Sediment trapping efficiency of modular steel check dam in laboratory experiment and field observation

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Abstract
From an observation on the debris flow in Landow torrent caused by typhoon Soulik on July 13, 2013, which was recorded by time-lapse photography, we found that the modular steel check dam can effectively trap debris flow and reduce the impact of debris flow, significantly protecting downstream bridge. This study carried out the reduced-scale test for the Landow torrent at Huisun Experiment Forest, to simulate the trapping efficiency of modular steel check dam to debris flow. The modular steel check dam with transverse beams has high trap efficiency compare to the dam without transverse beams. However, the sediment deposited significant decrease inside the check dam with transverse beams. The scaled model analysis of the modular steel check dam in field observation and laboratory experiment showed it had similar trapped efficiency of debris flow.

Key words: modular steel check dam**,** adjustable transverse beam**,** debris flow

1. INTRODUCTION

Check dams constructed in the river at the mountain mainly aim at trapping debris flow and driftwood. Wehrmann et al. (2006) basing on four principles as function, open type, construction materials, and stability analysis of dam, proposed new design standards and classifications to Austrian local dams, and according to their characteristics, classified dams into two types as close-type check dams and open-type check dams. Chen (2006) divided check dams into three types as close-type check dams, porous check dams, and open-type check dams in Taiwan. Armanini and Larcher (2001) discussed the patterns of open-type check dams, pointing out that in addition to the basic function of retaining sediment, the open-type check dam of different structures have additional features, such as flood detention, trapping driftwood or stopping debris flow, etc. The steel check dam adopted by this study is classified as open-type check dam, featuring that fine-grained sediment and river flow can through the dam, and there will be no accumulated sediment usually or when small and medium-scale flooding occurs, thereby ensuring that with sufficient trapping capacity of upstream sediment, it is able to play the function of regulating sediment when debris flow occurs. In addition, it also has the function of ecological continuity. Ono et al. (2004) pointed out that the main application of steel check dam can trap debris flow and driftwood, and stabilize the river bed. Since 1995, Japan started to extensively use steel check dam to trap debris flow.

A modular steel check dam improves the existing hard-to-change disadvantages of check dam structure. The assembling of longitudinal and transverse beams can be constructed independently, and then it could be freely configured to form a flexibly adjustable modular steel check dam. By dismantling of transverse and longitudinal beams, it also can adapt sediment transport, disaster prevention, and ecology for rivers environment in different basin condition. This concept also known as the “breathing check dam”.

To verify the function of modular check dam, we built a modular steel check dam at Landow torrent in Huisun Experiment Forest, National Chung Hsing University, and conducted a scaled model experiment by geometric similarity law with the field conditions. The experiments analyzed the different of the debris flow trapping phenomenon and efficiency with and without transverse beams were installed in modular steel check dam. In addition, to compare with the result of laboratory experiments and field observation, this study also took advantage of the debris flow event triggered by typhoon Soulik in Landow torrent on July 23, 2013, and recorded the debris flow trapping process of the modular steel check dam by time-lapse photography.

2. EXPERIMENT DESIGN

2.1 Experimental flume

To simulate the outbreak of debris flow, this study released all sediment and flow with specified grain sizes distribution and concentration instantly. After the short duration of debris flow outbreak, it provide water flow continually until the end of the experiment to simulate the influence of floods erosion on deposited sediment which was formed from the trapping debris flow by check dam. In addition, we access the sediment which passing through the dam at the end of the flume to analyze the sediment trapping mechanisms and effects of modular steel check dam.

This study measured the actual size of field channels and modular steel check dam, and used a 1/25 scaled model to prepare four kinds of experiment sediment with grain size of 4.50 cm, 2.84 cm, 2.07 cm, and 1.52 cm respectively for the grain sizes distribution of debris flow. In addition, a steel rectangular flume of 600 cm length, 48 cm width, and 60 cm height, with adjustable discharge was chosen for the experimental flume; and the gradient of the flume and the field was same as 9°.

2.2 Modular steel check dam design

To analyze the influence of sediment trapping efficiency between modular steel check dam with and without transverse beams, in the case of a dam with transvers beams, a dam module installed four transverse beams with interval in 2.00 cm (i.e. d_{50}), and the gap between the lower transverse beam and flume bed in 2.80 cm (i.e. d_{95}). A single dam module was 20.00 cm high and 7.20 cm wide. This experiment constructed four modules to form a modular steel check dam. The horizontal gap of each module was 4.00 cm (i.e. 1.5 times of the largest grain size, d_{95}); the gap between the outermost module and the sidewall of flume was 3.6 cm (1.28 times of d_{95}, Fig.1).

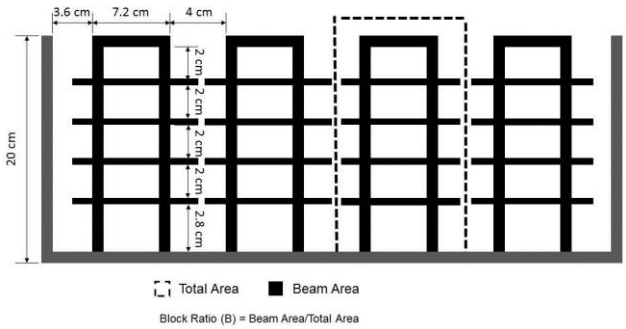

Fig. 1 Experimental model size diagram of modular steel check dam and the block ratio *B*

In the case of a dam, the dam module design and configuration were same as that of the experiment with transverse beams. To quantify the differences between with and without transvers beams the two experiment designs; we used the block ratio, B = beams area / total area, to define the ratio that a module blocked the sediment transport. The block ratio is 34.9% and 27.9% for with and without transverse beams in this study, respectively.

2.3 Experimental conditions and procedures

This experiment was made against two kinds of modular steel check dam with and without transverse beams, matching six discharges. Total 12 sets of experiment were conducted, and their experimental conditions are shown in Table 1.

Table 1 Experimental setting

Discharges (m^3/s)	Without transverse beams	With transverse beams (2.00 cm)
0.00451	R1	RS1
0.00695	R2	RS2
0.00889	R3	RS3
0.01162	R4	RS4
0.01477	R5	RS5
0.01819	R6	RS6
The block ratio of R1 to R6 is 27.9%		
The block ratio of RS1 to RS6 is 34.9%		

We prepared the specified concentration and amount of debris flow upstream the flume with a sluice, then the sluice open suddenly while the beginning of experiment to simulate occurrence of debris flow. Meanwhile, during the experiment, we continued to supply flow discharge in the flume. In addition, the sediment, which passed the dam, was received at the end of flume by timing. The

collection process was divided into four consecutive time intervals in 5 seconds, 10 seconds, 15 seconds, and 30 seconds respectively, and total receiving time was one minute.

3. DISCUSSION AND ANALYSIS OF EXPERIMENTAL RESULTS

This study divided the experimental process into three stages according to the characteristics of debris flow trapping and the sediment outflow. The first stage is that the debris flow's leading edges were trapped completely; the second stage, after the debris flow's leading edges were trapped completely, subsequent debris flow was trapped upstream the dam and became a retrogressive deposition; the last stage is continuous flooding flow that is to simulate the floods erosion process after the debris flow occurred.

3.1 Without transverse beams

Modular steel check dam without transverse beams in block ratio (B = 27.9%), only vertical beams can trap the debris flow's leading edges on upstream side of the dam. Since the trapping effect of modular steel check dam was mainly provided by the arched stacking efficiency between boulders and dam's components, part of debris flow's leading edges may enter into the open internal structure of steel check dam, and were trapped when touching the structure at downstream side of the dam. It led to a trapping zone within the dam (as Fig. 2 R1). The experimental process shows that delays from leading edges touching upstream side of dam to trapped completely: all of six experiment cases which without transverse beams, the time for debris flow's leading edges being completely trapped were within 5 to 6 seconds.

Although the completely trapped time were same in all of six experiment cases with different discharges, however, considering the purpose of this experiment was to simulate the debris flow burst with a same sediment concentration in the beginning, and the leading edges impacting duration was very short. It led to a similar completed trapped time between six different discharge cases.

3.2 With transverse beams

After the modular steel check dam was equipped with transverse beams, the sediment trapping behavior was significantly different with the experiment without transverse beams. Among which, the sediment trapped amount inside the dam interior was reduced a lot in comparison to the experiment without transverse beams. In addition, being affected by block ratio (B = 34.9%), debris flow's leading edges were trapped immediately upon in contact with the dam's upstream side, namely most sediment were trapped in upstream dam. Therefore, it could be said that the sediment trapping behavior in cases with transverse beams was similar to that of close-type check dam (Fig. 2 RS1, 3, 5).

By analyzing the sediment trapping process and comparing the cases without transverse beams, it could be found that the debris flow's leading edges completely trapped time was reduced to about 3 to 4 seconds with transverse beams which significant short trapping process, in comparison to 5 to 6 seconds of (B = 34.9%) while the dam modular without transverse beams. The hydraulic jump decreased the flow energy which located the upstream end of retrogressive deposition became faster towards upstream.

Figure 3 shows the rate of sediment transport which passing over the dam with transverse beams (solid lines, RS1, RS3 and RS6) and without transverse beams (dashed lines, Cases R1, R3 and R6). The period within 0 to 5 sec was the first stage, which the debris flow's leading edges were completely trapped, so no sediment yield downstream. The second stage was 6 – 15 sec, the debris flow deposited retrogressively upstream, and subsequent debris flow over the dam as bed load. Then the sediment yields reduced after the debris peak flow. The last stage was 16 – 30 sec; the debris flow stopped and was continuous flooding flow. The sediment yield approached zero in R1, R3, RS1 and RS3 experiments. However, in the cases with large discharges (R6 or RS6), the kinetic energy of flow were more easily to flush out the sediment insides the debris flow's leading edges, until the new arched stacking efficiency formed by the sediment grains and dam's beams again. Therefore, R6 and RS6 till had litter sediment yield in the last stage with a large discharge.

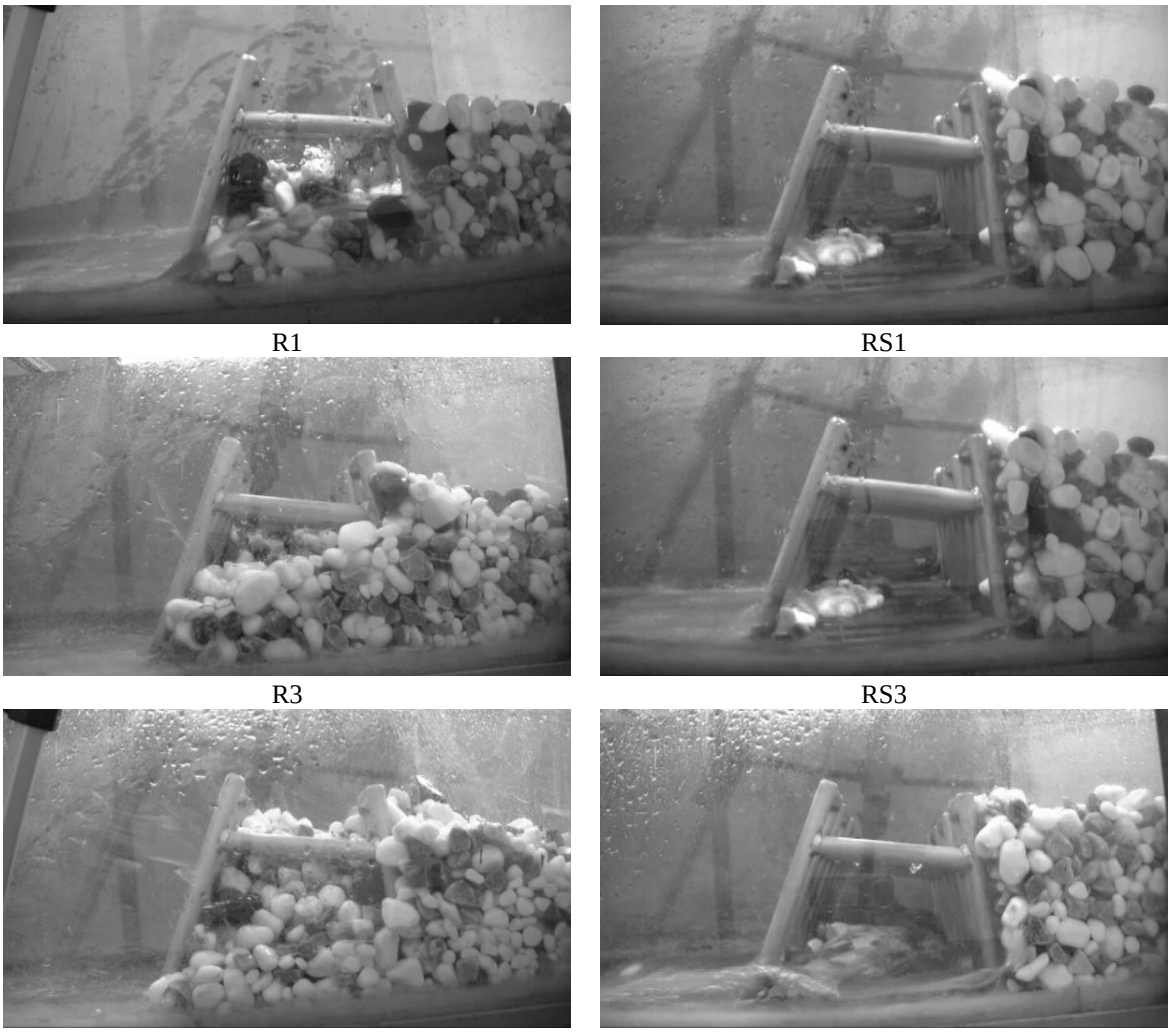

Fig. 2 Accumulated situation of modular steel check dam with and without transverse beams (side view)

Furthermore, in the case with/without transverse beams, the sediment discharge volume was affected, too. Namely, with transverse beams, dam's block ratio (*B*) increased, thereby reducing the time for debris flow's leading edges being trapped completely. Therefore, the quantity of sediment, which passed over the dam with a same discharge during 0 to 5 seconds in case with transverse beams, less than that of the experiment without transverse beams.

3.3 Grain deposition phenomenon of a dam

Comparing to total trapping sediment amounts of experimental process, it can be seen form Fig. 4 that the modular steel check dam without transverse beams, which trapped sediment by the stacking efficiency of vertical beams only, demonstrated the significantly lower sediment deposition rate. However, after the modular steel check dam equipped with transverse beams of 2.00 cm interval, its trapping sediment efficiency increased about 5.6%~15.3%; apparently, installing transverse beams to promote the grain deposition rate is feasible.

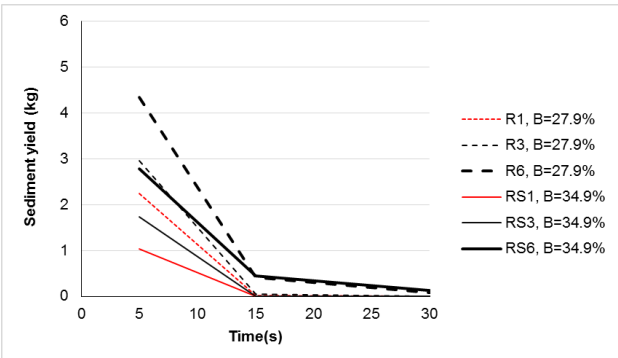

Fig.3 The hydrograph of the sediment passing the dam in experiment R1, R3, and R6 with and without transverse beams (0-30 seconds)

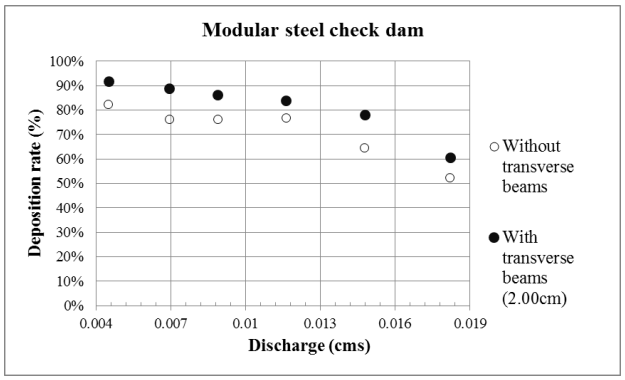

Fig. 4 The relationship between grain deposition rate and discharge.

4. COMPARISON OF LABORATORY EXPERIMENT AND FIELD SITUATION

We recorded the modular steel check dam trapped debris flow by time-lapse photography in Landow torrent caused by Typhoon Soulik on July 13, 2013. Based on the field observed time-lapse image, we compared to the laboratory experiment. Taking Fig. 5-(a) and Fig. 5-(b) as examples, both were the dams when debris flow just happened and touched the transverse beams, and which began to be trapped by modular steel check dam. Figure 5-(c) and Fig. 5-(d) shows that there were still some debris passing the steel check dam due to river flow flushed out in large floods current; however, most sediment was trapped. Regardless in laboratory experiment or the actual field observation, such phenomenon will occur, as shown in Fig. 5-(e). Fig. 5-(f), it shows that subsequent debris flow continued to accumulate, eventually flooded the dam area and passed the steel check dam.

This study made a field survey about such situation as the accumulated sediment at dam upstream and the sediment remained in the dam happened. The field survey data after Typhoon Soulik shown that the d_{95} of deposited sediment at the dam's upstream side was 0.70 m, and the d_{95} of the remained sediment in the dam was 0.60 m. In contrast, in the laboratory flume experiment, the d_{95} of deposited sediment at the dam's upstream side was 2.84 cm, and the d_{95} of the remained sediment in the dam was 2.70 cm.

After calculating by a 1/25 scaled model, it shows that both d_{95} of deposited sediment at the dam's upstream side was very similar. However, as for the sediment accumulated in the dam structure, the grain size remained in flume experiment after being converted by a scaled model was 2.70 cm, with about 10% errors in comparison to the d_{95} (0.60 m) of sediment remained in the field dam; namely, the sediment size remained in the dam of laboratory experiment was significantly larger than the grain size in the field dam.

(a)

(b)

(c)

(d)

(e)

(f)

Fig. 5 Comparison between laboratory experiment and field observantion

CONCLUSION

A modular steel check dam improves the existing hard-to-change disadvantages of check dam. Furthermore, this study analyzed the mechanism while the debris flow's leading edges trapped by the dam completely. We also compared with the experiment and field survey result to verify the sediment trapped capability of the modular steel check dam.

In the period of debris flow's leading edges trapped by dam completely, the result showed that the trapped process was not affected by supply of discharge, but controlled by original concentration of debris flows. It led to two completely trapped time in cases with and without transverse beams respectively, but similar time in cases with different discharge, by the experiment purpose which was to simulate an outbreak of debris flow.

We divided the experimental process into three stages according to the debris flow trapped efficient. The first stage is that the debris flow's leading edges were trapped completely. The second stage, subsequent debris flow was trapped upstream the dam and became a retrogressive deposition; however, there are some sediment over the dam as bed load. The last stage is continuous flooding flow that is no sediment yield except the high discharge flush the sediment within the check dam. The modular steel check dam with transverse beams had trapping sediment efficiency increased about 5.6%~15.3% compared the dam without transverse beams.

From an observation on the debris flow in Landow torrent caused by typhoon Soulik on July 13, 2013, which was recorded by time-lapse photography, we found that the modular steel check dam can effectively trap debris flow, reduce the debris flow hazard, and protecting downstream bridge significantly. The contrast researches of the modular steel check dam in field observation and laboratory experiment showed it had similar trapped efficiency of debris flow.

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