

Hydraulic model test on channel shifting and yielding woody debris on the fan after sediment disaster in the past

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Abstract. The re-movement of sediment and woody debris in torrents after huge sediment transport in the past could cause new flood and sediment disasters due to heavy rainfall events. However, it is not clear how re-movement of logs effects on bed variations such as bars and river channel divergence. In present study, hydraulic model tests were carried out referring to the magnitude of floods, that was over the plan size, in Tottabetsu River basin in August in 2016. These tests include different magnitudes of flood, suppling logs from bed/side bank erosion, and existence of sabo facilities. The key results were as follows: The presence of logs by bed/side bank erosions influences on the patterns of flows and sediment transport, because deposition of logs affects formation of bars. Difference of the magnitudes of the floods affects the activeness of the interaction between logs and sediment transport. In additions, the locations and slits of the sabo dam need to consider hydraulic conditions and characteristics of woody debris for appropriate control of sediment and woody debris.

1 Introduction

The re-movement of sediment and woody debris in torrents and rivers after huge sediment transport and deposition in the past could cause newly flood and sediment disasters due to future heavy rainfall events, because there are a lot of volume of sediment and woody debris deposition everywhere along the river and torrents.

There were heavy rainfalls in the Tottabetsu River basin due to the Typhoon No.10 (Lionrock) on 28th to 30th August in 2016. Figure 1 shows the location of the Tottabetsu River. The river is a tributary of the Tokachi River in Hokkaido in Japan, and has 44.0 km in length, 161 km² in basin area and 1/37 in bed slope. The basin area is 134 km² in upstream of the study area. Accumulated rainfall depth was 532 mm for three days at around 40.0 mm/h at the Tottabashi rain-gauge station of Ministry of Land, Japan and the value exceeded the previous record that was 314 mm in September in 2001 [1]. Huge amount of sediment and logs were transported and resulted in a lot of those deposition. The sabo master plan there needed to renew due to the sediment disaster in 2016.

Re-moving of woody debris yielded by bed and side bank erosion due to future floods could induce the flooding by blockage of piers and constriction of the river channel. In present study, hydraulic model tests were carried out focused on evaluating supposed phenomena, which can be taken place after sediment disasters in the past. Supposed factors in tests are the removing of woody debris, bed variation and side bank erosion, river channel divergence and so on, and

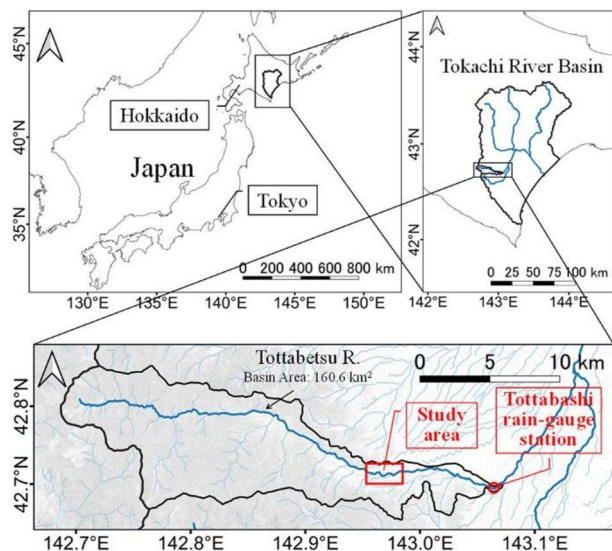


Fig. 1. Study area.

hydraulic model tests were carried out at the several magnitudes of flood referring to floods in Tottabetsu River basin in 2016.

2 Experimental model and conditions

2.1 Hydraulic model

Figure 2 shows hydraulic models of the Tottabetsu River with the 1/70 in the model scale. In the prototype scale, the length of the channel of study area is about 2.80 km and the width of the channel varies approximately from 50.0 m to 350 m including several narrow and wide flow

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sections with meanders. The depth of the movable bed was set to about 8.00 m. The mean longitudinal gradient of the bed is about 0.800 degrees (= 1/70). Two open-type sabo dams were set in Run1. Detailed information is shown in Fig. 2. The No. 1 sabo dam is re-constructing from closed to open-type sabo dam. Specification of this model test was based on the Froude similarity.

2.2 Measurement and conditions

Water, sediment discharge rate and total volume of sediment runoff were measured at the downstream end of the channel. The plane view and overhead view of the flow patterns and sediment deposition were taken by camera using UAV and scaffold, respectively. Water levels were measured at No. -3, No. -5, and the downstream end of the channel by servo-type level meters as shown in Fig. 2. Tracing dye (white paint) was used for visualization of flow patterns. Photographs captured by camera after each test were used to generate the three-dimensional topographic data. White papers with 80.0 × 80.0 mm were used for tracer of transverse surface velocity profiles of water. Logs were modelled by plastic materials for conifers floating on the water and submerged broadleaf trees, and the specific weight of those log models is 0.952 and 1.20, respectively. Logs were measured at downstream end and on the bed surface after experimental runs. Deposited logs were measured transversely and vertically along several measurement lines.

The representative values of grain size diameter are as follows: $d_{95} = 285$ mm, $d_{60} = 70.4$ mm. Herein, the symbols of d_{95} and d_{60} show the value of 95 % and 60 % of the percentage passing by mass. The values of 95 % and 50 % of the frequency distribution for log length are shown as L_{95} and L_{50} , and are set to 16.1 m and 8.00 m, respectively. The representative value of log diameter was set to 0.300 m as 50 % of frequency distribution of the diameter.

Logs supplied in the tests were consistent with conifers and broadleaf trees, which were the ratio 1:9, while the length of each type of trees was consistent with 16.0 m and 8.00 m in the ratio of 1:1. Sediment discharge was set in accordance with equilibrium concentration of 0.003. Total supplying number of logs were set to about 20,000 logs referring on the relationship between logs volume and total runoff volume of logs in Run1. Number of logs in Run2 was set to 0.25 times of that in Run1 as the total supplying number of logs. Logs are supplied in case of Run1-1, Run1-2 and Run2-2, and logs discharge rate are determined depending on water discharge. Water and sediment discharge rate and supplying number of logs are shown in Fig. 3, Fig. 4 and Table 1.

Hydrograph with process of decreasing to increasing stage was set in Run1-2 and Run1-3 to model logs runoff and removing in each stage after huge flood. Water discharge was supplied steadily in Run1-1, Run1-2 Run2-2 and Run2-3. Those values were plan size (770 m³/s) and the excess probability for return period of about 20 years, respectively. In Run1-1 and Run2-1, steady flow rate was supplied for forming the riverbed before each run.

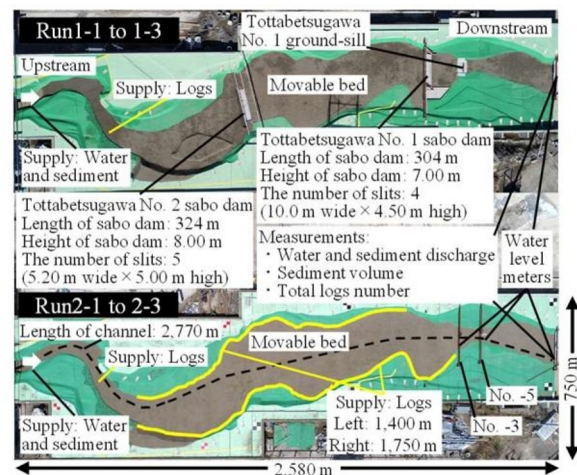


Fig. 2. Hydraulic models.

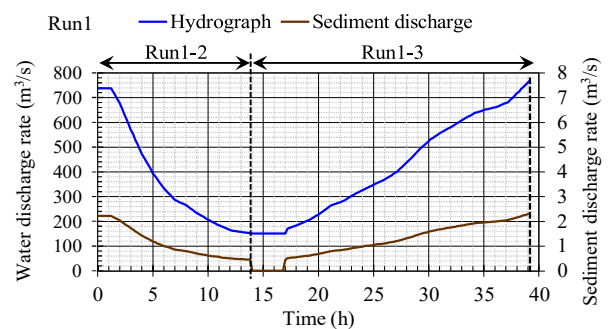


Fig. 3. Water and sediment discharge rate in Run1-2 and Run1-3.

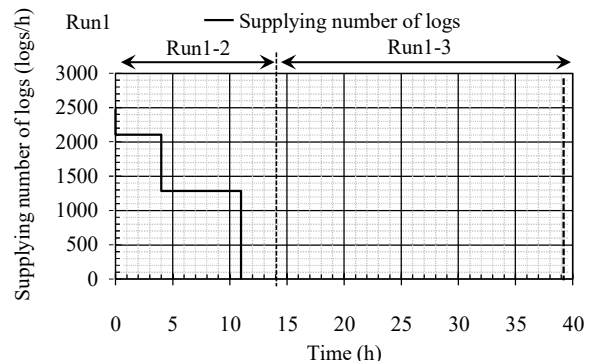


Fig. 4. Temporal changes of supplying number of logs in Run1-2 and Run1-3.

Table 1. Experimental conditions.

Run No.	Water discharge rate (m ³ /s) and duration (h)	Sediment discharge rate (m ³ /s) and sediment transport concentration	Supplying number of logs (logs/h)
Run 1-1	770 m ³ /s, 6.00 hours	2.32 m ³ /s, 0.003	2,487 logs/h from upstream end (During one hour)
Run 1-2	Hydrograph, and 17.0 hours shown in Fig. 3	Temporal changes shown in Fig. 3, and 0.003	Temporal changes shown in Fig. 4, from upstream end
Run 1-3	Hydrograph, and 22.2 hours shown in Fig. 3	Temporal changes shown in Fig. 3, and 0.003	Without supplied logs
Run 2-1	650 m ³ /s, 33.3 hours	1.96 m ³ /s, 0.003	Without supplied logs
Run 2-2	650 m ³ /s, 17.2 hours	1.96 m ³ /s, 0.003	314 logs/h (total) 192 logs/h from the upstream end, 122 logs/h from the side banks
Run 2-3	500 m ³ /s, 24.0 hours	1.50 m ³ /s, 0.003	Without supplied logs

3 Logs capturing due to slit dams

Figure 5 shows the plane view of topographical variation in Run1-3, Run2-2 and Run2-3.

In case of Run1-3, the logs were deposited on the inner edge of channel and front edge of the sand bar. The slit of No. 2 sabo dam trapped about 80 % of the total logs, that were almost broadleaf trees. The increasing of water level caused by slit blockage took place in about 200 m upstream of the No. 2 sabo dam. The main channel downstream of the No. 2 sabo dam was convergent on the right bankside without channel shifting. A little volume of conifer deposited in the slit of No. 1 sabo dam without slit blockage.

Figure 6 shows the temporal change of the sediment discharge rate measured at the downstream end. In Run1, the sediment runoff was less than half of the supplied

sediment discharge rate, and the temporal change had few fluctuations of runoff.

The reason for the large deposition of logs at the No. 2 sabo dam is that the ratio of the slit width to the length of logs ($= L_{95}$) at the No. 2 sabo dam is about 1:3.10, Whereas, the ratio of the No. 1 sabo dam is about 1:1.60, and means easy passing through the slit. The change of sediment runoff take place at about 5, 27 hours in raising/decreasing stage in Run1-2 and Run1-3, respectively. Flow discharge is $400 \text{ m}^3/\text{s}$ at that time, and results in the stopping of sediment runoff at the No. 2 slit dam and in the starting of sediment runoff at the No. 1 sabo dam without intercept of water level.

It is desirable to set appropriate multiple layout of dams and setting of slit width based on plane topography characteristic of sediment and logs runoff.

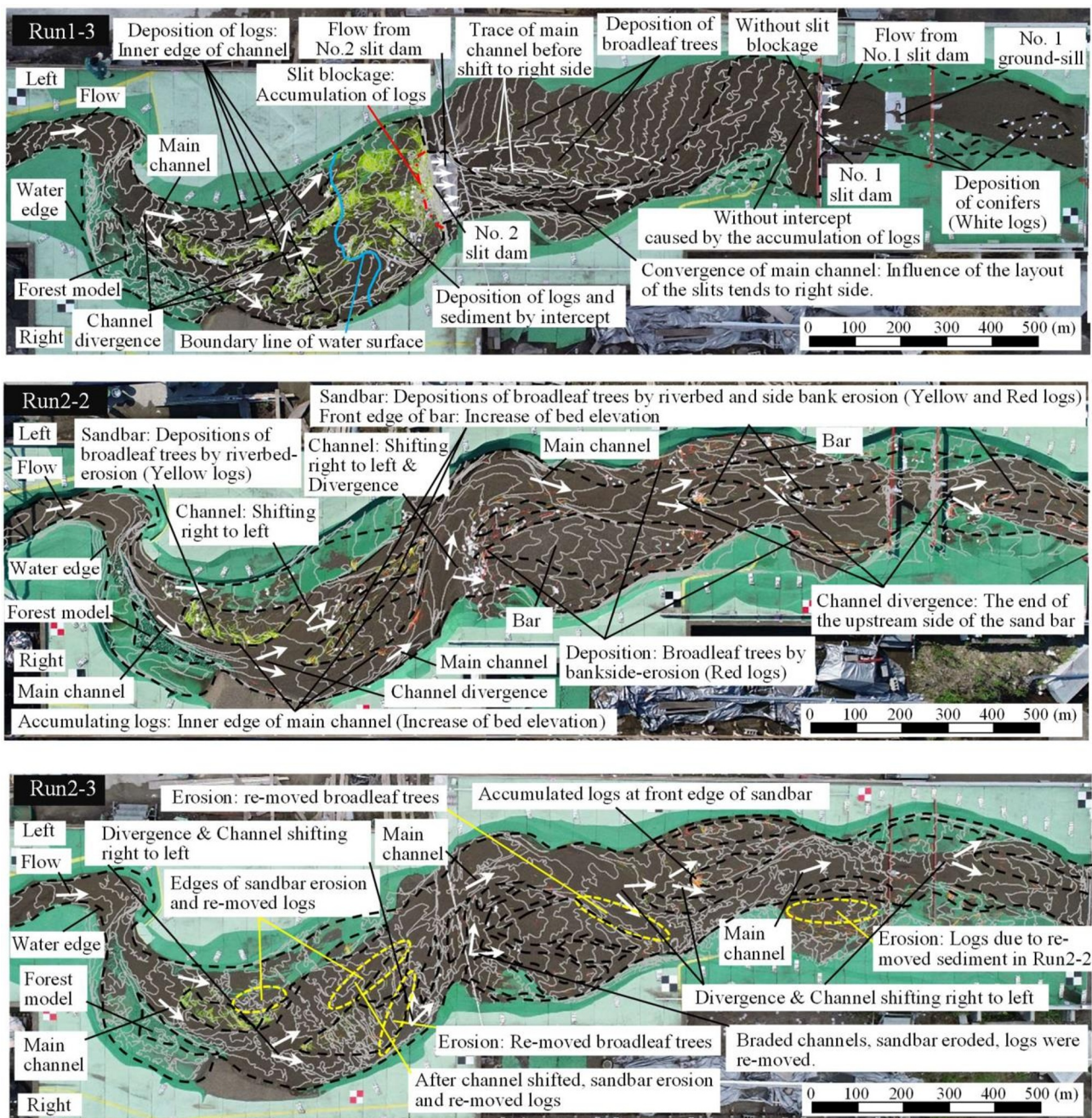


Fig. 5. The plane view and topographical variations in Run1-3, Run2-2 and Run2-3.

4 Influences of channel shifting on logs deposition

Let us discuss interaction between logs deposition and flow patterns in Fig. 5 and 6. Logs tend to accumulate along the water edge of flow channels or at front edge of sand bars in Run2. Channel shifting is dominant in Run2-2, and effects of logs deposition along the water edge on channel shifting and sand bars appear, because logs deposition could decide water flow patterns. Speed of channel shifting is also affected by logs deposition near the water edge of channel, and results in almost fixed channel edge and increasing sediment runoff by sediment discharge rate in Run1 and Run2. Braided small channels are formed everywhere in Run2-3. Trigger of braided channel depends on the rate of flow width to depth and additionally on logs deposition. Capacity of sediment transport decreases due to sediment and logs deposition by braided channel, and results in aggradation of the bed and decreasing of sediment runoff to downstream reach.

Present experiments focused on sediment runoff and effects of logs on sediment transport after huge sediment transport over the plan size. The values of sediment runoff vary from 0.300 to 0.750 for the inlet sediment discharge rate in Run2-2 and from 0.333 to 0.666 in Run2-3. Sediment runoff tends to increase due to mainly channel shifting and due to secondly braided channels corresponding flow rate, and the effect of logs on sediment runoff is significant. There are the variations of sediment runoff in time-developing. That means usual monitoring needs to carry out in the site for future floods.

The study is going to consider in detail for the relationship between bed variation and runoff rate of sediment and woody debris, and for those deposition.

5 Conclusions

Present experimental study was carried out supposing woody debris and sediment transportation after huge sediment transport and deposition in the past. The results obtained in present flume tests are as follows:

(1) Channel shifting of main channel takes place in wide flow area, and the flow width is determined by wide and narrow flow area at 650 m³/s in which double bar is formed. The flow channel becomes one channel and

point bars and is affected by deposited logs at the boundary between flow water and edge of sand bars. There are almost broadleaf tree, which occupy around 90 % in logs number, in upstream reach of Tottabetsu River basin. The broadleaf tree is usually submerged in flow water on the moving sediment particles. Sediment deposition takes place significantly in the wide flow areas and sediment deposition is control by the wide flow area.

(2) Braided channel is quite active in wide and narrow flow area at 500 m³/s in which hydraulic condition is in the boundary between double bar and alternate bar formation. The braided channel takes place everywhere and whenever in wide flow area, and the interaction is active between logs and sediment movement. The woody debris and sediment particles could be transported well at the flow discharge (500 m³/s) though capacity of sediment transport is less than that of 650 m³/s.

(3) Two sabo dams were arranged in the area in hydraulic model test to evaluate effects of woody debris deposition on sediment and logs capture. Huge amounts of logs are captured and deposited in the area of upstream sabo dam due to broadleaf tree that is a lot of the rate for total logs, though the sabo dam is a slit dam. The results could emphasize that the location and the opening of the slit need to consider hydraulic condition and characteristic of woody debris for appropriate control of sediment and woody debris. As shown in introduction, we focused effects of woody debris on sediment transport on the fan area after huge magnitude of woody debris events. Though mechanism needs to be clarified for woody debris flow in steep slope torrents, we will try to evaluate the interaction between steep torrents and fan area, taking into account effects of sabo facilities, debris flow mode and so on.

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References

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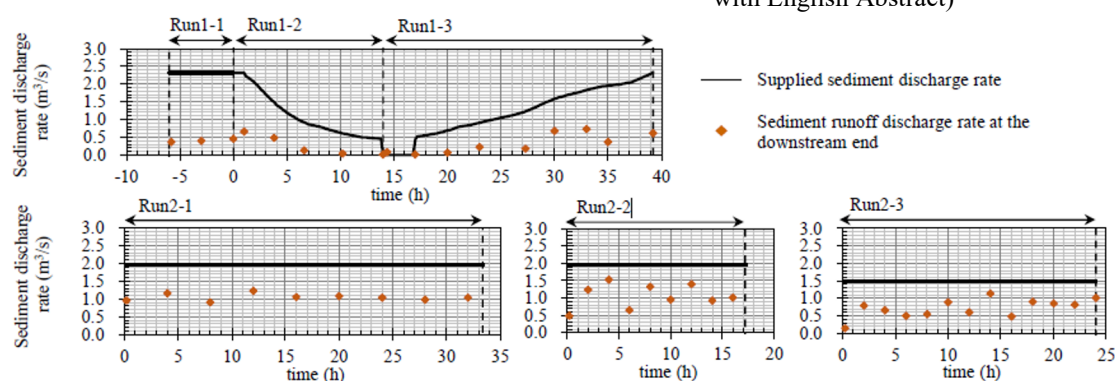


Fig.6. The temporal change of the sediment discharge rate, measured at the downstream end in Run1 and Run2.