Two large-scale test channels for overtopping and earthquakeflood compounded disasters

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Abstract

Extreme flooding is mainly to the result of climate change, but sometimes it is brought on levee breaches and a subsequent flood disaster. Most levee breaches are the result of overtopping. Furthermore, river levees are also sometimes damaged by compound disasters following an earthquake, flood, or tsunami. With this in mind, it is necessary to develop comprehensive reinforcement technologies for river levees against overflow, infiltrations, and earthquakes. In the present study, we introduced two types of large-scale test facilities: one was a large-scale open channel to examine the resistance of model levees against overtopping and infiltration. The other was a channel to evaluate compound disasters of earthquakes and floods or tsunamis. The former channel was 20 m long, 1.0 m wide, and 1.8 m high and used to evaluate the erosion process and stability of river levees with various reinforcements against overtopping and infiltration. The letter channel was used to conduct a model experiment for compound disasters due to an earthquake, flood, and/or tsunami using a new channel that was 33 m long, 0.60 m wide, and 1.0 m high. In this paper, we introduce the examples of these large-scale model experiment (LDR) is laid along the back slope of the levee using geogrid layers. The experiment's results suggest that LDR levees have a high resistance against overtopping and earthquakes.

1 Introduction

Extreme flooding is mainly due to climate change, but sometimes it is brought on by levee breaches and their subsequent flood disasters. As an example in Japan, a levee on the Kinugawa River collapsed in 2015 due to the heavy rains and flooding in the Kanto-Tohoku region. The water breached the levee, and several overflow points spread across a wide area (40 km²⁾ in Joso city, in the Ibaragi prefecture (see Nagumo et al., 2016). In Japan, overflow accounts for roughly 80% of factors that lead to levee breaches. The infiltration with water level higher designed H.W.L is also an important factor in levee breaches. Furthermore, compound disasters resulting from a flood and earthquake are concerning, as they can cause severe damage, especially in urban areas. With this in mind, it is necessary to develop comprehensive reinforcement technologies for river levees to protect against overflows, infiltrations, and earthquakes. For this reason, it is important to use test facilities where largescale levees can be used; this allows researchers to avoid the complexity of similarity law of model levees.

In the present study, we introduced two types of new large-scale test facilities: one (Channel 1) was a large-scale open channel to examine the resistance of model levees against overtopping and infiltration. The other (Channel 2) modeled the compound disaster of an earthquake followed by a flood or tsunami. Channel 1 was used to evaluate the erosion process and stability of river levees with various reinforcements against overtopping and infiltration. The levee height was set at 1 m in each condition. Channel 2 was used to conduct a model experiment for compound disaster due to earthquake, flood and tsunami.

Examples of the large-scale model experiments are shown in this paper. We also show the performance of a new type of levee in which LDR is laid along the back slope of the levee and introduced using geogrid layers (Kurakami et al., 2017).



Figure 1. Schematic view (a) and photograph (b) of the Channel 1

2 Overtopping tests in Channel 1

2.1 Outline of model tests

Figure 1 shows the schematic view and a photograph of Channel 1 used in the preset study. The open channel is 20 m long, 1.0 m wide, and 1.8 m high. The 1 m-high river levee was set in the middle of the channel, as shown in **Figure 1**. The front and back slopes of the levee had a ratio of 1:2. The width of the levee crest was 1.0 m. The thickness of the foundation below the levee was 0.30 m. **Figure 2** indicates the size distribution of Hokota sand, which was used as the levee's material. The median diameter D_{50} and ratio of fine material of Hokota sand were 0.22 mm and 8.4%, respectively. The optimum water content w_{opt} of Hokota sand is 13.5 %. The compaction degree D_c was set to 90%.

We set four reinforcement conditions: earthen levees with and without crest pavement, an armored levee with concrete panels covering the levee, and a new type of levee, referred to as an LDR levee, as shown in **Figure 3**. In the armored levee, concrete panels were laid on the surfaces of the front and back slopes of the levee. In the 2011 Great East Japan Earthquake, man armored-levee type seawalls collapsed due to the tsunami overtopping. To increase the resistance of armored levees against overtopping, we presented the LDR levee, in which the LDR is laid along the back slope of the levee with geogrid layers. To increase the above reinforcement, geogrid layers were introduced to connect the concrete panel with the drain layer and levee body.



Figure 2. Size distribution of levee materia

Overtopping tests were conducted for each reinforcement technique. In line with previous flood disasters, the overflow depth h was set as shown in **Figure 4**.



Figure 3. Schematic view of a new type of river levee, the LDR levee, presented by Kurakami et al. (2017)



Figure 4. Time series of overflow depth in the overtopping experiments

2.2 Summary of experimental results

To grasp the effect of the crest asphalt pavement against overflow erosion, **Figure 5** shows the time variations of the cross-sectional shapes in the earthen levees with and without crest pavement. The earthen levees without and with crest pavement collapsed at t = 2.5 min and 25 min, respectively (t: time from start of overflow). This shows that crest pavement plays a role in resisting overflow erosion.

Figure 6 shows the time series of residual rates for the cross-sectional area and the heights for all cases. The results revealed that the armored levee kept its initial shape until t = 60 min, indicating an increased residual due to the panels' presence. After t = 64 min, the scour protection at the toe of the back slope was outflowed, and the armored levee rapidly collapsed. In contrast, the residual rate in the LDR levee was almost 100%, because the concrete panels in the LDR levee did not



(b) Earthen levee with crest pavement

Figure 5. Temporal variations of the cross-sectional shapes in earthen levees without and with crest pavement.



Figure 6. Time series of the residual rates of the crosssectional areas and heights for all cases.

flow out. Thus, the LDR levee could maintain its initial height and cross-sectional shape for a long time (> 150 min).

Furthermore, the LDR levee prevented the erosion of the levee body, due to the laminar drain on its back slope, even after the gaps between surface panels exceeded 5 cm. Thus, we confirmed the validity of the LDR levee as a reinforcement technology against overflow erosion through the large-scale model tests. In the LDR levee, the levee's drain layer along the back slope appreciably reduced the seepage, compared to earthen levees. This means that the LDR levee can play a significant role as a reinforcement technology against infiltration, due to its drain layer.

- 3 Model tests in Channel 2 for compound disasters due to earthquake and flood
- 3.1 Outline of model tests



Figure 7. Schematic views of a new facility for model-levee tests for compound disasters of earthquake, flood, and tsunami (Upper: schematic view, lower: photograph).

Figure 7 shows the schematic view and photograph of Channel 2, which was used to simulate a compound disaster due to earthquake and tsunami. Channel 2 is composed of three parts: a channel for earthquakes, a connection, and a channel for flood and tsunami. The total length, width, and height of the channel is 33 m, 0.60 m, and 1.0 m, respectively. In the seismic experiment, the connection part is separated to the channels and the earthquake generator is set. This system can generate sine waves with a maximum acceleration of more than 1000 gal and period of 0.4–0.5 s. During the flood and tsunami experiments, the three channels are connected. The maximum discharge was about 0.15 m³/s in the channel.

3.2 Results

We conducted seismic and infiltration experiments to examine the fundamentals of seismic resistance of levees under infiltration and the effects of drain systems, such as LDR. The experiment's results showed that levee deformation, in the case of river water on the front slope of the levee, was significantly reduced because the river water took on a role like that of counterweight fill. The drain layer dissipated the excess pore water pressure and suppressed crest settlement, showing that the LDR levee has a high level of performance that can increase the resistance of the levee against seismic activity.

References

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