Conference Paper, Published Version

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12th International Conference on Hydroscience & Engineering
Hydro-Science & Engineering for Environmental Resilience
November 6-10, 2016, Tainan, Taiwan.

Experimental Study of on Flood Disaster 2012 in the Shirakawa River

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ABSTRACT

A heavy rainfall generated by a stationary front in rainy season attacked northern Kyushu, Japan, in July 3-14, 2012. In this paper, picking up the Tatsuta Zinnai 4 district, where is most vulnerable one to flood disasters in Kumamoto city, we investigated the flood inundation in detail by hydraulic model experiments and clarified the main factors that affect death or injury to people during floods, which include flow velocity, flow depth, and the degree to which people are exposed to the flood on evacuation routes.

KEY WORDS: The Shirakawa River; Hydraulic model experiments; Flood disasters; Evacuation routes.

INTRODUCTION

Existing hazard maps, however, do not fully reflect the opinions of the residents of flood risk areas. There is much room for improvement, and there are even cases where places that have been identified as high flood hazard areas are shown on hazard maps as refuges. Furthermore, although current hazard maps show flood depth information, they do not show flow velocity. Both flow velocity and flood water depth are information needed to evaluate the force of fluid working on the human body during evacuation. It is therefore necessary to perform highly reliable flooding simulation based on flooding analysis and physical model experiments. In cases where local residents' concept of risks deviates considerably from realities, the government's evacuation advisories and evacuation orders cannot be expected to be very effective. In such cases, human suffering due to a failure to make the correct evacuation decision will be inevitable. In reality, when evacuation is necessary because of flood risk, many local residents do not obey evacuation advisories or orders. It is meaningful, therefore, to identify the factors leading to such behavior in order to improve the disaster preparedness of the public.

At 6:41 am on July 12, 2012, the Japan Meteorological Agency issued a warning about heavy rains occurring mainly in Kumamoto and Oita prefectures, describing them as "heavy rains of an unprecedented magnitude that require the local residents to be on full alert." These typical end-of-rainy-season downpours inflicted unprecedented damage.

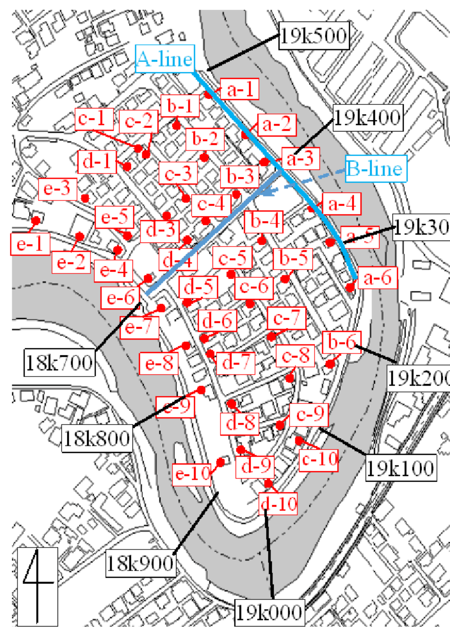

Fig. 1. Flooding area and depth measurement positions

The purpose of this study is to reproduce the flood flows in the Tatsuda Jinnai 4-chome area in Kita-ku, Kumamoto, resulting from the July 12, 2012 flood and the June 26, 1953 flood in hydraulic model experiments, analyze channel flow, land-side flood water depth and flood flow velocity, evaluate the flood risk level4) of evacuation routes and examine the tractive force of the flows in steep channel sections.

EXPERIMENT METHOD AND CONDITIONS

The model used for the purposes of the experiments, which is designed to model the entire flooding area in Tatsuda Jinnai 4-chome shown in Fig. 1, is a non-distorted 1/100-scale model measuring 450 cm in length and 450 cm in width. The sizes of features such as houses and their positions relative to other features such as alleys were reproduced according to aerial photographs and topographic maps. Each house model was fabricated with impermeable materials. The roads in the

Table 1 Installation discharge

Q (m^3/s)	Reason
1,500 m^3/s	・Present flood discharge capacity. ・Return period: 10 years.
2,000 m^3/s	・Return period: 30 years.
2,300 m^3/s	・Forward planning. ・Flooding in July 12, 2012. ・Return period: 150 years.
3,000 m^3/s	・Flooding in June 26, 1953. ・Return period: 150 years.

levee-protected (land-side) area were reproduced precisely at a scale of 1/100, and special (non-earthwork) levees were reproduced by installing thin plates. Houses were assumed to be 5 m high. Ground level was determined according to the elevation data obtained through airborne laser ranging. The left bank runs along the hillside, so there is no overflow from the left bank side. Overflow in excess of the discharge capacity, therefore, flows in and out over the right bank.

Similarity requirements were met by adjusting the Froude numbers of the model and the real landform so that they became the same. To reduce the influence of surface tension, the roads, buildings, etc. in the land-side area were wetted with water before starting the experiment.

The roughness coefficient of the bed of the real river channel is 0.034, which translates to a roughness coefficient of the bed of the 1/100-scale model of 0.016. To achieve the abovementioned roughness coefficient in the model channel, silicate sand having a d50 diameter of 5 mm was spread on the channel bed to create a surface having the required degree of roughness.

Flow velocity was measured by particle image velocimetry (PIV) and particle tracking velocimetry (PTV), both of which are widely used non-contact measuring methods, and the electromagnetic flow meter method, which is a contact-type point measurement method. Water level was measured with point gauges. Table 1 shows the flow settings.

EXPERIMENTAL RESULTS AND DISCUSSION

In-channel Water Level and Flood Water Depth

Fig. 2 shows the changes in mid-channel water level in the direction of flow at different flow rates, along with the changes in bed elevation in the direction of flow. As shown, at all flow rates, water level tends to show similar changes in the direction of flow. It can be seen that water level shows increases at 18k700, 19k000 and 19k300 at all flow rates. Since these locations correspond to bend entrances where phenomena similar to dam-induced backwater effects occur, it can be inferred that at 19k300, the water level rose because of the bend effect and the channel bottleneck effect.

Although the average bed slope in the section between 18k600 and 19k500 was 1/300, the water surface slope is was 1/377 at the flow rate of 1500 m^3/s, 1/415 at 2000 m^3/s, 1/407 at 2000 m^3/s and 1/452 at 3000 m^3/s. Thus, the water surface slope tended to be smaller than the bed slope and become smaller as the flow rate increased.

Visualization experiments were conducted. The experimental results

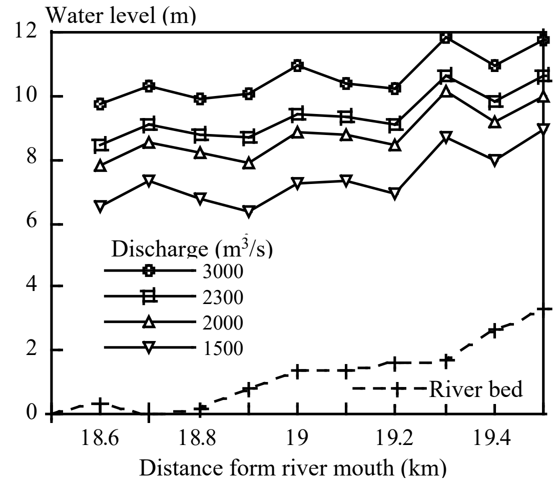

Fig. 2 Water level change in center of river channel

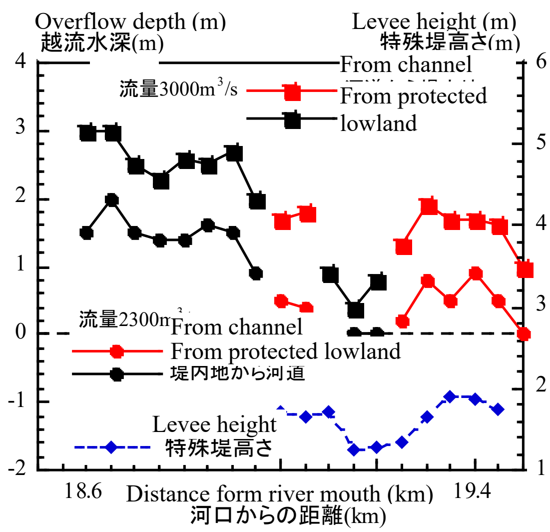

Fig. 3 Over flow depth in floe direction change

showed that the flood flow in the levee-protected area in Tatsuda Jinnai 4-chome tended, though certain variations were observed depending on the flow rate, to overtop the special levee in the 19k300–19k500 channel section from the river channel to the land-side area and return to the river channel in the 18k700–18k900 section. Thus, the flood showed a stream-type flooding pattern. Fig. 3 shows changes, in the direction of flow, in the depth of water overtopping the special levee from the river channel to the land-side area and from the land-side area back to the river channel. Fig. 3 also shows changes, in the direction of flow, in the height of the special levee built on the right-bank side. At the flood discharges of 2300 m3/s and 3000 m3/s, the flood water flowed into the land-side area from the river channel in two sections, namely, 19k000–19k100 and 19k300–19k500, and flowed out back to the river channel in two other sections, namely, 18k600–18k950 and 19k100–19k200. This suggests the reason why the water surface slope was small relative to the bed slope and tended to become smaller as the flow rate increased as shown in Fig. 2. To be more specific, as the flood flow that overtopped the levee from the river channel returns to it in the 19k100–19k200 and 18k600–18k950 sections, the lower momentum in

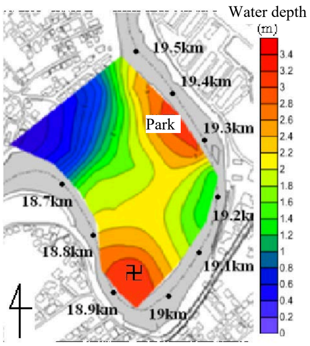

Fig. 4 Flooded depth

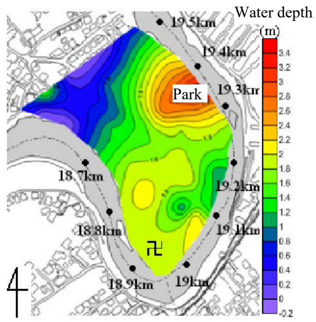

Fig. 5 Exp. depth in 2000m^3/s

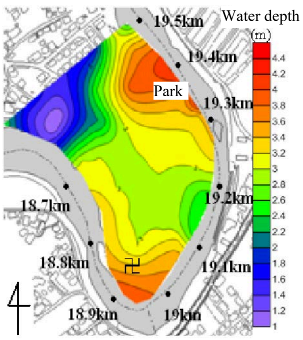

Fig. 6 Exp. depth in 2300m^3/s

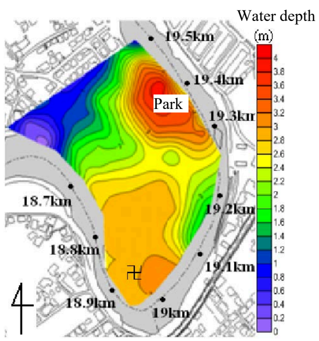

Fig. 7 Exp.t depth in 3000m^3/s

the land-side area is transported to the river channel so as to increase resistance, raise the water level and make the water surface slope smaller.

By using the measured values of overflow water depth and overflow width obtained through the measurement, the rate of flow from the river channel to the land-side area was calculated from the overflow formula. The inflow rates thus obtained were about 250 m^3/s when the flood discharge was 2300 m^3/s and about 1300 m^3/s when the flood discharge was 3000 m^3/s. Since the experiments were conducted under constant flow rate conditions, this means that water flowed into the land-side area at these rates.

Fig. 4 shows the flood water depth distribution in the land-side area determined from the flood marks left in the Tatsuda Jinnai 4-chome area flooded on July 12, 2012. The flood water depth here was defined as the height from the road surface to the level of the water that flooded the houses. Land uses in this area used to be agricultural (rice paddies and fields), but in May, 1971, the area was designated as an urbanization promotion area. In 1973, the Riverside Town Project was launched, and rapid urbanization has been underway since then. The residential land was mostly raised by 0.5 m to 1.0 m by filling to its present level, but the muddy flood water overtopped the special levee to turn the land-side area into part of the river. The mud transported from the Shira River buried the Tatsuda Jinnai 4-chome area, and two houses located near the water impact zone were destroyed by driftwood. Flood water depth was 2.3 m to 3.4 m in the low-lying land along the river channel between 18k800 and 19100 and reached the maximum value of 3.4 m at the bend near Rendai Temple's Tatsuda Branch Temple at 18k800. In the overflow section along the special levee between 19k300 and 19k500, flood water depth was 2.8 m to 3.3 m and was

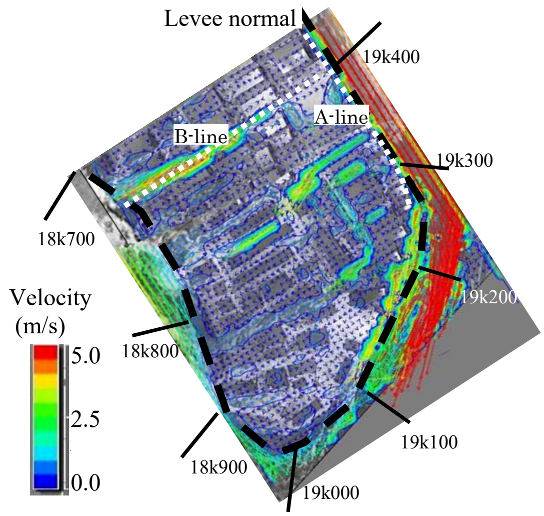

Fig. 8 Flood surface flow velocity in 2300m^3/s

maximized near the park.

Figs. 5 - 7 show the spatial distributions of flood water depths at flood discharges of 2000 m^3/s, 2300 m^3/s and 3000 m^3/s obtained through the model experiments. As shown, as the flow rate increased, flood water depth tended to increase, showing similar distribution tendencies. Comparison with Fig. 4 reveals that the flood water depth observed in the model experiments tended to be somewhat greater. As shown, the maximum value of 3.6 m occurred at a point immediately upstream of the park at 19k400, and another peak value of 3.0 m occurred at a point immediately upstream of the Rendai Temple's Tatsuda Branch Temple in the section between 18k800 and 19k100. At the flood discharge of 2000 m^3/s, a peak value of 3.0 m was shown at a point immediately upstream of the part at 19k400, and another peak value of 2.0 m was shown in the vicinity of Rendai Temple's Tatsuda Branch Temple at 18k800. At the flood discharge of 3000 m^3/s, a peak value of 4.2 m was shown at a point immediately upstream of the part at 19k400, and another peak of 3.8 m occurred at a point immediately upstream of Rendai Temple's Tatsuda Branch Temple at 18k400.

Flood Flow Velocity in the Land-side Area

Figs 8 - 9 show the spatial distributions of the surface velocity vectors of the flood water flow in the land-side area at the flood discharges of 2300 m^3/s and 3000 m^3/s, respectively, obtained through image analysis.

Surface velocity is significantly high in the two sections, A-line and B-line, shown in Fig. 1. In the A-line section, the flood flow that has overtopped the special levee from the 19k300–19k500 section of the river channel to the land-side area flows fast over the road along the special levee, and part of the flood water flows back from the land-side area to the river channel after passing through the 19k100–19k200 section of the special levee along the river channel. In the B-line section, the flood flow running fast along the A-line turns right at the house located in the water impact zone immediately downstream of the park on the right bank at 19k300, and a fast flow zone is formed along the B-line.

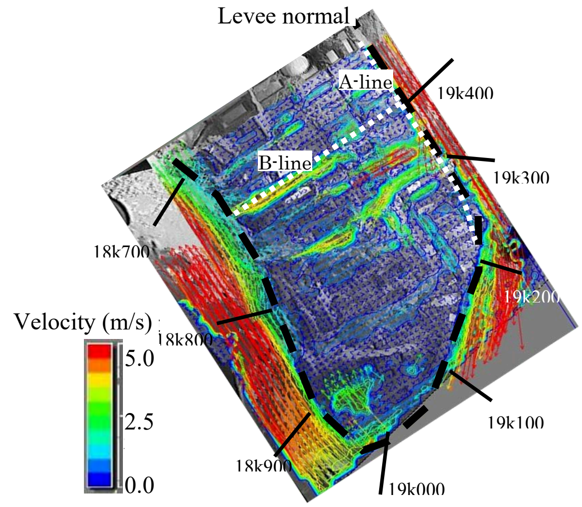

Fig. 9 Flood surface flow velocity in 3000m^3/s

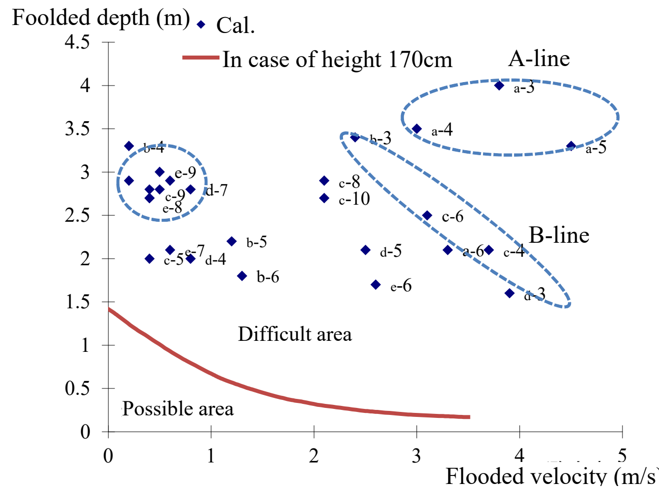

Fig. 10 Risk level of the land-side area in 2300 m^3/s

The maximum flow velocity along the A-line is 4.3 m/s when the flood discharge is 2300 m^3/s and 4.8 m/s when the flood discharge is 3000 m^3/s. The maximum velocity along the B-line is 3.1 m/s at the flood discharge of 2300 m^3/s and 3.7 m/s at the flood discharge of 3000 m^3/s. Thus, the flood flow velocity along the A-line is by far higher. It can also be seen that the direction of flow is mostly parallel with the B-line. In the vicinity of Rendai Temple's Tatsuda Branch Temple in the 18k800–19k100 section, flood flow velocity is low although flood water depth is large.

Risk Level Evaluation of the Land-side Area

Fig. 10 shows the risk level of the land-side area based on the flood water depth and flood flow velocity at the flood discharge of 2300 m^3/s. The solid line is the evacuation limit curve, and the rhombic marks represent the measurement points shown in Fig. 1. It can be seen that the most dangerous area is the A-line zone acting as an overflow section along the special levee, followed by the B-line zone.

At the height of the flood, the roads in the Tatsuda Jinnai 4-chome area were in an extremely dangerous condition because of the flood flow. If people living to the south of the B-line along the road, where flow velocity was very high, had tried to evacuate to the north, they would have been very vulnerable.

The muddy flood water contained large amounts of sediment and driftwood, which probably made the situation even more dangerous. This is an area that requires further study. It is believed that the residents left stranded made a wise decision when they decided to wait for public rescue.

CONCLUSIONS

In this study, a series of model experiments was conducted to simulate the stream-type overtopping flood event that occurred in Tatsuda Jinnai 4-chome, Kita-ku, Kumamoto, Japan. The surface velocity of the flood flow was also calculated by visualizing the flood water flow. The findings of this study are as follows:

(1) The flood flow in the Tatsuda Jinnai 4-chome area has been expressed in terms of surface velocity vectors and flood water depth, and the flood flow regimes at the flood discharges of 2000 m^3/s, 2300 m^3/s and 3000 m^3/s have been shown in detail.
(2) It has been shown, from both the surface flow velocity and flood water depth results, that at the height of the flood, when the flood discharge was 2300 m^3/s or 3000 m^3/s, the A-line and B-line areas shown in Fig. 1 could not be used as evacuation routes for pedestrians. The A-line zone and the B-line zone included areas where flow velocity exceeded 4 m/s and 3 m/s, respectively.

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