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Influence of heterogeneous sediment transport on the function of sediment control of a check dam

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Abstract To clarify the function of sediment control of a check dam, field investigations and flume experiments were carried out. It was clarified on the basis of actual data in field studies that a check dam has the function of sediment control. As a result of field studies and flume experiments, it was clarified that the formation of slope behind a check dam depends on sediment concentration when homogeneous sediment is transported, but that its formation does not depend on it when heterogeneous sediment is transported. When heterogeneous sediment is transported, its superior mobility plays an important role in slope formation. Therefore, we cannot solve the problem regarding the function of sediment control of a check dam without understanding of the characteristics of a heterogeneous sediment during transportation.

INTRODUCTION

Now, in Japan, in planning for sediment control, we must pay special attention to the influence of erosion control (Sabo) facilities on the environment and landscapes. This means that we must carefully consider how to prevent sediment disasters, whether we truly need to set up facilities or not, which facilities we should select and where we should locate these facilities. For this consideration, it is necessary to further clarify the functions of Sabo facilities for control of sediment transport.

A check dam is the most important facility to prevent sediment disasters, but the function of sediment control has been evaluated for the convenience of the Sabo planning rather than on the basis of the realities of sediment transport. We have not yet the full understanding of this function. To clarify its function on the basis of the realities of sediment transport, we carried out field investigations and flume experiments.

CHANGES OF LONGITUDINAL SLOPE IN THE UPPER REACHES OF A CHECK DAM

Higashigochi basin and the 1982 rainstorm

The Higashigochi basin is located in the high up-lifting zone of the Southern Japan Alps and gets a mean annual precipitation of more than 3000 mm. Intense rainfall is due to typhoons in August and September and the Baiu (rainy) season between late

June and mid-July. The basin is sedimentary rocks consisting of sandstone and shale.

The Higashigochi stream flows down from a height of 2406 m (Mt Aonagi) to 770 m (where it meets with the Oi River) in altitude for only about a 10- km total length. The San-nosawa check dam, which was constructed at a height of 14 m in 1976, is located at approximately a 5 km-upper-point from the confluence (Fig. 1).

In early August 1982, typhoon No. 10 caused a serious rainstorm in the basin. Rainfall for three days totalled more than 900 mm and maximum hourly rainfall was 70 mm, recurrence interval of which was more than 30 years. The 1982 rainstorm gave a considerable change to the longitudinal profile of the upper reach of the San-nosawa check dam.

To clarify the realities on the function of sediment control of the check dam, we surveyed longitudinal and cross-sectional profiles in late September 1982 and in August 1985, and we investigated the 1982 deposits which were caused by the 1982 rainstorm. Also, we used a design drawing made by the Tokyo Regional Office of Forestry Agency in 1976.

Changes in longitudinal profile before and after the 1982 flood

Construction of the check dam was started in 1975 and was finished at the end of 1976.

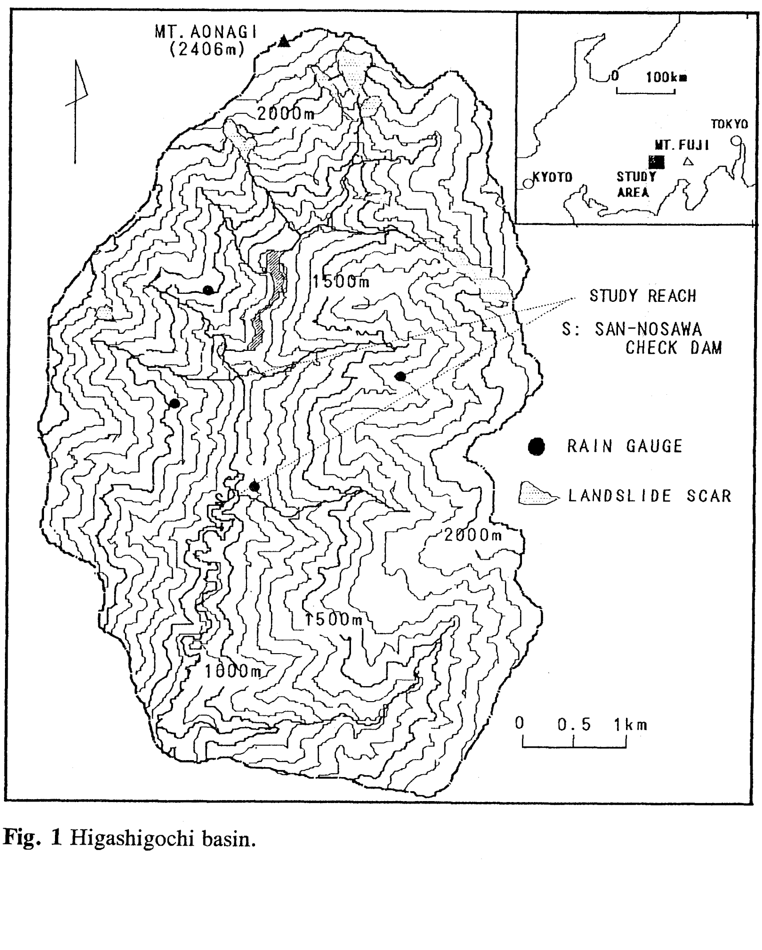

Fig. 1 Higashigochi basin.

In the course of the construction, deposition on the upper reach of the check dam had already begun, and the rainstorm of 1977 caused full deposition behind the check dam. According to the design drawing, the slope before the completion of the check dam was roughly 6%, but after the completion the ordinary sediment supply altered the original slope into a gentle slope of 3% in a shorter span of 0.5 km (Fig. 2). This shows that in the case of the ordinary sediment supply, the ratio of depositional slope behind the check dam to the original slope exists between 1/2 and 2/3 which is generally used as the design value of the Sabo planning.

The 1982 rainstorm produced a huge sediment consisting of sand, small cobbles (16-64 mm), pebbles (4-16 mm) and boulders from the headwater regions. This extreme sediment supply, recurrence interval of more than 30 years, not only caused rotational aggradation but also flattened the stream bed temporarily. At the same time the top positions of aggradation in the upper reach of the check dam almost formed in a line without the influence of original stream shape and form, and the slope of the top bed altered from 3 to 4.7% in a longer span of 1.8 km (Fig. 2). This shows that the larger sediment supply is, the steeper the depositional slope becomes behind a check dam, and that the larger the sediment supply is, the more influence it has on a check dam. As mentioned above, a new profile formed by active aggradation is not affected by the original shape and form of the stream. This shows that the nature of sediment itself, which was supplied from the upper stream, plays an important role in the formation of slope behind a check dam at a depositional stage. While original shape and form plays an important role at the erosional stage (Maita, 1991).

Just after the 1982 rainstorm, the next rainstorm which had a total rainfall of more than 500 mm and maximum hourly rainfall of 35 mm hit the basin in mid-September 1982, but it brought little sediment from the headwater regions. Therefore, erosion for the 1982 deposits caused degradation of stream bed, and the bottom bed of upper reach

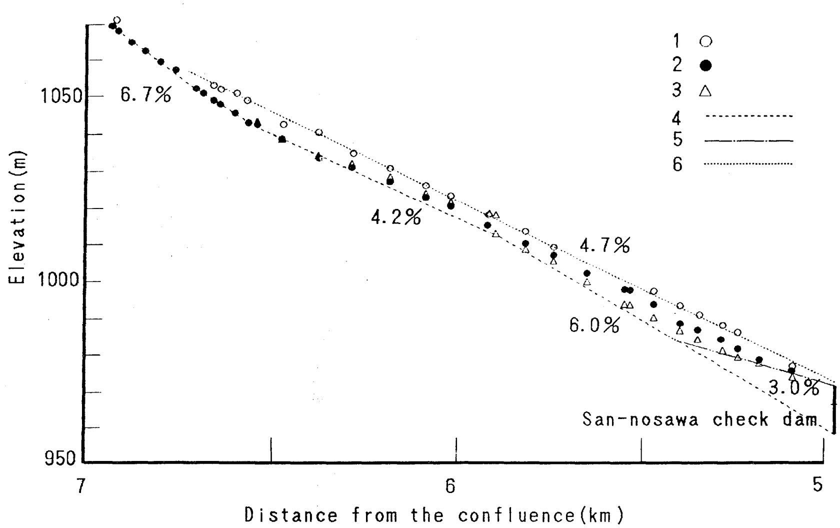

Fig. 2 Changes of profile before and after the 1982 flood.
1: Top positions of the bed formed by the 1982 flood, 2: Bottom positions of the bed formed by the flood in September 1982 just after the 1982 flood, 3: Bottom positions of the bed in 1985, 4: The original profile of the reach, 5: The profile formed by the flood in 1977, 6: The top profile of deposition formed by the 1982 flood.

from a 6.1 km-point already almost returned to the former profile, but the slope between a 5.5 km-point and the check dam has not returned yet to the former slope of 3%. After that, several rainstorms hit the basin until 1985. They almost returned the profile formed in 1982 to the former profile in the study reach except a range of influence of the new check dam which was under construction at a 5.8 km-point in 1985 (Fig. 2).

As shown in Fig. 2, when a large flood caused an extreme sediment supply a large quantity of sediment was temporarily stored behind the dam, and it was transported to downstream in later floods. The sequence of these phenomena show that a check dam retards sediment transport as sediment moves downstream. This is the function of sediment control of a check dam. In spite of the fact that it was incorporated in the planning of the Sabo, it was not fully clarified on the basis of actual data. Therefore, the results of this investigation are important as an actual example to demonstrate the function. However, it is difficult to clarify its function using only field studies. Therefore, we carried out flume experiments in an attempt to understand what decides a slope.

FLUME EXPERIMENTS ON THE FORMATION OF SLOPE BEHIND A CHECK DAM

Experimental methods

A sediment-feed flume, 5 m long, 20 cm wide and 23 cm in height, was used in this study. It has a rectangular weir of 5 cm in height at the end. A belt-conveyor 1.5 m long was used for controlling the sediment feed rate into the flume. Flume slope was fixed at 8.4%. Water discharge was kept constant at 1000 cm^3/sec for all runs. Two sizes of material were used in this study (Table 1). If the Froude's similar condition with a 100 in the ratio of prototype dimension to model dimension is applied to the experiment, and if the similar condition of sediment transport, which is one in the ratios of $U_* U_{*c}$ in a model to U_*/U_{*c} in a prototype (here U_* is friction velocity and U_{*c} is critical friction velocity), is applied to the experiment, under given conditions, the flow of the flume corresponds roughly to the flow of 100 m^3/sec transporting large cobbles (60-70 mm) and boulders (about 500 mm) in the actual stream. This is very roughly equivalent to the partial state of sediment transport in the Higashigochi basin during the 1982 flood. Although this experimental model was not made perfectly as a prototype, this experiment is fully useful for the purpose which is the understanding of essential qualities of sediment transport.

Formation of slope by the feed of sand or gravel or mixtures

As soon as sediment feed was started, not only the depositional front with submerged slope of the repose gradually advanced into the pool behind the weir, but also depositional rear just below the hydraulic jump expanded to the upper stream. After the front reached the weir, rotational aggradation began. It continued until dynamic equilibrium was established. When the position of depositional rear and depositional

Table 1 Characteristics of sediment used in the experiments (units: mm).

	d_{16}	d_{50}	d_{84}
Sand	0.84	1.0	1.2
Gravel	4.6	5.2	5.8

Table 2 Experimental results on the formation of slope.

	Run name	Sediment concentration (%)	Discharge (cm^3/s)	Sediment feed rate (g/s): sand	gravel	Mean depositional slope (%)
A	S1	0.5	1000	5	0	1.3
	S2	1	1000	10	0	1.4
	S3	2	1000	20	0	2.6
	S4	4	1000	40	0	4.1
	G1	0.5	1000	0	5	6.2
	G2	1	1000	0	10	7.0
	G3	2	1000	0	20	7.1
B	M1	1.5	1000	5	10	5.0
	M2	2	1000	10	10	3.6
	M3	3	1000	20	10	3.5

A: Uniform-sized grains. B: Mixtures of different-sized grains.

slope approximately remained stable, we judged that the system reached dynamic equilibrium. After that, we stopped the run and measured elevation every 20 cm along the flume to calculate the bed surface slope.

Conditions and results of the experiments are shown in Table 2. Mean slope was obtained by using the method of least squares for mean elevation of stream bed. As shown in Fig. 3, when uniform grains of sand or gravel were transported in proportion to sediment concentration increased, the slope formed by sand or gravel became steep and in the case of the same concentration, the slope formed by gravel was nearly four times as steep as the slope formed by sand. This shows that slope behind a check dam depends only on sediment concentration when homogeneous sediment is transported.

When sand was added into the flume, keeping the feed rate of gravel constant, the slope decreased with the increasing feed rate of sand (M1, M2 and M3 in Fig. 3), whereas the total sediment increased. This shows that sand ratio to mixture plays an important role in the formation of slope. If the role of sand in mixture for the formation of slope was decided in accordance with the ratio of uniform-sized sand to uniform- sized gravel, the slope would be M1' or M2' or M3' in Fig. 3. But, M1 or M2 or M3 of the slope formed by the experiment is gentler than M1' or M2' or M3'. This is because of the superior mobility of mixtures (Ikeda & Iseya, 1988), the degree of which may be shown in the difference between M1' and M1 or between M2' and M2 or between M3' and M3. This shows that slope does not depend on sediment concentration and the superior mobility of mixtures plays an important role in the formation of the slope when a heterogeneous sediment is transported.

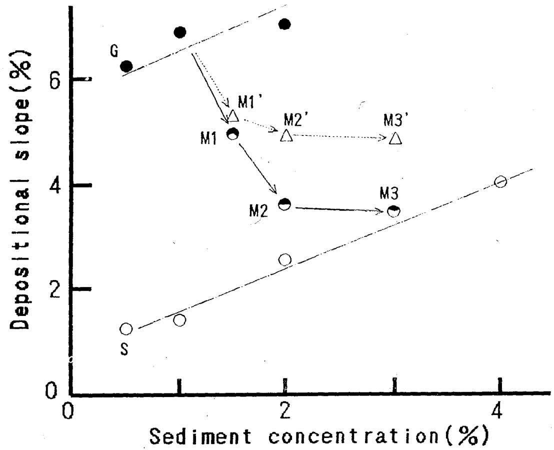

Fig. 3 Relations between formation of slope and conditions of feed rate. S: Uniform-sized sand, G: Uniform-sized gravel, M1: Mixture (S:G = 0.5:1), M2: Mixture (S:G = 1:1), M3: Mixture (S:G = 2:1). M1', M2', M3': When slope was simply decided in accordance with the ratio of uniform-sized sand to uniform-sized gravel.

Deformation of slope by the feed of sand or gravel

Mixtures of sand and gravel in the ratio of 1:1 were fed into the flume until dynamic equilibrium was established. When it was reached, sediment feed was discontinued. The water of 1000 cm^3/sec only ran down on the flume until static equilibrium, which was in the state without bed load transport, was established. After that the run was stopped temporarily and the measurement of stream bed was carried out. Then, the run was restarted under a sand feed rate of 10 g/sec (sand-concentration of 1%) or gravel feed rate 10 g/sec (gravel-concentration of 1%). It was continued until dynamic equilibrium was established. When it was reached, the run was stopped and the measurement was carried out.

Table 3 shows conditions and results of the experiments. As shown in Fig. 4, when the flow of sand-concentration of 1% ran down on the static equilibrium slope of 2.7%,

Table 3 Experimental results on the deformation of slope.

	Run name	Discharge (cm^3/s)	Sediment feed rate (g/s): sand	gravel	Mean depositional slope (%)
A	MW1	1000	0(10)	0(10)	2.7
	MW2	1000	0(10)	0(10)	2.8
B	MS	1000	10	0	2.6
	MG	1000	0	10	6.3

A: Experiment on the formation of static equilibrium slope. This slope was formed by the running water on dynamic equilibrium bed. Parentheses in the Table are the feed rate to establish dynamic equilibrium.
B: Experiment on the deformation of the slope by feeding sand or gravel.

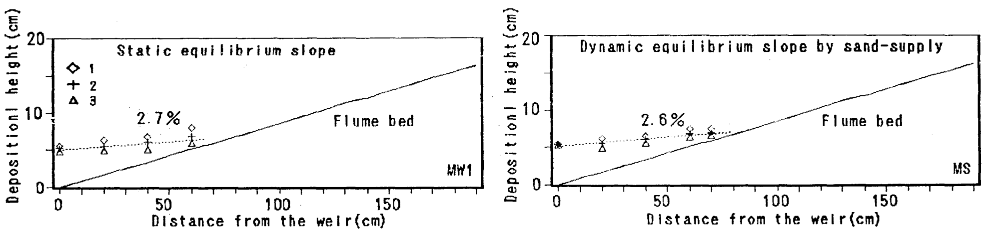

Fig. 4 Deformation of slope by the sand feed.
1: Maximum height, 2: Mean height, 3: Minimum height.

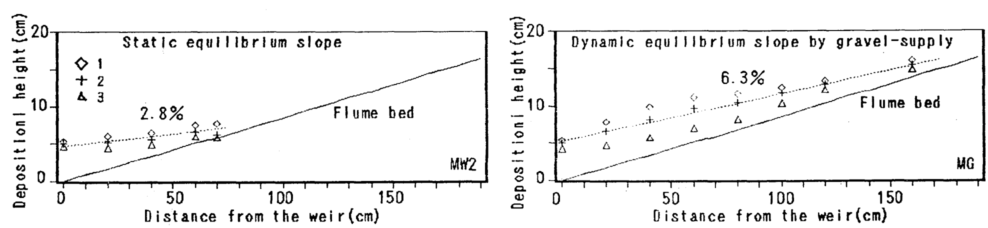

Fig. 5 Deformation slope by the gravel feed.
1: Maximum height, 2: Mean height, 3: Minimum height.

it changed the slope only a little. When the flow of gravel-concentration of 1% ran down on the static equilibrium slope of 2.8%, it remarkably changed the slope of 2.8% into that of 6.3% (Fig. 5). This shows that grain size of supplied sediment plays an important role in the deformation of slope.

CONCLUSION

As a result of the field investigation, it was clarified on the basis of actual data that a check dam has the function of controlling sediment transport. The acting degree of the function depends on the relation between the slope formed by extreme sediment supply and the slope formed by ordinary sediment supply. Generally, the former slope is called as "flood slope" and the latter one is called as "stable slope" in the Sabo planning. Within the limits of the field investigations, it seems that the "flood slope" depends on the quantity of sediment supply, and that the "flood slope" roughly returns to the stable slope. However it is difficult to know the relation between the formation of slope and sediment quality by means of field studies.

As a result of flume experiments to clarify the relation between the formation of slope and sediment quantity and quality, it was clarified that the slope behind a check dam depends on sediment concentration when homogeneous sediment is transported, but that the slope does not depend on sediment concentration when heterogeneous sediment is transported. The superior mobility of heterogeneous sediment in transportation plays an important role in slope formation. Also, it was clarified that the grain size of supplied sediment plays an important role in slope deformation.

Therefore, we cannot solve the problem on the function of sediment control of a check dam without understanding the characteristics of the heterogeneous sediment in transportation.

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