subzero temperatures and low flow velocities prevail a considerable additional load on the structure may be created due to icing. Due consideration should be given to it in designing the driving gear for shiplift chambers. In choosing driving gear capacity the possibility of its freezing to the rails and the effect of fragmented ice accumulations at the water edge etc. are to be taken into account.

Symbols

Q = heat flux; h, h_{red}, h_i = total and reduced plate thickness, thickness of ice, respectively; ϑ_1, ϑ_2 = air and water temperature, respectively; ρ = latent heat of phase transition; γ_i = volume weight of ice; λ, a, c = thermal conductivity and thermal diffusivity coefficients, heat capacity, respectively; τ = time; $t_{i,0}$ = initial ice temperature; $P_0, \Delta P$ = initial weight, variation in weight of plate, respectively;

$Bi = \frac{\alpha h}{\lambda}$, $Fo = \frac{a \tau}{h^2}$ are the Biot and Fourier numbers, respecitvely;

$K = \frac{\Delta P \cdot \rho}{P_0 \cdot c_i (-t_{i,0})}$ is criterion of phase transition;

$\theta = \frac{\vartheta_2}{t_{i,0}}$ = dimensionless temperature.

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CONTROL OF ICE CONDITIONS DOWNSTREAM FROM HYDRAULIC POWER PLANTS WITH REFERENCE TO NAVIGATION PROBLEMS

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ABSTRACT

Considered is the problem on extending the navigation period on river reaches downstream from hydro power plants through control of the discharge and the temperature of the water released downstream. Increased water releases as well as withdrawal of warm water from the deep layers of the reservoir result in an increased length of the area of open water below the power plant, a later freeze-up and an earlier break-up, which ensures favourable conditions for extending the period of navigation in the river reach considered.

SOMMAIRE

Le rapport traite le problème de prolongation de la navigation sur les rivières en aval des aménagements hydro-électriques par la régularisation des lâchures et de la température d'eau. L'augmentation des lâchures, ainsi que le prélèvement de l'eau plus chaude dans les couches de fond conditionnent l'augmentation de la longueur de la clairière dans le bief aval, la prise avancée de la rivière et la débâcle prématurée, ce qui crée les conditions favorable pour prolonger la période de navigation sur le tronçon considéré de la rivière.

The navigation period in the river reaches downstream from medium - and high-head hydro power plants can be extended through control of the discharge and the temperature of the water released downstream.

The ice conditions in the river reaches below hydro power plants are different from the natural ones, since here, in addition to general physico-geographical factors, the ice regime is affected by the discharge and the temperature of the water released from the reservoir. Downstream from hydro power plants with large reservoirs there is an area of water keeping free of ice throughout the winter. The size of this area may vary considerably depending on the amount of the water released as well as on the water and air temperatures. At high flow velocities, with resulting high turbulence, the water within the ice-free area will cool (and under certain meteorological conditions will become supercooled) producing frazil. Usually the ice cover downstream from hydro power plants forms as the ice edge progresses upstream. The downstream floating masses of frazil ice accumulate against the ice edge forming the ice cover. High water stages associated with freeze-up cause upstream propagation of the backwater zone, with the ice edge progressing in the same direction due to decreased flow velocities in this zone. This upstream propagation of the ice edge ceases only when the length of the ice-producing stretch is reduced thus diminishing the rate of cooling of the water in the open area and consequently the amount of frazil produced therein. At high flow velocities the upstream propagation of the ice edge is accompanied by ice jamming. Such is the general scheme of ice formation downstream from hydro power plants with large reservoirs.

On a regulated river water discharges in winter are usually greater as compared with natural streams. The temperature of the water flowing from the reservoir downstream is higher too. The water temperature in a given reservoir will increase with increased period of water exchange. This can be illustrated by the Ust-Kamenogorsk hydro power plant.

1. Winter (years)	1953-54	1955-56	1957-58	-59
2. Period of water exchange (days)	35	30	26	17
3. Mean water temperature (°C)	0.43	0.33	0.24	0.16

With the period of water exchange in the Bratsk reservoir increased from 110 to 470 days (during the filling of the reservoir) the mean water temperature from January through March grew from 0.61°C to 2.29°C.

The water temperatures immediately below the dam are rather uniform due to high turbulence of the flow, though in certain periods the temperature difference across the flow width may be considerable. It should be noted that the distribution of temperatures across the flow width immediatly downstream from the dam (in the tailrace channel, etc.) is governed by the power plant operating regime.

Further will be discussed the effect of the depth of submergence of water inlets on the water temperature past the dam. The water temperature in reservoirs is known to vary from layer to layer. Such a differential distribution of temperatures as well as the depth of water inlets determine the water temperature and consequently the ice conditions below the dam. E.g., the outlets at the headwaters of the Neva are shut with vertical-lift gates provided with flaps. In winter when the water is discharged through the tilted flaps, with the gates closed, it is selected from the cold surface layer of the reservoir, while in the case when the water is released from under the gates, it is drawn from the bottom layers. The resulting temperature difference is 0.3°C. The effect of the depth of submergence of inlets at large hydro power plants on the downstream water temperature is even more pronounced. Thus a higher water temperature past the Kamskaya hydro power plant, as compared to the mean water temperature immediately upstream from the plant, is accounted for by the location of the intake structure whose sill is at an elevation practically equal to that of the river bottom before the dam. In such intakes the water is withdrawn from deep warm layers, as was the case with the Bukhtarma hydro power plant where the temperature of the water discharged through the bottom outlets was by 1.0 - 1.2°C higher than that of the water passing through the turbine intakes located at a higher elevation. In its turn, the temperature of the water discharged through the surface outlets was by 0.6°C lower than that of the water discharged through the hydro-turbine units. The results of thermal studies carried out at the Krasnoyarsk and the Bratsk hydro power plants show that the downstream water temperature is governed by the intake elevation. The character of the upstream progression of the ice edge below a hydro power plant depends on the meteorological conditions, the discharge and the temperature of the water released downstream, and the morphometric factors. While the meteorological and the morphometric conditions are independent of the power plant operation, the water discharge, and to a somewhat less degree, the downstream water temperature are governed (as mentioned above) by the operating regime of the plant and the intake location.

As evidenced by observational data, the maximum upstream propagation of the ice edge in the vicinity of an operating hydro power plants is considerably delayed as against the natural freeze-up date. The period of the maximum proximity of the ice edge to the dam is usually rather short and varies from 1 to 10 days, as at the Irkutsk hydro power plant. The period when the ice edge stays below the maximum proximity section may be relatively long. E.g., at the Irkutsk hydro power plant it reaches 20-60 days. In case of small variations in water discharges at a power plant their effect on the upstream progression of the ice edge is negligible, while with considerable daily variations in water discharges this effect is more pronounced. E.g., at the Novosibirsk hydro power plant operating under peak load conditions the zone of stable ice cover is 20 km downstream from the plant. Upstream from this zone the ice position depends on the amount and the temperature of the water released downstream as well as on the meteorological conditions. At the Ust-Kamenogorsk hydro plant the ice edge stayed at about 10 km downstream from the dam for several years. Commissioning of the Bukhtarma hydro power plant, located further upstream, resulted in an increased water temperature in the reservoir of the Ust-Kamenogorsk hydro power plant. Thus the area of open water downstream from the plant extended up to 30-40 km, which is another evidence for the effect of the temperature of the water released on the length of the ice-free water area downstream from the power plant. Table 1 presents data on the maximum proximity of the ice cover edge to the dam.

Table 1

Minimum length of open water area downstream from hydro power plants

River	Hydro power plant	Observation period	Maximum proximity of ice edge to power plant, km
1	2	3	4
Volga	Gorki	1955-60	0.8 - 2.5
	Volzhskaya named after V.I.Lenin	1956-58	8.2 - 12.0
	Volzhskaya named after the XXII C.P.S.U. Congress	1959-61	4.5 - > 50
Don	Tsymlyanskaya	1953-57	1.0 - 7.0
Angara	Irkutsk	1956-63	4.2 - 49.4
	Bratsk	1961-68	14.5 - 69.0
Neman	Kaunas	1959-65	5.0 - 21.0

As seen from Table 1 the minimum length of the polynya at some low-head hydroelectric plants (e.g. Gorki, Tsymlyanskaya etc.) is less than 10 km.

At high-head plants with high-capacity water storage such as the Irkutsk, Bratsk etc. the length of the polynya may amount to 50 km or more.

Table 2

Characteristics of the winter	Water temperatures, ^{o}C	Water discharge, m^3/sec 2000	3000	4000
Warm	1	17.9	25.3	29.8
	2	38.0	55.0	63.6
	3	55.2	81.6	95.3
Average	1	15.7	22.4	27.4
	2	33.0	47.0	55.3
	3	48.5	70.9	82.6
Cold	1	10.3	14.9	19.2
	2	24.4	36.4	42.2
	3	36.0	53.5	63.6

In Table 2 are given the dimensions of the polynya downstream of Bratsk dam calculated by the heat balance method at release discharges of 2000, 3000 and 4000 m^3/sec and water temperatures of 1^{o}, 2^{o} and $3^{o}C$ during cold, average and warm winters. The principal equation is

$$\ell = \frac{Qc\gamma(t_d - t_e)}{SB},$$

where ℓ is polynya length; Q = release discharge; S = heat transfer; B = river width at the estimated reach; c = heat capacity of water; γ = volume weight of water; t_d = downstream water temperature; t_e = water temperature at a distance from the plant (assumed to be $0^{o}C$). In evaluating the polynya length with the ice edge receding the water temperature at the edge was obtained from calculations.

The polynya length included in this case an additional river reach with a decaying ice cover where water temperature dropped from $t_e \neq 0$ to zero at melting. Th. value of S was calculated proceeding from meteorological data making allowance for water temperature variations along the reach.

The data listed in Table 2 reveal for instance that at a discharge of 3000 m^3/sec and water release temperature of $1^{o}C$ in a warm winter the polynya length reaches 25.3 km. With water releases increasing to 4000 m^3/sec at identical meteorological and thermal conditions the length of the polynya extends to 4.5 km.

The difference in meteorological conditions between a warm and an average winter reduces the polynya length only by 2.9 km. At the same time a 1°C variation in the water release temperature increases the polynya length by 29.7 km other things being equal. Observation data demonstrate that water release discharges and temperatures have the most pronounced effect on the dimensions of the polynya downstream from the Bratsk dam, hence in order to augment the length of the polynya water releases must be increased and water intakes located as far from the water surface as possible.

Data on the Bratsk hydroelectric plant may be cited by way of example to illustrate the effect of water discharges on the rate of the ice edge recession. In the spring of 1973 the ice edge receded from the Bratsk dam at the rate of 5 km per day (at a discharge of 2200 m^3/sec).

Heitening of the discharge up to 4000 m^3/sec permitted to increase the ice edge recession rate to 15 km per day. Thus a polynya almost 300 km long was rather quickly created downstream from the Bratsk dam.

Analysis of the data on the downstream pools of the Bratsk and other high-head hydroelectric plants with large water storages indicates that the duration of the ice cover differs for different river reaches.

Ice cover formation starts earlier and the break-up begins later on river reaches remote from the power plant as compared to those in its vicinity. E.g. the difference in the duration of ice cover between the river reaches at a distance from the plant and those in its neighbourhood amounts from 4 to 5 months downstream from the Bratsk hydroelectric plant. Consequently the navigation periods on the river reaches nearer to the plant are longer (by 4 to 5 months below the Bratsk hydroelectric power plant) than farther downstream. In the vicinity of the dam site where the polynya remains open during the whole winter (at Bratsk there is a polynya from 15 to 70 km long) navigation is possible throughout the winter. Control of downstream ice conditions by varying water releases was effected at the Irkutsk and other hydroelectric plants. Experience proved the efficiency of these measures. With water releases and water temperatures increasing the upstream advance of the ice edge became slower in autumn and the spring break up began earlier resulting in the extension of the navigation period below hydroelectric power plants.

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TRANSVERSE FLOW IN THE UPPER APPROACH OF A SLUICE CHAMBER CLOSELY JOINED TO A WEIR

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ABSTRACT

The waterway on the middle reaches of the river Elbe and operational shortcomings of the navigation structures situated closely to the weir.

Adjustment of the dividing wall, removing some of the mentioned troubles. Example of the adjustments carried out.

Research results obtained with aerodynamic equipment and with a water model of the dividing-wall adjustment for the dam at Kostelec n/L.

Recommendations for the procedure in solving these problems using.

SOMMAIRE

La voie navigable du milieu de l'Elbe et les insuffisances des ouvrages pour la navigation, situés étroitement près du barrage.

L'adaptation des murs de guidage, éliminent quelques obstacles allégués ci-dessus.

Les exemples des adaptations appliqués. Les résultats de recherche d'adaptation des murs de guidage pour le dégré de Kostelec n.L., atteints sur un modèle aerodynamique et un modèle hydraulique.

La marche à suivre du procédé recommandé pour trouver la solution de cette problèmatique par la méthode du modèle reduit.

On the canalized middle sector of the river Elbe, in the section Mělník - Chvaletice under construction, there are 15 sluice gates (Fig.1) in operation, under construction or reconstruction, respectively. In seven of them, the navigation chamber is built close to the weir, where by the water-power utilization of the barrage is in all cases on the opposite bank than the water - power plant.

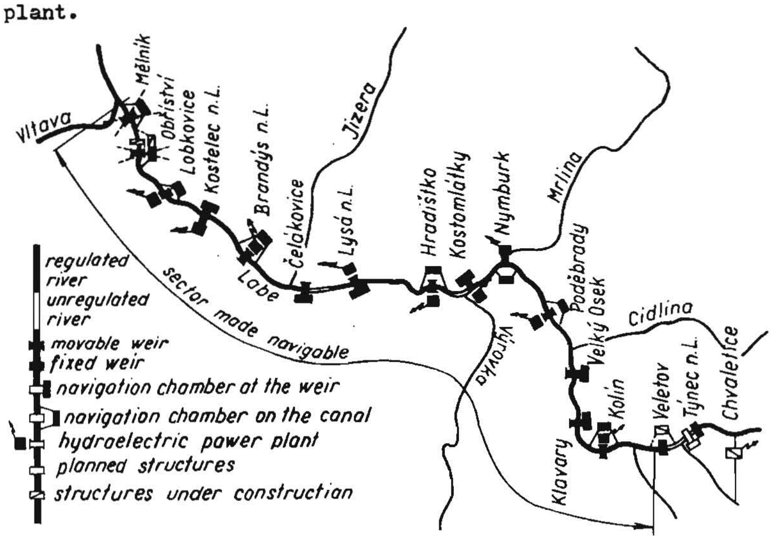

Fig.1 Layout of the Middle-Elbe waterway

After completing the weirs under construction and after putting the Chvaletice thermal powerplant in full operation, the freight transport on the Middle-Elbe waterway will increase from an average of 210×10^3 t/yr in the period 1961 - 1971 to 4300×10^3 in 1978 , i.e. about 20 times /1/. With the increased navigatión density, the safety of the ships entering the approaches without cómplicated manoeuvring is demanding greater attention.

1. OPERATIONAL SHORTCOMINGS IN NAVIGATION STRUCTURES SITUATED VERY NEAR THE WEIR

a) With higher river discharges there oćcurs a flow contraction with a vortex at the upper dividing wall cutwater of the ap -

proach, both in the approach and in the riverbed at the dividing wall. The vortex in the riverbed decreases the discharge capacity and changes (usually deteriorates) the flow in the weir profile.

During the flow round the dividing wall cutwater, the point velocities reach high values and the vertical velocity components and increased turbulence intensity in the vortex with a vertical axis close to the wall in the riverbed may cause deep scours at the wall. The scour depth and the bottom area affected by it are proportional to the flow velocity and to the extent of narrowing of the flow cross-section. This phenomenon is for the structure the more dangerous the shorter the dividing wall, even if the mere lengthening of the dividing wall cannot prevent its occurence. The scour size at the cutwater can be also affected by the movable gates manipulation on the weir.

Due to this scour,part of the dividing wall at Klavary collapsed during the flood in spring 1946 and in 1948 the remaining part, founded on pilots, collapsed.

E.g. a scour of 2,7 m depth in the arenaceous marl of the dividing wall cutwater /2/ was ascertained at the Kostomlátky lock.

b) The flow direction change in the place of the dividing wall cutwater, resulting from the narrowing of the river channel by the approach width, and secondary flow in the approach in the shape of a cylinder with a vertical axis adversely affect the entry of the ships and especially of boat trains from the free river into the upper chamber approach. This danger increases in the case of a combination of higher discharges and the action of lateral winds, especially when the boats are empty.

The forces which deviate the vessels from the trajectory in the direction to the dividing wall are proportional to the square of the transverse component of the flow velocity and depend on the boat shape and the area of the main cross-section with a view to the transversal velocity component. To determine the magnitude of the moments and forces acting upon the vessel is practically possible only experimentally, preferably by using not distorsed large-scale hydraulic models, mainly because the presence of the boats affect and frequently also considerably changes the flow in the approach.

The danger of the vessel being sucked by the flow into the dividing wall cutwater increases proportionally with the decrease in the controlability of the boat be the helm, i.e. with the decrease of the relative boat velocity due to the longitudinal flow velocity component. For this reason it is greater at the entry the upper approach then at the exit and it grows with the discharge increase in the river and with the decreasing distance of the dividing wall cutwater from the mouth of the navigation chamber.

Assuming the magnitude of the transverse water velocity component in the area of the dividing wall cutwater to be 0,2 m/s in the upstream water and up tp 0,3 m/s in the downstream water /3/, it must be limited in the navigation chamber mouth area to the order of only cm/s.

c) The problem of siltation of the approaches on the Middle-Elbe with suspended sediments and fine-grained bedload is of importance mainly for the lower approach, as was shown both by research /4/ and operational experience. The results of this research is included in the paper presented by LIBÝ at this Symposium.

2. CONSTRUCTION OF THE UPPER APPROACH DIVIDING WALL

The dividing wall must be judged from two points of view:

a) of the stability of the vessel proper and its potential effect on the function of additional structures (weir, hydroelectric power plant),

b) of navigation safety and its potential effect on the capacity of the waterway.

From the point of view of the creation of a local scour and the safeguarding of the dividing wall stability, the wall must be designed for a discharge, where the probability of exceeding is usually less than the probability of exceeding the maximum navigation discharge. From the viewpoint of limiting the transverse velocity components in the approach, i.e. with a view to safety and comfort of navigation, the dividing wall must be considered for maximum navigation discharge. On the sluice gates of the Middle-Elbe a gradual substitution of the upper mitring swing-gates of the navigation chambers by gates which permit the passage of part of the discharge through the navigation chamber is presumed. Their suitable manipulation results evidently in the marked reduction of scour formation at the dividing wall cutwater and its design can thus be judged mainly by navigation requirements.

According to the present research results and operational experiences /2, 3, 4, 5, 6/, these problems can be best solved from mentioned two points of view by a dividing wall through which water can partially flow, or by a dolphines with a curtain wall. The shape, dimensions and number of openings (pillars) must be determined

a) by the approach cross-section riverbed ratio,

b) by the ratio of that share part of the discharge belonging in front of the dividing wall cutwater to the riverbed part which passes into the approach to the total discharge and

c) by the cross-section velocities in the riverbed in front of and behind the dividing wall cutwater.

This leads us also to the conviction that there is no sole design of the dividing wall, or sole pier shape, that would simultaneously affecting the requirements of economy as well as the navigation and stability and that the number of openings and piers, respectively, must be designed on the basis of model research. It seems to be proved, that the necessary length of the part of the dividing wall, through which the water flows, is, with a view to its stability, considerably shorter than the length necessary from the viewpoint of navigation safety.

On the Middle-Elbe one dividing wall through which the water flows has been completed up to present, substituting the collapsed dividing wall at Klavary. The layout of the part through which the water passes is indicated in Fig.2.

3. RESEARCH RESULTS OF FLOW IN THE UPPER APPROACH OF THE NAVIGATION CHAMBER at KOSTELEC n.L.

The flow in the surroundings of the upper dividing wall cutwater and in the approach was studied on a aerodynamic under -

pressure model and on a hydraulic model with fixed bottom. On both models the measurements were carried out for two adjustments of the dividing wall: for the existing wall and for a wall extended by a part through which the water flows, chossing similar shape and dimensions as those of the dividing wall at Klavary.

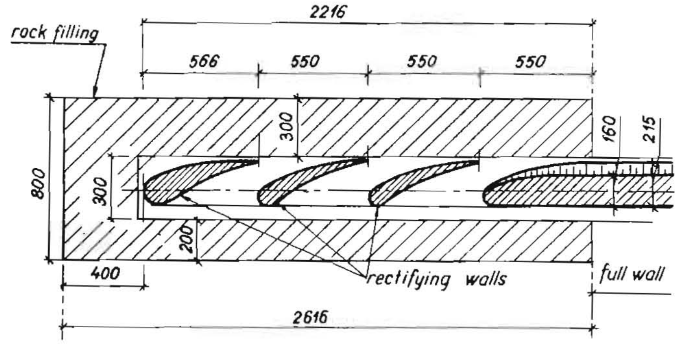

Fig.2 Dividing wall with through-flow openings

On the aerodynamic model the vector trends and velocity values were studied : the trends by means of threads with polysterene beads on the end and the values by means of a hot-wire anemometer DISA type 55 D 00. For the conversion of model velocities to real velocities discharge and area scales were used.

On the hydraulic model, the streamlines and the local velocity at the water level were determined by photographing glowing floats with interrupted exposure.

The evaluation of the experiments showed that the longitudinal velocity component, measured in a straight line parallel with the dividing wall shifted 10 m in the direction to the trajectory, remains for both wall construction alternatives at maximum navigation discharge at a value of about 0,35 to 0,40 m/s up to a distance of 20 m in front of the dividing wall cutwater, then they decrease quickly in the direction to the navigation chamber mouth to a negligible value.

In points close to the bank, the value of the longitudinal velocity component is affected to a distance of 60 to 80 m in front of the dividing wall cutwater, the approach width being about 40m.

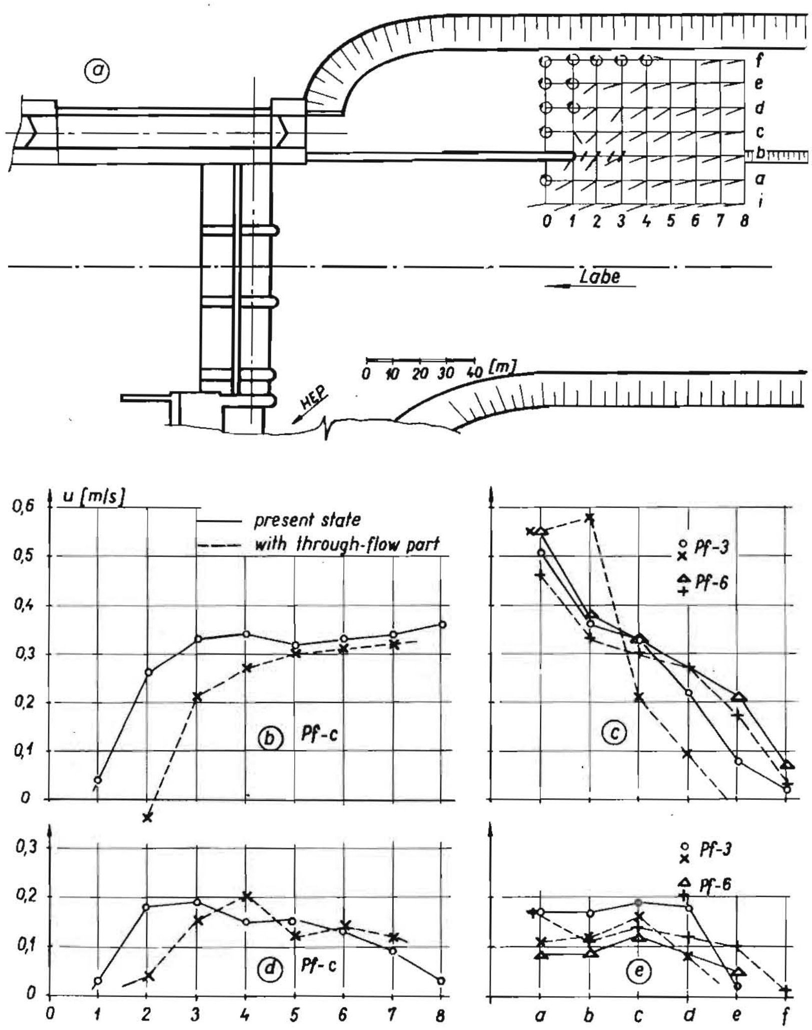

Fig.3 Velocities in the fairway in front of the dividing wall cutwater

The transverse velocity components reach, in a distance of 10 to 40 m in upstream direction in front of the dividing wall cutwater and transversally to a distance of 20 m from the dividing wall axis in the two adjustments about 0,20 m/s,i.e. they lie at the max.permissible limits, after JAMBOR /3/.At higher river discharges, difficulties with the entry of the boats from the free river into the approach can be expected. However the range of these higher transverse velocities, is wider for the full wall /Fig.3/.

The results obtained on the aerodynamic model were confirmed by measurements on the hydraulic model /Fig.4/.

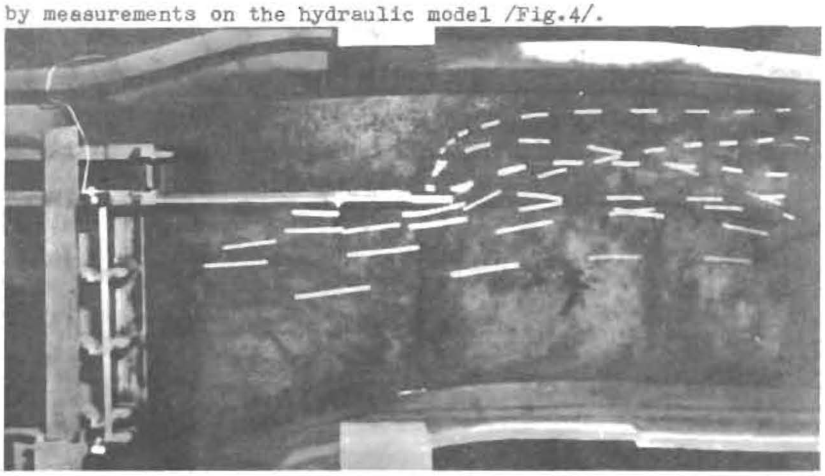

Fig.4 Surface stream - lines in the upper chamber

The length of the part of the dividing wall, through which the water flows, was designed for the navigation chamber at Kostelec /4/ originally only with a view of preventing the formation of scours. It has been shown that if it has to meet also the requirements for increased navigation safety and comfort,that part of the wall must be considerably lengthened.

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ACTIVITY FOR THE PREVENTION OF ICE DAMAGE IN HUNGARY

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ABSTRACT

An organized activity /ice breaking,explosion/ for the prevention of ice damage is continuously pursued by the Hungarian Water Service on the Hungarian rivers in winter. In order to perform the ice breaking problems a fleet of up-to-date ice-brakers have been developed and special explosive charges for ice-perforation and blasting are at our disposal.

SOMMAIRE

En hiver, l'Authorité des Eaux Hongrois conduit une activité organisée contre les dommages des glaces sur les rivières /rompage et explosion des glaces/. Pour accomplir ces devoirs une escadrille des bateaux contreglaciers modernes était dévelopée et des charges d'explosives sont à la disposition d'elle pour trouer et exploser des glaces.

Over the centuries much damage has been caused in Hungary by recurring ice-flood disasters. In recent decades the ice floods of 194o, 1941 and 1956 caused considerable devastations. One of the tasks major of the Hungarian Water Service is to avert the danger of ice floods, i.e.,the development of ice protection activities primarily on the Danube and Tisza Rivers but also on minor watercourses.

Ice conditions on rivers are influenced by meteorological, hydrological and riverbed morphological factors.

The Hungarian section of the Danube, which represents the greatest ice danger among the Hungarian rivers, is influenced, by the combined effect of the oceanic, Mediterranean and continental climates. In unfavourable cases the spring floods and the drifting ice masses arriving from the upper sections of the Danube River due to the effect of the oceanic climate will find cold air masses and steel-hard ice cover along the Middle-Danube. Owing meteorological conditions the development of ice drifts is likely to occur every 3-4 years.

Due to more favourable meteorological factors the spring floods on the Tisza River will usually find decayed ice which it can easily lift and carry away.

Other rivers in Hungary are either under the influence of the above mentioned effects or are only of local danger when ice is developed on them.

Over the 127 km long section of the Danube River below Budapest which is critical from the point of view of ice runs, the hydrological factors are also unfavourable. There are no major tributaries which could contribute to the breakup and removal of the ice cover.

The morphology of the riverbed over same section of the Danube River is unsatisfactory, - in spite of the considerable volume of river regulation works.

Overdeveloped bends, sand bars, narrow channel and floodbed sections alternate here. It is characteristic that standing ice is more frequent and of longer duration over this section than over the others.

During the river regulation works of the last century, due to economic reasons, generally narrow flood beds were left on the rivers of medium and small size in Hungary. This can easily cause critical raised water levels when ice jams develop.

It has been observed that whereas the appearance and the amount of drifting ice depend primarily on temperature conditions, the stopping of ice, and the development of ice jams is influenced besides temperature and hydrological conditions by the morphological characteristics of the riverbed.

Therefore the prevention of ice-jam floods must be based on the elimination of the morphological causes in the riverbed through river training measures.

River regulation plans take a long time to realize. For the improvement of flood levees still loo million m^3 earth must be placed and in the regulation plan of the Hungarian section of the Danube River the use of some 2,1 million m^3 rip-rap is envisaged.

Up to the termination of river regulation works and also in the regulated riverbeds effective protection against ice danger and adequately used ice-destroying methods /ice-breaking blasting/ are necessary, due to non influenceable meteorological conditions.

The objective of ice destruction activity on the rivers of Hungary is to ensure the unhindered and harmless passage of great flood discharges.

Of the methods of ice-destruction discussed in literature and tested in practice the use of ice-breakers and the supplementary blasting have proved most effective under the conditions prevaiting in Hungary.

In Hungary the planned development of icebreakers was started after 1956. As early as in winter 1957-1958 already 6 auxiliary icebreakers have been used. The first, modern icebreaker with a 600 HP Diesel engine was put to service in January, 1959. On the basis of foreign experiences the first 600 HP icebreaker vessel with a socalled "wobbling" equipment was launched in 1964. Here on two axes reaching from stem to stern two excentric weights of 6 metric tons each are mounted and displaced by 18o^{o} relative to each other. In movement these import a wobbling motion to the vessel about both horizontal axes. Compared to normal vessels the ice breaking capacity of these ships is 5o% higher.

The 1300 HP "wobbling" vessel of the Hungarian ice-breaker fleet on the Danube River was completed in 1968. This vessel is able to work in fog and also during night due to its special equipment for navigation and telecommunication.

The most modern 1440 HP ice-breaker, the 11th in the sequence of construction was finished in 1972./Figs.1. and 2./.

Fig. 1

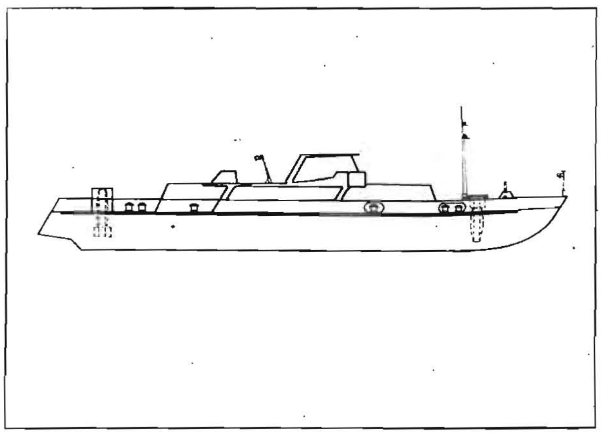

Fig. 2

In order to supplement the work of the large vessels 300 HP small icebreakers of shallow draft have been constructed. The smallest 170 HP icebreakers can be transported on road and used even on small rivers. The Hungarian icebreaker fleet consists today of altogether 20 up-to-date icebreakers. These vessels were designed and built in the Shipyards of Balatonfüred in Hungary. The vessels are used for towing when no ice exists.

The icebreakers are used on the Danube to secure the continuous passing of the ice in the period of primary ice-drifting, debaying of a standing ice cover and reducing the danger of jams during secondary ice-drifting. At times of standing ice on the Danube the icebreakers have the following tasks: to secure jam-free and even development of the ice cover, to cut and maintain a 30-40 m wide continuous iceless corridor in the standing ice cover, to destroy incipient jams.

During secondary drifting the vessels must continuously destroy and eliminate the ice cover.

On the Tisza River and on its tributaries icebreakers are only used in periods of secondary drifting.

During winters colder than average, in the period of primary drifting ice jams as thick as 4-8 m can build up which the icebreakers are uncapable of penetrating. The jams are broken up most expediently by blasting.For ice blasting a range of advanced and safe charges and detonators have been developed in the Hungarian Water Service.

For perforating and making holes in the ice so-called ice-perforator Marges are used /Fig.3/. The perforator series consist of cumulative charges of different strength which when placed and detonated on the surface of the ice develop a hole of 0,6-2 m of diameter in a 1-5 m thick jam. Through these holes the cylindrical, waterproof, up-to-date charges with a weight mounted on their bottom can be introduced below the ice to break up the ice jams /Fig.4/.

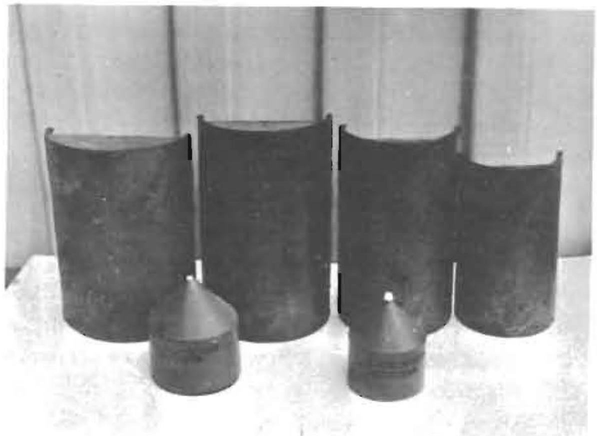

Fig. 3

Fig. 4

To further shatter the cracked ice cover and to reduce the size of larger floating ice floes so-called "flinging" charges mounted in a plastic sleeve are used.

Ice covers of moderate thickness are cut into pieces by plastic-hose charges placed on the ice surface.

Ice is usually broken up from the downstream end. In a wide ice-cover or in a jam a corridor is blown along the main current line. On both the Danube and the Tisza rivers plans for blasting the expected drifts have been prepared in advance on several sections where jams are likely to develop. On medium and small rivers blasting is an important supplement to ice-breaking.

In Hungary, activities for the prevention of ice damage are managed and directed by the National Water Authority.

Besides the up-to-date icebreakers and the methods for ice blasting, the ground and aerial observation and the telecommunication system developed by the Water Service is of importance.

Long range planning objectives include the development of the icebreaker fleet mainly with transportable small vessels for use on minor rivers; the application of helicopters in blasting operations; and the perfection of blasting methods.

In its activities for preventing ice damages the Hungarian Water Service collaborates with the neigh bouring countries. For example on the Danube, on the 227 kms long section of common interest the Hungarian icebreakers effectively help the Yugoslavian Water Authorities under the water agreement between the two countries.

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EXAMEN DES RELATIONS EXISTANT ENTRE LES FORMATIONS DE LIT ET LA DESCENTE DE LA GLACE

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ABSTRACT

The natural shape of rivers is a result of complicated system of natural phenomena. Human interveniences in order to reducing damages must be adapted to this complicate system, which to approach by getting acquainted with relationships among morphological parameters is the aim of this study.

SOMMAIRE

La forme naturelle des fleuves est le résultat du régime complexe des phénomènes naturels. Les interventions humaines tendant à réduire les dégâts doivent s'intégrer à ce système compliqué que l'étude veut approcher par la connaissance des relations existant entre les paramètres morphologiques.

INTRODUCTION

Les cours d'eau et les vallées alluviales représentent un des facteurs des plus importants du point de vue du développement humain. Sous l'influence du changement du régime d'eau le lit du cours d'eau fuyant dans la vallée alluviale est en mouvement continu et s'efforce d'atteindre l'état d'équilibre correspondant à sa pente, aux matières charriées et au matériel du lit.

L'aménagement des cours d'eau et la lutte contre les dégâts commis par eux-mêmes exigent en général certaines interventions se faisant sentir au fait surtout dans l'accélération ou bien au ralentissement des processus naturels.

La première condition de l'efficacité des interventions réside dans la connaissance approfondie des processus naturels.

L'amenée de la glace - se formant sur les cours d'eau en hiver - sans dégâts est également un motif pour les interventions humaines.

Au profil des gués, lors de l'étiage d'hiver et en conséquence de la forme inconvenable du lit, les glaces flottantes peuvent s'arrêter ou bien se prendre formant un barrage de glace qui provoquera une crue glaciale.

Je cherche à parer aux dégâts dus à la glace par le développement des gués convenables qui peuvent être atteints - outre le dimensionnement fait sur la base des régularités de l'hydraulique - par l'établissement de l'équilibre du cours d'eau. L'examen de la régularité des paramètres morphologiques m'a prêté une grande aide dans ce travail.

Mantuano, J.

Examen morphologique du lit des cours d'eau

La connaissance du processus de l'évolution des formes naturelles du lit assurerait les conditions morphologiques pour les interventions. L'eau, le moyen de transport est le tenant de l'énergie érosive à la fois; l'envoi, la matière charriée sert directement le travail erosif et en se déposant elle dirige le ruissellement dont résultent le fond de la vallée alluviale et le cône de déjection s'étendant sur la pleine. Le lit changeant toujours joue un rôle important au travail formant la vallée; la forme et le déplacement du lit découlent directement des conditions locales et du déplacement des matières charriées.

C'est l'eau qui développe la série des méandres qui ne sont pas fixes en général, évoluent avec le temps et modifient de cette façon la pente du lit, soit le profil longitudinal, afin d'établir l'état d'équilibre.

La régularité de l'état naturel du fleuve à lit changeant est une processus physique complexe dont la détermination précise est impossible sous la considération de chacun des facteurs l'influençant.

D'après nos observations:

a./ le profil longitudinal du cours d'eau fuyant dans sa propre alluvion change entre deux seuils conformément à la relation exponentielle /Sternberg/.

b./ le seuil d'érosion influence la ligne horizontale du lit /Galli/

c./ la longueur de l'arc change également avec le changement de la pente du fleuve;

d./ il y a une relation entre l'ondulation du fond du lit et le rayon des arcs du fleuve. Le fond du lit est le plus profond au point culminant du méandre et il est le plus haut au point d'inflexion /Fargue/.

La configuration du fleuve est la conséquence d'un processus déterminable. Elle est pour ainsi dire le résultat des dispositions naturelles. Ce phénomène peut avoir un caractère accidentel ou bien peut être le résultat de l'interaction des évenements.

En effet les phénomènes accidentels se produisent toujours dans des circonstances identiques, cependant leur cours est influencé par de nombreux facteurs ayant chacun un effet moins important et inobservables pour nous, donnant toutefois un autre effet d'ensemble à chaque fois, ce qui explique les résultats différents du phénomène. Bien que le processus se déroule dans ses détails suivant la loi de la causalité, il se terminera de cette façon d'une manière nous paraissant accidentelle et imprévisible.

Comme je viens de dire, le phénomène résulte de l'interaction de plusieurs évenements dont le déroulement est influencé par beaucoup de facteurs également. Ayant déterminé la relation des facteurs s'influençant réciproquement nous pouvons préjuger pour l'issue du phénomène.

Le nivellement horizontal des cours d'eau, ainsi que l'enregistrement des données de leurs profils longitudinal et transversal, et du niveau d'eau rendent possible de déterminer plusieurs paramètres morphologiques.

Par la suite j'étudie les résultats comme des paramètres statistiques, afin d'exprimer les observations avec des chiffres à l'appui, tout en tenant compte du raisonnement esquissé plus haut et recourant aux pas à résumer en ce qui suit. J'ai approché l'état d'équlibre du lit de fleuve par des relations mathématiques dont les résultats m'ont donné des indications sur la méthode de l'amenée de la glace sans dommages.

1./ Les paramètres déterminés comme éléments statistiques peuvent former une relation de répartition à un variable ou à deux variables, ou bien une relation de régression à deux ou à plusieurs variables. Si les éléments statistiques sont indépendants, nous avons affaire à une répartition à variable de probabilité, si par contre ceux-ci ne le sont pas, on peut supposer une relation mathématique. J'ai étudé l'indépendance par test non-paramétrique des hypothèses statistiques, c'est-à-dire par le test χ^2.

2./ C'est sur la base des tests des hypothèses que je voulais déterminer la régularité des éléments statistiques.

Parmi nos fleuves formant leur lit librement c'est au fait la Drave qui a gardé son état naturel jusqu'à nos jours. /Les travaux de régularisation unitaire ont été interrompus en 1915 et ce n'est qu'une section de 70 km environ qui est régularisée sur la longueur de 240 km/.

Sur nos autres cours d'eau la régularisation peut être considérée comme presque terminée. Aussi étudie-je une section de la Drave /entre Barcs et Örtilos/, une section de 10 km du Raab, en aval de Nick, ainsi que la section du Danube s'étendant entre Dunaföldvár et la frontière sud du pays. Par cet examen je désire souligner, à quel point est-il nécessaire de connaître les relations morphologiques, pour pouvoir établir l'état d'équilibre d'un fleuve et pour pouvoir lutter contre les dégâts causés.

J'ai étudié les régularités admises

a/ entre la distance /X/ mesurée du seuil supérieur du fleuve et l'altitude au dessus du niveau de la mer du fond du cours d'eau /Y/

b/ entre le rayon du fleuve /R/ et la longueur de l'arc /L/;

c/ entre la distance mesurée du seuil supérieur du fleuve /X/ et le rayon /R/ et la longueur de l'arc /L/ du fleuve;

d/ entre la différence de profondeur de fond mesurée au point d'inflexion et au point culminant du méandre d'amont de celui-ci /h/ et entre le rayon /R/ et la longueur de l'arc /L/ du méandre d'amont de l'inflexion, par la méthode de la statistique mathématique.

Outre la supposition des quatre relations de paramètres l'examen permet encore plusieurs possibilités d'étude que je ne peut traiter ici, vu le cadre restreint de cette étude.

Les résultats de tests des hypothèses d'indépendance figurent dans le tableau I.

Tableau I.

RESULTAT DE L'EXAMEN DE L'INDEPENDANCE

Paramètres	Drave	Raab	Danube
$Y - X$	34,27 %	57,13 %	95,72 %
$R - X$	57,42 %	74,47 %	96,28 %
$R - L$	27,13 %	36,41 %	97,01 %
$\Delta h - \frac{R}{L}$	41,17 %	65,17 %	98,23 %
$h_o - \frac{Q}{R}$	40,93 %	65,2 %	96,57 %

Critère: Au dessus de 95 % les couples d'éléments sont indépendants.

Conclusions

Sur la base des résultats de l'examen de l'indépendance on peut établir que sur la section étudiée de la Drave et du Raab il y a une relation entre les paramètres morphologiques dont il résulte que le phénomène s'effectue conformément à la loi de la causalité tout en maintenant une relation entre les résultats influencés par maints facteurs.

La section considérée de la Drave a gardé son état naturel jusqu'à nos jours; peu d'ouvrages de régularisation ont été construits /seulement 6 km régularisées sur 80 km/ tâchant également de fixer l'état naturel du fleuve.

Le résultat de l'examen de l'indépendance reflète aussi ce fait, étant donné que parmi les trois cours d'eau ce sont les paramètres morphologiques mesurées sur la Drave qui démontrent la meilleure relation.

En témoignage des observations systématiques s'effectuant depuis 1876 sur la section étudiée de la Drave des crues provoquées par des embâcles ou des barrages de glace ne se sont pas produites.

L'intervention humaine n'a pas exercé une influence nuisible sur l'état naturel de la section de 10 km du Raab ce qui est exprimée également par le pourcentage favorable de la relation de dépendance. On n'a pas enregistré des crues causées par l'embâcle ou des barrages de glace.

En cas du Danube les paramètres morphologiques sont indépendants dont il résulte que l'évolution du phénomène n'est pas dirigée par la loi de la causalité, mais par des évenements semblant accidentels, c'est-à-dire l'effet de la régularisation a un aspect fortuit.

Les travaux de régularisation effectués sur la section étudiée du Danube ont abouti à troubler l'état d'équilibre ce qui est appuyé de l'indépendance des paramètres et aussi des crues glaciales revenues 15 fois pendant les 80 ans passés.

Les crues ont été causées par des embâcles et des barrages de glace, en suite des mauvais gués ou bien de la manque d'harmonie entre le rayon et la longueur d'arc inconvenable.

Sur la Drave et le Raab ont peut supposer l'équilibre dinamique du fleuve vu que les régularités observées se font valoir sur le fleuve courant dans sa propre alluvion et la relation peut être exprimée par voie mathématique.

Parmi les cinq sortes de fonctions étudiées en vue de déterminer la relation entre les phénomènes naturels j'accepte celle qui démontre un minimum d'écart entre les valeurs calculées et empiriques. Cette condition a été satisfaite par la relation $y = ae^{bx}$ dont les constants déterminés figurent dans le tableau II, sous l'indication des valeurs de regression.

Tableau II.

		Drave			Raab		
		a	b	R %	a	b	R %
y	x	122,28	-0,0030	97,22	138,2	-0,00624	82,17
R	X	239,87	0,00931	80,80	1962,0	-0,3125	67,12
R	L	187,27	0,00018	98,28	137,72	0,022	77,78
Δh	R/L	16,48	0,0021	68,72	0,779	0,1501	78,27
h	Q/R	4,718	1,098	93,71	2,294	0,8602	74,12

Tenant compte des relations, il peut être établi que sous l'effet des seuils, le rayon des méandres change le long du profil longitudinal, mais une relation étroite existe en même temps entre le rayon du méandre et la longueur de l'arc. Le rayon et la longueur de l'arc du méandre influencent la différence de la profondeur de fond mesurée au point culminant de l'arc et au point d'inflexion, c'est-à-dire l'ondulation de la ligne de fond. Le débit s'écoulant, la longueur de l'arc et la plus grande profondeur d,'eau mesurée au point culminant du méandre sont en relation étroite également. Par ces quelques mots, à l'appui des résultats du tableau II j'ai voulu souligner la complexité du lit formé par le fleuve que j'ai chercher à approcher par la détermination des relations entre les couples d'éléments géométriques existant dans ce régime.

Si,lors de la régularisation nous négligeons les régularités correspondant à l'équilibre morphologique, cela amène à la formation de mauvais gués et des écueils qui peuvent arrêter les glaces flottantes lore de l'étiage d'hiver, tout en provoquant des crues glaciales /crue d'hiver sur le Danube en 1956/.

La mise en jeu des paramètres morphologiques permet d'influencer avantageusement l'écoulement de la glace sans dégâts pour l'étiage d'hiver.

Sur la base des observations le minimum du matelas d'eau nécessaire est connu pour assurer la descente de la glace sans dégâts.

Dans le cas du Danube la relation entre les paramètres morphologiques démontre la manque d'équilibre ce qui exclut la détermination des relations. Ces dernières decennies de nombreux nivellements ont été faits sur le Danube ce qui rend possible d'établir la relation exprimable mathématiquement entre les paramètres déterminés sur la base de ceux-ci, et d'effectuer une intervention avantageuse du point de vue morphologique. Un examen de ce caractère a été effectué sur la Drave. J'ai eu l'occasion d'étudier les enregistrements de six périodes de 1842 jusqu'à l'heure qu'il est, et les résultats obtenus ont démontré un écart de 10 % des paramètres indiqués au tableau II. Pour le changement du profil longitudinal j'ai établi une régularité séparée.

Par ce court rapport j'ai tâché de soutenir qu'il était possible d'approcher l'équilibre dinamique des fleuves par des examens morphologiques et d'effectuer des interventions efficaces par cette voie également.

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REGULATION OF THE RIVER BED BY MEANS OF CANALIZATION

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ABSTRACT

In order to increase water power for ice passing-through and establishment normal conditions for navigation canalization of the Kura and Araks rivers was carried out.
Canalization was carried out by means of pioneering bed establishment with its subsequent erosion by water power.
The results of field observations and theoretical generalizations are given in this paper.
A large area of the river was embraced by the field observations, efficiency of canalization on water level reduction(on energy increase)and the new bed stabilization were revealed, the relation between canalized bed and hydraulic elements of stream was established.
Stabilization conditions of canalized bed were revealed by the theoretical invesigations.

SOMMAIRE

Au but de l'augmentation de l'énergie d'eau pour transmission la glace et pour établir les conditions normales pour la navigation dans les fleuves Koura etArax, on a canalisé leurs lits. On l'a canalisé à l'aide du lit pionnier avec l'érosion suivante par l'énergie d'eau.
Dans le rapport on donne les résultats des observations dans la nature et des sommaires théorique.
Un grande région du fleuve était embrassé par l'observation de nature,on réglait l'éffectivite de la canalisation de la diminution du niveau de l'eau (l'augmentation de l'énergie) et de stabilisation du lit niveau; on a établit la corrélation du lit canalisé avec les éléments hydrauliques de la forme et des conditions de la stabilité du lit canalisé.

The Kura and Araks rivers on their way from sources to mouth make much work washing away their beds in the upper stream and depositing erosion products in the lower stream.

As a result of century-old work on soils transport from the upper sections to the lower ones, the rivers of Azerbaijan run on crests of their own deposits. These rivers in their lower reaches are characterized by heavy-developed meandering. One meander falls on every 5km of the Kura river developed profile. Approximately 88% of the total river length the stream runs in the sinuous channel of highly irregular shape in the plan. The rivers sinuosity is characterized by sinuosity coefficient, equaled to the ratio of bend along channel (L) to its length in direct line (ℓ) :

$$K = \frac{L}{\ell}$$

According to the Kura and Araks rivers sinuosity coefficients were calculated; they are equaled to 2.2 and 1.7 /1/, respectively.

The Kura and Araks rivers meanders ,sometimes of greatly small radius, prevent drifting of ice, create ice-blocking and prevent the normal conditions for navigation. In the flood these meanders, creating aflux, promote water levels increase in the river. Water overflows the banks and submerges the adjoining fertile soils. In order to increase water power for ice passing-through and for establishing normal conditions for navigation, canalization of the Kura and Araks beds was carried out.

When canalizing the rivers we were seeking to:

a) choose correctly the routes of canalized section in the plan;

b) fix the smallest initial section of pioneering canal with the following water power use for further river bed washing to let pass the total water discharge.

To provide with these requirements when desighing it's necessary to guide with the following propositions:

1) The new bed tracks must connect river pools, which protects the depths maintaining and leads the bed after its formation to the type of river pool sections.

2) In order to protect banks stabilization, the new bed track must represent a slightly bent curve of a large radius in the plan.

3) The new bed axis must be smoothly sided with the axis of adjoining river sections.

River canalization was carried out by means of their bends linearization;A simple bend as well as a complex one was linearized.

We've carried out the prolonged field observations on canalized river sections. The brief investigation results on the rivers Kura and Araks are given below.

The observations include the Kura river section in the lower stream of 600km length and the Araks river section -50km. 78 bends were linearized in total.

/1/ IBAD-ZADE Yu.A. Opyt borby s navodneniyami.(The experience of flood-fighting) Izd.Akad.Selskovo Khoz.Nauk AzSSR,Baku, 1960.

Rivers canalization was carried out by means of explosion for ejection and creation the pioneering canal of 10-30m in width and 2.0-4.0m in depth along bottom. Time which is necessary for new bed development was determined by using the formula:

$$t = \frac{W_P}{W_C} = \frac{\gamma W_P}{21{,}6 \rho_g g (Q_n - Q_o)}$$

W_P - washing volume; W_C - average daily washing; $\rho_g = \rho_{TP} - \rho_o$ -additional stream turbidity at the beginning of washing; ρ_{TP} - stream transportating capacity; ρ_o - turbidity in the conditions of life; Q_n - discharge at the beginning of washing; Q_o - average annual flood discharge at the end of washing.

Transportating capacity of stream is determined according to the formula: /2/

$$\rho_{TP} = \varepsilon \lambda \frac{v^3}{gRW_o}$$

λ - bed resistance coefficient; ε - parameter, depending on energetic structure of the stream; W_o - average settling velocity, estimated according to the data given in our paper. /3/

Washing intensity in time is submitted to Pearson curve, type Y(fig.1).

The investigations showed that with prescribed requirements the pioneering canal completely makes the way for water discharge in 1-1,5 years of operation. The experimental data treatment, given in Fig.2, showes that in canalized bed formation two periods are observed.

First - from the moment of new bed action to the period when its cross-sections reach the dimensions, completely passing the river discharge(right branches of the curves). At the first period as washing bottom and banks, carrying capacity is increased and hydraulic elements in it are steadily rised.

Second - corresponds with the left branch of the curves, where hydraulic elements increase occurs, owing to the new bed filling and the cross-sections tend to stable conservation. The second period corresponds with the formed new bed. This circumstance is confirmed by the curve of energetic stream characteristic with washing (fig.3), where at the initial period of slot development with the increase of washing value Froude number is intensively increased and then becoming more gentle, asymptotically approaches the abscissa axis. (Froude number $Fr = \frac{\alpha v^2}{g h_{cp}}$). This circumstance indicates that the total stream power was spent for bed formation.

The intensity of stream hydraulic elements formation in time is represented in Fig.4.

/2/ IBAD-ZADE Yu.A., NURIEV CH.G. Raschot otstoinikov(Settlers design) M., Stoiizdat, 1971.

/3/ IBAD-ZADE Yu.A., ALIEV R.O. Srednyaya gidravlicheskaya krupnost chastits nanosov(Average settling velocity of sediment particles) B., Trudy Bak.filiala VNII VODGEO, vyp.YI, 1971.

It's known that with stream divarication, one of the distributaries takes away the main mass of bed loads. Loads deviate into the old bed; this considerably causes its disappearance. The investigations showed that maximum aggradation of the old bed occurs, when 75% of water discharge passes through the new bed.

Water discharge dependence of the new (Q_n) and the old (Q_p) channels upon streams width in the old and new beds is expressed by the experimental relationship:

$$\frac{b}{B} = \eta \left(\frac{Q_n}{Q_p} \right)^{0,5}$$

So it's quite natural a question With wich relations will the total discharge be passing through the new bed? The experiments showed that with the relations b/B = 0.7–0.8, the total discharge passes through the new bed. Besides, the experiments gave the opportunity to establish the connections between the new bed clear opening (ω) and hydraulic radius (R) from water discharge which are expressed by the formulas:

$$b = 16.4 \; Q^{0,26}$$

$$\omega = 3.2 Q^{0,84} \; (\text{ for } Q < 425 m^3/sec)$$

$$\omega = 8.6 Q^{0,68} \; (\text{for } Q > 425 m^3/sec)$$

$$R = 0.48 Q^{0,57} \; (\text{for } Q > 900 m^3/sec)$$

$$R = 0.8 Q^{0,46} \; (\text{for } Q < 900 m^3/sec)$$

The investigations carried out, allowed to observe the reduction of flood water level. Comparison of water level note in the initial line gauge before and after canalization is a measure of level reduction. The level notes of the same discharge are subjected to comparison. Since canalization of rivers was not complete but with gaps, i.e. there were some river sections of natural condition, the levels reduction was calculated for these sections, too. The coincided curves of the levels due to water discharge, showed that with river canalization, level reduction in separate sections range from 0.5 to 1.0 m.

The theoretical investigatios described in our papers/4,5/ proved that hydraulic elements of bed may be expressed by the formulas:

width along water edge $B = 2 h_m \, ctg \frac{\alpha}{2}$

clear opening area of stream $\omega = \frac{4}{3} h_m^2 \, ctg \frac{\alpha}{2}$

/4/ IBAD-ZADE Yu.A.Gidravlika spryamleniya izluchin rek(Hydraulics of river bends linearization) B.,Izd.Ak.s/n AzSSR,1961.

/5/ IBAD-ZADE Yu.A.,KIYASBEILY T.N. Formirovanie rusel rek (Formation of river channels) B.,Izd.AN AzSSR,1966.

hydraulic radius $R=\frac{2}{3}h_m\frac{\sin\alpha}{\alpha^*}$

maximum depth $h_m=0{,}866\sqrt{\frac{Q}{V_{np}ctg\frac{\alpha}{2}}}$

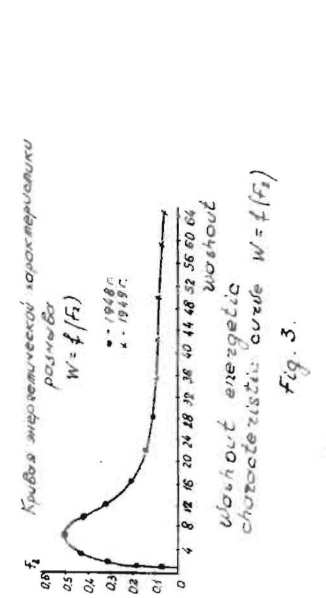
hydraulic gradient $J=1{,}718\frac{V_{np}^2 n^2}{[h_m(\frac{\sin\psi}{\psi})]^{1{,}334}}$

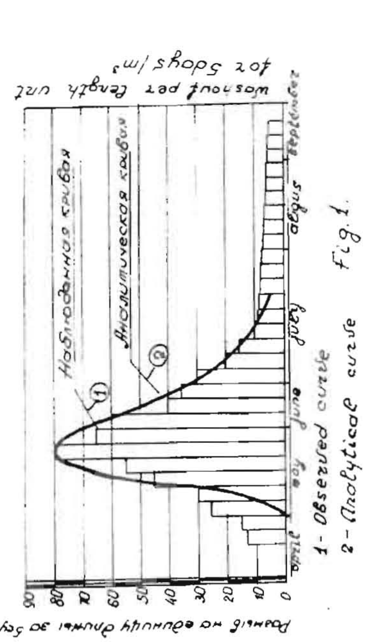
where h_m - maximum depth of stream; α - an angle of tangent to water edge line; α^* - a half of central angle, formed with circuit radius perpendicular to tangent curves with water edge line, where $\alpha^*=\alpha$ (in radians); V_{np} - nonscouring velocity; Q_p - computed discharge; ψ - an angle of hydrodinamic slope stabilization.

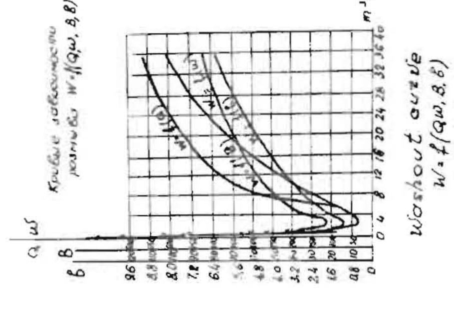
Construction of stable bed shape must be carried out according to the methods, given in our papers /4,5/.

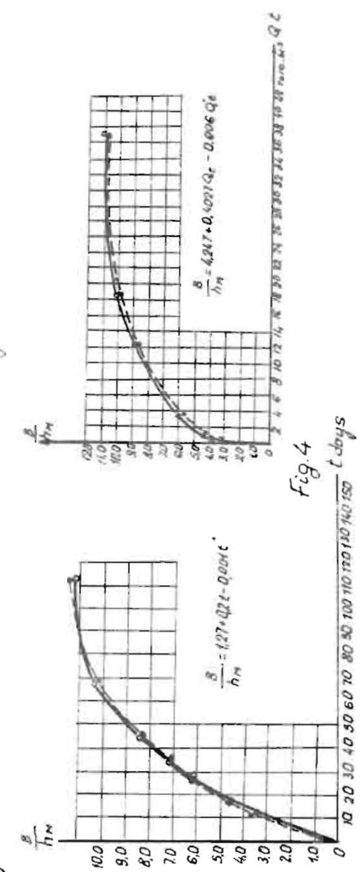
CONCLUSIONS

Field and theoretical investigations of the Kura and Araks rivers canalization showed their high efficiency in pressure ice-fighting, development of conditions for navigation and flood water levels reduction. For river canalization designing and hydraulic bed parameters determining, the corresponding methods of computation are recommended in the paper.









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HYDRAULICS OF RIVER MORPHOLOGY FOR FLOW WITH AN ICE COVER

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ABSTRACT

Investigations were made to study experimentally and analytically the evolution of self-formed sediment beds, flow depths and bed slopes of stream channels with an ice cover under aggrading hydraulic conditions in open channel flow such as occurring in rivers, reservoirs and lakes. The solution of problems involving the transportation of solids in channel flow requires the use of a flow resistance equation in conjunction with a solids transport formula with due regard to the bed geometry. Analytical methods based on this principle have been utilised to study river morphology with an upper ice cover constraint. The discharge of ice beneath the cover was simulated in the laboratory using polyethelene pellets. Hydraulic models served to verify the theory.

SOMMAIRE

Des recherches expérimentales et analytiques ont été faites pour étudier l'evolution des dépôts sédimentaires, de la profondeur de l'ecoulement et des pentes du lit dans des cours d'eau à écoulement libre tels que les rivières, les lacs et les réservoirs, quand ils sont recouverts d'une couche de glace et dans des conditions d'alluvionnement. La solution de problèmes impliquant le transport de solides dans un cours d'eau exige l'emploi d'une équation de la résistance à l'écoulement en rapport avec une formule de transport des solides en tenant compte de la géométrie du lit. Des méthods analytiques fondees sur ce principe ont été utilisées pour étudier la morphologie de la rivière contrainte par une couche de glace. Le fleuve de glace sous cette surface a été simulé dans le laboratoire par des boulettes de polyethelène. Des modeles hydrauliques ont vérifié la théorie.

INTRODUCTION

In colder climates, ice covers often form in rivers, reservoirs and lakes over a large part of the year. The extended period of time of the presence of these ice covers together with their considerable thickness often cause important morphological changes in the river system.

Sediment deposition patterns and channel scouring characteristics would be influenced by the ice cover besides the discharge capacity and river water elevations. In the more severe cases where the stream is shallow, the stream channel could be frozen over its entire depth. If hanging dams (1) are formed, their presence would aggravate appreciably stream flow conditions.

This paper describes the study of the evolution of self-formed sediment beds and the manner in which an ice cover influences their formation.

EXPERIMENTAL PROGRAM

The profiles of sediment beds formed in stream channels were observed in a series of hydraulic models. Sediment beds were formed by feeding sediment at the upstream end through a calibrated hopper. Two uniform sizes of quartz sand of specific gravity 2.65 with mean diameters of 0.20 mm and 0.60 mm were used. To simulate the ice cover and ice discharge, polyethylene plastic sheets and pellets, which have a specific gravity very close to natural ice, were used.

Water was supplied from a head tank connected to an inlet channel which could be varied to observe the effect of different entrance conditions. A centrifugal pump-motor unit circulated the water which was measured by means of a triangular notch. An outlet weir controlled the water elevation. Point gages located above the channel and over stilling wells were used to measure water depths and bed slopes. Bedforms and sediment configurations were photographed after bed contours were properly defined.

BED EVOLUTION

A simulated ice cover of polyethylene plastics was first formed over the stream channel at a steady discharge. Sediment in the form of quartz sand was fed into the channel from the upstream end from an elevated hopper through calibrated openings. The sediment initially accumulated at the inlet until the entire width of the stream is filled. When stable hydraulic conditions were achieved, sediment bed load was propagated as sand waves at the top and deposited on the steep leading face. Topset and foreset beds with a lesser amount of bottom sediments could readily be identified (Fig. 1). The stream was able to self adjust itself with respect to its flow depth and bed slope but with its sides constrained, and, hence, possessed two degrees of freedom (2).

Bedforms were also observed and the manner of determining their formation was explored. The ability to predict the type of bedform associated with any flow condition is essential in the utilisation of the bed transport and resistance equations to calculate sediment discharge and other hydraulic parameters.

Considerable research (3, 4) has been done to study the physical state of the bed for given flow parameters. A well known method is Simons' diagram (4) relating bedforms to stream power and grain diameter. Stream power is defined as τV in which τ = shear stress; V = mean velocity.

BED LOAD TRANSPORT EQUATIONS

In computing sediment discharge, flow depths, and bed slopes, it would be necessary to have a bed load equation besides a flow resistance relation. Three better known equations which could be used for this purpose are given in Henderson (5) and Brown (6), namely:

Kalinske: $$\frac{q_s}{d(\tau_o/\rho)^{1/2}} = 10\left(\frac{\tau_o}{\gamma(S_s-1)d}\right)^2 \qquad \text{...(1)}$$

Einstein: $$\frac{q_s}{d^{3/2}G(g(S_s-1))^{1/2}} = 40\left(\frac{\tau_o}{\gamma(S_s-1)d}\right)^3 \qquad \text{...(2)}$$

Shields: $$\frac{q_s\ S_s}{qS} = 10\ \frac{(\tau_o-\tau_c)}{\gamma(S_s-1)d} \qquad \text{...(3)}$$

in which q_s = unit sediment discharge; τ_o = shear stress; τ_c = critical shear stress; S_s = specific gravity of sediment; q = unit water discharge; γ = specific weight of water; ρ = density of water; d = grain size; G = sediment parameter.

Eqs. (1) to (3) were evaluated from laboratory observations. Kalinske's and Einstein's equations were found to give better correlation than the Shield equation. As the Kalinske equation permits greater facility in manipulation, its use is preferred.

FLOW RESISTANCE EQUATIONS

Boundary shear resistance can be determined by using equations specifically derived from laboratory flumes with mobile beds or from rigid boundary open channel skin friction formulae modified to take into account the bedforms associated with the flow.

Liu and Hwang (3) developed an exponential type of resistance equation based on laboratory observations using erodible bed models:

$$V = C_a\ R^x\ S^y \qquad \text{...(4)}$$

in which the coefficient C_a and the exponents x and y assume different values depending on the type of bedform and sediment size. The symbols R and S denote the hydraulic radius and energy gradient respectively.

Skin friction in rigid boundary open channel flow is frequently determined from the Manning and the Chezy equation, viz:

Manning: $$V = \frac{1.49}{n}\ R^{2/3}\ S^{1/2} \qquad \text{...(5)}$$

Chezy: $$V = C\ R^{1/2}\ S^{1/2} \qquad \text{...(6)}$$

in which V = mean velocity; n = Manning's roughness coefficient; C = Chezy's coefficient. Manning's and Chezy's coefficients, when applied to fluvial hydraulics, are modified to take into account both surface roughness as well as form roughness due to the various type of bedforms. Einstein and Barbarossa (7) postulated that the hydraulic radius R can be considered to consist of two parts, R´ and (R-R´) in which R´ represents the value due to surface roughness; (R-R´) denotes the additional portion of the hydraulic radius due to moving sediment beds.

Doland and Chow (8) made use of the concept of the dual function of the hydraulic radius in extending the role of Strickler's expression for Manning's n (9):

$$n = \Phi\left(\frac{R}{k}\right) k^{1/6} \qquad \ldots(7)$$

where

$$\Phi\left(\frac{R}{k}\right) = \frac{0.0342}{(R'/R)^{2/3}} \qquad \ldots(8)$$

in which k = roughness height. Substituting Eqs. (7) and (8) into Eq. (5) gives:

$$V = \frac{43.5}{k^{1/6}} (R^{2/3})(R'/R)^{2/3} S^{1/2} \qquad \ldots(9)$$

Eq. (9) becomes a mobile flow resistance equation. Curves of values of (R´/R) were presented by Chow (9) as functions of $(R/k_{65})^{1/3}$ and (k_{35}/RS) where K_{65} and k_{35} denote grain size just larger than 65% and 35% respectively of the material derived from a mechanical analysis curve.

Richardson and Simons (10) utilised the Chezy equation and extended the coefficient C to conform with different types of bedforms much in the same manner as suggested in the derivation of Eq. (9). Based on extensive laboratory flume observations, the recommended value for C for dunes is:

$$\frac{C}{g^{1/2}} = 7.4 \log \frac{D}{d_{85}} \left(1 - \frac{\Delta RS}{RS}\right)^{1/2} \qquad \ldots(10)$$

in which D = flow depth; d_{85} = grain size just coarser than 85% of the material obtained from mechanical analysis. Roughness due to bedforms is accounted for in Δ(RS) which denotes the increase of RS. Substituting the value of Chezy's C from Eq. (10) into Eq. (6) gives:

$$V = 7.4\, g^{1/2} \log \frac{D}{d_{85}} \left(1 - \frac{\Delta RS}{RS}\right)^{1/2} (RS)^{1/2} \qquad \ldots(11)$$

The determination of Δ RS from the parameter RS can be obtained graphically (10) or from the empirical relation obtained from the graph:

$$\Delta\, RS = 0.875\, RS - 0.0001 \qquad \ldots(12)$$

BED CONFIGURATION

The mean bed slope of the sand waves, under steady state transportation of bed load, can be determined by using simultaneously a solids transport equation in conjunction with a boundary resistance equation in which form and surface resistance are both considered. Kalinske's bed load equation Eq. (1) has been used successively with the Liu-Hwang Eq. (4), Doland-Chow Eq. (9) and Richardson-Simons Eq. (11) in analysing the experimentally observed bed slopes. In formulating the energy slope equation from a combination of the transport and resistance functions, the shear stress is given by:

$$\tau_o = \gamma RS \qquad \ldots(13)$$

The slope relationships obtained in this manner are:

Kalinske-(Liu-Hwang):

$$S = [0.0474\ q_s\ d(C_a/V)^{5/2x}]^{1/(2.5-\frac{5y}{2x})} \qquad \ldots(14)$$

Kalinske-(Richardson-Simons)

$$S = \frac{K^2(0.0001)}{(V(K_o)^{-1/5})^2 - K^2(0.125)} \left[\frac{1}{R}\right] \qquad \ldots(15)$$

where

$$K = 7.4\ g^{1/2}\ \log\ (D/d_{85}) \qquad \ldots(15A)$$

$$K_o = \left[\left(\frac{\rho}{\gamma}\right)^{1/2} \left(\frac{q_s(S_s-1)d}{10}\right)\right]^{-1/5} \qquad \ldots(15B)$$

Kalinske-(Doland-Chow)

$$S = \left[\frac{0.218\ q_s d}{V^{15/4}} \left(\frac{(R'/R)^{2/3}}{0.0342\ k^{1/6}}\right)^{15/4}\right]^{8/5} \qquad \ldots(16)$$

The slope equations given by Eqs. (14), (15) and (16) were evaluated by comparing them with the observed bed slopes in the channel where a simulated ice cover of uniform thickness was formed. The Kalinske-(Richardson-Simons) Eq. (15) was found to give the best correlation followed by Kalinske-(Liu-Hwang) Eq. (14) and Kalinske-(Doland-Chow) Eq. (16).

Bedforms observed in the laboratory flume were mainly dunes with some ripples. The method of identifying bedforms by application of Simons' diagram (4) using stream power and grain diameter, although did not give total agreement with observations, it was, however, encouraging.

CONCLUSIONS

Eq. (15), obtained from a combination of the Kalinske bed load function and the Richardson-Simons resistance equation, described adequately the bed slopes observed in laboratory stream flows with a simulated ice cover.

The application of Simons' diagram relating stream power and grain diameter to predict bedforms did not correspond completely with observed bed configurations. However, sufficient agreement was observed to indicate that the criterion showed promise.

ACKNOWLEDGEMENT

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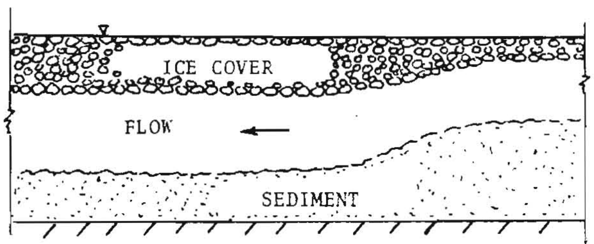

FIG. 1 SCHEMATIC DIAGRAM

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Budapest 1974 Hungary

ICE REGIMEN AND CHANNEL CONSTRICTION ON RIVER BED GEOMETRY

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ABSTRACT

The stream channel is constricted when spur dikes and bridge piers are placed in the waterway. In northern climates, temperatures are sufficiently low to cause an ice cover to form for a considerable part of the year. This paper deals with the study of the effect of an ice cover on the erosion of the river channel which has been reduced in width by the presence of engineering structures. Analytical and experimental methods were used to derive the dimensionless functions. Polyethylene sheets and pellets, which have a specific gravity very close to natural ice, have been used to simulate the ice cover and ice flows with quartz sand as the bed material. The results would be useful in design.

SOMMAIRE

Le cours d'eau est rétréci quand on y insère des digues éperons et des piles de ponts. Dans les climats du nord, une couche de glace recouvre l'étendue d'eau pendant une grande partie de l'année. Cette étude traite des effets de la couche de glace sur l'érosion du lit d'une rivière rétrécie par des constructions mécaniques. Des méthodes expérimentales et analytiques ont été employées pour obtenir les fonctions sans dimensions. Des feuilles et des boulettes de polyethylène ayant une gravité spécifique presque identique à celle de la glace naturelle ont été utilisées pour simuler la couche et le fleuve de glace. Le lit était constitué de sable de quartz. Les résultats seraient utiles dans la préparation de projets de construction.

INTRODUCTION

In the colder countries, ice covers of varying thicknesses are formed over stream channels for a considerable part of the year. The uneven and appreciable thickness of the ice as well as the long period of their presence, can often cause significant changes to the river bed and banks. In the more easily erodible alluvial and sand bed streams, a brief seasonal regime condition could be attained during the cold period of the year; hydraulic conditions prevailing during this time could be critical with respect to some engineering structures, such as, scour around bridge piers.

Spur dikes are frequently employed to increase river depths for navigation by chanelling the flow through a narrower opening to cause erosion of its bed. Another function of spur dikes is to deflect the stream towards the central part of the channel to avoid scour of its banks. To enable the design of economic spans, bridge piers and abutments are used in river crossings. A reduction of the waterway area results whenever an engineering structure is placed in the path of the stream. The effect of this constriction would be to cause erosion around the structure, if the channel bed is erodible, due to the increased velocities. Scour of the river bed and sides would continue some distance downstream of the obstruction.

This paper deals with the interaction of the ice cover together with channel constriction on river bed geometry.

EXPERIMENTAL PROGRAM

An 18 inch wide x 24 inch high x 50 ft. long channel with plexiglass sides was used to investigate bed erosion around spur dikes. Plywood was used to fabricate the spur dike models. Eccentric single spur dike layouts protruding from one side and twin symmetrical configurations were used in the observations (FIG. 1).

Polyethylene sheets and pellets with specific gravities very close to natural ice were utilised to simulate ice covers and ice discharges. A 10 inch thick quartz gravel bed was provided to study bed erosion. The uniform gravel has a mean size of 1/8 inch, a specific gravity of 2.65 and an angle of repose of 30 degrees.

Water was circulated by a centrifugal pump-motor unit and the discharge was measured by an electronic flow meter. Clear water was used in all the experiments. Point gages were used to record water elevations.

ANALYSIS

For the case of flow with a free surface without an upper ice cover, the parameters which influence the maximum scour depth, D_m (FIG. 2), around the spur dike for a given bed material can be expressed as:

$$D_m = f(H, V, g, M, \theta) \qquad \ldots(1)$$

in which D_m = maximum scour depth measured from the tailwater to the lowest point of the bed.

H = flow depth upstream of the spur dike.

V = mean approach velocity

g = acceleration due to gravity

θ = skew of the dike in radians referred to the centre line of the river channel.

M = spur dike opening ratio

$= Q_b/(Q_a + Q_b + Q_c) = Q_b/Q$

Q_a = discharge of the left panel bounded by the left bank.

Q_b = flow through the central stream panel.

Q_c = discharge of the right panel.

Q = total river flow.

Using the Manning equation, the bridge opening ratio can be expressed as:

$$M = (A_b\ R_b^{2/3})/\ A\ R^{2/3} \qquad \ldots(2)$$

where A = total flow area of the stream

R = hydraulic radius.

Suffix b refers to the central channel.

Eq. (2) assumes that the roughness and energy gradient of the center and side panels are sensibly of the same magnitude.

By means of the Buckingham-π theorem, Eq. (1) can be transformed to:

$$\frac{D_m}{H} = f(F,\ M,\ \theta) \qquad \ldots(3)$$

in which $F = V/\sqrt{g\ H}$ represents the upstream Froude number. It is postulated that Eq. (3) can be written as:

$$\frac{D_m}{H} = C(F)^{k_1}\ (M)^{k_2}\ (\theta)^{k_3} \qquad \ldots(4)$$

The coefficient C and the exponents $k_1 \ldots k_3$ are to be determined by experiments in conjunction with statistical methods.

RESULTS AND DISCUSSION

In deriving the numerical values of the exponents of the non-dimensional groupings in Eq. (4), the experiments were designed to permit only one term to vary at a time.

The value of the exponent k_1 was obtained first by varying the Froude number over a wide range and maintaining the dike opening ratio and skew angle constant. Under these conditions, Eq. (4) is reducible to,

$$\frac{D_m}{H} = C_1 (F)^{k_1} \qquad \ldots(5)$$

where

$$C_1 = C(M)^{k_2} (\theta)^{k_3} = \text{constant}. \qquad \ldots(6)$$

The value of k_1 was determined from log-log plots over a range of M = 0.50, 0.61, 0.67, 0.75, 0.83 and 0.90 to give $k_1 = 2/3$. A typical graph of D_m/H vs F for the case M = 0.67 and $\theta = \pi/2$ radians is shown in Fig. 3(A).

In a similar manner, the values of the exponents associated with the dike opening ratio, skew and coefficient were found to be $k_2 = -1$ (Fig. 3B), $k_3 = -0.043$ (Fig. 3C) and C = 2.62.

Eq. (4) can now be written as:

$$\frac{D_m}{H} = 2.62\ (F)^{2/3}\ (M)^{-1}\ (\theta)^{-0.043} \qquad \ldots(7)$$

The influence of an ice cover and ice discharge was studied by using polyethylene pellets and sheets to simulate undercover ice runs and cover respectively. The effect of undercover roughness and hanging dams (1) on bed configuration was also observed. The observations indicated that the presence of a cover immediately upstream of the dike had the most pronounced effect on erosion. An increase of cover thickness caused additional scour due to the reduced flow depth and hence higher velocities. The maximum scour depth with an ice cover can be computed using Eq. (7) in which the upstream flow depth is taken to the bottom of the cover. The bed profile was very sensitive to an accumulation of ice on the approach channel as it caused the velocity filaments to plunge towards the bed.

Research on the erosion of the stream bed around bridge abutments and spur dikes have been made by Laursen (2, 3), Garde (4), Hedman (5), Apelt (6), Coleman (7), Karaki (8), Liu (9), Inglis (10), Neill (11), Shen (12), Khosla (13), Blench (14), Gill (15) and others. While a theoretical solution of the problem, particularly for the case when an ice cover is present, has yet to be achieved, the work of Shen (13) is encouraging.

CONCLUSIONS

Eq. (7), which is derived from experimental and analytical methods can be used to compute the maximum depth of scour around a spur dike with an ice cover taking the approach depth measured from the bed to the top of the cover.

An accumulation of ice immediately upstream of the dike has a pronounced effect on erosion.

The presence of hanging dams significantly increased local scour at the area and downstream of it where these obstructions are present.

ACKNOWLEDGEMENT

The research grant provided by the National Research Council of Canada is gratefully acknowledged.

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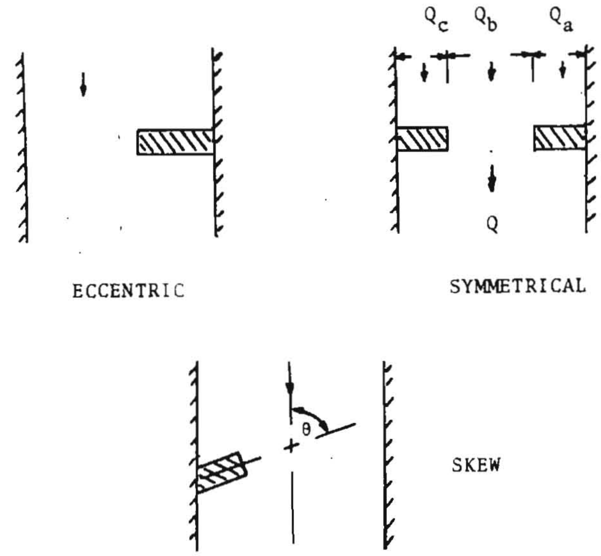

FIG. 1 LAYOUT OF SPUR DIKES

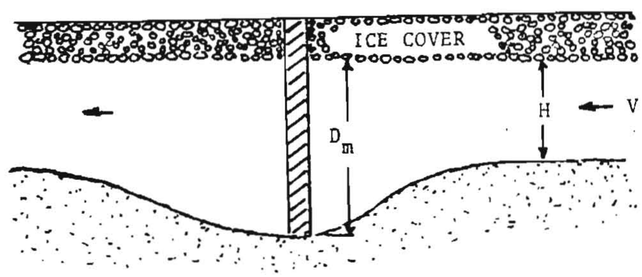

FIG. 2 DEFINITION SKETCH

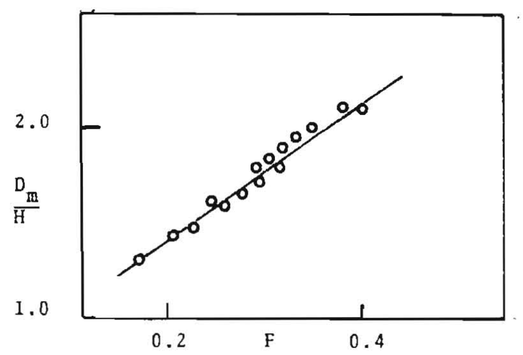

FIG. 3A

D_m/H vs F

M = 0.67

$\theta = \pi/2$

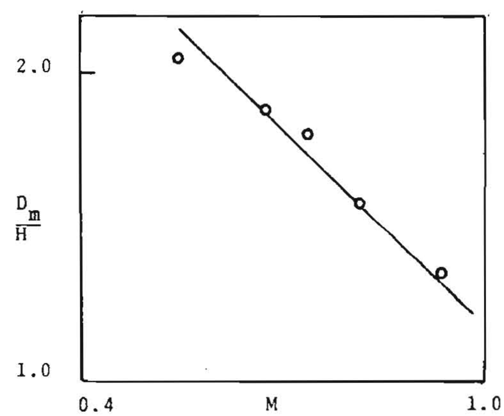

FIG. 3B

D_m/H vs M

F = 0.20

$\theta = \pi/2$

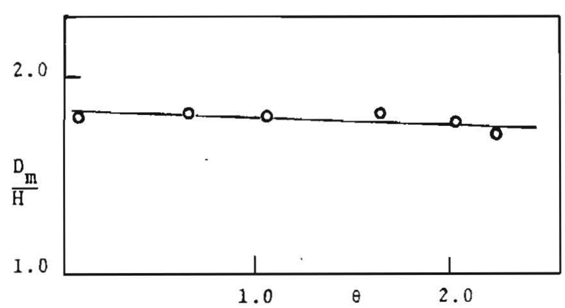

FIG. 3C

D_m/H vs θ

F = 0.20

M = 0.67

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SAFEGUARDING WINTER OPERATION OF A PUMPING STATION ON THE RIVER OHŘE

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ABSTRACT

In rivers with the production of frazil ice, there occurs in dam reservoirs frazil accumulation, which impedes the water withdrawal from these reservoirs. To safeguard the operation of the intake, certain measures must be taken to control the inflow of frazil into the reservoir and to prevent the formation of frazil accumulation at the intake structures. The paper describes the solution of this problem by means of coffer dams made of rock material in the river Ohře to protect the pumping station, and summarizes the findings obtained during a two-years´ operation.

SOMMAIRE

Dans les rivières avec la formation du fraisil il se produit dans les bassins de retention l´accumulation du fraisil empêchant la prise d´eau dans ces bassins. Pour assurer l´opération de l´installation de captage il faut prendre des mesures nécessaires pour limiter l´afflux du fraisil dans le bassin et empêcher la formation du fraisil près de l´installation de captage. On décrit ici la solution du problème à l´aide des barrages de retention en blocs de pierre réalisée sur la rivière Ohře en vue de la protection de la station de pompage en faisant le résumé des connaissances obtenues par l´exploitation de deux ans.

The lack of service water in the industrial region of the Bílina watershed is solved by the delivery of water from the river Ohře. At kilometre 129.3 in the river Ohře, there is a pumping station which pumps water into an open supply canal delivering water to the river Bílina. With increasing requirements for water supply the significance of this source increases, too. Since 1967 it has become necessary to ensure a permanent defectless operation. With this requirement there erose also the problem of ensuring the winter operation of the water intake for the pumping station.

The water from the river is withdrawn by a bank intake structure in the dam reservoir. The dam has a fixed height of 1.8 m. The maximum water quantity withdrawn is 3.3 m^3/sec and the minimum 1.1 m^3/sec, respectively.

The bottom slope of the river above the intake is approximately 2.2 ^{o}/oo. In winter a great quantity of frazil ice is produced in the river. The frazil is transported into the dam reservoir from a distance of 33 km, i.e. from the dam reservoir which retains the frazil from the upper reaches of the river. In the whole section above the pumping station dam, there is only one small reservoir, today already considerably silted, which retains partially the frazil only in the case of low water flows (Fig. 1). The greater part of the frazil is held back in the pumping station reservoir, where it accumulates and fills the whole reservoir.

This situation was even aggravated by the construction of a smaller dam, called the Kadaň dam, below the pumping station. The impounded level of the reservoir inundates the pumping station dam (Figs 1 and 2). The new reservoir retains the whole entering frazil. An immense frazil accumulation is created which always affects the intake structures of the pumping station. If these frazil accumulations occur at high operational levels, there is also the danger that the pumping station becomes flooded (Fig. 2).

The frazil accumulation blocks the intake structure, and the water withdrawal is made almost impossible. In this situation was it possible to ensure only a pumping capacity of 0.6 m^3/sec in 1967-1971 and that with extremely high operation costs.

The withdrawal difficulties cannot be prevented by the adjustment of the inflow. The solution can be found only by discovering a way of preventing the frazil accumulation to penetrate or of reducing the inflow of frazil ice into the reservoir. For this reason all known methods of retaining frazil were tested. The main object of this investigation was to find an inexpensive solution permitting rapid realization, without requiring special attendance. The most suitable seemed to be small rock-fill dams built in the river reservoirs to retain the frazil. The design was based on the observations of the winter regime of the river in 1968-1971. In view of the magnitude of the frazil flows and the limited possibilities of creating a sufficiently large retaining space by a small dam, there were two dams included in the design instead of one. The first one must be near the pumping station reservoir to limit the formation of frazil ice to the smallest possible extent. The placing of the second dam is governed by the following factors: the possibility of creating the greatest possible retention space, proportional distribution of the river section, construction costs, danger of enthreatening structures along the river.

In the given case, the design of the first dam utilized with advantage an old broken weir situated 2.5 km from the end of the pumping station reservoir. In front of the old weir body a rock--fill dam was built overtopping the crest of the original weir by 0.8 m (Fig. 3a). With the same material were also filled the broken-down parts of the weir (Fig. 3b). The dam is 132 m long and in its crest it is 4 m high. Its average height is about 1.7 m. The filling was done in one layer. The crest was topped with a gravel riprap to enable the travel of vehicles during the construction. The total volume of stone used for the filling of the dam amounted to 1 360 m^3. The dam construction was carried out during low water stages and the dam was completed without deviating the water flow. The dam increased the water level in the reservoir by 1.2 m. This led to a considerable decrease in the flow velocity and created conditions for the formation of an ice cover. In frost periods the discharge in the river is 10 ÷ 20 m^3/sec, exceptionally up to 50 m^3/sec. The water velocity is then 0.06 ÷ 0.11 m/sec. After the formation of the ice cover, frazil ice is retained and produces frazil accumulations.

The second dam is placed at a distance of 13.9 km from the pumping station dam in the natural river-bed. Its detailed placing was influenced by the possibility of approach to the river and the necessity of preventing the flooding of the adjoining road and railway. This dam was built in the same way as the first one. Its height is about 2.2 m and the crest width is 5 m. The downstream face has a slope of about 1:3. The dam crest is 58 m long. The total volume of stone used for the construction of this dam was 1 390 m^3.

In both cases material from local quarries was used, which considerably lowered the construction costs. The two dams were completed in 1971. The length of the construction period was adversely influenced by the low loading capacity in the quarries. But even thus the building of one dam did not exceed a period of six working days.

Operation Results

The first dam at km 132.8 exhibits at present sufficient stability. During the two years of operation no failure was experienced and it needed no repairs. The max. discharge in this period was 75 m^3/sec, which corresponds to an average discharge per metre of dam width of $q = 0.57$ m^2/sec. The discharge reached or exceeded on the average once in 5 years amounts to 265 m^3/sec. The ice cover was produced in the reservoir on the first day of the occurrence of ice phenomena on the river. In winter 1971/72 it appeared at a discharge $Q = 19$ m^3/sec, i.e. at a flow velocity $v = 0.10$ m/sec, at a mean day air temperature of $t = -5.0^{\circ}C$ and in the winter 1972/73 at $Q = 18$ m^3/sec and $t = -5.5^{\circ}C$. During both winter periods, frazil accumulation occurred reaching into a distance of 3.2 km upstream. The slope of the frazil accumulation surface was about 1.3 $^{o}/oo$. The whole frazil ice was held back in the reservoir and none managed to get through the dam. The volume of the frazil accumulation was about 0.5 mil.m^3. In the section between the dam and the end of the pumping station reservoir only very little frazil ice was produced and did not approach the pumping station intake, but stayed at the end of the reservoir.

The second dam at km 143.2 is not sufficiently stable. After being damaged by holiday-makers, it partly broke down. Up to the present only a harmless discharge of 75 m^3/sec passed the dam - corresponding to an average discharge of $q = 1.3$ m^2/sec per metre of dam width. The formation of the ice cover takes place later than in the first reservoir. In winter 1971/72 it was 2 days and in the following winter even 8 days later. The surface froze with a great frazil discharge after the growth of bank ice and after the sinking of the water flow. In both winter periods the discharge during freezing of the surface was $Q = 14 \div 15$ m^3/sec, the average flow velocity was $v = 0.11$ m/sec and the mean day air temperature was $t = -9.5^oC$ and $t = -6.5^oC$, respectively. As soon as the surface was frozen, frazil accumulation took place, which spread only to a distance of 1.4 km, i.e. to a place where the river has a gradient of 3.7^o/oo. The gradient of the frazil accumulation was about 1.5^o/oo. In this frazil accumulation about 150 000 m^3 of ice were caught. By further inflow of frazil, the accumulation increased and the frazil ice passed through the reservoir into the downstream river.

Conclusions

Experience from two years' operation does not allow to reach final conclusions about the percentage of safeguard of the winter regime in pumping stations. The two winter periods were relatively mild with normal water discharges. At discharges of above 20 m^3/sec and heavy frost the creation of frazil ice will be greater and the measures taken will probably be not so efficient as in the years 1971-1973, when it was possible to hold back the complete inflowing frazil in front of the pumping station impounding reservoir.

Present experiences have shown, however, that the first dam at km 132.8 is suitably placed. The river-bed is here wide with a slight bottom slope. By the little height of the dam a large retaining capacity of the reservoir was obtained. The small flow velocity supports the formation of an ice cover in the first day of frost appearance on the river. When frazil accumulation occurs, there is no danger to the structures along the river. The combination of the dam with the old weir is advantageous. The weir was thus cheaply repaired and obtained a new function.

The situation of the second dam at km 143.2 was affected by structures along the river and by the possibility of approach to the building site. It was built in a narrow part of the river-bed with a large bottom gradient. This affected its height and holding capacity of the reservoir. The relative discharge per metre of dam width (q) is high. In high dams with a large relative discharge their stability is much more difficult to maintain. The dam profile used is unsuitable and will have to be changed to a shape similar to that of the first dam (Fig. 3b). The great bottom slope prevents the greater spreading of the frazil accumulation upstream. The volume of the retained ice is small. With the first dam, at the same building costs, the effect reached was much higher. For the performance the placing of the dam is decisive.

The proposed measure is the first of its type in Czechoslovakia. It was designed as a temporary step with the aim of ensuring a quick protection of the pumping station and to obtain the necessary experience and findings in this field, which will be used in the definite solution as well as in other constructions.

The solution is very effective. The costs for its completion are lower than exceptional operational costs of the pumping station during four winter seasons. The damage arising from the failure of water supply would be, however, several times higher than the costs of this protective measure.

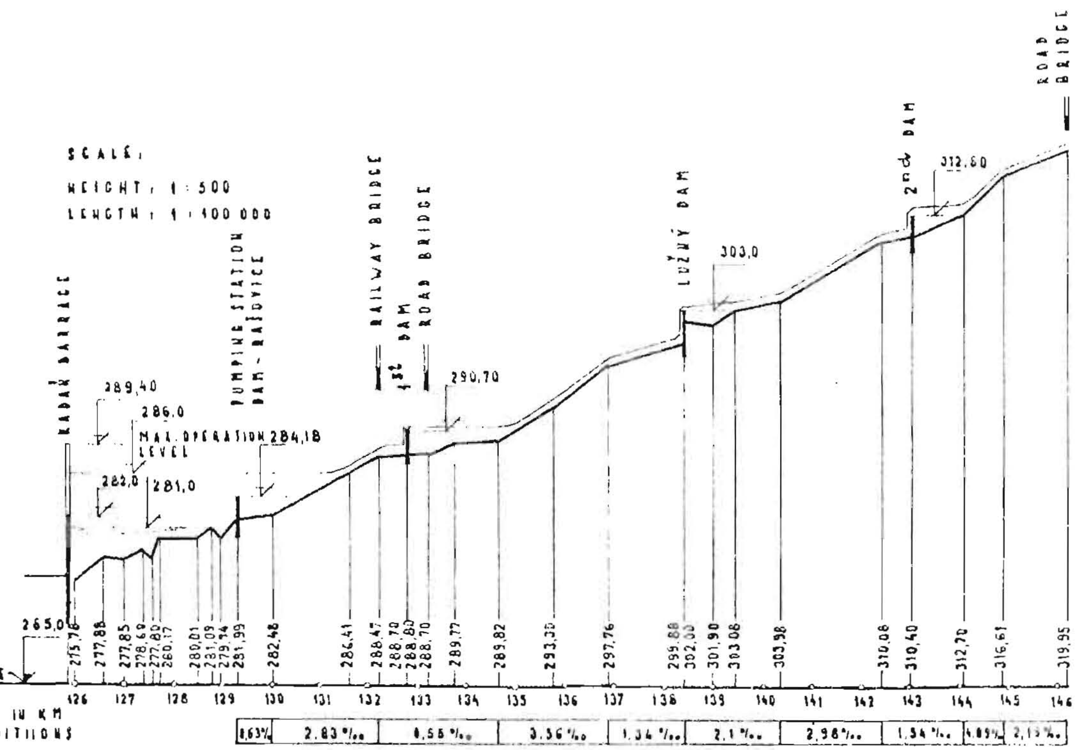


FIG. 1. LONGITUDINAL PROFILE OF THE OHŘE RIVER

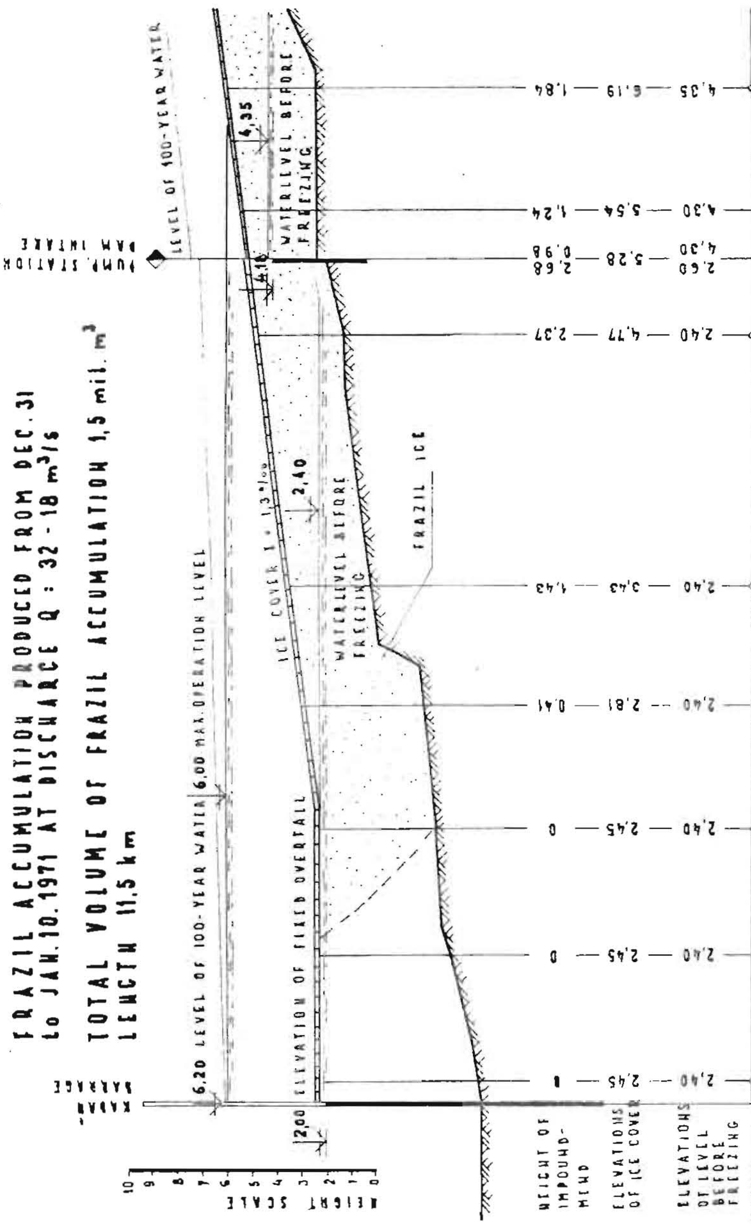
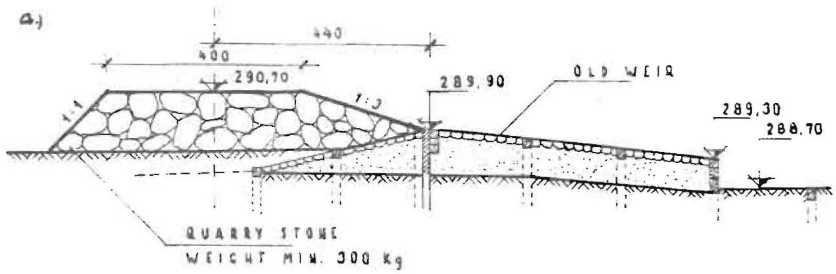


FIG. 2. FRAZIL ACCUMULATION IN THE RESERVOIR OF THE KADAŇ BARRAGE ON THE RIVER OHŘE

a)



b) REFILL IN PLACES OF BREAK-DOWN OF OLD WEIR

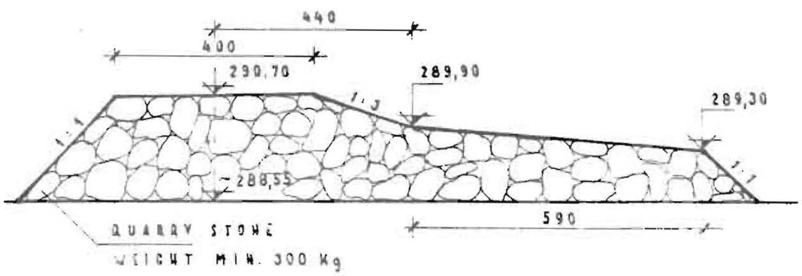


Fig.3 MODEL CROSS-SECTIONS THROUGH 1st DAM

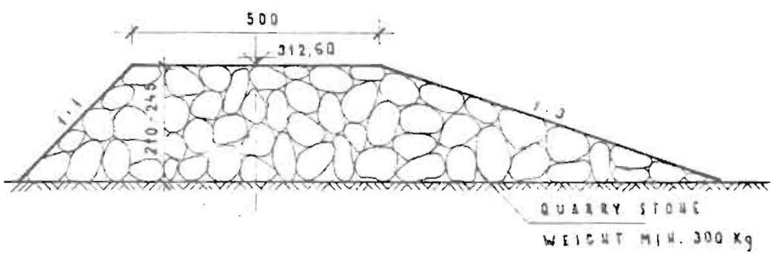


Fig.4. MODEL CROSS-SECTION THROUGH 2nd DAM

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THE OBJECT AND SOME RESULTS OF HYDRAULIC RESEARCH ON WINTER REGIME IN CZECHOSLOVAK NAVIGABLE RIVERS

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Institute of Water Management, Bratislava ČSSR.

ABSTRACT

Brief characterization of the winter regime in Czechoslovak navigation waterways.

Requirements put on the hydraulic research in connection with winter regime problems of navigation waterways. Possibilities of hydraulic model research and problems of model similarity in hydraulic research of the winter regime.

Hydraulic research results obtained from the passage of floating ice from the navigation canal through the structures of the water scheme Gabčíkovo.

SOMMAIRE

Le caractéristique concis du régime d'hiver des voies navigables tchécoslovaques.

Les exigences présentées au recherche hydraulique en cohérence avec les problemes du régime d'hiver des voies navigables. La possibilité d usage des modeles réduits et les questions de leur conformité au prototype en cas du régime d'hiver.

Les résultats de recherche hydraulique du passage des glaces du canal navigable par-dessus des uovrages d entreprise de distribution d eau de Gabčíkovo.

On the territory of Czechoslovakia they are following types of navigable waterways:

a/ free, natural navigable rivers - e.g. Czechoslovak Danube river reach km 1872.2 - 1850.2; the frontier part of the Czecho-slovak-Hungarian Danube km 1850.2 - 1708.2 and the lower reaches of the Czechoslovak Elbe river km 68.9 - 109.2;

b/ rivers made navigable by canalization structures - e.g. the Vltava river in the lower reaches between the Slapy Reservoir and the approach into the navigation canal Vraňany-Hořín in a length of 80.2 km with 8 locks; the Elbe river from Ústí to Kolín in a length of 152.8 km with 20 locks;

c/ artificially created waterways - canals, although only to a smaller extent;

d/ isolated waterways on larger water reservoirs used mainly for recreation purposes.

From the point of view of winter regime, the character of Czechoslovak waterways is also very varieted due to different climatic conditions, morphology of the watershed and hydrological conditions and to a considerable degree it is also influenced by the effect of man as to the specifically different usage of rivers also for o ther purposes than for navigation.

The winter regime on the Czechoslovak Danube is characterized by a heavy ice passage /ice motion/ and the potential creation of ice barriers, which restrict navigation and very often threaten the safety of vessels. According to the data given in /1/, the freezing phenomena, i.e. ice cover and ice jams and barriers on the Danube river in Bratislava cross-section last in average /in the period 1895-1965/ 8.5 day/year. The longest freezing period was in 1947: 65 days; during the whole observation period there were of course also years without ice phenomena.

At present in the canalized sections of the Vltava and Elbe rivers they are in operation essentially two types of gated weirs - judged again with a view to the winter regime:

- needle weirs of the old type where the needles, have to be removed during the whole winter period; navigation operations are there in the winter season practically impossible,
- controlled weirs of newer construction with a massive dam, which can impound the water permanently the whole year through.

In the first case the freezing period is shorter - Elbe river at Mělník during the period 1880-1965 7.6 day/year - in the second case longer - Elbe river at Nymburk in the period 1905-1965 28.6 day/year. In the navigable lower reaches of the Vltava and the Elbe rivers /the last below the confluence with the Vltava/, the discharges of relatively warmer water from the large reservoirs of the Vltava Cascade have shown a more favourable effect in recent years.

In the future the character of the winter regime on the Danube river - as a whode - should change considerably after the construction of the dam below Bratislava; on the middle reaches of the Elbe river the construction of the thermal power plant at Chvaletice should evidently affect the duration of the freezing period by the discharge of cooling water. In the more distant future, after the completion of the Danube-Odra-Elbe Canal, this greatest navigation waterway passing through Czechoslovakia will exhibit specific characteristics as far as the winter regime is concerned.

Its utilization will not have the sole purpose of navigation, but is will serve also in a comprehensive way other water management purposes and this will necessitate the coordination of all requirements including that of the canal operation in winter.

The problems of winter regime in navigation routes from the viewpoint of hydraulic research can be basically characterized as the solution of conditions for the creation and maintenance of a free navigation route. This includes mainly the research of flow in reservoirs and dam impoundments with a view to thermal water stratification, research on the ice cover breaking by mechanical means - compressed air, pressure water, icebreakers - and research on the flow during the floating ice removal from the navigation route.

Up to present there does not exist in any czechoslovak water research institute an ice-thermal laboratory, and therefore the possibilites of hydraulic model research of winter regimes are limited only to the solution of suche problems where the direct effect of air and water temperature on the phenomena investigated may be neglected. This restriction of the possibilities of hydraulic model research is, especially from the point of view of future needs of the water traffic in Czechoslovakia, rather unpleasant and it will be necessary to do something in this way. At present, hydraulic problems requiring investigation, whilst maintaning thermal conditions, have to be solved by research methods /which are neitherfrom the time nor economy aspect too suitable/ carried out directly under natural conditions, or perhaps on request in ice-thermal laboratories abroad.

The present equipment of hydraulic laboratories in Czechoslovakia, therefore, permits only to conduct hydraulic model research on problems of running water with ice. Naturally even this solution is necessary for the improvement of navigation operations in Czechoslovak waterways, especially with a view to the increase of their future capacity. This is proved by the hydraulic research results obtained in recent years in the hydraulic laboratories of the Water Research Institutes in Prague and in Bratislava as well, as will be shown below.

In the modelling of flowing water with ice from the point of view of navigation, the majority of cases deals with the simulation of the motion of floating ice floes, both single and in agglomerations, in the river flow. In this case the gravity forces predominate in the hydraulic model and for the extrapolation of the phenomena studied from the model into reality, the Reech-Froude law of mechanical similarity os used. Its application requires maintenance of the identity of the so-called Froude's number both on the model and in reality. In order to ensure, at least to a greater extent the similarity between the friction resistance in the model and in reality, the basis of hydromechanical similarity, while applying Reech-Froude's law for viscous liquid flow, is the complete geometrical similarity. When using a liquid of the same density in the model as well as in reality, for the simulation of ice floes material of the same density must be again used, to ensure the same relative submergence of the floating ice floes and thus the geometrical similarity of the floating bodies and forces acting upon these bodies and aroused from them. The modelling of ice floes using real ice plates in reduced scale causes certain technological difficulties and for this reason in the majority of cases, ice foes are represented by plates of other material with about the dame density, e.g. some types of wood, paraffine, polystyrene, etc. In this case, of course, is it not possble to maintain the conditions of similarity of ice strength and model phenomena associated with the breaking of ice floes, etc.

In the preparation of the project of power-generation and navigation utilization of the Danube river in the ford section below Bratislava, the problems of winter regime have become of paramount importance. The completed water scheme consisting of a gated weir, a long derivation canal with a remote hydroelectric power plant equipped with additional auxiliary outlets and two locks will alter completely the present winter conditions on the Danube. The Czechoslovak sector of the Danube, as a significant international navigation route with fairly heavy traffic, must even after the completion of the new structures have an as short as possble enforced winter break in navigation. The project sounts with the fact that in the reservoir as well as in the derivation canal the trajectory will be kept navigable in the winter period by use of icebreakers. Of course, the ice broken by icebreakers has to be removed from the trajectory. The solution of the most suitable conditions for the ice removal and passage through the structures of the projected water scheme was the rask of hydraulic research carried out both in the Water Research Institute Bratislava and in Prague.

The discharge of the ice floes through the structures of the water scheme is consumpting water and hence leads to considerable power-generation losses. This is why the problem of the correct solution of the complete water scheme as well as single constructional details also from the point of view of safe and continuous transport of ice floes to the outlet devices and safe passage of the ice floats through the structures is of such paramount importance.

In the Bratislava Institute, a model research dealing with hydraulic problems of keeping the Danube river navigation route free from ice floes in the approach canal to the hydroelectric power plant and locks was carried on .In the first place it required the evaluation of the feasibility of using the auxiliary outlets of the power plant and locks for the transport of ice floes from headwater to tailwater with regard to water consumption. In case of emergency, it was possible to use for the transport of ice floes various combinations of the two mentioned devices including additional discharge of a certain water quantity even through the power plant proper.

At first, the flow conditions in the approach to the auxiliary outlets were methodologicaly measured on an aerodynamic modlel in the scale M = 1:1000/500, the water consumption for the passage of ice floats was studied on a hydraulic model in the scale M = 1:70. The ice floats were simulated by paraffine plates of polygonic shape in dimensions corresponding to ice floats with an average width of 5 m and thickness of 0.6 m.

The research results of all possble alternatives of ice floats transport through the different parts of the Danube river water scheme have shown that

a/ with a view to the minimum water consuption for the transport of broken ice from headwater canal, the best solution is the si simulataneous function of the auxiliary outlets and the power plant, however, with a certain risk of ice accumulation in the space in front of the power plant and blocking of the auxiliary outlets /overfolls/.

b/ with a view to the minimum time necessary for ice floats transport the best solution is the simultaneous function of all structures, i.e. locks, auxiliary outlets, as well as the power plant, again with the risk of ice accumulation in front of the power plant and in front of the approach to the locks.

c/ with a view to a safe and continuous ice floats motion, the best solution is the independent function of locks.

The results of these investigations are described in greater detail in /2/, where also the technical interferences into the conception of the structures of the total Danube river water scheme for the safe transport of the ice floats with economically feasible water consuption are discussed.

In the Water Research Institute in Prague a model research was carried out solving the hydraulic problems of the actual transport of ice floats through the upper approach to the locks. The project of this Danube river navigation - power generation water scheme assumed that through the locks there will be discharged, in addition to the ice floats, also a part of the flood discharges. This fact has naturally an effect on the total technological design of the locks.

The object of the study was

a/ to determine the necessary height of the overfall jet for the passage of the ice floats over the upper lock gates;

b/ to determine the suitable constructional adjustments of locks with a considerable headwater - tailwater difference /H = 23.3 m/ to obtain sufficient damping of the ice float kinetic energy;

c/ to test the feasibility of the adjustments proposed for the transport of ice as well as for a part of flood.

For the hydraulic investigation a model of a half of the upper navigation approach in the scale M = 1:33.3 was used. The real ice floats, which according to previous hydrological studies /3/ reach the dimensions of 5x5 m and thickness of 0.7 m, were again simulated by paraffine plates. The research results will be thus, while neglecting the ice strength similarity, on the safe side. The evaluation of the flow conditions during the discharge of both water and water with paraffine plates was at first carried out by the method of visual observation using a film camera and later, since it was not easy to determine whether the ice floes were falling down to the very bottom of the model, by an acoustic method. A common microphone was attached to the model structure, /made of wood/ and plexiglass and during the tests a tape recorder was in operation. This sound recording permitted to distiguish clearly the direct impact of the modelled ice floats on the bottom of the locks from the mutual collisions of the individual ice floes. The acoustic record together with the direct visual observation enabled us to evaluate the feasibility of the tested adjustments.

As lock gates the double sector gates are used with the lower sector adjusted for the possible direct additional filling of the lock using the outflow under the partially lifted gate. The transfer of a part of the flood discharge can be then achieved by further lifting of the when the water flows under as well as over /Fig.1/ or over sectors completely dropped down.

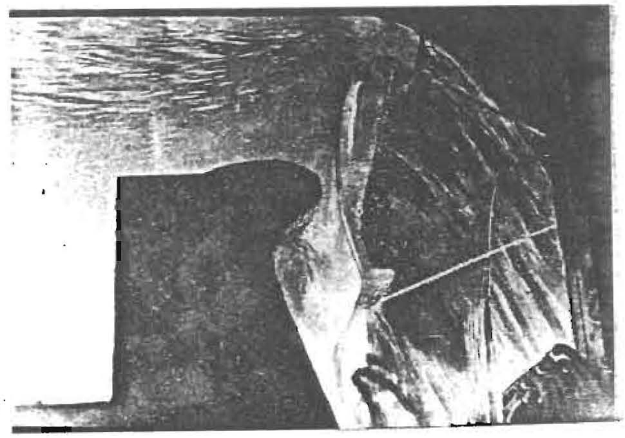

Fig.1 The model of tainter lock gate

The first tests showed that for the continuous inflow of ice floes of the given dimensions and for their safe passage over the lock gates, it is sufficient to lower the sectors in order to produce an overfall jet with a height of h = 2,5 m. The passage of ice floes through the locks was tested for several modification of the upper part of the lock. The object of all modifications was to attain a sufficient dampening of the kinetic energy of the overfalling ice floats in tailwater and to prevent direct collision of the ice floats with the lock bottom. The deepening of the lock bottom in the upper lock section and the creation of a 6.0 m deep stilling basin did not prove successful and in addition, this adjustment resulted in unsurpassable difficulties with the lock foundation and in the dispositional design of the by-passes for filling. With the second type of adjustments we tried using rectifiers of the water jet flowing under the gate-to let the ice floats fall flatly on the tailwater surface, but also these efforts were in vain. Another alternative showed a certain success. We placed a bulky guide wall into the lock in the shape of the lower enveloping curve for the overfall jet carrying the ice floats. In its lower part this guide wall continued through a circular arch in to a horizontal line. In this case there was no longer a strain on the lock bottom by the direct impact of the ice floats, however, the guide wall proper would suffer greatly and hence would have only a short life. The final recommended alternative solved the problem in such a way that by introducing the guide wall into the lock out of the range of the overfall jet carrying the ice, the water rises in the upper lock section and in turn reduces the height from which the ice floats fall into the tailwater and facilitates the dampening of their kinetic energy /Fig.2/.

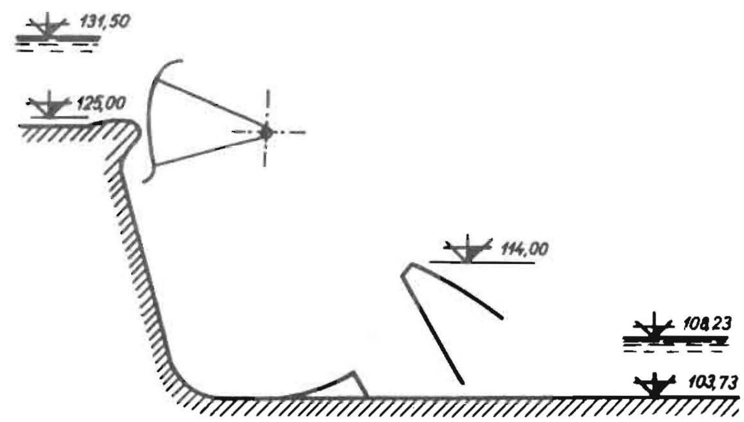

Fig.2 The recommended modification of navigation lock

The upper side of this wall we designed in the form of an underpressure less overfall surface calculated for a water jet with which a part of flood discharges will pass through the locks. Between the lock bottom and the lower edge of the fixed guide wall, a clear space of 1.0 m was left. The dampening of the ice floe kinetic energy was supported also by dissipators placed in the lock bottom, rectifying the bottom water jet /flowing below the sector gate/ against the overfalling ice floes. The flow under this final adjustment is shown on /Fig.3/.

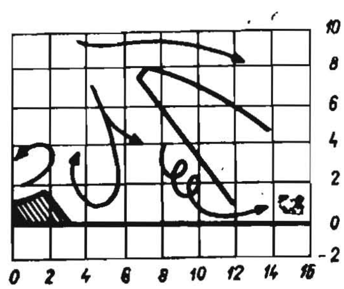

Fig.3 The flow-sheet of the flow under recommended modification of navigation lock

The resulting arrangement improved the conditions for the ice floe transportt through locks to such a degree that the overfalling ice floes do no longer hit the bottom, except during their further movement between the upper approach and the fixed guide wall where the ice floes hit the lock walls and bottom with considerably dampened energy.

Hence the hydraulic model research has, shown, that the solution of even such a complicated problem is possible.

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INTERNATIONAL SYMPOSIUM ON RIVER AND ICE

Budapest 1974 Hungary

STUDIES ON THE EXTENSION OF WINTER NAVIGATION IN THE ST. LAWRENCE RIVER

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ABSTRACT

The St. Lawrence Seaway is closed to navigation from mid December to about 1 April. In a continuing programme aimed at extending the navigation season, the Department of the Environment is carrying out studies of the ice regime in the Seaway section from Montreal to Lake Ontario. Ice growth patterns, as a function of time, position, and yearly weather changes, are described. It is concluded that using field data, remote sensing, and historical records, a theoretical model can be constructed to predict breakup much more accurately than is presently possible.

SOMMAIRE

Études sur le prolongement de la navigation d'hiver sur le fleuve St-Laurent.

Le St-Laurent est fermé à la navigation à partir de la mi-décembre jusqu'aux environs du premier avril. Dans un programme dont le but est de prolonger la saison de navigation, le Departement de l'environnement poursuit ses études dans la section du chenal maritime de Montréal jusqu'au lac Ontario. Les patrons de croissance de la glace sont décrits comme une fonction du temps, de la position et du changement annual de la temperature. Nous concluons qu'en se servant de données prises sur le champs, de la télédétection et des records historiques, un modèle théorique peut être construit pour prédire la dispersion de la glace avec beaucoup plus de présicion qu'il en est présentement possible.

The Montreal to Lake Ontario section of the St. Lawrence Seaway is 292 km in length. A vessel traversing this section rises 69 m through seven locks. In 1971, ocean vessels carried over 19 million tons of cargo in 2600 transits through the Seaway[1]. At present, the St. Lawrence Seaway is closed to navigation from mid December to about April 1st. However, technical improvements to the locks, including insulation of the gates, ice flushing systems, and ice diversion channels have helped make possible a season extension from 234 days in 1960 to 260 days in 1970[2]. While year round navigation is technically possible, the best hope for further extension to the season at present lies in improved methods of combatting ice formation at the end of the season in December, coupled with an improvement in breakup date forecasting to enable optimum use of every possible navigation day.

Objectives

During the winter of 1972 and 1973, in a continuing programme aimed at extending the navigation season, the Department of the Environment carried out studies of the ice regime in the Seaway section from Montreal to Lake Ontario[3]. Using data collected in the field over a period of 4 to 5 winters, plus information from remote sensing, historical records, and meteorological statistics, a model will be constructed to forecast ice conditions in this area of the St. Lawrence River. The final product will be maps incorporating the classification of prevailing ice conditions important for navigation and breakup, and an accurate prediction of Seaway opening up to 45 days in advance.

Ice Navigation

It is now possible with the use of remote sensing to forecast at the time of formation of the primary ice layer[4], the distribution of ice types[5] at the time of breakup. With the addition of continuous ice thickness profile measurements along the Seaway at the height of the winter, the performance of a vessel at breakup can be predicted. Figure 1 shows a section of false colour infra-red aerial photography taken on 27 January, 1972 at 2740 m over the St. Lawrence River ship channel. This is accompanied by a map showing ice type distribution based on interpretation of the photography with the aid of visual ground observations, and sampling. The following legend applies to Figure 1 and provides a definition of the two ice classifications considered useful for ice navigation:

Dynamic Ice - ice that has been formed by congealing of floating ice fragments under conditions of movement such as high winds, waves or turbulence.

Static Ice - Ice that has formed uniformly in one location with no large scale movement.

It can be seen that ice type boundaries are clearly delineated on aerial photography at the time of freeze-up. The shipping channel has large areas of smooth

Figure 1. Aerial false-colour infrared imagery of the ship channel taken from 2740 m , 27 January, 1972.

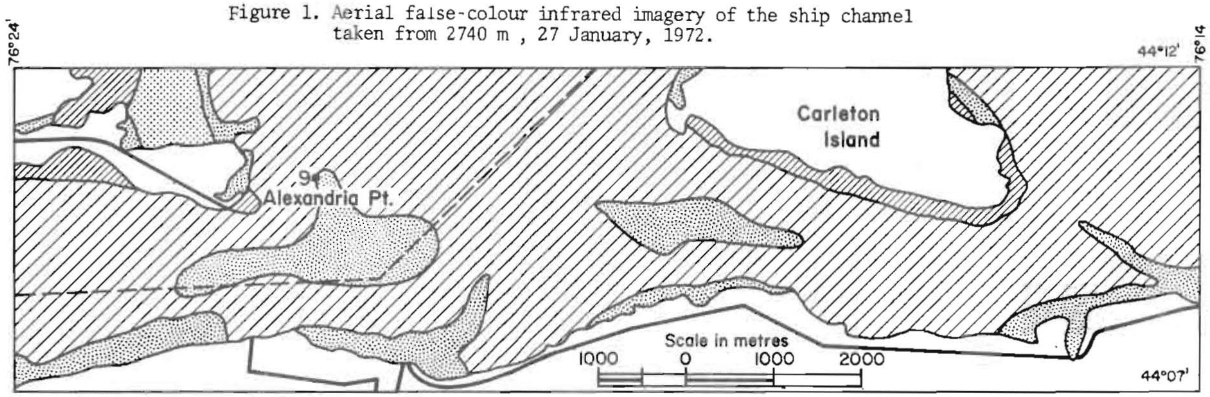


Figure 1. Distribution of static and dynamic ice at the time of ice formation, 27 January, 1972, as interpreted from imagery.

uniformly structured floes with smaller areas of rough agglomerate ice formed when a previously smooth young ice sheet was broken up by wind and wave action and allowed to refreeze. Ice observations were made during the cruise of a light Canadian Coast Guard ice breaker over a 160 km section of the St. Lawrence River - 19 January to 21 January 1972 - two weeks prior to breakup. The warm weather conditions prevailing at this time provided the worst conditions for ice-breaking, as the frictional resistance under slushy surface conditions appeared much greater than when the ship was breaking a relatively dry sheet with ambient temperatures below freezing. Total thicknesses encountered ranged from 18 cm to 51 cm with varying proportions of superimposed snow ice, and clear secondary ice. Rates of advance varied from 0.3 kn in heavy agglomerate ice of 40-50 cm thickness, to 5 kn through a uniform sheet with 15 cm snow ice and 5 cm clear ice. When operating on the limit of the continuous icebreaking capability of the vessel, only a subtle change in ice characteristics, an increase in the proportion of snow ice, or an additional few cm of ice thickness, would force the vessel into the ramming mode with a drastic reduction in speed from 1.5 kn to 0.3 kn. Qualitatively, for a given thickness of ice, the vessel appeared to experience increasing difficulty as the ice type progressed through clear ice to agglomerate to snow ice. Such an observation is borne out by experienced icebreaker captains and would seem to be related to differences in frictional resistance between different ice types. Naturally, temperature variations, snow cover, and ridging may completely reverse this order of difficulty. Consequently, it would appear that for any future commercial ice navigation, the ability to map out ice types and provide detailed ice thickness data will be invaluable.

Ice Growth

In discussing ice growth, the terms primary, superimposed, and secondary ice are commonly used. Primary ice is the first type of ice of uniform structure and texture which develops on a water body. Secondary ice forms beneath the primary layer, parallel to the heat flow. It may be in the form of columnar ice, deposited frazil slush, or snow slush. Superimposed ice, which always forms on top of the primary layer, is snow ice produced from snow precipitation, surface melt, rain or flooding of the ice cover.[4]

The history of an ice cover during a normal winter can be broken down into three distinct phases. Phase one represents the period of growth of secondary ice which, in a normal year, stops after sufficient snow covers the top of the ice. Phase two commences when the growth of the secondary ice has stopped. The only increase in ice thickness is due to the accumulation of superimposed ice from snow. This condition will last for most of the winter. Phase three is characterized by the melt of the secondary ice, at the ice-water interface, from warm water flowing into the river from Lake Ontario. This phase is of short duration. There is almost no melt from the surface of the snow ice. The solar radiation causes only internal melting, resulting in a weakening of the ice.

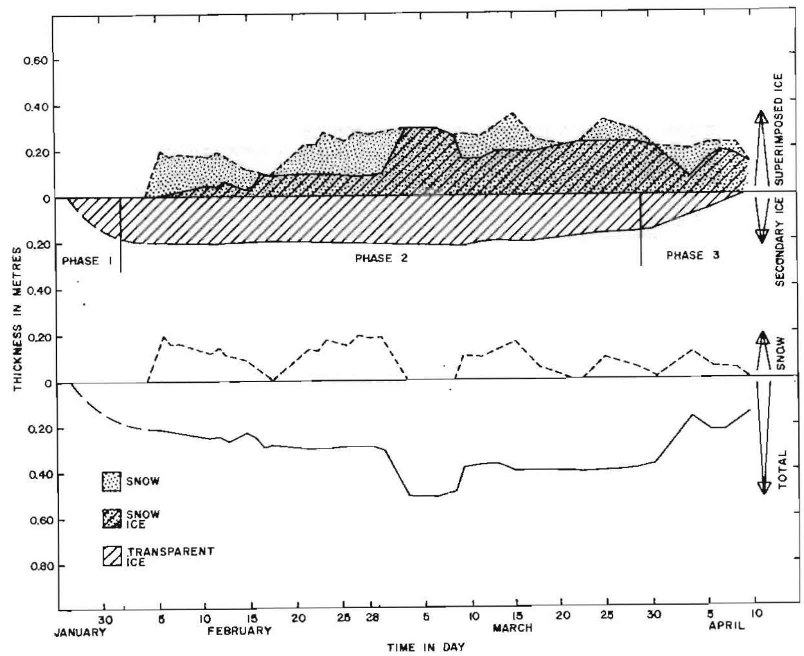


Figure 2. Ice thickness vs. time-Lake Ontario Entrance, 1972

Figure 2 is a detailed plot of ice thickness vs. time at one measuring site showing these three growth phases for the winter of 1972. Freeze-up occurred on 26 January. Six days later the growth of the secondary layer stabilized at 20 cm, remaining constant throughout Phase two until 29 March. During Phase two, the superimposed ice layer built up to a thickness of 10 cm. On 29 February, a short period of air temperatures above freezing combined with 20 cm of snow on the ice surface to produce melt, and a subsequent rapid increase in superimposed ice when the air temperatures assumed normal values. Similar melt-freeze cycles caused several more 5 - 15 cm fluctuations in superimposed ice thickness over 4 day periods. On 29 March the water temperature rose sharply and Phase three in the growth process began with a steady depletion of the secondary ice layer from beneath. The superimposed ice layer continued to fluctuate in thickness until the cumulative sum of degree days below freezing reached a maximum on 9 April, after which surface melt became a steady process. When all the secondary ice had been depleted, the warm water started to melt the newly exposed snow ice layer. Finally, at a thickness of about 10 cm the ice cover broke up into floes and drifted downstream. Over the 13 day duration of Phase three, water temperatures rose from 0.1°C to 0.8°C. If no snow and superimposed ice are present, the absorbed solar radiation causes extensive melting at the grain boundaries, causing the ice cover to disintegrate within a very short time. Such a situation existed in 1973. Combined with a water temperature rise of over 0.5°C in 5 days, it promoted an early breakup on 10 March. In any given winter, ice growth patterns vary considerably along the 292 km length of the St. Lawrence River between Montreal and Lake Ontario. The South Shore Canal near Montreal, geographically the most northerly canal in this section of the Seaway normally reaches the freezing point 2 to 3 weeks before the Iroquois Lock, 177 km upstream. Lake Ontario is the heat sink for maintaining water temperatures above the freezing point, and as the outflow proceeds North-east downstream, the water is chilled. The cooling effect is accentuated by the low current velocities in the canal, with the result that the first severe ice problems start near Montreal[2]. For example, in 1971 the first reported freeze-up date for the South Shore Canal was 19 December, while the Lake Ontario entrance, 290 km upstream, did not freeze initially until 25 January, 1973. Figure 3 shows the ice thickness variations in the shipping

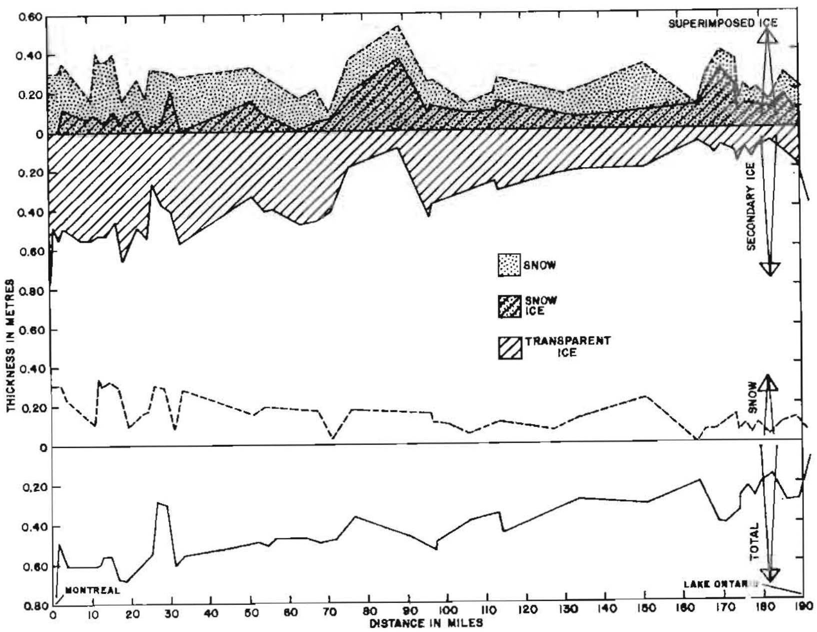


Figure 3. Ice thickness vs. Distance, February 25,1972

channel moving upstream from Montreal on 25 February, 1972. As would be expected, the superimposed ice variations are random, but the secondary ice exhibits a steady decrease in thickness from about 50 cm at Montreal to 10 cm near Lake Ontario. This pattern of decreasing secondary ice thickness with distance upstream exists throughout the winter.

There are dramatic differences in ice growth from one winter to the next. For example, though freeze-up occurred 20 days earlier in 1973 than in 1972, the new clear ice layer was covered immediately with 5 - 7 cm of snow which remained until 15 January. Cold air temperatures during this period, which could have built up a strong secondary layer, were rendered less effective by the snow insulation. In the period 15 January to 21 January high air temperatures, rising water temperatures (0.07°C - 0.16°C), and zero snowfall, rapidly destroyed the young ice sheet in many sections of the river. Even after colder weather enabled the sheet to reform, secondary ice growth did not reach Phase two until a rapid rise in water temperature (0.5°C) on 1 March and air temperatures above 5°C caused a permanent breakup on 9 March, 4 weeks earlier than in 1972. Figure 4 shows the major meteorological differences between the two winters that contributed to such striking differences in ice growth.

Conclusions

Consequently, it can be seen that any model that is constructed to successfully predict breakup up to 45 days in advance, will have to cope with such unusual conditions as those in the winter just described. With more detailed data it is felt that a successful theoretical model can be constructed. We must have detailed measurements of current and water temperature at various positions along the river. An extremely important parameter about which more information will soon be available is the relationship and time lag between heat absorption in Lake Ontario and water temperature fluctuations in the River. Studying large scale energy budgets for the Lake may give us our most accurate advance warning of impending water temperature increases in the Lake outflow. By constantly monitoring ice thickness variations with an air-borne FM or impulse radar unit[6], and knowing the distribution of ice types at time of formation, it will be possible by the winter of 1974 to provide an accurate first test for a theoretical model. Combined with detailed meteorological forecasts, and historical records of previous weather conditions and ice distribution, it should be possible to provide a much more accurate prediction of breakup than is available at present. Such information will be invaluable to foreign shippers in scheduling ship movements to coincide with the earliest possible opening of the Seaway. Looking into the future, preliminary studies have been made to prove the feasibility of pumping large quantities of relatively warm subsurface water from Lake Ontario into the St. Lawrence River to reduce ice thickness[7].

Figure 4. Meteorological Data.
Comparison 1972-1973.

Lake Ontario Entrance

Degree days below $0^{o}C$.

	Dec.	Jan.	Feb.	March
1971-72	72	156	250	111
1972-73	190	150	238	0

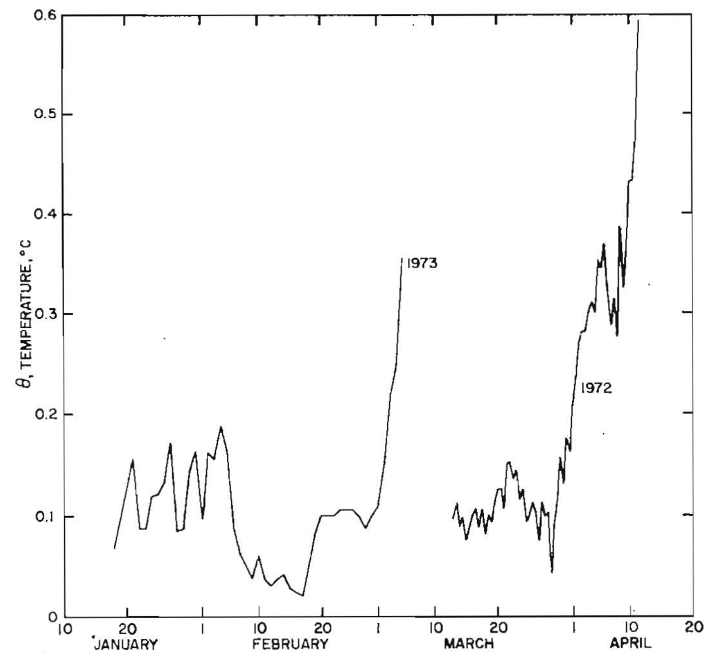
Snowfall (cm)

	Jan.	Feb.	March
1971-72	46	73.5	54.5
1972-73	14	21.6	4.6
Normal	50.5	37	27

Montreal

	Dec.	Jan.	Feb.	March
1971-72	228	262	334	167
1972-73	278	250	306	0
Normal	206	312	256	72

	Jan.	Feb.	March
1971-72	33	89	46
1972-73	20	48	17
Normal	53.5	56	35.5



Water temperature vs. time-Lake Ontario entrance 1972&1973. Depth 3.0 m.

Acknowledgements

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ICE-CUTTING OPERATIONS IN RIVER ICE CONTROL

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ABSTRACT

An experience with a self-propelled ice-cutting machine used for ice control in the reservoir of a low-head hydro power plant in Siberia is described. It is shown that ice-cutting operations ensure an earlier break-up in the reservoir as compared to the upstream river reaches. The need for further optimization of the design of ice-cutting machines is emphasized.

SOMMAIRE

L'auteur décrit l'expérience acquise lors de l'exploitation d'une machine automotrice brise-glace prévue pour le contrôle de la débâcle dans la retenue d'un amenagement hydro-electrique de basse chute en Siberie.

Grace à cet engin la débâcle sur ce tronçon commence plus tôt que sur les tronçons amont de la rivière.

Les recherches ultérieures sur le perfectionnement de la construction des machines brise-glace sont à souhaiter.

Low-head hydro power plants on rivers with a stable ice cover generally contribute to ice troubles in the vicinity of hydraulic structures during spring break-up. Particularly, the chances for ice jamming in the reservoirs of such power plants are very high. In some cases trouble-free passage of ice is also a problem.

The magnitude and complexity of ice problems depend on a variable combination of such factors as the morphometric features of river channels, the severity of winters, the intensity of temperature rise in spring, the arrangement and design of ice-passing facilities, the hydraulic parameters of the flow, the thickness, strength and size of ice fields.

The ice problems mentioned above can be considerably alleviated or completely eliminated by regular preventive measures ensuring ice control in spring.

Ice control measures consist in accelerating ice break-up within the reservoir or, if necessary, downstream from power plants as well. The following basic methods are well-known and adopted in the U.S.S.R. for regular ice control in spring (R. 1) :

- weakening of ice by applying dark material or chemicals;
- disintegration of ice by ice-breakers;
- cutting of ice by ice-cutting machines;
- demolition of ice by explosives;
- strengthening of the ice cover for delaying break-up at the upstream sections of the river.

Ice-breakers and ice-cutting machines are most efficient and reliable in controlling the ice cover break-up without affecting the environment. However, in some cases the application of ice-breakers is limited by the shallowness of rivers and reservoirs. Under such conditions self-propelled ice-cutting machines are one of the most efficient means of river ice control, since their operation does not depend on the flow depth or weather.

Below will be described an experience with a self-propelled ice-cutting machine which was used for ice control in the reservoir of a low-head hydro power plant on a Siberian river in which by the end of the winter the thickness of the ice cover reaches 1.0-1.2 m.

The milling machine for cutting ice (type ЛФМ) was designed by the Gorki Polytechnical Institute named after A.A. Zhdanov (GPI). It is a self-contained unit which cuts slots in the ice cover as it travels over the ice surface (R. 2)

The type ЛФМ machine is equipped with a face-and-side cutter of 2 mm in diameter which makes cuts 15 cm wide in an ice cover up to 1.5 m thick. Propellers in the shape of gradually tapering hollow cylinders of 0.7 m in diameter are driven by a 115hp motor. The cylinders are filled with foam plastic for increasing the buoyancy of the machine. The weight of the machine is 4.8 t.

In the reservoir under consideration by the moment of break-up there is an ice-free water surface upstream and downstream from the dam. In the remaining 7 km-long upstream part of the reservoir the ice cover keeps at a constant elevation and presents a problem both during break-up and when passing ice through the dam. This critical section 180-230 m wide was chosen for carrying out of ice cutting operations in the spring of 1972 and 1973.

Planning of ice-cutting operations involves their scheduling and establishing the direction and the sequence of ice-cutting routes as well as the possibility of accelerating break-up at the section to be treated by the machine.

The layout of slots envisaged three longitudinal slots, two of them at a distance of 10-30 m from the banks and one in the middle of the river channel. The longitudinal slots were crossed by transverse ones at intervals of 30-60 m. When choosing this layout the following factors were taken into account: the absence of large ice flanges before break-up thanks to constant water levels in the reservoir; the feasibility of the separation of ice fragments from a monolithic ice mass; the width and the shape of the reservoir; the thickness and the strength of ice; and optimum ice-cutting methods.

Ice-cutting operations in the spring of 1972

The operations started when day-time air temperatures rose above zero. The mean daily air temperatures varied from -7°C to -4°C. The ice 70-90 cm thick was covered with a layer of snow 20-30 cm deep. The operations continued for 7 days. By the end of this period the mean daily air temperatures rose above zero and the snow melted away from the ice surface. A total of 12000 lin.m of slots were made during 7 days. At a distance of 2.5 km upstream from the ice cover edge transverse slots spaced 15-40 m were cut, the average length of slots being 110 m (Fig. 1).

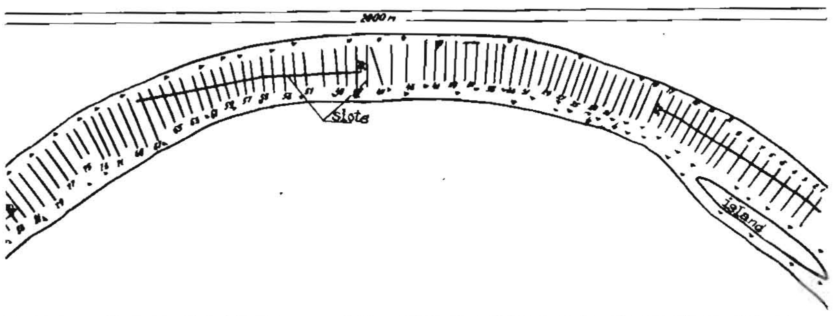

Fig. 1. Layout of slots cut in the ice cover of the reservoir, spring 1972.

The adopted layout was not accomplished because of certain troubles with the ice-cutting machine. With the ice 60-80 cm thick and the snow layer 20-30 cm deep the efficiency of the ice-cutting machine was 150 lin.m per hr. When the ice surface became free from snow the efficiency of the machine increased up to 210 lin.m per hr. Thus the presence of snow results in the reduction of the efficiency, some of it being spent on the compaction of snow.

At mean daily air temperatures of -2°C to +5°C the slots were frozen to a depth of 8-10 cm. However, 10 days after the completion of the ice-cutting operations all the slots were free of ice. During this period the water level in the stretch considered was decreased twice by 0.8-1.0 m. Part of the ice cover over a length of 400 m upstream of the ice edge was torn away and floated towards the power plant. As there were no longitudinal slots along the banks, ice floes would not separate from the ice cover in the stretch where ice-cutting operations were being performed.

When the ice cover was going to break up, the drawdown of water in the reservoir was stopped. No ice jamming occurred during break-up in the stretch where the ice cover had been cut by the machine (Fig. 2).

Fig. 2. General view of the ice-cutting machine making slots in the ice covered with a layer of snow 20-30 cm deep.

Ice-cutting operations in the spring of 1973

The operations began a month before break-up, as soon as the mean daily air temperatures rose above zero. By this time the ice thickness in the reservoir ranged between 0.8 and 1.0 m. The ice was covered with a continuous snow layer 20-30 cm deep.

The sequence of ice-cutting operations was as follows. First, a continuous 6.5 m-long longitudinal slot was cut along the channel from the end of the backwater zone downstream to 500 m, distance from the ice cover edge. At mean daily air temperatures from +2°C -5°C the slot was frozen to a depth of 12-15 cm during 4 days.

Then transverse slots averaging 110 m in length were cut in the upstream direction at intervals 30-60 m.

Finally, longitudinal slots extending over 1-1.5 km were cut along the banks.

A stretch 4.5 km long was treated in the way described. Upstream of this stretch transverse slots in the ice cover were spaced 100-150 m. In the remaining 1.2 km-long stretch transverse slots were not provided. The general layout of slots is shown in Fig. 3.

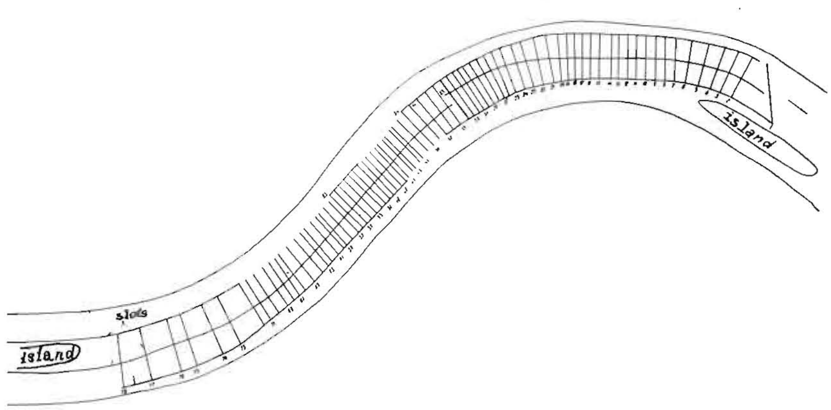

Fig. 3. Layout of slots cut in the ice cover of the reservoir, spring 1973

Thus the major part of the ice cover within the reservoir was divided into separate areas of about 50x50 m (Fig. 4).

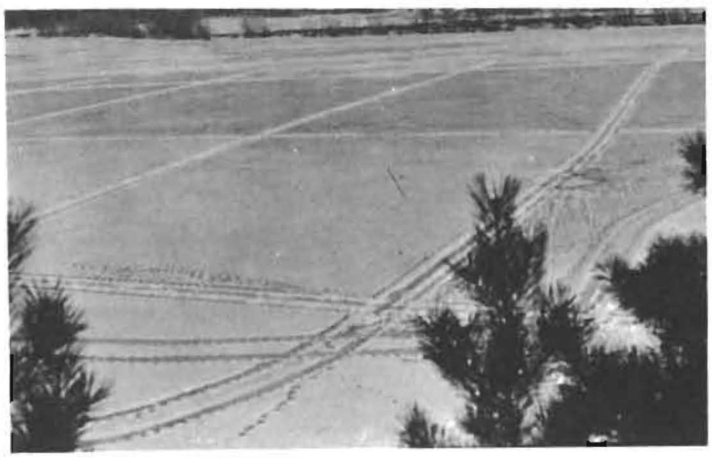

Fig. 4. Layout of ice-cutting routs on the ice cover in the downstream part of the reservoir, spring 1973.

The longitudinal slots along the banks upstream of transverse slot No 72 were cut only to a depth of 0.72 m, leaving an undisturbed bottom layer of ice 0.1-0.3 m thick. At mean daily air temperatures of -5°C to +2°C all the slots were frozen to a depth of 12-15 cm during the first three days. The freezing was accelerated due to accumulation of ice chips produced by the milling machine.

14 days after the beginning of ice-cutting operations the snow accumulated on the ice surface melted away. Three days later the operations were completed.

A total of 27 km of slots were accomplished during the given period, 16 km accounting for transverse slots. The efficiency of the ice-cutting machine reached 250 m/hr with the ice cover 0.7-0.9 m thick and the snow layer 10-15 cm deep, the ice temperature being 0°C. The ice had a two-layer structure (the upper layer of snow ice and the lower one of frazil ice) undisturbed by the spring thaw.

With the first drastic increase in the inflow to the reservoir the ice cover began to break up from the ice edge to transverse slot No 35 and to drift downstream. With a further rise in the water level by 0.2-0.3 m the ice in the remaining part of the reservoir broke up too.

The attempts to accelerate the break-up within the critical area by decreasing the reservoir level by 1 m in the spring of 1973 proved less effective than in the spring of 1972 because upstream of the ice edge there was an ice field 500 m long thrust against the river banks.

As a result of the ice-cutting operations carried out in the spring of 1972 and 1973, the break-up within the reservoir occurred earlier than in the upstream river reaches. A greater volume of work executed in the spring of 1973 ensured an earlier break-up(by two days in 1973 and by 15 hours in 1972).

Conclusions

A two-year experience with a self-propelled ice-cutting machine in the reservoir of a low-head hydro power plant proved the technical and economical efficiency of these ice control measures. The layout adopted envisages cutting of the ice cover by a series of longitudinal and transverse slots at an average interval of 50 m. The initial and final dates of ice-cutting operations must be established with reference to the thickness and the strength of the ice cover, the efficiency and the weight of the machine and the volume of operations to be performed. Ice-cutting operations proved most effective when accompanied by variations in the water level. Further research is needed for optimizing the design of ice-cutting machines.

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USE OF ACOUSTIC EMISSION IN FORECASTING ICE BREAKUP AND ICE JAMS

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ABSTRACT

This paper reports on the research on the application of acoustic emission techniques to problems of forecasting ice jams and ice breakup in rivers. Simple experiments have been conducted to correlate acoustic emission and temperature changes in ice. Based on these results feasibility of monitoring acoustic emission activity, predicting ice breakup and forewarning of ice jams have been discussed.

SOMMAIRE

Introduction

The capability to accurately forecast river ice breakup can be of significant value in the effort to control the movement of ice in a river. This is especially true with respect to the problem of ice jamming when loss of life or property may result from the rapid buildup of water and possible ice flooding above a jam. The formation of ice jams in rivers is a complex process that has been studied in detail by a number of researchers (1,2). Basically there are two types: a simple jam with an accumulation of ice floes floating in front of a solid cover, and the dry jam in which ice floes are jammed between a cover and the river bottom thereby severely cutting off the flow. The latter process is unstable and difficult to predict but the simple jam can be predicted with some certainty. Local conditions such as slope, plane contours, type of river bed and valley can be used along with general hydro-meteorological conditions such as melting conditions or environment, thickness, sequence of breakup, and development of innundation current speeds.

Much of the research on ice jam formation (1-3) suggests that forecasting of the time of ice breakup, even with a rough probability, is of substantial significance in forecasting jamming. In constrast to the ice formation process which can be more readily predicted, the breakup is difficult to forecast because it depends upon a variety of factors including heat exchange with the atmosphere, wind and local hydraulic conditions. Consequently, while it is unlikely that a single general method will predict this phenomena under all conditions it should be possible to forecast breakup under restricted conditions.

The breakup process itself is a complex process of weakening of the ice and fracture which is accompanied by changes in stress and strength. Forces are applied to the ice by thermal and hydraulic action and the breakup finally occurs by a fracture mechanism. Indirect assessment of the forces on the ice cover such as by means of wind velocity or current or stage measurements coupled with heat flow calculations based on meteorological conditions have been used with some success to predict breakup (1,2,4). However, since it is ultimately the mechanical strength of ice which determines the failure loads, it would be of great value in forecasting if some simple means were available for ascertaining the mechanical properties, in situ. Such measurements would necessarily be local in nature and consequently the forecasting based on this data would be restricted. Of course, critical portions of a river system could be pinpointed and studied in detail.

The present paper discusses the application of acoustic or stress wave emission measurement and analysis to the problem of forecasting river ice breakup. The basic techniques are less than twenty years old and have been under development largely in the field of material science. It is proposed here that the acoustic emission activity in an ice cover can be correlated with its mechanical properties and the degree of mechanical or thermal loading. A correlation between this activity and mechanical strength for sea ice under uniaxial compression has been previously demonstrated by the authors (5), and in the present paper, a laboratory correlation of acoustic emission activity in a floating ice sheet with thermal loading is demonstrated.

Acoustic Emission

Acoustic emission may be defined as stress waves spontaneously generated within a body of material when subjected to stresses. This phenomenon should not be confused with ultrasound testing procedures in which an ultrasonic pulse is transmitted into a material and its subsequent reflections are studied. Acoustic emissions are generated from within the material and have been attributed to a variety of causes including, microcrack or macrocrack generation, dislocation movement, grain boundary effects, or a combination of these and many other sources. Even though the correlation of acoustic emissions with their causes is still an active subject of research in metallic as well as nonmetallic materials, the technology has been successfully applied to the nondestructive testing of structures made of metals and alloys, to concrete construction and to rock mechanics. (These issues have actually been considered for some years in seismology under the title "microseismic activity").

Early observations of acoustic emission have been attributed to tin smiths who observed "tin cry" or "twinning" during deformation of tin. Audible sounds or clicks were noted during heat treatment of steel. These clicks are related to martensitic transformation (6). Of course, anyone working with ice or familiar with ice has observed audible sounds during mechanical or thermal loading.

The first systematic study of acoustic emission was made by Kaiser in 1950 (7). Later his work was followed by Schofield (8), and others (9). Most of these early investigations were restricted to a frequency range well below 60 kHz. A significant development was made by Dunnegan, et. al. (10) in 1964 when the instrumentation technique was improved and it became possible to conduct experiments in the range of 100 kHz to 1 MHz. Since then acoustic emission has become a subject of active research and many interesting and useful applications have been reported (11).

Acoustic Emission in Ice

Researchers studying ice are familiar with the fact that when audible sounds are emitted by ice, macrocracking is taking place. Energy release in the form of stress waves, i.e., acoustic emissions, occurs long before macrocracks are generated, however. These emissions are of much higher frequency, above 100 kHz, and lower level, approximately 100μbar, than the former. The precise mechanisms responsible for their generation are not clear but certainly microcrack activity must play a role. It is the measurement and interpretation of these acoustic emissions that are important in forecasting the macrocracking which initiates breakup.

In the past, the problem of acoustic noise generation in ice has received scant attention in the open literature. Cracking has been recognized as a basic process in the deformation of ice, especially in creep behavior (12,13). Fracture has been explored by Goetze (14) and Weeks and Assur (15). Noise generation has specifically been investigated by Milne (16,17) and Bogorodskii, et. al. (18). Milne's referenced work includes a comprehensive bibliography of his noise research with coworkers at the Canadian Defense Research Establishment. The Russian work (18) proposes with rather sketchy experimental evidence that hydrodynamic cavitation and ejected particle vibrations are the major sources of ice noise. All of the work reported on noise measurement deals, however, with observations below about 10 kHz. Furthermore, no attempts have been made to link noise measurements to strength properties; rather, the effort has been more toward explaining the noise spectrum in terms of ice behavior.

The present authors have investigated acoustic emission in both sea and fresh water ice subjected to unconstrained compression (5). Sea ice specimens were prepared from sea water obtained from the Atlantic Ocean. Both sea water and fresh water slabs were frozen in a 38 cm. by 90 cm. container heavily insulated on all sides and the bottom to simulate the freezing conditions in nature. Specimens were cut from the 6 to 12 cm. thick slabs that were allowed to form on 20 to 35 cm. deep water. Some similarity between the sea ice prepared in this way and that found in nature was established by comparing the salinity at appropriate temperatures.

Acoustic emissions were detected using both a Dunnegan Research Corp. transducer and a miniature high frequency piezoelectric accelerometer. The signals were amplified, filtered and analyzed using an instrumentation system similar to that shown in Figure 1. It may be of interest to note that up to 80 dB of amplification was required with a transducer with sensitivity, -85 dB., reinforced to 1 volt per μbar and typical of presently available designs. The cumulative number of events in the frequency band from 100 kHz to 200 kHz signal strengths above a preset threshold was recorded versus a loading parameter. Power spectral density measurements of the accelerometer signals over the 0 to 50 kHz band were presented for fresh water ice.

Based on these tests, the authors concluded that both fresh water ice and sea ice are copius sources of acoustic emissions when subjected to compressive loading. Emission signals from fresh water ice and sea ice display distinctly different signal patterns in the temperature range studied. It was also demonstrated that the rate of acoustic emission could be correlated with mechanical strength and could be used to predict the failure loads and failure strains. The tests were conducted at different temperatures, however, the temperature for each test was kept constant by using an environmental chamber in the test machine. The results show that emission patterns were different at different temperatures.

Acoustic Emission in Ice Under Thermal Loading

The breakup of an ice cover, as noted above, is promoted by thermal loads as well as mechanical. In certain instances thermal input may be the critical load and consequently it is necessary to investigate whether or not acoustic emission activity can be correlated with this type of loading. This is an important consideration because in other cases thermal loading may not be the critical factor and acoustic emissions so generated must possibly be separated from other causes.

Milne (17) has studied underice noise in some detail using hydrophones located in remote instrument packages on the ocean bottom beneath ice covers. The frequency range covered was below about 10 kHz. and measurements were made over periods of days. His results show a clear correlation of underice noise with the diurnal solar heating and cooling cycle and Milne concluded that the source of this noise was in the ice cover. Specifically, he attributed the noise to thermal tension cracking.

In order to ascertain whether low level acoustic emissions such as observed during mechanical loading occur as well under thermal heating, a simple series of tests were conducted by the authors. Since the primary interest was with the forecasting of river ice breakup, fresh water ice was used instead of sea ice. A 3-5 cm. thick layer of solid "black" or columnar ice was produced in the specially insulated container described earlier using as a temperature above the surface of from 10° to 15°F. The slab was allowed to float on the underlying water and a Dunnegan Research Corp. Model 140 piezoelectric acoustic emission transducer was frozen to the surface near the center of the 83 by 29 cm. slab. A thermocouple was embedded about 0.6 cm below the surface as well. All tests were carried out in a 0.62 cubic meter commercial chest freezer. An instrumentation system as diagrammed in Figure 1 was used to record and analyze the number of emissions occurring above a threshold level in the frequency band from 100 kHz to 200 kHz. This band was selected to utilize the peaked resonant response of the piezoelectric transducer at about 150 kHz. Bandwidth limitation was also required to maintain adequate signal to noise ratio with gains which were up to 80 dB.

Typical results from two series of tests are presented in Figures 2 and 3. In the first figure tne cumulative number of emissions are shown as a function of time for thermal loading which consisted of exposing the upper surface of the ice slab to an ambient air temperature of about 76°F. The temperature 0.5 cm below the surface is also shown clearly indicated a steady 0.2°F per minute rise after the test initiation followed by a reversal at termination. The event totalizing electronics reset to zero after reaching full scale and consequently the cumulative emission curve is shown discontinuously. It is immediately apparent that significant acoustic emission activity develops in fresh water ice for changes in surface temperature of less than a few degrees. The actual total number of emissions is not of direct interest here since it is a function of the bolume of material under load. Rather, the shape of the curve is important. The slope or rate of emission is seen to abruptly increase on exposure of the ice to heatings and to remain almost constant during the interval until exposure is terminated. At this point, the activity markedly drops off. Although it is not shown here, this process appears to be repeatable over 10 to 20 minute intervals.

Figure 3 shows the results of a test in which a 15 by 15 cm. square area of a 3 cm. thick slab of ice was dusted with a flat black spray lacquer and then subjected to infrared heating from a 150 W incandesant photo flood lamp located about 40 cm directly above. A thermocouple was embedded 0.5 cm below the surface of the dusted area and the acoustic emission transducer was located near one end of the slab, about 35 cm away. As before, the emission activity increases abruptly when the lamp is turned on and decreases on extinction.

A quantitative comparison between the number of emission or rate of emission in Figures 2 and 3 is misleading because different thresholds were used. However, there does appear to be some correlation in both cases between the rate of emissions and the rate of change in temperature of the ice. At present only a qualitative correlation can be suggested and further work is clearly in order. It is obvious from these simple tests, though, that acoustic emissions are produced by thermal loading and it seems reasonable to expect that Milne's observations could profitably be extended to higher frequencies.

Applications to Breakup Forecasting

The results of cimple laboratory tests with artificially prepared ice demonstrate that acoustic emissions are produced in ice under both mechanical and thermal loading. These emissions are produced from the onset of loading and the results from compressive tests suggest that it may be possible to predict maximum strength and failure. Acoustic emissions under thermal loading are produced for changes in temperature of less than a few degrees. This fact itslef offers a potential method for evaluating the meteorological input to an ice cover, but at the same time, if this effect cannot be separated from emissions due to mechanical loading, each will confuse measurement of the other. Precise quantification in the analysis of acoustic emission data has yet to be attained; however, rasearch in this direction is under way in a number of fields. Two approaches are possible: deterministic and nondeterministic or statistical. In the first approach a cause/effect relation is determined directly while in the latter a probabilistic model for the source of emissions is constructed. In either case both time and frequency domain characterizations are required. For the present study only simple time domain analysis has been performed, and although further analysis of the cause/effect relation would be of value, it is felt that such results would be misleading because of the resonant, frequency selective response of the transducer used. This limitation may be removed with the recent availability of flat response wideband transducers.

Nevertheless, it seems reasonable to expect that a rough correlation between gross emission activity and the overall mechanical state of "quality" might be obtained. Obviously, there will be thermally induced emissions appearing on a diurnal cycle but long term changes such as might result from gradual weakening of the ice cover should be evident. Acoustic emissions from direct mechanical loading would be superposed on the cycle and their presence above a critical rate of occurrence could signal imminent breakup.

The breakup process in a river varies somewhat from year to year depending on meteorological factors but as described by Deslauriers (1), it can be considered in three phases: Pre-breakup, drive and wash. The pre-breakup period begins with the increase of river discharge when solar radiation begins to melt the watershed snow cover. The increased discharge puts the ice cover under stress and substantially increased acoustic emission activity should result. This would provide prior indication of the pre-breakup fracture and subsequent formation of ice-free reaches. Accurate forecasting of this phase is important because the probability of jam formation is greatest.

The drive phase begins as the remaining ice-reaches finally begin to give way and concludes when the river is cleared of ice. During this phase, acoustic emission activity monitored in the stron ice-reaches could provide an indication of their integrity and a forewarning of their impending breakup.

In all these considerations it must be recognized that certain portions of the river are more critical than others in the initiation of breakup. Clearly, it would not be possible to employ measurements from a single location only, but rather, acoustic emissions measurements at several critical locations would be required. Source location schemes using triangulation techniques with multiple transducers have been successfully used in pressure vessel testing to locate weld flaws, for example, It is possible that this procedure could be used over short reaches of a river, but it is more likely that alterations in propagation times due to nonhomogeneities in the ice would render the technique useless.

To conclude, the authors feel that acoustic emission monitoring and analysis offers a potentially useful tool to predict river ice breakup. The technique has limitations and is not suited for a general survey, but in applications over selected critical portions of a river it should prove of value. Included in this category would be local situations such as might exist around hydraulic structures. In this case emission activity could provide a forewarning of unusual or severe ice forces on structures. At present it is not possible to make precise quantitative assessments based on acoustic emissions alone, but it is felt that the development of both deterministic and statistical models should relieve this problem. For instance, signal amplitude discrimination might be used to characterize the energy release in much the same way that pulse height analysis is employed in nuclear physics.

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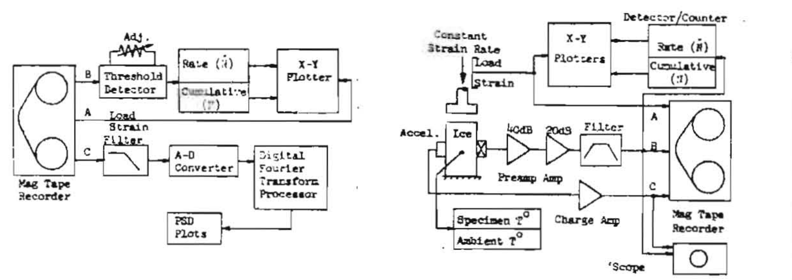

Figure 1. Instrumentation for recording and analyzing emissions. (accelerometer not used in reported work).

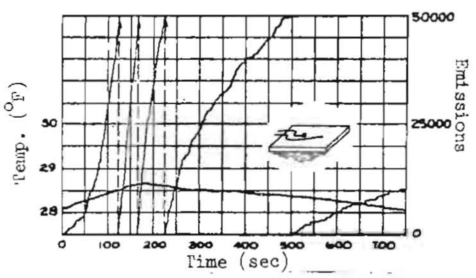

Figure 2. Acoustic emission counts from floating ice slab due to ambient temperature change.

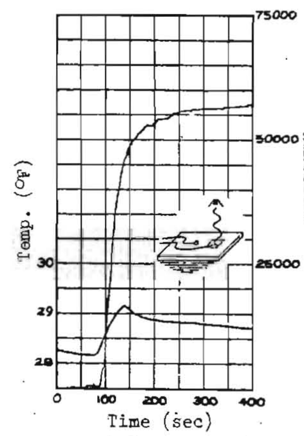

Figure 3. Acoustic emission counts from floating ice slab due to infrared heating of a dusted patch.

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OBJECTIVE ICE OBSERVATION ALONG THE SOUTHERN SECTION OF THE RIVER DANUBE IN HUNGARY AND THEIR PRACTICAL USE IN ICE CONTROL

by:
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ABSTRACT

The study reports about the morphology of the reach in question of the Danube River, about great ice-floods thereof and about the methodology of piloting of ice-breakers. The paper also discusses the directives for prevention of ice-floods by means of riverregulation. The available qualitative data during hydrological preparatory work must be substituted by objective quantitative measurements. Therefore measurements of ice-thickness must be performed daily by ice-breakers at 30 locations and the ice-cover should also be registered by photogrammetric methods with 10 pictures taken daily from a certain high point. Measurements are evaluated in terms of mathematical statistics. Expected values, variances and confidence limits are calculated. The authors introduce the concept of ice yield which can be calculated with the help of subsequent photographs. As a result a manual for forecasting for the prediction of freecing over of the river-reach has been developed.

SOMMAIRE

L'article traite les caractéristiques du secteur en question du Danube, les grandes crues causées par d'embacle, la methodologie de la direction de la flotille des brises-glaces et les principes des travaux de la régularisation du fleuve de ce point de vue. Pour y avoir une base bien fondée il faut changer les méthodes qualitatives par les mesures objectives et quantitatives. Ainsi on mesure, d'un brise-glace dans 30 point l'epaisseur de glace et par 10 photo, prise sur une hauteur riverain, nous calculons les pourcentages des surfaces des glacons. L'élaboration des données se fait par les methodes statistiques: on calcule la moyenne, la variance et les intervalles de confiances. On introduit la notion du debit de glace: on le calcule a l'aide de l'appréciation de deux photos succesives. Par ces elements quantitatis, on a élaboré des abaques pour prévoir le vitesse, du developpemont de la couverture du glace.

Characterisation of the ice regime of the Danube river reach and the more notable ice floods

From the aspect of development of ice floods the river reach between Vukovár /1.333 kilometres from the mouth/ and the bridge at Dunaföldvár /1.560 km/ is considered most dangerous. For the protection statt the fact is of special importance that the main charachteristics of the development of ice flood waves can not be predicted with such a high degree of accuracy as it is already possible in the case of summer floods. The conditions and phenomena causing ice floods which can generally be classified as meteorologic, hydrologic, morphological and geographic ones have already been dealt with by many researchers.

In the appearence and movement of ice important role is played by the meteorolgic conditions. Based on the daily mean temperatures the negative sum of heat needed by all means for the appearance of ice and for freezing over can be estimated statistically. According to the data of Dr. S, Horváth the sum of heat preceeding the first appearance of ice is 13,7 °C, at Budapest and 19,7 °C at Baja, and that needed for freezing over is 98,9 °C and 79,8 °C respectively.

The effect of hydrologic conditions, of water regime and of channel fullness is not unambiguous. In the case of a low stage the river is considerably fed by subsurface sources. Through this water being relatively warm and having a constant temperature, the appearance of ice is delayed, however, on the other hand at low water the various river-training works will emerge, accelerating thus the cooling process of water, that is, - at the same time - the appearance of ice. In many cases even certain factors seeming otherwise negible - e.g. the amount of suspended matter or the degree of mineralization - may also play an important role.

The effect of tributaries is of importance in the period of ice drifting. In most cases, in the smaller watercourses ice appears soones so that the initial base of ice appearance in great rivers is essentially formed by these tributaries.

From among the tributaries it is the river Drava by which ice conditions along the river reach in question section are influenced. In the period of ice drift - which is of primary significance in the development of ice floods - the Danube reach in question, is influenced by the ice conditions of the river Drava.

The most favourable case occurs when the disappearance of Danube ice is preceded by that of Drava ice.

In the case of an incidental coincidence of these, the formation of an ice barrier is very likely to occur.

Bed morphology- characterised by the width and depth of the bed, by curvature conditions and by slope - is playing an important role in the cooling process and it is a determining factor with respect to the points where ice comes to a stillstand.

In the river reach being dealt with there are six spots to be considered most dangerous from the point of view of ice accretion. These spots can be characterised by sharp bends, bed contraction and difficulties of navigation.

Such spots are: Sárospatak bend /1475-1470 km/, Baja bridge /1480 km/, Koppány bend /1484-1482 km/, Gemenc bend /1498-1494 km/, Paks bend /1534-1532 km/, and Ordas bend /1537-1536 km/.

From the point of view of ice motion - with respect to the geographie situation - two fundamental types can be distinguished: rivers flowing southbound or northbound. From among these two types it is the second one in which the inclination to the occurrence of ice floods is stronger. In the development of ice floods the general character of the rivers is determined by the ratio between the direction of flow and that of thaw. From this aspect the situation of the river Danube is unfavourable because the direction of thaw and that of flow are nearly the same. Warming-up proceeding along the flow direction is a well-known preliminary condition of ice flood development.

The ice motion and flood charachteristics of disastrous ice floods occured in the last hundred years - in 1876, 1891, 1893, 1940, 1941 and 1945 - were exceeded by those of the flood in 1956 so that ice conditions usually developing are to be characterised by describing the latter one.

In December, 1955 and in January, 1956 the monthly means of air temperature were higher than the normal values of these months. In the Alps, the precipitation attained the normal value but no substantial snow cover has developed there. Based on weather conditions, a mild or average winter and average river regime were to be expected.

However, in February, 1956 a considerable change occurred in the weather conditions. On January 26th, weather turned cold, followed by a rapid and intense cooling down. In Baja on February 17 th, air temperature was as low as - 24,7 centigrade, the minimum observed.

Owing to the heavy cold weather begun in the second part of January, at the end of this month a rather scattered ice began to drift and after a continuous increase of thickness on February 5th, ice cover developed between the southern border and Dunaszekcső. In the subsequent days this ice cover proceeded upstream and on February 8th, it reached Dunaföldvár. The motion of ice started on March 5th. The bombardments and ice blast executed daily at different places were not able to break the ice cover and to keep it moving. On March 8th, at Paks, on March 9th, in the bends at Dunaföldvár and Dombori and on March 10th, in the Korpád bend ice-barries developed. Between the 11th and 14th March, as a consequence of ice-barriers, maximum stages exceeding the former flood lavels have developed. At a few places the crest of levees was exceeded by the water. Then at Dorozlás and in Baja, dambreaks happened. After the breakdown of ice-barriers at Dunaföldvár and Dombori, both downstream and upstream Baja the crest of levee was exceeded by water over a reach of considerable length. At this time, on March 13th, a whole series of dambreaks occurred. Before noon, upstream Baja 6 dambreaks were recorded and in the afternoon - downstream - there were further 14 breaks. In a short time, 24 dambreaks developed along the leftside levee and 6 breaks along the right-side one, on account of the ice flood. All this resulted in the over-flooding of vaste area and a few villages had to be evacuated. The Hungarian Danube reach became entirely clear of ice by March the 19th.

Prevention of the development of ice floods; controlling of the activity of ice-breaker fleet.

In Hungary on the river Danube and its tributaries, ice-breaker ships and different explosive devices are used to break up coherent ice cover and to liquidate ice barriers, ice accretions and ice cloggings.

In the Hungarian Danube reach - based upon experiences made during the last 10 years - the liquidation of ice accretions and of ice barriers and a considerable diminishing of the danger of ice floods were successfully achieved by using ice breakers of 300-1.440 HP. For conditions prevailing on the Danube, the principles of ice breaking to be performed by ice-breaker ships have been formulated by M.Boker.

These principles are to be summarized as follows:

a./ in the period of primary ice drift, the maintenance of a continuous ice motion, the delaying of freezing over and reducing of the possibility of icebarrier development;

b./ in the period of ice cover development the securing of an even freezing-over without allowing the formation of barriers;

c./ in the ice cover once frozen over, the creation and continuous maintenance of passages, and, by means of eliminating discontinuous ice cover, the attaining of a more uniform distribution of ice;

d./ destruction of accretions and of barriers;

e./ in the course of secondary ice drift beginning together with melting, the securing of our even drifting-off of ice.

The guidance of the activity of ice-breakers, participating is performed in a co-ordinated way along the entire length of the river to be protected. At the beginning of the primary ice drift /early winter/ when ice cover is about 25-30 per cent of water surface the small fleets of ice-breakers - consisting of 2-3 ships - are kept in readiness. After the start of medium /30-50 %/ ice drift and of shore ice development, the ice-breakers begin their work. The ships sail along their river reach several times up and down and disintegrate both the shore ice and floating ice by means of generating waves, sailing at a constant speed, In the period of a heavier ice drift sailing, before all in the bottlenecks and sharp bends, the delaying of freezing-over is the duty of the fleet. The discontinuous ice cover is fully destroyed. In this period, the aims is to make pass the possible greatest amount of floating ice to the lower part of the river.

When the ice drift attains to 80-100 per cent and according to meteorologic and hydrologic forecasts, a lasting cooling-down can be expected without a rising of the water level and, if in the river reaches being inclined to freeze over the development of ice cover has already been completed, the duty of the ships is to promote the smooth freezingover. The activity of ice-breaker groups has to be directed so as to have ice cover grouping upstream and a freezingover along the entire length of the river reach. After the complete freezing-over the opening of the passage, 15-20 m wide, has to be commenced immediately by sailing upstream.

This passage has to be maintained by sailing along it daily to assure the rapid accessibility toward accretion sites if perforce a flood wave would occur.

One of the first phenomena of spring melting is that in some places, ice cover is sliding down and gets underneath the ice cover of the downstream river reach. In these cases, the downward release of ice - by means of demolishing it by proceeding upstream - has to be started without delay. To demolish accretions, barriers - with respect to vaulting phenomena - the search for the surroundings of the shoulder points or places may prove successful.

In general, the technology of ice breaking is the following: the ice-breaker - using her kinetic energy - sails continuously forward in the ice field until she is stopped by the thicker ice cover. The ticker block of ice is broken by manoeuvring forward and backward, by running upon the ice called "ironing". The ships stronger than 600 HP are provided with a ramming equipment so that these ships can proceed forward even in the thicker ice by their "nodding" /ramming/ motion. Ramming is produced by big counterweights mounted on the forebody and afterbody of the ship with an excentricity of 180 degrees between them and driven by special auxiliary engines. The deployment form of the ships is triangle /V-formation/, so that in front of the group of ships, generally one of the ramming type is sailing as a leading ship.

The work of ship groups is guided in a co-ordinated way along the entire reach of the river by means of USW-receiver-transmitter units, based on terrestrial and aerial observations.

<u>Prevention of ice floods by river training measures.</u>

The bed conditions of rivers being inclined to cause ice floods are characterised by their primitive state, the existence of several branches, unregulated foreshore, shallows, bottlenecks, meanderings, lack of navigability and the partial or whole lack of river training. Also on the reach in question of the river Danube, almost all disastrous floods were caused by the development of ice barriers.

If follows from the properties of ice phenomena that in the period of ice drift /that is, of ice vaulting/, the low-water channel conditions, in the period of ice accretion, ice-barrier and ice clogging development, the mean - stage channel conditions and in the course of ice flood development, the flood-channel conditions are of decisive importance.

With regard to ice motion, the dimensions of a bed are sufficient when excessive depths and contractions have not developed and the favourable channel sections have been stabilized. In branches, the reezing over is usually finished sooner than in the main channel so that the density of ice floes will suddenly increase. Branches having no closures affect the ice motion of the river unfavourably. At the point of inflexion in an excessively wide river bed no sufficient water depth can develop. At central fords of this type in shallow river sections, ice is stopped easily.

The dimencions, width, topography, type of vegetation, building density and water conveyance of the foreshores generally wary within wide limits. The role of the foreshores is of special importance from the point of view of ice flood development. In contractions of the flood channel there are usually unobjectionable bed conditions and adequate depths.

It is characteristic of the Danube reach in question, that on the one hand, ice becomes rarely stopped in the contractions of the flood channel, but on the other hand, great danger is caused if ice accretion, ice-barrier, ice clogging is developing just there. On the narrow foreshore, flow is unable to by-pass obstacles without being dammed up and water level will rise instantaneously, the only way autflow being the spilling over the levees, so that finally the disaster can not be avoided. This is what happened in 1956 near Dunafalva and Dombori.

When elaborating river training designs has begung in the last century, first of all the possibility of ice motion was considered and the interests of navigation were thought to have a secondary importance. As on the Danube reach in question rather the width than the depth of bed increased, the constriction of the channel became the main target to be realized by training walls while at the forking points, secondary branches have been closed by traverse dams. Training channel width has been assumed to 450 m.

According to the general plan of river training, elaborated in 1952, the channel width has to be reduced to 400 m both at the apex of bends and along the transition sections. The training width was intended to be realized by congitudinal works - especially by bank protection structures - along the concave side of benda and by traverse structures along the convex side. The traverse structures are partly groins and partly wing dams with a horizontal crest. As the purposes of river training the possibility of unhindered motion of ice and the securing of navigation channel with a minimum depth of 2,5 m and with a minimum width of 200 m were regarded. Depth is related to the navigation low water determined by the Danube Comission.

Preceding the river-training plan elaborated in 1961, only a training of the channel for medium waters was carried out. However, in the new programme also law-water bed training has been included for a shorter river reach upstream Paks. The constriction of medium waters is foreseen by training walls and constricting dikes - both of them situated on one side only - and by closing the branches. To this end the river training method corresponding to the standard profile had been chosen by applying the structures of the two types fasing one another. The river reach was divided into two parts: the one above Paks and the other below Paks.

In the training plan the creation of a zone free of vegetation in the foreshore has been foreseen in order to promote the unhindered runoff of ice floods.

Quantitative ice observations performed along the Danube reach between Dunaföldvár and the southern border.

By the observations of ice phenomena /ice drift, freezing over, break-up, disappearance/, - introduced in the past decades - valuable but mainly qualitative characteristics have been obtained.

Based on these observations covering several decades such types of forecasting aids and methods have been developed by aid of which the forecast of these qualitative characteristics - that is, of ice phenomena - can be performed more or less successfully.

The quantitative characterisation of the nature and of the development of ice cover may yield important informations about the prevention of ice floods and about the fighting against the latter. For this reason recently the observers are expected to report the data of the percentage of water surface covered by ice and the data of ice thickness, however, without giving methods for these observations.

So the afore-mentioned two quantitative indicators are determined by the observers of different aptitude and disposition in different ways and with a varying accuracy.

It may be assumed that the coverage of water surface is estimated by sight, standing on the bank and the thickness of ice is measured on the drift ice carried by water onto the river bank.

The estimate of ice cover percentage - performed at a flat observation angle - is highly uncertain. Even the estimates given by the same observer standing in the same position may easily differ by 30-40 %.

As for the ice floe "carried by water onto the river banks" this kind of ice to be measured from the banks is produced rather seldom by ice drift preceding the freezingover process.

Thus, one may conclude that such observations are charged by subjective errors to a higher extent than in other cases.

The magnitude of ice coverage depends on the momentary situation. Within the same period of arbitrary length different magnitudes are to be observed at the different instants. E.g. the assessment of a single big floe and of the great free water surface behind this floe depends also on the fact whether the floe can be found within the sampling reach selected or has already left it.

Also the thickness of floes is influenced by many factors manifesting themselves even in the same day in different ways in the case of different floes.

The thickness of floes - supposing unchanged weather and water temperature conditions - is modified by multiple accidental processes of jamming, disintegration and sticking.

Obviously both the coverage to be observed in different instants - and the measurable thickness of floes are measured data referring to random events, that is, measured data refer to elementary events of stochastic variables. /Ice coverage reminds of the rarget model used in probability theory and the data of ice thickness reminds of the series of any measurement data/.

Thus, next to the uncertainty of subjective observations, one also should be aware of the fact, that the problem turns around the observation of data, having a random - variable character, influenced by random processes of events.

To eliminate the subjective error from observation data, a type of measurement methode have to be elaborated which data measured are recorded by instruments, that is by physical means. Due to the random - variable charachter of the phenomenon, instead of particular observations statistic sampling should be performed to characterise the probability variable with an acceptable accuracy.

Preparation and execution of measurements.

The possibility of objective data collecting was given on the one hand by the ice-breakers being in service on the river Danube, and on the other hand by cameras fixed at a sufficiently high level.

Measurement of ice thickness - by means of icebreakers - was to be extended over the whole Danube and has been made by a direct method.

No special preparations were required for the measurements. The thickness of floe fixed by grappling hooks was measured by means of a floding rule. Using large size /3 m/ rules, the thickness of ice floes was to be measured also farther from their edge.

Pictures taken by the camera show the coverage of the river amid momentary conditions to be used as basic data for any further processing.

However, to take pictures some preparation works had to be made along the river reach to be observed. For this purpose the mostsuitable five points, namely the top of the loess wall near Dunaföldvár, Paks and Dunaszekcső and the top of the granaries of Baja and Mohács were chosen were tripods with a fixed head have been built in.

At each station, on both sides the end points of two cross sections laid out perpendicularly to the mainstream, with a distance of 60 m in between them have been marked by boards differing conspicuously from the navigation signals. The network of co-ordinates having a mesh length of 60 m, has been constructed by the so called "diagonal" method on the basic photograph.

The result of ice measurement consiste of 10 photographs taken subsequently from the elevation points with a time interval of 60 seconds /Photo 1 and 2/ and of 30 ice thickness measurements performed from the ice-breakers by means of random sampling. The elevent film shot was made with a prolongated exposure. By the aid of a picture taken this way, the standing and moving ice can be told apart. /Photo 3/.

Processing of measurement data

The network of reference points are transferred onto the entlarged pictures by the contact method displaying thus the perspectively transformed picture of the 60 x 60 m network. By the aid of this network the measure of coverage is determined first in percentage and converted later into sq. metres.

The determine the travel velocity of ice floes in the individual photographs along the upper cross section line characteristic points are marked and these points are to be along direction of flow, identified in the picture taken subsequently.

Interconnecting these points the velocity diagram of ice floes can be obtained - through network of 60 x 60 m mesh size and by using intervals of 60 seconds between the subsequent pictures the obtaining of results in m/s dimension is secured -

Ice yield.

Ice yield is calculated first as surface yield with dimension of sq. m/sec.

The partial yield of individual calculationstrips can be obtained as the product of the mean surface calculated by the aid of two subsequent pictures and of velocity calculated by using the same two pictures, divided by the base length of 60 m.

The total ice surface yield is the sum of the partial yields of the zones, thus on the basis of 10 subsequent pictures 9 results of ice yield calculations can be obtained daily.

Statistical data processing.

The results of ice measurements can obviously be considered as being results of "experiments" related to random events. Hence, for their processing mathematical, statistical methode are needed.

The thickness of ice has been "estimated" by using the arithmetic mean of measurement data and the corrected empirical variance of the results has also been calculated.

Measurement data - owing to their fulfilling the criteria of central critical distribution - are of normal distribution.

By the aid of this assumption and of the Student test - serving the examination of a random variable having unknown variance and mean and being of normal distribution - the tolerance zones of different significance levels have been plotted, related to the average ice thickness. /Fig. 1./

The mean value, variance and the tolerance zones having significance level corresponding to average coverage of 10 data observed daily on ice surface, have been calculated similarly.

By the aid of processing the 9 data observed daily on ice surface yield, calculation the average yield of ice surface and the average tolerance zone of this yield have been obtained.

Using the ice thickness data the ice volume yield can also be calculated in dimension of cu. m. per second. The value of ice volume yield is assumed to be the product of the means of ice surface yield and of ice thickness.

Assuming the measurement errors of ice surface and of ice thickness to be mutually independant random variables having normal distribution, the variance of the estimate related to ice volume yield can be approached by means of the difference between the products of the secondorder moments of the above two characteristics and the products of the aquares of the first-order moments of the same two factors.

On the basis of variance and of the fictitions Student distribution of a degree of freedom

$$n = 2\frac{n_1 n_2}{n_1+n_2}$$

the tolerance zones of this ice volume yield are to be calculated as well /in the formula the number of ice thickness measurements is represented by n_1 and that of ice surface yield observations by n_2, being 30 and 9 respectively/.

Measurement data are plotted in graphs monthly for each station.

Beside the extreme and average values of air temperature influencing ice conditions and beside the data of water temperature and of river stages, the curves of the mean values of ice thickness, of ice coverage, of ice surface yield and of ice volume yield have been plotted together with their tolerance zones.

To make easier the evaluation of data the curves representing the daily change of the data enumerated that is the figures characterising both ice growth and ice melting have also been plotted.

The use of ice measurement data

On the basis of objective quantitative ice observations commenced only in 1971, quantitative relationships suitable for forecasts are not to be constructed so far. Many years have to pass until the connection between the quantitative characteristics of ice and the hydrologic factors can be analysed statistically.However, obtained so far the data - and considering also certain physical conditions - may yield informations capable of promoting highly the efficient control of ice-breaker activity. For example,beyond the knowledge of ice coverage percentage, by the knowledge of ice surface yield it is possible to estimate at a very high degree of accuracy the time-dependent size of an ice field likely to develop behind an ice accretion in a certain cross section - if there is no ice jam - or, dealing with ice volume yield, the mase of ice to block the channel. With these data available the head of the emergency staff is able to decide, whether he should deploy ice-breakers to liquidate an ice flield developed - or to let then open a passage through it. To estimate the velocity of ice field development a slide rule-like aid has been constructed in the basic graph of which the summarized value of cross section area per currant metre of the river /Danube/ had been plotted in the function of distance measured from the mouth. On the movable sheet of the aid, drawn on a transparent plate, the different surface yields can be found along a family of obligue radii. Matching the adjustment point of this graph and the point of ice stop observed, the length of ice field to develop in the next hours can be estimated. /Fig. 2./


Photo 1


Photo 2

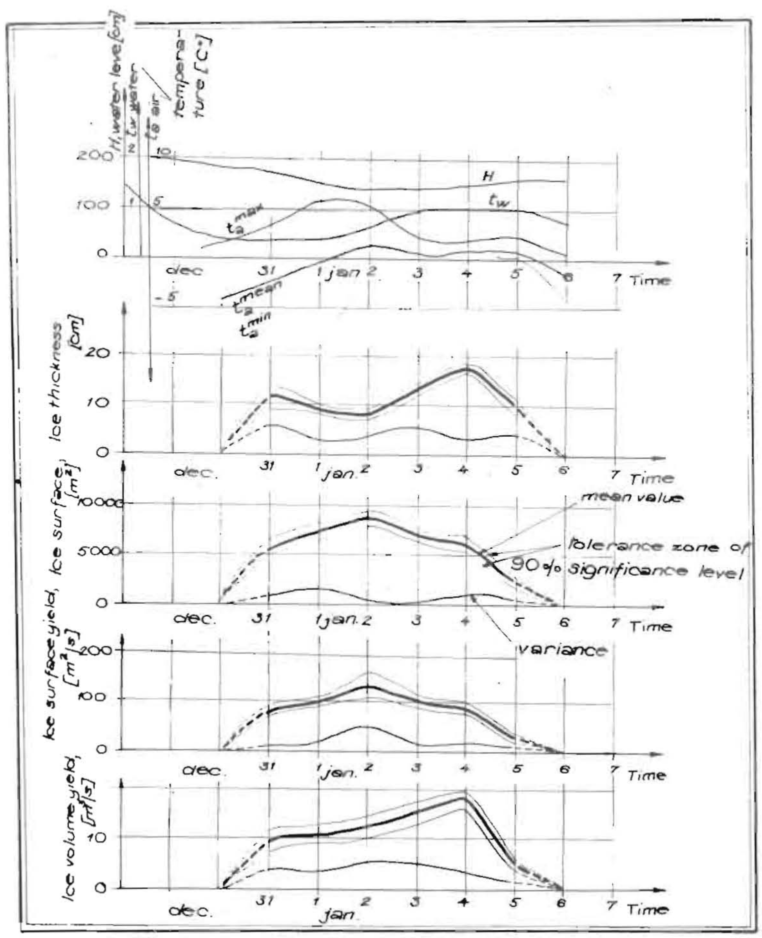
H, water level [cm]
t_w water
t_a air
tempera-ture [C°]
H
t_w
t_a^{max}
t_a^{mean}
t_a^{min}
Ice thickness [cm]
Ice surface, [m²]
mean value
tolerance zone of
90 % significance level
variance
Ice surface yield, [m²/s]
Ice volume yield, [m³/s]
dec.
jan.
Time

Fig. 1.

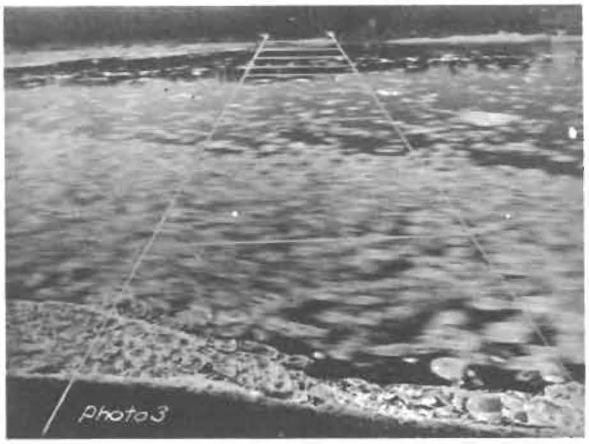
Photo 3

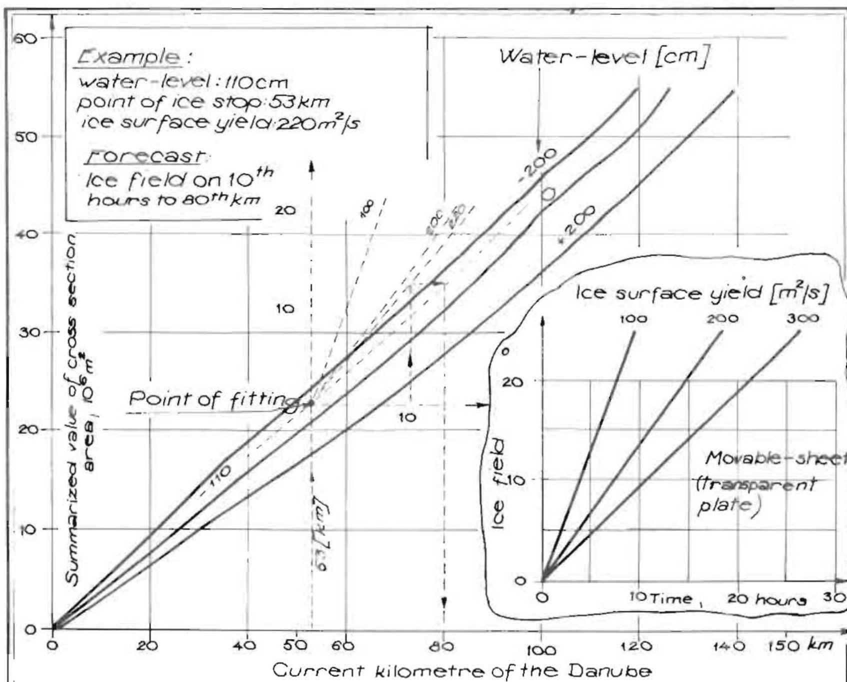
Example:
water-level: 110cm
point of ice stop: 53km
ice surface yield: 220m²/s
Forecast:
Ice field on 10th hours to 80th km
Water-level [cm]
Point of fitting
Ice surface yield [m²/s]
Ice field
Movable-sheet (transparent plate)
Time, hours
Summarized value of cross section area, 10⁶m²
Current kilometre of the Danube
km

Fig 2

IAHR/PIANC IAHR/PIANC

International Association for Hydraulic Research
SECTIONS FOR FLUVIAL HYDRAULICS AND FOR ICE PROBLEMS

Permanent International Association of Navigation Congresses
SECTION OF INLAND NAVIGATION

INTERNATIONAL SYMPOSIUM ON RIVER AND ICE

Budapest 1974 Hungary

LONG RANGE FORECAST OF ICE-EFFECTS ON THE MIDDLE CURRENTS OF THE DANUBE RIVER

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ABSTRACT

In the present work attempts are made to make a longer range forecast of the characteristics of ice-effects for a period of a year, for this reason, dinamical-statistical method is used for the prediction of macroprocesses by basing the calculation on multiple correlation. Results of the general determination of the reliable prognosis demonstrated that for a given method the most reliable results are abtained by forecacting for an elongated period of the effects of ice and give the period when the ice starts. The accuracy to forecast continnation imples that the coefficient of correlation R=0,63-0,90, guarantee P=70-90%. Prognosis for the begining of ice effects characterises the following values of correlation coefficient R=0,65-0,84 guarantee method P=74-90%. This method already seems sucessful in the first attempt and can be exact with further proofs.

SOMMAIRE

It is well known from literatures that investigations in the fields of long range forecasts of ice-effects in the Danube river was done for a period of 1-3 months. In the present work attempts are made to make a longer range forecast of the characteristics of ice-effects for a period of a year. For this reason dinamical-statistical method is used for the prediction of macro-processes by basing the calculation on multiple correlation /1/. This work was done in the Leningrad Hydrometeorological institute under the supervision of V. A. SHELUTKO by using electronic calculation machine Razdan-2.

The main essence of dynamical-statistical method of prediction formulated by I. M. Aliekhin arrived at the following conclusion that comlex natural macroprocesses are formed by stochastic probability of the common type.

Some of the most important conditions for using dinamical-statistical method are the concrete use of statistical structural functions. Thise functions are calculated by the following equality

$$R(\tau) = \frac{1}{G_t \; G_{t-\tau}} \; M \left| d(t) \; d(t-\tau) \right| \qquad /1/$$

where G_t and $G_{t-\tau}$ - root mean square deviation series corresponding to the original period of observation up tiel $N-\tau$ to the period τ - the end of observation, N - period of observation, $d(t)$ and $d(t-\tau)$ the values of the given series which deviated from the normal τ - shift value.

Calculation is based with consideration for the internal regularity of the increase in the predicting element by using the lineal equality.

$$d_t = k_1 \, d_{t-1} + k_2 \, d_{t-2} + \dots \quad \dots + k_n \, d_{t-n} = \sum_{\tau=1}^{n} k(\tau) \, d(t-\tau) \qquad /2/$$

where d_{t-1}; $d_{t-2} \dots \; \dots d_{t-n}$ values of temporal series of macroprocesses for the years of observation d_t - extrapolation /prediction/ term of series $k_1 \dots$ - optimal coefficients of lineal extrapolation /consecutive coefficients $k(\tau)$, $\tau = 1,2\dots$ farther, these values are found with extrapolation operator series, $d(t)$ for a given period of a year./

Number of terms n. Numbers not found in equation /2/ are calculated experimentally abraining up to 15-30. Calculation of extrapolation operator $k(\tau)$ can be obtained by solving the following equations /3/ using Gaus method

$$\begin{array}{l} k_1 R_o + k_2 R_1 + \dots \quad \dots + k_n R_{n-1} = R_1 \\ k_1 R_1 + k_2 R_o + \dots \quad \dots + k_n R_{n-1} = R_2 \\ \dots\dots \quad \dots\dots\dots\dots\dots \quad \dots\dots\dots\dots \\ k_1 R_{n-1} + k_2 R_{n-2} + \dots \quad \dots k_n R_o = R_n \end{array} \qquad /3/$$

Results obtained by the calculation of $k(\tau)$ for different values of n give the prediction value by selecting the optimal coefficient of extrapolation for the given optimal period.

On the basis of selecting optimal number of terms n the extrapolation operator give the representation about general correlation functions, which give theoretical estimanon of the possible maximum accuracy of extrapolation. General correlation function involues successive values of comon correlation coefficients $R(n)$ which is defined by the equality equation

$$R(n) = \sqrt{1 - \frac{D_n}{D_{n-1}}} \qquad /4/$$

where D_n - determinant of mean matrix with /n+1/ coluums constructed by the use of the correlation funtion $R(\tau)$ D_{n-1} main minor of the determinant. For the estimation of $n_{opt.}$ we used successive empirical sorrelation coefficient between real and prognostic terms of the series for varions values of n and also successive values of criterion cases

$$\delta_n = \frac{D_d(n)}{D_{d_r}(n)} \qquad /5/$$

where $D_d(n)$ u $D_{d_r}(n)$ corresponding dispersion error of prediction and dispersion of real series for varions values of n . For absolute accuracy of prognosis $\delta = 0$ real if $\delta \leq 0{,}64$ in this case prognosis is statisfactory. For sufficient contions stationary series $R = \sqrt{1-\delta}$

Primarily, quantitative estimation of equality /2/ is done with the aid of special parameters called period average correlation function

$$t_R = 2 \quad \frac{\tau_{lost} - \tau_1}{N-1} \qquad /6/$$

where τ_{lost} u τ_1 - abscissa corresponding to the last and first points of untersection of the horizontal axis on the average in the field of calculation of the value $R(\tau)$ N - total number of points intersecting or touching this curve in horizontal line. For $t_R \geq 6$ the use of dinamical-statistical method will ve successful.

Results obtained by the calculations of correlation functions by series for morc than 70 years are depieted in fig. 1. From analysis of graphs plotted by fields of points follous that internal bounding of series d characterise by few correlation coefficient which in absolute values do not exceed 0,2-0,3. Mean period of correlation function defined by equality /6/ for all calculated series by which prediction is afforded equal 6 years of more.

Generally, calculatid values t_R and the points in the graphs testify about the wide correlation which are the analising series; consequently the equality /2/ justifies the mathematical and physical basis. The determination of each of the consecutive terms of the series in relation to each of the subsequent term at a distance of τ years is insisnificant; however, the sum of the terms of those series in relation to the former, putting into consideration summary common correlation function R_n which is quite large and ranges from 0,7-0,9.

For this by correlation functions of the series we can calculate extrapolation operators $k(\tau)$ from optimal values n and extrapolation function were selected the greatest correlation coefficient buiding the real and prediction values $R_{d_r d_{pr}}$. Following from optimal variant, calculation was done by selecting the reliable values n_{opt} comparing them with the cases of criterion δ and the values of guaranted prognosis

$$P = \frac{N-m}{N} 100\%$$

where N - number of reliable prediction for a given series m- number of unsatisfactory prognosis. That is, prediction with errors Δd ranging from about 20% beyond the calculated values. The results of the general determination of the reliable prognosis demonstrated that for a given method the most reliable results are obtrained by forecasting for an alongated period of the effects of ice and give the period when the ice strarts.

The accuracy to forecast continuation of ice effects for a year imples that the coefficient of correlation forecasted and the real values of R ranges from 0,63 to 0,90 and the criterion category δ from 0,19 to 0,61. Guarantee method P = 90% at the upper section of the River for natural guarantee P_{nat} = 59%. On the remaining portions guarantee method goes up to 70% with natural guarantee are than 50%.

Prognosis for the begining of ice effects characterises the following values of correlation coefficient R = 0,65-0,84 δ = 0,25-0,61. Guarantee method oscillates from 74% to 90% where natural security obtains from 56% to 71%. In fig. 2 for a given series shoun the values of real and prognosis. From these values it is abvions that reliable forecast accurately defines the changes in the given case.

In some cases it becomes possible to be exact by forecasting graphically $d_{pr} = f(d_r)$ u $\Delta d = f(d_r)$.

From the obtaindd resulte we can sory that it is satisfactory so fax as they are in the region of long range forecast ihthin the time limit. This method already seems successful in the first attempt and can be exact with further proofs.

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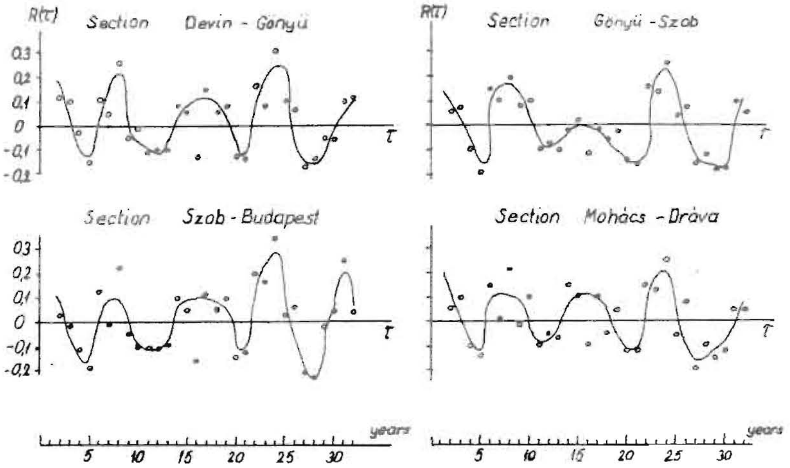

Fig. 1. Autocorrelation functions

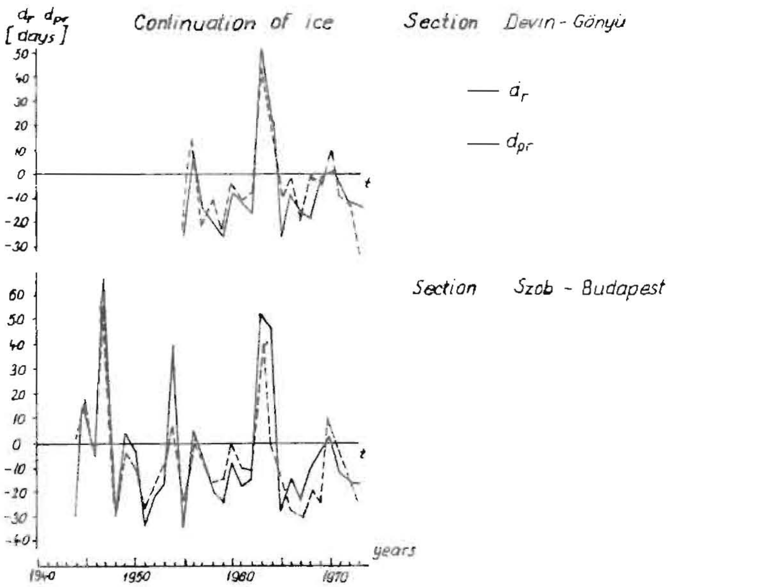

Fig. 2. Resoults of forecast

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I. Mátrai

General Lecture on Subject C

EFFECTS OF RUNOFF REGULATION

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General Lecture on Subject C

EFFECTS OF RUNOFF REGULATION

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ABSTRACT

Reservoir dams and barrages regulating runoff increased recently in both number and importance. Complex water projects and industrial water uses especially cooling water from large fossile power stations have brought about substantial changes in the thermal household of rivers. River canalisation has enhanced the significance of water traffic. Recent studies on thermal household, control of ice movement, design of structures and on the necessary protection against adverse ice effects will be reviewed subsequently.

SOMMAIRE

Le nombre et l'importance des réservoirs et des barrages de rivière avaient augmenté dans la dernière décennie. Les grandes ouvrages complexes et l'utilisation de l'eau industrielle avaient changé fortement le bilan de température des rivières.L'influence des eaux de refroidissement des grandes centrales thermiques est très importante sur le développement de la débâcle. L'importance de la navigation est aussi augmentée.Ils en resultent des nouvelles tâches dans le domaine de recherche des phénomènes glaciales. Un résumé des résultats et des expériences récentes relatives aux influences des ouvrages, dans le domaine du bilan de température, et dans la protection contre l'effet nuisible de la débâcle est donné.

Introduction

In the wake of the rapid increase of water demands in the second half of the 20th century there occurred a successive decrease in the number of streams capable of meeting these demands in their original, unregulated condition. The reduction of peak discharges and the augmentation of dry-weather flows has called for the construction of an increasing number of reservoirs with huge storage capacities, with the storage space attaining as much as 200 thousand million m^3. These are suited to retaining runoff volumes of several years, to discharge them successively in a controlled manner. Considering no more than the 25 largest reservoirs constructed during the past two decades or under construction presently, it will be realized that the aggregate storage space is sufficient to retain round 2.000 cubic kilometres of water. With their new water surfaces extending to several thousand square kilometres, these lakes cause substantial changes in the thermal budget of the streams, as well as in the ice phenomena observable in lakes under cold climates.

The regime of flat, lower river sections is considerably modified by river barrages which in general affect the runoff volumes to a minor extent only, yet their influence is all the more pronounced on the stream and on the riparian areas. These lower reaches are situated as a rule along densely populated industrial areas. The hydrological and temperature conditions, as well as the quality of water is fundamentally affected by the water uses along such reaches. The limit of thermal pollution in streams is receiving growing attention, especially in view of the thermal and nuclear power stations of several thousand MW capacity constructed recently. Thermal and chemical effects consequent upon industrial development play an increasingly decisive role in utilising the supplies represented by the rivers.

The conditions of rivers crossing industrially developed regions are all too familiar. Some forecasts for the Rhine have predicted that owing to the thermal pollution due to the cooling water of the contemplated thermal stations, the allowable limit capacity will be attained over some reaches as early is in 1975. Over the reach between Mannheim and Mainz which receives the highest thermal load, the temperature would increase in Autumn and in Sommer to 19 and 28 Centigrades, respectively.Assuming the rate of increase to continue unchecked the temperatures would reach 29, respectively 35 Centigrades by 1985.

For covering daily peak power demands high capacity pumped storage schemes have been realised, but also the hydroelectric stations built into the channel operate with discharges fluctuating between wide limits during a day. In the upper and lower reservoirs of storage schemes the level may fluctuate as much as 10 to 20 m within a few hours, but the changes in stage downstream of river barrages attain also the order of several metres. These variations must also be considered in studies related to ice phenomena.

Artificial links between river basins have been built in growing number all over the world, on the one hand for transporting water to regions of shortages, on the other hand for improving water traffic. Navigation interests call for ice restriction periods as short as possible, so that the study of phenomena related to the formation and movement of ice, as well as to the aversion of adverse affects assumes primary importance.

Such canals are used frequently for supplying cooling water to thermal stations. The return water of elevated temperature may reduce considerably the quantity and adverse affects of ice in the canal. Downstream of cooling water discharges long icefree reaches are observable over which winter navigation can be maintained readily.

The runoff control structures outlined in the foregoing are of considerable influence on ice conditions as well.

Subsequently a brief review will be presented on recent results and experiences collected during studies and research on the effect of runoff control structures, on the thermal budget,on controlling ice movement, on the design of hydrotechnical structures and on the aversion of adverse ice effects.

Factors affecting the thermal budget in streams

The construction of dams and river barrages results in artificial lakes with greatly increased surface areas over the original conditions, as a consequence of which the heat exhange across the surface is radically changed.

Another important factor is that as a consequence of backwater the flow velocity is appreciably reduced, in large reservoirs virtually to zero, as a consequence of which turbulence is largely eliminated. Conditions approach those in lakes, concerning which rather adequate empirical formulae are available.

With the development of the ice cover, with the reduction of velocity and turbulence, the opportunity of overcooling and frazil ice formation is minimized. Phenomena in large reservoirs can be described fairly well on the basis of ample theoretical results and field observations.

In the case of river barrages which cause only minor changes in regime, the phenomena are much more complex, especially where the retention level is variable and where the barrage incorporates a power plant which is operated as a peak load station thus giving rise to appreciable daily stage fluctuations.

Frequent disturbances of flow conditions during construction and subsequently the effects due to operation may cause radical changes in channel morphology. Such affects are described in paper C3 on the basis of experiences gained with barrages in the Soviet Union. After a transition period silting as well as scouring,subsequently following a period of relative stability, continuous degradation has been observed. This process has been traced on the Wolga river by observations made regularly for 17 years downstream of the Gorkyi barrage. Silt deposits accompanying scouring may cause ice jams in ice-run periods.

River barrages influence also the morphology of the stream section affected, in that the river tends to become more sinuous upstream and less sinuous downstream of the structure. The decrease in sinuousity is beneficial for ice travel in the tailwater, whereas the increase upstream is adverse in its effect.

The phenomena caused by canalisation extending to long river sections are rather well understood. The examples of the Main river illustrates strikingly the ice conditions over a completely canalised river section. Before development the river was rather narrow and shallow and thus overcooling occurred rapidly. The large storage spaces created by development represent great heat capacities. Cooling at the surface results in the formation of a solid ice cover within a short period, which offers protection against further cooling.

As a general conclusion it may be stated that canalisation of the entire river length creates improved ice conditions over the original, natural situation.

The effects are not that positive at single river barrages. In connection with the Danube barrages contemplated in Hungary detailed studies were undertaken by Dr.S.Horváth,who analysed the experiences made at barrages constructed earlier over the upper reaches of the Danube.

In the backwater reach, in the vicinity of the barrages the surface ice cover is formed within a relatively short period.Subsequently ice appears also at the upstream end of the reach over the section uneffected by backwater. Depending on the velocity of flow the ice, or frazil ice is arrested or carried under the existing ice cover and as a consequence the flow cross section is substantially reduced. For this reason the upstream and of the backwater reach is critical for ice jamming.

The change in the thermal regime of rivers as a consequence of backwater causes major changes in the length of the ice period critical for navigation. This is why at barrages contemplated under cold climates it is essential to predict also the changes in the ice period. Studies performed for the full Hungarian section of the Danube have established the changes in the frequency of ice runs and solid ice covers likely to occur after the construction of barrages.

The authors of paper C5 have estimated analytically the changes in ice cover conditions caused by the Dunakiliti barrage, which forms part of the common Czechoslovakian-Hungarian power project contemplated. From data for the period 1927 to 1964 it was concluded that after the barrage is commissioned,the ice covered may develop in some years 20 to 40 days earlier than under original conditions but in some cases it may be delayed by a few days. The theoretical data are in fair agreement with actual observations made at some power developments in Austria which have been operated for a number of years.

The thermal regime is greatly influenced by industrial and communal withdrawals and wastewater discharges. Most important of these is the effect of high capacity thermal stations. Besides the biological effects, the ice phenomena are also affected considerably in the winter period by the cooling water of elevated temperature. Concerning the longer period of navigation the effect is positively beneficial since owing to the great amounts of heat introduced into the stream ice-free reaches of several kilometres in lenght may occur downstream of the discharge point.

The heat budget is influenced further by wastewater discharges, occasionally by the presence of other chemical substances. For instance foam on the water surface may act as an insulating layer like the ice cover. Diverse suspended polluting substances may form crystal nuclei and affect thus ice formation.

The factors affecting the length of icefree sections are analysed in paper C4. Downstream of shallow reservoirs ice-free reaches of 13 to 15 km length, while below deep reservoirs such of 20 to 60 km length may occur. Detailed data are given on various sections of the Wolga river affected by reservoirs. Accordingly, over the upstream, colder section ice running occurs 10 to 15 days later in the reservoir than on the stream, whereas over the lowest section the phenomenon is reversed in that melting in the reservoir occurs 10 to 15 days earlier than in the river. Under favourable conditions the bulk of ice has time to melt in the reservoir and is broken up by a flood wave only, so that the effect of running ice is felt over a short section only.

Control of ice movement

Besides the velocity of flow or the channel morphology affecting the latter, the movement of ice is influenced first of all by wind. A wealth of hydraulic observations,theories and data are available concerning the laws governing the movement of frazil ice and ice floes, but much research is still needed before these phenomena can be described in an exact manner.

In the absence of wind the movement of ice depends primarily on bed forms. The phenomena in regular channels are fairly easy to trace, whereas in compound and irregular channels, especially if the flow cross-section is influenced by the ice itself, not even model tests are capable of yielding reliable information,owing to difficulties in conversion to prototype dimensions. A better understanding of ice movement phenomena is urgently needed in the interest of desinging earth or other structures to deflect, guide or prevent adverse ice movements especially in shallow, plain-land channel impoundments of compound cross-section.

The movement of ice is greatly affected by wind. Strong winds over wide water surfaces, especially in the absence of topographical features or plant barriers moderating the wind pressure may cause high waves and may drive the broken ice towards the lee shore. The magnitude and configuration of the resulting ice jams depend on the kinetic energy of the ice floes and also by the configuration of the bank.

Rather little is known about the formation of ice jams along lake shores. The magnitude of ice jams on the lee shore may attain 10 to 15 m. Shore ice is piled up in different forms depending on the strength, duration, changes in direction of wind, on the quality of ice, on wave action, etc.

The phenomenon of ice jamming and the movement of ice floes is dealt with in detail in paper C6 referring to the example of lake Simcoe in Canada. It is stated that ice jamming is not necessarily related to strong winds. Wind velocities of 6.75 m/sec may already cause the ice to pile up where other conditions are favourable.

A special case of ice jamming occurs in the basins of pumped storage plants. In some basins the daily level fluctuation may attain 10 to 15 m. Ice formation is greatly influenced by the inclination of the slope. Steeper slopes were found to cause less ice to form. In the asphalt-lined upper basin with a slope inclined at 1:2,5 of the Geesthacht pumped storage plant at Hamburg, ice jams as high as 3 m occurred in the winter 1962/63. Much less ice formed in the basin of the Vianden reservoir in Luxemburg, where the slope is inclined at 1:1.75.

Ice floes piled up on flood levees may create dangerous conditions. Ice floes of higher kinetic energy may virtually cut across earth structures. Several alternative methods may be used for avoiding or reducing the effect of dangerous jams. The levee embankment should be designed with a mild slope and with a great mass. Small sepths before the levee are favourable since the ice flows get more readily stuck. The ice floes can be deflected effectively by earth structures as well. Where operating conditions permit, the water level should be lowered for the period of ice running in order to arrest the floes on the lower parts of the embankment as described in paper C7.

Design of structures and their protection against ice

For the proper desinging of hydrotechnical structures the phenomena related to winter operation, to the formation, effects and passage of ice must be considered already in the designing stage in the interest of minimizing the potential adverse affects. In finding the general arrangement of river barrages and in fitting them into the river, the considerations related to ice impose frequently more severe restrictions on the designer than the conditions prevailing in ice free periods.

The realisation of conditions favourable for navigation is of special importance in the interest of minimizing restrictions on winter navigation. Depths and transverse currents in the bays usually required in the arrangement of barrages, affect not only the sediment-, but also the ice regime. For favourable ice conditions the power station is preferably arranged on the concave, side, where less sediment is transported. The ice accumulating on the concave side tends to form rather early a solid ice cover.The arrangement of the navigation locks on the side opposite to the power station is favourable, first of all to facilitate the passage of ice.

The example of an unfortunate barrage arrangement is quoted in paper C2, in discussing the flow pattern in the tailwater of the barrage and statements of general validity are made for eliminating adverse flow phenomena.

The length and arrangement of the weir spans present a crucial problem, especially where heavier ice runs are expected. The model tests commonly adopted for estimating flow conditions yield little information on ice-run conditions.

In the winter operation of weirs, navigation locks and other structures, a variety of alternative methods are available for controlling adverse ice effects and the freezing of structures. In the northern hemisphere the structures should be arranged wherever possible in a manner that the closing organs of the weir should be exposed to sunshine from south-east to south.

Diverse heating methods have proved in general effective.Such methods include electric heating, infra-read heating, the circulation of warm air and other methods.

Advanced steel structures and hydraulic hoists are gaining in popularity since they are less subject to freezing than earlier chain hoists.

For keeping weir gates premanently in operating condition it is common practice to release a small discharge continuously over the weir. This, however, involves the wasting of supplies which could be used for more valuable purposes and may not be justified where winter discharges are low.

Considerations to be remembered in designing and operating waterways for winter conditions are pointed out in peper C1. The observation thereof will result in sound solutions especially where strong winds are anticipated. Difficulties and problems in navigation due to the poor design of bridges crossing navigable channels are also mentioned in the paper.

Summary and conclusions

In the foregoing it has been endeavoured to review the effects resulting from the realization and operation of runoff control structures in the winter period. It will be noted that concerning the ice phenomena in winter there is ample theoretical knowledge, research information and operating experience available.

The phenomena related to the construction of major reservoirs and dams are rather less complicated and consequently more intensively explored than the winter conditions related to barrages on the lower reaches of rivers and to navigable canals. As a consequence of high rate industrial development and water uses along the lower river reaches, human interference is more pronounced and variable.

Subsequently a few problems and subjects will be mentioned in which further research is believed to promote the better understanding of phenomena related to ice:

1. Complex heat budget studies along the full length of backwater reaches.

2. The influence of cooling water discharges on the winter regime of rivers and canals.

3. The effect of diverse pollutions on ice formation.

4. The effect of foam and polluting substances on the formation of surface ice and of the ice cover on rivers.

5. Perfection of observation techniques on rivers stronghly influenced by industrial diversions and wastewater discharges.

6. Effect of peak load operation at channel impoundment hydroelectric stations on ice conditions upstream and downstream of the plant.

7. Perfection of model tests on winter ice conditions for obtaining better information on the movement of ice.

8. Studies on the regularities of ice jams at river banks and lake shores. The effect of the shape and dimensions of the ice floes and of slope inclination on ice jamming.

9. Design of slope linings for higher resistance to ice effects.

10. Protection of flood levees and earth structures against ice.

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8

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Contributions to Subject C
EFFECTS OF RUNOFF REGULATION

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BUDAPEST 1974 HUNGARY

INTRODUCTION

Navigation facilities should be designed for good control and safe maneuvering of ships in all weather conditions; the width, depth, and alignment of channels and dimensions of turning areas susceptible to ice formation must be adequate for safe navigation. New work, and maintenance dredging is very expensive and there may be problems involved with the disposal of dredged materials. Therefore, consistent with the requirement that facilities be safe for navigation, their dimensions must be minimal. The problems of engineering design, controllability, safety, and economy of operating the ships in susceptible ice forming areas along with cost of initial construction, maintenance and enlargements of navigation facilities have to be carefully considered. This is to provide for smooth operation and to avoid costly accidents for inadequately designed channels and turning areas, and an excessive cost of constructing and maintaining the overdesigned navigational facilities. There are principally two kinds of channels to contend with: open-type, in wide waters, natural or dredged channels often constituting deepest portion of a bay, river or strait, Fig. 1; restricted-type, confined waters, excavated channel or canal, restricted inland sea extension, canal between islands or between mainland and islands Fig. 2.

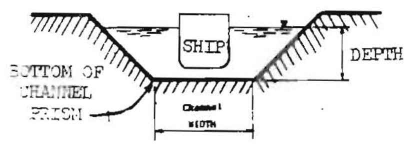

FIG. 1 - RESTRICTED -TYPE CHANNEL

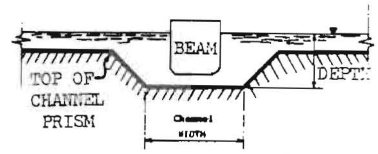

FIG. 2 - OPEN - TYPE CHANNEL

In view of the constant increase in vessel sizes, projects for improving channels and turning areas, straightening of curves and deepening, as well as increasing the widths of the various sections of channels, are being requested by navigation interests. Adequate channels and turning areas which will enable safe execution of all the maneuvers needed by the vessels at reasonable cost are required. It should be kept in mind that proper locations, alignments, and dimensions for channels and turning areas with due consideration of vessel properties and maneuverability, wind, wave, current, ice problems, and visibility are necessary for safety, and to avoid excessive initial and maintenance dredging.

The following factors influencing the design of width and alignment of channels, and dimensions of passing and turning areas required for vessels should be considered: (1) controllability of ships; (2) the human element; (3) forces external to the ship such as effects of winds, waves, ice and currents on the path of ships in the open-type and restricted-type waterways. The effect of depth under keel in channels. The effects of ship location in the channel. The effects of passing ships. The effect of the flow conditions on the ice formation, drift, jamming and breakup; (4) optimum direction of channels; (5) turns in channel direction; (6) channel width in turns; and not discussed here (7) dimensions of turning basins and anchorages.

HUMAN FACTORS AND ALIGNMENTS

In order to avoid grounding or an accident with other vessels or with structures during ice conditions, the captain, pilot, and helmsman should be experienced and possess good knowledge and control of the vessel, know its peculiarities in handling, and be well-acquainted with the layout of the channel. They should be able to make fast evaluations of adverse conditions caused by the ice and be capable of making timely decisions. To counteract effect of the hostile environment, in consideration of human element, the channels should have adequate width and depth and as straight alignment as possible. The channels should enable the control of vessels and their course during icy conditions at a reasonable and safe speed with full regulation of propulsion and rudder, based upon the judgment of captain, pilot, and navigator.

The vessel's course is not a straight line, but normally erratic, even when expertly steered and under very favorable environmental conditions. Its path width amounting up to two beams of the vessel in sheltered waters and without ice, will be much wider while negotiating a channel with an unfavorable layout in bad weather subjected to ice interference.

In open-type channels, a path of the transiting vessel will often be wider than in restricted types beceuse of the action of ice, winds, waves and currents, thus, requiring an increase in width of channel, as the vessel may be compelled to proceed in a yawed condition in order to maintain the course (Fig. 3). Also, floating buoys delineating the channel may be displaced over their anchor locations in direction of the moving ice, wind, waves or current, or their combination, as compared to summer still-water conditions. This effect of displacement of channel buoys would be more pronounced in areas of larger tidal variations, on account of greater required length of buoys' anchoring chains making them slack more at low tides. Moving ice may also submerge, damage or even destroy buoys, may break their moorings or the ice cover may form over buoys rendering them inoperative.

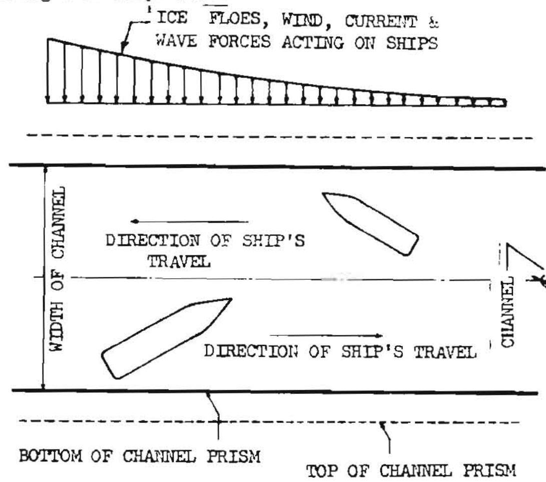

FIG. 3-TWO SHIPS IN AN OPEN TWO-WAY CHANNEL EXPOSED TO ICE, WINDS, CURRENTS & WAVES

The best alignment ofachannel would be a visible straight run oriented parallel to the winds, waves, tides, and currents. Day or night will make a great difference in controlling the vessel and the safety in the channel, along with other factors such as ice, snow, rain, or visibility. They have to be contended with and their effects counteracted by a special type of channel illumination, advising pilots by radio based on radar observations; and resorting to 1-way traffic in 2-way channels.

The optimum direction of channels should be as parallel as possible to the resultant forces external to the vessel to minimize the effects of ice, winds, waves, tides and currents; should be consistent with the involved human element; should allow enough time to enable execution of required maneuvers even in time of impaired visibility. The conditions shall be provided by an adequate design of channels for maintaining full control of vessels under adverse environmental factors. For effects of channel side slopes see (4).

BENDS IN CHANNEL DIRECTION: Turns in channels should, preferably, not be employed unless nature dictated or necessary due to layout configuration or high cost of construction or maintenance to avoid the turns. This is because any change of the channel's direction causes changes in flow and velocities and increases greatly possibility of ice jams in winter as compared to the straight section and makes navigation more difficult. The path of a ship in a bend is wider than in straight sections of the channel and its width tends to increase with an increase in curvature of the bend. Because the direction of the ship constantly changes, moment, side, and hydrodynamic forces develop, making it far more difficult to keep the course in bends than in straight runs. Turning of a vessel in bends has to be made at the proper time to prevent contact with bottom or banks, particularly if the ship proceeds against a current or in ice floes. The locations have to be determined at which the rudder shall be put over for turning. In following curves the vessel gets out of directional ranges and thus keeping its course becomes more difficult. The channel bends could be followed by visual piloting, or using buoys marking edges of channel, shoal waters, protruding objects, or other landmarks.

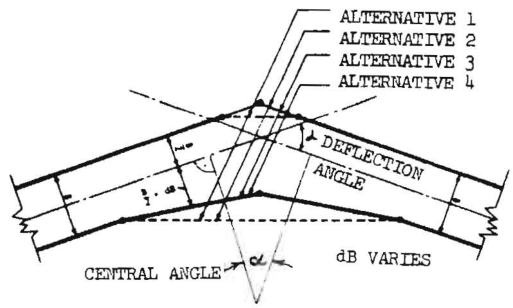

FIG.4-STRAIGHT LINE TURN-ALTERNATE METHODS OF WIDENING

Turns Without Introduction of Arc. - A change from one direction of the channel into another can be accomplished without the introduction of a curve at the intersection of straight runs. A widening by flattening the interior of the channel, a so-called cutting off, may be all that is required. One of the bends in the Panama Canal, La Pita with B = 300 ft (91 m), dB = 227 ft (69 m) and a 31°(deflection angle) has a configuration as shown in Alternative 4 (Fig. 4). Its use for an open-type channel is justified; however, in restricted channels such a change in a cross-sectional area may cause undesirable disturbances in the flow pattern, resulting in a change of hydrodynamic forces acting on a ship. An angle of intersection of about 20° - 30°, may be acceptable, in the writer's opinion, for an open-type channel, and perhaps one-half of this value for a canal.

RADIUS OF CURVATURE & MAXIMUM CENTRAL ANGLE

A vessel making any turn, no matter how small, proceeds usually along a circular curve with a linear velocity constantly changing direction. which in effect is a tangent to the curve. If the change of direction is appreciable or if the maneuvering characteristics of vessels frequently using the channel are poor, an introduction of curve in the channel is warranted. A force has to be supplied, usually by rudder to effect a change in the straight direction of the vessel. The hydrodynamic forces acting on a vessel in a curve are greatly affected because of changing directions and the complexity of the variables involved. For calm water, without ice, the minimum radius or maximum central angle will depend on characteristics of the least maneuverable vessel using the channel, its size and rudder effectiveness, depth of water, and width of the channel. The larger the vessel the smaller the central angle of the curve should be for the same speed of transit and width of the channel. Certain criteria were established by Refs. 1, 2, and others for radii of curvature in turns of the channel; these appear to be predominantly a function of different parameters such as (1) Angle of deflection; (2) the vessel's properties and speed of travel; (3) the channel's characteristics, depth, width, and current; and (4) visibility, obstructions, and aids to navigation.

The radius of the curvature could be related to the deflection or deviation angle (Fig. 5) equal to the central angle between the radii at point of tangents, or to the length of the ship for speeds up to 10 mph. Some rules practiced can be enumerated for curves. According to Ref. 2: (1) Minimum R = 3,000 ft (915 m) for the ship to proceed under its own power; (2) if R=1,200 ft (366 m) - 2,000 ft (610 m), tug assistance is required; (3) if the deflection angle of the curve is larger than 10, the channel should be widened at the inside curve; (4) the tangent length, T, between the consecutive curves, where there are no obstructions, should be 1,000 ft (305 m) or two lengths of the largest ship, 2L, using the channel, whichever is larger; and (5) reverse curves should, preferably, not be used.

According to (1) the radius of curve for vessel speeds 8 mph to 10 mph should be: R = 3 L min (length of the largest ship operating in channel) for central angles smaller or equal to 25°. For central angles larger than 25° but smaller than 35°, R = 5 L min. For central angles over 35°, R = 10 L min.

Other criteria are: R min = 4,000 ft (1,220 m) for ship lengths L < 500 ft (153 m); R min = 7,000 ft (2,135 m) for ship length L = 500 ft (153 m); and R min = 7,000 ft (2,135 m)-10,000 ft (3,050 m) for ship length larger than 500 ft (153 m) but smaller than 700 ft (214 m). If those values for radii cannot be provided, the channel should be widened at the inside curve. Where minimum requirements for radius cannot be met and the channel cannot be widened tugs shall be used.

In practice, certain criteria must sometime be violated as for example in the Chesapeake and Delaware Canal. A 7,000-ft (2,140 m) minimum radius is used in this canal 450-ft (137 m) wide and 35-ft (10.7-m) deep with the central angle varying from 6° to 48°. Two-way traffic is permitted for vessels with a maximum length of 500 ft (153 m) and a beam of 70 ft (21.4 m). The canal's maximum radius is 8,046 ft (2,450 m), used with the central angle of 52°, the largest in the canal.

CHANNEL WIDTH IN BENDS

A vessel, during maneuvering in bends, will deviate from its course toward the banks and across the center line of the channel by varying amounts, appreciably more than in straight runs. (For channel width in straight reaches, see Ref. 3 pp. 41-46.) Therefore, channel bends are usually widened to provide more space for maneuvering. Additionally, in colder climates, vessels have to confront resistance of the ice to be broken, frictional resistance of broken ice elements and their accumulation against ships' hulls. Their difficulties will increase with a decrease of vessels' tonnage. Further free floating blocks and pieces of broken ice move, subjected to action of currents, waves and winds, decreasing the available width of waterways for safe maneuvering of ships. Piling up of broken ice may constitute a danger to navigation requiring still wider channels to accomodate the mass of ice. At times the traffic may be suspended by the process of ice accumulation.

The entire amount of channel widening could be added to the width of the channel in the turn on the inside curve (Fig. 5) or it could be split on the inside and outside curves equally or unequally on both sides of the channel's center line to produce symmetrically or unsymmetrically-widened bends, respectively (5), Fig. 7, Fig. 9 & Fig. 10.

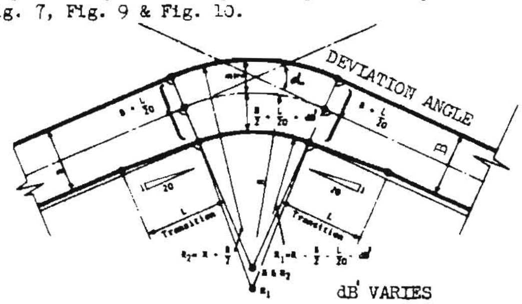

FIG. 5 - UNSYMMETRICALLY- WIDENED TURN
WITH STRAIGHT TRANSITION SECTIONS

In the past, various attempts were made to determine the required widening based on radius of curvature alone as used in the Kiel Canal or the combination of radius with the length of the largest vessel as submitted by De Miranda for PIANC XIV Congress(1) and others. Nevertheless, there is a deficiency in investigative and research programs in providing a sound basis for determination of the width's increase in bends of channels. The tests for various turns conducted for non ice conditions are not conclusive (3), p. 45, Table 3. They show, however, that the 26° parallel constant width bend provided the best controllability in flowing water for vessels in various investigated channels, such as a 40° widened bend, a 26° parallel widened bend, a 13° double bend, and a La Pita bend.

The increase of channel width in bends could be considered as a function of a number of parameters such as the angle of deflection (Fig. 5), length, beam, and controllability of the vessel, radius of curvature, and environmental conditions. To the extent that safety and controllability should be considered, the speed of the vessel and helmsmanship would also have an effect on the required increase of width in bends. For fair weather parameters considered in determining the required increase in width of channel in turns, see Ref. 3, p. 46. The increase of width in Ref. 3, is proposed to be directly proportional to the angle of channel deflection, speed, and length of the vessel, and inversely proportional to the radius of curvature, the sight distance, and the ship controllability. Because of the human elements involved, the widening of bends in the open-type channel as opposed to a restricted-type may even have a higher priority due to the problems of not always having a clearly visible delineation of open-channel boundaries and a tendency of helmsman to relax in wide-open waters more than in canals.

Widening of curves creates transition areas from the regular width in straight runs, to a greater width in curves. The transition causes changes of the flow with resulting asymmetric hydrodynamic forces, as the ship enters varying width sections in transitions, especially when there are currents, in fair weather without ice. Because of disturbances in flow caused by the transition and widening, easement curves may be considered from tangents to bend which should be as gradual as possible to enable a somewhat smoother change from regular to widened sections in bend. If a straight line transition is used, a minimum rate of widening should be about 1 to 20 (Fig. 5).

When a curve is not used, widening of the channel may be accomplished at the inside angle as described in a previous section (see Fig. 4) with four alternate delineations. This method of widening is particularly suited for the open-type channels, where disturbance in flow due to the abrupt change of section would not be as harmful as in canals. During the tests (7) such a 31° bend resembling Alternative 4 of Fig. 4 was installed for an approximate widening from 300 ft (92-m) to 527 ft (161-m). The tests established that a 720 ft (220-m) long tanker would have difficulty in maneuvering around such a bend, although a 450-ft (137-m) long Liberty ship would perform very well with speeds up to 7 knots.

The advantage of using curves versus straight line bends at the intersection of tangents would be: (1) A smoother traffic transition from one direction of a straight-channel section to the next; (2) a better conformance with the flow of traffic; (3) a better flow of water and ice; (4) a good maneuvering performance for a vessel in parallel constant width bends; and (5) less dredging work for a parallel bend as compared to a straightline bend. A disadvantage could be more difficulty in laying out the curved channel and maintaining the dredging alignment during the excavation and maintenance, particularly in open-type channels.

STRUCTURES OVER THE WATERWAY

The location of a bridge over a waterway subjected to icing, in order of preference, should be approximately as listed:

a. At a site enabling construction of a high elevation structure with abutments outside of reach of ice accumulation

b. in the narrowest possible location of the waterway consistent with the free flow of ice

c. it should be constructed only over the straight runs of channels, because, in bend, the direction of ship's travel constantly changes, which calls for wider channel. Visibility may be impaired by the bridge piers or abutments; also, control of the vessel is more difficult than in straight sections of the channel

d. where the conditions as enumerated in a. & b. are not possible or not existent, a dependable protection of abutments, piers and shores should be provided from the effects of ice dam rupture and subsequent flooding (4).

The damage from overflowing, climbing ice, flows increased in volume and velocity, and bursts of water in channels should be prevented and, wandering of navigational channel in the body of a river under the bridge should be forestalled.

The minimum length of the tangent in the channel when approaching a bridge should be increased in comparison with the case where no bridge is involved. The reason for this is that a ship should have a constant, steady-bearing course for a safe passing through the bridge opening. If a drawbridge is involved, a stop of the vessel may be necessary in case the bridge is not open to the channel traffic. For such a situation, widening of the channel and provision of anchorage or mooring facilities, or dolphins at a proper distance from the bridge could be a convenience enabling a ship to wait for the bridge span to open. For a 2-way channel, this would mean provision of two anchorage areas, one on each side of the drawbridge. There must be enough length of tangent available in order to make possible attaining a safe speed of the ship for passing through the restricted width of the bridge opening to provide a good and safe control of the ship during the passage. Similarly, the tangent should also be long enough after passing the bridge to permit correction of heading and position of the ship, often changed in reference to channel center line, because of necessary yawing during maneuvers under the bridge.

CLOSING REMARKS

Waterways are affected by the ice formed; its subsequent movements pose problems for operations, for safety of vessels, for navigation aids, and for structures. Therefore the observation and study of ice conditions, pressures and their influence on navigation aids and structures (possibly by model studies) are necessary in order to institute control of ice formations and its movement, including ice prevention. as much as possible. Also to check and regulate ice movements by directing, guiding, barring, inducing movements, protecting, relieving and properly aligning the channels, service facilities, protective works and navigation aids. This is to decrease harmful effects of ice on the structures, channels and operations by damage or destruction, or ice accumulation preventing waterways from being operative.

Waterfront structures' safety can be accomplished by the ice floe deflectors and by-passes, by constructing shields and, best of all by the proper alignment of channels during the design to reconcile requirements for service, navigation performance, and the prevention of damage from ice for both structures and for berthed vessels. A prerequisite to the maintenance of traffic in ice conditions is to design channels incorporating measures for moving the ice. employment of adequately powered vessels and surveillance of channels enabling prediction of the critical situations.

For an efficient channel layout more information and research is needed on the performance of various ships using the waterway in the various alignments, conditions of flow, freezing and ice characteristics including its strength, thickness, dimensions of broken ice, accumulations, and a prediction of ice jam formation. Reliable navigation aids should be developed.

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IMPROVEMENT OF THE FLOW CONDITIONS IN THE LOWER APPROACH OF A WRONGLY SITUATED LOCK AND DAM

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ABSTRACT

Entrance into the lower approach of the navigation chamber and difficulties with its wrong placing - influence of additional factors. Theoretical and experimental analysis of the difficulties experienced on the example of one lock and dam of the Middle-Elbe waterway. Present findings of the investigation of proposed measures (correction of the bed of the fairway, rectifiers of the water flow, partial discharge of flood waters through the navigation chamber). Possibilities of more general application of some of the investigation results.

SOMMAIRE

L´entrée dans des profonds menées des écluses et des difficultés de son mal emplacement - l´influence des facteurs suivantes.

L´analyse teorique et expérimentale nait de difficulté d´un cas (incident) du barrage de l´Elbe canalisé.

D´après les connaissances des recherches d´expériences des mesures proposés (correction de profondeur de voies navigable, les redresseurs de courant d´eau, passage d´une partie de crue par l´écluse).

Généralisation des connaissances auxquels les efforts de recherche hydraulique ont abouti.

1. OPERATIONAL SHORTCOMINGS IN THE LOWER APPROACHES OF LOCKS AND DAMS - GENERAL

When selecting sites for locks and dams in the design of the river route it must be borne in mind that the placing of the different structures must be compatible with the design of the route for the adjoining river sections. Special attention must be devoted to the entrance into the lower approach of the navigation chamber. In this singularity there occurs a sudden widening of the discharge profile which in turn leads to the occurrence of transverse currents which endanger the entrance of vessels into the approach and causes bedload settlement in the exposed part of the navigation route near the end of the dividing wall. At the same time it is evident that great care must be devoted to the reduction of the ratio between total riverbed width and approach width. DOLEŽAL /3/ critically evaluated the conceptional solutions of the above mentioned consequences which were suggested by quite a number of authors. He evaluated that there have been published only very few results, since these problems are not quite clear and they are difficult both from the aspect of theoretical explanation and practical solution. E.g. : JAMBOR /7/ dealt with the comparison of the opening of the navigation canal into the convex river bank (initial solution design) and the opening of the navigation canal into the concave riverbank (new solution design). Based on hydraulic research results, ČÁBELKA /1/ /2/ recommened the following conception for the layout of the different structures : to place the dam close behind the river bank (which is the most suitable solution for geological, topographical and other reasons); to place the lock with the approaches in the channel so that the approaches open into the concave side of the reverse- sense bends; in addition he recommended for power-generation to use a certain type of effectively designed power plant situated on the other bank than the navigation chamber. To Čábelka's suggestion author should like to add that it appears to him justified to apply the findings on transverse circulation and to open the lower approach into the inflection point, where the concave bend joins the convex one.

Unfavourable from the point of view of lower approach siltation is also the case when at higher discharges the water flows over the dividing wall between the approach and riverbed and fine bedload settles in the space of the lower approach. This last mentioned operational shortcoming can be alleviated either by highering the crest of the lower dividing wall above the flood water level or by implementing the navigation chamber with such gates which would llow to pass part of the discharge through the navigation chamber.

2. OPERATIONAL SHORTCOMINGS IN THE LOWER APPROACH - WRONGLY SITUATED LOCK AND DAM - ANALYSIS OF DIFFICULTIES AND SUGGESTED CORRECTIVE MEASURES

The extreme example of a wrongly situated lock and dam on the Middle-Elbe waterway is the one at Kostelec n.L. (layout of the Middle-Elbe waterway see paper by DOLEŽAL and SKALIČKA, presented at this symposium). To the defect that the lower approach does not open into the inflection point (between the convex and concave bend) but directly into the concave bend must be added the fact that in this place the regulation of the riverbed has not been completed. In the bottom of the riverbed there is a rock which has not been removed to the planned level (the rock reaches with its oval cross-section from the opposite bank roughly into the middle of the riverbed - see Fig.1 and 2) and has caused hydraulically unfavourable velocity distributions accompanied by increased bedload transport and sedimentation in the fairway (at the cutwater of the lower dividing wall).

The required theoretical and experimental investigations were carried out by DOLEŽAL-LIBÝ-SKALIČKA /5/ in parallel on a hydraulic model (depth scale 1 : 40, length and width scale 1 :60) and on an aerodynamic model (depth scale 1 : 200, length and width scale 1 : 300).

For methodological reasons the corresponding experiments were carried out with the following modifications of the models: hydraulic model - movable bed made of quartz sand and movable bed made of ground fruit kernels; aerodynamic model - fixed bed and movable bed made of flour. The study on the hydraulic model was fo-

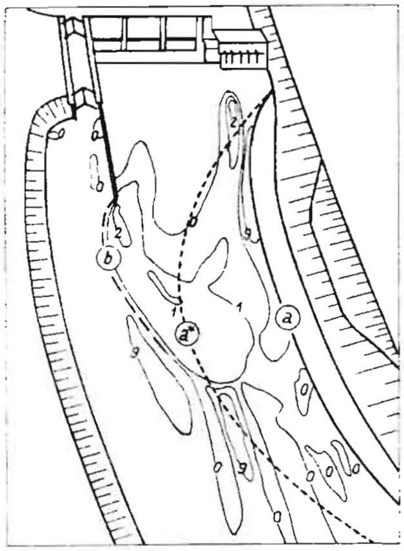

Fig. 1

Illustration of experiments after the removal of the rock along the recommended line (navigation chamber closed; mitring swing-gates)

Explanations:

a* - planimetry of original rock

a - planimetry of removed rock along recommended line

b - enveloping curve of dune planimetry

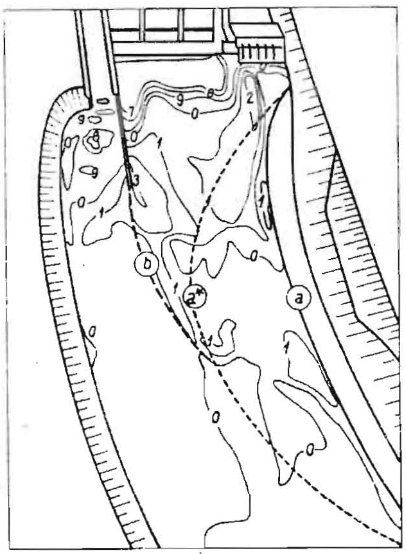

Fig. 2

Illustration of experiments after the removal of the rock along the recommended line (navigation chamber open; simulation of design interference)

Explanations (contd.):
zero contour line corresponds to elevation 160,00 m above sea level
(8 ... 158,00 m above sea level)
(9 ... 159,00 m -"-
1 ... 161,00 m -"-
2 ... 162,00 m -"-).

cused to the investigation of bed forms, the study on the aerodynamic model to the measurement of the velocity field.

The results of the theoretical and experimental study in the lower approach of the Kostelec lock and dam have proved that for the appearance of the dominating bed form (so-called dune), beginning at the end of the lower wall and continuing obliquely downstream accross the fairway , it is sufficient - without removing the rock in the bottom - to attain a discharge of $Q = 300\ m^3/s$, which is markedly lower than the one-year water ($Q_1 = 510\ m^3/s$). In this section of the river Elbe, as URBAN /8/ has shown, this discharge is also the limit for the beginning of bedload movement (the riverbed width at Kostelec n.L. is 90 - 100 m; the regulation is to 600 m^3/s ; the navigation depth after removal of siltation is 210 cm; water depth in the fairway after the sediment removal is 250 cm).

It has been demonstrated that without interference with the present conception of the lock and dam, the most effective way to improve navigation conditions is the removal of the rock sill along the line derived from the study of the velocity field on the aerodynamic model (KUBEC-DOLEŽAL-LIBÝ-SKALIČKA /6/) and confirmed by research on the hydraulic model. It has been shown that the height of the settled bedload in the space of the fairway below the lower approach of the navigation chamber was reduced to a value less than 1,00 m as well as to a partial deviation of the dune from the trajectory.

Interesting were also the results of tests using slab rectifiers of the water current. The use of one or more rectifiers with the slab length of 15 m and height 0,75 m proved satisfactory (their upper horizontal edge was situated 1,00 m below the hydrostatic level of the permanent impoundment in the lower lock and the lower edge divided the distance of the upper edge from the bottom to one half). As far as their planimetry is concerned, the best results were obtained when they were placed near the medium third of the lower dividing wall so that they were directed tovards this wall and formed an angle of 30° with it. DOLEŽAL-LIBÝ-SCHMIDT /4/ informed in their paper that the form of siltations behind the dividing wall had quite different characteristics than in the case of the original state. Even though the single tests were comparable only qualitatively, it can be stated that by using the rectifiers, it was possible to reduce the level of srttled sediments to one half of the original height. About the placing of the upper horizontal edge of these rectifiers 1,00 m below the hydrostatical level of the permanent impoundment it must be added that this was done with regard to the winter regime (a compensation factor was also the necessity to ensure a sufficient effect of the rectifier after the slab height reduction and to prevent the formation of scours behind them).

Simulating the interference into the design of the lock and dam (i.e..when 1/7 of the total discharge Q = 600 m^3/s was passed through the navigation chamber), it was found that a further, this time considerable deviation of the dune planimetry (which starts from the end of the dividing wall) from the trajectory takes place (as can be seen by comparing Fig.1 and 2). It is true that when passing part of the discharge through the navigation chamber yet another dune was produced. This dune is,however, localized closely behind the end of the lower dividing wall and its removal can be accomplished operatively in a considerably shorter time than in the case of the previous dune.

From the observations of results obtained on the hydraulic and aerodynamic models it was found that the dune planimetry (on the hydraulic model) corresponds with the ground plan projection of the dividing area between the transit flow and the cylinder of the backflow (on the aerodynamic model). These findings allowed also to formulate the presumptions that the study of problems of the lower approaches can be carried out in a first approximation on aerodynamic models and only the resulting alternatives were made more precise on hydraulic models. From tests with movable beds in the hydraulic and aerodynamic models it followed that it is possible do attain a certain qualitative agreement in the interpretation of results from aerodynamic and hydraulic models.

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RIVER CHANNEL TRANSFORMATION DOWNSTREAM FROM HYDROELECTRIC PLANTS

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ABSTRACT

Alteration of the natural hydrologic river regime due to hydraulic project construction results in transformation of the downstream channel. Field observation data on channel degradation below 20 major hydroelectric projects in the U.S.S.R. are analysed and generalized. Defined are the most essential manifestation of river channel metamorphosis which are to be incorporated into the design of hydroelectric projects and flow control structures downstream from them.

SOMMAIRE

Les perturbations du régime hydrologique naturel des cours d'eau imputables à la construction des aménagements hydroélectriques conditionnent la transformation du lit en aval de ceux-ci. Les résultats des observations "in situ" sur la transformation des lits en aval de plus de 20 grands aménagements hydroélectriques de l'U.R.S.S. sont analysés et généralisés. On définit les manifestations principales du processus de la transformation des lits qui doivent être prises en considération dans les projets des aménagements hydroélectriques et des ouvrages d'économie hydraulique dans leurs biefs aval.

Construction and operation of hydraulic projects brings about drastic changes in the natural hydrologic regime of rivers. The modifications are manifested chiefly in redistribution of discharges within the year, in a partial or complete deposition of the solid sediment load within the water storage as well as in pronounced fluctuations of discharges and water stages throughout the day due to the adjustement of power generation in case the project incorporates a power plant. Under the impact of these factors the natural river channel is transformed in conformity with the altered conditions. Both for engineering practice and theory it is vital to gain an insight into river channel processes below dams. A reasonably substantiated prediction of probable channel transformations is of major importance in the design of hydraulic projects. Such a forecast is essential in ensuring standard operation conditions for the hydroelectric project, navigation, bridge piers, water intakes and structures downstream from dams. The conventional calculation procedures of downstream channel transformation processes adopted at present do not make allowances for all the aspects of this complex phenomenon with an accuracy adequate for engineering practice purposes. In 1962 at the B.E. Vedeneev VNIIG under M.E. Faktorovich a research program was started with the aim in view of collecting and analyzing field observation data on long-term operation of the downstream pools of upwards of twenty major hydroelectric projects in the U.S.S.R. A part of the generalized findings up to 1963-1964 is already published R. 1, 2 . More recent data on the operation of the projects corroborated and amplified the conclusions drawn earlier and permitted to single out the most essential features of the phenomena which must be included in the design of hydraulic and flow control structures and navigation facilities on regulated river reaches, viz.:

1. During the construction and initial operation stages of the project the river channel constricted by cofferdams, and later on, by structures is subjected to intensive local degradation mainly due to unfavourable hydraulic conditions when construction discharges are passed through the unfinished dam blocks while the downstream protection work is yet incomplete. Channel scour (including that of cofferdam material) may yield a sediment load much in excess of the sediment load much in excess of the sediment transport capacity of the natural stream. Below structures the flow deposits the greater part of its sediment load forming a channel bar, with its crest elevation gradually rising. Local scour decreasing, the growth of the bar slows down, and its crest moves downstream. The channel bar creates downstream from the structure a temporary backing that usually diminishes with time owing to the progressive degradation of the bar, the shifting of the deposition zone downstream, and the general lowering of downstream water stages.

Striking examples of the process are furnished by the construction and primary adjustment-and-operation periods of the Gorki, Kuibyshev and Saratov hydroelectric projects on the Volga river. E.g. aggradation below the dam of the Volga power plant named for V.I. Lenin (the Kuibyshev project) which led to the formation of the Morkvashin channel bar resulted in somewhat higher downstream water stages already in 1956 (the first year of operation). In 1958 the backing due to the bar reached 55 cm. Later step-by-step degradation of the river channel downstream from the power plant and the downward shifting of the sediment deposition zone reduced the backing, and in 1967, i.e. by the time of the construction of the Saratov water storage downstream, it amounted to 10 cm. Scour of the constricted channel of the Volga and local degradation below the Gorki Dam during the construction stage 1953-1956 resulted in the deposition of the washed out material (including that from cofferdams) in the channel of the Volga 7 km below the dam site. The length of the aggradation zone reached nearly 10 km in 1956; the backing affecting the dam structure came up to 25-40 cm.

2. After the cessation or a temporary stabilization of local scour the clarified flow from the water storage induces a progressive degradation of the downstream channel, the zone with the highest aggradation rate shifting further downstream. In the vicinity of the dam river bed degradation becomes predominant. Later on the zone of scour moving in the wake of the deposition zone extends by degrees to embrace a longer reach, while that upstream becomes more stabilized; hence no marked channel transformations occur there, and the sediment load is not materially enhanced. Scouring of the deposited sediment is seen to be effected by a practically sediment-free flow, which after becoming sediment-laden due to scour, redeposits the sediment load lower along the stream bed.

The phenomenon common to the predominant majority of the projects studied is most clearly manifested below the Gorki Dam on the Volga. It can be established indirectly judging by the altered position of the channel bars which limit navigation below the dam (Fig. 1).

3. In the course of degradation and aggradation processes below dams called forth by the altered hydrologic regime the river bends are straightened and the difference between the channel depth in pool and bar reaches lessens. Hand in hand with channel bar degradation and bed aggradation in pools caused by the interaction between the regulated flow and the channel, canalization is furthered by dredging channel bars, with the waste material dumped into pools; the canalized river channel losing the specific features of river morphology. The river reaches below the Tsymlyanskaya, Gorki, Nizhne-Svirsk and some other projects may be cited as examples.

4. River channel transformation processes, which exhibit a tendency towards diminishing of both degradation and aggradation phenomena, and stabilization on long river reaches, are markedly intensified during heavy floods. Augmentation of channel transformations of the Don below the Tsymlyanskays dam after the heavy flood of 1963 recorded in R. 2 was again discernable after the 1968 and 1970 floods whose peak discharges while remaining below the maximum discharges of the 1963 flood were well above the releases and the flood rate of the preceeding years.

5. Lateral erosion, which may be enhanced due to a number of causes in a regulated river, is an essential factor in channel transformation processes. One of the reasons accounting for increased lateral erosion directly below a structure is a change in the course of the flow and the redistribution of the discharges between individual river reaches downstream. Sometimes bank erosion occurs under the action of waves generated by passing ships or waves of different origin, e.g. below the Uglich and Verkhne-Svir hydroelectric power projects the former type of wave effect is observed, while at the Kuibyshev Dam bank erosion clearly noticeable along the whole length of the 3 km reach below the spillway dam is induced by waves due to spillway operation.

Intensive discharge regulation throughout the day is another cause of the growth of lateral erosion. Caving in and landslides along the banks were marked after the passage of water release waves below the Gorki Dam on the Volga, and the Novosibirsk Dam on the Ob'.

This phenomenon seems to develop on account of heavy piping in the bank slope material brought about by the seepage flow directed towards the river channel during an abrupt lowering of water stage.

6. During winter operation of hydraulic projects waves produced by diurnal regulation may cause ice pushes and the formation of heavier ice dams and ice jams as compared to those under natural conditions. They may be associated with downstream channel degradation as was the case at the Nizhne-Svir power plant. Almost every year because of diurnal water stage fluctuations due to power generation adjustment at the Volga hydroelectric plant named for the XXIInd KPSU Congress water release waves set in motion

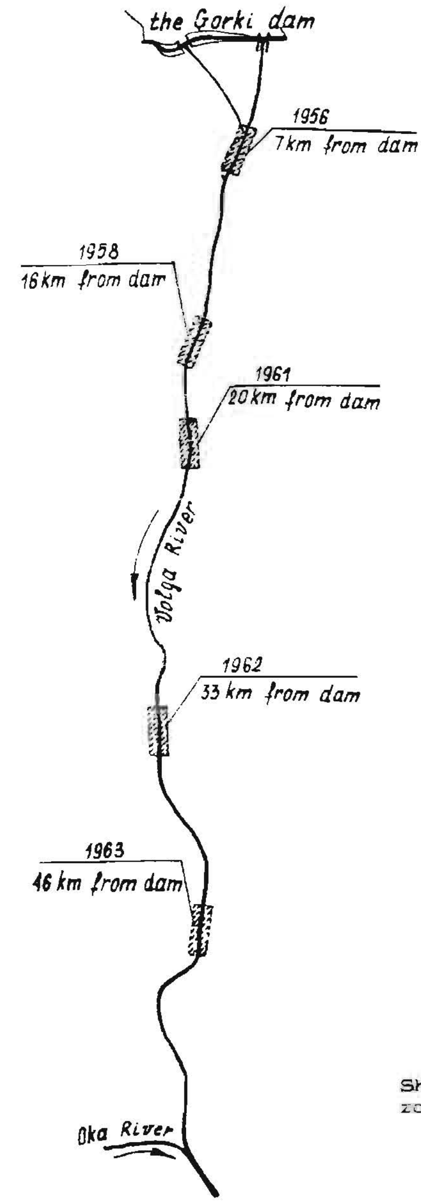

Fig. 1

Shifting of the maximum aggradation zone below the Gorki hydroelectric project on the Volga river ice floes which are rafted forming ice jams and damming the main channel of the Volga. Repeated violent passage of the flow through the left branch brought about heavy channel erosion and almost doubled the cross-section of the flow. Now the discharge capacity of the branch equals that of the main channel.

7. Channel transformations induced by a hydroelectric power plant lead to downstream water stage fluctuations. The latter are characterized by the displacement of the water stage discharge curve with respect to its position at the commissioning of the power plant. Downstream channel transformations in the construction period sometimes result in the shifting of the position of the water stage discharge curve with reference to that of the long-term average curve for the natural river channel already by the time when the plant is to be put into service. Observations conducted revealed varying degrees of variations in downstream water stages almost in every case below hydroelectric plants which are not affected by impoundment downstream. The changes are illustrated in Table 1 and Figure 2 where graphs of water stage fluctuations are presented together with peak water discharges below the Tsymlyanskaya and Gorki plants. The combined graphs clearly demonstrate the intensification of river channel transformation processes (see item 4) and the associated lowering of the downstream stage subsequent to heavy floods.

The data displayed in Table 1 and Figure 2 indicate that the process of river channel adoptation to the altered conditions downstream from a number of large hydraulic projects cannot be viewed as accomplished notwithstanding the long service period. Among the more troublesome consequences of the process is the necessity of increasing water releases to ensure design navigation depth, which may involve the premature drawdown of the water storage, and, finally, the reduction of the part of the hydroelectric plant in covering the peak power load demands especially in low water years. Simultaneously lowering of downstream water stages may disrupt normal operation of downstream water intakes necessitating design changes. Taking into account commonly encountered manifestations of the downstream channel transformation processes listed above in the design of hydraulic projects permits to foretell the probable consequences due to their construction and operation and utilize the foretold changes in the hydrologic conditions of the river to optimize the techno-economic coefficients in the multipurpose operation of water storages.

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Table 1

Water stage fluctuations (cm) with respect to design water stages below hydroelectric projects at mean long-term water discharges

River	Hydroelectric project	Mean long-term water discharge m^3/sec	Put into service	Observation period (yr)	Period of service								
					0	1	2	3	5	7	10	15	By the end of observation period
Volga	Rybinsk	1120	1940	16							-52	-52	-52
	Gorki	1690	1956	15	+26	+26	+26	0	0	0	-16	-35	-35
	Kuibyshev	7620	1955	12	0	+13	+38	+55	+46	+35	+19	–	+10
	Volgograd	7960	1959	11	0	0	-12	-19	-20	-24	-36	–	-42
Kama	Perm'	1630	1954	7	0	0	0	0	-20	-35	–	–	-35
	Votkinsk	1710	1961	10	0	-35	-25	-25	-25	-40	-50	–	-50
Ufa	Pavlovka	336	1959	12	-30	–	-39	–	–	–	-47	–	-47
Don	Tsymlyanskaya	675	1952	19	0	-24	-24	-48	-68	-68	-68	-96	-115
Dnieper	Kiev	1050	1964	7	0	-34	-34	-40	-65	-65	–	–	-65
	Dnieproges	1650	1932	23	–	–	–	–	+6	–	–	-44	-44
Neman	Kaunas	293	1959	12	0	-17	-28	-40	-46	-68	-68	–	-80
Kura	Mingechaur	397	1954	2	-80	-94	-107	–	–	–	–	–	-107
	Varvary	397	1957	10	-40	-58	-66	-80	-92	-92	-112	–	-112
Ob'	Novosibirsk	1640	1957	9	0	-14	-28	-37	-50	-67	–	–	-71
Irtysh	Ust'-Kamenogorsk	629	1953	10						+20	+20	–	+20

Note: 1. Rise in and lowering of water stage are designated by the signs + and –, respectively.

2. For the Mingechaur hydroelectric power plant the data refer to 1951 water stage; for the Varvary to the 1953 one (at a site 20 km below the dam).

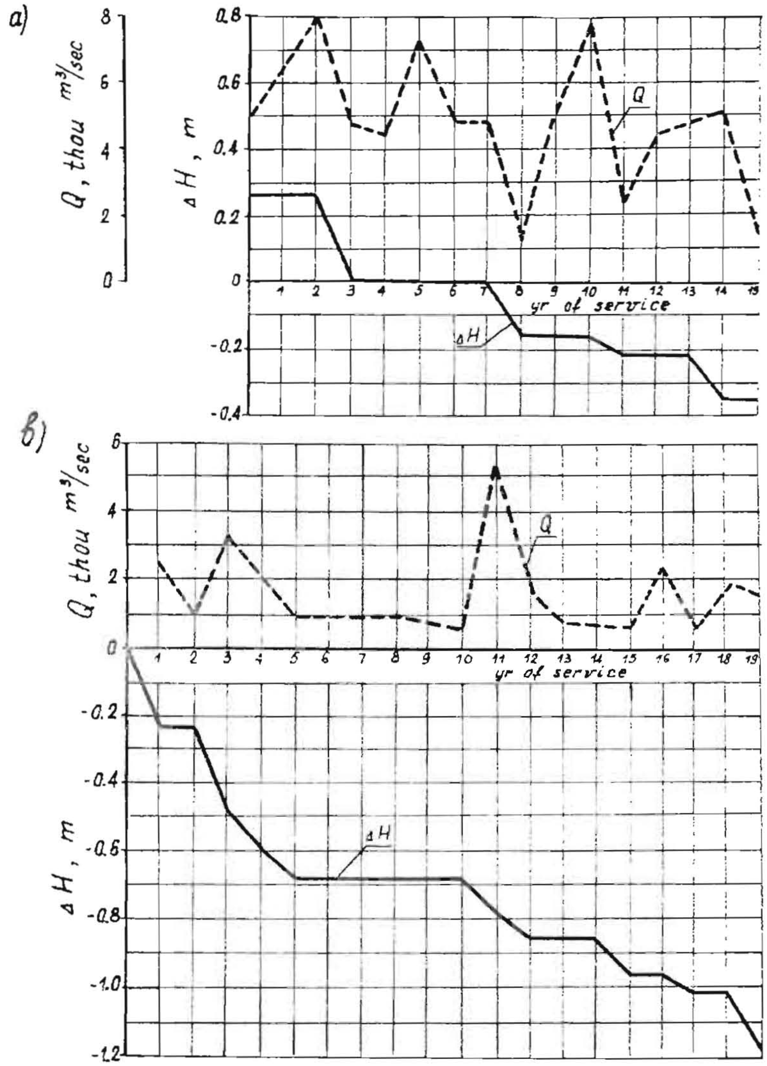

Fig. 2. Water stage fluctuations, ΔH , against design water stages at mean long-term water discharges below the Gorki (a) and Tsymiyanskaya (b) hydroelectric projects and the peak values of discharges, Q

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"EFFECT OF RUN-OFF CONTROL ON ICE REGIME OF RIVERS AND TERMS OF NAVIGATION"

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ABSTRACT

The river run-off control, with the help of the water storage reservoirs, entails considerable changes in the river ice regime. The water freezing and ice break-up processes under dammed conditions, become calmer as compared to the natural river conditions. Within the transient region, however, favourable conditions for ice-jam formation occur.

Analysis of process of the break-up of the rivers and near-by lakes makes it possible to forecast the time the reservoirs are cleared of ice. In the majority of cases the reservoirs are liberated from the ice at a later time compared with the river and it shortens the navigation period.

Creation of dammed stretches allows to conduct the ice-breaking operations and it can stop the ice jam formation in the backwater tail zone and speed up the navigation opening.

Run-off control can facilitate the break-up conditions of the river in the downstream reach. Smooth increase of warm water releases from the reservoir drives away in advance the ice edge down the river, making the ice break-up conditions of the river in the downstream stretch easier.

Changes in Ice and Thermal Regime of Rivers due to Construction of Hydraulic Structures

The ice regime of rivers depends on the climatic conditions of the river basin as well as on the thermal and hydraulic regimes of the river.

The flow control performed by storage reservoirs created by damming the rivers entails changes in hydraulic and thermal and, hence, the ice regimes of the river.

The water flow velocities in dammed stretches of rivers decrease considerably resulting in favourable conditions of freezing of the headwater. Unlike the rivers with flow velocities depending on severe ice conditions associated with formation of ice jams, cream and frazil ice, the process of ice formation in the dammed stretches of the rivers is limited by the surface layers of the water. The autumn ice drift is not observed as a rule. On frazil rivers within the transient region favourable conditions for ice jam formation can occur.

Duration of freesing of the dammed stretches of the rivers depends on the wind regime and air temperature during the period of cooling the water and ice formation.

Ice usually covers all the storage reservoirs located in the regions with frosty winter. Even those created on mountain rivers where frazil ice drift and shore ice can be usually observed are covered with ice.

Reduction of flow velocities in dammed stretches of rivers favours formation of thicker ice cover. Theoretical calculations and field observations show that on storage reservoirs created on lowland rivers the ice thickness is about 15-20% higher as compared to the natural river conditions. On frazil ice rivers with heavy stream current the ice cover on the reservoir can be thiner than under natural river conditions.

Damming of rivers effects on the spring ice break too. In storage reservoirs of a considerable capacity the ice, due to low current velocity, usually melts on the spot. After opening the spillway dam only separate ice floes broken away from the ice field at the dam at the break of the water surface can pass to the downstream pool.

Due to this fact, the storage reservoirs sometimes become free from ice somewhat later than the rivers. In this case ice jams can be formed in the transient region.

The dynamics of ice dams formation in these cases is as follows.

Decrease of water velocity in the backwater zone retards the ice break in the upstream pool. The ice drift starts on the river upstream of the storage reservoir in the transient region. The ice cover forms the ice jams. On frazil rivers frazil ice (ice jams) accumulated in autumn and winter within these zones favours formation of ice dams.

The water levels resulting from the ice dams can be equal to natural water levels of this river. Sometimes they are higher. Increase of water levels due to ice dams entails flooding of riverain territories and damage of riverside structures.

Rossinsky K.I.

Creation of storage reservoirs changes winter thermal regime. In dammed stretches of the river the water temperature in winter is somewhat higher than that of free-flowing water. Under natural conditions the water temperature does not exceed 0.05°, while in shallow storage reservoirs it is 0.3° - 1.0° and in deep ones with slow current - 1.5° - 2.0°.

A river stretch free from ice (polynia) is formed downstream of the dam due to relatively warm water flowing out from the reservoir. The length of such a stretch changes depending on meteorological conditions, water releases from the reservoir, its temperature and the existance of backwater created by a hydroelectric project located downstream.

The spacing between the ice formation start profile and the dam is determined by the following equation:

$$\mathcal{L}_0 = \frac{T_{init} - \frac{C_o}{\alpha_K}}{C_o - S} \gamma \sigma q \qquad \text{where} \quad (1)$$

T_{init} - temperature of water released to the downstream pool; °C

C_o - heat emission of the water surface $\frac{cal}{m^2\ day}$;

α_k - heat transfer coefficient $\frac{tn\text{-}cal}{m^2\ °C\ day}$;

S - heat flow intensity $\frac{tn\text{-}cal}{m^2\ day}$;

γ - water volume weight $\frac{t}{m^3}$;

σ - heat capacity factor $\frac{tn\text{-}cal}{t\ °C}$;

q - specific water discharge $\frac{m^2}{day}$.

In downstream pools of hydroelectric projects with shallow reservoirs the length of polynia ranges from 3 to 15 km, while downstream of deep reservoirs it ranges from 20 to 60 km.

During the cold winter periods the ice edge shifts to the dam but while it getting warmer the edge retreats downstream.

The speed of the ice edge shifting depends on the heat emission of the water surface and spacing between the ice edge and the ice formation start profile is determined by the equation:

$$V = \frac{d\mathcal{L}_K}{dt} = \frac{1}{\beta h}(C_o - S)(\mathcal{L}_K - \mathcal{L}_o) \qquad \text{, where} \quad (2)$$

h - thickness of ice cover, m;

β - latent heat of ice melting equal to 80 $\frac{tn\text{-}cal}{t}$.

The modern experimental and theoretical investigations allowed for working out the technique of engineering calculation and forecasting of the winter ice and thermal regime upstream and downstream of the dam (1,3,4).

Freeze-up and Ice Break-up on Reservoirs

The navigation period on rivers depends on the time of freeze-up and ice break-up in dam pools.

The beginning of ice formation in reservoirs is responsible for suspension of navigation. Ice in reservoirs and under natural river conditions practically begins to be formed simultaneously. An appreciable effect on the time of ice cover formation has the wind: windless weather favours quick ice cover formation throughout the reservoir while windy weather retards freeze-up and the largest and deepest part of the reservoir can be covered with ice from 5 to 30 days later than the river. But even in windy years ice covers the along-shore side of the reservoir , the river harbours, ship moorage areas and the river itself at the same time.

The time when the reservoir becomes entirely free from ice complies with the time of opening navigation. For different rivers and even for different stretches of the same river this time can vary with regard to that under natural river conditions in the spring.

On rivers flowing from the South to the North and in latitudinal direction a break-up appears under dynamic effect of the flood i.e. under "forced" conditions. The beginning of ice drifting on those rivers takes place as a rule after a spring rise of water. The more water level by the moment of the break-up, the more arduous are conditions of ice drifting. Reservoirs on those rivers due to absence of a "forced" break-up in the zone of backwater effect are freed from ice at a later time compared with the river.

On river flowing from the North to the South a break-up appears by disintegration of ice under the effect of spring heat before the flood rise of the water level. Reservoirs on those rivers are liberated from ice simultaneously with the river and in even earlier sometimes.

Spring ice conditions of reservoirs take intervening position between ice conditions of stagnant reservoirs (lakes) and those of natural rivers.

Analysis of particulars of the break-up of rivers and nearby lakes which to a certain extent can serve as analogues of proposed reservoirs makes it possible to forecast the time when the proposed reservoirs are cleared of ice /5/.

For the first time this method of forecasting the time of break-up of the ice in the reservoirs was employed when designing hydroelectric schemes on the Volga river.

A considerable length in latitudinal and longitudinal directions motivates a variety of conditions of the break-up.

The upper sections of latitudinal direction of the flow break up simultaneously under the action of the flood; the lower ones of longitudinal flow break up gradually in upward direction as the weather gets finer.

Apart from features of the break-up the time of crearing of ice is governed by duration of the ice drift at different sections; in the upstream reaches of the river the ice-drift is considerably shorter than that of the downstream reaches.

It is accounted for by the fact that on the lower sections of the river aside from the inherent ice the ice from the northern reaches where the melting of the ice begins at a later time drifts.

According to information available on break-up of the ice in the lakes along the course of the Volga river it has been revealed that the lakes of the upstream reach are debacled 10-15 days later than the river; the lakes of the middle course are debacled simultaneously with the river and the lakes of the lower course are broken 15-20 days earlier than the river.

The reservoirs feature the same sequence as the lakes. The Upper Volga reservoirs are broken 10 days later than the river in the upstream reach /2/. The reservoirs of the middle course are liberated from the ice at the same time as the Volga river on the average before construction of hydroelectric schemes and the Volgograd reservoir. is liberated from the ice in some years earlier than the river.

The experience of reservoir operation shows the validity of forecasts /6, 7/.

The procedure of forecasting of reservoir debacle has been confirmed by observations of the Bratsk reservoir on the Angara river and the Krasnoyarsk reservoir on the Jenisei river at the area of the mentioned reservoirs are flowing in longitudinal direction from the South to the North. Under natural conditions the break-up of these sections of the rivers appears in downward direction along the river course by the break of the ice with the flood at air temperature below zero.

Under conditions of backwater liberation from ice takes place 15 days later than on the river at the average due to the later break-up and absence of ice drift.

Break-up of the ice in the downstream reach is effected by driving-away of the ice edge with hot water from the reservoir without intensive ice drift. By the spring the speed of driving of the ice edge increases due to warm weather and higher solar radiation.

Consequently liberation of the river from the ice in the downstream reach for about 100-150 km takes place much earlier than in the river which is important for navigation. Transit navigation is determined by the break-up of the ice in the reservoir which in its turn shortens the period of transit navigation.

Consequently the beginning of navigation on the rivers depends mainly on the time of breakup.

The problem of extension of navigation period can be settled by the use of different methods accelerating the melting of the ice in reservoirs. The most efficient method consists in the use of ice breakers of different types.

Effect of Flow Control on Ice Conditions of Upstream and Downstream Reaches of Hydroelectric Schemes

Construction of hydroelectric schemes makes it possible to control to a certain extent ice conditions of upstream and downstream reaches.

The presence of the reservoir favours even and uniform ice in the backwatered reach. Moreover as it has been mentioned above on the rivers which are broken up under dynamic effect of the flood as a rule ice gorges and dams are formed which results in serious after-effects.

Even and uniform congelation and break-up of the ice in the reservoir assist the ice breaking operations before the spring break-up which can terminate the formation of ice gorges and start navigation earlier.

Construction of a cascade of hydroelectric stations will eliminate the formation of ice gorges in the transient region of the downstream reservoir.

The flow control together with the proper operation of the hydroelectric station does not impair the ice conditions downstream the structure.

The ice clearing (polynia) in the downstream reaches of hydroelectric stations resulted from releases of relatively hot water is of thermal origin and consequently water temperature in it as a rule is possitive and only at a strong cold snap (when the ice edge is moving towards the dam) supercooled water can appear. Therefore under normal conditions of water releases the ice clearings in downstream reaches involve no difficulties associated with ice formation.

Alteration of water releases from the reservoir exercises an effect on length of the ice clearing; under other similar conditions the increase of water discharges results in elongation of the ice clearing. At even and uniform increase of water discharges the ice edge is gradually melted with warm water of the reservoir and flowing downstream. Thus releases of warm water from the reservoir at even change of discharges provide the early removal of the ice in the downstream reach and facilitate conditions of the break-up. The length of this section varies from tens to 300-400 km depending on determining factors.

For fighting against ice gorges appearing in the area of construction of Ust Ilim hydroelectric project by the increased water releases at the end of the winter from the Bratsk reservoir the ice edge was driven away downstream from the area of the ice gorge formation. Using this method, the ice edge by the spring was driven away by 300-350 m downstream the river, facilitating conditions of the ice breaking in the area of construction of the Ust Ilim hydroelectric project.

Proceeding from the above said, the cascade of hydroelectric projects, from the ice regime considerations, is recommended for construction in downward direction of the river flow and through the hydroelectric project. Then the ice regime, within the reservoir area is improved by the backwater effect

Rossinsky K.I.

and in the areas free from the backwater located between the reservoirs by the warm water releases.

It should be remembered, that the sharp increase of water discharges may results in the ice break-up downstream of the polynia and in the formation of ice jams and ice-hummocks, threatening with the deterioration and flooding of river banks. In certain cases, the ice cover is moved away and the ice drift starts in mid-winter. Hence, the sharp increase of releases should be eliminated.

On small rivers, the artificial increase of winter releases from balancing reservoirs leads to formation of ice hamps and as a result-to undersirable waste of water for ice formation/8/

The correct choice of conditions of water releases from the balancing reservoirs allows to control the water losses for ice formation.

The conditions of water releases are determined from the morphometric river characteristics, i.e. from the specially assigned curve with gradually decreased or constrant releases during the entire winter period.

Under the conditions of backwater effect, from the side of hydroelectric project located in the downstream reach, the influence of water releases upon the ice regime is inconsiderable.

So different influence of water releases on the ice conditions of the downstream reach allows, using the specially assigned conditions of water releases, to control the river ice conditions downstream of the reservoirs.

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FORECASTING OF ICE PHENOMENA ON THE DANUBE

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ABSTRACT

For the winter navigation prediction of first freeze-up and of ice -cover formation both in natural conditions and in artificial reservoirs is essential.

Because of it we concentrated our ef orts on the freeze-up date forecasts worked up on the heat-balance basis complemented by the synoptic-situations method, all this being checked on existing water development with a relatively good agreement rate between calculated and observation values.

SOMMAIRE

La gestion de la navigation dans la période d'hiver exige la prévision du commencement des phénomenes des glaces ainsi que du commencement de la couverture totale de glace sur les flueves dans les conditions naturelles et sur les retennes des oeuvres hydrotechniques.

A cose de cela nous avous dirigé nos études vers la prévision du commencement des phénomenes des glaces basée sur la balance thermique, laquelle nous avous complémentée par la méthode de la prévision a l'aide des situations synoptiques. On a vérifié cette méthode sur les oeuvres hydrotechnique existantes et les résultats out donné une bonne concordance des valeurs calculéés et mésurées.

On the Danube, the biggest river flowing through the ČSSR territory, the basic occurence probability of ice phenomena varies between P = 0,86 and 0,81, and thus poses a great problem not only for navigation, but also for flood-protection. It may be expected that following erection of the planned Gabčíkovo-Nagymaros water complex this problem will reappear in new quantitative and qualitative dimensions.

By analysing sequence and build-up of various forms of ice phenomena we can establish factors influencing the beginning, development and termination of this process. Those are mainly climatic conditions, meteorological situations with hydrological conditions linked to them, hydraulic-morphological characteristics of the river bed, and other conditions created by human activities. Dependent on which factor has been given preference, or taken for the base, various methods of evaluation of ice formation were created.

HEAT BALANCE METHOD

of solution of various water and other questions related to ice regime of streams and reservoirs was minutely elaborated by Soviet scientists. It was partly applied in our conditions too, particularly the forcasting methods by Rymsha and Donchenko /1/, but first of all by Shulyakovsky /4/.

For designing the future Danube water scheme below Bratislava we mean its upstream end which will have to face extraordinarily strong ice effects - we had to determine how would the freeze-up date change as compared with the original state, e.i. the natural river conditions. We utilized the method of calculation of ice phenomena beginning based on the heat balance according to Shulyakovsky.

This procedure is very exacting as far as the data and correct use of physical relations are concerned; neither the laboriousness of the calculation is to be underestimated - taking into account possible number of combinations, use of computer is recommendable/.

Basic relation for calculation of freeze-up date

Conditions for ice formation on the water surface may be determined from the heat balance on the water-air interface

$$A + B = 0 \qquad /1/$$

wherein A is heat transfer, during the cooling period directed towards the surface, and B is resultant of following component heats: radiation balance R which includes global radiation Q and effective radiation J_g , heat consumed or released during evaporation or condensation LE , during turbulent exchange processes P heat related to preciptation falling within a unit of time upon a unit of water surface area.

The vertical heat flux A is a composite function of various mechanical properties of the relevant environment /e.i. water/. For practical calculation needs, it is expressed by the relation

$$A = \alpha\,[\vartheta - \vartheta_{pv}] \qquad /2/$$

wherein for ϑ most conveniently used is the average vertical or profile temperature, ϑ_{pv} being the water surface temperature,and

α the heat transfer coefficient. Then Egn. /1/ may be written as

$$\alpha(\vartheta - \vartheta_{pv}) + B = 0 \qquad /3/$$

If the temperature ϑ_{pv} decreases to the freezing point, it is the moment of beginning of ice formation on the surface. For this instantaneous condition, ϑ_{pv} will be equal 0. Let us denote the remaining quantities α_n, B_n, and ϑ_n, and the freeze-up condition may be expressed through the followin inequality:

$$\alpha_n \cdot \vartheta_n \leq -B_n \text{ or } \vartheta_n \leq -\frac{B_n}{\alpha_n} \qquad /4,5/$$

Inequality /5/ shows that ice phenomena beginning is possible when average profile or vertical water temperature is equal or less than the negative value of ratio $\frac{B_n}{\alpha_n}$. Starting from this relation, for determination of freeze-up date it is necessary to know

- average profile or vertical water temperature ϑ_n ;
- resultant of heat components on the surface B_n ;
- coefficient of heat transfer to the surface α_n .

For this purpose we had to accomplish a detailed analysis of relations necessary for determination of the balance equation members which would best satisfy conditions of our locality, and to introduce some simplifications.

Concretization of the balance relation for the freeze-up date

For the calculation model we assumed fictional existence of the Danube River scheme at Hrušov from as late as 1927 /like the Kachlet Water Scheme in Austria/. We knew the real beginnings of ice phenomena in natural river conditions for all this period. Values to be obtained for the assumed water scheme conditions were considered to be satisfying in case they indicated earlier or the same freeze-up date compared with the really observed one. Calculation results can be found in Tab.1.

In the 1927 to 1964 period there were 5 winter seasons without ice phenomena occurence, and for 1931/32, 1940/41 and 1941/42 seasons we had no data, e.i. we could use statistics from 29 winter seasons /100 %/. From this, 38 % calculation results did not satisfy the introduced condition /no ice phenomena observed, or freeze-up lagging behind the real incidence/.

In 48 % of investigated cases, the fictional calculation model indicated earlier /by 1 to 40 days/ freeze-up date than was really observed, and 14 % of occurence correspond with observation data. By means of this method we determined freeze-up date with 62 % conforming-to-the-condition results. Moreover, we had the possibility to confront the obtained values with observation data from Austrian water developments. Our information being for 1962/63 and 1963/64 only, we bring comparisons but for these two seasons.

On the basis of information and of calculation results evaluation, we have devised freeze-up date forecast for different alternatives of the future Danube water scheme near Bratislava, taking into account various possible hydrological and climatical conditions. We had at our disposal also a hydraulic and air model of the reservoir which enabled us to determine, for our calculation purpo-

Tab.1. Comparison of real and calculated freeze-up date

winter season	real	calculated	calculated freeze-up date	
	freeze-up date		earlier	later
			then real /days/	
1927 - 28	19.12.	17.12.	2	-
1928 - 29	21.12.	19.12.	2	-
1929 - 30	12. 2.	*	-	-
1930 - 31	13. 1.	12. 1.	1	-
1931 - 32	21.12.	&	-	-
1932 - 33	16. 1.	15. 1.	1	-
1933 - 34	4.12-	5.12.	-	1
1934 - 35	10.1.	11. 1.	-	1
1935 - 36	22.12.	23.12.	-	1
1936 - 37	14. 1.	14. 1.	0	0
1937 - 38	28.12.	*	-	-
1938 - 39	18.12.	27.12.	-	9
1939 - 40	1. 1.	2. 1.	-	1
1940 - 41	17.12.	&	-	-
1941 - 42	29.12	&	-	-
1942 - 43	6. 1.	7. 1.	-	1
1943 - 44	@	-	-	-
1944 - 45	25.12.	27.12.	-	2
1945 - 46	7. 1.	9. 1.	-	2
1946 - 47	17.12.	17.12.	0	0
1947 - 48	@	-	-	-
1948 - 49	27.12.	22.12.	5	-
1949 - 50	23. 1.	23. 1.	0	0
1950 - 51	@	-	-	-
1951 - 52	29. 1.	29. 1.	0	0
1952 - 53	9. 2.	8- 2.	1	-
1953 - 54	4. 1.	2. 1.	2	-
1954 - 55	@	-	-	-
1955 - 56	31. 1.	30. 1.	1	-
1956 - 57	21. 1.	18. 1.	3	-
1957 - 58	28. 1.	*	-	-
1958 - 59	13. 2.	16. 1.	28	-
1959 - 60	14. 1.	13. 1.	1	-
1960 - 61	19. 1.	18. 1.	1	-
1961 - 62	@	-	-	-
1962 - 63	15. 1.	6.12.	40	-
1963 - 64	5. 1.	15.12.	21	-

* - not satisfying the condition
& - no data available
@ - no ice phenomena incidence

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ses, the hydraulic characteristics that are to prevail in the real scheme conditions.

Tab.2. Real freeze-up dates on Austrian water developments

Winter	Kachlet	Jochen-stein	Aschach	Ybbs	Hrušov fore-casting
1962 - 63	5.12.	5.12.	in course of erection	6.12.	6.12.
1963 - 64	17.12.	17.12.	17.12.	17.12.	15.12.

METEOROLOGICAL SITUATIONS, AND THEIR INFLUENCE ON THE ICE REGIME

Methods of long-term forecasts of ice formation and break-up on the rivers and reservoirs are based on relation of the freeze-up date to previous atmospheric processes. Influence of the latter may be evaluated with the help of various characteristics which make it possible to comprehend the nature and intensity of atmospheric circulation. Mean values of meteorological elements, e.g. territorial distribution of monthly everage air temperatures, or of athmospheric pressure values and their deviations from the standard may be used.

That is why the Hydrometeorological Institute in Czechoslovakia evaluated weather situations on the basis of synoptic maps for all days of year throughout the period between 1946 and 1965 /2/. We were interested mainly in thermal nature of the situations as characterized by long-range temperature standard of every day /1901 to 1950 period everage/, by the deviation from standard and by daily mean temperature

Thermal nature of particular situation is the best aid in anticipating further development of temperatures, and may be useful for forecast of ice phenomena formation.

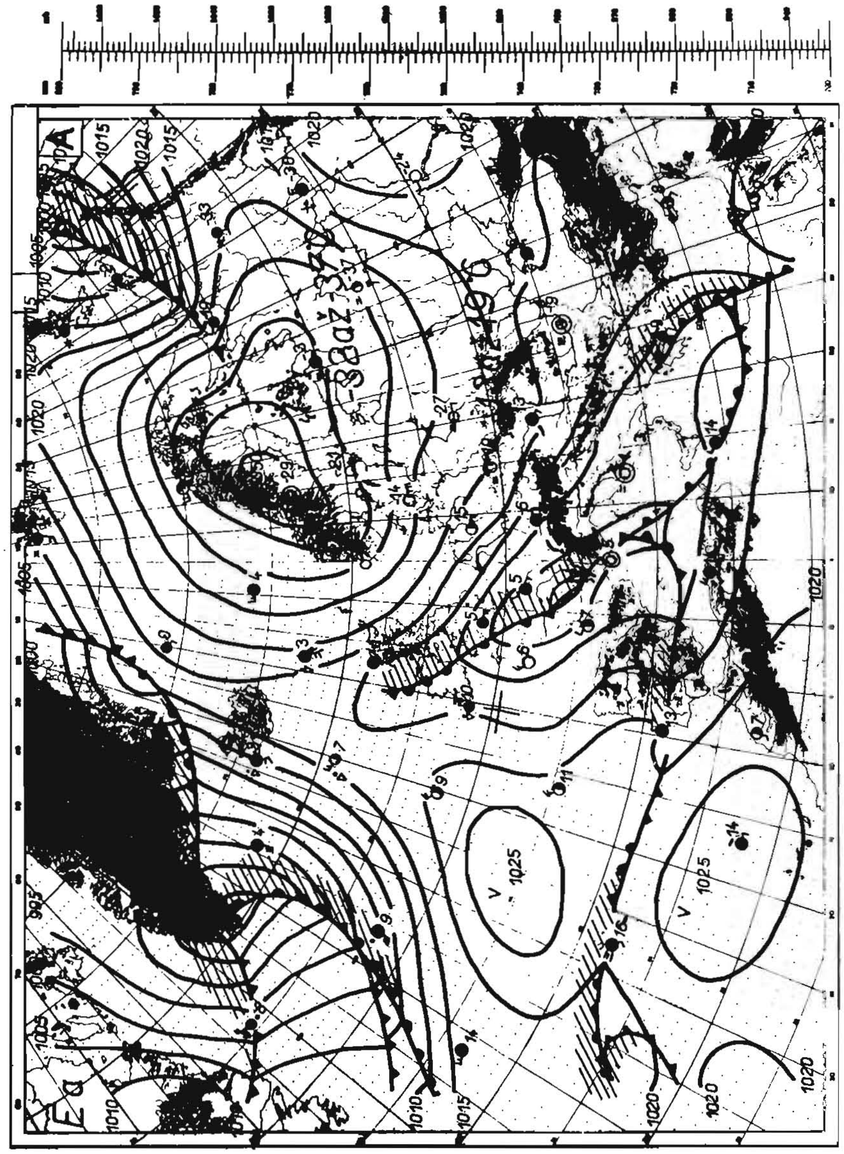
In total, cyclonal situations /65 % days in a month/ prevail over anticyclonal ones /about 35 %/ in the winter periods. But the coldest situations arise during eastern anticyclone /E_a, Fig.1/, of very cold character are also northeastern anticyclone days /NE_a/ as well as days of anticyclone over the Central Europe /A_c/, and of northern and northeastern cyclones /N_c, NE_c/.

Analysis shows that the freeze-up is bound mainly to E_a /23 days/, A_c/18 days/, NE_a and NE_c /8 days each/ situations, all of them being of predominantly cold nature in winter periods.

CONCLUSIONS

By checking the balance methods /Shulyakovsky, Donchenko, etc/ we came to an opinion that after some precision, and assuming right choice of input data, they may be - with the help of computer - really utilized for ice phenomena forecast in conditions created by future water schemes.

Different courses of probability of freeze-up dates, of durations and break-ups of ice phenomena in natural state and in new conditions allow us to judge on what influence would the water scheme exert upon the ice regime.



On the other hand, synoptic situations make it possible to anticipate trends and rates of air mass cooling and heating over relevant areas and, according to our practice, to make estimations of beginning and occurence of ice phenomena on a short-range-forecasting level.

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ICE PILING ON LAKESHORES: WITH SPECIAL REFERENCES TO THE OCCURRENCES ON LAKE SIMCOE IN THE SPRING OF 1973

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ABSTRACT

The paper studies the piling of ice on lakeshores. It is found that ice piling is not a static, but a dynamic event. Ice piling on shore occurs when ice floes, under the action of wind over an open water fetch, ram into the shore or shore-fast ice. The kinetic energy of the ice floes is converted into the potential energy of the ice piles. It is found that a strong wind is not necessary for ice piling. Ice piles will occur under a wind of less than 6.75 m/s if other conditions are favourable. Meteorologically, a shift in wind direction from offshore to onshore is a necessary condition for ice piling. The tarrying of a storm centre over an area will loosen the ice floes and promote ice piling. Ice piling is found to only occur in an [illegible] freezing temperature. Equations are derived which give the width of an open water fetch required for ice piling, the speed of the ice floes for ice piling, the height of an ice pile and the relevant factors. It is proposed that damage to shore line properties may be avoided by encouraging the piling of ice at a point offshore. Field data from the ice piling occurrences on Lake Simcoe in the spring of 1973 are used in the study.

SOMMAIRE

Le sujet de ce rapport est l'étude de l'accumulation des glaces sur les rivages des lacs. Cette accumulation des glaces se révèle être un phénomene dynamique, et non pas statique. Elle se produit lorsque les glaces flottantes (la banquise) dont la vitesse et l'élan sont augmentés par l'action du vent sur l'eau libre, heurtant le littoral, ou la glace qui s'y est déja fixée. L'énergie cinétique de la banquise se transforme en énergie potentielle, en s'accumulant. Pour provoquer l'accumulation, le vent ne doit pas forcément être très violent. Elle peut en effet se produire avec un vent de 6.75 m/s si les autres conditions sont favorables. Du point de vue météorologique, il faut un changement de direction du vent, du large vers la côte. Si une tempête demeure pendant un certain temps au dessus d'une région, la banquise se dessérera, facilitant ainsi l'accumulation. La phénomène ne se produira qu'avec des températures au dessus de 0°. Certaines équations dérivées nous renseignent sur la largeur requise de l'étendue d'eau libre pour provoquer l'accumulation, sur la vitesse nécessaire de la banquise, sur la hauteur de l'accumulation et sur les facteurs déterminants. Pour éviter le détérioration des propriétées littorales, nous proposons une methode qui provoquera de l'accumulation, au large des côtes. les références utilisées proviennent des études faites sur le lac Simcoe au printemps 1973.

ICE PILING ON LAKESHORES: WITH SPECIAL REFERENCES TO THE OCCURRENCES ON LAKE SIMCOE IN THE SPRING OF 1973

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INTRODUCTION

In cold regions, ice forms in lakes and reservoirs in winter. Under certain weather conditions, the ice cover breaks up and the ice floes are driven by wind and current on shore and pile up against the shoreline. Ice piling on shores is a spectacular phenomenon. It also damages shoreline properties. In the spring of 1973, ice piled up on the shores of Lake Simcoe, Ontario, causing considerable damage and public concern.

The present paper will study the structure of an ice pile, the mode of its formation, the meteorological conditions under which ice piling is likely to happen, the factors which affect ice piling and a proposed method to avoid ice piling damage to shoreline properties. Although Lake Simcoe is used to illustrate the phenomenon, the analysis of this study should be generally applicable.

Little is known quantitatively on the piling of ice on lakeshores and seashores. A descriptive paper on ice piling against coastal structures on seashores and lakeshores was written by Bruun and Straumsnes (1970). They reported that a height of 10-15 m may be reached by an ice pile under the action of strong wind and current and that a sloped bottom favours ice piling. Additional work was done by Bruun and Johanneson (1971). They reaffirmed the previous findings by Bruun and Straumsnes and reported an observation on the building up of an ice pile in half an hour. In their paper, Bruun and Johanneson considered that the ice first breaks into ice floes, which, when pushed by wind and current against a shore, pile up into piles. They drew an analogy between the piling up of rubbles in front of a bulldozer and the piling up of ice. Allen (1970) considered the piling of ice is controlled by the thrust force on the ice floes. From the static equilibrium between the thrust force, the weight of the ice sheets which form the pile and the friction force, he derived an equation which relates the height of an ice pile to the thrust pressure, the thickness of the ice sheet, the density of the ice pile and the base angle of the pile. As it will be seen from the present study that ice piling on lakeshores is a more complicated phenomenon than simple static piling. More has yet to be done for fully understanding the ice piling problems.

ICE PILING OCCURRENCES ON LAKE SIMCOE IN THE SPRING OF 1973

1. Geographical Characteristics of Lake Simcoe

Lake Simcoe (see Fig. 1) is a lake of 743 km^2 located approximately 50 km north of Toronto, between Georgian Bay of Lake Huron and Lake Ontario. The maximum length of the lake is 47 km approximately. The depth of the lake is from generally less than 18 m at the northeastern end to 40 m at Kempenfelt Bay at the western end. The depth at the southern Cook Bay is shallow at generally less than 15 m. At the central part of the lake, the depth is from 18-30 m. The lake level is 216.5 metres above sea level. The land immediately surrounding Lake Simcoe is less than 305 m above sea level. About 48 km to the north-north east and about 48 km to the south-west of Lake Simcoe, the lands rise to an elevation of 305-610 m above sea level.

The northeastern shore of Lake Simcoe is mature. There are many beaches and shoals along the shore. The southwestern and the northwestern shores are younger and beaches and shoals are not so evident.

Lake Simcoe is a resort area for Toronto residents and numerous cottages are built along the shoreline.

Ice forms over Lake Simcoe every winter reaching the maximum thickness of about 0.5 m by the end of February or early March.

2. Description of the ice piling occurrences on Lake Simcoe in the spring of 1973

Based on the information obtained from field inspections and interviewing local residents, the ice piling events on Lake Simcoe in the spring of 1973 may be reconstructed.

The first ice piling occurred on March 10. The exact time of ice piling could not be established. On that day, it was very foggy in the morning. Within the limit of visibility, the near shore region of the lake was observed to be completely ice covered. A continuous crack approximately [illegible] km from the shore was noted off Eight Miles Point parallel to the shoreline. Under the action of onshore winds, ice piled up against the northwestern shore from Simcoeside to Eight Miles Point, with Simcoeside being the more affected area. The height of the ice piles was not recorded but was believed to be low. Following the ice piling, an open water gap was noted off the shore beyond the shore-fast ice. During the day, the wind also drove the ice sheet from the southeastern shore. At Beaverton, an open water gap of approximately [illegible] m between the ice sheet and the shore was created. Ice fishermen were stranded on the ice and had to be rescued.

The next ice piling occurred on March 11 at 1300 hours at the Oro area. At Oro park, local residents noted ice piles of [illegible] m height. Before the ice piling, the nearshore region of the lake was covered by an ice cover of about 20 cm thick. The ice piling process was completed in 10 minutes.

The third ice piling was a major one; it began on March 16 at [illegible] hours and ended on March 17 at 0130 hours. The area affected was the northwestern shore from Eight Miles Point to Big Bay Point except the sheltered areas. On March 15 and during the daytime of March 16, the weather was warm and the wind blew from the westerly and south-westerly directions. The lake appeared completely ice covered except for a narrow open water gap of about [illegible] m along the lakeshore. The gap was closed as wind shifted to the opposite direction. Ice piling followed the closing up of the gap. Again the ice piling was observed to be a fast process. An ice pile was built in a matter of a few minutes. As a result, ice piles of 9 m height were built up at Eight Miles Point and at Big Bay Point. The ice ran up on shoreline properties, overturned boat houses and boat ramps and damaged some cottages (see Fig. [illegible]). During the ice piling, the wind had temporarily shifted to the northerly direction before shifting back to the northeasterly direction. This shifting of wind produced two rows of ice piles on the shore of Eight Miles Point (see Fig. [illegible]). On March 17, the wind shifted to the northwesterly and the westerly directions. The ice sheet was pulled away from the shore, leaving the ice piles behind and created an open water gap of about 0.75 km wide.

The fourth ice piling occured on March 31. On that day, local residents at Eight Mile Point noticed a large open water gap about 760 m wide along the shore. In the afternoon, the ice sheet began to move inshore. At that time, the wind did not appear to be strong and there was little wave action in the lake. The water gap was closed in about an hour. The ice then began to pile up by rafting (see next section) from 1630 to 1730. The rate of growth of the ice piles was approximately 13 cm/min. When an ice sheet slid over another ice sheet, it moved smoothly without breaking and piling until it hit an obstacle, then it rafted again and started to pile up. Ice rafting and overriding (see next section) were observed during the evening. At one point it was seen that at a distance of 30 m from shore, ice piled to 10 layers at approximately 3 m above water and at a distance of 46 m, ice piled to 3 layers at approximately 1 m above water. Ice piling continued to take place overnight. Ice piles more than 9 m height were seen the next morning (see Fig. 4).

PROCESS OF ICE PILING

Based on field inspections and reports from local residents, a typical ice piling on the shore of a lake may be summarized as follows: Ice piling usually follows the shifting of wind from the offshore to the onshore direction. Before ice piling, the nearshore region of the lake is usually covered by a shore-fast ice sheet the width of which may be from the order of 30 m to the order of 1.6 km in magnitude. The lake itself would also be ice covered. The ice floe on the main part of the lake can be quite large. An open water gap exists between the shore fast ice sheet and the main ice body on the lake. The open water gap is created by the preceeding offshore wind. As the wind shifts to the onshore direction, the main ice on the lake drifts towards shore and gradually closes up the open water gap. (On the other side of the lake, the ice sheet is pulled away from the shore and creates an open water gap.)

As the main ice drifts onshore, the shore fast ice is also pushed by the wind against the shore. Ice ridges sometimes form as a result of compression. As the wind strengthens and the lake becomes more agitated, longitudinal fractures in the direction of the wind begin to develop. The spacing of the longitudinal fractures is of the order of magnitude of one hundred metres. The fractures divide the shore fastened ice into ice strips. Under the action of wind, the ice strips buckle and crack into ice floes. The fracturing and breaking of the shore fast ice happen only during the first ice piling on a lake or after a cold spell when the shore fast ice re-freezes as a continuous sheet. When the shore fast ice is narrow, the fracturing and cracking of the shore ice do not occur. When the main ice body from the lake rams onto the shore ice, beside the further breaking down of the shore ice and the main ice into smaller floes, the ice floes begin to telescope and pile up in the following 3 ways:

1. Overriding - The upwind flow rides on the downwind floe (see Fig. 5a and Fig. 6). This mode of telescoping is the most common when the wind is strong and the surface of the water is agitated. The overriding ice floe slides smoothly over the underridden ice floe until it is stopped by the shore or other obstacles, usually an ice block frozen to the ice sheet or an existing ice pile, it then begins to pile up. When an ice floe rides up an existing ice pile, it remains smooth and intact except for small fractures. When the ice floe overshoots the pile, the overshot part breaks off, disintegrates into small ice cubes and falls to the onshore side of the pile (see Fig. 7). Some of the ice cubes fall to the offshore side of the pile and accumulate at the base. These broken ice pieces, being repeatedly pushed up the pile by new ice floes and falling down the slope again, become much finer than the ice cubes on the onshore side. The quantity of the broken ice pieces on the offshore side of an ice pile is

small and the smooth ice floe surface can be easily exposed by scraping the broken ice pieces off the surface by hand.

2. Undersliding - The upwind floe slides under the downwind floe (see Fig. 5b) until it meets the previous ice floe. The downwind floe then appears to be sitting on a large piece of ice floe. The undersliding of ice floes does not occur as often as the overriding case. In the Lake Simcoe case, there was less than one undersliding floe for every 10 overriding floes. Undersliding possibly results when the downwind floe of two contacting ice floes is momentarily lifted up by wave action and the upwind floe slides under it. It is interesting to note that when undersliding occurs, the piling up seems to come to an end (see Fig. 8).

3. Rafting - The drifting ice from the lake first presses against the shore fast ice, then the contacted edges buckle, turn upwards and break off. The upwind ice floe will then override the downwind floe with the broken ice piece sandwiched between them (see Fig. 5c). The overriding floe slides over the shore fast ice easily until it meets an obstacle, then it either rafts again and continues to proceed or begins to pile up. Rafting is the predominant mode of ice floe telescoping when the wind is not strong and there is little wave action in a lake. On Lake Simcoe, rafting was observed on March 31 with the incoming ice floes from the lake moving at a velocity of approximately 23 cm/s. It was also observed that the broken ice pieces in front of an ice pile formed by rafting are fine in size (see Fig. 4). This is understandable as the broken off ice pieces from rafting are ground between two ice floes as the overriding ice floes slide forward.

Piling can occur by all the above modes simultaneously, but generally one mode will predominate.

An ice pile usually consists of a gentle apron and an abrupt piling. Measurements at Lake Simcoe showed that the gentle apron slope of an ice pile is of the order of 1 in 300. For the ice pile itself, the maximum slopes measured were about 45° and the common slope was about 30°. The onshore and offshore slopes of the ice piles were about the same.

METEOROLOGICAL PARAMETERS WHICH AFFECT ICE PILING AND THEIR PHYSICAL INTERPRETATION

To determine the meteorological parameters which affect the ice piling on Lake Simcoe, the wind and temperature data from Malton International Airport weather station and Muskoka Airport weather station were plotted against time as shown in Fig. 9. The plotted weather data were hourly averages. The Malton and Muskoka stations are approximately 160 km apart along an approximately south-north line with Lake Simcoe midway between them (see Fig. 1). It is seen from Fig. 9 that weather data at the two stations follow a similar trend and consequently the weather data may be applicable to the ice piling on Lake Simcoe. Greater fluctuation in velocity are recorded at Malton than at Muskoka. This may be due to the effect of lake breezes from Lake Ontario and the urban environment. To filter the local weather effect, for the Malton data, the wind direction and speed were not plotted if the wind was less than 2 m/s and showed great fluctuation. The weather data used were for the periods of March 5-20, 1973 and March 26 - April 6, 1973. In the first period, the first three ice pilings occurred and in the second period, the fourth ice piling occurred. The time of the ice piling occurrences is also shown in Fig. 9. As the exact time of the first ice piling was not known, two dotted lines are drawn to indicate the period in which the first ice piling happened.

Before attempting to derive a general rule for ice piling, the meteorological conditions associated with each ice piling are noted and their physical interpretations are made as shown below:

1. First and Second Ice Pilings, March 10 and 11

It is seen from Fig. 9 that before the ice piling, the air temperature over Lake Simcoe had been above freezing for several days except for short intervals. From the beginning of March 7 to noon, March 9, the wind had been continuously shifting from the southeasterly direction anti-clockwise back to the southeasterly direction. On the day of the ice piling (March 10), immediately prior to the event the wind over Malton and the wind over Muskoka showed great differences both in speed and direction. Ice began to pile up when the wind shifted to the easterly direction and began to increase.

From a meteorological point of view, the gradual shifting of wind direction over an area means the passing of a storm centre over the area. The wind data from March 7 to March 9 thus indicate the passing of a storm centre over the Lake Simcoe area. The great difference in wind direction and speed on March 10 and 11 indicate the tarrying of the storm centre over the Lake Simcoe area. Thus, one comes to the conclusion that the passing of a storm centre and the tarrying of the storm centre over Lake Simcoe was the reason for the first and second ice piling occurrences on Lake Simcoe.

One may now look at the matter from an angle of dynamics. From the weather plot, one notes the striking feature that the ice pilings did not occur when the wind was the strongest or was blowing persistently in the onshore direction. It is seen from Fig. 9 that from March 5 to 7, although strong wind had been blowing persistently in the easterly and the southeasterly directions and at times reached a speed of 12.5 m/s, no ice piling was reported. Thus, ice piling obviously is not a static consequence of ice sheets being pushed by wind and current against the shore. On the contrary, ice piling is a dynamic event. Ice piling occurs when ice sheets, which have attained a sufficiently high velocity under the action of wind and because of their great mass possess great momentum, ram onto the shore-fast ice. Part of the kinetic energy of the in-coming ice sheets is used in breaking the shore ice and the ice sheets themselves, part is used to overcome friction and part is converted into potential energy by piling up on the shore. In fact, only by such a dynamic event, can heaps of ice be built in a matter of a few minutes.

With the above understanding in mind, we may now examine the first two ice pilings on Lake Simcoe from a dynamic point of view. Following a persistent southeasterly wind, the wind shifted gradually anti-clockwise 360° back to the easterly direction. This shifting wind loosened the ice sheets from the shores. From 0000 March 8 over a period of about 20 hours, the wind blew in the northwesterly direction and drove ice sheets from the northwestern shore of the lake. As the wind shifted back to the easterly direction comparatively quickly, the ice sheets were moved back again towards the northwestern shore. The existence of an open water fetch or gap caused by the preceeding northwesterly wind permitted the ice sheets to gather speed. During the tarrying period of the storm centre, although the ice floe did not gain noticeable additional speed, sufficient energy was imparted by the wind to maintain their velocity. The arrival and ramming of the moving ice sheets onto the shore thus caused the first ice piling from Simcoeside to Eight Mile Point. Another patch of ice floes, moving towards Oro Park over a longer fetch of water and under an increasing wind, built up a greater momentum and piled on the Oro shore to a greater height.

It is seen from Fig. 9 that a strong wind is not necessary for ice piling. If the open water fetch is sufficiently long, ice floes with a velocity sustained by a wind of 4.5 m/s to 6.75 m/s is sufficient to produce ice piling.

One can easily see that no ice piling will occur when the wind shifts before the ice floes gather speed and hit the shore. It is also clear that if the open water fetch is short, a strong wind will be required to impart a sufficiently high velocity to cause ice piling. Similarly,too low a wind will never produce a high enough velocity for the ice floes to pile up although the open water fetch is long. As velocity is the determining factor, ice piling should also occur when two ice sheets moving at different velocities ram into each other. Ice piling will also occur in a windless day if the ice floes have acquired sufficient momentum from an earlier wind. In Lake Erie, a huge ice sheet of approximately 1.6 km x 1.6 km was seen from a helicopter ramming onto the shore on a windless day and built ice piles up to 4 m high in a matter of minutes (Foulds 1973).

2. Third Ice Piling, 2300, March 16 to 0130, March 17, 1973

For this ice piling occurrence, it is seen from Fig. 9 that prior to the ice piling, the wind showed a continuous shifting in direction from the easterly direction anti-clockwise back to the northeasterly direction. From 1300, March 15 to 1300, March 16, the wind blew persistently in the westerly and the northwesterly directions. The wind drove the ice off the northwestern shore and created an open water fetch. As the wind quickly shifted to the northeasterly direction in the night of March 16, the ice floes were blown towards the shores with a sufficiently high velocity and produced major ice piles at Eight Mile Point and Big Bay Point. It is noted from Fig. 9 again that when the ice piling occurred, the wind was only slightly more than 6.75 m/s.

Following the ice piling, the wind shifted to the northwesterly direction and blew at a great strength up to 13.5 m/s for several days. However, no ice piling was reported on the southeastern shore. A study of the temperature records shows that over this period, the air temperature was below freezing. The ice floes therefore could have been frozen to the shore or frozen to each other. In fact it is seen from Fig. 9 that ice piling stopped as soon as the air temperature dropped to the freezing point. This indicates that the friction between ice floes increases greatly as soon as the temperature drops to freezing. Thus, ice piling is not likely to happen when the temperature is below freezing.

3. Fourth Ice Piling, 1630 to 1700, March 31

It is seen from the weather plot that before the ice piling, a storm centre stayed over the Lake Simcoe area for several days as shown by the great difference in wind strength and direction over the Malton and Muskoka weather stations. The fluctuation in wind speed and direction associated with the storm centre loosened the ice floes on the lake. Immediately prior to the ice piling, from 1000 to 1400, March 31, after blowing several hours in the northwesterly direction, the wind shifted quickly to the easterly direction, indicated the moving of the pressure centre out of the region. Ice piling began not long after the wind had shifted to the easterly direction at 1630 hours. Again it is seen from the weather data that the ice piling occurred at a wind velocity of about 6.25 m/s. Although the wind increased to twice this strength later and remained blowing in the same direction, no further ice piling occurred.

Based on the above discussions, one may draw the following conclusions:

1. Ice piling is not a static, but a dynamic process. Under the action of onshore wind, ice floes pick up sufficient momentum over a length of open water fetch. When the moving ice floes ram onto the shore or the shore fast ice, ice piling occurs. During ice piling, the kinetic energy of the ice floes is used to overcome friction, to break ice sheets and to be converted into potential energy of the ice piles.
2. A strong onshore wind is not a requirement for ice piling on lakeshores. Ice piling can occur at a wind speed of less than 6.75 m/s when other conditions are favourable.
3. An open water fetch is necessary for ice floes to gather up sufficient speed for ice piling. A shift of wind from the offshore direction to the onshore direction over a short period enables the ice floes to use the whole open water fetch for speed gathering and consequently promotes ice piling.
4. The fluctuation of wind strength and direction and the shifting of wind help to loosen the ice floes and promote ice piling.
5. Ice piling will not occur at below freezing temperatures.

DYNAMIC ANALYSIS OF ICE PILING

With the physical process of ice piling in mind, we may now proceed to study: (1) the relationship between the speed of the ice floes, the size of the ice floes, the strength of the wind and the width of the open water fetch, and (2) the relationship between the height of an ice pile, the size of the ice floes and the velocity of the ice floes.

1. Relationship between the speed of an ice floe, the size of the ice floe, the strength of wind and width of the open water fetch

From the preceeding sections we understand that an open water fetch is necessary for ice floes to gather up speed before piling on the shore. Here we shall study the width of the open water fetch and the time required for an ice floe to obtain the critical velocity for ice piling.

For an ice floe of unit width, length L, thickness T and moving at a velocity V_i towards the shore under an on-shore wind V_w (see Fig. 10), the wind drag and the water drag acting on it are respectively

$$D_a = C_a \frac{\rho_a}{2} (V_w - V_i)^2 L \qquad (1)$$

and

$$D_b = C_b \frac{\rho_b}{2} V_i^2 L \qquad (2)$$

where ρ_a is the density of ice, ρ_b is the density of water, C_a is the drag coefficient between air and the ice floe and C_b is the drag coefficient between water and the ice floe. In writing eq. (2) it is assumed that there is no current component in the on-shore direction. Since the speed of an ice floe is much less than that of the driving wind, V_i may be dropped from eq. (1). Using the drag coefficients of Brunn and Johanneson (1971) and defining the onshore direction as the positive x direction lead to the following equation of motion for the ice floe:

$$V_w^2/3600 - (dx/dt)^2/4 = (\rho_i N T/9.8)\, d^2x/dt^2, \qquad (3)$$

where ρ_i is the density of the ice floe and N is the coefficient of virtual mass due to the moving water. The above equation does not include the form drag force which is negligible since the thickness of an ice floe is much less than its length. With the numerical constants used, eq. (3) is in the kg-m-s units. If the position at which the ice floe has zero velocity is chosen as the origin of x, eq. (3) may be integrated and gives

$$\ln \{(1/30 + V_*)/(1/30 - V_*)\} = t_*, \qquad (4)$$

where V_* is the non-dimensional velocity of the ice floe and t_* is the non-dimensional time and are defined respectively by

$$V_* = V_i/V_w = (\frac{dx}{dt})/V_w \quad \text{and} \quad t_* = t/(60N\rho_i T/9.8V_w) . \qquad (5)$$

In obtaining the above result, the wind speed V_w is assumed constant. Based on eq. (4), V_* is plotted against t_* as shown by curve A in Fig. 11. The numerical integration of curve A gives the non-dimensional distance of travel

$$x_* = \int_0^{t_*} V_*\, dt_* = x/(60N\rho_i T/9.8). \qquad (6)$$

x_* is also plotted against t_* as shown by curve B in Fig. 11.

As shown in Fig. 11 that the non-dimensional velocity of the ice floe asymptotically approaches 1/30 as t_* increases. This in fact is expected as it is seen from eq. (3) that when the acceleration term approaches zero as time progresses, the velocity of the ice floe approaches 1/30 the wind velocity. It is seen from curve A that when $t_* = 3$, the ice floe attains 90 per cent of its terminal velocity. Thus the time needed for an ice floe to gather 90 per cent of its terminal velocity is approximately

$$t = 3/(60N\rho_i T/9.8V_w) = 18.5\ N\rho_i T/V_w . \qquad (7)$$

Using a coefficient of virtual mass of 2, a density of ice of 920 kg/m^3, for an ice floe of 0.3 m thick under a 6.75 m/s wind, the time required for the ice floe to obtain 90 per cent of its terminal velocity is calculated from eq. (7) to be 25 minutes. From curve B, it is seen that when this velocity ($V_* = 0.03$) is attained, the non-dimensional distance travelled by the ice floe is $S_* = 0.044$. In dimensional form, the distance travelled is

$$x = 0.044\ (60N\rho_i T/9.8) = 150 \text{ m},$$

when the same value of N, ρ_i is used.

The above calculated time and distance would tend to be underestimated as the time for stopping the offshore motion of the ice floe by the onshore wind, the time for initially loosening ice floe and the mutual interference of neighbouring ice floes are not considered. A factor of 2 probably will be sufficient to take the above factors into account.

The above theoretical calculations are supported by the Lake Simcoe observations. As mentioned in the earlier parts of the paper, an ice piling occurred almost immediately following the shift in wind direction from off-shore to on-shore and the width of the open water fetch prior to the events was of comparable dimension to the calculated width.

2. The building of an ice piling by moving ice floe

The piling up of ice floes is a process of energy conversion. For a moving ice floe of length L, thickness T and velocity V_i approaching an ice pile (see Fig. 12), the work and energy equation may be written as

$$(N\,\rho_i TL)V_i^2/2 = W_f + (\rho_i g H^2 T)/(2\sin\beta) + W_c \tag{8}$$

where the left side term of the equation is the kinetic energy of the ice floe, N again takes into account the virtual mass of the moving water, W_f is the work to overcome friction, the second term on the right is the potential energy of the piling up part of the floe and W_c is the work required to fracture the ice floe. Symbol g is the gravitational acceleration and is equal to 9.8 m/s^2. The above equation stands whether the oncoming ice floe hits the ice pile directly or it hits some other loosened ice floes in front of the ice pile first and forces them to pile. However, in the latter case, telescoping may take place and some of the kinetic energy will be used to overcome the friction between the telescoping ice floes. W_c is difficult to estimate and may be dropped from the above equation by making allowances to the friction term. To find the work for overcoming friction, from Fig. 12, one has

$$W_f = \int_0^{\frac{H}{\sin\beta}} f\,\rho_i\, gTS\cos\beta\, dS = \frac{1}{2}\, f\,\rho_i\, gT\,\frac{\cot\beta}{\sin\beta}\,H^2 ,$$

where f is the coefficient of friction. The substitution of the above expression into eq. (8) and noting that the terminal velocity of the ice floe is 1/30 the wind velocity results in

$$H = \frac{V_w}{30}\sqrt{\frac{N\,L\,\sin\beta}{g(1+f\cos\beta)}} \tag{9}$$

The kinetic friction coefficient between two smooth ice slabs sliding at a relative velocity of 4 m/s is 0.02 (Handbook of Chemistry and Physics, Chemical Rubber Publishing Co., 1971). For the ice piling study here, a friction coefficient of 0.1 may be used to allow for the roughness of the ice floes and the work required to fracture the ice floe. With this value of f and a value of 2 for N, for an ice slab of 150 m long driven by a wind of 6.75 m/s approaching an ice pile of base angle 45°, the height of the ice pile is calculated from eq. (9) to be 1.2 m.

The above height is for a two-dimensional case, or for ice piling over all the frontage of the ice floe. In reality, this is seldom the case. Because the irregular shape of an ice floe, ice piling would occur over only part of its frontage while the other part remains in water. If the portion of the frontage of an ice floe involved an ice piling is 1/10, which is the order observed in some of the Lake Simcoe ice piles, the calculated height will be 12 m as attained by some of the Lake Simcoe piles.

Eq. (9) indicates that less height will be attained by ice piles of smaller base angle β. This was indeed observed on Lake Simcoe. Field inspections showed that for most high piles, the base angle was of the order of 45°. Field observations also showed that higher piles were formed by larger floes as shown by eq. (9).

DAMAGE ON SHORELINE PROPERTIES BY ICE PILING AND THE PREVENTATIVE MEASURES

By now the physical process of ice piling has become clear. When ice piles, the kinetic energy is converted into potential energy. From a shore erosion point of view ice piling is a good thing for otherwise the kinetic energy of the drifting ice floes would be absorbed by the shore itself. For the Lake Simcoe ice pilings, there was only one lot front of about 100 m wide which showed signs of beach damage (see Fig. 13). At this location, the ice floe broke into small pieces before piling and the broken ice pieces were piled up in an irregular manner. Apparently the ice floe had dug into the beach before being crushed and pushed up and may have occurred because there was no shore-fast ice to shield the beach from the incoming ice floes. For shoreline protection it is therefore desirable to maintain a strip of shore-fast ice.

As mentioned before, Bruun and Straumsnes (1970) found that a sloped shore favours ice piling and recommended vertical walls for coastal structures. Based on the present study, it is seen that although a vertical wall would delay the piling of ice at least until a slope is built by the ice floes, all the kinetic energy of the incoming ice floes must be absorbed by the walls.

As an ice climbs up an ice pile, its kinetic energy is gradually converted into potential energy. If the ice floe possesses greater kinetic energy than the potential energy corresponding to the height of the pile, the ice floe will overshoot the pile. The overshot part then will break and fall to the front of the pile. The broken ice pieces falling to the front possess only the kinetic energy which is associated with their individual mass and are incapable of doing much damage. It is observed at Lake Simcoe that many trees of 3 or 4 cm diameter remained intact even when buried partly by the front part of an ice pile. On the other hand, if the overshot part of the ice floe is met by an obstacle before breaking off, then the whole ice floe will act as an energy reservoir and the overshooting ice floe is capable of doing great damage (see Fig. 2).

It may also be noted that after an ice floe has climbed up to the highest point under momentum, it will slide back under gravity, until a static equilibrium is reached and the height of the ice pile is then controlled by static equilibrium. Because of this ice piles after an event do not show the highest height attained by the ice piles. After an ice piling event and the wind shifts to the offshore direction, the piling ice may slide back into the lake (see Fig. 14 and compare it with Fig. 2). Sometimes the piling ice may break off during sliding back, leaving part of it on shore. The shear surface shows quite clearly the laminar structure of an ice pile (see Fig. 15).

Since damages to shoreline properties are caused by the kinetic energy of the moving ice floes, one could protect the shoreline properties by initiating the conversion of kinetic energy into potential energy well offshore. A possible way of initiating ice piling would be to set up ice wedges in the form of ski jumps at a distance from the shore before the break up. The ice wedge then could cause an early piling of the incoming floes before they reached the shore. However, systematic investigation of this remedial method has yet to be done.

DISCUSSIONS

Although some physical insight has been gained and certain conclusions have been reached from the present study, there still remains much to be done. For instance one could study the effects of the slope of the shore on ice piling; the factors which affect the size of ice floes and the effect of the geometric shape of an ice floe on ice piling. From the present study, it is seen that ice piling is a short time event. The gustiness or the instability of the wind could therefore be of some significance for ice piling. In the present study, it was assumed that there was no onshore current which should be rectified. If the onshore current may not be neglected, the equation of motion would be more complicated and the coefficient of virtual mass would have a different value.

ACKNOWLEDGEMENT

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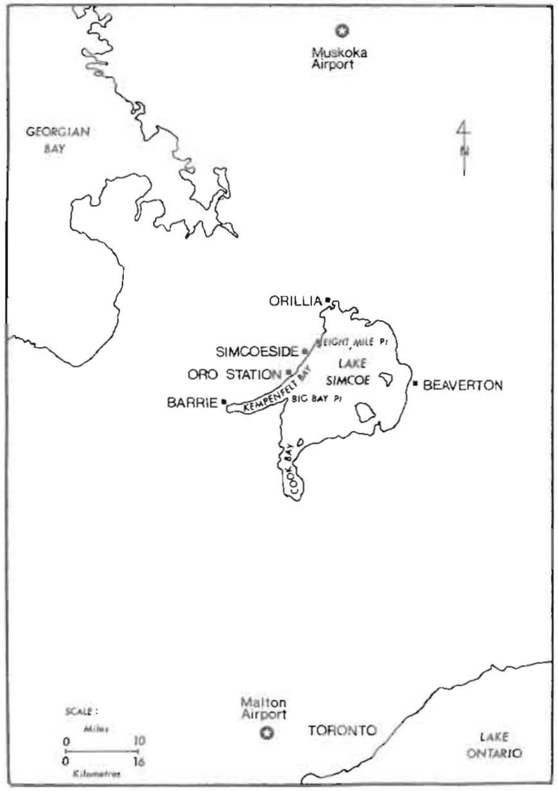

FIGURE 1: GEOGRAPHICAL LOCATION OF LAKE SIMCOE

FIGURE 2: A COTTAGE DAMAGED BY ICE PILING AT LAKE SIMCOE.

FIGURE 3: TWO ROWS OF ICE PILES OFF EIGHT MILE POINT.

FIGURE 4: A HIGH PILE PRODUCED BY THE 4th ICE PILING

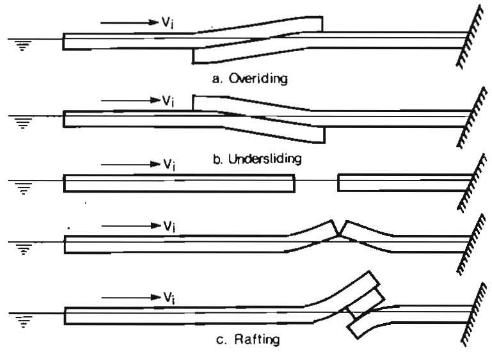

FIGURE 5: THREE MODES OF TELESCOPING OF ICE FLOE

FIGURE 7: BROKEN ICE PIECES ON THE ONSHORE SIDE OF AN ICE PILE

FIGURE 6: AN OVERRIDING ICE FLOE ON LAKE SIMCOE

FIGURE 8: AN UNDERSLIDING ICE FLOE ON LAKE SIMCOE

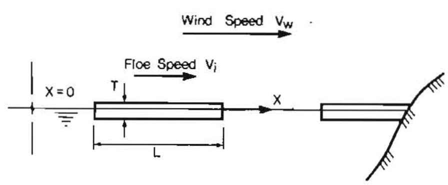

FIGURE 10: DEFINITION DIAGRAM OF ICE FLOE MOVING ONSHORE.

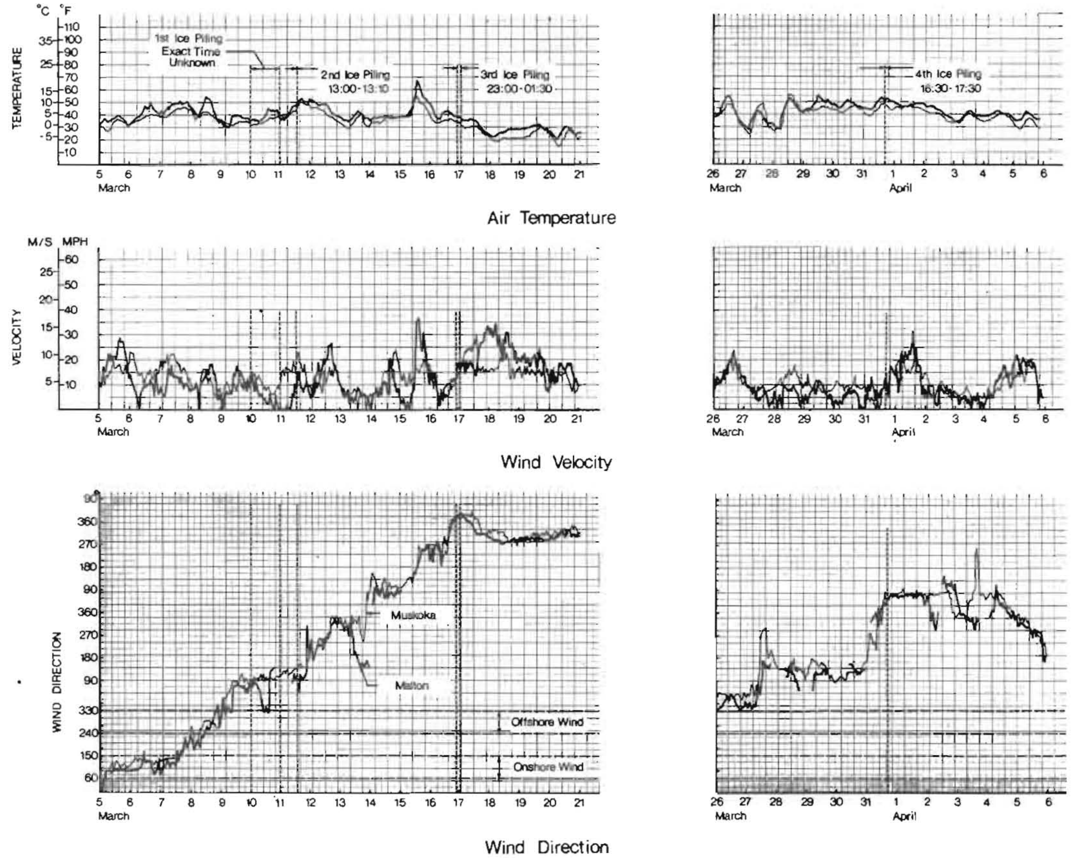

FIGURE 9 : WEATHER DATA FROM THE MALTON & MUSKOKA WEATHER STATIONS (March & April 1973)

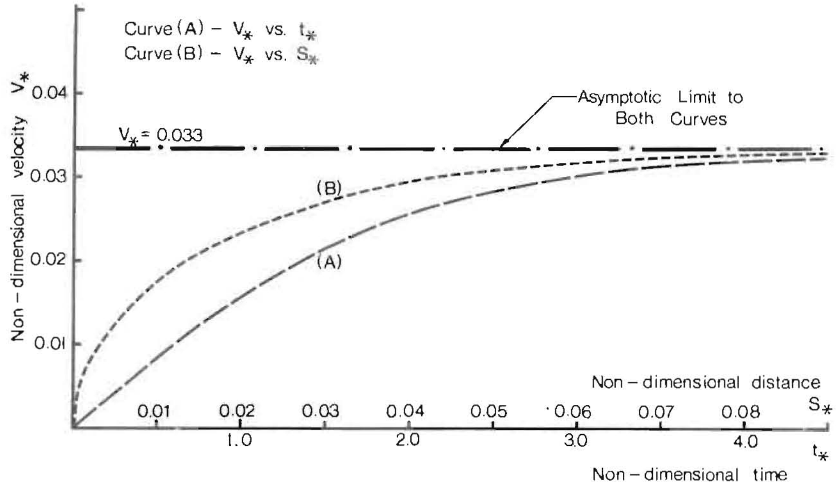

FIGURE 11: MOTION OF ICE FLOE UNDER WIND.

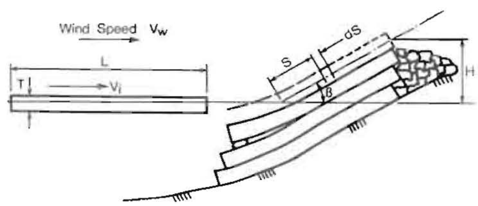

FIGURE 12: PILING OF AN ICE FLOE.

FIGURE 13: SHORE EROSION CAUSED BY ICE PILING.

FIGURE 14: RECESSION OF AN ICE PILE

FIGURE 15. LAMINAR STRUCTURE OF AN ICE PILE.

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ICE PROBLEMS IN LAKES AND IN LARGE IMPOUNDMENT RESERVOIRS ON CANALIZED RIVERS

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ABSTRACT

At times of flood large wind-generated waves and intensive currents may be generated in wide flood beds. During ice carrying floods the drifting ice floes are driven towards the lee-side levees. Along the backwater reaches in canalized rivers, or along the banks of impoundment reservoirs there is no protective forest belt before the levees, the slopes of which must therefore be protected.

The conditions under which wind-generated ice jams are liable to form along the banks, as well as the potential measures for avoiding damages are considered.

SOMMAIRE

Lors des grandes crues les vents engendrent des vagues et courants remarquables dans les masses d'eau des champs d'inondations étendues. Dûe à l'influence du vent, les glaces flottantes des crues glaciales se deplacent dans la direction des digues de sous le vent.Dans les bassins de retenues des rivières canalisées et dans les lacs d'accumulations y manquent les bandes forestières protectrices habituées, établies le long des digues et des rives. Donc il faut prendre soin de la protection des rives et côtes..

L'étude examine les conditions de la formation des embâcles (barricades de glace) de près des rives et traite les possibilités de l'élimination des dégats éventuels.

At times of floods with running ice and in the absence of major air movements, the travel of ice floes is affected solely by the flow conditions in the river. On the other hand,in periods with strong winds and at locations where the width of the exposed water surface attains, or exceeds a certain extent, further on, where there are no high banks, or dense and tall vegetation on the windward side bank, so that the fetch length is sufficient, wind generated waves and currents may result in the water body.If there are in addition floating ice floes on the water surface, these are set into movement and carried downwind.

In such cases the movement of ice floes is controlled by the resultant of currents due to gravity and wind action, further of the movement imparted to the ice floes by wind.

Where the ice-free fetch is long, the wind-generated currents and wind imparted movement of the ice floes govern fundamentally the direction of movement and the velocity of floating ice floes.

Where the vicinity of banks, or buildings does not affect wind-generated water- and ice movement, the velocity of ice floes moving downwind will increase continuously even if the wind force remains constant. The increase tends asymptotically to a final value, the magnitude of which depends on the wind force,but which is attained only where the distance is sufficient. Further movement occurs then with this velocity. If the floes strike an obstacle (solid ice, banks, or structures) they accumulate and the resulting jam remains stationary, or continues to move.

Jam formation is accompanied by energy transformation,whereby some of the kinetic energy accumulated in the floes is transformed into potential energy in the course of jamming, the rest being consumed by work expended for overcoming friction and for deforming and destroying structures and objects encountered in the path of travel. Where the kinetic energy is very large, very great, significant ice jams may be formed, which cause considerable damage to the banks and structures.

The phenomenon described occurs regularly in Hungary on Lake Balaton. Under the influence of northern gales ice jams form along the southern shore, the height of which attains repeatedly several metres. The phenomenon, although to a much lesser extent, occurs on the Danube as well at locations, where the flood bed in the wind direction is wide enough.

In the wide backwater impoundments on canalized rivers and in storage reservoirs wind generated ice movement and jamming must always be anticipated where at ice breakup the fetch in the prevailing storm direction is more than a few hundred metres. The lee shores and the structures on them need protection.

The conditions for the occurrence of the phenomenon and the possibilities for averting the damage can be investigated by a dynamic analysis of ice movement.

At the interface of fast moving air and the water, as well as of the ice floes floating on them a shear stress is generated and energy is transmitted to water and the floating ice floes. As a consequence of the energy transmitted the water at and near the surface, is displaced together with the floating ice floes in the direction of wind.

If the ice floe moves faster, or slower than the water flowing in the wind direction, a shear force is induced at the ice-water interface, which tends to retard, or accelerate the movement of the floe.

The effect of lake currents due to gravity should be neglected here. Consider a floe of unit width, thickness $\underline{h}$, length $\underline{L}$ in the direction of wind and density ϱ_j, which moves at time $\underline{t}$ at the velocity $\underline{V}_{j(t)}$ downwind under the effect of wind of velocity $\underline{U}_z$ measured at height $\underline{z}$ above the water- and ice surface. The current velocity of the water is $\underline{V}_{viz}$.

Considering exclusively the forces acting in the horizontal plane, in the direction of wind and due to wind effects, the movement of the ice floes can be described by the following expression

$$\varrho_j \, h \, L \frac{dV_{j(t)}}{dt} = \tau_{jL} F_j - \tau_{jV} F_j = \varrho_{lev} \, c_j (U_z - V_{j(t)})^2 \, \cdot$$

$$\cdot \, L - \varrho_{viz} \, c_{jv} \, (V_{j(t)} - V_{viz(t)})^2 \, L \; \ldots . \qquad (1)$$

In the first term on the right-hand side of the expression

τ_{jL} is the surface shear stress due to wind friction at the ice surface, in the second term τ_{jV} is the shear stress on the ice-water interface, in kp/m^2 units.

The following boundary conditions apply:

at time $t = 0$: $V_j = V_{viz} = 0$

at $x = 0$, i.e., at the beginning of the fetch, on the windward edge of the free water surface both V_j and $V_{viz} = 0$

The differences $(U_z - V_{j(t)})$ and $(V_{j(t)} - V_{viz(t)})$ vary in the course of movement.

On the basis of Eq.(1) the velocity $V_{j(t_i)}$ of the ice floe can be formed at the end of the path $x = x_i$ together with the time t_i needed for travelling the distance.

At obstacles the size and development of the ice jams, thus the destructive power thereof depends on the kinetic energy carried by the ice floes, or ice field:

$$E_j = \varrho_j\, h\, L\, \frac{V_j^2}{2} \tag{2}$$

For using Eqs.(1) and (2) in computations the following quantities must be determined:

1. The limit values of ice thickness h and of the length L of the floe, or floating field, which depend on local conditions and are decisive for the upper limit of kinetic energy.
2. The magnitude of the shear stress coefficients C_j and C_{jV}.
3. The local variations in the periods between the breakup and complete melting of the coherent ice cover, as well as the direction, duration and velocity data on the winds expected during these periods.
4. The expected length of open water surface before shores and structures endangered by jam formation usually before a lee shore. In other words the critical fetch length over which the floating ice is accelerated.

For practical purposes the critical extreme values are probably of interest and reasonable estimates play an important role here. To assist in these estimates attention is called to certain trends:

a) The size and destructive power of the forming jam are controlled eventually by the mass and velocity of the striking ice. The factors increasing the striking velocity of ice:
   - the velocity and indirectly the duration of wind,
   - the fetch length,
   - current coinciding with the direction of ice movement, which at longer fetches may result in a considerable velocity increment. See Eq.(1).

b) The dimensions and destructive power of the ice jam are greater if large coherent floes strike the obstacle. The large floes tend to become pushed over each other at the obstacle, but break up mostly near the top. The smaller pieces slide down the lee side of the jam, but cause no major damage. Where the run slope is steep, the jam remains usually stationary, while on flat slopes the jam, or coherent ice floes may be pushed further inland and cause considerable damage and destruction.

c) The destructive effect of jamming can be reduced by preventing the possibility of deformation work taking place during breaking into pieces.

In order to prevent and avert damages due to jamming, further to promote winter operation of reservoirs the following considerations should be remembered:

1. Before designing the reservoir and the bank protection structures thereof, further before selecting the locations for harbours and ice sluices, the following information should be collected for a particular area:
   - Periods with running ice.
   - The direction of strong winds likely to occur during this period.
   - On the basis of the foregoing, the shore sections exposed to ice jamming should be selected. In determining the wind directions, allowance should be made for the effect of cur-

rounding mountains and hills, which may deflect the direction and modify the velocity of wind. It is expedient to rely on the records of a wind vane operated at such locations.

2. Harbours should be situated wherever possible along the windward shore.

3. Ice release sluices are effective along the lee shores where the broken floes are accumulated. Where there are considerable gravity currents in the reservoir, the influence thereof on the movement of ice should also be taken into account.

4. Damages to the shores due to ice jamming can be averted by inducing the jam to be formed farther away from the shore, or by preventing its formation altogether. The following potential alternatives should be considered:
   - Where compatible with reservoir operation, the level should be lowered, causing ice to stop and jam before the bank slope.
   - At constant water level interception and jamming should be promoted by structures situated before the banks and deflecting the ice upward.
   - Causing the ice in the vicinity of the shore to settle on the bottom.

5. The levees enclosing impoundment reservoirs should be constructed with a wide crest, capable of accomodating the jamming ice and arresting it thereby. In view of the large masses accumulated, the movement of a once formed jam further inland would cause severe damage.

6. Where artificial ice breaking is resorted to, the ice cover before exposed lee shores should be left intact. Also, methods of ice breaking, which would lead to the development of wide, ice-free water surfaces and thus long fetches should be avoided.

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SOME ASPECTS OF THE ICE FORMATION IN RIVER RESERVOIRS

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ABSTRACT

Observations are here presented which concern the formation of a sheet of ice in a river reservoir and the development of ice displacement caused by the drifting of ice upstream in the reservoir. The observations were made at rivers in the eastern alpine area. An attempt will be made to describe the experiences and findings concerning the formation of ice and the resulting rise in water levels.

Introduction

In the transition area of a free-flowing river with high current velocity and a reservoir with low current velocity, the effects of ice formation and ice drift on the water levels are difficult to register; however, they are of great importance for practical operations.

With large river reservoirs it may be assumed that, statically, the ice formation takes the form of a smooth, solid sheet of ice, as is the case with lakes after the necessary shifting of the water's temperature stratification has taken place. The temperature of the water surface drops to 0° C and the speed at which the heat of the water surface is given off into the atmosphere exceeds the heat replaced by the underlying strata of the water or from the river bottom. Once the solid sheet of ice has formed, it acts as heat insulation and hinders a further progressive freezing of the reservoir. Thus, with the climatic conditions in the alpine area, the thickness of the statically formed sheet of ice generally does not exceed 0,2 m to 0,5 m.

The question remains, does the solid sheet of ice in the reservoir form sooner than the drifting ice floes in the free-flowing river; and if yes, where in the reservoirs do the drifting ice floes meet the solid sheet of ice.

Considerations and results

Observations made at alpine rivers showed that the movement of ice in the free-flowing stretch of river generally begins with air temperatures between -5^{o} C and -13^{o} C (average, -10^{o} C), depending upon the water temperature degree on the first day of frost.

In reservoirs where the ratio of storage capacity to average low water flow of one day is greater than 1, the solid sheet of ice in the reservoir always forms before the ice movement begins when a steady height of raised water level is maintained at the weir.

Investigations at various reservoirs of the power stations on the River Inn and the River Drau showed that a connection exists between the upper end of the sheet of ice forming in the reservoirs, the average current velocity, the sum of air temperatures below 0^{o} C and the thereon dependent water temperature. (Fig. 1)

It could be established that first the average current velocity V_m at the upper end of the freezing reservoir increases with the sum of daily freezing temperatures. V_m approaches a constant limit value between 0,3 and 0,4 m/sec after a sum to daily freezing temperatures of -60^{o} C to -70^{o} C is reached. This would mean that after such a sum is reached, the end of the solid stretch of ice lies in that particular reservoir profile which can be characterized by an average current velocity between 0,3 and 0,4 m/sec. The lower values seem to apply to narrow reservoirs and the higher values to broad reservoirs.

With higher average velocities, the turbulence of the water becomes so great that a solid sheet of ice cannot form even with an increase of the sum of daily freezing temperatures. These findings, however, are disturbed by various influences such as wind, the introduction of sewage, etc., but, according to practical exerpience, the range of scattering created thereby is not very large.

The engineer is now always faced with the difficult job of stating or estimating a priori the rise in water level as a result of ice formation.

The commonly held belief is that a solid sheet of ice in a reservoir transforms the open water course into a pressure "pipe line", and as a result of an increase of the wetted perimeter to approximately double the size, it causes considerably higher losses of flow and thus a rising of the water level. This assumption is not applicable for the observed river reservoirs on the rivers Inn, Drau and Enns. Also with a change in the water flow, a solid sheet of ice is able to form well by means of elastic and plastic deformations when the breadth of the water level is 100 m or more, as in the reservoir on the upper Inn, for example.

The rise of the water levels observed upstream from the solid sheet of ice is caused by ice displacement; i.e. the accumulation of ice floes on the solid eheet of ice. The ice floes are pushed upright and packed together; they are in part driven underneath the solid sheet of ice in the reservoir.

Experience has shown that the ice floes pushed under the solid sheet of ice are moved further by the water current. They are also made smooth by the somewhat warmer water under the solid sheet of ice, and in part they melt. Further ice displacements under the solid sheet of ice can generally only occur where the ice floes are able to settle as a result of irregularities in the cross-section but also as a result of an unfavorable current distribution in the water. Ice displacement at the end of the solid sheet of ice develops upstream and, in a regulated river bed, leads to a rise in water levels which generally reach, at the most, the yearly high-water level on the guage. (Table 1)

Ice breakup is characteristic for ice displacement. Immediately after the maximum water level is reached, ice breakup can occur as a result of the high static and dynamic pressure of the increased tractive force but also as a result of the ice becoming smooth on the underside. This ice breakup causes a temporary drop in the water level, as may be clearly seen in the recordings made at the River Drau (Fig. 2). Experiments in our laboratory have qualitatively proved the occurence of ice breakup in the expanse of pack ice.

The maximum rise in water level resulting from ice displacement always occured very early in the frost period and never at the end of a longer frost period. Thus, the rise in water levels seems largely independent of the sum of freezing temperatures in winter and of the further advance of ice displacement upstream.

The highest rise in water levels generally occurred at a point in the river when the ice displacement reached that point. Presumably, the water level drops again even with sustained frosty weather due to the fact that the packed ice floes are smooth on the underside and as a result of the heat-insulation characteristic of the solid sheet of ice. (Fig. 2)

Further observations concern the melting of the solid sheet of ice and the ice displacement in a river reservoir. It is surprising that when temperatures are above 0^{0} C for a short time, only a minor rise,of $1,0^{0}$ C in water temperature, or even a rise in the negative air temperature, is enough to melt the ice in a very short time. Experience in the alpine area has shown that the solid sheet of ice begins to melt at air temperatures of approx. - 5^{0} C and upwards. The thickness of the sheet of ice becomes less with a decrease of frosty weather. When the frosty weather conditions cease, the ice sheet dissolves very rapidly. The melting process is primarily dependent upon the temperature and current velocity of the water which influence the quantity of heat discharged to the sheet of ice.

On the River Drau, the formation of ice came to a standstill when air temperatures were around - 10° C. The displaced ice already began to melt at air temperatures of - 5° C, and at average air temperatures of - 1° C, all the displaced ice had melted. On the River Salzach, the melting of the displaced ice began at an average air temperature of - 4° C, whereby however, maximum daily temperatures of - 1° C occurred. The 17-km long ice pack which still remained when the average air temperature was - 4° C dissolved completely when the air temperature on the two succeeding days rose to + 1° C and + 3° C.

Summary

Measurements and observations made previously in the eastern alpine area showed that the water levels rose to a maximum of 2 to 3 meters as a result of ice displacements in the reservoirs of larger rivers. The maximum water levels always lasted for a short time only. Further, variously high water levels occurred in connection with ice breakup; however, these levels were still below the maximum. The often feared catastrophe of thaw flood waters coming together with an ice sheet in a reservoir did not occur because a minor increase in water and air temperatures leads to very intensive melting processes.

Limiting the rise in water levels locally is possible due to the oonnection between the sum of freezing temperatures and the average current velocity. In the author's opinion, it seems necessary to intensify measurements and observations at reservoirs during winter, and above

all, to develop measuring instruments with which it should be possible to analyse hydraulic processes and to determine the ice formation and the melting process under a solid sheet of ice and under an ice park.

River	Year	Rise in water level [m]
Drau (Annabrücke)	1962/63	2,63
Inn (Rosenheim)	1962/63	0,75
Drau (Schwabegg)	1964/65	1,57
Inn (Prutz-Imst)	1959/60	2,20
	1961/62	2,20
Main (Data: Office of water and Navigation, Passau)		2 - 3
Lech		
Donau (Jochenstein)		2 - 3,50
Donau (Kachlet)	1962/63	2,74
Salzach	1955/56	3,00
Enns	1962/63	0,5 - 0,8

Table 1

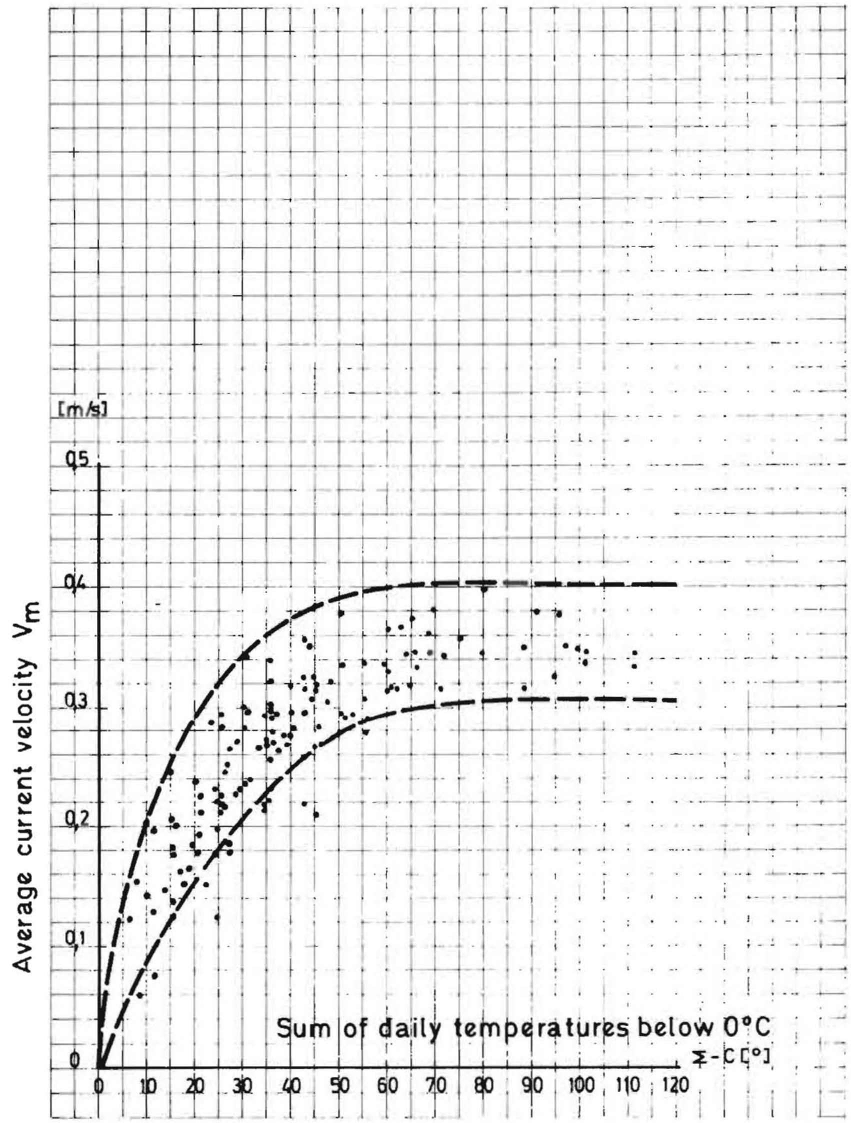

Fig. 1 Boundary position of the solid sheet of ice in a river reservoir in relation to V_m
(measurements of Innwerk A.G.)

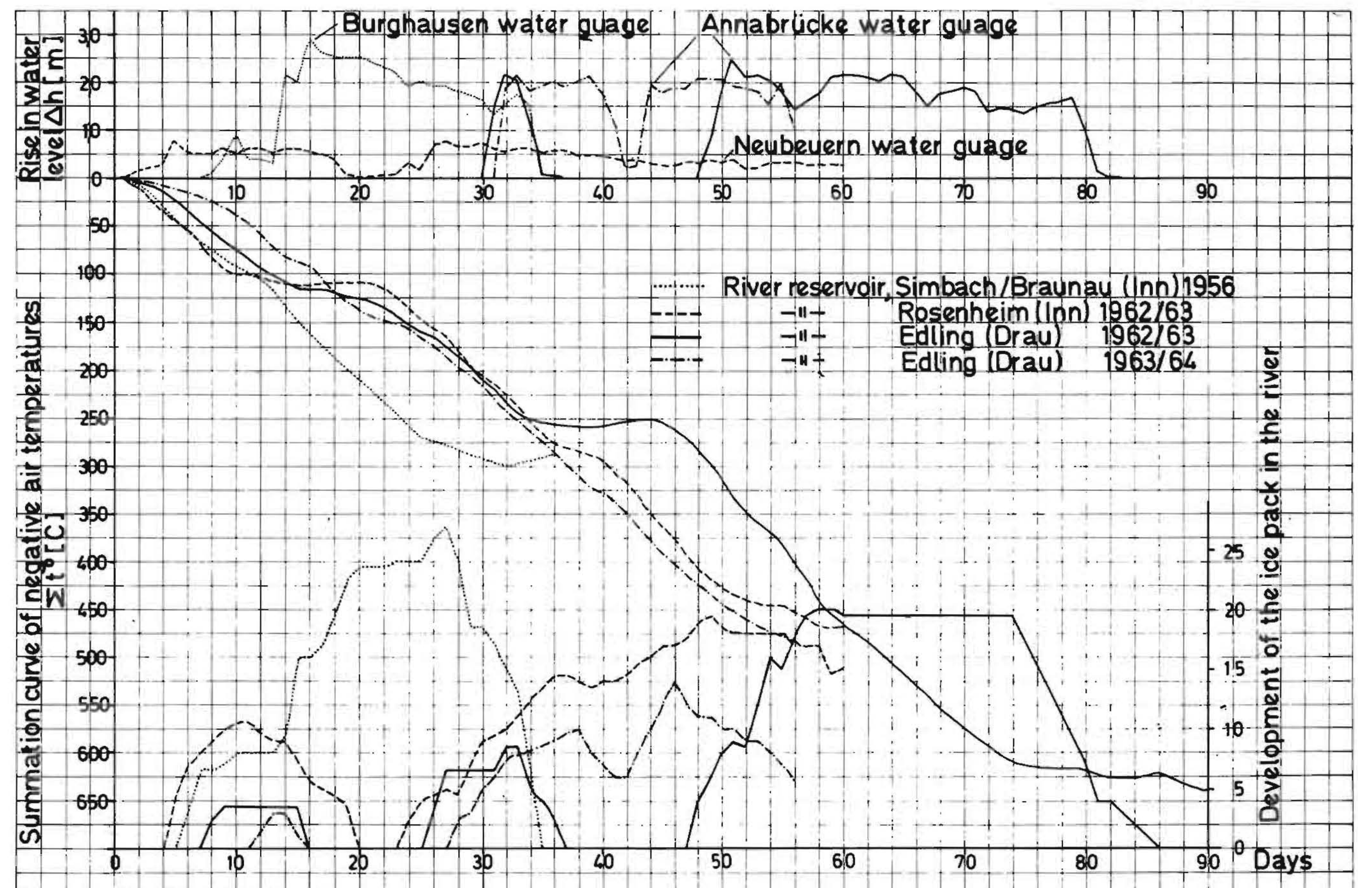

Fig. 2 Connection between ice pack, rise in water level and sum of negative air temperatures

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SYMPOSIUM

RIVER & ICE

J. Szenti

ON THE ACTIVITY OF THE LOWER DANUBE VALLEY DISTRICT WATER AUTHORITY IN THE BAJA STUDY TOUR REGION

Preprint

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RIVER REGULATION, CHANNEL MARKING SERVICE AND ICE CONTROL ALONG THE LOWER DANUBE RIVER SECTION

(Between River Stations 1560 and 1433 km)

by J.Szenti, Civ.Eng., Director

Lower Danube Valley District Water Authority, Baja,
Hungary

Baja Region

Along the lower section of the Hungarian Danube (Fig.1), that is between the southern state frontier and the Dunaföldvár bridge the tasks of river regulation and channel marking are the responsibility of the Lower Danube Valley District Water Authority (Baja) which is responsible for ice control as well.

The purpose of river regulation is to ensure the passage of both floods, ice and sediment without any damages by creating such a state of bed which is able to eliminate disastrous floods, the harmful development of shallows, bankslides, and deterioration. On navigable river reaches, the development of a navigation channel with the prescribed dimensions related to the navigation and regulation low water determined as decisive level - should also be promoted by regulation work.

Dealing with river regulations high-water regulation and bed regulation (mean-water and low-water regulation) can be distinguished.

High-water regulation is concerned with preventing floods from diffusion spreading and causing damages. Its most important objective is to make the protected area as large and as valuable as possible. The tracing of the levees and the formation of the flood bed are included in it.

By mean-water regulation such state of bed should be created in which the passage of both ice and sediment is unobstructed (Photo 1).

The task of low-water regulation is to assure the minimum dimensions - both width and depth - of the navigation channel under the navigation water level, within the mean water bed.

In the early stages of flood control only the inhabited areas had been surrounded by flood levees. Along the Danube reach between Dunaföldvár and the state frontier the construction of levees started in the last decades of the last century and nowadays the length of levees along the right-hand bank is already 229 km and along the left-hand bank 154,9 km. Along both banks the levees have been constructed with regard to the prescribed design flood level.

River regulation started in the thirties of the last century

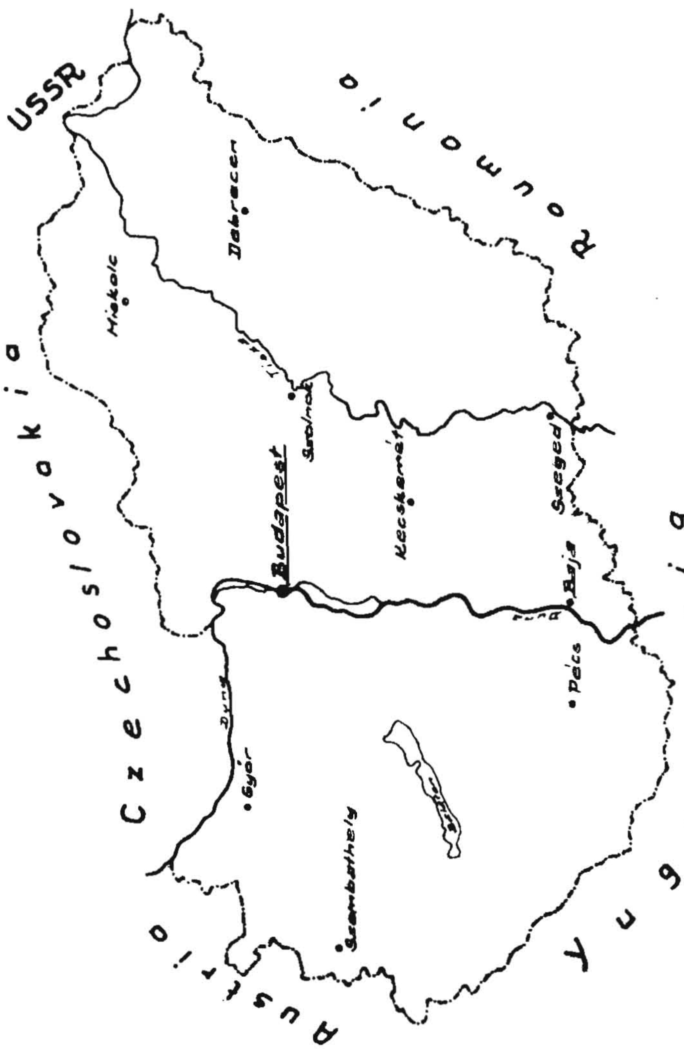

Fig.1

J.Szenti

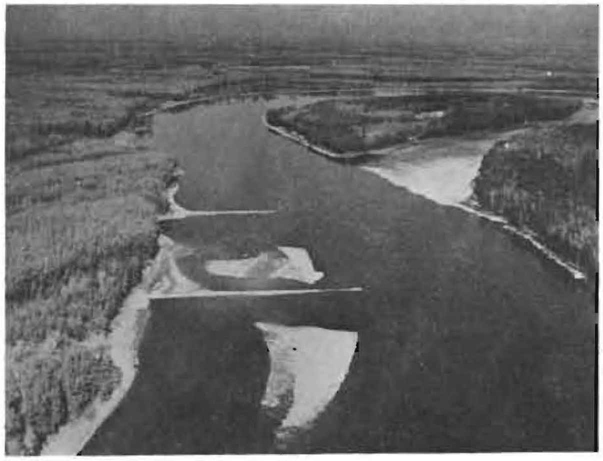

Photo 1

by cutting the large river bends. In this period the Danube section in question was shortened by about 60 km, however, the stabilization of the banks was omitted. Only at the turn of the century was it recognized that also the ramifications of the river must be closed and the banks stabilized by means of rip-rap works. Therefore the branches were gradually closed and the main bed was confined by bank protection works and parallel dykes along both banks to a width of 450-500 m. Consequently the Danube has become embedded and the level of both the mean and low-water has become lower. However, later this width has proved too great. The position of the main current is constantly changing in transverse direction.

The new general mean water regulation program has been elaborated in 1952 and improved in 1961. Also the present river regulation works are executed on the basis of this program.

The main point of the program is to cinfine the bedforming mean waters escaping in the ramifying branches into a uniform main channel of 400 m width. By doing so a deep bed being free of bars for ice travel and the required channel depth and width for navigation can be produced. In order to realize these objectives, along the concave banks of the Danube longitudinal dykes, bank protection works and fills; along the convex bank confinement groynes and in the branches closing dams were planned. In designing the bends the existing regulation works had to be considered. The general regulation program fixed the tracing of the river section and both the site and volume of the regulation works needed for forming this trace. In the spacing of works the fundamental requirement was that the regulation line be fixed in plan along both banks at the level of mean water.

In the course of regulation works completed thus far 78 km bank protection, 25 km parallel dyke, 127 branch closures and 24 spur dikes have been completed thus far. As a result thereof the so called "Wild beds" have been eliminated and the main current has become more or less stable.

The purpose of channel marking is to mark a safe navigation channel having a trace, width and depth corresponding to the prevailing bed regime. Over this particular Danube section the minimum dimensions of the safe navigation channel are as follow:

radius of curvature	500 m
width of navigation channel	150 m
depth of navigation channel	2.5 m

These dimensions are to be ensured regardless of variations in stage.

The task of the marking service is to mark both edges of the navigation channel on the banks and in the bed by means of well visible conventional marks. This activity makes possible for the helmsmen to direct their vessels safely by day and by night within the channel.

Along the 127 km long Danube section the highly responsible duty of marking is accomplished by the District Water Authority. From the headquarters at Baja two groups start each day onto their own river sections. The crew of a marking group consists of five persons (helmsman, engineer, three marking men or sailors). Both vessels are provided with radar equipment and ultrasonic sounding device.

The hull and deck of the vessel are designed to make possible the transportation of marking equipment (marks, batteries, etc.) and the execution of marking work from board.

The marks are manufactured at the workshop of the District Water Authority. The navigation channel is marked if possible on the bank by means of permanent marks by which emit flashing signals for navigation by night.

If made necessary by bed conditions permanent floating marks with flashing signals are also operated. The edge of sand bars appearing in the low-water period are marked by means of the so-called "blind buoys".

When in the low-water period the minimum dimensions of the navigation channel are not available, the lack of sufficient width and depth is reported to the Hydrographic Department in Budapest by means of red telegram form. These data are published by this service on the daily map of stages and also through the Hungarian Broadcast at 13.45 o'clock daily.

The shape, colour and the dimensions of the navigation marks and the duration of flashes were determined in the navigation regulations of 1970 (Photos 2 and 3).

Photo 2

Photo 3

The primary task of river regulation is the maintenance of the navigation channel and it is the marking service which is responsible for the regular observation of the changes and modifications occuring in it. The employees of this service take care of the marks at the river stations, observe the changes in steep banks and in both the low-water and high-water bed. Initiated by their reports the sounding tachymetric survey of the bed are performed out of turn in the critical river sections and the river regulating measures are carried out to prevent impending bed deterioration.

Ice control starts with ice observation and with organizing the ice reporting service. Along the 127 km long Danube section ice observation is performed by 20 levee keepers. They foreward reports about ice conditions and stages for the central inspection twice a day, where the data are processed immediately.In the period of ice jam hazards, stages are observed as necessary on several occasions a day. Ground informations are checked occasionally by aerial observation too. In the case of emergency aerial observations are performed on several occasions a day. The magnitude of ice coverage is fixed also by means of photo series taken at five cross sections.

According to the observations performed from the middle of the last century, over the 227 km long river section between Dunaföldvár and Vukovár (River Stations 1560-1333 km) the danger of ice floods is so great that in 1955 this section of the Danube was declared of common interest by both Hungary and Jugoslavia.

Accordingly the job of ice control is performed on the basis of coordinated orders. The work of control is guided by central (Budapest, Belgrade, Zagreb) and by local (Baja, Sombor, Osijek) liaisons.

During emergency periods a micro-wave network is operated to maintain contact. The local liaisons inform each other about ice conditions each day and the work of ice breakers is coordinated also by them. Over this section of the Danube ice control is performed primarily by means of ice-breakers. However, local control by bombardment and ice blasting has also been attempted with little success.

The ice-breaker fleet of the water service consists of 16 ice-breaker vessels with engines from 300 to 1440 HP; (see Photo 4). Five units of the fleet are equipped with yawing equipment.

According to the experiences gained during the last decade, over this section of the Danube when by the sum of the negative daily mean temperatures reaches the value of 20°C then ice drift, and when the value of 80°C is attained, then freezing over of the river can be expected. The sum of positive temperature preceding the breakup of the ice cover is 20.9°C at Baja. The daily lowest air temperature fluctuates between -10 and -30°C. Temperatures around -30°C can already be considered extreme at Baja.The thickness of the ice cover is generally between 1.0 and 1.5 m. In sections with jams ice thicknesses of 3-4 m are frequent but at some sites even 6-8 m have been observed.

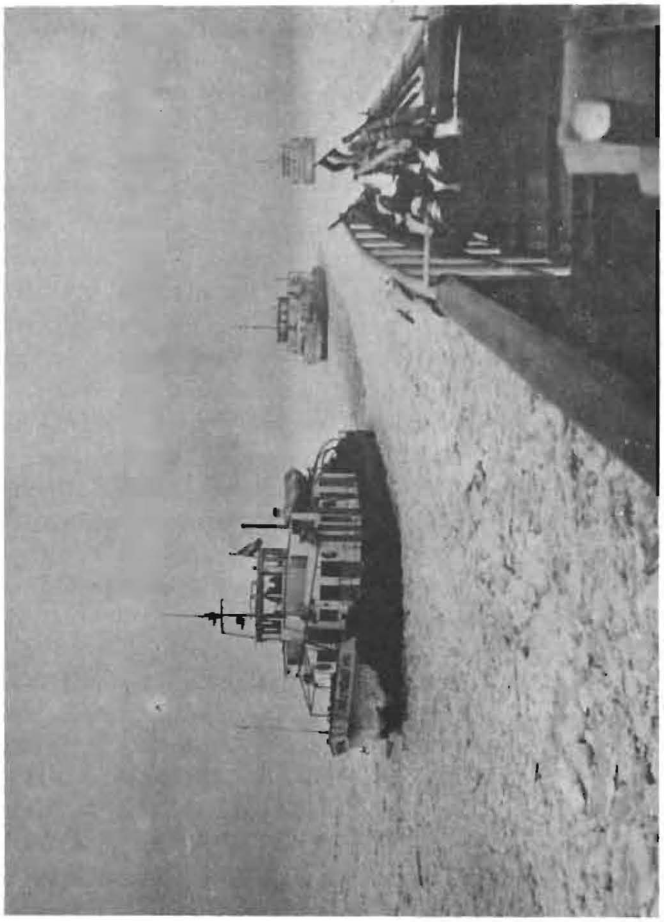

Photo 4

The task of ice breaker groups is to ensure the continuity of primary ice drift; to promote the development of a solid ice cover; to start again the ice field by breaking it up from the downstream end and, finally, to initiate secondary ice drift. For accomplishing these tasks 4-5 Hungarian vessels are rented annually by the Jugoslavian water authorities.

The ice-breakers work in five groups.Two of them are engaged in Jugoslavian area.

When an ice coverage of 30 per cent is reached,the groups of ships sail to their bases of operations. In the case of primary ice drift of 30-50 per cent density along the whole river section belonging to the groups, ice is broken up by artificial wave action, the narrows are widened and the ice cover is kept in continuous motion by disintegrating both collar and shore ice. When the ice drift attains to 80-100 per cent density and at the same time a long cold spell is expected, the task of the vessels is to promote the "smooth" freezing over of the river. In this period the jams have to be destroyed and - by means of breaking up the ice cover in the upstream section - the development of a uniform ice cover has to be ensured until an even freezing over develops along the whole river section.

In the ice field a passage is maintained — generally near the main current — to ensure the easy accessibility of any section of the river.

The criterion of initiating the secondary ice drift is the presence of either drifting ice or an open water surface downstream from the ice cover. The stationary cover can only be destroyed with the ice-breaker vessels working upstream. If necessary, the passage in the ice field can also be used to make the ice-breakers capable to reach any Danube section under the ice cover starting from their base of operations. By initiating secondary ice drift the springtime development of ice jams and the danger of ice flood - the consequence of the jams — can be reduced. By making the ice cover travel down quicker, the involuntary winter break of navigation can be shortened.

Until now the characteristic of disastrous floods was that the flood wave originated from melting in the upper basin ran over the standing continuous ice cover in the lower Danube section. The ice cover was raised and broken by the arri ing flood wave and after a period of only several hours the unexpected secondary ice drift started. The ice masses started in this way formed jams in the overdeveloped bends and in narrows, and the water level rose by 3-5 m along a Danube section 30-50 km long. The levees could not withstand the resulting water head and e.g. in 1956 the levees along this Danube section breached at 24 points.

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Budapest 1974 Hungary

HUNGARIAN ICEBREAKER FLEET

L. HONFI

Director
River Regulation and Shingle Dredging CO.
Budapest, Hungary

ABSTRACT

The building construction of an icebreaker
Tasks of the icebreaker Fleet
Technology of the work of icebreaking
Technological problems of the serviceing and repairing of the ships
Principal data and measurements of the ships

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SOMMAIRE

HUNGARIAN ICEBREAKER FLEET

According to written records ships, in Europe, as protection against ice were employed for the first time in 1856. The s/s „POLLUX" tried for the first time, on the river Elbe, in the vicinity of Hamburg to break up the stationary icefield on the frozen in river. The first ship built expressively for icebreaking had been put into service in 1871 and was in service till 1957 on the Lower Elbe. By utilizing the experiences gathered during 100 years of icebreaking service it was possible to increase the icebreaking capacity of the ships and the efficiency of using them aggainst ice.

The Danubian Icebreaker fleet in Hungary is operated by the Enterprise for River Regulation and Shingle Dredging who stays under the direction of the NATIONAL WATER AUTHORITY of HUNGARY (Office) and in his sphere of activity performs tasks extending to the whole country.

The icebreakers-standing under governmental management- were built in the Hungarian Ship and Crane Building Yard between the years of 1959 and 1966 for dual purposes. Each ship can be used as well for icebreaking as for towing. The icebreaker unites were developed from the towingboat types and their main task is to perform the icebreaker service.

In what do these fluvial icebreakers differ from the ships able (designed) exclusively for towing. The answer to this question is given on tables I–II–III–IV. The modifications-without exception-increase the efficiency of the ships and their security in service under ice conditions.

To whitstand the heavy stresses deriving from icebreaking, the stem has been strengthened correspondingly. (Table I.)

The shaping of the deck, sheering towards the stem developed from the fact that the icebreakers have to go astern frequently.

The framing strengthened by longitudinal and transversal iceframes and most of all the increased thickness of the sideplating where it may come in contact with ice, increase significantly the solidity of the hull.

The spur (construction) built on the stem gives an increased protection to rudder and ship's propeller.

The fact that the rudder is supported from below increases the solidity and duration of the steering gear and consequently the security of the ship.

To icebreaking only unprotected (turning free, without Kort's ring) propeller can be used, as the Kort's ring can be easily damaged, deformed and broken down (torn off).

The elastic shaftcoupling protects greatly the main-engine and the shaftsystem. If the propeller knocks against ice (starts to get jammed) frictional force (braking) or elastical changement of shape takes over the excessive stress. (Table II.)

For icebreaking propellers with greater pitch and thicker blades are used as greater speed is required than towing. The thicker blades give greater strength (solidity) of propeller. (Table III.)

The building in (instalment) of the swinging arrangement (device) increased significantly the efficiency of the ship compared with the traditional icebreaker type. (Table IV.). This mechanical construction (device) compels (forces) the ship to have a definite separate motion (movement). In this way the singular points of the ship-when the ship is under way-move along a spiralshaped trajectory. The swinging arrangement is built in in the bow and in the stem of the ship and consists of eccentrically rotating masses with their respective counterweigths being at 180° degrees form each other.

The prolongued use of the swinging arrangement creates for the living organism a very unusual state (sensation). The direction of the generated rotation changes constantly and consequently the equilibrium (equipoise, balance) becomes unstable and the effort to regain it causes an increased physical stress.

The majority of the Hungarian icebreakers operates on the Danube. Their main task consists to avert iceflood (when the ice melts or forms barricades on the river) dangerous to the southern riverain territories of the Danube. They perform their task in the vicinity of the common Hungaro–jugoslavian border partly on Hungarian partly on Jugoslav territory. On this section of the Danube there are many dangerous places in the riverbed, sharp turnings, shoals where ice very often stops, piles up and forms barrage.

The ships generally-when the ice shows a thickening (frequency) of 30% at Budapest or water is falling rapidly – in order to pass the southern shoals with security –, leave Budapest before the situation starts to get serious as they must be at their station in time. They work generally in pairs – one traditional icebreaker and one with swinging arrangement. In this way they can help eachother in need. An oilcarrier anchored in the winterharbour at Baja takes care to supply the necessary fueloil to the icebreakers.

The icebreakers perform the following tasks when ice is drifting or breaking up on the river.

They give on request aid to ships under way. They tow into winterharbour on request and put into security pontoons and other floating harbour installations.

They watch and superwise, especially at the designated dangerous places the drifting and flowing downriver of the ice, and attempt to prevent the stopping of the ice or the forming of a barrage, with all available means.

They break and split up the bigger, conjuncted drifting ice floes. If in spite of all efforts the ice stops drifting and becomes stationary, icebreakers have to retire to some place below the frozen in section which is considered as dangerous place.

When ice is stopped on the river for a considerable distance, does not drift, icebreakers receive the following tasks: they must break up the ice, clear and keep clear the places pointed out where ferries are operating.

They must open a channel in the stopped ice.

The must break up eventual icebarrage or icefloe and make them drift downriver.

They must break up and tear off the ice formed along the shore and on the shoals.

But the breaking up of the frozen in section can not be started before the drifting of the ice is not assured (made possible).

The decision of the tasks to be given to the icebreakers depends allways from the expected change of the meteorological situation.

If for instance cold weather of long duration may be expected the breaking up of the ice must be stopped as at 20 degrees below zero the Danube acts as an icefactory. On a single night a layer of ice of the thickness of 5 cm may form.

The icebreakers execute their work generally by daylight. Nightwork can be ordered only on exceptional cases. To render it possible each ship is fitted out with projectors of great capacity.

For nightwork only the most experienced crew can be detailed.

The icebreakers on breaking up the stationary ice, move constantly ahead and alternatively astern. The traditional icebreaker without the swinging device, runs with great speed against the ice, glides on it and so the ice under the weight of it cracks and breaks off. The breaking capacity of the ships fitted out with swinging arrangement is further augmented by the rotating energy mechanically generated. They brake the ice formed at the shoreline by artificially produced waves. The ship runs with a relatively great speed along the ice formed and attached to the shoreline, produces of course strong waves which in their turn break up and detache the ice from the shore. Over the shoals, at a low waterlevel only ships with a small draught can be used.

The icebreakers of the Danube spend yearly generally 4 to 5 hundred servicehours in breaking ice which is about the 12 to 15% of the total yearly servicehours. Notwithstanding of this fact the 45 to 55% of the yearly repaircost is mainly due to damages suffered during icebreaking. The ice scrapes off every year the paints and other protective materials applied against (rust) corrosion. The ship's propeller and the steering gear can suffer damages many times. The ship's hull, stuck in the ice has to bear sometimes pressions surpassing the limit of watertightness of the sideplating and of the whole construction. The frames, the sideplating, watertight bulkheads, inside coverings and fenders suffer sometimes lasting deformations. Hull-repaire is a specially costly work because it can be executed only after complete removal of the inside coverings, fittings and other structural parts in way of the damaged frames.

To keep in service the icebreakers, to provide for quick repaire of the damages (change of propeller) costly fitting, lifting and machineing instalments are neccessary which require a considerable capital. (Table V–VI–VII–VIII.)

The motordriven slipway (hauling system) of the Enterprise is functioning in the Central Shiprepairing Works at Budapest. With this the icebreakers, at 120 cm waterlevel at Budapest, can be drawn out of water in a few hours.

The motordriven slipway (slipdock) is at the disposition of all Branches of the Hydrographic Service.

During the period of the protection against ice the Shipbuilding Works of the Enterprise at Baja is constantly keeping watch. Here a crew of technicians ana fitters equipped with a rolling workshop cares for the quick repaire of any damage. Considering its central position of the section of the Danube under our protection (Table IX.) a sparepart deposit has been established here.

The work of protection against ice on the Danube is directed by the Hydrographic Direction of the Lower Danube. In its central offices the adjutants (assistants, despatchers) of the Company are are at all times on duty.

The icebreaker Fleet kept in service by the Enterprise for River Regulation and Shingle Dredging consists of a flagship and a ship of the line. It is characteristic for each ship that they are fitted out with WT (wireless telegraphy) sender and receiver and the mainengine can be teledirected (telecontrolled) from the wheelhouse (Bridge).

The flaship (Table X.) has 1300 HP capacity two ship's motors and is fitted out with swinging arrangement. Its overall measurements are:

Length:	40,5 meters
Breadth:	9,03 meters

Draught:	17 decimeters
Displacement:	389 tons

The ship is fitted out with a Radar installation and so she can navigate by restricted visibility or in fog.

The ships of line (Table XI.) are partly fitted out with swinging arrangement, partly not. They have 600 HP capacity and one engine. Their overall measurements are:

Length:	32,8 meters
Breadth:	7,35 meters
Draught:	17 decimeters
Displacement:	268 tons

The icebreakers receive every year till the first of December the obligatory, planned, preventive overhauling (maintenance) and expect the drifting of the ice in completely repaired condition.

The ships have more than tenthousand component parts and the safe managing and handling of it requires a work of great responsability as from the crew of the ship as from the personnel of the management.

L. HONFI

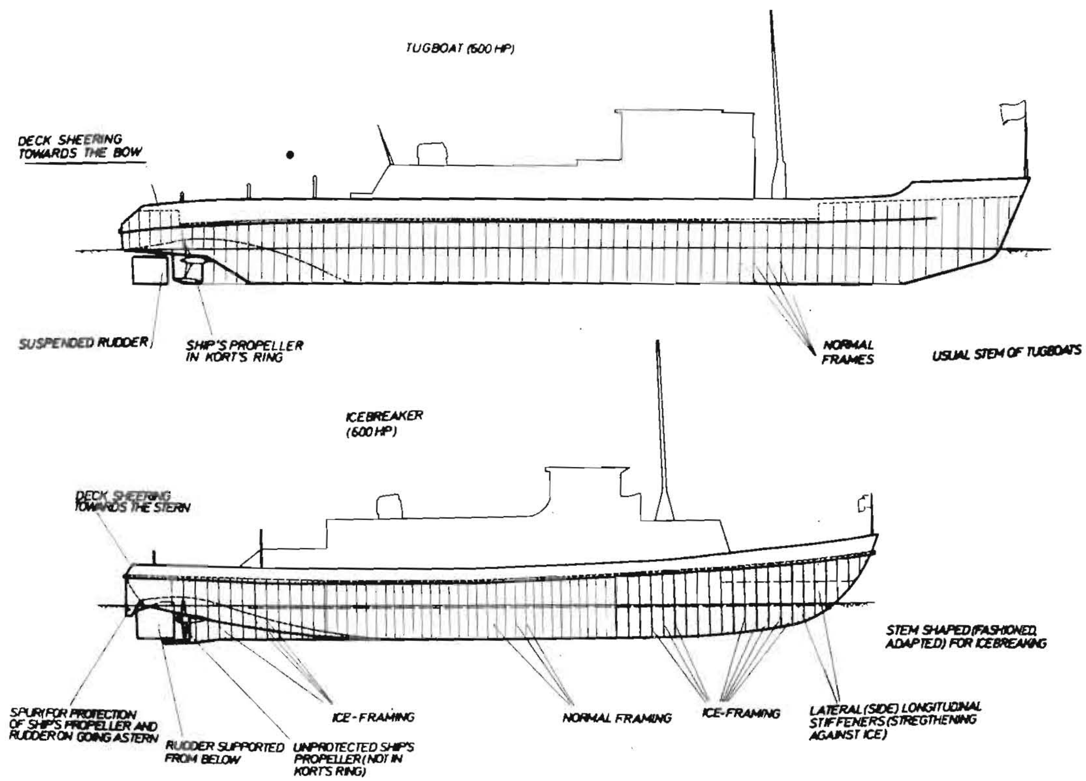

Table I.
Comparison between the hullconstruction of an icebreaker with that of a fluvial tugboat's

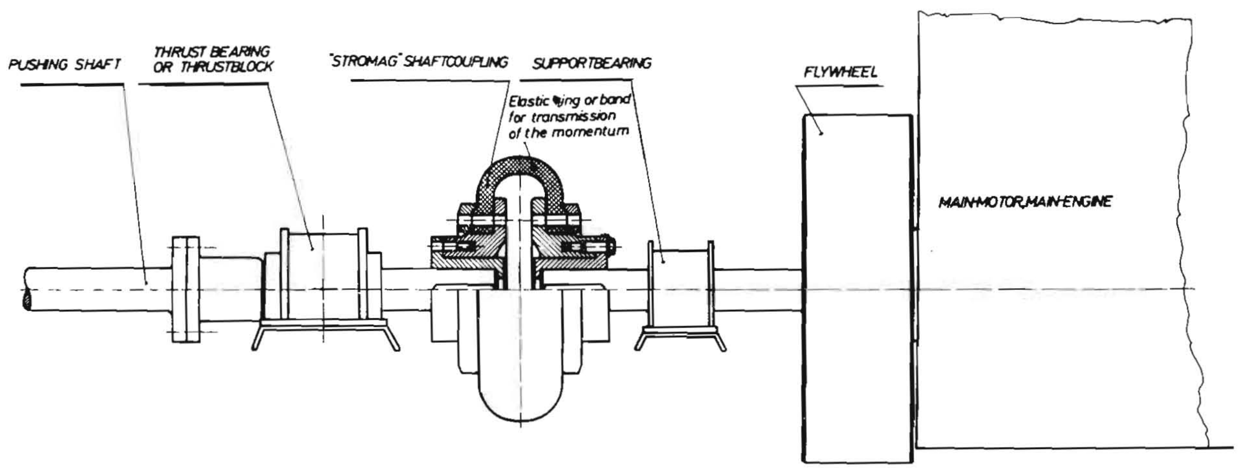

Table II.
Elastic coupling of the mainengine to the pushing shaft.

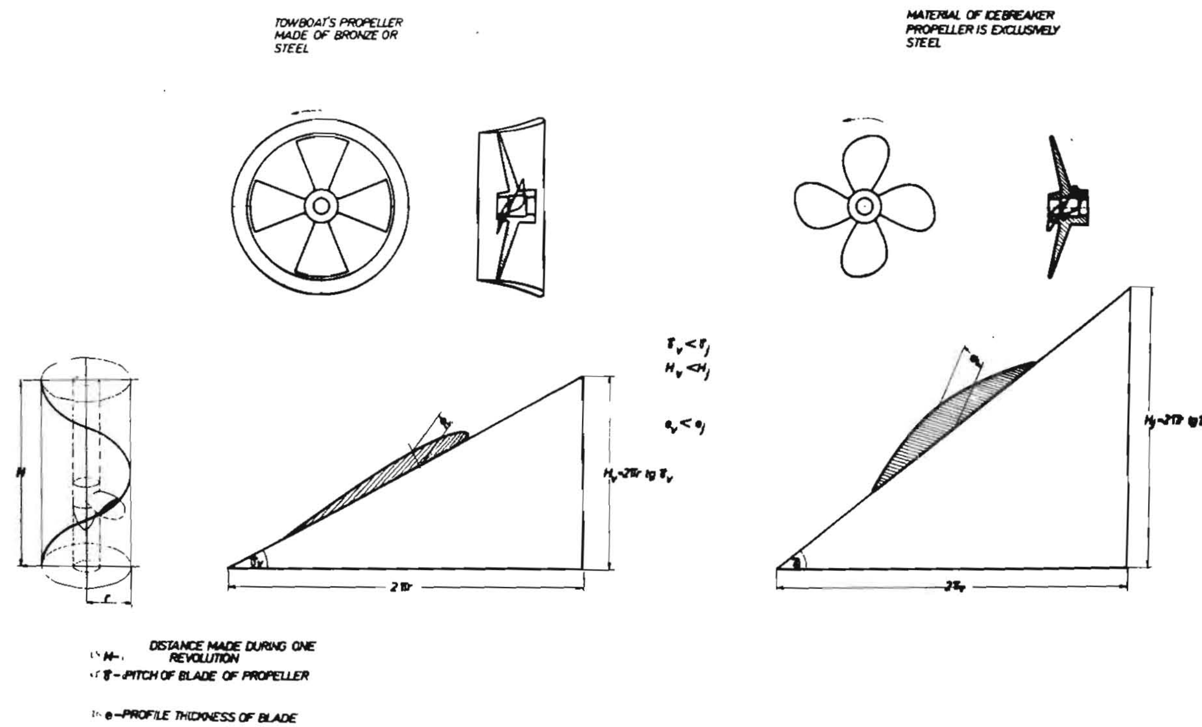

Table III.
Comparison of the ship's propeller of an icebreaker with that of a tugboat's

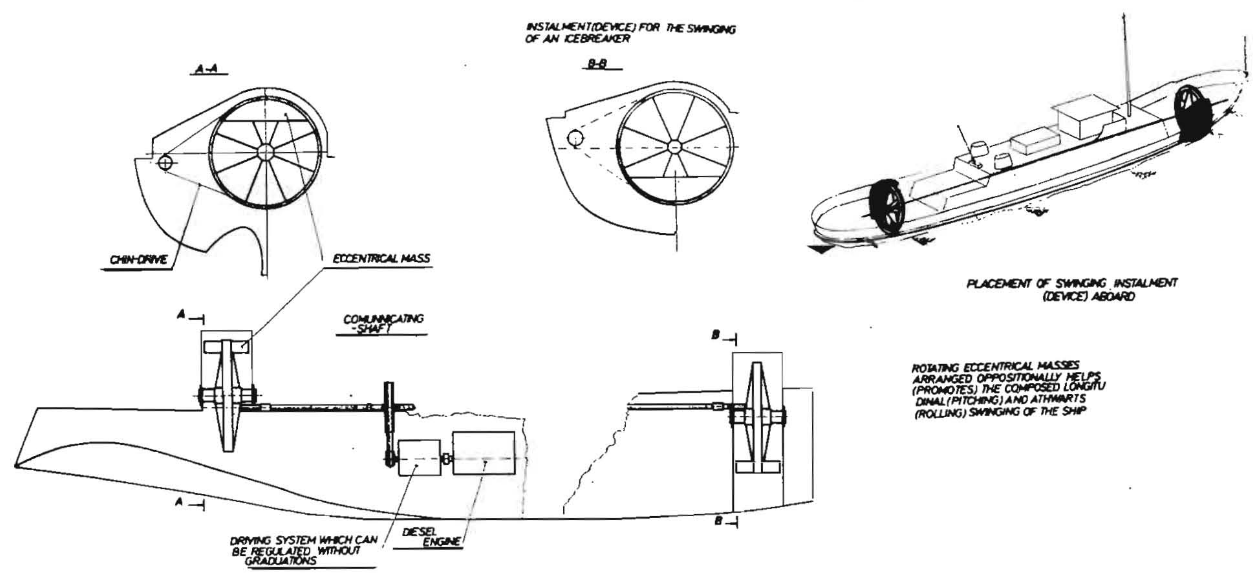

Table IV.
The swinging arrangement (device)

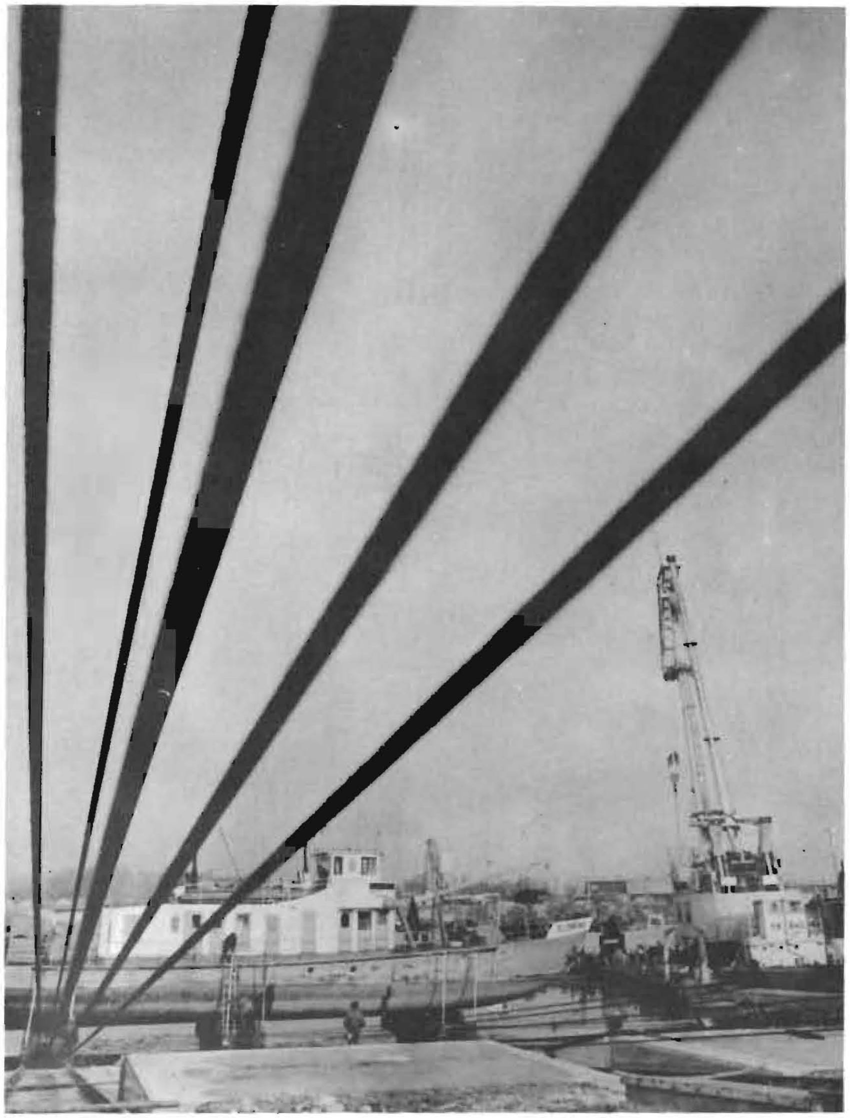

Table V.
The 20 ton fitting crane of the Enterprise for River Regulation and Shingle Dredging

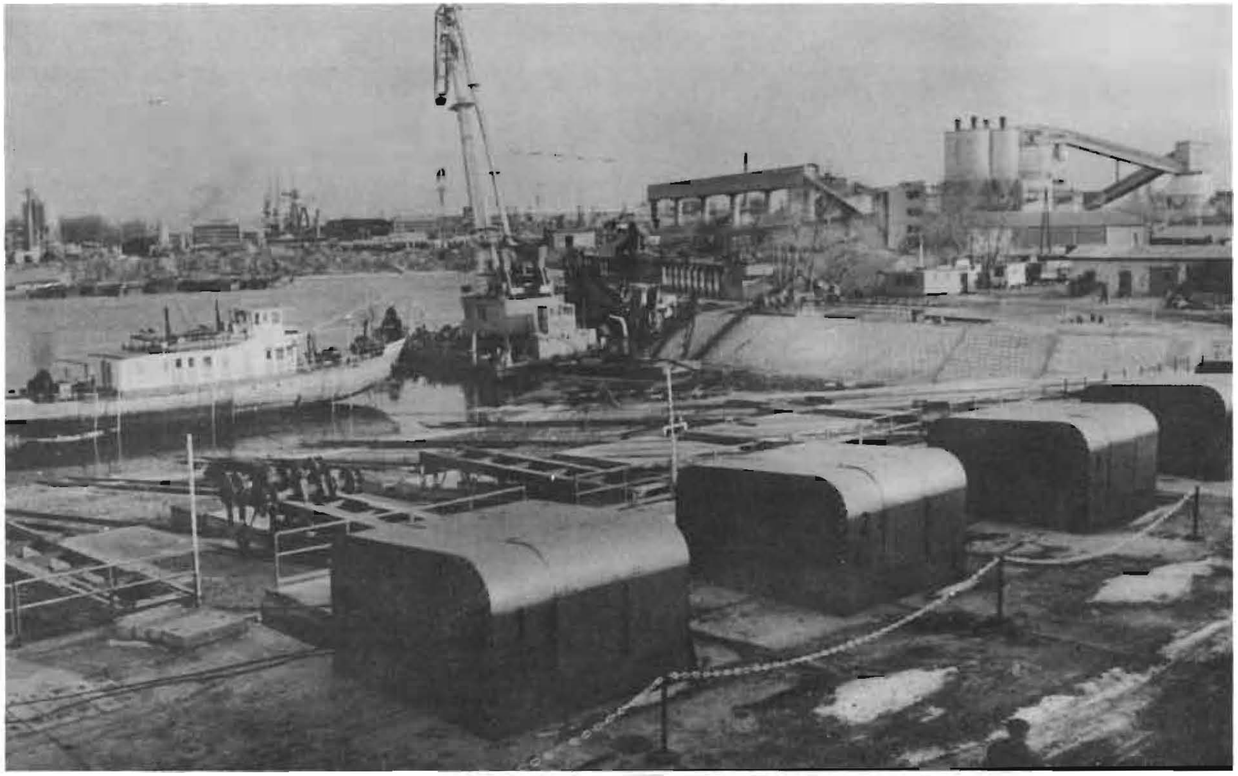

Table VI.
Motordriven slipway in the repaireworks of the „FOKA" Co.

Table VII.
Drydocking by slipway of an icebreaker

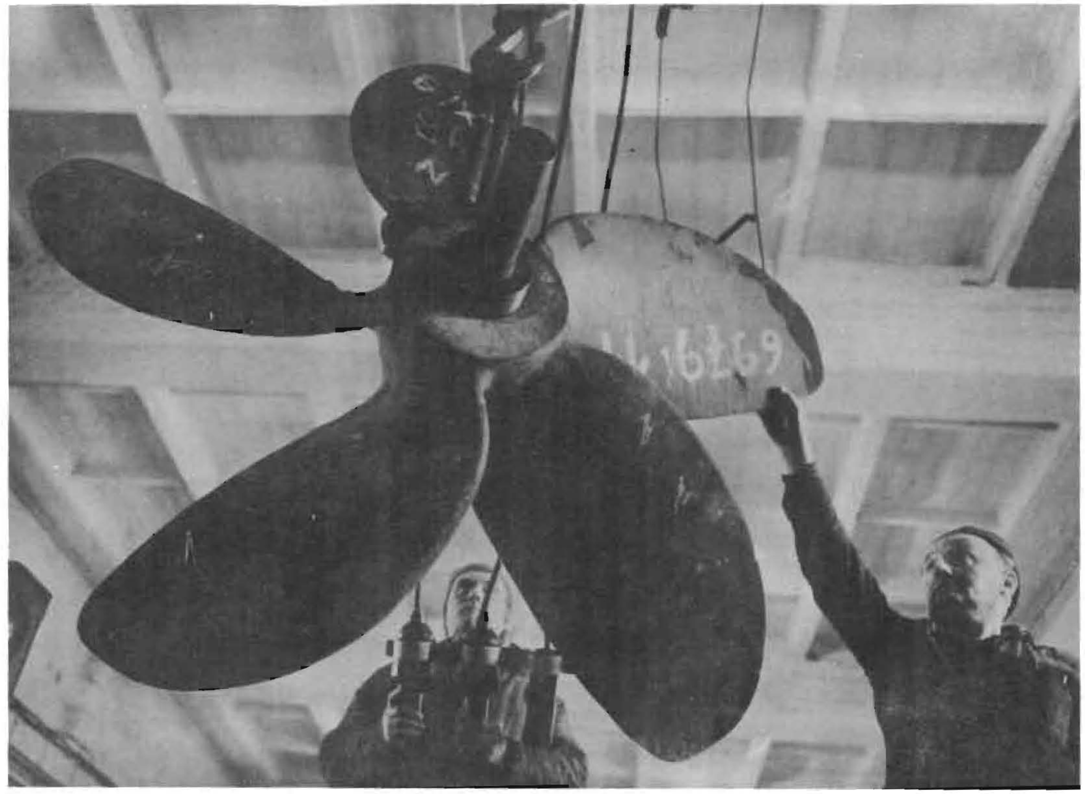

Table VIII.
Controll of a ship's propeller

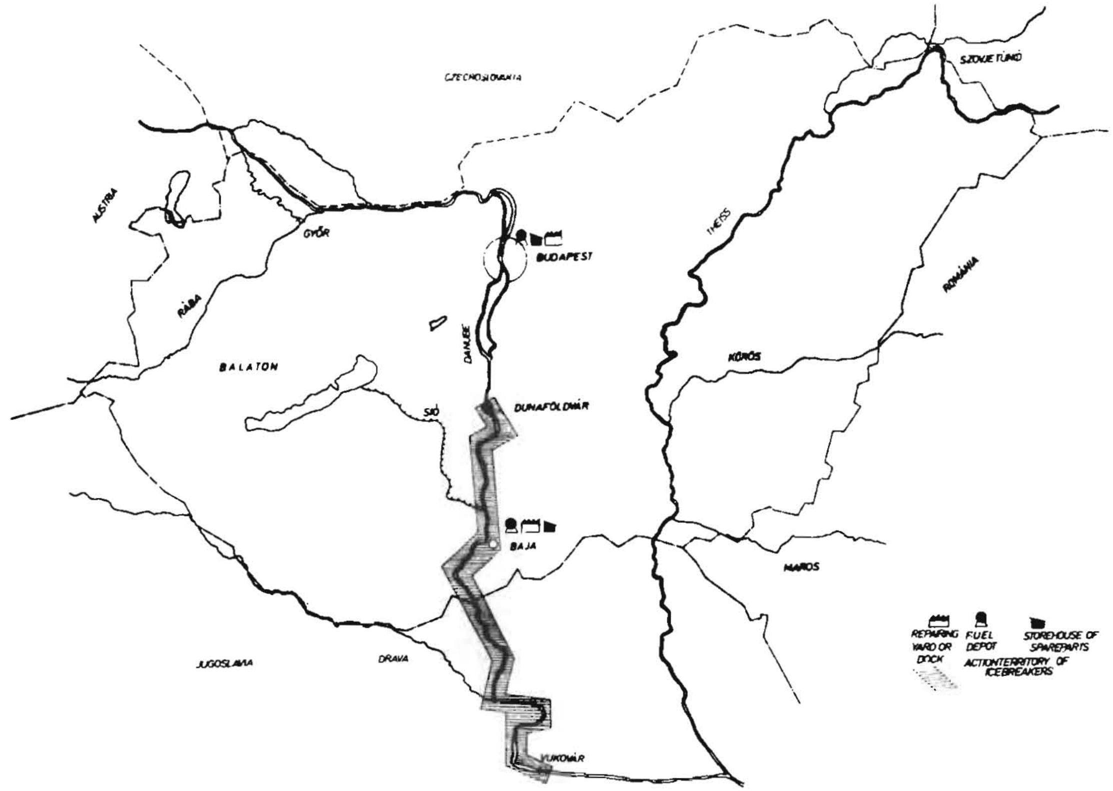

Table IX.
Territory (Range) of service of the icebreakers and their bases of repaire

Table X.
Flagship in operation

Table XI.
A ship of the line

Felelős kiadó: Dr. Stelczer Károly

VIZDOK

Készült a Vízügyi Dokumentációs és Tájékoztató Iroda sokszorosító üzemében, Budapest VII., Kazinczy u. 3/b. — 73/1230 — F. v.: Szabó Gyula