6TH INTERNATIONAL CONFERENCE
ON FLOOD MANAGEMENT
September 2014 - São Paulo - Brazil

INCREASE METHODS OF DRAINAGE DISCHARGE OF INUNDATED WATER IN LOW FLAT LAND CONSIDERING BED DEFORMATION CHARACTERISTICS

Hiroshi Takebayashi[1], Sornthep Vannarat[2] and Saifhon Tomkratoke[2]

1. *Disaster Prevention Research Institute, Kyoto University, Japan*
2. *LSSR Lab., NECTEC, NSTDA, Ministry of Science and Technology, Thailand*

ABSTRACT: Drainage characteristics of inundated water on the lower Chao Phraya River in Thailand is introduced. Furthermore, drainage methods of inundated water on low flat land areas have been discussed by use of the results of horizontal two dimensional bed deformation analysis. Installation of shortcut channel in a fully developed meandering channel can decrease the water surface elevation in the upstream area of the shortcut channel. However, water surface level increases in the downstream area of the shortcut channel and risk of inundation increases there. Most of the confluences between the Chao Phraya River and irrigation channels are located along the outer bank. However, water surface level along the outer bank is higher than that along the inner bank during floods. As a result, drainage discharge of inundated water from the irrigation channel to a main channel will increase, if the confluences between the main flow and irrigation channels are located along the inner bank. Furthermore, a groin at the upstream of the confluences can decrease the water surface level there. As a result, drainage discharge of inundated water from the irrigation channel to the main channel increases.

Key Words: Inundation, Drainage method, Low flat land area, Meandering channel, Bed deformation analysis

1. INTRODUCTION

In the autumn of 2011, Thailand was the scene of a severe flood. It started at the end of July, and, as time passed, the inundation area moved southward, spreading down along the Chao Phraya River. In October, the floodwaters reached the mouth of the river and inundated some parts of Bangkok. More than 800 persons were killed and over 20,000 km^2 of farmland were damaged. Many manufacturing factories were also damaged, causing severe disruption to the manufacturing supply chain.

The channel geometry of the Chao Phraya River in the downstream area in the fully developed meandering channel. Hence, the drainage velocity of the flood water is very slow. Additionally, the river flows in the low flat land and the inundated water flows back to the Chao Phraya River slowly. As a result, the inundation period tends to be longer. Hence, the fast drainage method of the inundated water is expected to be developed. In this study, the horizontal two dimensional analysis is performed to discuss the fast drainage method of the inundated water.

2. OUTLINE OF CHAO PHRAYA RIVER AND DRAINAGE CONDITIONS OF INUNDATED WATER

2.1 Outline of Chao Phraya River

Figure 1: Irrigation canals around the Chao Phraya River (Ransit area, Google Map)

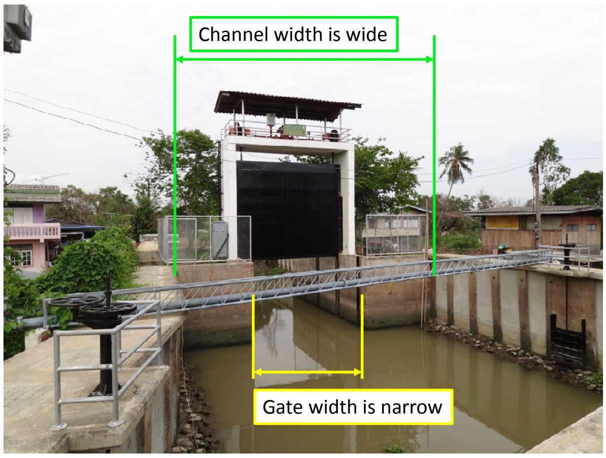


Figure 2: Gate in an Irrigation canal

Figure 3: Elevated canals

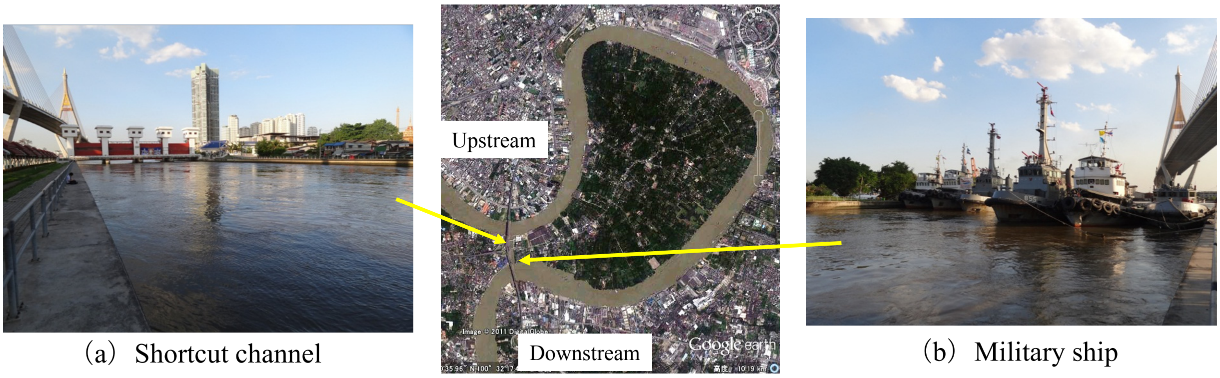
The river basin area amounts to about 160,000km^2, which covers almost 1/3 of the total area of Thailand. More than 40% of the population of the country and about 60% of GNP are concentrated there. The total length of the river is about 1,100km. Its upstream reach is located in the mountainous northern area and the downstream reach is a delta area.

The river slopes are 1/4000 to 1/5000 in the middle reach (about 200–400 km from the river mouth) and 1/50,000 to 1/60,000 in the downstream reach (0–200 km from the river mouth). The river bed difference is only 2 m from Ayutthaya to Bangkok, a distance of 200 km. The Chao Phraya River has a very mild slope, without much discharge ability. At Bangkok, the design flood discharge amounts to 3,600m^3/s. Consequently, if rains fall over a wide area of the river basin and floodwater increases, the river is likely to overflow.

2.2 Drainage conditions of inundated water

There are many irrigation canals in the Chao Phraya River basin, because the rice cultivation is very active. It is considered that the inundated water can be drained to the Chao Phraya River by these irrigation canals. Here, the drainage conditions of inundated water by irrigation canals in the Chao Phraya River basin is introduced.

Figure 1 shows the map of Rangsit area where is in the north of Bangkok. As shown in the figure, many irrigation canals are connected to the Chao Phraya River. Most of these confluent points are located at the outer bank of curvature. It is considered that the outer bank has the advantage to intake the water from the Chao Phraya River to irrigation canals, because the water surface level along the outer bank is higher than that along the inner bank. However, it is considered that the inner bank has the advantage to drainage the water from the irrigation canals to the Chao Phraya River during decreasing process of a flood, because the water surface level along the inner bank is lower than that along the outer bank.



(a) Shortcut channel (b) Military ship

Figure 4: The Chao Phraya River and a shortcut channel

Figure 2 shows a gate in an irrigation canal. As can be seen, the gate is much narrower than the width of the irrigation canal, because all canals in the Chao Phraya River basin are not for the drainage of inundated water. During the survey, no gates wider than 5 m is seen, and no cross-section with multiple gates is seen. Width of all gates openings is about 4 m, and gate cross-sections had only one gate regardless of the wide width of the irrigation canal. Consequently, irrigation canals had little drainage capacity.

Figure 3 shows an elevated channel connecting the irrigation canals with the ocean. The elevated channel works to prevent the intrusion of saltwater into the irrigation canal. Water in the irrigation canal is sent to the elevated channel by use of pumps. The drainage discharge of the floodwater here is therefore limited by the power of the pumps, while discharge from upstream increases. The pumps were not designed to drain floods. Furthermore, if the pumps fail, drainage discharge decreases further. In order to prevent saltwater from entering the irrigation canal, many pumps are installed near the ocean and where canals meet large rivers.

In order to drainage the inundated water from the irrigation canals to the Chao Phraya River, the water level in the Chao Phraya River must be lower. Hence, the drainage of the water from the Chao Phraya River to the ocean should be considered together. Figure 4 shows the satellite image of the Chao Phraya River around Bangkok. As shown in the figure, the Chao Phraya River around Bangkok is the fully developed meandering channel and retention time of the water in the river tends to be longer. The meandering channel in Figure 4 has a shortcut channel. The shortcut channel is constructed for the electric power generation. Hence, the channel width is about 70m which is very narrow comparing to channel width of the Chao Phraya River. Hence, the shortcut channel is not enough to drainage the flood discharge. During the flood in 2011, as shown in Figure 4 (b), the military ships pull alongside in a cross-section and the ships are connected and fixed each other by chains. The screws of the military ships are rotated at full power and they try to drainage the water to the ocean.

3. NUMERICAL ANALYSIS METHOD

3.1 Purpose of analysis

As shown in Chapter 2, there are many canals and shortcut channels in the downstream area of the Chao Phraya River. However, the structure of those channels are not suitable to drainage the inundated water fast. In this study, two methods are discussed. One of them is the method how to drainage the inundated water from floodplains to a big river (the Chao Phraya River). Effect of the location of the confluence between the big river and an irrigation canal on the drainage discharge is discussed. Furthermore, the effect of the setting of groin at the upstream of the confluence on the drainage discharge is discussed. The other is the fast drainage method in the fully developed meandering channels. Effect of the increase in the water discharge in the shortcut channel on the bed deformation in and around the shortcut channel is discussed.

Table 1: Hydraulic conditions and the water discharge in the irrigation channels

	Shortcut channel	Irrigation channel	Groin	Discharge in main channel (m^3/s)	Calculated discharge in irrigation channel (m^3/s)
Case 1-1	No	—	—	3500	—
Case 1-2	Yes	—	—	3500	—
Case 2-1	—	No	No	3500	—
Case 2-2	—	No	No	500	—
Case 2-3	—	Inner bank in upstream region	No	3500	119
Case 2-4	—	Outer bank in upstream region	No	3500	-49
Case 2-5	—	Inner bank in downstream region	No	3500	84
Case 2-6	—	Outer bank in downstream region	No	3500	-122
Case 2-7	—	Inner bank in upstream region	Yes	3500	159

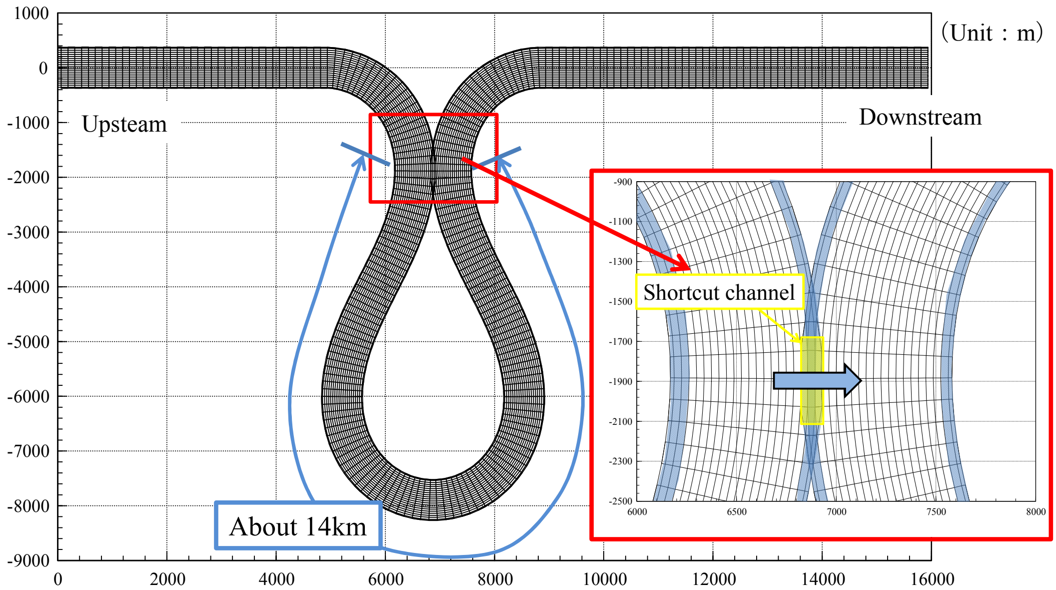


Figure 5: Numerical grids (Case 1)

3.2 Framework of numerical analysis

Numerical analysis is performed by use of horizontal two dimensional bed deformation analysis (Takebayashi, 2005). The equations are written in general coordinate system. The water velocity near bed is calculated by use of the curvature of streamlines of depth averaged water velocity (Shimizu & Itakura, 1991). The strength coefficient of the secondary flow is 7 (Engelund, 1974). Bed material is treated as non-uniform sediment. Both bed load and the suspended load are considered. Bed load is estimated by modified Ashida-Michiue formula (Ashida & Michiue, 1972, Liu 1991, Kovacs & Parker, 1994). Suspended rate of the sediment at the reference height is estimated by Lane-Kalinske equation (Lane & Kalinske, 1941). The transport equation of depth averaged concentration of suspended load is solved and the non-equilibrium characteristics of suspended load is considered.

3.3 Hydraulic conditions

Two kinds of channel geometries are used. Table 1 shows the hydraulic conditions and some of calculated results.

The effect of the shortcut which is constructed to the fully developed meandering channels is analyzed in Case 1. Figure 5 shows the numerical grids. The horizontal channel geometry is one wavelength of the Sine-generated curve. The maximum meandering angle is 117 degree. Three grids along both banks are for the floodplains. The channel width is 600m, the channel length in the meandering region is about 14km without a shortcut channel. The cannel length becomes 0.5km by the shortcut. The longitudinal bed slope of the main channel is 1/10000. The initial cross-sectional geometry is rectangular. The water discharge is 3500m^3/s and the water depth at the end of the calculation domain is 7m. Figure 6 shows the size distribution of bed material. The mean diameter is 0.1mm. The bed material size is decided by use of the field data. The number of size class is 7 in the analysis. As shown in Figure 5, the numerical grids at the short cut channel are overlapped and the overlapped 3 meshes in the longitudinal direction of the main channel is used for the shortcut channel. There is no shortcut channel in Case1-1 and short cut channel exists in Case1-2.

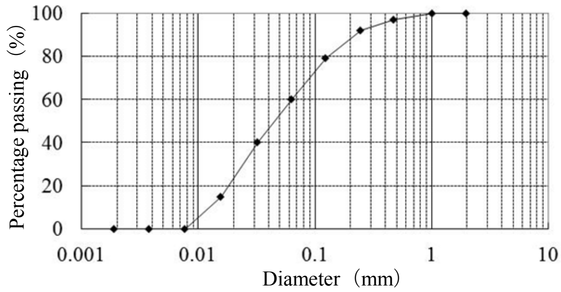


Figure 6: Initial size distribution of bed material

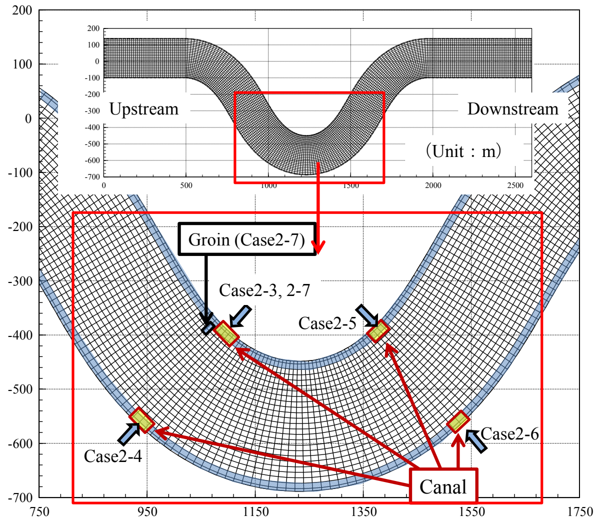


Figure 7: Numerical grids (Case 2)

Meandering channel with smaller maximum meandering angle is used for Case 2 and the channel geometry is decided considering the channel geometry of the Chao Phraya River in Rangsit area. Effect of the location of the confluence between the big river and an irrigation canal on the drainage discharge is discussed in Case 2. Furthermore, the effect of the setting of groin at the upstream of the confluence on the drainage discharge is discussed. Figure 7 shows the numerical grids. The horizontal channel geometry is one wavelength of the Sine-generated curve. The maximum meandering angle is 60 degree. Three grids along both banks are for the floodplains. The channel width is about 200m. The longitudinal bed slope of the main channel is 1/10000. The initial cross-sectional geometry is rectangular. The elevation difference between the bed and floodplain surfaces is 15m which is smaller than normal depth for 3500m^3/s. The water discharges are 3500m^3/s and 500m^3/s and the water depth at the end of the calculation domain is normal depth. Bed material is the same as that in Case 1.

As shown in Figure 7, the irrigation canals are connected to the main channel at the upstream and the downstream regions of the inner and outer banks. The channel width of the irrigation channels is about 35m. The water velocities in the irrigation canals are calculated by use of the water surface slope at the side boundaries of the calculation domain (upstream boundary of canals). The water surface elevation at the calculation boundaries in the canals is 1m lower than the floodplain elevation. Here, the floodplain surface and irrigation bed are treated as rigid bed; sediment can be deposited there but bed lower than the initial level is not eroded. The irrigation channels are not considered in Cases 2-1 and 2-2. The difference of the water surface elevation between the right and the left banks during a flood is discussed in Case 2-1. The difference of the water surface elevation between the right and the left banks during low flow is discussed in Case 2-2. An irrigation canal is set at the upstream region of the inner bank in Case 2-3, at the upstream region of the outer bank in Case 2-4, at the downstream region of the inner bank in Case 2-5, at the downstream region of the outer bank in Case 2-6, respectively. A non-submerged groin are set at the upstream region of the inner bank in Case 2-7.

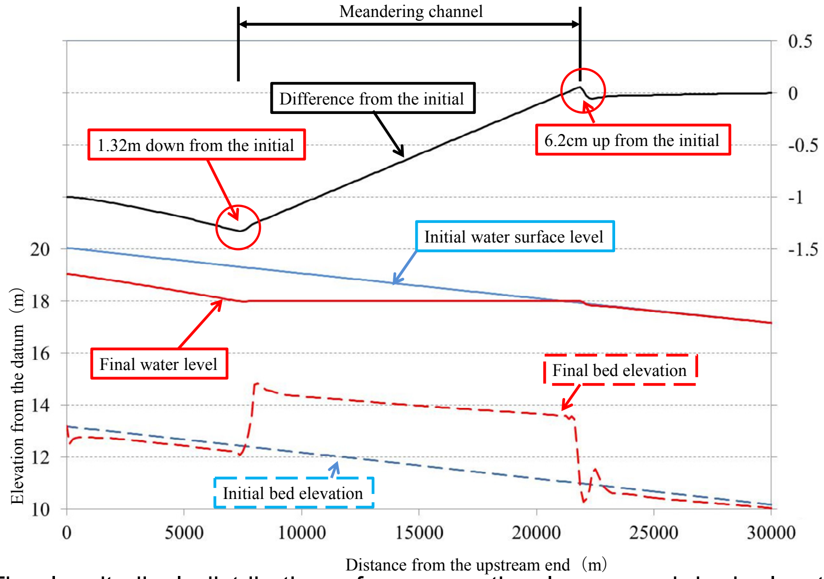


Figure 8: The longitudinal distribution of cross-sectional averaged bed elevation and the difference of cross-sectional averaged water depth from the initial value (Case 1)

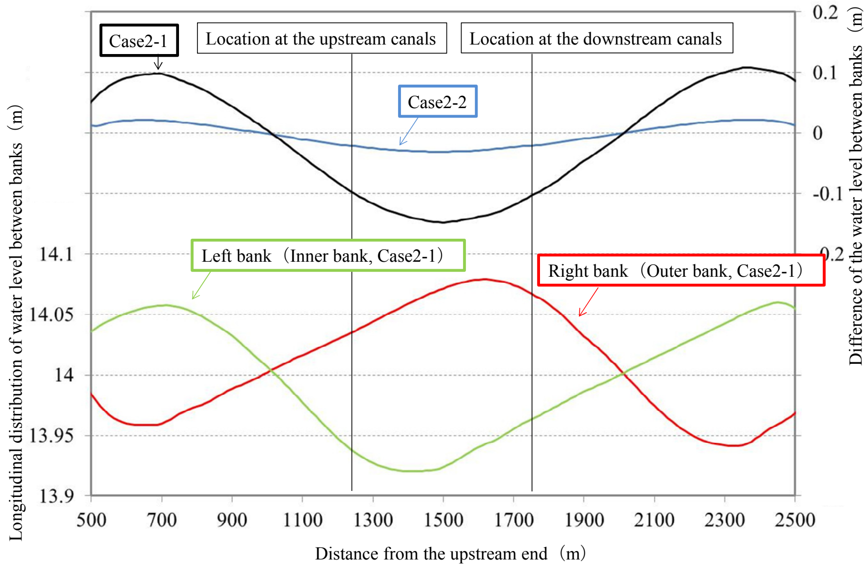


Figure 9: The longitudinal distribution of water level along both banks (Cases 2-1 and 2-2)

4. RESULTS AND DISCUSSION

4.1 Effect of the shortcut channel

Figure 8 shows the longitudinal distribution of cross-sectional averaged water depth and bed elevation in Case 1-1 and Case 1-2. The water surface elevation in Case 1-2 is 1.32m lower than that without shortcut channel. This result indicates that the shortcut channel is effective to decline the water surface elevation and the drainage of the inundated water from irrigation canals in the upstream region of the shortcut channel. On the other hand, the water surface elevation with shortcut channel in the downstream region of the shortcut channel is 6.2cm higher than that without shortcut channel. This result indicates that the risk of the flood is increased slightly in the downstream area and the drainage of the inundated water takes longer time. Furthermore, the bed elevation in the meandering channel in Case 1-2 is aggradated with time, as a result, the most of water flows in the shortcut channels.

4.2 Effect of the confluence location of an irrigation canal on the drainage discharge

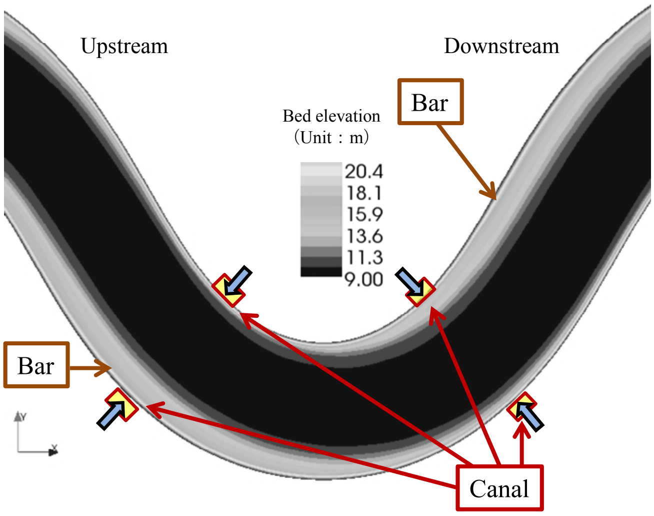


Figure 10: Bars in the meandering channel (Case 2-1)

Figure 9 shows the longitudinal distribution of water surface elevation along the both banks in Case2-1 and Case2-2. The maximum difference of the water surface level between both banks is 15cm during flood and 3cm during low flow. This result indicates that the confluence location between the main channel and an irrigation channel does not affect on the intake of the water during low flow.

Table 1 shows the water discharge in irrigation canals in Cases 2-3, 2-4, 2-5, 2-6 and 2-7. The water discharge from the irrigation canals to the main channel is a positive value in the table. The water discharge is maximum at the upstream region of the inner bank (Case 2-3) and the next is the irrigation canal at the downstream region of the inner bank (Case 2-5) among Cases 2-3, 2-4, 2-5 and 2-6. The two irrigation canals at the outer banks cannot drainage the inundated water to the main channel. The discharge from the main channel to the irrigation channel is maximum at the downstream region of the outer bank (Case 2-6), because the flow concentrates there. The difference of the discharge in irrigation canals between the inner banks and the outer banks depends on the water level as shown in Figure 9. The difference of the discharge in inner bank irrigation canals between the upstream region and the downstream region depends on the difference of sedimentation. As shown in Figure 10, sand bars are formed along the downstream region of the curvature of the inner bank and sediment is deposited in the irrigation canals. As a result, the water discharge in Case 2-5 is smaller than that in Case 2-3.

Next, the method to increase the drainage discharge is discussed. As shown in Table 1, the non-submerged groin which is set at the upstream region of the irrigation canal can increase the drainage discharge. Figure 11 shows the longitudinal profile of water level along the inner bank in Cases 2-1 and 2-7. As shown in Figure 11, the water level at the confluence between the irrigation canals and the main channel is decreased in Case 2-7 and the decrease in the water level contributes to the increase in the drainage discharge. Additionally, the suspended sediment does not deposit at the downstream region of the groin, because the water flow from the irrigation canal suppress it.

5. CONCLUSIONS

The drainage conditions of inundated water by irrigation canals in the Chao Phraya River basin is introduced and the horizontal two dimensional analysis is performed to discuss the fast drainage method of the inundated water. The obtained results are summarized as follows.

(1) There are many irrigation canals in the downstream floodplains of the Chao Phraya River. The canals are constructed only for agricultural purpose and does not have the flood control functions.

(2) The channel geometry of the Chao Phraya River in the downstream area is fully developed meandering channel. Construction of shortcut channels to the meandering channel decrease in the water level in the upstream area dramatically. On the other hand, the water level in the downstream area increases slightly. This result indicates that the risk of the flood is increased in the downstream area and the drainage of the inundated water takes longer time.

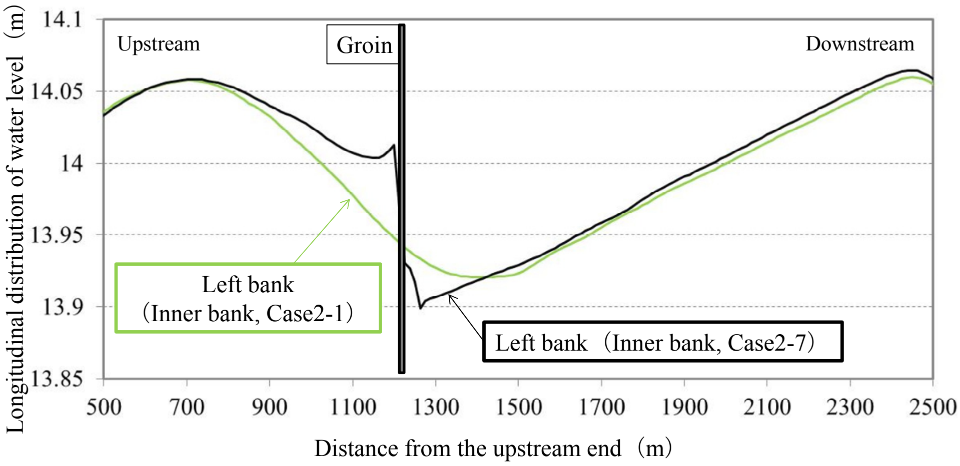


Figure 11: The longitudinal profile of water level along the inner bank (Cases 2-1 and 2-7)

(3) Drainage discharge of the inundated water from the irrigation canals becomes maximum at the inner bank in the upstream area of the curvature, because the water level is lower and the sand bar is not formed.

(4) The non-submerged groin which is set at the upstream of the irrigation canal can decrease in the water level at the confluence between the irrigation canals and the main channel and the decrease in the water level contributes to the increase in the drainage discharge.

6. ACKNOULEDGEMENTS

This work is funded by JST J-RAPID (Representa-tive: Hiroshi Takebayashi), Grant-in-Aid for Scientific Research for young researchers (B) (Representative: Hiroshi Takebayashi), RIC Research Fund (Representative: Hiroshi Takebayashi).

7. REFERENCES

Agnes Kovacs and Gary Parker, A new vectorial bedload formulation and its application to the time evolution of straight river channels. J. Fluid Mech. Vol. 267, pp. 153-183, 1994.

B. Y. Liu, Study on Sediment Transport and Bed Evolution in Compound Channels. Thesis presented to Kyoto University, 1991.

Frank Engelund, Flow and bed topography in channel bends. Jour. of Hy. Div. ASCE, Vol. 100, No. HY11, 1974.

Hiroshi Takebayashi. River Configuration in Middle-Lower Reach of River Basin, Journal of Japan Society of Fluid Mechanics, Vol. 24, pp. 27-36, 2005.

Kazuo Ashida and Masanori Michiue. Study on hydraulic resistance and bed-load transport rate in alluvial streams, Proc. of JSCE, No. 206, pp.59-69, 1972.

Lane, E. W. and Kalinske, A. A. Engineering calculation of suspended sediment, Trans. A.G.U., Vol. 22, 1941.

Yasuyuki Shimizu and Itakura,Tadaoki. Calculation of flow and bed deformation with a general non-orthogonal coordinate system, Proc. of 26th IAHR Congress, Madrid, Spain, C-2, pp.41-48, 1991.