INFLUENCE OF SEDIMENT COMPOSITION ON BREACHING PROCESS OF MODEL RIVER LEVEE

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ABSTRACT

In recent years, floods have been occurring in various places due to the effects of climate change, and one of the serious damages arises due to the breach of river levees. As in the case of western Japan heavy rains in July 2018, a levee breach can cause serious damage to house and people in the basin. Therefore, it is an urgent task to understand the mechanism of river levee breach for disaster prevention and mitigation. The authors have investigated experimentally the breach process of model levee composed of sand, clay and gravel. We also examined the effect of clay and gravel on the collapse mechanism of levee by conducting experiments with various content ratio of clay and gravel. In this study, we examined how the erosion process of levee in which clay and gravel were contained is different from that only made of sand, and the significance of the existence of clay and gravel in the levee is made clear.

Keywords: *River-levee break, overflow, cohesive sediment, erosion, clay*

1. INTRODUCTION

In recent years, we have often experienced a torrential rain, which is due to the effects of climate change. Therefore, inundation damage has occurred frequently in various places in Japan. One of the most serious damage was caused by river levee breach. For example, a heavy rainstorm in the Kanto and Tohoku regions in September 2015 caused the levee collapse of the Kinugawa River. In July 2018, another damage was caused by the heavy rains in western Japan. River levees are important structures that will be our final defense line to protect our lives from the river floods. Considering the above, it must be important dynamically elucidating the mechanism of collapse for disaster prevention and mitigation. In this study, a series of experiments was conducted on this mechanism by small-scale model levee experiments. On this topic, two representative studies of the existing studies on levee breach are described here. Fujita et al. conducted a model experiment focusing on the process of levee collapse (Fujita, Tamura, and Muramoto, 1984). Shimada et al. conducted a full-scale experiment in the Chiyoda Experimental Channel in Tokachi River, Hokkaido (Shimada, Yokoyama, Hirai, and Miyake, 2011). However, as far as the authors know, there is almost no research on the effect of mixture ratio of gravel, sand and clay on the levee collapse. The authors have started a systematic arranged experimental research on this collapse mechanism of river levee since April 2015 (Sekine, Sato, and Suga, 2018; Sekine, Suga, and Matsuura, 2019). According to these studies, it was found that the levee which was composed of the mixture of clay and sand becomes much hard to erode and collapse due to the cohesiveness of sediment. In this study, we try to clarify the effect of the content ratio of gravel, sand and clay on the mechanism of levee collapse. In this paper, it was paid particular attention to the fact that the erosion resistance of the levee is significantly improved if some part of sand is replaced by gravel under the condition that clay is contained to some extent.

2. OUTLINE OF THE EXPERIMENT

2.1 Experimental apparatus

Summary of the experimental apparatus is shown in Figure-1. The height of the model levee is 0.15 m, and the foundation ground is 0.05 m. In this experiment, the space surrounded by the levee and the channel wall was regarded as a river, and water was injected into this space to generate a flow over the levee.

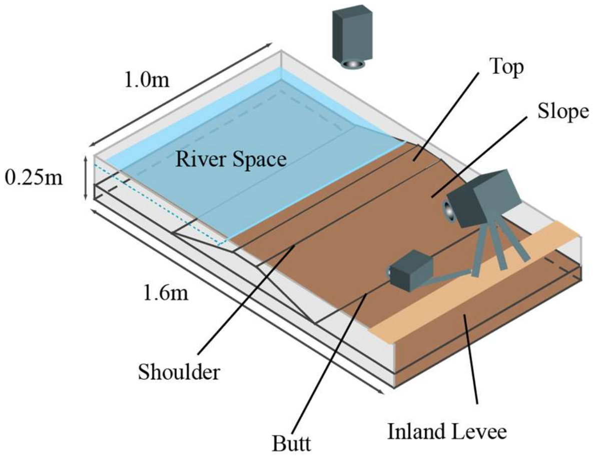

Figure 1. Experimental setup

Table 1. Experimental conditions

	Case 1	Case 2	Case 3
Clay Content *R_{cc}* (%)	0	30	30
Gravel Content *R_{gc}* (%)	0	0	30
Time to Breach	100	3960	No Breach

2.2 Sediment composed of model river levee

Silica sand No.1 (particle diameter 4.3 mm), silica sand No.7 (particle diameter 0.15 mm), and T.A. kaolin (particle diameter 7.0×10^{-3} mm) were used as gravel, sand, and clay, respectively. Specific gravity of each type of sediment equals to 2.65. In this paper, the three experiments of Cases 1 to 3 shown in Table 1 are explained for discussion. In Table 1, the clay content R_{cc} represents the "weight ratio of clay to the total weight", and the gravel content R_{gc} represents the "weight ratio of gravel to the total weight".

2.3 Experimental procedures

The experimental procedure is as follows.

(a) The materials in dry condition are composed of sand, clay, and gravel. Sediment and water were mixed until it becomes uniform.

(b) On the experimental flume bottom, the material prepared in step (1) was put and compacted to create the foundation ground. And then, wooden frames were set up at the locations 0.5 m and 1.07 m from the upstream end of the flume, and the material was put to make a lump of sediment as test sample. The size of the test sample is 1 m wide, 0.57 m deep, and 0.20 m high. In order to make compaction of it uniformly, the lump of sediment was compacted in three different layers. For compaction, a concrete cylinder (diameter 0.15 m, height 0.3 m, mass 12.0 kg) was used, and rolling was done 100 times for each layer. We took care not to make a weak point between the layers.

(c) After the wooden frame was removed, the lump of sediment was cut out. And a levee body was made with a top width of 0.05 m, a height of 0.15 m, and a slope angle of 30 degree. In order to prevent from overflow near the side wall of the flume in the stage of experiment, the surface elevation of levee top around its central axis was slightly lower than the other. In this paper, this portion is called "notch" which is lower by about 6 mm than the other portion of levee top.

(d) The profile of the levee before the experiment was measured by a set of the device consisting of an ultrasonic displacement sensor and a laser displacement sensor.

(e) Two ultrasonic water level gauges were set up above the water surface of river space. In addition, three cameras were also set up to take photograph as shown in Figure. 1.

(f) Water injection into a model river space was started. As the water level in the river space rises, the flow over the levee starts to occur near the center axis of the levee, and the flow on the top reaches the back shoulder. In this experiment, time was set to zero at this moment. At this stage, the water discharge injected in this space is 160 cm^3/s. In order to prevent sudden drop of water level due to the progress of levee collapse, the water injection rate is increased so that the water level in the space is kept constant. The upper limit is 500 cm^3/s, and if the flow rate over the levee exceeds this maximum value, the water level cannot be constant anymore, and it drops gradually. The experiment was finished when the erosion and collapse of levee progressed sufficiently and the water surface in the river space becomes much lower than the initial level. In Case 3, however, it took an extremely long time before levee collapse. Therefore, the experiment was finished when 6 hours had passed.

(g) Finally, the profile of the levee was measured in the same manner as that explained in (d).

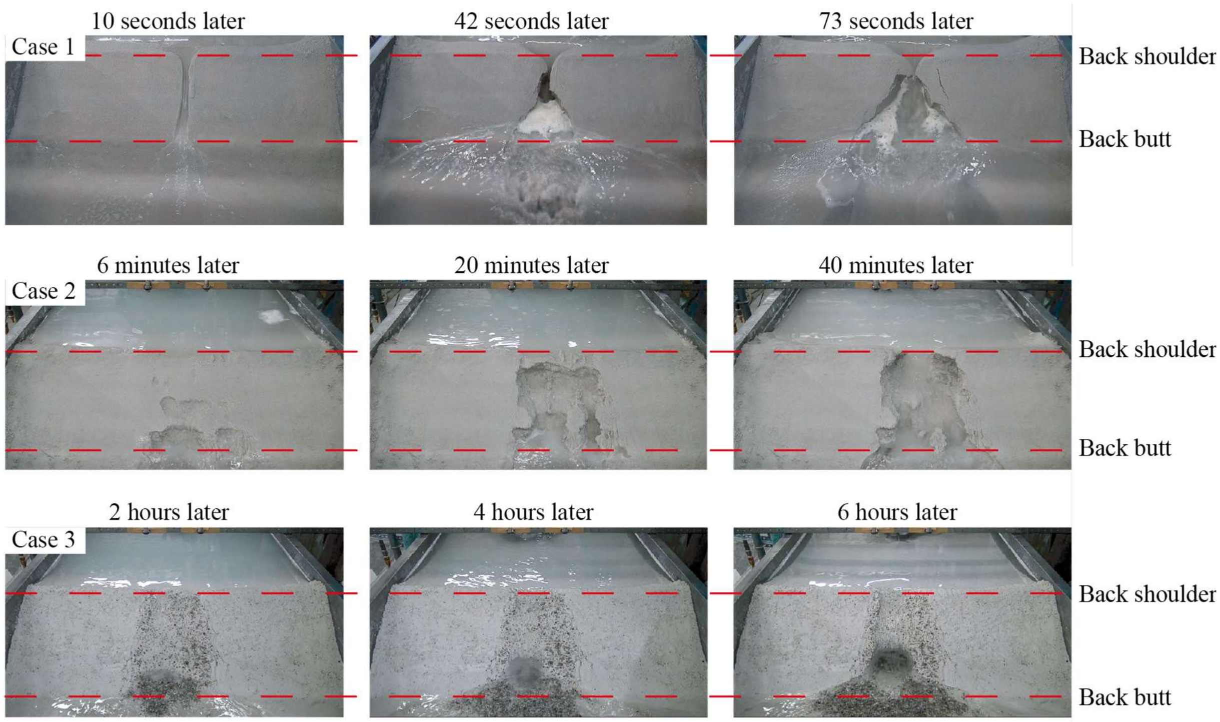

Photo 2. Breach process of model levee

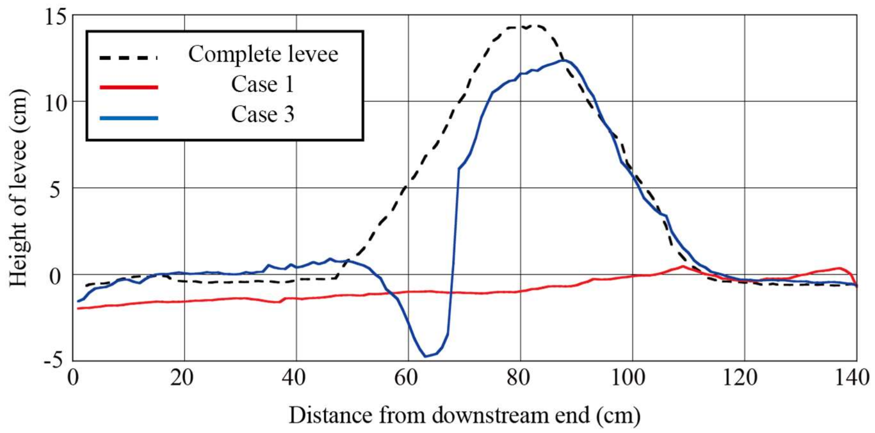

Figure 3. Terrain height of levee

3. COLLAPSE PROCESS OF MODEL LEVEE

In this section, the process of levee collapse is discussed. The content ratio of gravel or clay as well as sand in the levee is important parameter to be fixed in a series of experiments. Figure 2 shows a series of photographs in Case 1 (upper), Case 2 (middle), and Case 3(lower), from which we can recognize the process of levee collapse. Each is an image of the levee taken from an open air diagonally. The dotted red lines in Figure 2 represent the back shoulder and the back butt of levee. Figure 3 is the longitudinal profile of levee measured by laser placement sensor at the end of each experiment. In Table 1, the time required for levee collapse are listed under each condition. No collapse occurred in Case 3.

3.1 Collapse process of levee made only of sand

In Case 1, model levee is composed of sand only. After the beginning of the flow over the levee, the erosion initiates on the back slope and proceeds downward with forming a narrow channel. When the erosion reaches the foundation ground, lateral erosion becomes dominant, and the channel side wall starts to be eroded. As a result, the width of the channel increases rapidly. When this lateral erosion reaches the bottom of the levee, the sediment mass above it loses its support, and then cracking and collapsing is repeated, causing the channel mouth to be opened widely.

3.2 Effect of clay on the collapse process of levee

As is seen from the results of Case 2 where clay is contained in the levee material in addition to sand, the process becomes different from the above in Case 1. In this case, the erosion on the top edge and the back slope of levee has occurred hardly. Even at about 2 minutes from the beginning of the overflow, the erosion was still slight, and erosion occurred only near the back butt. Then, erosion progressed from back side to front slope of levee with a step-like topography being formed gradually. After that, when the erosion along the top reaches the front shoulder of levee, vertical erosion due to overflow becomes dominant, and the step disappears.

3.3 Effect of gravel on collapse process of levee

In Case 3, model levee was composed of the materials including gravel in addition to sand and clay. Erosion in such case started to occur on the back slope in a manner that sand and clay on the surface of levee were washed out by the running water, and then the exposed gravel moved down on the slope. The erosion on the levee surface was very slow and no stepwise erosion was observed. As time goes on, however, the erosion on back slope side toward the river space side proceeds slowly because remarkable local scour occurs near the back slope. Under these conditions, the levee collapse did not occur even at 6 hours from the beginning of the overflow.

3.4 Influence of clay on collapse process

The effects of clay on levee collapse process are discussed here by comparing the experimental results of Case 2 with that in Case 1. It is obvious that the erosion resistance of levee in Case 2 is much higher than the one in Case 1 due to the adhesiveness of clay. Furthermore, the erosion rate tends to be smaller as R_{cc} is larger, which results in significant time lag before collapse occurs. If this rate is too large, however, loss of stability and independence of levee becomes dominant.

3.5 Influence of gravel on the collapse process

The effects of gravel on the erosion process are discussed by comparing the results between Case 2 and Case 3. From the comparison, it was found that if the levee contains gravel in addition to clay and sand, the levee would be more difficult to break. This is because the interlock effect between the gravel particles. In this state, the gravel particles keep contact with each other and the gap among them is filled with clay and sand, resulting in a mechanically strong structure.

4. CONCLUSION

In this study, the levee composed only of sand and the levee containing clay and gravel in the sand were examined, focusing on the difference in erosion characteristics and the process of breach. Followings are the summary of this study.

(1) In the case of the model levee made only of sand, erosion proceeds vertically along the surface of the levee, and then lateral erosion and the levee collapse occurs for a short period of time. On the other hand, if the clay is contained by a certain ratio or more, the erosion proceeds in different way to form steps and pools on back side of levee.

(2) There is an appropriate volume ratio of gravel and clay to sand can exist to prevent from levee collapse. If the levee is composed of certain amount of clay and gravel in addition to sand, its erosion resistance can be improved significantly in comparison with the levee composed of sand only. This means that the mixture ratio is extremely important to make the levee be hard to collapse.

It is still a problem to clarify this ratio dynamically. We plan to continue our research and address many remaining issues.

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