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Lecture Note

Online monitoring of suspended sediment at the Zhicheng Gauging Station on the Yangtze River

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Lecture-3

Online monitoring of suspended sediment concentration at the Zhicheng Gauging Station on the Yangtze River

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Abstract: In recent years, river hydrometry technologies have been developing rapidly, but sediment measurement technology is still in the bottleneck period. Especially in the field of online monitoring technology, there is still a long way to go from laboratory to practical application. Zhicheng Gauging Station, located in the upper section of the middle reaches of the Yangtze River, which is downstream the dam of the Three Gorges and Gezhouba hydropower station. They followed the basic technical principle of sediment measurement, according to the sediment characteristics of the gauging station, chose the TES-91 infrared light sand-measuring instrument to carry out the adaptability test and precision experiment, and has been successfully put into use. This lecture briefly analyzes the innovation thought about suspended sediment monitoring methods, and takes ZhiCheng Gauging Station as an example, introduces the experiment process and results of suspended load on-line monitoring, evaluate the efficacy of the on-line monitoring scheme, and discusses the stability, environmental adaptability of online monitoring solution. Here also hands out a preliminary discussion about the sediment's source and composition characteristics, distribution features in the cross-section, and further technical research, technical standards and other aspects, which aims at promotion and application.

Key Words: Method progress; Suspended sediment concentration; On-line monitoring; Middle reaches of the Yangtze River; Application

With the hydrologic data acquisition technology becoming more mature and stable, and the rapid development of computer, network, information, artificial intelligence and other technologies, the hydrometry work will move towards visualization, automation and intellectualization, and the online monitoring of hydrologic elements will become an important symbol of the hydrologic modernization. It is a significant attempt to break through the bottleneck of sediment monitoring technology by actively carrying out experiments, and it is an important content of the construction of smart hydrology [1]. In this document, we describe a successful case of on-line monitoring of suspended sediment at a hydrometric station, for reference.

1 A review of the basic techniques for suspended sediment measurement in rivers

Sediment measurement refers to the measurement of the form, quantity and evolution process of sediment movement in a river or water body, and the calculation of the scour and sedimentation volume in a certain section of a river or water body, including the suspended load discharge, bed load discharge, bed material measurement and sediment particle size analysis. ***Suspended load*** is sediment suspended in water and moved with the stream by the turbulent action of the current [2]. ***Suspended load discharge measurement*** is an operation to measure the quality of suspended sediment passing through a cross-section of a river or channel in unit time [2]. Here mainly introduces the suspended load discharge measurement.

1.1 Overview of measuring methods for suspended load in rivers

In order to obtain the total amount and process in a time section of suspended load through a certain cross-section of a river, the whole works consists of single sediment measure, measurement arrangement and data compilation.

1.1.1 Single sediment measure

There are two commonly used methods for measuring suspended sediment: direct measurement and indirect measurement. Direct measurement method is to directly measure the instantaneous suspended load with an instrument at a measuring point, this methodology requires that the flow velocity at the inlet of the instrument is equal to or close to the natural flow velocity and without disturbance to the flow. The indirect measurement method is to measure the average sediment concentration and average flow velocity in a period with two instruments at a measuring point, and multiply the two to get the average sediment load discharge in the period. We currently use indirect measurement in China. The direct measurement method is seldom used because the method cannot guarantee that the inlet velocity of the instrument is equal to the natural velocity.

The method selection of suspended load discharge measurement is related to the hydrologic characteristics of the station, the precision requirements and the facilities and equipment conditions. The commonly used methods are ***Sectional sediment transport rate method*** or ***Cross-section mixing method***, both of which conform to the principle of segment discharge weighted method [3]. ***Sectional sediment transport rate method*** calculates the suspended load discharge by the segment discharge weighted method, which divided by the discharge to obtain the mean sediment concentration of the cross-section. At present, the asynchronous sediment measuring method is also used, that is, the discharge and the sediment transport rate measurement are not carried out at the same time, and the segment discharge weight can be replaced by the comprehensive results of the stream gauging station or the weight of the near time discharge measurement result.

Onetime single suspended load sediment measurement, generally requirements measured the suspended load discharge at a cross-section and the mean sediment concentration at the cross-section. The classical approach is, arranging several sampling verticals on the cross-section, arranging a number of sampling points on each vertical or directly sampling of the vertical by using ***Depth-integrating method***, measuring the point or vertical sediment concentration directly or assaying in a laboratory, weighted calculating suspended load discharge by using segment discharge, dividing by the discharge to get the mean sediment concentration of the cross-section. Or according to a certain method, mixing the water samples of all sampling point or vertical in the cross-section, measuring the mean sediment concentration at the cross-section directly by assaying the mixed water sample of the whole cross-section, and multiplying the discharge of the cross-section to obtained the sediment transport rate of the cross-section.

The theoretical methods of ***Cross-section mixing method*** mainly include ***Equal-segment-area cross-section mixing method*** and ***Equal-part-discharge cross-section mixing method***. The ***Equal-***

segment-area cross-section mixing method requires that the partial area represented by each vertical should be equal, and each vertical should have the same sampling method. If it is a time-integrating sampler, the inlet pipe diameter, sampling method and sampling duration of the vertical should be the same. In practical application, according to the different hydrometric conditions, there are some varietal methods such as area weighting and sampling duration weighting. The ***Equal-part-discharge cross-section mixing method*** requires that the sampling volume of each vertical and the partial discharge represented by it should be equal. In addition, there is also a cross-section mixing method with equal water surface width, and a round depth-integrating trip with same speed. About the arrangement of sampling verticals in the cross-section. The number and position of verticals of sectional sediment transport rate method shall be determined by test. Without test, there shall be no less than 10 for first-class stations, no less than 7 for second-class stations and no less than 3 for third-class stations [3]. The vertical position can be determined by using unit sediment transport rate turning point method, equal sectional sediment transport rate method or equal part-discharge method. The verticals of the cross-section mixing method are generally arranged in the center of the analyzed partial cross-section.

The index sediment concentration measure methods of those stations, which use the index and cross-section average sediment concentration relation curve method for sediment data processing, mainly include representative line method, equal discharge multi-line method, mainstream multi-line method and cross line method.

The vertical measure methods of suspended load discharge can be ***Point-selecting method***, ***Depth-integrating method*** and ***Vertical mixing method***. Point-selecting method mainly has five-point method, three-point method, two-point method, one-point method and so on. Vertical mixing methods include mixing method according to sampling duration ratio or mixing method according to sampling volume ratio.

In order to obtain the sediment concentration data of a water sample or a mixed water sample, the collected water sample needs to go through the steps of volume measuring, settling and concentrating, processing and weighing (oven-dry method, filtration method, displacement method), and calculating the sediment concentration, and the time period is more than 1 day to several weeks. As a comparison, if we use a sediment concentration meter, we can obtain the real-time sediment concentration data on site by measuring water sample directly.

1.1.2 Measuring frequency control

In order to measure suspended load discharge integrally, the measurement frequency should be reasonably arranged, and the changing process of sediment transport rate should be controlled. The times of the measurements in a year should be mainly distributed in the flood season. The requirement of measurement frequency control is related to the data processing method.

The general rules are:

(1) When the cross-section mean sediment concentration hydrograph method is used for data processing, measurement times should be able to control the whole process of sediment concentration change.

(2) In the case of index and cross-section average sediment concentration relation curve method, index sediment concentration measurement should control the change process of sediment concentration, the cross-section average sediment concentration and the equivalent index sediment concentration measurement should meet the requirements of relation curve determination and control the turning point of the relation curve changing.

(3) When using the hydrograph method of index and cross-section average sediment concentration ratio to process data, the measurement times should be evenly distributed and the turning points of the proportional coefficient changing should be controlled, and should distribute measurement times at the main turning points of flow discharge and sediment concentration.

(4) When the discharge and sediment discharge relation curve method is used to process the data, the measurement times distribution should be able to control the changing process of the main flood peak, a small number of measurements should be distributed in the normal-flow and low-flow period, and the measurement number distribution of sediment transport rate should meet the requirements of data process and relation curve determination.

1.1.3 Data Process

In order to obtain the daily, ten-day, monthly, annual or one flood process's sediment runoff, sediment runoff modulus and the variation process of cross-section average sediment concentration, it is necessary to compile the original data of suspended sediment, that is, to conduct identification, collation, analysis, statistics, review, compilation, publication or storage according to scientific methods and uniform specifications.

The classical methods for the suspended sediment data processing include: ***Cross-section mean sediment concentration hydrograph method***, ***Index and cross-section mean sediment concentration relation curve method***, ***Index and cross-section mean sediment concentration ratio hydrograph method***, and ***Discharge and sediment discharge relation curve method*** [4]. In recent years, the ***Nearby station's index sediment correlation relation curve method***, and the ***Water-sediment ratio coefficient correlation method*** have also appeared [5].

1.2 An overview of suspended sediment measuring instruments

At present, the commonly used suspended sediment measuring instruments mainly include two types: sampler and sediment concentration meter [3]. The sampler can collect the water sample, and then obtain the sediment concentration and grain-size distribution through the water sample treatment and analysis. The sediment concentration meter basically can only obtain the sediment concentration on site, and generally do not take water samples. There are also sediment measuring meters that can carry out particle size analysis on site. Appropriate instruments should be selected according to measuring methods, site environment and instrument technical indicators. Hydrometric stations need to comprehensively consider water and sediment characteristics, equipment conditions and precision requirements to select instruments with better performance and reliable and efficient measuring methods.

The sampler includes instantaneous sampler and time-integrating sampler. The time-integrating sampler mainly includes the pressure adjustable time-integrating sampler, the collapsible sampler, the ordinary bottled sampler, etc. The instantaneous sampler mainly includes the horizontal sampler, the vertical sampler, etc.

The sediment concentration meter mainly includes radioisotope sediment concentration meter, optical sediment concentration meter, acoustic sediment concentration meter, vibrational sediment concentration meter and so on.

1.3 Overview of online monitoring technology

Since the 21st century, the emergence of new technologies and new instruments has made it possible to monitor sediment rapidly and measure it online in real time. The technology of directly sediment measuring with sediment meter has been developing rapidly. This kind of instrument places the instrument or measuring prober directly into the measuring point in the water to measure the sediment concentration in real time. At the same time, advanced software technology is used to analyze and calculate the original measurement results, and the real-time remote transmission of measurement information is realized through the communication network. This kind of all-weather, continuous, fixed-point observation and the real-time transmission of data to the shore station constitute the basic framework of the suspended sediment online monitoring technology. In practical application, environmental adaptability, measurement accuracy, stability, reliability of the instrument, the representation of the measurement points (areas), and the economy and practicability of the scheme are also the factors affecting the application.

2 Innovative idea of monitoring method of suspended sediment

2.1 Problems Facing

Many hydrometric stations are facing two problems in the stream, sediment measuring. On the one hand, is affected by the project, the relations between stage and discharge, discharge and sediment concentration, and movement rules of water and sediment have changed, the relationship between each hydrologic element become more and more complex, the traditional hydrometry and data processing are encountering some difficulties. On the other hand, flood control and disaster reduction, water resources management and water environment and ecology protection put forward more stringent requirements aiming at hydrologic services. Under the premise of ensuring the accuracy of hydrometry, it is more and more urgent to improve the timeliness of hydrometry. Sediment measure is most complicated in all hydrologic element measurements. Automatic measuring and reporting of stage, water temperature, precipitation, evaporation and other elements have been realized many years ago. More and more discharge rapid monitoring and online monitoring are appearing, but efficient sediment monitoring technology is still the bottleneck to be broken through.

In Changjiang Hydrology, a hydrologic organization of a major member country of the International Organization for Standardization Technical Committee on Hydrology (ISO/TC113), vast number of hydrologists are innovating continuously. Many systematic studies were done, such as requirements for hydrologic service system, hydrometric management system, the discharge measurement method innovation, sediment measurement method innovation, hydrologic monitoring for emergency response and practical technology, hydrometric accuracy control technology, new hydrological data processing technology, adaptability of hydrometric standard, etc. They accumulated experiences, and achieved rich results [6]. Since the beginning of this century, in order to improve the time efficiency of suspended sediment measurement, turbidimeter, LISST series instrument, OBS and other field sediment measurement instruments have been introduced into Changjiang Hydrology, which have been used in the sediment comparative gauging in the upstream, downstream and estuary reaches of the Yangtze River respectively, and achieved some practical effects. However, it is almost difficult to find a universal new instrument or new method due to the long line and wide area of the Yangtze River Basin and the complex and diverse sediment characteristics. Such as in the Jingjiang reach of the Yangtze River, although some stations which have no sediment monitoring tasks have taken a big step forward ***Total factor***, ***Full time***, ***Full range*** on the on-line monitoring, the traditional method on sediment monitoring, which needs field sample collection, analysis in laboratory, is still dominant. It is badly in need of the technology progress in rapid sediment measurement, online sediment measurement.

2.2 Ideas to solve problems

In order to meet the requirements of precision, timeliness and scientific reduction of labor intensity simultaneously, it is still necessary to combine the principle of hydrometry with new instruments, new techniques and new methods. Usually there are the following methods:

(1) Improve and optimize classical measure methods. Firstly, the single measure scheme can be optimized, improve sampling efficiency (such as using multi-cabins instantaneous sampler, reducing measuring verticals or points, implementing cross-section mixing method for time-integrating sampler, etc.), or improve water sample analysis efficiency (such as field analyzing with turbidimeters, accelerating concentrating, drying and weighing, etc.). The second is to optimize the measuring frequency control, such as analyzing better data processing method to simplify the measurement, using sediment forecasting information to optimize the measurement layout, using the edge sand rapid test to assist the measuring times arrangement. The third is to optimize the data processing method, seeking a more efficient processing method. Fourthly, to optimize the hydrometric manner, such as tour gauging, intermittent gauging. Fifth, to explore the optimization and integration of the entire production process.

(2) Use the field sediment measuring instrument to quickly measure on site. One method is to collect water samples on site and measure the sediment concentration with sediment concentration meter. Another type method is to measure the sediment directly without sampling, which can be used for online monitoring. In this kind of method, the conversion or switch between instrument perception and traditional sediment concentration (usually a unit of weight) should be solved, as well as the problems such as environmental adaptability, measurement point (or line, region) representativeness, multi-sensor combination, average sediment concentration algorithm model and so on. Theoretically, the real-time online system can work continuously all day long, and the sediment changing process can be controlled more completely. But, the problem of process data information simplifying should be solved in the data processing phase.

(3) **Scan and perceive cross-section sediment concentration directly.** For example, ADCP is used to measure the acoustic scattering signal strength distribution, and the sediment concentration distribution shall be calculated indirectly by the correlation between the scattering signal strength and sediment concentration [7].

(4) **Measure sediment by remote-sensing technology.** For example, uses satellite remote-sensing technology to measure sediment, which is a method from a large scale, is a non-contact method, has gone beyond the scope of hydrometric station's measure means [8].

(5) **Other physical or chemical methods.**

Measuring single mean sediment concentration at a cross-section accurately, and measuring sediment concentration changing process completely, are all effective ways to improve hydrometric accuracy of suspended load for hydrometric stations. And, to implement on-line monitoring by using the method met the single measuring precision requirements, not only can improve the quality of measurement, also can improve the measurement conditions, reduce labor intensity. It is a new direction of sediment measurement technology innovation.

2.3 Discussions on the conditions of an on-line monitoring system

An online monitoring system for suspended sediment measuring shall at least meet the following conditions:

(1) The instrument can accurately perceive the sediment concentration and its changing process. Its stability, reliability and accuracy can meet the specification requirements and production needs, and its endurance capacity can meet the requirements of long-term online work.

(2) The system equipment can adapt to the work environment, effectively deal with the bad weather such as scorching sun, rainstorm, wind and waves, and can adapt to different sediment concentration, different water depth, flow velocity, water temperature, water quality and aquatic biological environment.

(3) The representative points (representative lines, representative areas) can be found in the measure river reach/cross-section. The measure parameters and measure frequency are controllable, and the representativeness, reliability and consistency of the data can meet the production needs.

(4) The timeliness, reliability and security of information transmission can meet certain requirements, and the shoreline station can obtain the sediment concentration data information and equipment running status information in time.

(5) The precision of measuring and processing can meet the requirements of relevant specifications and data using needs.

(6) It is helpful to improve efficiency and improve the level of science and technology. It is simple to construct, convenient and easy to use, and the economic cost is acceptable.

3 On-line monitoring experiment at Zhicheng Gauging Station [9]

At present, the instruments that can be used for real-time on-line sediment measurement are all directly measuring instruments. Radioisotope sediment concentration meter, photoelectric sediment concentration meter, acoustic sediment concentration meter and vibrational sediment concentration meter have been developed successively in the world. However, these instruments have not been widely used because of the lack of matured products. Among the hydrometric stations in Jingjiang Reach, we selected Zhicheng Station for experiment. Hach turbidity meter, LISST-100X, BT2600 field sediment measuring instrument and TES-91 online measuring instrument were successively tried, all of which were optical sediment measuring instruments. Among them, TES-91 instrument had strong applicability and high efficiency.

3.1 Brief introduction of Zhicheng Gauging Station

(1) Basic information of the station

Zhicheng Gauging Station is a national basic hydrometric station and an important entrance control station of the Jingjiang Reach of Yangtze River. Founded in 1925, is located in Yidu City, Hubei Province. It collects basic hydrologic data for the country, and provides hydrologic data for flood control and drought control, rational allocation of water resources and river regulation of Jingjiang Reach and Dongting Lake. On the right bank of 20 km upstream the measuring cross-section, the Qingjiang River enters the Yangtze River, about 64 km upstream is the Gezhouba Hydropower Project, and about 103 km upstream is the Three Gorges Dam. The station has a catchment area of 1,024,131 km², and the monitoring elements include precipitation, stage, discharge, suspended sediment concentration, suspended sediment grain-size distribution, soil bed load, pebble bed load, bed material, etc. The hydrometry crossing facility is a hydrometric boat.

(2) The characteristics of river reach and hydrometric cross-section

Zhicheng measuring reach is on a straight transition segment between two bends. The straight reach is about 3 km length, slightly narrow at the upstream and wide at the downstream, as shown in Figure 3.1-1. In the channel, the river is between 1200 ~ 1400 m wide when it’s middle or high stage, which belongs to the wide-shallow river. The riverbed of the gauging cross-section is composed of sands and reef. The runoff of Zhicheng Station mainly comes from the upstream trunk stream of the Yangtze River and the Qingjiang River.

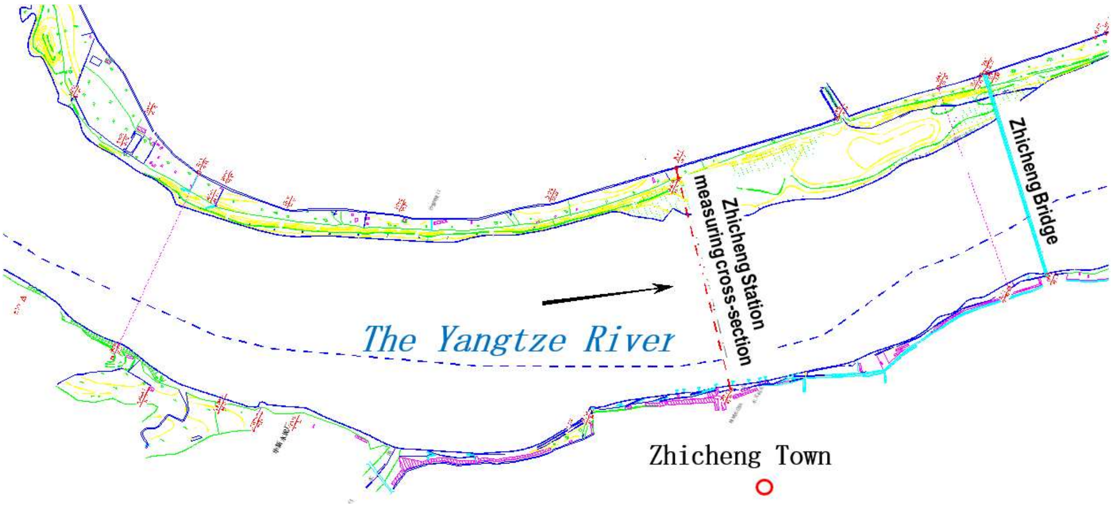

Fig. 3.1-1 River pattern diagram of the measuring reach of Zhicheng Gauging Station

According to the existing data, a total of 16 measured data before flood season from 1991, 2001 and 2006 to 2019, drew the multi-year possible maximum cross-section diagram, as shown in Figure 3.1-2. After the water storage of Three Gorges Reservoir, the erosion of the riverbed in the downstream reaches of the dam is particularly severe due to the discharge of clear water. Under the influence of erosion over the years, the riverbed shape of the measuring cross-section has changed from "V" to "U", which has a great influence on the hydrologic characteristics of this station. In recent years, the cross-section of Zhicheng Gauging Station has tended to be stable.

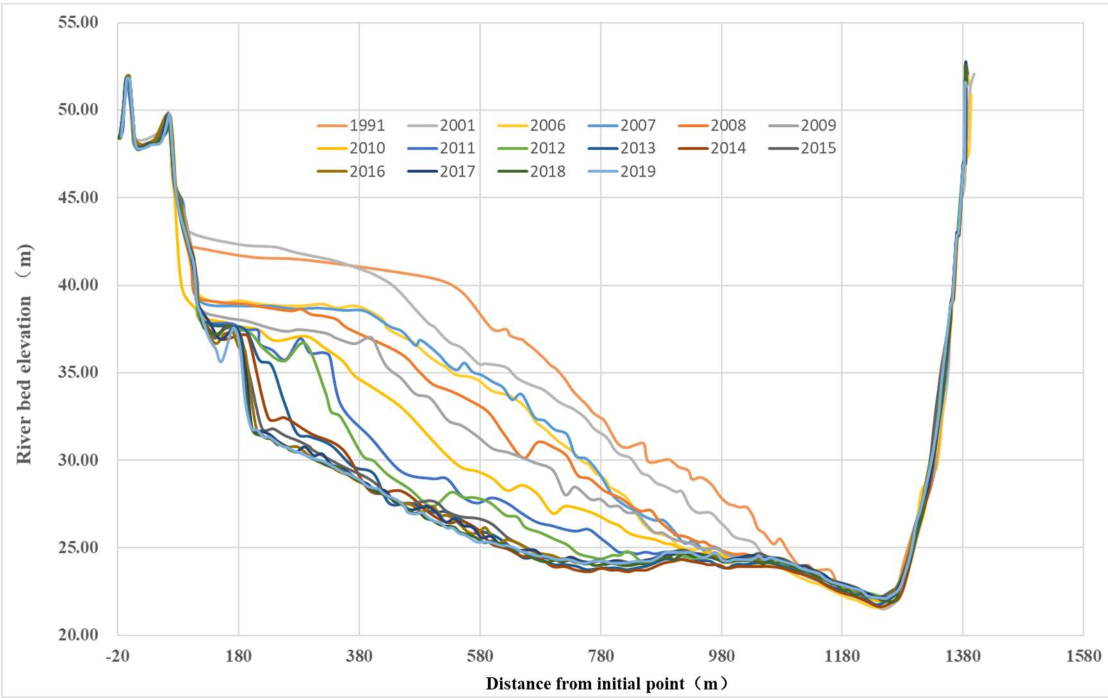

Fig. 3.1-2 Multi-year possible maximum cross-section diagram of Zhicheng Station

(3) Sediment properties

The runoff of Zhicheng Gauging Station mainly comes from the upper reaches of the Yangtze River and its tributary Qingjiang River, and the sediment mainly comes from the upper reaches of the

Yangtze River, which is also affected by the scouring and silting in the downstream reaches of the dam. Before the impoundment of the Three Gorges Reservoir, the multi-year average suspended sediment runoff was 37690×10^4t, and the multi-year average suspended concentration was 0.856 kg/m^3. After the operation of the Three Gorges Reservoir, the sediment in the downstream of the dam decreased sharply. The multi-year average suspended sediment runoff in Zhicheng station was 2989×10^4t, the multi-year average sediment concentration was 0.068 kg/m^3, and the minimum sediment concentration was 0.002 kg/m^3. The maximum sediment concentration was 1.52 kg/m^3. Since 2016, the sediment concentration varies between 0.002-1.16 kg/m^3, and the sediment concentration is generally less than 0.30 kg/m^3 during **NOT** the sediment-discharging periods of Three Gorges and Gezhouba. Since 2007, the median particle diameter of suspended sediment varies from 0.005 to 0.018 mm, and the maximum particle diameter varies from 0.603 to 1.09 mm.

3.2 Introduction of TES-91 online sediment concentration monitoring system

(1) System composition

The system consists of monitoring instrument, RTU, communication network, data center and so on. The monitoring instrument is composed of a single or multiple TES-91 sediment measuring sensors; RTU includes data acquisition controller, wireless transmission module, anti-thunder protection device, field LCD displayer, solar power supply system; The communication network adopts GPRS, Beidou Satellite or other communication methods; The data center consists of servers, user computers, software, and so on. The main components and topological relations of the system are shown in Figure 3.2-1.

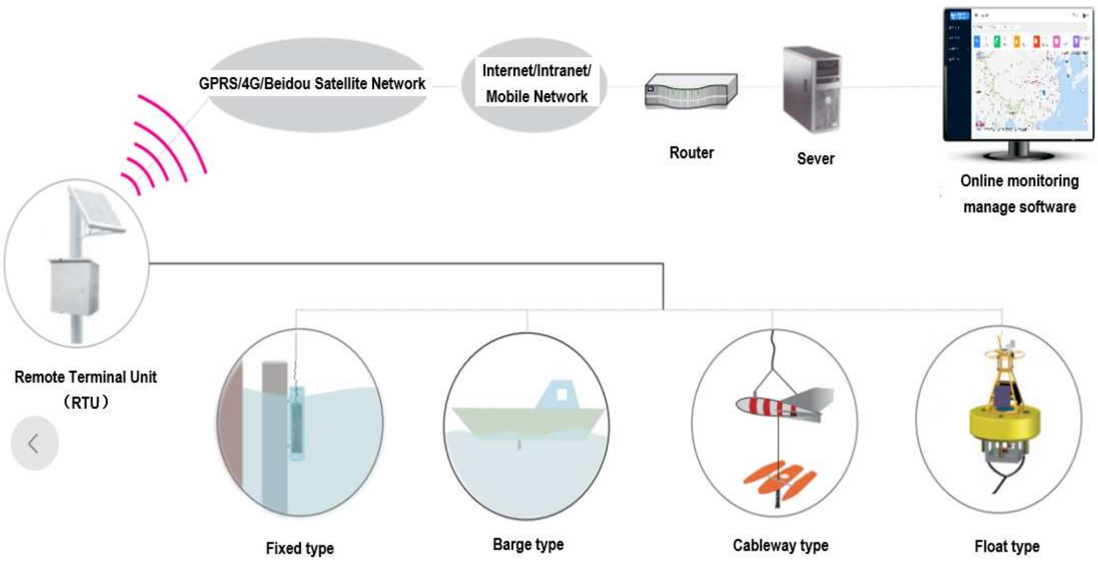

Fig. 3.2-1 Topology of online sediment concentration monitoring system

(2) Operating principle of the system

The kernel of the system is an infrared optical sensor, as shown in Figure 3.2-2, which mainly monitors the infrared light scattering signal with the scattering angle between 90° and 135°, measures the sediment in the water by the backscattering and the side scattering sensors, and directly outputs the sediment concentration through mathematical model conversion.

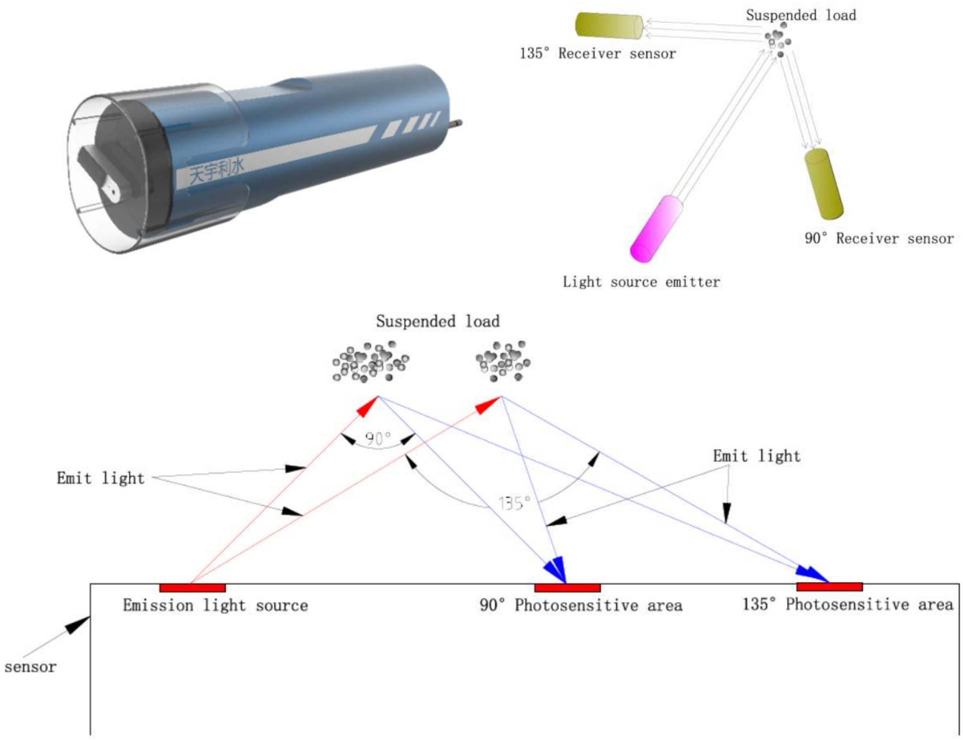

Fig. 3.2-2 Infrared optical sensor for sediment concentration online monitoring

They calibrated the measurement range, accuracy, self-protection level and environment requirements of the on-line sediment monitoring system. The main technical parameters are shown in Table 3.2.

Table 3.2 Main technical parameters of infrared optical sensor for sediment concentration online monitoring

Measuring range	0.001-120 kg/m^3
Accuracy of measurement	5% of the reading
The flow velocity	Less than 6.0 m/s or 19.8 ft/s
Measure ambient temperature	0 to 55 ℃
Main materials of sensor	Titanium alloy, sapphire, PVC, fluorine rubber and so on
Calibrate	Multi-point calibration is performed according to sediment homogeneity
Protection grade	IP68/NEMA6P

(3) System functional characteristics

The system supports multiple sediment measurement sensors, which can automatically set the number of single cleaning times and cleaning interval according to the measurement frequency of sediment concentration. The data center can receive the sediment concentration data of multiple cross-sections at the same time, be responsible for monitoring the whole sediment concentration measuring system, and complete the tasks of real-time collection, storage and data handling. It supports remote bidirectional control of the operating state of the instrument and modification of acquisition instructions.

3.3 Adaptability test

In 2019, Zhicheng Gauging Station introduced TES-91 online sediment concentration monitoring system on the basis of a lot of investigations. Before the formal comparative test, it was installed at the tail of Zhicheng Hydrologic Pontoon for experimental comparative test on April 5, 2019, to check the stability of the instrument and whether it fits the sediment characteristics of Zhicheng Station.

(1) Test method

Carry out synchronous comparative test between traditional method (horizontal sampler, oven-dry method weighing) and TES-91 online measurement at the same position. Try to establish a model through the TES-91 instrument indicating value and the sediment concentration of traditional method, analyze the reliability of the instrument model.

(2) Test results

Fifty sediment concentration samples at the same location were collected, and the sediment concentration was 0.019 ~ 0.188 kg/m^3. Establish a correlation between the indicated value of TES-91 and the sediment concentration at the same location, as shown in Figure 3.3-2. The results showed significant correlation, the correlation coefficient is 0.9802, the mark test $u = 0.14$, the curve fitting test $u = 0.86$, the deviation-data test $|t| = 0.97$, are all qualified. The random uncertainty was 16.4%, and the systematic error was 1.6%, which met the requirements of relevant specifications.

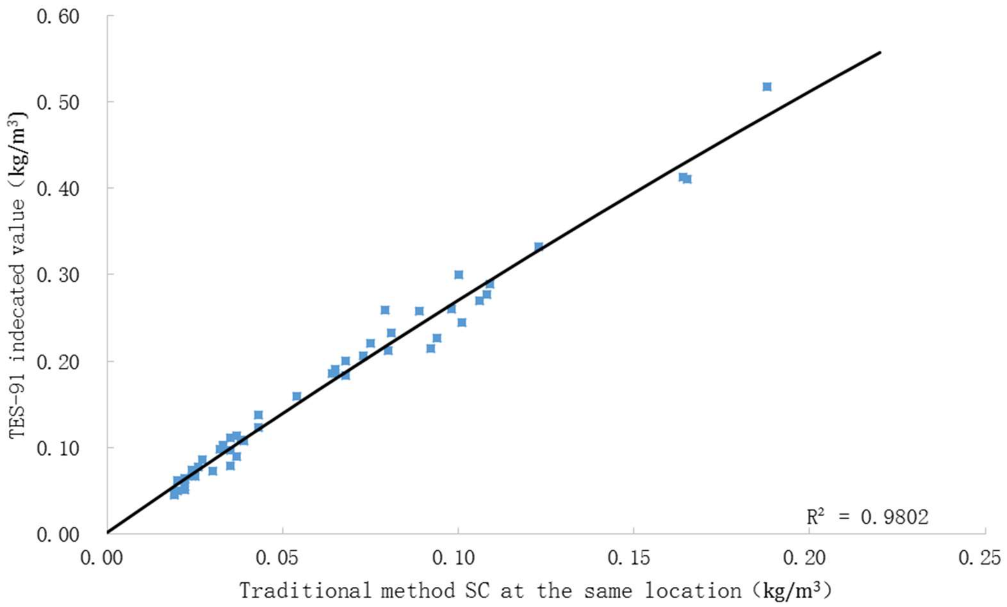

Figure 3.3-2 Data relationship between TES-91 and traditional method at the same location

3.4 Accuracy test

The accuracy comparative test of TES-91 sediment measuring instrument was carried out in Zhicheng Gauging Station from Jan 1st to Sep 30th, 2020.

(1) Instrument installation

In 2020, the accuracy comparison test of TES-91 online sediment concentration monitoring system has been officially carried out. Considering the uniform distribution of suspended sediment in the test reach of Zhicheng Station, the sand measuring sensor were installed at the tail of a fixed navigation vessel about 1km downstream from the 930m distance from initial point of the measuring cross-section. The relative position of the monitoring platform is shown in Figure 3.4-1. TES-91 sediment concentration sensor enters 1.30 m depth into the water, with the lens facing down. Troubleshooting needs to be done in time if pop up abnormal data or winding objects.

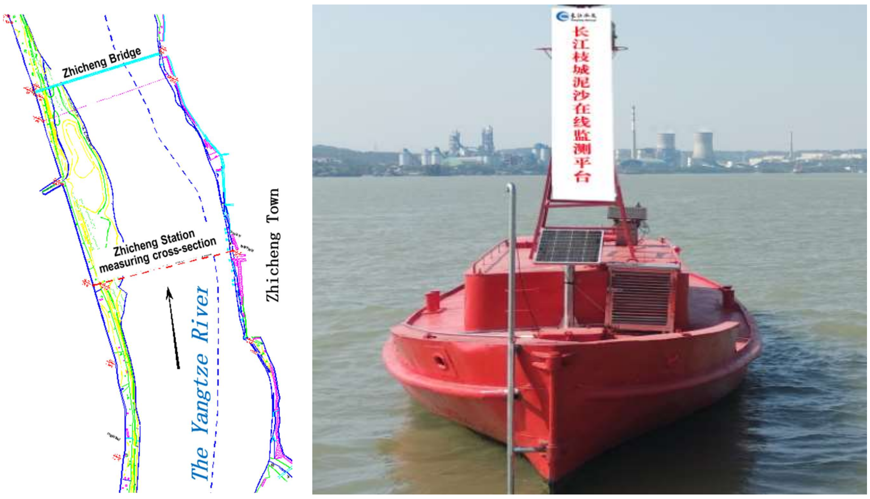

Figure 3.4-1 Online Sediment Monitoring Platform of Zhicheng Station

(2) Test methods and results

① **instrument measurement accuracy, stability test.** A horizontal sampler was used beside the TES-91 instrument to sample, and then dry and weigh in laboratory. A total of 111 samples were collected from January to September in 2020. The original method measured sediment concentration from 0.003 to 0.972 kg/m^3, and the TES-91 instrument's simultaneous reading value were from 0.003 to 1.158 kg/m^3. Correlation was established between the sediment concentration measured by the original method and the indicated value of TES-91 for analysis and evaluation. Correlation coefficient was 0.9969, and the correlation was shown in Figure 3.4-2. Using the data with sediment concentration greater than 0.1 kg/m^3 in the relationship curve to inspection, the sample size N = 54, the mark test u = 0.68 (significance level a = 0.25, accepted value is 1.15), the curve fitting test u = 1.37 (inspection-free), the deviation-data test $|t|$ = 0.00 (significance level a = 0.10, accepted value is 1.67). All three tests are qualified; the random uncertainty is 13.0% (allowable 18.0%), and the systematic error is 0% (allowable 2%), which meets the requirements of the Code SL 247.

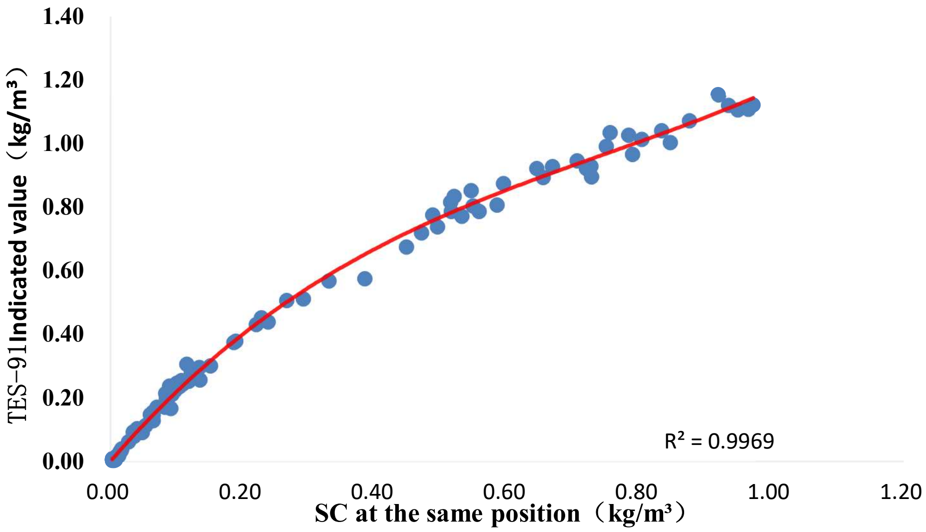

Fig. 3.4-2 Relationship between TES-91 reading and sediment concentration (SC) at the same position

② **Analysis about representativeness of monitoring points.** Establish the correlativity between the sediment concentration at the nearest position by the monitoring sensor and the mean sediment concentration at the cross-section of Zhicheng Station, to analyze the representativeness of monitoring points. Therein, used a horizontal sampler to sample at the measuring cross-section of Zhicheng Station, and used oven-dry mothed to obtain the sediment concentration, collected 67 samples of mean sediment concentration at the cross-section. The measured mean sediment concentration was 0.003 ~ 0.972 kg/m^3, and the measuring method is shown in the table below.

Table 3.4-1 Suspended load measuring mothed and vertical scheme of Zhicheng Station

Method	Sampling line & point amount	Vertical's distance from initial point (m) (increase or decrease with stage fluctuation)
Point-selecting method	15 ~ 18 lines, 5 points per line	100, 300, 500, 700, 780, 840, 900, 930, 960, 990, 1020, 1060, 1100, 1140, 1180, 1220, 1260, 1290
Vertical mixing method	9 ~ 12 lines 2 points per line	100, 300, 500, 700, 840, 900, 960, 1020, 1100, 1180, 1260, 1290
Asynchronous sediment measuring method	8 lines 2 points per line	700, 840, 900, 960, 1020, 1100, 1180, 1260

A correlativity was established between the nearest position by the monitoring sensor and the mean sediment concentration at the cross-section of Zhicheng Station, with a correlation coefficient of 0.9983. See Figure 3.4-3 for the correlativity. All the three tests are qualified; The random uncertainty and systematic error are to meet the requirements of the Code SL 247. This is also the superiority of the distribution characteristics of sediment concentration in Zhicheng reach. It is this characteristic that can realize that the online monitoring point and the conventional method of sediment measurement are not in the same cross-section.

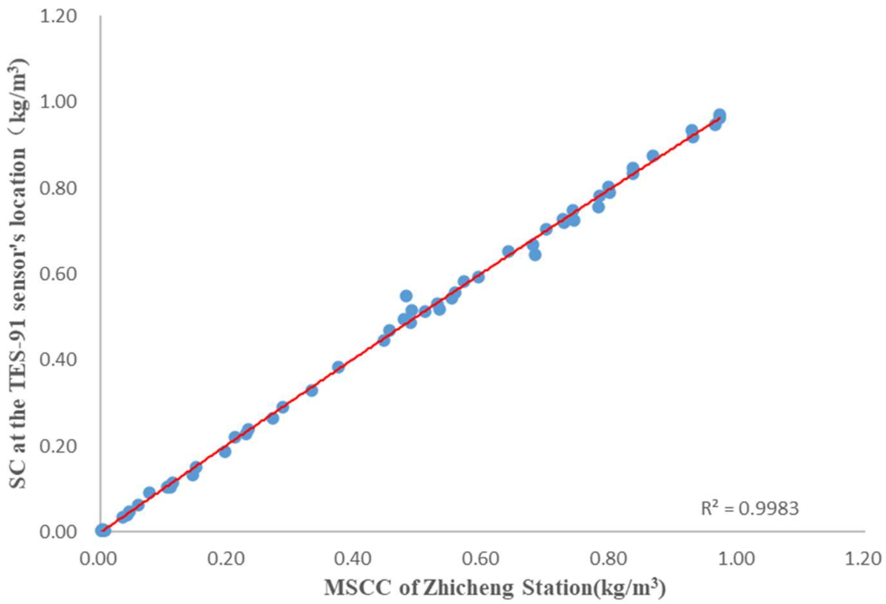

Fig. 3.4-3 Relation diagram of sediment concentration at the sensor's location and mean sediment concentration at the cross-section (MSCC) of Zhicheng Station

③ **On-line monitoring curve calibration test.** Finally, a direct correlativity was established between the value of TES-91 online measuring instrument and the mean sediment concentration at the cross-section of Zhicheng Station to determine the working curve of the online monitoring system. A correlation was established between the indicated value of TES-91 and the mean sediment concentration at the cross-section of Zhicheng Station, with a correlation coefficient of 0.9933. See Figure 3.4-4.

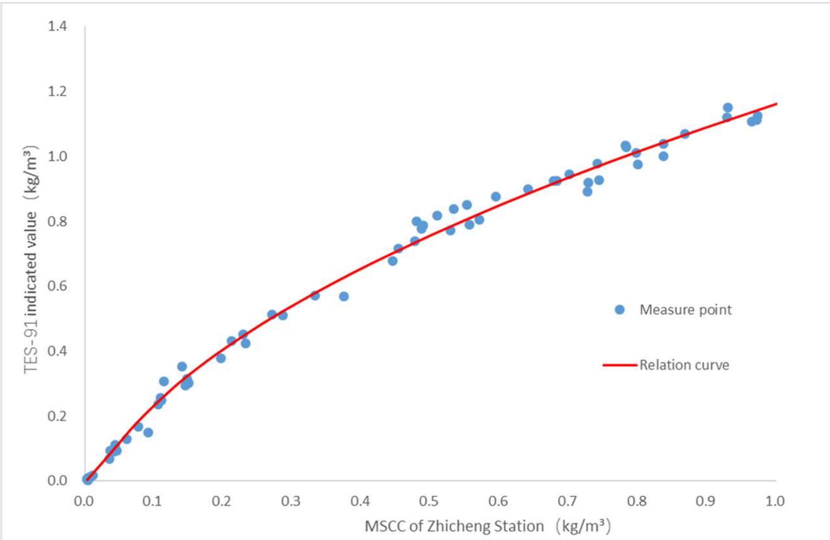

Figure 3.4-4 Relationship between TES-91's indicated value and Zhicheng Station's MSCC

Using the data with sediment concentration greater than 0.1 kg/m^3 in the relationship curve to inspection, the sample size N = 49, the mark test u = 0.00 (significance level a = 0.25, accepted value is 1.15), the curve fitting test u = 2.74 (inspection-free), the deviation-data test | t | = 0.20 (significance level a = 0.10, accepted value is 1.05). All three tests are qualified; The random uncertainty was 14.2% (allowable 18.0%), and the systematic error was 0.2% (allowable 2%), which met the requirements of the Code SL 247. The test data are shown in Table 3.4-2.

Table 3.4-2 Test table of relation curve between TES-91 and *MSCC*

No.	Measure No.	TES-91's value (kg/m^3)	Measured *MSCC* (kg/m^3)	Reading *MSCC* from curve (kg/m^3)	Deviation $P_{(i)}$ (%)	$P_{(i)} - \bar{P}$	$(P_{(i)} - \bar{P})^2$
1	27	0.235	0.106	0.101	4.95	4.75	22.56
2	18	0.249	0.111	0.108	2.78	2.58	6.66
3	17	0.257	0.109	0.112	-2.68	-2.88	8.29
4	30	0.295	0.145	0.131	10.69	10.49	110.04
5	73	0.302	0.150	0.136	10.29	10.09	101.81
6	22	0.308	0.114	0.140	-18.57	-18.77	352.31
7	31	0.314	0.148	0.143	3.50	3.30	10.89
8	21	0.353	0.140	0.166	-15.66	-15.86	251.54
9	32	0.377	0.196	0.181	8.29	8.09	65.45
10	33	0.424	0.232	0.212	9.43	9.23	85.19
11	72	0.432	0.212	0.217	-2.30	-2.50	6.25
12	71	0.452	0.229	0.232	-1.29	-1.49	2.22
13	69	0.510	0.286	0.275	4.00	3.80	14.44
14	70	0.514	0.270	0.279	-3.23	-3.43	11.76
15	67	0.568	0.374	0.323	15.79	15.59	243.05
16	68	0.571	0.332	0.326	1.84	1.64	2.69
17	66	0.679	0.445	0.423	5.20	5.00	25.00
18	65	0.716	0.453	0.458	-1.09	-1.29	1.66
19	64	0.740	0.477	0.483	-1.24	-1.44	2.07
20	63	0.773	0.528	0.517	2.13	1.93	3.72
21	42	0.776	0.487	0.521	-6.53	-6.73	45.29
22	43	0.786	0.489	0.531	-7.91	-8.11	65.77
23	62	0.790	0.556	0.536	3.73	3.53	12.46
24	44	0.800	0.480	0.546	-12.09	-12.29	151.04
25	61	0.806	0.570	0.551	3.45	3.25	10.56
26	41	0.818	0.509	0.564	-9.75	-9.95	99.00
27	40	0.838	0.533	0.587	-9.20	-9.40	88.36
28	39	0.851	0.552	0.601	-8.15	-8.35	69.72
29	38	0.875	0.594	0.629	-5.56	-5.76	33.18
30	45	0.892	0.726	0.648	12.04	11.84	140.19
31	60	0.898	0.641	0.656	-2.29	-2.49	6.20
32	46	0.920	0.728	0.681	6.90	6.70	44.89
33	59	0.924	0.682	0.686	-0.58	-0.78	0.61
34	37	0.925	0.678	0.688	-1.45	-1.65	2.72
35	47	0.928	0.743	0.691	7.53	7.33	53.73
36	58	0.944	0.700	0.711	-1.55	-1.75	3.06
37	48	0.976	0.799	0.750	6.53	6.33	40.07
38	34	0.978	0.741	0.753	-1.59	-1.79	3.20
39	49	1.00	0.836	0.782	6.91	6.71	45.02
40	57	1.01	0.797	0.795	0.25	0.05	0.00
41	35	1.03	0.783	0.816	-4.04	-4.24	17.98
42	36	1.04	0.782	0.825	-5.21	-5.41	29.27

No.	Measure No.	TES-91's value (kg/m^3)	Measured *MSCC* (kg/m^3)	Reading *MSCC* from curve (kg/m^3)	Deviation $P_{(i)}$ (%)	$P_{(i)} - \bar{P}$	$(P_{(i)} - \bar{P})^2$
43	56	1.04	0.836	0.832	0.48	0.28	0.08
44	55	1.07	0.867	0.873	-0.69	-0.89	0.79
45	50	1.11	0.964	0.921	4.67	4.47	19.98
46	51	1.11	0.971	0.929	4.52	4.32	18.66
47	54	1.12	0.928	0.936	-0.85	-1.05	1.10
48	52	1.13	0.972	0.945	2.86	2.66	7.08
49	53	1.15	0.930	0.982	-5.30	-5.50	30.25
Sample volume:		N =49		Number of pluses: 24		Number of symbol exchanges: 33	
Mark test:		u = 0.00		Allowable: 1.15 (significance level a =0.25)		qualified	
Curve fitting test:		u = 2.74		Inspection-free			
Deviation-data test:		$\lvert t \rvert$ = 0.20		Allowable: 1.05 (significance level a =0.10)		qualified	
Standard deviation:		Se (%): 7.1		Random uncertainty (%): 14.2		Systematic error (%): 0.2	

Zhicheng Station's program has been approved in 2021 and now is officially put into operation. When the scheme is deployed, the calibration curve is to be transformed into a node table for the software model of the on-line monitoring system, and the interpolation calculation can be carried out by using ***Lagrange Interpolation Formula of Unary Three Points*** or ***Spline Function Interpolation*** method.

3.5 Effect of online monitoring solution

(1) Technical effect

In terms of single measure, compared with the horizontal sampler, the stability of the online monitoring data is better. The horizontal sampler, its accuracy affected by large disturbance to flow, sudden perfusion, sediment pulsation and other factors. The online system's parameters such as the average sampling time of the instrument can be set to effectively eliminate the influence of pulsation. The measuring data can be obtained in real time without waiting for 1 days or even several weeks. It can well meet the requirements of sediment flood-reporting.

In terms of measuring frequency control, the measuring arrangement of the original scheme is from several times a day to once a few days, which may lead to the risk of missing sediment peak and turning point. After the implementation of online monitoring, any period can be set according to the need in theory, to continuously monitor the changing process of sediment concentration, which is more beneficial to improve the quality of the data results.

In the aspect of data processing, after the implementation of online monitoring, the ***MSCC*** can be deduced from the working curve according to the indicated value of the online monitoring system, and the ***MSCC*** hydrograph method can be used for processing.

The theoretical errors of the data results obtained by the online monitoring system mainly consist of the following parts:

E_{online}= f (instrument perception error, model representativeness error, process control error, data processing error)

In practical application, it can also be evaluated by comparing the results of new and old methods. Take Zhicheng Station as an example:
In order to verify the consistency of the sediment concentration measurement results sequence of the TES-91 online sediment concentration monitoring system and the data of old method, the sediment concentration data of the two methods from January to September 30, 2020 were respectively processed, to generate the online daily average sediment concentration and daily sediment transport rate for comparative analysis, as shown in Figure 3.5-1. It can be seen from the figure that there is a good relationship between the daily average sediment concentration and sediment transport rate of online system and the results from measured data of old method, with a high coincidence degree.

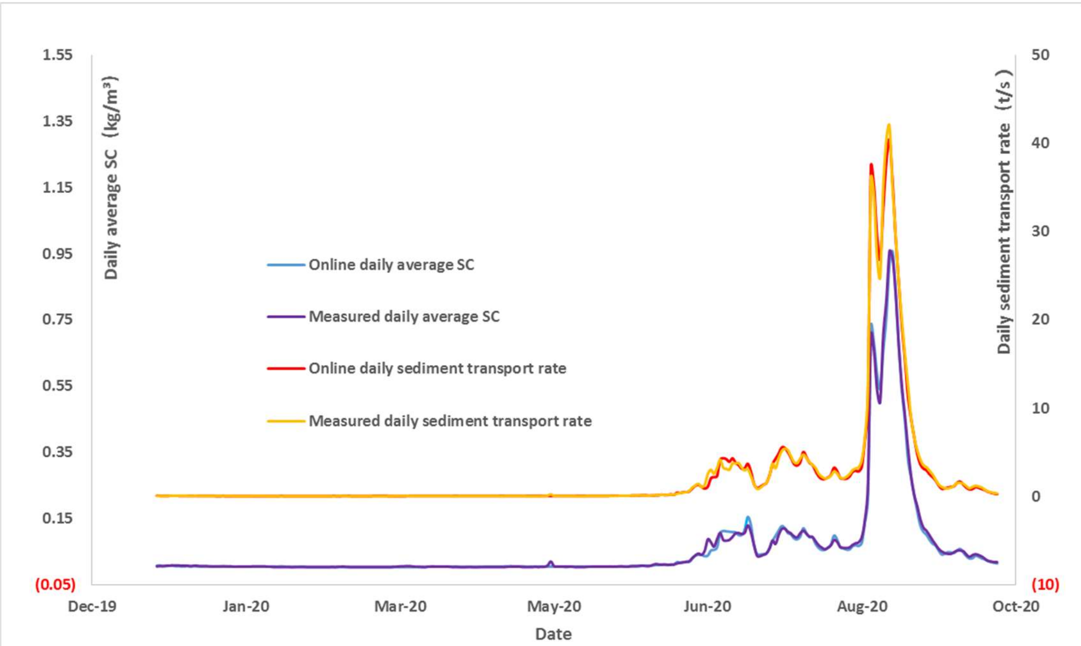

Fig. 3.5-1 Daily average sediment concentration and daily sediment transport rate hydrograph comparison with online monitoring and conventional method

In addition, the maximum annual sediment peak was extracted for the instantaneous sediment concentration comparison (see Figure 3.5-2), and the comparison effect was also good.

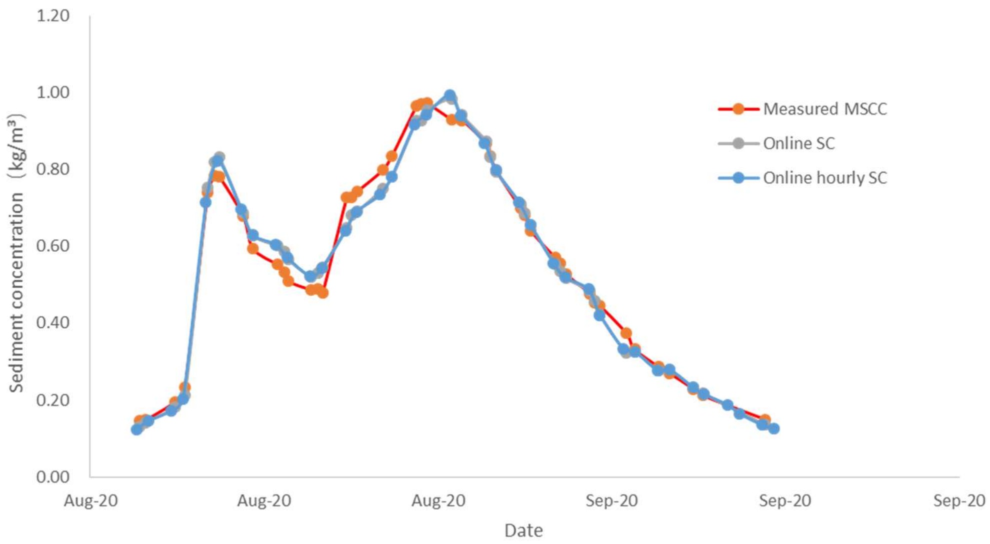

Fig. 3.5-2 MSCC hydrograph comparison with online monitoring and conventional method

See Table 3.5-1 for the statistics of sediment transport from January to May, from June to September, and annual sediment load of the two methods. The total sediment transport calculated by the two methods is equivalent, with a relative deviation of -1.1% from January to September. The maximum sediment load was mainly concentrated in June to September, accounting for 99.0% of the total sediment load from January to September, with a relative deviation of -1.0%.

Table 3.5-1 Statistical table of the proportion of sediment load and the error of comparison

The processing method	Subject	Jan to May	June to September	Annual (January - September) sediment load
Measured sediment concentration	Sediment load ($\times10^4$t)	51.54	5383	5440×10^4t
	Proportion %	0.9%	99.0%	
Online sediment concentration	Sediment load ($\times10^4$t)	50.86	5327	5380×10^4t
	Proportion %	0.9%	99.0%	
Relative error of sediment load %		- 1.3%	- 1.0%	1.1%

(2) Comprehensive efficiency

Before the online monitoring system was put into operation, the index and cross-section average sediment concentration relation curve method was used to measure the suspended sediment in Zhicheng Gauging Station. From 2015 to 2020, the MSCC measurements were 40, 39, 45, 72, 45, 79 times respectively, and the index sediment measurements were 220, 229, 244, 297, 255, 258 times respectively. After the online monitoring system is put into operation, the work content is adjusted to check and maintain the online instrument, and measure 3-5 times MSCC a year (15-30 times during the parallel period of the two methods) for checking the stability of the curve and to calibrate it, which can greatly emancipate manpower, improve efficiency and save cost.

(3) Sediment warning or forecasting function

Zhicheng Station is located in the most upstream of Jingjiang Reach, which can play the role of an outpost. The online monitored sediment concentration data can be shared by all hydrometric stations of Jingjiang Bureau in real time, so that the measurement opportunity of suspended sediment transport rate of other stations can be arranged accordingly. When the upstream sediment inflow process changes, when the Three Gorges Reservoir or Gezhouba Project implements sediment delivery schedule, or other sediment events occur, the online monitoring system of Zhicheng Station will act as an early warning role. By comparing the sediment concentration of Zhicheng station with that of other stations, a model can be established for sediment forecasting.

4 Discussion on application problems

4.1 Applicability of Zhicheng Station

Since the experiment in Zhicheng Station has only been conducted for less than 2 years, the online monitoring scheme still has potential risks, such as scheme stability and environmental adaptability.

(1) About the stability of the scheme

As for the inflow and sediment source conditions, since 2016, except for June-August in the main flood season, the sediment concentration of Zhicheng Station is generally less than 0.30kg/m^3. The relatively large sediment concentration in June-August is mainly due to sediment delivery schedule of the Three Gorges Reservoir or Gezhouba. sediments washed down were almost fine particles, and suspended sediment evenly distributed in the cross-section. Therefore, online monitoring can be implemented with fewer representative points (even one point). In fact, since the 1990s, under the comprehensive influence of the change of precipitation conditions, the construction of reservoirs in the trunk streams and tributaries, the implementation of soil and water conservation, the closure of mountains for forest cultivation and the prevention and control of rocky desertification, as well as the sand-mining in the river channel, the incoming sediment from the upper reaches has prominently decreased [10]. After the construction of the Three Gorges Dam, the sediment incoming conditions (drainage of clear water) will continue in the future, unless special sediment yield or disturbance events occur downstream of the dam, it is unlikely that the sediment distribution characteristics of the Zhicheng Reach will have a great abrupt change. Additional countermeasures adopted in the production plan are as follows: online monitoring is carried out in parallel with the original method for one year, and then conventional methods are used to test the stability of the model relationship for a certain number of times each year. Once changes occur, the model is analyzed and adjusted in time, and the conventional measure method is resumed in time when special sediment regime occur. When the sediment concentration exceeds the scope of application in production, comparative measurement should be carried out in time to extend the working curve or model and expand the monitoring scheme.

(2) About environmental adaptability

In the test, it was found that sunshine intensity had no significant influence on the underwater sensor operation of the instrument. However, severe weather such as storms would lead to sediment production in local areas along the shore, which would render the sediment concentration unrepresentative. Therefore, the instrument should be installed far away from the shore, best in the main stream. The impact of sailing vessels on the safety of the online monitoring platform needs to be considered. The method adopted at Zhicheng Station is to install the instruments on a position-fixed navigation vessel. The strength of the mounting bracket should be able to withstand the impact of the water flow. Water floating objects and the entanglement of suspended plants will lead to data distortion, and there is also a risk of crashing or washing away the probe. Appropriate safety protection measures should be taken. Microorganisms, algae, snail shells may be attached to the surface of the instrument, it is necessary to clean the surface of the protective mirror in time. In order to ensure the consistent background of each measurement, the lens should be cleaned for each measurement. Underwater camera monitoring equipment can be installed to deal with possible problems in time.

4.2 Generalizability

(1) Matching of sediment characteristics

TES series of instruments mainly use near-infrared light to measure sand, which belongs to optical sediment concentration meter. In the inside model of the instrument, it involves the conversion of length unit to mass unit. The parameters are different with different sediment characteristics, so the localized parameters need to be calibrated in the test stage. The factors affecting the measurement by optical method include geometric characteristics, gravity characteristics, hydraulic characteristics of sediment, and physical and chemical characteristics for fine sediment, and biochemical characteristics for clay, etc. If the sediment source and sediment composition of a station are stable, the adaptability of the instrument is strong. The calibration model in the laboratory is theoretical, and the actual calibration work is generally carried out synchronously in the river field with the existing sediment measurement method, and the instrument development party are required to participate in the complicated situation.

(2) The uneven distribution of sediment

Suspended movement is a process of interaction between gravity action and turbulent diffusion action. The distribution of sediment concentration on the vertical generally increases from the water surface to the river bottom. The change gradient of sediment concentration also varies with the thickness of sediment particles. The thicker the particles are, the greater the change is, and the change of the gradient of fine sediment is very small. The vertical distribution of high sediment concentration is relatively uniform, but the thickness of sediment gradation has no obvious effect on the vertical distribution of sediment concentration. The transverse distribution of sediment concentration is related to the river channel pattern, cross-section shape, sediment particle composition and sediment transport capacity of flow. Several common vertical distribution models of sediment concentration have already been summarized by insiders [11].

After the completion of the Three Gorges Dam, the sediment concentration in Zhicheng and other stations has become very small, and some commonly used distribution models are no longer applicable. Vertical distribution of measured sediment concentration on each vertical line of several typical measurements at Zhicheng Station is shown in Figure 4.2-1, and transverse distribution features are shown in Figure 4.2-2.

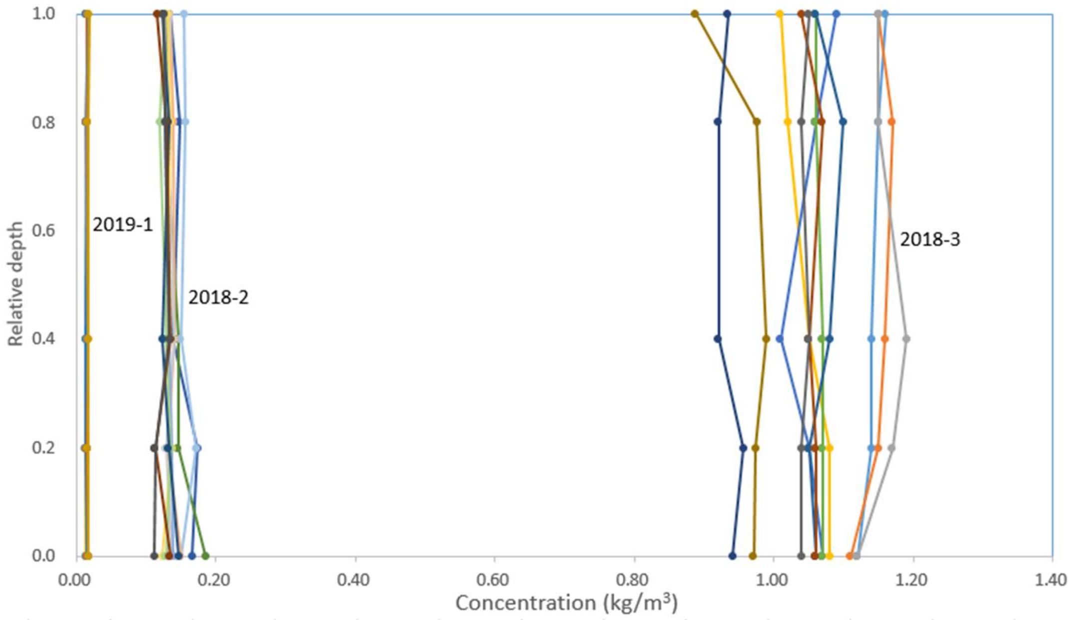

Fig. 4.2-1 Vertical distribution of measured sediment concentration at Zhicheng Station

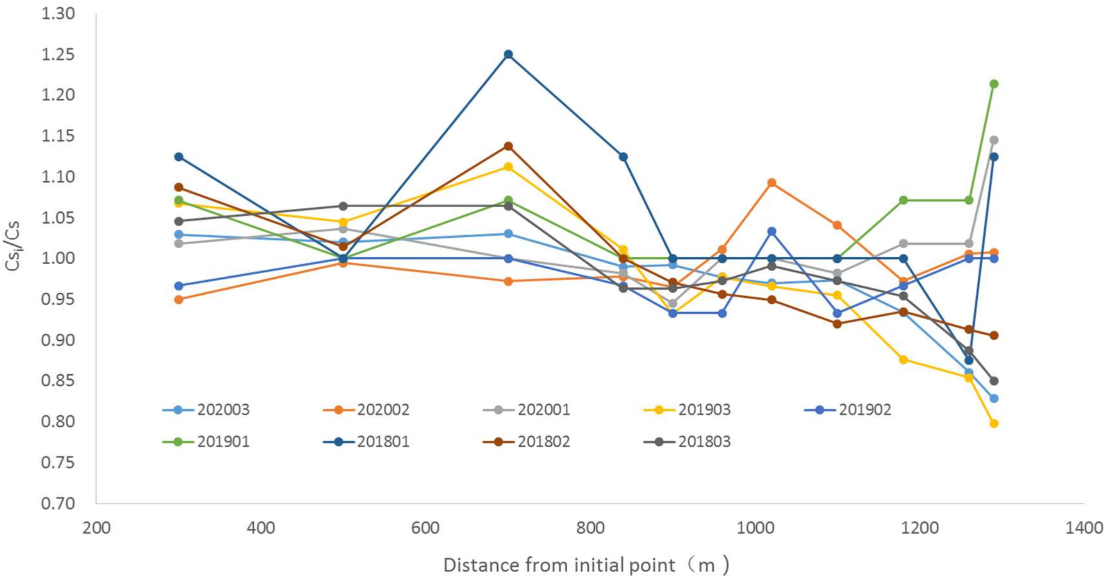

Fig. 4.2-2 Horizontal distribution of the ratio of vertical sediment concentration to cross-section sediment concentration in Zhicheng Station in recent 3 years

Zhicheng Station has a unique characteristic of relatively uniform sediment distribution, so only one measuring point is representative. Other stations may need to select 1-2 or more vertical lines, and select 1-2 or more points on each vertical line. Generally, the position of monitoring instrument should be selected on the basis of historical sediment data analyzing. For example, a floating platform can be installed on an index sediment sampling vertical for monitoring. Sometimes the instrument probe can also be installed on Bridges, underwater pile platform and other buildings for monitoring, which needs to consider the technical, economic, safety and other conditions to make the choice. For fine sediment, small sediment concentration and high sediment concentration flow, the mean sediment concentration in the cross-section is expected to be monitored online with fewer representative points.

(3) Circumstances of no monitoring platform building

Temporary no monitoring platform construction in the adaptability test phase, or difficult to construction monitoring platform due to such as river conditions, hydrometric conditions, shipping influences, economic conditions, security factors, we can carry out comparative gauging with traditional method on the hydrometric boat, hydrometric cableway, at first, adopts rapid monitoring mode to solve the problem of sediment concentration results onsite obtaining, then gradually transit to on-line monitoring when conditions are ripe. Jingjiang Hydrology has carried out experiments in Shashi Gauging Station (which used hydrometric boat, horizontal sampler) and Xinjiangkou Gauging Station (which used hydrometric cableway, time-integrating sampler). The preliminary test results of Xinjiangkou Station are shown in Figure 4.2-3. Comparative tests will be carried out sequentially in 2021.

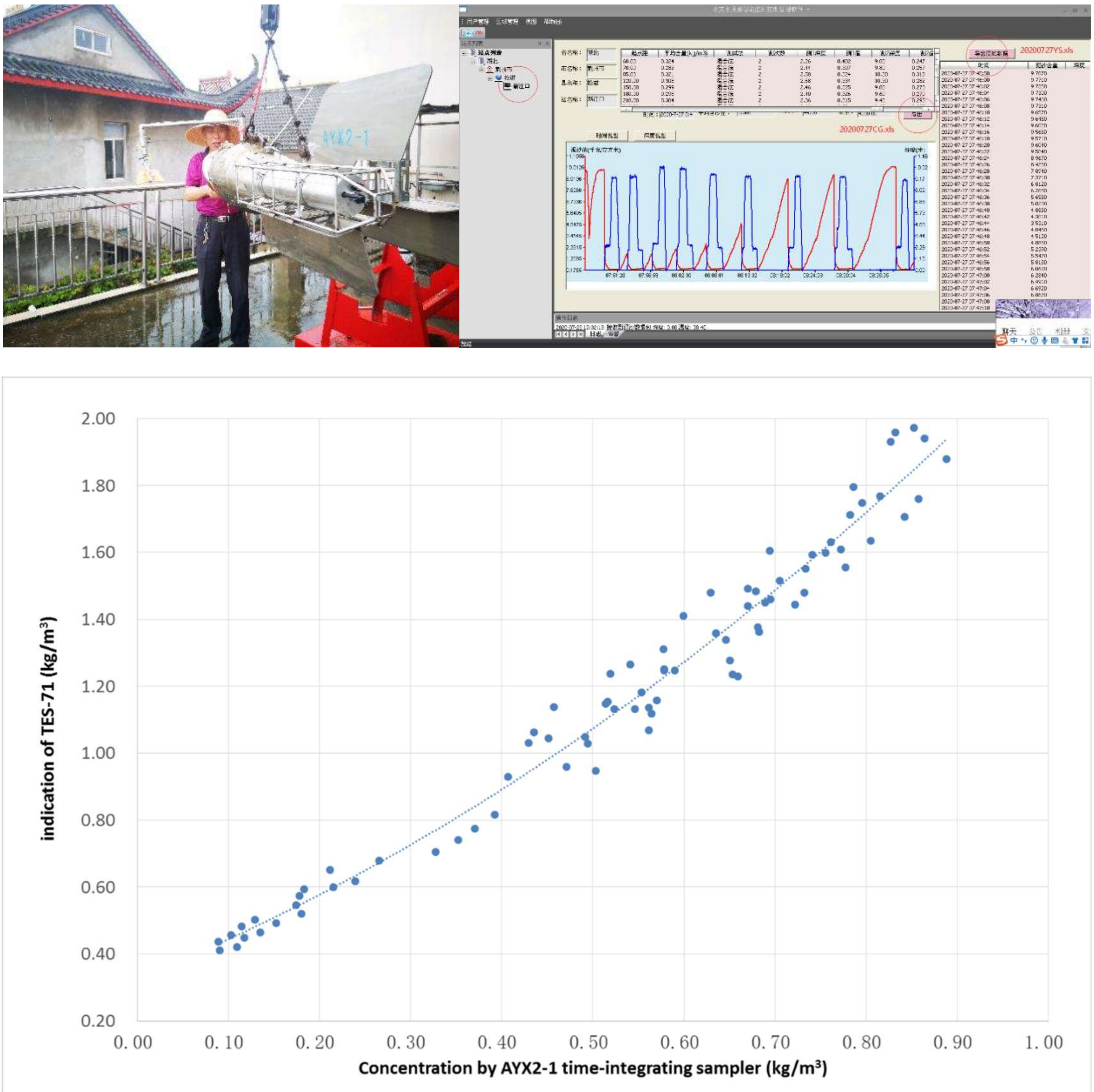

Figure 4.2-3 Rapid Sand Measurement Tests of Xinjiangkou Gauging Station in 2020

(4) Other circumstances

If needs the sediment concentration distributed data along the cross-section or along the vertical line, may adopt the rapid or online monitoring mode according to the river conditions and data using requirements. The rapid monitoring method is also suitable for tour gauging or mobile non-station work, which can reduce sampling, handling, water sample treatment, sediment concentration calculation and other parts. For new hydrometric stations, rapid monitoring tests can be used first, and then on-line monitoring can be decided according to the conditions.

(5) About further research and technical standards

At Zhicheng Station, the instrument accuracy comparison test was carried out, and the data sequence was compared and analyzed with the original method. When calibrating the working curve, the sediment concentration of the samples collected by the horizontal sampler (the original method) was taken as the analysis base, which was beneficial to ensuring the continuity of the data sequence. However, due to the influence of sediment pulsation and sudden perfusion in the sediment measurement by the horizontal sampler (correspondently, the intake flow velocity of the time-integrating sampler may be different from the natural flow velocity), further study is needed to determine whether the working curve of the calibration best represents the actual situation.

In addition, online monitoring is a new technology. Compared with traditional methods, changes have taken place in the aspects of information perception, single sediment concentration calculation, measurement frequency control, data processing, etc. Online monitoring has tended to be integrated in the workflow, so it is necessary to summarize technical guidelines and formulate technical standards in time. Among them, when determining the allowable error index, factors such as the importance of data, the demand of data users, the possible accuracy level under realistic conditions, economy and so on should be comprehensively considered.

5 Summary and Outlook

5.1 Conclusion

The suspended sediment online monitoring test succeed in Zhicheng Gauging Station, and accumulated experience during its operation, which can be used as a reference for hydrometric stations with similar conditions. The following conclusions can be drawn from the experiment at Zhicheng Station:

(1) When selecting an online sediment concentration monitoring system, the adaptability of the method, the adaptability of the environment, the stability and reliability of the sensor, the accuracy of the working curve or model, and other factors should be considered first. The working curve or model is related to sediment characteristics, so local parameter calibration is generally required. When sediment characteristics change, analysis should be carried out in time to revise model parameters. The TES-91 near-infrared online instrument selected by Zhicheng Gauging Station showed that the correlation coefficient between the indicated value of the instrument and the sediment concentration at the same position was 0.9969 after the parameter calibration of the working model. The relation curve passed three tests, and the error indexes all met the requirements.

(2) The online scheme deployment of hydrometric stations should follow the basic technical principles of hydrometry. It is advisable to analyze the vertical and horizonal distribution characteristics of sediment concentration based on historical data, select the representative points (or representative lines, or representative areas) for suspended sediment online monitoring, and formulate a comparative gauging scheme by integrating technical, economic, and safety factors, and draw up a monitoring model based on the comparative gauging results. When the sediment distribution characteristics of the station change, the analysis should be carried out in time and the monitoring scheme should be revised. The distribution of sediment concentration in the measured reach and cross-section of Zhicheng Station is relatively uniform, and only a point (1.30m below the water surface of the vertical line of the middle thalweg) is used as the representative point. The model relationship of the online system is good in the range of sediment concentration from 0.003 to 0.972 kg/m^3 (indicated value range: 0.003 to 1.158), and the correlation coefficient is 0.9933. The results and errors of the three tests meet the requirements of production and application. The results of the new and old methods are well compared and the eigenvalues are corresponding. Compared with traditional methods, online monitoring of suspended sediment concentration can greatly reduce labor intensity, liberate manpower, improve efficiency and save cost.

(3) Generally, the online monitoring system should have the functions of continuous operation and real-time remote transmission of data, so as to remotely query the sediment concentration data and the working status of the system. The real-time monitoring sediment concentration information can be shared within the station network, and the data from upstream stations can be used for downstream sediment warning or forecast.

(4) Online instrument platform and holder are important components in the system, and their construction quality directly affects the quality of sediment concentration monitoring results. If it is difficult to realize online monitoring at the moment due to insufficient conditions, the hydrometric boat or hydrometric cableway can be used to realize rapid monitoring comparative test with traditional methods first.

(5) Online monitoring is a new technology. Compared with traditional methods, changes have taken place in the aspects of information perception, single sediment concentration calculation, measurement frequency control, data processing, etc. Online monitoring has tended to be integrated in the workflow, so it is necessary to summarize technical guidelines and formulate technical standards in time. When determining the allowable error indexes, factors such as the importance of data, the demand of data users, the possible accuracy level under realistic conditions, economy and so on should be considered comprehensively.

5.2 Looking forward

The main methods of river sediment monitoring include water-sediment balance method and cross-section topographic method. For example, in the middle and lower reaches of the Yangtze river, on the demand level, sediment balance analysis is important basis for reasonable evaluation about the impact to the river by reservoir group built, is key support to the administration and protection of rivers and lakes [12]. But due to the limitation of realistic conditions, calculated scouring and siltation volumes differences can be produced between sediment balance method and cross-section topographic method [13], sediment measuring and monitoring technology research tasks are still hard. Suspend sediment is the main part of river sediment and the key content of hydrologic sediment monitoring. The on-line monitoring can solve the main contradiction of sediment monitoring by water-sediment balance method. At the same time, it should be noted that the monitoring of suspended sediment concentration is only a part of the total sediment measuring [14]. At present, on sediment particle size analysis, laser particle size meter can effectively improve the analysis timeliness, on bed load measuring, relevant domestic and foreign institutions have been in the study of pebble bed load online monitoring system, but, new technology on soil bed load measuring, bed material measuring is infrequent.

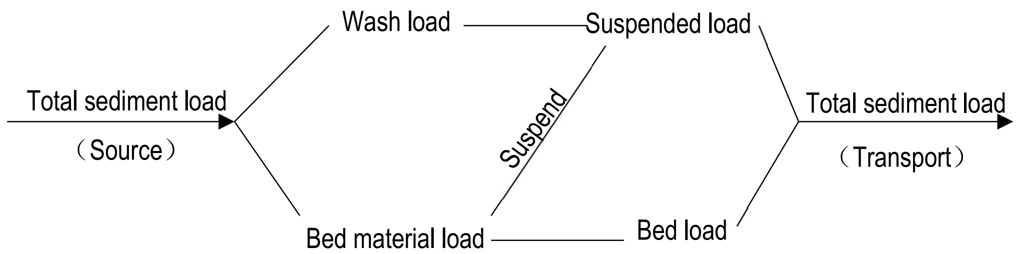

Fig. 5.2 Schematic diagram of sediment classification according to sediment movement mode

In recent years, Jingjiang Experiment and Training Base of IRTCES has done a lot of experimental research on sediment monitoring technology. In terms of equipment improvement and development, the development and introduction of multi-cabins sampler, near-bottom suspended load sampler, single-door and double-doors bucket bed material sampler, bed load sampler and sampling holder improvement have been carried out. In terms of sediment measurement research, we have carried out near-bottom suspended sediment measuring test, turbidimeter sediment measuring test, LISST sediment measuring test, ADCP sediment measuring test, infrared light sediment measuring instrument test, laser particle size measuring instrument test, online bed load monitoring equipment investigation, shallow profiler riverbed survey test, multi-beam depth sounder observation of sand wave movement and other works. In terms of technical research, we have carried out research on touring and silting amount in alluvial rivers [15], research on the technology of inland water boundary survey, and summarizing of the technology of sediment survey and investigation [16], and achieved certain results. Due to the complicated rules of river sediment movement, there are still many problems to be solved, and there is still a long way on sediment research.

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