RECENT TRENDS IN JAPANESE SABO MODEL EXPERIMENT TECHNOLOGY

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ABSTRACT

The Japanese Public Works Research Institute began conducting sabo model experiments in 1968 to investigate the supercritical flow regions of steep rivers and to study mountainous areas with large quantities of sediment discharge, and have planned several sabo structures. The nonprofit Civil Engineering Research Laboratory has now taken over these sabo experiments (Oda *et al.* 2002). Its sabo models focus on four main issues: woody debris, landslide dams, slit-type sabo dams, and debris flows. The experiments mainly use physical models, usually constructed of mortar and reduced to 1/20–1/100 scale. This report summarizes the results of a recent typical sabo model experiment. We will present an outline of the physical model as well as the results of an experiment using a straight flume to prevent landslide dams from forming and application of a geographic-features model to assess problems related to landslide dams and woody debris.

Keywords: Experiment, landslide dam, physical model, woody debris.

OUTLINE OF THE PHYSICAL MODEL

This experiment used a physical model because numerical calculations cannot accurately reproduce certain phenomena, such as scouring around a structure, collapse of a natural dam due to changes in the riverbed, and the behavior of woody debris. A physical model experiment clearly presents these phenomena visually, making it a good way to inform residents about plans for preventative sabo structures for valleys at risk. This type of experiment also enables community participation from valley residents and the active exchange of opinions.

This type of experiment generally uses a 1/20–1/100 scale physical model made of mortar. For accuracy, the model requires the most recent cross section, the longitudinal profile, and the proposed plan, and also includes existing structures reduced according to the appropriate scale.

In this model, incidental structures included water supply structures in the model's upstream end, the valve to control discharge, structures for measuring flow quantity, drainage and sand traps in the model's downstream end, and a tower for photography or video recording. The movable riverbed was composed of material (mainly sand) with a grain size distribution

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corresponding to prototype sediment. We conducted natural dam and debris flow experiments to generate the likely composition of sand in the local area, and reduced it using the appropriate scale. Woody debris models often incorporate cylindrical pieces of wood to represent tree trunks (without considering roots and branches). This helps to determine the amount, length, and width of woody debris based on a tree survey of the locale.

WOODY DEBRIS EXPERIMENT (WITHIN THE PHYSICAL MODEL EXPERIMENT)

Experiment to evaluate the effects of of woody debris countermeasure structures

The distance from a mountainous area to the mouth of a river is shorter in Japan than in many other countries. In mountainous areas, many trees are flowed out due to collapsing hillsides and riverside erosion due to flooding caused by typhoons and other disturbances. When these trees arrive at the river mouth as woody debris, they can cause serious damage to ships, and as the woody debris flows into harbors, it can float in fishery areas and obstruct fishing boat traffic. Moreover, even if woody debris does not reach the river mouth, water levels increase when it gathers at river structures, such as piers, generating floods. In such situations, the pier can be damaged or become dislodged, adding to the woody debris.

Photo 1. Accumulation of woody debris at a bridge pier.

Photo 2. Accumulation of woody debris at a fishing port.

This section presents a case study of a woody debris countermeasure facility proposed for the Nodaoi River. This location, in the city of Yakumo, Futami-gun, Hokkaido, was subject to flooding from 1997–1999 when woody debris accumulated at a bridge pier (photograph 1) and at the fishing port (photograph 2).

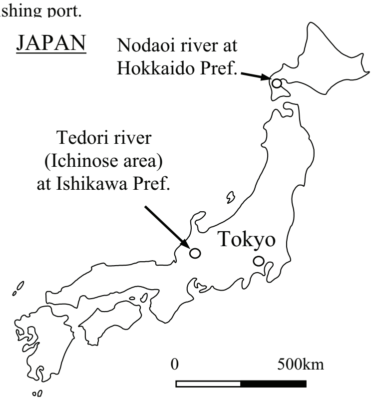

Figure 1. Location of target rivers.

Figure 1 illustrates the location of the Nodaoi River, and Table 1 presents its field dimensions. The river has the following characteristics:

1) Its geographical features are primarily curved, and the river bank has partially collapsed.
2) Trees grow densely up to the river bank, and woody debris appears in the river.
3) An embankment has been completed in the downstream region, and the protected

lowlands are used as pastures, *etc.*
4) The railway, roads, and residential areas have extended to the vicinity of the river mouth.

Table 1. Field dimensions of the Nodaoi River.

Items	Dimensions
Catchment area	79.7km^2(at Designed ground sill)
Design discharge	950m^3/s(Return period is 100 years)
Design volume of woody debris	9,700m^3
Average length of woody debris	8.7m
Average diameter of woody debris	28.3cm
Average grain diameter of sediment	7.0cm(90% grain size is 12.0cm)
Average riverbed gradient	1/120 (In model area)
Extension of basin	1.5km(In model area)

Outline of the experiment

The goal of the experiment was to develop effective structures to prevent damage by catching the woody debris that flows from the upstream region.
The model's kinematic similarity is shown by Froude's law, and the main experimental conditions were as follows:
1) Model scale: 1/60.
2) Model area: See Figure 2.
3) Hydrographs: The model used the planned hydrograph and a hydrograph of the Nodaoi River from September 2001 (see Figure 3).
4) Supply of woody debris: We based the amount of woody debris on the distribution of floating volume ratio, but only included woody debris supplied by flow over a period of 30 years.
5) Bed material: See Figure 4.
6) Amount of sand: Equilibrium sand volume corresponded to the flow hydrograph.

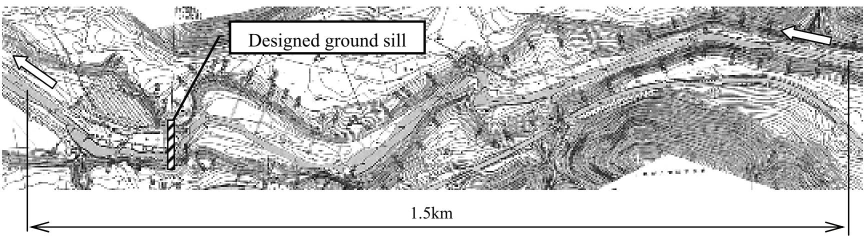

Figure 2. Plan of the objective area.

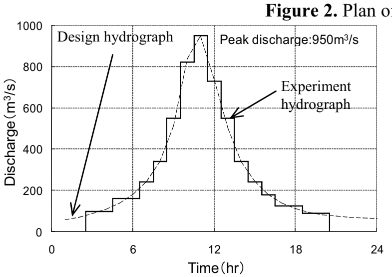

Figure 3. Planned hydrograph and experimental hydrograph.

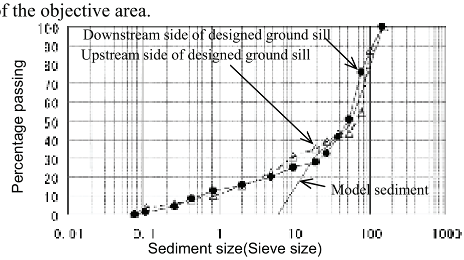

Figure 4. Sand distribution.

Results of the experiment using the original plan

In areas where wood is trapped in a ground sill spillway, researchers generally suggest preventing damage from woody debris by catching wood. However, this type of countermeasure facility tends to block the entire spillway ground sill section with trapped woody debris, resulting in an abnormal increase in the upstream water level of the ground sill spillway (in this case, 4.2 m; see Photo 3 and Figure 5). In addition, most of the bedload from upstream accumulates in the upstream section of the ground sill. This causes a major scouring in the riverbed downstream of the ground sill, and results in unsafe conditions in the ground sill base (see Photos 4 and 5).

Results of the experiment using the revised plan

To address the above problems, we developed a plan to trap woody debris in wider areas of the river (Figure 6). We set up piles upstream of wider areas for flow control, so that woody debris would be led to this area. The effect would begin after woody debris was caught between the piles, as piles themselves rarely obstruct flow. Here, we set up three rows of piles; each row was composed of three piles, spaced 4.0 m apart, and the three rows were spaced 8.0 m apart in the direction of the flow.

Photo 3. Upstream water level when a ground sill traps woody debris.

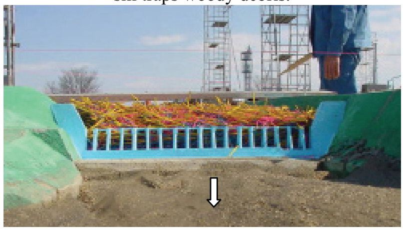

Photo 4. Trapped woody debris.

Photo 5. Scouring at an embankment leg downstream of a ground sill.

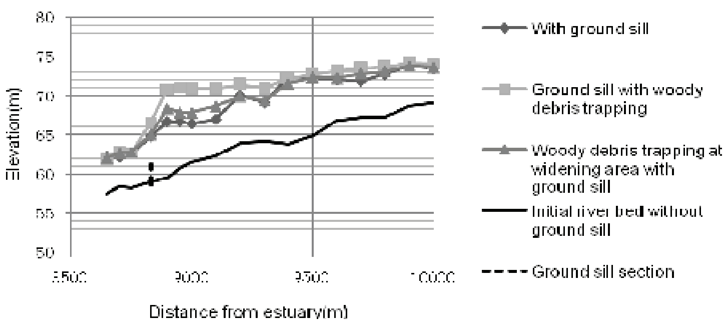

Figure 5. Comparison of water levels.

Next, we set up piles in the wide area downstream to catch the woody debris that flowed in. Here, we set up piles over a distance of 30 m; piles were installed in pairs at the upstream edge, spaced 2.0 m apart and at intervals of 6.0 m to catch woody debris. The piles were set up on the same side as in the original ground sill shore plan, but the upstream water level rose by only 1.7 m, in contrast to the rise of 4.2 m that resulted from the original plan for catching the woody debris (Figure 6). In addition, the revised plan solved the problem of decreased downstream riverbed, because sand could flow between the pilings. Results indicated that the revised plan ensured flood control, and that 84% of woody debris was trapped (Photo 6).

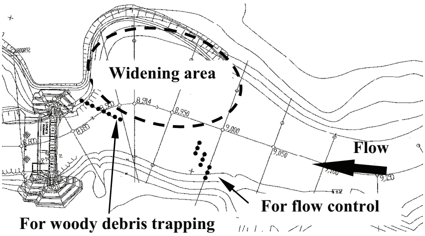

Figure 6. Sketch of the revised woody debris countermeasure plan.

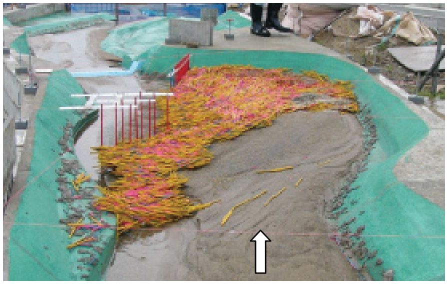

Photo 6. Woody debris trapped using the revised plan.

LANDSLIDE DAM EXPERIMENT

Experiment to evaluate landslide dam collapse countermeasures

A landslide dam can be formed by disturbances, such as landslides, large-scale collapse, or debris flow (Photo 7). The dam could block a river, and the resulting debris flow and flood during its collapse can cause disasters, such as flooding in the downstream region. To prevent damage from the natural collapse of a landslide dam, it is important to understand the characteristics at the peak discharge during collapse, *e.g.*, flooding start time and duration. Therefore, Japanese researchers have begun to examine these characteristics among disasters caused by landslide dams from a crisis-management perspective, with the goal of installing preventative sabo structures in areas in which landslide dams are likely to form.

Photo 7. The Tohyama River appears to be blocked by a debris flow from the Yunosawa River (this photograph was taken after a collapse in August 2005; Ministry of Land, Infrastructure and Transport, Chubu Regional Development Bureau, Tenryugawa Joryu RiVer Office, Sabo Intelligence Section).

To date, most sand movements, such as debris flows, have been simulated using physical models and calculations, and sabo structures have been planned based on the results. However, while some studies have performed measurements of landslide dam collapses (Mizuyama *et al.* 1989; Ishikawa *et al.* 1992), relatively few studies have planned sabo structures using landslide dam experiments and calculations. Mizuyama *et al.* conducted basic research on landslide dam collapses (1987, 1989), as did Takahashi *et al.* (1988, 1993), and Oda *et al.* (2006). These studies investigated issues such as changes in the time of peak discharge during collapse, the process of bank collapse caused by landslide dams, and dam overtopping discharge. However, in these experiments, landslide dams had heights of 20–30 cm. In contrast, our experiment focused on the type of landscape dam that may cause a disaster downstream, so our model applied a large-scale, high landscape dam. We then examined characteristics such as changes in the time of peak discharge during collapse and dam overtopping discharge among these larger landscape dams.

We investigated landslide dams that were taller than the dams in previous experiments. This enabled us to plan appropriate preventative sabo structures to minimize destruction from a landslide dam and to conduct basic experiments concerning the collapse of landslide dams. Before any of the large-scale model experiments were carried out, we conducted preliminary experiments on the base in the rectangular flume section; we used these results to determine the main factors affecting the flow quantity as a landslide dam collapses. This section presents changes in peak discharge during a collapse based on the difference between the inclination of the landslide dam and particle size, and changes in the time of peak discharge during collapse. In particular, we examined the causes of overflow during the main collapse of a landslide dam (Mizuyama *et al.* 1987, 1989).

Photo 8. Collapse of a landslide dam (60 m in height) by erosion.

Our dam model was based on a disaster that occurred in 1934 caused by the collapse of a landslide dam in the Ichinose area of Ishikawa Prefecture (in the Tedori River region). We built our model at a scale of 1/60; the original dam had a height ranging from 30–60 m. Landslide dams with a height of 60 or 30 m contain about 7 million cubic meters of water and about 5 million cubic meters of sand or about 1.5 million cubic meters of water and about 1.4 million cubic meters of sand, respectively. When we reduced these values by a scale of 1/60, both models were large-scale: the former had a height of 1.0 m, a sand volume of about 23 cubic meters, and an upstream water volume of 32 cubic meters; the latter had a height of 0.5 m, a sand volume of about 6.3 cubic meters, and an upstream water volume of 7.0 cubic meters (Photos 8 and 9, respectively).

Photo 9. Collapse of a landslide dam (60 m in height) by rotational slide.

Outline of the rectangular flume experiment

We constructed a model landslide dam in a rectangular flume with a width of 0.5 m, a bottom inclination of 2.8° (1/20.6), a depth of 1.3 m, and a length of 7.0 m (Figure 7). We measured water levels using a servo type water meter. We set four installation locations and set the sampling time to 100 ms. Overflow discharge at the landslide dam section was downstream into a square weir (Figure 7). Table 2 lists the experimental conditions. In all cases, the dam height was 1.0 m and the inflow discharge was 3.13 l/s. The crown length of the landslide dam was measured in the direction of the flow. We used three upstream and downstream slopes (1:2, 1:4, and 1:5). In Experiment 5, we changed the volume of water upstream of the landslide dam to 6.07 cubic meters.

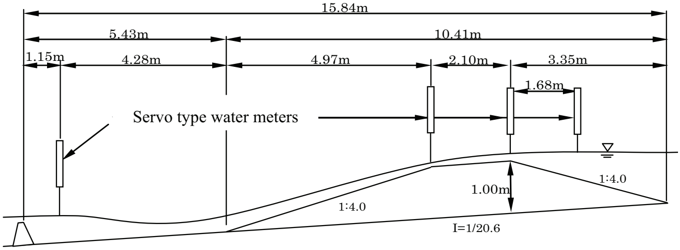

Figure 7. Installation of the landslide dam and setting the water gauge.

Table 2. List of experimental conditions (parameters for landslide dams).

Exp.No	Length of crown(m)	Angle of slopes	Sand volume*) (m^3)	Mean diameter of experimental sand
1	2.100	1 : 4	3.13	dm=0.25mm
2				
3				dm=0.755mm
4	1.050	1 : 2	1.53	
5		1 : 4	2.60	
6		1 : 2	1.53	
7	0.525	1 : 4	2.34	
8	1.050	1 : 5	3.18	
9	2.100	1 : 4	3.13	dm=1.44mm
10				dm=5.14mm

Results of the rectangular flume experiment

1) Relationship between slope, particle size, and peak discharge during overflow

Figure 8 presents the relationship between landslide dam slope and peak discharge during overflow. All cases were subject to the same conditions, excluding slopes. Peak discharge increased as the slope increased. Erosion of a landslide dam probably progresses more rapidly during overflow when the slope is steep, so slope is a major factor in peak discharge during collapse.

Figure 9 presents the relationship between particle size and peak discharge during overflow. All cases were subject to the same conditions, excluding particle size. Peak discharge

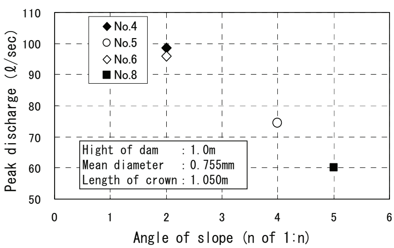

Figure 8. Relationship between landslide dam slope and peak discharge.

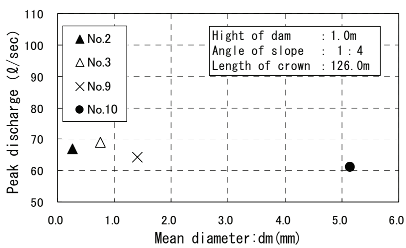

Figure 9. Relationship between particle size and peak discharge.

decreased when average particle size increased. However, peak discharge decreased by as much as about 40% when the landslide dam was composed only of sand, when it was cohesive (Oda *et al.* 2006). Particle size did not appear to have a major effect on peak discharge when the dam was cohesive.

2) Time of peak discharge during collapse

We examined time until generation of peak discharge; overflow began when the water overflowing a dam passed the downstream shoulder. Using the average particle size, crown length, and downstream slope as parameters, we obtained the following results:

a. The time to peak discharge increased when the crown length increased (Figure 10).
b. The time to peak discharge increased when slope decreased (Figure 11).
c. The time to peak discharge increased when average particle size decreased (Figure 12).

These results appeared throughout the range of the experiment. We determined peak discharge when the water level at the downstream shoulder of the dam began to decrease (Figure 13). These results indicate that the time to peak discharge increased because the time to erosion increased even at the upstream shoulder of the landslide dam after overflow. Moreover, water levels rose temporarily due to rapid accumulation from the side when the average particle size was fine. Although the reasons for this are unclear, this increase in water level may have delayed collapse of the landslide dam.

We examined countermeasure structures experimentally under various conditions. For example, we used cement milk spraying and concrete blocks to cover the model's crown and downstream slope. These were intended to reduce peak discharge by decreasing the erosion rate of the downstream slope. The results indicated that it was possible to reduce peak

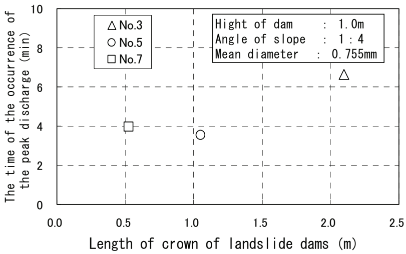

Figure 10. Relationship between landslide dam crown length and the time of peak discharge.

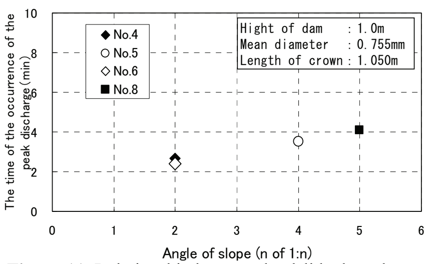

Figure 11. Relationship between landslide dam slope and the time of peak discharge.

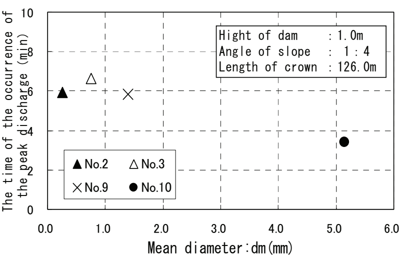

Figure 12. Relationship between mean particle size and the time of peak discharge.

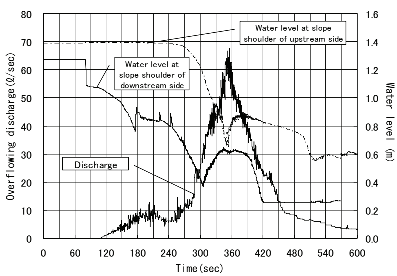

Figure 13. Temporal variation in the rate of overflow discharge and water level at the shoulder of a landslide dam (No. 2).

discharge by decreasing the erosion rate of the downstream slope. However, questions remain about the short time period during which a landslide dam is formed and its formation characteristics.


Photo 10. Physical panorama of the model (scale 1/60).

Outline of the physical model experiment

Figure 1 shows the position of the river in a model landslide dam using geographical features. Table 3 lists local parameters, and Photo 10 shows a physical panorama. The experiment was conducted with the following goals:

a. To experimentally determine peak discharge and sediment balance of the assumed landslide dam during its collapse from overflow water.
b. To determine ways of improving safety in the downstream region.

The experiment used the following main conditions:

1) Model scale: 1/60.
2) Model area: The upstream end was the range where water was collected by the landslide dam and the downstream end was the existing preventative sabo dam.
3) Bed material: Average riverbed gradient is 20.3cm

3.3.1 Results of the physical model experiment

This experiment was performed to examine peak discharge and sediment balance of a landslide dam with a height of 30 m. At collapse, local peak discharge was 2,000 m^3/s. Experimental observations indicated that the stream overflowed

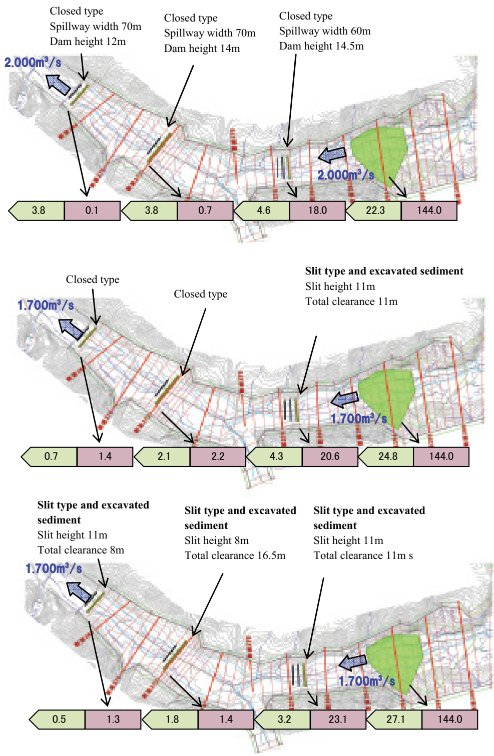

Figure 14. Discharge and sediment balance after experiments (Unit: × 1,000 m^3).

Table 3. Field dimensions of Tedori River.

Items	Dimensions
Catchment area	42.0km^2(at Landslide dam)
Design discharge	581.5m^3/s(Return period is 100 years)
Average grain diameter of sediment	20.3cm
Average riverbed gradient	1/20.6 (In model area)
Extension of basin	3.0km(In model area)

completely at the wing of the sabo dam, directly below the landslide dam. We confirmed an excessive peak discharge (planned discharge in this river was 582 m^3/s). The sediment balance indicated that during the collapse of the landslide dam, about 80% of sand accumulated directly below the dam. The decreases in sand volume and peak discharge during the collapse of the landslide dam revealed the following methods for improvement:

1) In a closed type sabo dam, the ability to catch and store water and sand can be improved by excavating sediment.
2) Switching from the closed to the slit type sabo dam can usually reduce sand accumulation.

These methods for improvement had almost no effect on sand accumulation, but peak discharge decreased slightly from 2,000 m^3/s to 1,700 m^3/s, probably as a result of their application. Future studies will focus on the development of more effective preventative sabo structures and improving the safety of downstream regions.

CONCLUSIONS

We conducted a case study of a sabo dam on a steep river in Japan.As described so far, the experiments using topographic models have been applied for drafting the planned layout of erosion control facilities which conform to social needs. However, since experimental examinations have not been well known as a means of drafting plan layouts, it cannot be said that the experiments are generally an acceptable means of examination.

The experiments using topographic models are characterized by ensuring that regional residents easily understand through visual presentations the state of possible sediment disaster and the effect of the planned erosion control facilities. Therefore, from now on it is necessary to appeal to and assure regional residents that the experiment is a useful means of settling on an effective erosion control plan. In fact, the use of experiments in the open forum examination meeting of the regional resident participative type among others is increasing. It is further necessary to enhance the social awareness and recognition of the experiments and to devise a method more appropriate for the visual presentation of the results of hydraulic erosion control model experiments.

Moreover, the verification of the calculation model through a hydraulic model test is important for the progress of numerical simulations. To this end, the enhancement of the precision of the hydraulic model experiments will be an important subject in the future. Technical subjects which are involved in the execution of experiments are enumerated as follows.

1) Riverside erosion : In order to reproduce the riverside erosion caused by running water, it is necessary to know the nature of the material of field riversides such as grain size and moisture content ratios. A method for investigating riverside conditions and material and techniques used in the model for reproducing riverside are now important subjects.
2) The resistance of trees (rootstock) : Recently, there can be seen many plans such as green erosion control plans in which the natural environment is considered of great importance. The reproduction of trees in a riverside channel is significant in making the direction of flows such as water level and flow direction in the river channel close to actual field conditions in addition to developing proper visual effect demonstrations. Many conventional erosion control experiments have been prepared with no provision that trees lean or uproot and flow out even during flood events. However, it is actually often seen in the field that trees do in fact lean or uproot and flow out at the time of flooding. In order to reproduce such field condition, it is necessary to examine the similarity between the actual

field state and the experiment with respect to the resistance of trees (rootstock) and to reproduce the limitations on the lean and/or uprooting and runoff state of trees in a model.

3) The selection of bed material for use in the experimental model: At present, the bed material for use in an experimental model is reduced in scale based on the particle size distribution obtained from field surveys. Since sediment for use in the experiment consists of sand excluding the fine grains, the particle size distribution of the sand for use in an experiment is different from that of the actual field bed material. Consequently, the behavior of small flux in the actual field where the fine grain content of the small flux moves while suspended in the flux cannot be modeled in the experiment. Therefore, it can be considered that when the above behavior of small flux continues over a long period of time, the movement of fine grain in the actual field would in fact cause riverbed fluctuations. In order to reproduce the behavior of the small flux precisely in an experimental model, it is necessary to examine the bed material so that the behavior of fine-grained sediment can be reproduced in a reduced scale model.

4) The similarity of complex phenomena (e.g.; the concurrence of a suspension phenomenon and a traction phenomenon) : Suspension phenomena and traction phenomena occur simultaneously in the field at the time of flooding. Similar conditions can also be seen in the experiments. At present, the Froude's similarity is applied to most of the experiments because the traction phenomena are controlled more by gravity than viscosity. However, due to the influence of viscosity on the suspension of the fine grain content of bed material being considerable, the Froude's similarity is not applicable to the experiment. Further examination is necessary to reproduce the field phenomena precisely.

ACKNOWLEDGEMENTS

We would like to thank Hokkaido Prefecture Government Oshima Subprefectural Office Hakodate Public Works Office, Ministry of Land, Infrastructure and Transport, Hokuriku Regional Development Bureau, Kanazawa River and Road Office and Ministry of Land, Infrastructure and Transport, Chubu Regional Development Bureau Tenryugawa Joryu River Office.

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