# A Study on The Traditional Flood Management in Jobaru River Basin by Geotechnical and Hydraulic Engineering Approach

**Koichiro OHGUSHI [a] and Takenori HINO [b]**

[a]Graduate School of Science and Engineering, Saga University, Professor
[b]Institute of Lowland and Marine Research, Saga University, Associate Professor

# 地盤工学的・水工学的アプローチによる城原川流域の伝統的治水に関する研究

**大串　浩一郎 [a]・日野　剛徳 [b]**

[a]佐賀大学大学院工学系研究科・教授
[b]佐賀大学低平地沿岸海域研究センター・准教授

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## Abstract

In 17th century in Japan, full-scale countermeasures against flood disasters were carried out. The Saga Plain includes such flood damage prevention facilities everywhere. At present, several facilities of the flood control are left and can be seen as historic remains. It is significantly useful to find out and restore these remains and clarify their functions to consider a future flood control including catchment basin operations. In this study, overflow embankments and open levees of the Jobaru River are focused as the investigated field for estimating a controlled water flow spreading the retarding basin with sediment transports. We adopted a geotechnical sampling method to obtain a plate-like sample that can be easily analyzed for estimating water flow velocity, flow direction and a process of sediment settling. An additional investigation of numerical simulation is implemented to estimate water flow on the retarding basin from the overflow embankment. One dimensional flow analysis of Jobaru River gave a boundary condition for two dimensional simulation of flood flow on the retarding basin. The results of geotechnical investigation and hydraulic approach show the controlled water flow in the retarding basin in the residential area. This result gives a quantitative consideration about the flood control including catchment basin operations.

## 要旨

17 世紀の我が国では洪水災害に対する本格的な対策が実施された。佐賀平野にはここかしこにそのような洪水防御のための治水施設が存在する。現在、そのいくつかは遺構として残っている。これらの治水遺構を発見・復元し、その機能を明らかにすることは、流域対応の将来の治水を考える上で非常に重要である。本研究では、城原川の野越や霞堤を研究対象とし、堤内地に土砂と共に広がる制御された水流を推定した。氾濫流速や流向、土砂の堆積過程の予測を容易に解析できる板状の地盤採取法を採用した。さらに、数値シミュレーションにより、野越から堤内地へ広がる氾濫流の推定を行った。城原川の１次元流れ解析により堤内地の氾濫流の２次元流れ解析のための境界条件が得られた。地盤調査と水理解析の結果は、堤内遊水地における制御された水流を示した。この結果により、流域対応を含む治水の定量的な考察を与えた。

Introduction

In 17th century in Japan, full-scale countermeasures against flood disasters were carried out. The Saga Plain includes such flood damage prevention facilities everywhere. At present, several facilities of the flood control are left and can be seen as historic remains. Some flood damage reduction facilities are still effective. In the year of 2000, the River Council in Japan intermediately reported "The ideal method of the effective flood control including catchment basin operations". It is significantly useful to find out and restore these remains and clarify their functions to consider a future flood control including catchment basin operations.

In the Saga Plain, the flood control including catchment basin operations have been adopted 400 years ago. This concept is to keep a slow river flow and divert risks to a whole river basin in order to suppress a flood disaster as a result. Jobaru River is located in east Saga Plain and it has 4 open levees (Kasumi-Tei) and 5 overflow embankments (Nokoshi). Its river basin includes not only the open levees or overflow embankments but also auxiliary levees in the residential area (Mizuuke-tei) and retarding basins. These flood control facilities have important roles as a systematic countermeasure against floods.

In this study, overflow embankments and open levees of the Jobaru River are focused on the investigated field for estimating a controlled water flow spreading the retarding basin. The flow may be bounded by auxiliary levee to give a designed water flow. The past floods carried not only water but also sediments to the retarding basin for many times. Underground soil must include information of past flood flow and carried sediments those had been settled on the ground surface in the past. Therefore, we adopted a geotechnical sampling method to obtain a plate-like sample that can be easily analyzed for estimating water flow velocity, flow direction and a process of sediment settling.

An additional investigation of numerical simulation is implemented to estimate water flow on the retarding basin from the overflow embankment. One dimensional flow analysis of the Jobaru River gave a boundary condition for two dimensional simulation of flood flow on the retarding basin. For an accurate and detail simulation, ground height data are obtained from an airborne laser profiler so that very fine geometrical dataset could be given to the computation.

## 2. Study Areas

### *2.1. Jobaru River*

Jobaru River originates from Mountain Seburi of Saga Prefecture, Japan. Fig.1 shows the studied area. The Jobaru River is one of the tributaries of Chikugo River which is the largest river in Kyushu Island. Jobaru River joins the Sagae River and Chikugo River thereafter and flows into the Ariake Sea that has the largest tidal range in Japan. The maximum tidal range at Suminoe, the head of the bay is

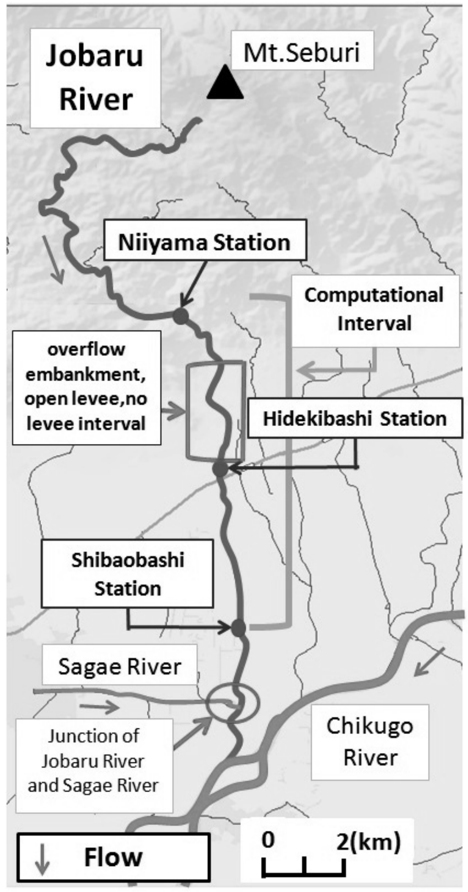

Fig.1 Jobaru River in Saga Prefecture, Japan


Fig.2 Overflow embankment of the Jobaru River (Tsurunishi District, Kanzaki Ciry, Saga Prefecture)

about 6m. A catchment basin area of the Jobaru River is about 64.4km$^2$ and a length of the trunk watercourse is about 31.9km. The number of living people inside the river basin is about 10 thousands.

Full-scale countermeasures against flood disasters were implemented in the Jobaru River Basin of the Saga Plain in Japan during 17th century by riparian technical groups including Chief Retainer Hyogo Naritomi (Kishihara, N., 2007). There are many flood damage reduction facilities in the river or near the river of the Saga Plain. For examples, there had been many retarding basins, overflow embankments (Nokoshi), open levees (Kasumi-Tei), flood restraining forest belt, and auxiliary levees in the residential area. Original flood control technology of the whole river basin with collaborations of these flood damage reduction facilities is gradually elucidated[1,2].

*2.1.1. Overflow Embankment (Nokoshi)*

Along the midstream Jobaru River, there are 5 overflow embankments that were used aggressively to introduce the river water into the retarding basin in order to decrease the water surface level of the Jobaru River downstream as shown in Fig.2 and 3. These overflow embankments are called "Nokoshi" in Saga Prefecture. Fig.4 shows the locations of overflow embankments in the Jobaru River.

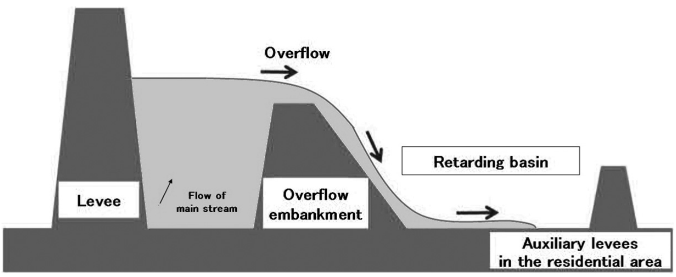


Fig.3 Flood management using overflow embankment, retarding basin and auxiliary levees in the residential area

*2.1.2. Open Levee (Kasumi-Tei)*

Not only the overflow embankments but also 4 open levees exist along the Jobaru River as shown in Fig.4. The open levees are one of the discontinuous levees and are called "Kasumi-Tei" in Japan. They were used especially in the steep stream. For the drainage of landside water or inundated water due to upstream levee breach to the main stream and tentative storage of flooded water, the open levees gave significant roles. When the water level in the landside reaches to the crest of the open levee, the water behaves as one body with fluid in the main stream.

## 3. Methodology

### *3.1. Computational analysis*

*3.1.1. One dimensional analysis of open channel flow*

In this study, it has been necessary to give overflow discharges from overflow embankments or open levees of the Jobaru River. Therefore, an unsteady one dimensional open channel flow is simulated at first to obtain the overflow discharges from these discontinuous levees. From July 11th to 15th in 2010, flood occurred in the Jobaru River and at several discontinuous levees overflows were seen. In this study, the flood during this period is simulated at first.

Precipitation during these period was recorded 700mm at Ifuku where is mountainous area of the Jobaru River

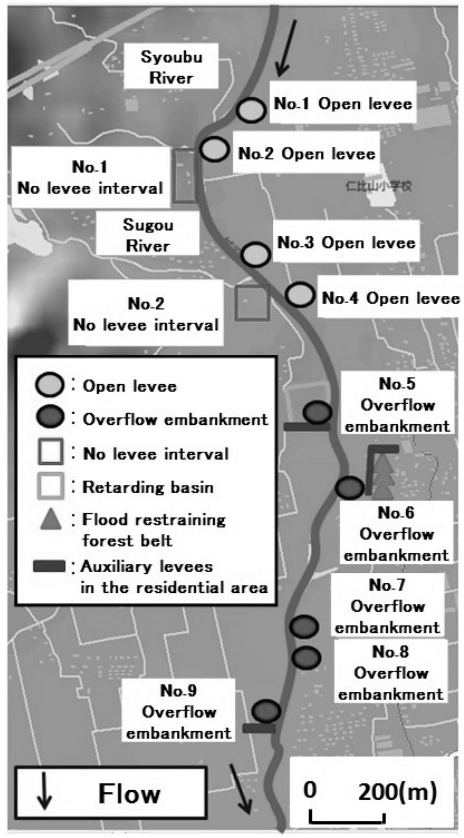


Fig.4 Locations of overflow embankments, open levees, no levee intervals, etc along the Jobaru River.

Basin. Maximum discharge was recorded 318.11$m^3$/s at Hideki and maximum water level was recorded 4.66m at the same place. The warning water level of inundation danger at Hideki is 4.32m then refuge advice was given to the inhabitant. Overflows from the open levees are seen in this flood.

As one dimensional analysis, MIKE11 was used to obtain each cross section's discharges and water levels. Used cross section data for every 200m interval is from the survey results in March, 1997 by the Ministry of Land, Infrastructure, Transport and Tourism of Japan (MLIT). For calculations of water flow from the open levees or overflow embankments, the retarding basins are modelled to be other rivers which are connected with the main stream by adding the relation of the Honma's weir formula. There are 2 intervals where no levee exists. The ground height near no levee intervals and retarding basins are accurately obtained from laser profiler's data surveyed in 2006 by MLIT.

As an upstream boundary condition, flow discharge is given at Niiyama. As a downstream boundary condition, water level at Shibao Bridge is given. Manning's roughness is given by n=0.028 for low-water channel and n=0.035 for high water channel.

For much larger floods, the modelled floods are generated by multiplying the factor 1.1, 1.2, 1.3, 1.4 and 1.5 against flow discharge at Niiyama station and as the downstream boundary; the calculated normal depths for each discharge are given at the Shibao Bridge.

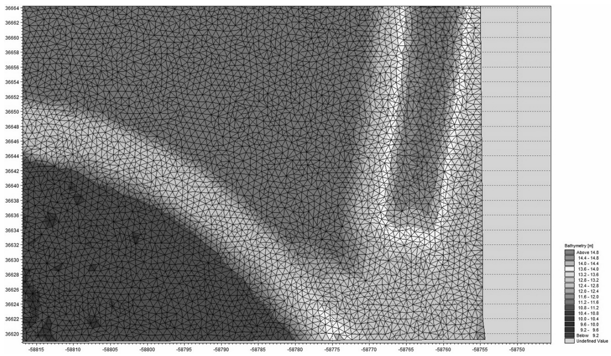

Fig.5 Unstructured computational mesh to calculate flood flow on the retarding basin. Ground height data are given by Laser Profiler's data

### *3.1.2. Two dimensional analysis of flood flow*

No.5 overflow embankment and its retarding basin are focused for geotechnical investigation which will be explained later. After obtaining the overflow discharges from the open levees and overflow embankments, the resultant inflow discharge can be given to two dimensional computational analysis of flood flow on the retarding basin as a boundary condition. The basic equations for the numerical simulation are 2-D continuity equation and equation of motion as follows:

$$\frac{\partial h}{\partial t}+\frac{\partial h\bar{u}}{\partial x}+\frac{\partial h\bar{v}}{\partial y}=0 \qquad (1)$$

$$\frac{\partial h\bar{u}}{\partial t}+\frac{\partial h\bar{u}^2}{\partial x}+\frac{\partial h\overline{vu}}{\partial y}=-gh\frac{\partial \eta}{\partial x}-\frac{\tau_{bx}}{\rho_0} \qquad (2)$$

$$\frac{\partial h\bar{v}}{\partial t}+\frac{\partial h\overline{uv}}{\partial x}+\frac{\partial h\bar{v}^2}{\partial y}=-gh\frac{\partial \eta}{\partial y}-\frac{\tau_{by}}{\rho_0} \qquad (3)$$

where $h$ : water depth, $u,v$ :depth averaged velocity components, $\rho_0$ : water density, $\eta$ :water surface displacement, $\tau_{bx},\tau_{by}$ :bottom shear stress components. The boundary inflow discharge is given by the resultant overflow discharge calculated by one dimensional simulation with a multiplying factor=1.4. Manning's roughness coefficient is set to n=0.064 for the whole retarding basin.

Equations (1) to (3) are transformed to the unstructured grid of triangle computational mesh. An area of triangle mesh is less than 5m$^2$. For an accurate and detail simulation, ground height data are obtained from an airborne laser profiler and are applied to the triangle unstructured mesh so that very fine geometrical dataset could be given to the computation as shown in Fig.5.

### *3.2. Geotechnical Investigation*

The authors adopted a geotechnical sampling method to obtain a plate-like sample that can be easily analyzed for estimating water flow velocity, flow direction and a process of sediment settling. Fig.6 shows an aerial photograph of the studied area where the auxiliary levee in the residential area is seen.

Fig.6 Aerial photograph of the studied area, the retarding basin near the overflow embankment, "Yago Nokoshi" for two dimensional numerical analysis and geotechnical investigation

Fig.7 shows how we take the soil sample of the retarding basin. This instrument is called "Geoslicer" which was developed by Hiroshima University, Japan Nuclear Cycle Development Institute (JAEA in present) and Fukken Co., Ltd. [3, 4, 5, 6]. On June 9, 2011, a preliminary investigation was held at first by using a Handy Geoslicer at the retarding basin near the overflow embankment, named Yago Nokoshi. The Handy Geoslicer is 10cm wide, 1.5-2.0m long. Their trapezoidal cross section between flanges, measured 10cm by 2-3cm. It consists of a sample tray and a shutter plate. At 5 points in the studied area, the Geoslicers were descended to depth of 1.5-2.0m. Based on the results obtained from the preliminary investigation, a main geotechnical investigation was held on November 12, 2011. Fig.8 shows an illustrated Geoslicer for the main geotechnical investigation. In this investigation, a crane truck was used to hoist the Geoslicer that was 45cm wide, 3.5-4.2m long. The sample tray was first driven by a weighted vibrator. Secondly, the shutter plate was driven by the same instrument. After both the sample tray and shutter plate were driven, both are connected together at the top using a pin. Then the Geoslicer and sampled soil were pulled up from the ground without vibrating for not giving any disturbance to the sample.

Fig.7 Soil sampling by using a "Handy Geoslicer"

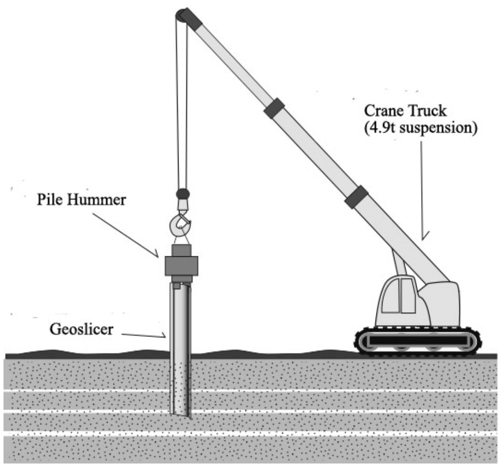


Fig.8 Geoslicer driven by Crane and Pile Hummer for the main geotechnical investigation

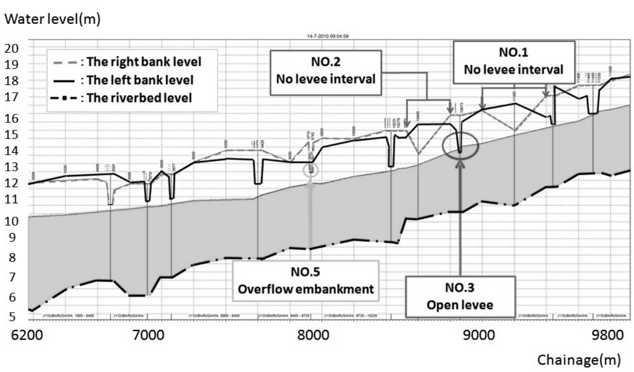


Fig.9 Longitudinal water level distribution of the Jobaru River in July 14, 2010.

## 4. Results and discussions

### *4.1. Results of Computational Simulation*

Fig.9 shows a longitudinal distribution of water level in the Jobaru River obtained by the result of one dimensional simulation for the flood in July, 2010. At No.3 open levee, the flood water is seen to flow out into the retarding basin. The overflow from No.3 open levee continues about 1hour and the maximum overflow discharge is 2.13m$^3$/s. Fig.10 shows the comparison between the calculated results and observed one. The calculated results consist of two cases; one is the case with overflow embankment, open levee and no levee interval, another is the case without them. There is little difference between them because the overflow discharge is low. However, there is a little difference between the observed water level and calculated ones. One of the reasons is that the discharge at Niiyama station as the upstream boundary condition is assumed to be same with that of Hideki where the river discharge is observed. The second reason is that the roughness coefficient is assumed to be constant along the river but it should be different due to vegetation existence.

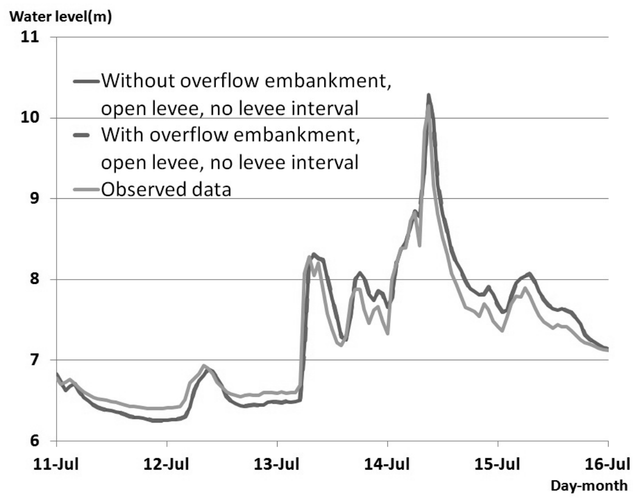


Fig.10 Comparison of water level at Hidekibashi station from July, 11 to 16, 2010.

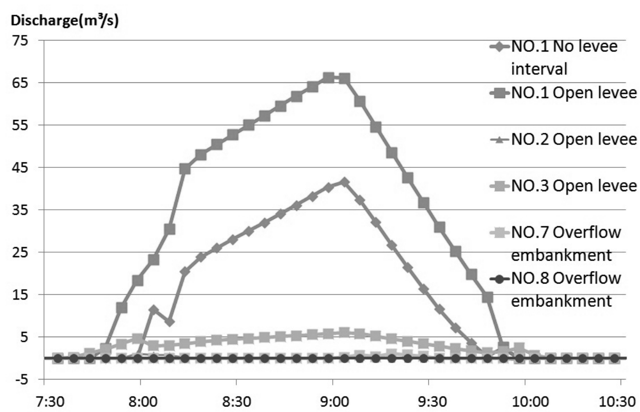


Fig.11 Overflow discharges from each discontinuous levee of Jobaru River in case of 1.5 times flood against the flood of July, 2010.

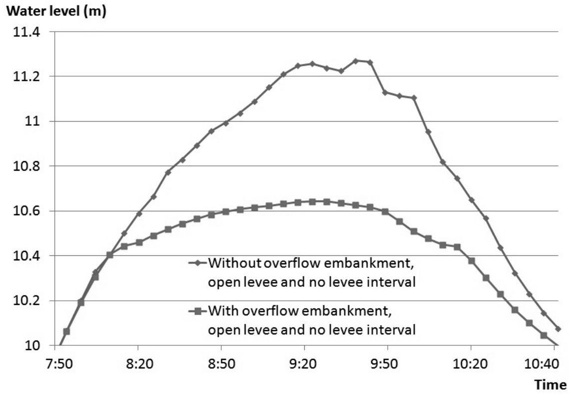


Fig.12 Water level changes in time at Hideki for both the case of all discontinuous levees considered and the case of no discontinuous levee considered

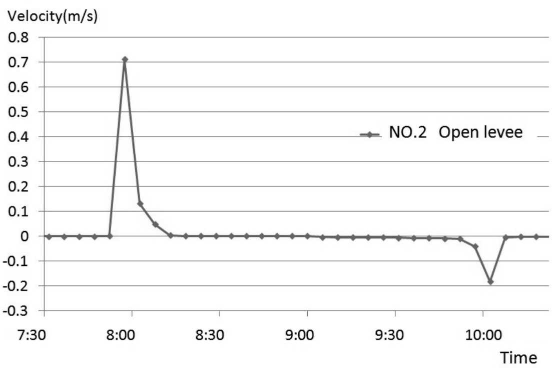


Fig.13 Water velocity change in time on the No.2 open levee. A positive value means the water flows out to the retarding basin.

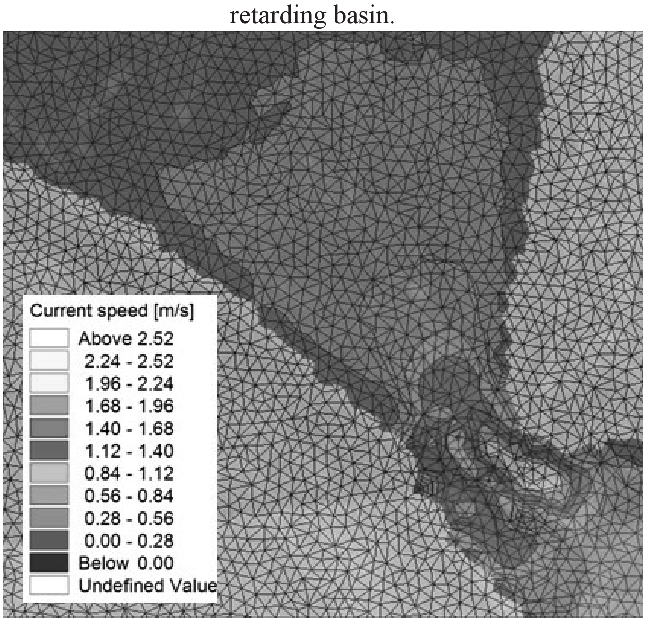


Fig.14 Flood flow near the No.5 overflow embankment simulated by two dimensional flood analysis

In cases of modelled floods for much larger discharges, overflow discharges increase as shown in Fig.11. In this figure, the factor multiplied to the original flood is 1.5. The No.1 open levee has the most overflow among all open levees and overflow embankments because its overflow width is largest. The second large discharge is seen at the No.1 no levee interval. Both the No.1 open levee and the No.1 no levee interval occupy almost 90% of all overflow discharges from the discontinuous levees in Jobaru River. In Fig.12, the water level changes at Hideki in time for both the case of all discontinuous levees considered and that of no considered are compared for the 1.5 times flood against the flood of July, 2010. The maximum difference of water level is about 0.62m. If the river discharge increases, the overflow discharge increases and the increase of water level is suppressed due to the discontinuous levees like the open levee.

Fig.13 shows the velocity of overflow at the No.2 open levee in the case of 1.5 times flood against the flood of July, 2010. In the open levee, the water inside the retarding basin reversely flows into the main channel after the water level decreases in the main channel. The numerical model simulates these characteristics. Nowadays, the heights of the open levees and the overflow embankments are different from those in the past and are heighten almost 1m and more. Therefore, the overflow discharges and velocities of these discontinuous levees are different from the past and may be less than the past situations.

Fig.14 is the result obtained from two dimensional flood flow analysis at the No.5 overflow embankment named Yago Nokoshi. The maximum velocity is about 2.5m/s in this case. But after overflowing and falling to the retarding basin, the water velocity decreases to less than 1 m/s and after spreading, it is suppressed less than 0.5m/s. Therefore, the sediment transported to the retarding basin may be settled down near the overflow embankment behind.

*4.2 Results of Geotechnical Investigation*

Using the Geoslicer soil sampling in the main geotechnical investigation, 8 locations soil samples were obtained as shown in Fig.15. The locations GS-4, GS-7 and GS-8 are close to the overflow embankment. Sand or silt is seen at the layer 30cm deep. Fig.16 is a close photograph of the sample GS-7. Usually in the wet hinterland, the suspended and transported clay or silt only deposit. The fact that the sand layers were found only near the overflow embankment can be explained by the situation that the sand transported by the flood flow from the overflow embankment was not transported so far due to sudden decreasing of flow velocity.

Sediment's ages of the sampled stratums were estimated by using radioactive carbon. The age estimation by radioactive carbon is a method to measure the age by using carbon isotope involved in the carbide of plants or animal's corpse. The carbon isotope $^{14}C$ has 5730 years as a half-life. The $^{14}C$ included in the atmosphere at a constant ratio is taken to the plant by photosynthesis. No other new $^{14}C$ is taken except photosynthesis, therefore fixed $^{14}C$ in the plant remains reduce by half in 5730 years after its death. Measuring how large $^{14}C$ is included in the sample gives how old the sample passed the time. In case of animal's corpse, the animal took a plant with a fixed $^{14}C$ so that the same estimation of age can be possible. In the main investigation, wood splinter with several mm sizes for all samples are targeted. It should be noted that the estimated age is just for the wood splinter, not for the sediment year itself. When the sample is taken, upper stratum's content may be pulled down to the lower stratum and a substance indicating a new age may be mixed. However, in the case of Geoslicer, the width of the sample is large and stratum structure can be also observed so that a sampling error in case of pulling down can be removed.

Fig.17 shows classified sediments columns and estimated age of the stratum by radioactive carbon method. In each soil column, the sediment observed at lower layer consists of river stream sediment, mainly sand and gravel. This means that the old Jobaru River stream is located here in the past. In a natural condition, a river stream meanders and changes its stream location. A wood splinter obtained at 235m deep layer of GS-1 showed the period was about AD1470±20years. Therefore it means that until year 1500, the studied area was in the meandering river. The mainly silt layer on the river stream sediment is considered wet hinterland sediment in the flood plain. Especially in the lower layer of this stratum consists of many growing plant remains. The estimated period for GS-2 of 130 deep is about AD1640±30years, while one for GS-8 of 92cm deep is about 1570 ± 20years. The upper layer of the wet hinterland sediment does not include plant root so much. Moreover, a little sand layer has been seen at GS-2 of 30-60cm deep. In the wet hinterland, usually suspended and transported silt and clay deposit only. The fact that the sand layer has been seen only near the overflow embankment means that the sand has not been transported because flow velocity decrease after overflow from the overflow embankment.

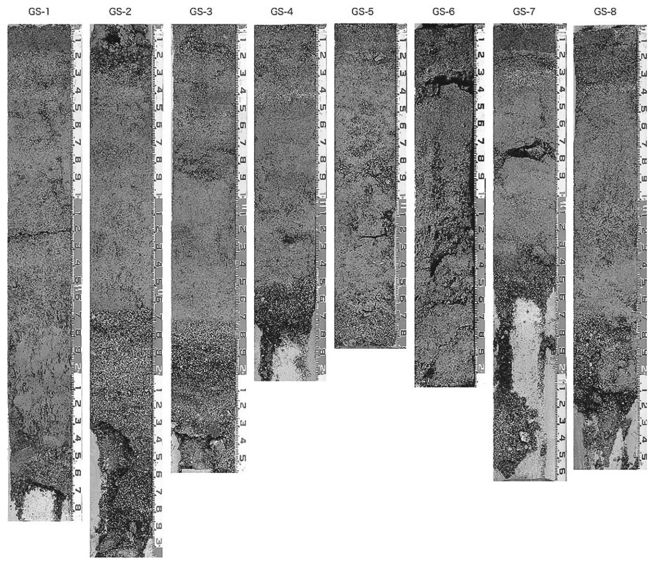


Fig.15 Soil samples' photographs which were obtained by the Geoslicer Investigation at Yago Nokoshi's retarding basin on Nov.12, 2011

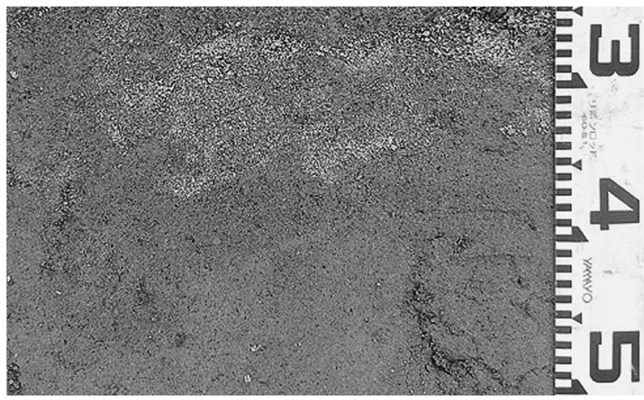


Fig.16 A close photograph of the sample GS-7. The sand appears at the 30-40cm deep layer.

## 5. Conclusions

The traditional flood control countermeasures like overflow embankments and open levees of the Jobaru River are focused on the investigated field for estimating a controlled water flow spreading the retarding basin. The numerical simulation is implemented to estimate water flow on the retarding basin from the overflow embankment. One dimensional flow analysis of the Jobaru River gave a boundary condition for two dimensional simulation of flood flow on the retarding basin. In the two dimensional numerical simulation, the maximum velocity is about 2.5m/s at the overflow embankment. But after overflowing and falling to the retarding basin, the water velocity decreases to less than 1 m/s and after spreading, it is suppressed less than 0.5m/s. Therefore, the sediment transported to the retarding basin may be settled down near the overflow embankment behind. Using the Geoslicer soil sampling in the main geotechnical investigation, 8 locations soil samples were obtained. Sediment's ages of the sampled stratums were estimated by using radioactive carbon. The classified sediments columns and estimated age of the stratum by radioactive carbon method correspond to the water flow behaviour in the retarding basin after overflow from the overflow embankment. In this study, from geotechnical and hydraulic engineering investigation, quantitative characteristics of the traditional flood control countermeasure in the Jobaru River are well obtained. For further research, it may be necessary to have a sediment transport characteristics in detail.

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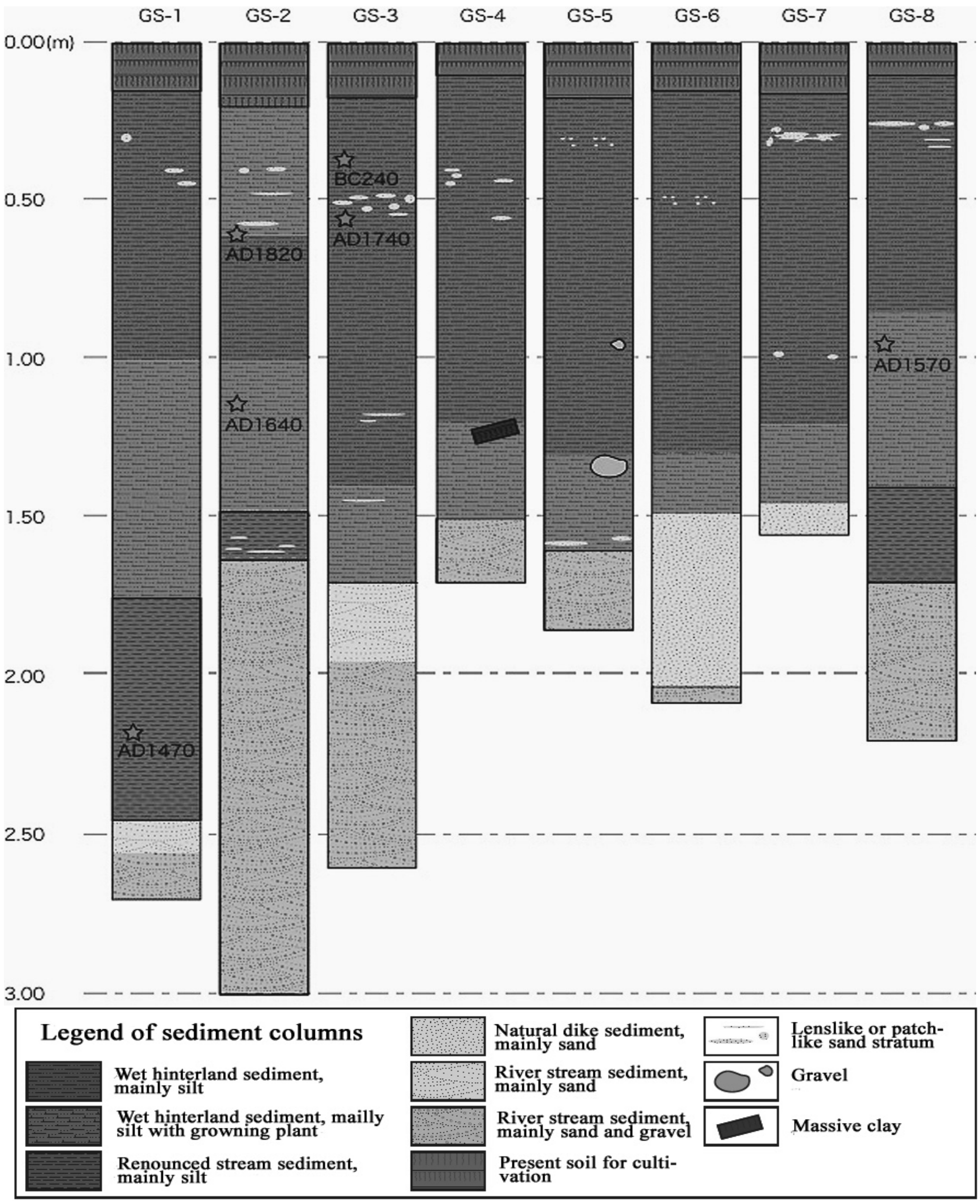


Fig.17 Sediment columns' map obtained from observation of soil samples taken by the Geoslicer. Red stars and years show the location of wood splinter and the estimated age by carbon isotope $^{14}C$