

ROLE OF CHIKUGO RIVER'S OLD MEANDERING AND INFLOWING TRIBUTARIES WITH CUT-OFF CHANNELS

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ABSTRACT

Chikugo river has many cut-off channels nowadays but there are many old meandering waterway still existing. All inflowing tributaries into Chikugo River do not connect directly to main stream of present Chikugo River but flow into the old meandering waterway of this river. A cut-off channel and old meandering waterway with inflowing tributaries are analyzed in the both cases where a tide is effective or not effective. In this study, the role of old meandering waterway and tributaries with cut-off channels is considered hydraulically. As a results, the old large meanderings are considered to be used for the traditional irrigation system of this area, ship transportation and flood control. Moreover, from 2-D inundation analysis, during flood period, the connecting system between inflow tributaries and the old meandering waterway can decrease the overflowing velocity in the case of exceeding the designed flood discharge of each tributary

Keywords: meandering, cut-off channel, tributaries, ship transportation, inundation analysis

1 INTRODUCTION

Chikugo River is a primary river in Kyushu island, Japan with a trunk length of 143 km and a catchment area of 2,860 km². This river's basin consists of four prefectures, that is Kumamoto, Oita, Fukuoka and Saga. Because of the severe meandering of its watercourse, many cut-off channels were constructed to increase the capacity of flow rate of Chikugo River from Edo era to Meiji, Taisho Syowa periods (Kase River Irrigation and Drainage Office, 1973; Kishihara, 2016). Especially, Sakaguchi, Komorino, Tenkenji and Kanashima are called four major cut-off channels in Chikugo River (Chikugo River Construction Office, 1976). Although constructions of these cut-off channels have been completed, many old meandering waterways still exist and all inflowing tributaries into Chikugo River do not connect directly to main stream of present Chikugo River.

It was found that tributaries of Chikugo River, such as Iryu River, Kiritohshi River and Shozu River were flowing separately into Chikugo River in Keicho period (1596 - 1615) from Hizen map of Keicho period. On the other hand, in Shouhou period (1645 - 1648), a part of Shozu River flowing south disappeared and extended to south-west and reached to the old meandering waterway of Chikugo River same as other two tributaries (Culture Heritage Online, 2018). In between the above period from 1632 to 1643, a riparian technical groups including Chief Retainer Hyogo Naridomi made a 12km long Chiriku Levee from Chiriku to Sakaguchi on the right side of Chikugo River. Shozu River's reroute was considered to be implemented in this period (Eguchi, 1977). Tributaries flowing into lower reach of Chikugo River are not flowing into Chikugo River directly but are much seen that they are once flowing into the old meandering waterway of Chikugo River. However, the reason why this system was introduced was not sufficiently clarified yet.

On the other hand, because the downstream part of the Chikugo River is lower than the surrounding area so that water flows through the lowest area of the plain. This means it is difficult to use water in the downstream part of Chikugo River before the pumping system has been introduced. For this reason, Ao intake has been carried out for a long time by utilizing the large tidal difference of the Ariake Sea. "Ao" means freshwater flowing from upstream of the river, and is lifted to the surface because the specific gravity of sea water in the Ariake Sea is larger and the seawater gets into under the fresh water. Therefore, during high tide in the Ariake Sea, fresh water was taken from rivers and waterways in the downstream region of the Chikugo River by using sluices or pumps for agricultural use historically in this area. Usage of Ao intake water was ended when the management was unified by the completion of Chikugo estuary weir in 1985 (Igarashi, 1996; Teramoto, et.al., 2016).

Moreover, in this area, boats were used for mass transport of goods until the railroads and roads were developed after Meiji era. Sagae River connected east and west from Saga Castle town to the Ariake Sea through Chikugo River (Miyachi, 2009; Ohgushi and Nagahata, 2016). Through this river network, many goods were transported. There were many crossing boats going and coming between the both riverbanks of Chikugo River. The tidal difference of the Ariake Sea is about 5 to 6 m at Suminoe, the innermost area of this bay, which

is largest in Japan. Therefore, many problems seemed to occur in the river transport as a result of the influence of the tide in the rivers and waterways connected to the Ariake Sea.

In this study, we conducted a one-dimensional unsteady flow analysis of the old meandering watercourse in the middle and lower regions of Chikugo River and the tributaries flowing into this meandering part to clarify these hydraulic interactions and their functions such as water use, flood control, etc. In addition, two-dimensional inundation analysis was implemented for this regions.

2 METHODOLOGY

In this study, one-dimensional unsteady flow analysis and two-dimensional inundation analysis were implemented for the land including the lower reach of Chikugo River and the meandering waterway. The analyzed period is from June 20 to July 31, 2007. For consideration of water use of this river, the period during which floods did not occur and the spring tide occurred was focused, that is around July 19, 2007. On the other hand, for consideration of flood control, the period around July 7 with a large flood is focused. The flood around July 7, 2007 is a flood occurring with one tenth possibility. Used riverbed topographical data are provided from Chikugo River Office of the Ministry of Land, Infrastructure and Transport and the River and Sabo Section of Saga Prefecture Government. For one-dimensional analysis, a 200m pitch cross sectional data with temporal increment of 1 second. Manning's coefficients are 0.020 for Chikugo River, Hayatsue River and Morodomi River and 0.032 for other small tributaries.

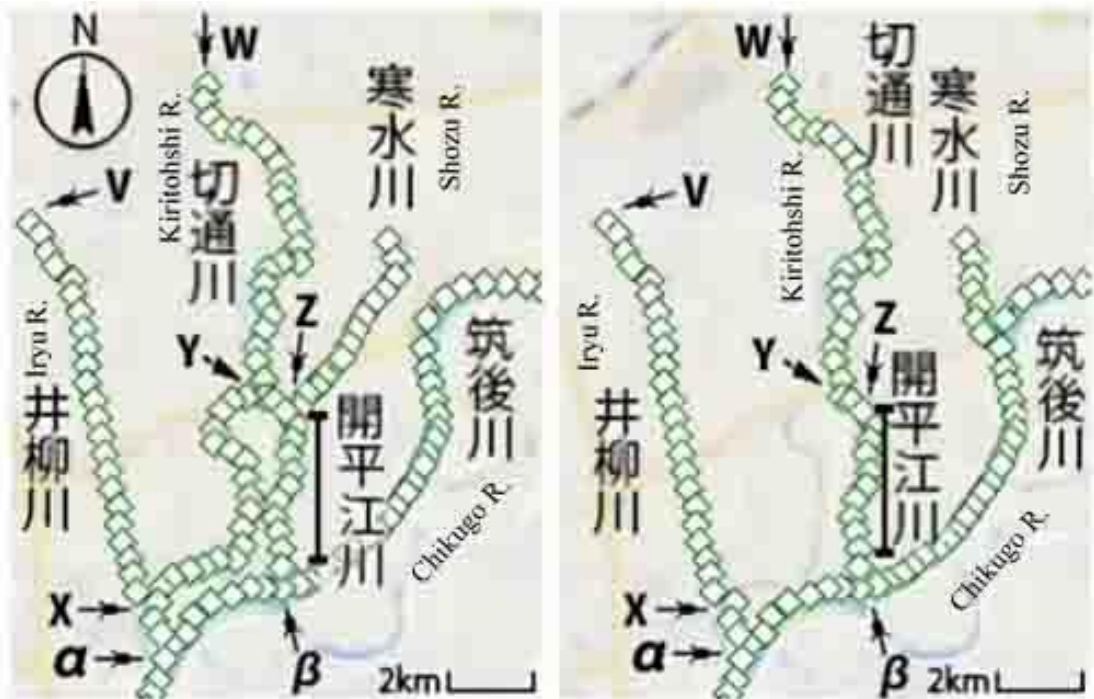
Study areas are shown in Figure 1. Study Area No.1 is affected by the tide of the Ariake Sea. Study Area No.2 is not affected by the tide. Study Area No.1 and No.2 are shown respectively in Figure 2 and 3. In order to consider the effect of the meandering waterway on the flood control, the presence and absence of the meandering waterway are compared using overflow depth from the levee, overflowed volume and interval of overflow. On the other hand, to consider the effect of the meandering waterway on water use, the water level of the tributaries is compared during high tide and low tide of the Ariake Sea. Especially in Study Area No.1, the interval between Kiritohshi River and Kaitaiegawa River is focused (interval of $W-Z-\beta$) shown in Figure 2.

Compared cases of Study Area No.1 are Case A in which the present condition is used and Case b in which the old meandering waterway is deleted virtually and each tributary flows into Chikugo River directly. In Study Area No.2, we focused to Houman River. Compared cases of Study Area No.2 are Case 1 in which the present condition is used, Case 2 in which the old meandering waterway that is now a part of Houman River is deleted virtually and each tributary flows into Chikugo River directly, and Case 3 in which Komorino cut-off channel is deleted virtually and the old meandering waterway is assumed to be a main waterway of Chikugo River. Case 4 is almost same as Case 1 but the boundary condition of the upstream discharge is set to be a design high water discharge. Case 5 and Case 6 are the cases same as Case 4 but upstream discharges multiplied by factors 1.1 and 1.2 respectively.

As the boundary conditions for Study Area No.1, measured flow rates just downstream of the Chikugo estuary weir were used at the upstream boundary of Chikugo River, whereas measured water levels at the mouth of the Chikugo River and Hayatsue River were given at the downstream boundary. With respect to Shozu River, Kiritohshi River and Iryu River, the measured water levels at observation stations were converted to the flow rates using the cross sectional shape and Manning equation. Figure 4 shows measured flow rates just downstream of the Chikugo estuary weir and measured water levels of 3 tributaries' upstream boundaries and river mouth of Chikugo River. On the other hand, as the boundary conditions for Study Area No.2, measured flow rates at Katanose of Chikugo River, and other tributaries' observation stations are given as the upstream



Figure 1. Study Areas (Study Area No.1 and No.2) in the Chikugo River basin



Presence of the old meandering (Case A)

Absence of the old meandering (Case B)

Figure 2. Considered cases with respect to the presence or absence of the tributaries' inflow to the old meandering waterway in Study Area No.1

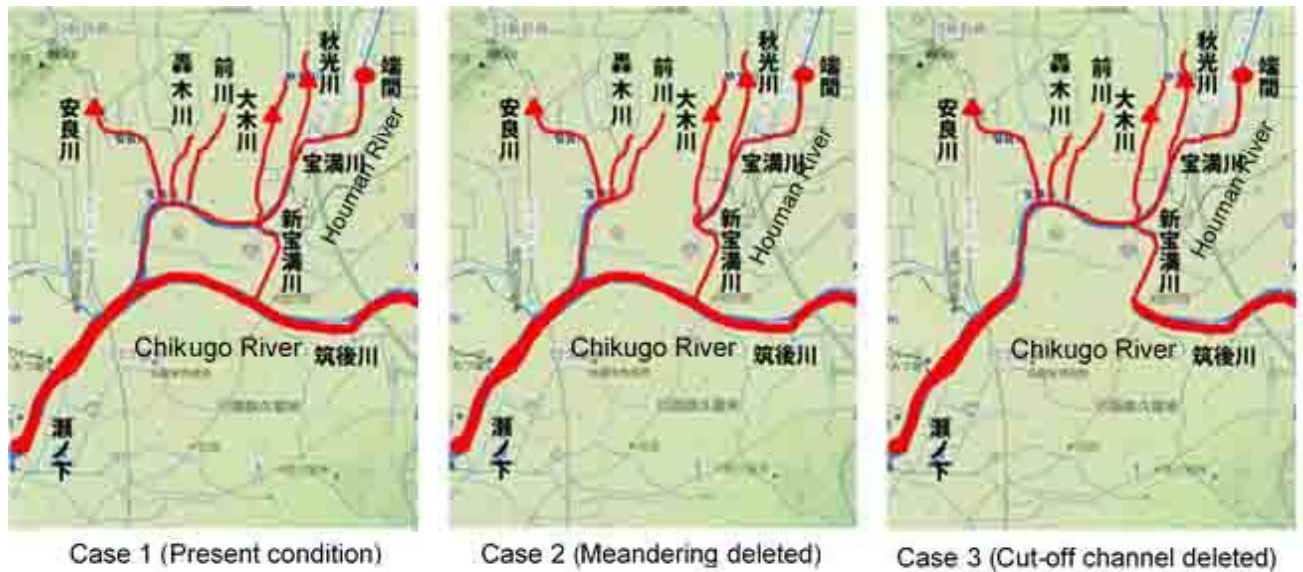


Figure 3. Compared cases with respect to the presence and absence of the meandering waterway or cut-off channel in Study Area No.2

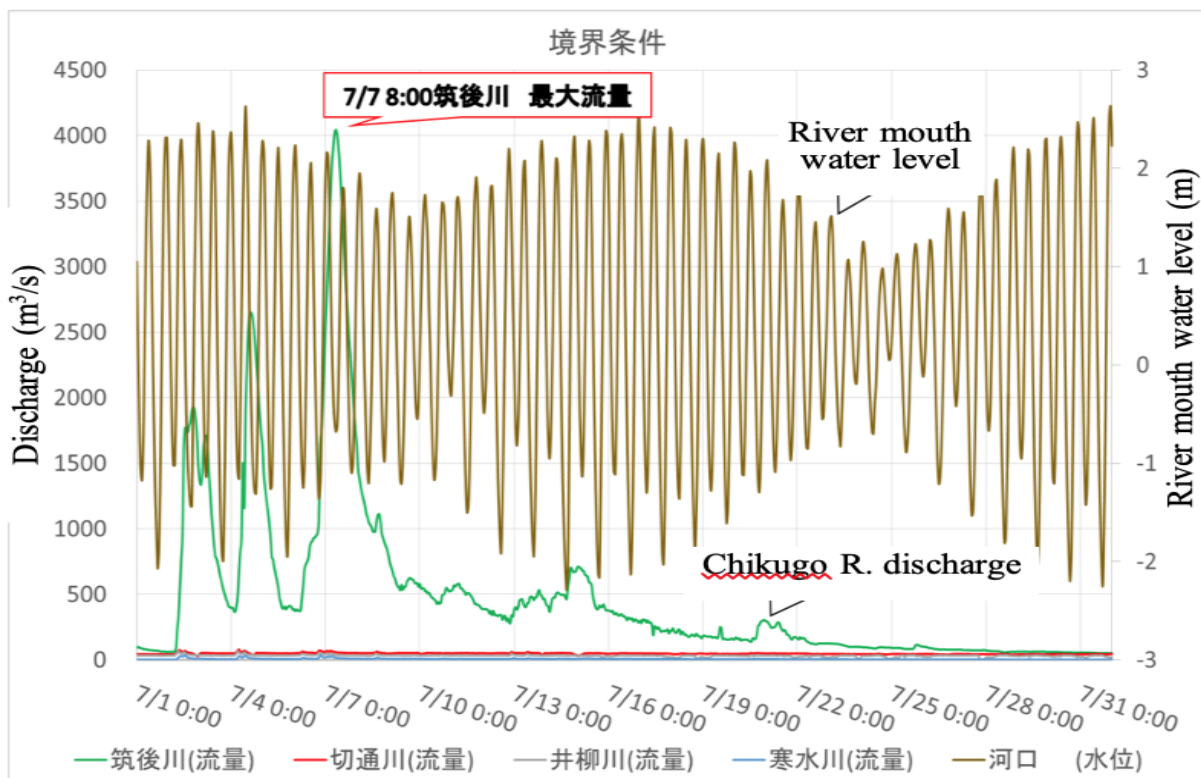


Figure 4. Boundary conditions for Study Area



Figure 5. Locations of boundaries for calculation in Study Area No.2

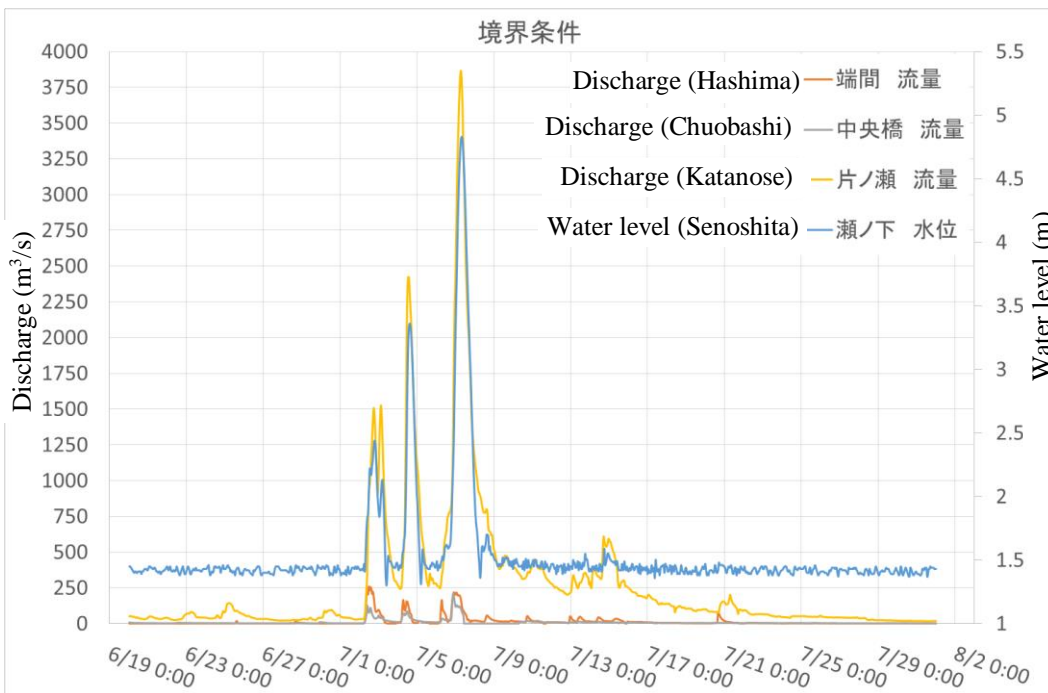


Figure 6. Boundary conditions for Study Area No.4

boundary conditions. Observed water level of Senoshita is given as the downstream boundary condition. Figure 5 shows locations of boundaries of this simulation. Figure 6 shows the boundary condition for Study Area No.2

3 RESULTS AND DISCUSSIONS

3.1 Study Area No.1

The longitudinal distributions of water levels along the meandering waterway were compared in the case of presence and absence of one river inflow among three rivers into the meandering waterway at the time of high tide and low tide for July 1, 2007. Among them, the influence of the inflow of Kiritoishi River was the largest. Figure 7 shows a comparison of the water level distribution along the meandering waterway calculated under this condition. The abscissa of this figure shows a part of flow path of the meandering waterway between X and Y in Figure 2 (the inflow points of Iryu River, Kiritoishi River and Shozu River on the way are taken as a, b and c, respectively). The maximum water level difference is about 1.4 m, and its location is 400 m downstream from the confluent point of Kiritoishi River. Since the water level decreases are also seen at the confluent point of Chikugo River, the water level of Chikugo River can also rise due to the flow of the river to the meandering

waterway. This seems to have given an advantageous effect to the transfer place and other river transportation in Chikugo River.

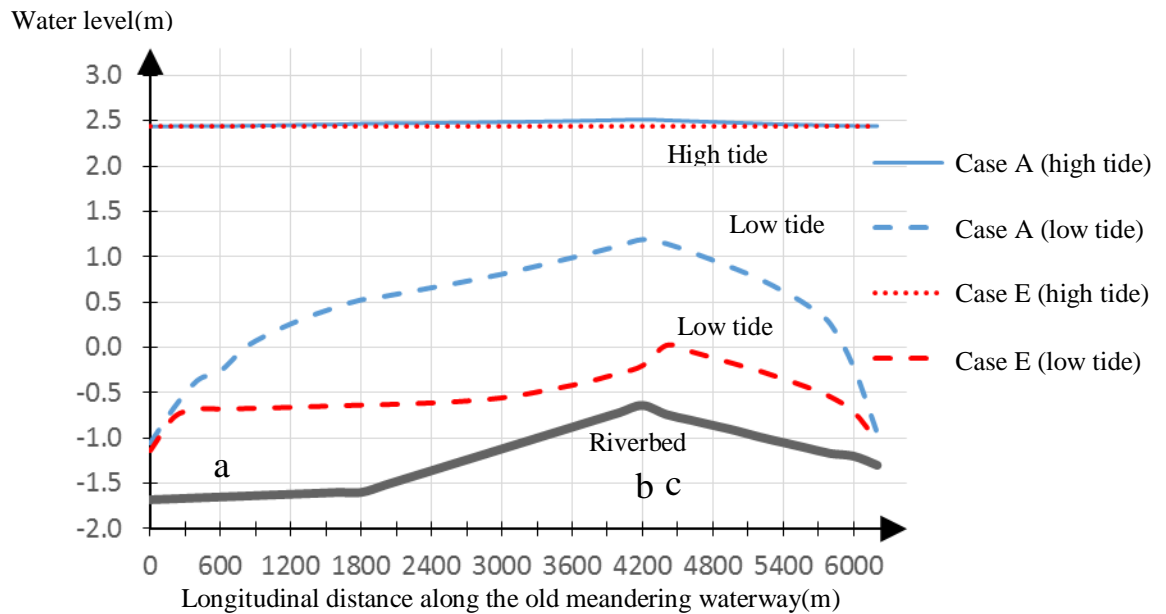


Figure 7. Comparison of the water surface distribution by the inflow of Kiritohshi River into the old meandering waterway (Case A: Presence of inflow, Case E: Absence of inflow) for July 19, 2007.

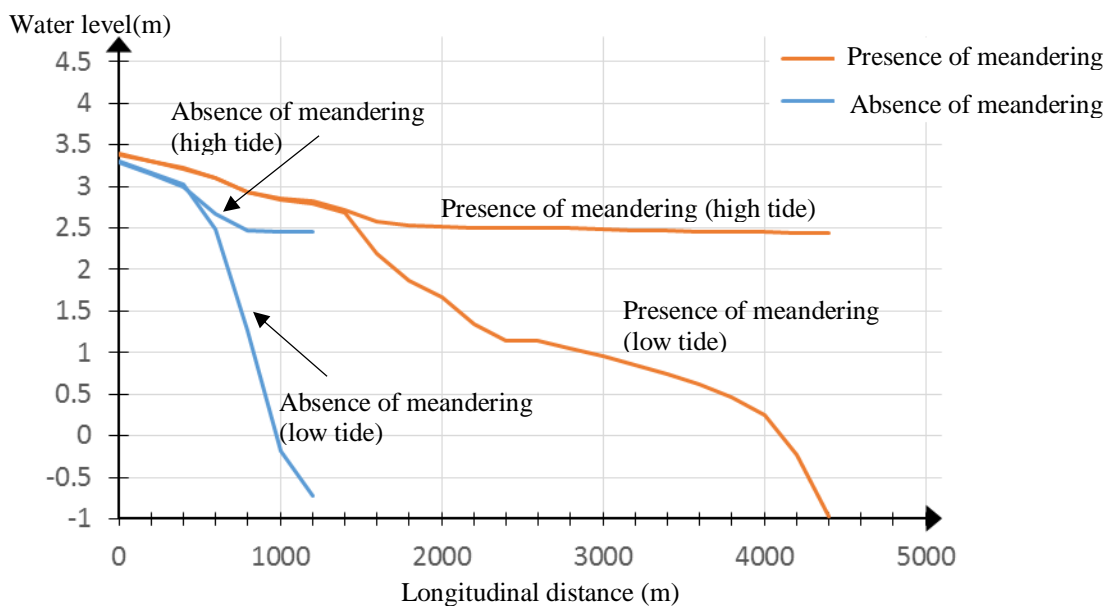


Figure 8. Comparison of the water surface distribution of Shozu River by the presence or absence of the old meandering for July 19, 2007.

In order to estimate how much the water levels of tributaries themselves change because some amount of water is stored there by the tributaries' inflow to the meandering waterway, two cases are compared. One is the case (current state) where the tributaries flow into the meandering waterway. Another is the case Shozu River, Kiritohshi River, Iryu River flow directly into Chikugo River main stream without temporal storage in the meandering waterway.

Figure 2 shows a part of compared cases. The route of Shozu River is changed to south and directly connected to Chikugo River from Z without connecting to the meandering waterway. With respect to Kiritohshi River, a case that the flow path from Y to Kaitaiegawa River without considering the western half flow path of

the meandering waterway and a case that the flow path from Y to the west half of meandering waterway only considered without considering the eastern half flow path of meandering waterway. In the latter case, we also compared the existence of confluence with Iryu River. The cross-sections between Z of the Shozu River and

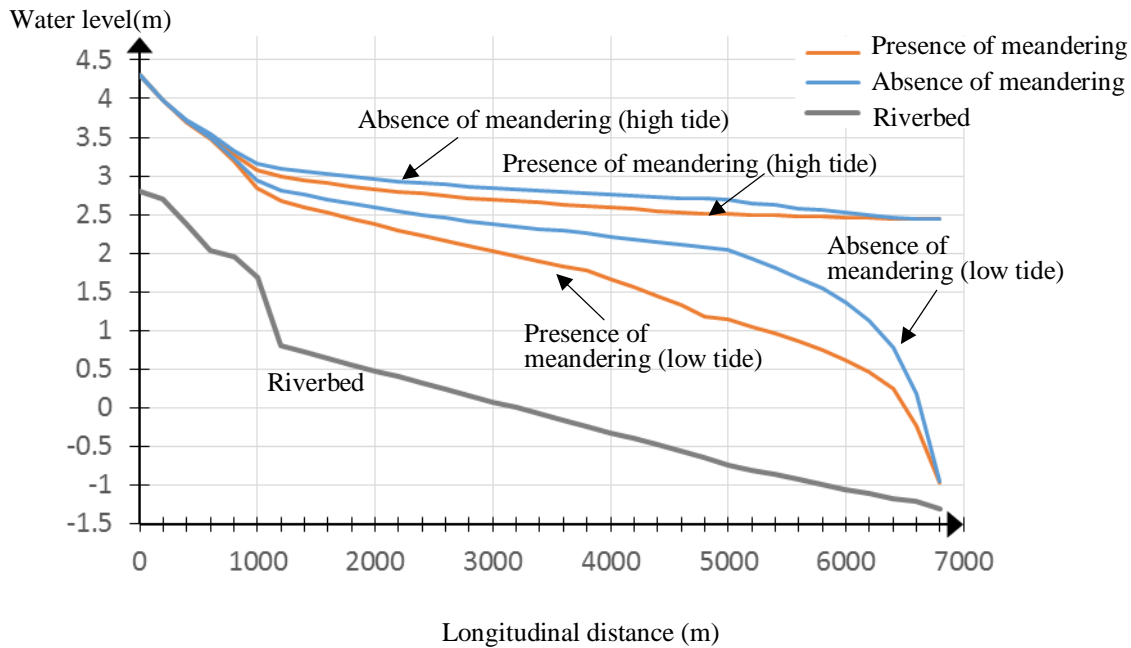


Figure 9. Comparison of the water surface distribution of Kiritoishi River by the presence or absence of the old meandering for July 19, 2007.

the confluent point to Chikugo River and the cross-sections from Y of Kiritoishi River to Kaitaiegawa River confluent point were linearly interpolated.

Figure 8 shows a comparison of the calculated results of the water levels of Shozu River both in the case of presence and absence of the meandering waterway for July 19 2007. The abscissa of the figure shows a distance from water level observation point shown in Figure 3 to the downstream. The route of Shozu River was switched at Z shown in Figure 5 to the meandering waterway. The calculation results show that the water surface shape of Shozu River becomes mild because of the existence of the meandering waterway. It is thought that switching of the river route increased the flow path distance and a bed slope becomes mild. In addition, comparing the water level difference at the time of high tide and low tide, it was found that the water level difference is small when there is a meandering waterway. By using meandering waterway, it is thought that there is a buffered effect against the influence of the tide.

For both Shozu River and Iryu River water levels become lower when there is no temporary storage in the meandering waterway, while for Kiritoishi River it becomes higher when there is no temporary storage there. This reason is explained in the following. The storage of water into the meandering waterway causes the increase of water level of the meandering waterway but this water comes from Kiritoishi River. Moreover, by letting 3 rivers flow into the meandering waterway, it seems to give the benefit to Kiritoishi River as flood control, to Iryu River and Shozu River as conveniences of fresh water intake, river transportation, etc.

A comparison of the longitudinal distribution of water level of Kiritoishi River both in the case with and without the meandering waterway for July 19, 2007 is shown in Figure 9. In the case with the meandering, the water level becomes lower than the case without the meandering because the water diverges to west and east. The meandering waterway functions as a buffering device due to the temporary storage effect against the tide of the Ariake Sea.

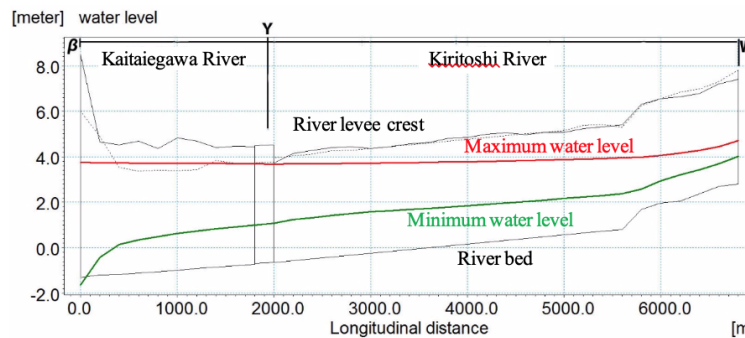


Figure 10(a) Longitudinal water level distribution of Kiritoshi R. and Kaitaiegawa R. with the old meandering waterway for July 7, 2007.

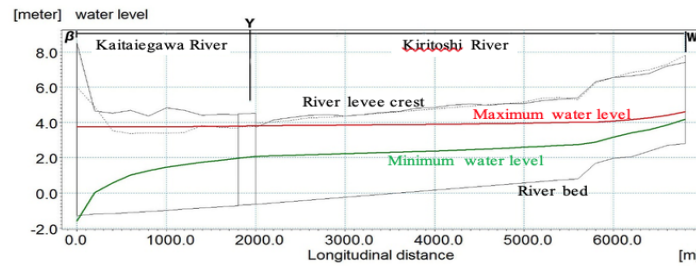


Figure 10(b) Longitudinal water level distribution of Kiritoshi R. and Kaitaiegawa R. without the old meandering waterway for July 7, 2007.

Next a case during flood occurring is considered, that is in July 7, 2007. In this case, water overflows from the river levee due to excess of discharge. Longitudinal water level distributions with and without the old meandering waterway are shown in Figure 10(a) and 10(b) respectively. In the case with the old meandering waterway (Case A), overflow depth is 10cm less than the case without the old meandering waterway (Case B). This means that the volume of the river is increased by the old meandering waterway, so that the overflow depth decreased. This effect can mitigate the pressure to the river levee as a result. To estimate the overflow discharge, an overflow formula (Honma formula) is applied.

Figure 11 shows comparison of inundation depth with and without the old meandering waterway in Study Area No.1. Maximum inundation depth of Case A is about 0.4m, whereas that of Case B is about 0.6m. This means that the old meandering waterway has a storage effect for the flood. In the case with the old meandering waterway, overflowed water goes to the area surrounded by the old meandering waterway. This area is thought to be treated as retarding basin before. A total overflowed volume is 1,004.2 thousands m³ for the case with the old meandering waterway, whereas it is 981.3 thousands m³ for the case without it. The number of overflow from the river levee is 28 for the case with the old meandering waterway. On the other hand, it is 13 for the case without the meandering one.



Figure 11. Comparison of inundation depth with the old meandering (left) and without it (right) in Study Area No.1

3.2 Study Area No.2

Figure 12(a), 12(b) and 12(c) show the longitudinal water level distributions of Houman River, Chikugo River and Shin Houman River in the cases with the old meandering waterway (Case 1), without the old meandering waterway (Case 2) and without cut-off channel (Case 3) respectively for July 7, 2007. In Case 1, the watercourse divides to Houman River and Shin-Houman River so that the maximum water level upstream of diversion point decreases. On the other hand, in Case 2, water level distribution in Houman River increases because there is no diversion. In this case, there remains capacity against much heavier flood. In the case without cut-off channel

Figure 13(a), 13(b), 13(c) and 13(d) show comparison of inundation depth for Case 1, 3, 4 and 6 for the same time. As upstream boundary conditions, the discharges of Chikugo River at Katanose, Kose River at Chuobashi, Houman River at Hashima and other small tributaries, such as Akimitsu River, Daigi River, Mae River, Todoroki River and Yasura River are given by the observed or estimated values. As downstream boundary condition, the observed water level at Senoshita of Chikugo River is given. Although upstream discharge in Case 3 is about one third or one fourth of Case 4, magnitude of inundation of Case 3 becomes larger due to without cut-off channel. Maximum inundation depth of Case 3 is about 3.6m, whereas that of Case 4 is about 3.0m. Comparing with other case, Case 4 and Case5, in which the upstream boundary's discharge is increased by the factor, 1.1 or 1.2, the inundation depth of Case 3 is maximum. In each case, overflow from the tributaries of Houman River, such as Akimitsu River and Todoroki River occur at first. For the future flood control measures, it is important to consider these small tributaries' flood control.

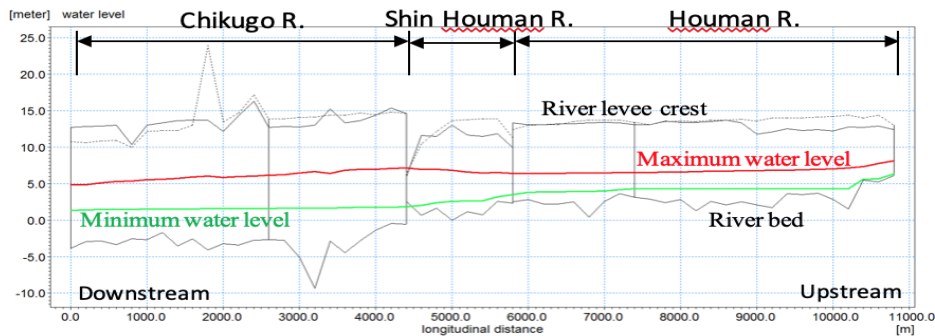


Figure 12(a) Longitudinal water level distribution of Houman R., Chikugo R. and Shin Houman R. with the old meandering waterway for July 7, 2007 (Case 1).

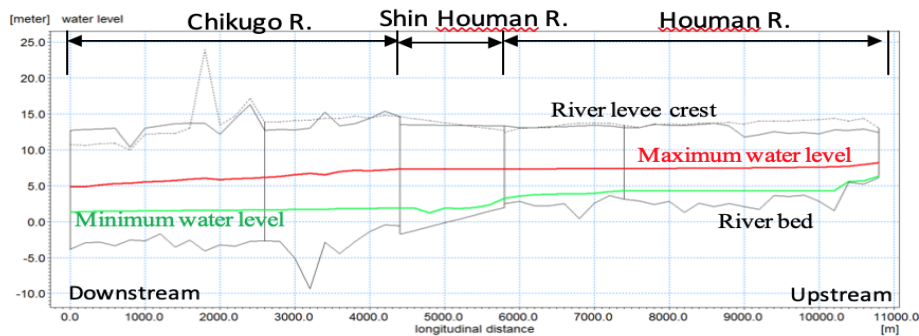


Figure 12(b) Longitudinal water level distribution of Houman R., Chikugo R. and Shin Houman R. without the old meandering waterway for July 7, 2007 (Case 2).

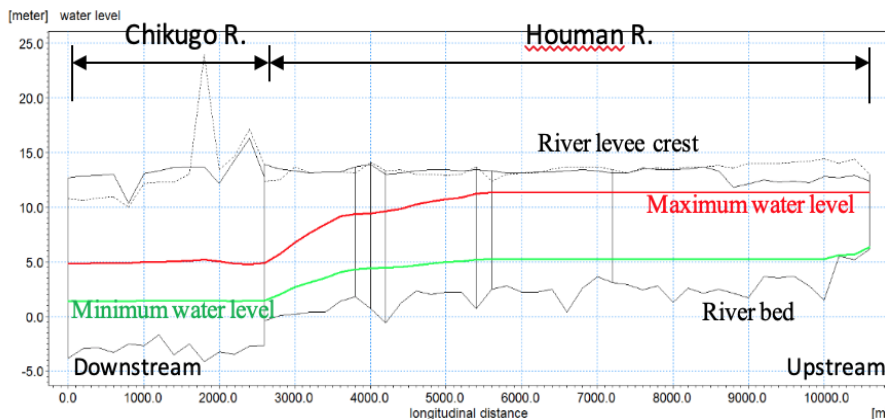


Figure 12(c) Longitudinal water level distribution of Houman R., Chikugo R. without cut-off channel for July 7, 2007 (Case 3).



Figure 13(b). Calculated result of inundation depth distribution in Study Area No.2 at 14:00, July 7, 2007 without cut-off channel (Case 3)



Figure 13(d). Calculated result of inundation depth distribution in Study Area No.2 at 14:00, July 7, 2007 with 1.2 times design high water discharge. (Case 6)



Figure 13(a). Calculated result of inundation depth distribution in Study Area No.2 at 14:00, July 7, 2007 for the present condition. (Case 1) (No inundation)



Figure 13(c). Calculated result of inundation depth distribution in Study Area No.2 at 14:00, July 7, 2007 with design high water discharge. (Case 4)

4

CONCLUSIONS

In this study, the effects of Chikugo River's old meandering waterway and inflowing tributaries with cut-off channel are studied in two study areas. In Study Area No.1, where the tide of the Ariake Sea is effective, the following things are apparent, that is, (1) whole tributaries' water level are balanced to be effective for fresh water intake (Ao intake) and river transportation., (2) During flood overflowing water is induced to the inside of the old meandering waterway as a retarding basin., (3) Reducing overflowing discharge by the old meandering waterway's levee to protect the levee. In Study Area No.2, where the tide of the Ariake Sea is not effective, the following results are obtained, (4) Using cut-off channel, inundation damages are mitigated., (5) The old meandering waterway is used as a storage to decrease the inundation depth in that area.

ACKNOWLEDGEMENTS

This research was conducted partially by the River Foundation under the research grant in FY2018 with the research of "Hydraulic Engineering Study of the role of the old meandering waterway and inflowing tributaries in Chikugo River (research representative: Koichiro Ohgushi)". In carrying out the research, the Chikugo River Office of the Ministry of Land, Infrastructure, Transport and Tourism and the Saga Prefectural Public Work Office provided valuable data and documents. We deeply appreciate persons and organizations concerned.

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