Experimental Studies on Landslide Dam Stability Under Surge Action

Peng Ming(✉) and Jiang Mingzi

Department of Geotechnical Engineering,
Tongji University, Shanghai 200092, China
pengming@tongji.edu.cn

Abstract. The rapid rise and fall of the water level in the upstream reservoir area of a landslide dam may trigger slope sliding into the reservoir, leading to huge surge wave. The stability of landslide dams under the action of landslide surge is seldom studied and of the target in this paper. Landslide dam model tests with the height of 80 cm and width of 317 cm were performed in a water flume with a full length of 42 m. Three sine waves with the maximal height of 5, 10 and 20 cm were produced in the upstream reservoir with water depth of 55 cm. It is found from the tests that the surge wave would cause erosion and sliding on the upstream slope. A steady and flat slope would remain when the wave height is low. The erosion became larger and the finally steady slope became flatter with the increase of the wave height. When the surge wave surpasses the dam crest, significant erosion would occur in the downstream slope, leading to overtopping failure. The pore water pressure periodically varied with the wave. The area far from the upstream slope has a delayed and weak response to the pore pressure of the wave.

Keywords: Wave flow flume · Landslide dam · Landslide surge

1 Introduction

In some areas where geological structure is active and extreme climate disasters occur frequently, it is easy to induce dammed lake. Due to the rapid rise of water level in the upstream reservoir area, a large number of landslides may be induced, which can easily cause large surge, and will cause serious damage to the dam. When the landslide surge acts on the landslide dam, it will bring serious threat to the life and property safety of the downstream people.

At present, the most model test of landslide dam is to study overflow in the natural state. There is a lot of research in this area. For example Zhang et al. [1] carried out a flume test for the different internal slope and material. Wang et al. [2] considered the influence of the upstream peak flow on the dam breach. The research on the stability of landslide dam under the action of landslide surge mainly contains the following aspects: Risley et al. [3] calculated the overtopping wave volume of Usio landslide dam in Pakistan. Xu et al. [4] studied the effect of landslide surge on the dam under the conditions of different landslide water entry area, landslide height and distance from the water entry point to the dam site. Lin et al. [5] established an ISPH model to simulate the process of landslide surge climbing over the dam.

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The existing research methods are mainly theoretical analysis and numerical analysis methods. Therefore, in order to better assess the impact of landslide surge on landslide dam stability, the corresponding model tests are needed. In this paper, the stability of landslide dams under the action of landslide surge is studied in wave flume model tests.

2 Experimental Design

2.1 Test Device

The experiment was carried out in the wave flume experiment system of Tongji University. The flume length is 42 m, width is 0.80 m, height is 1.25 m. The measurement system of pore water pressure consists of pore water pressure gauge and dynamic strain gauge. During the test, the deformation and displacement of the dam are monitored by high definition camera.

2.2 Dam Material

In this paper, the landslide dam model is formulated according to the particle size distribution curve of Donghekou landslide dam [6], as shown in Fig. 1. The particle size distribution of the dam material represents the particle distribution characteristics of the fine-grained landslide dam. The basic physical properties of dam material, as shown in Table 1. In the experiment, the method of stratified compaction is adopted and the thickness of each layer is 10 cm.

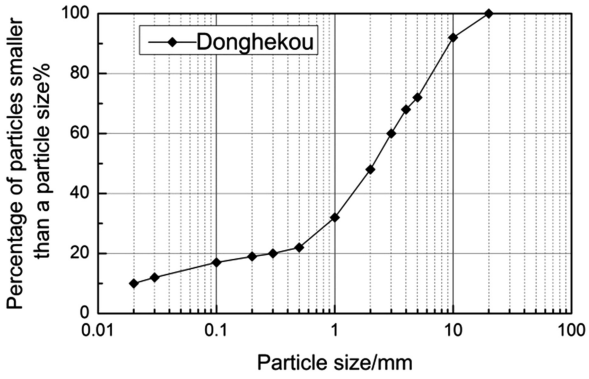


Fig. 1. Grain size distribution curve of Donghekou landslide dam

Table 1. Basic physical properties of dam material

Dry density	Minimum dry density	Maximum dry density	Compactness
1.78	1.44	2.05	0.642

2.3 Model Shape, Size and Layout of Test Equipment

In order to study the general law of stability of the landslide dam under the action of landslide surge, this paper does not choose a specific landslide dam as the prototype. According to the size and shape characteristics of the landslide dam, combined with the size limitation of the wave flow flume, the selected dam shape and size is shown in Fig. 2.

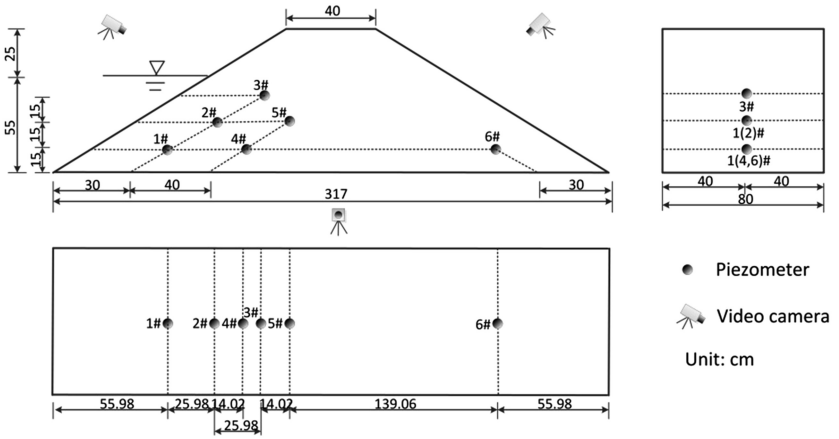


Fig. 2. Layout of instrument and equipment

In the test, 6 gauges are parallel to the upstream dam slope and are arranged in the central position of the dam along the width of the dam. In addition, in order to monitor the deformation and displacement of the dam during the test, three cameras are set up, as shown in Fig. 2.

2.4 Test Scenarios

Three scenarios were set up in the test. The upstream water level of the dam is 55 cm, and the wave period is set to 2 s. The wave heights are 5 cm, 10 cm and 20 cm respectively, as shown in Table 2. After each test scenario is completed, the dam is refilled and repeated the test steps.

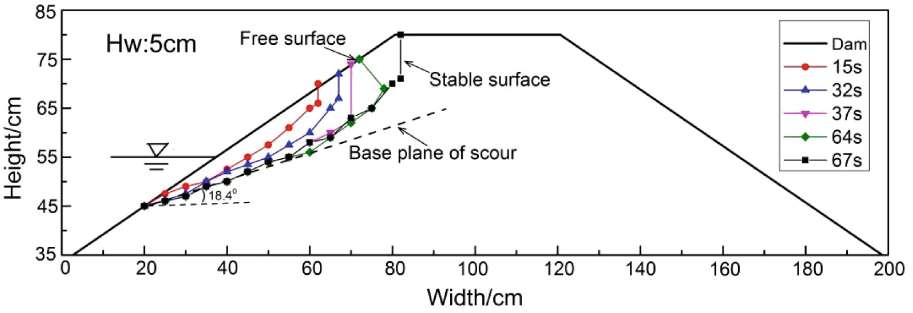
3 Experimental Results and Analysis

3.1 Erosion Characteristics

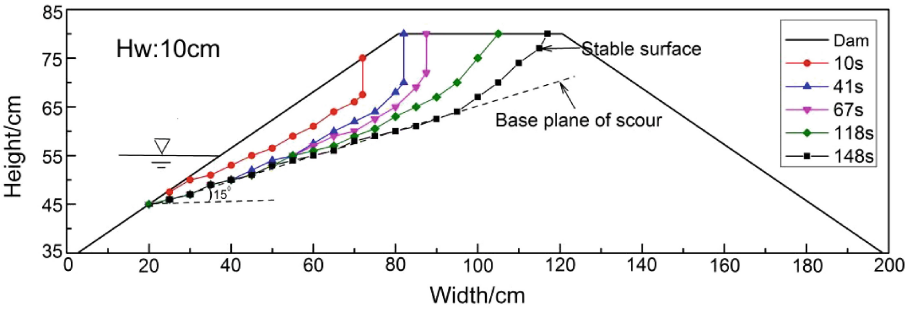
In scenario 1, the wave height is 5 cm (Hw:5 cm). The failure process of the dam under this scenario is shown in Figs. 3(a) and 4. After the wave starts, the waves scour the upstream dam slope and gradually forms a scour datum plane, as shown in the dashed line in Fig. 3(a). The subsequent scour processes are developed on the basis of this

Table 2. Test scenarios

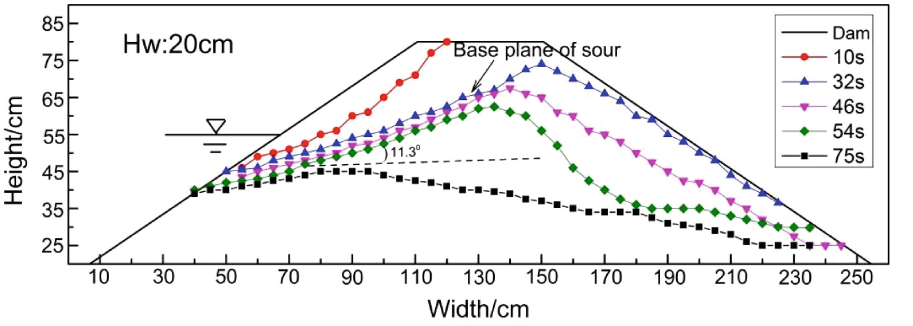
Scenario	Water depth (cm)	Wave height (cm)	Period (s)	Dam material	Wave form
1	55	5	2	Donghekou landslide dam	Regular wave
2		10			
3		20			



（a）Scenario 1



（b）Scenario 2



（c）Scenario 3

Fig. 3. Schematic diagram of dam failure

datum. In the process of wave scouring, the upstream dam slope will continue to suffer from local instability. Finally, as the wave climbing height is not enough to cause further scour of the dam, the upstream dam slope will form a stable scour surface and the process continues until wave making ends.

In scenario 2, the wave height is 10 cm (Hw:10 cm). The erosion process of wave to the dam is similar to the scenario 1, as shown in Figs. 3(b) and 4. In this scenario, the failure area of the dam is further increased, and finally a stable scour surface is also formed.

In scenario 3, the wave height is 20 cm (Hw:20 cm). Unlike the working scenario 1 and scenario 2, the waves not only will scour the upstream dam slope, but also climb over the dam crest, causing erosion of the dam crest and downstream dam slope. Then the dam began to rapidly burst. When the wave stop erosion, a stable erosion surface is formed or the dam breaks completely (see Figs. 3(b) and 4).

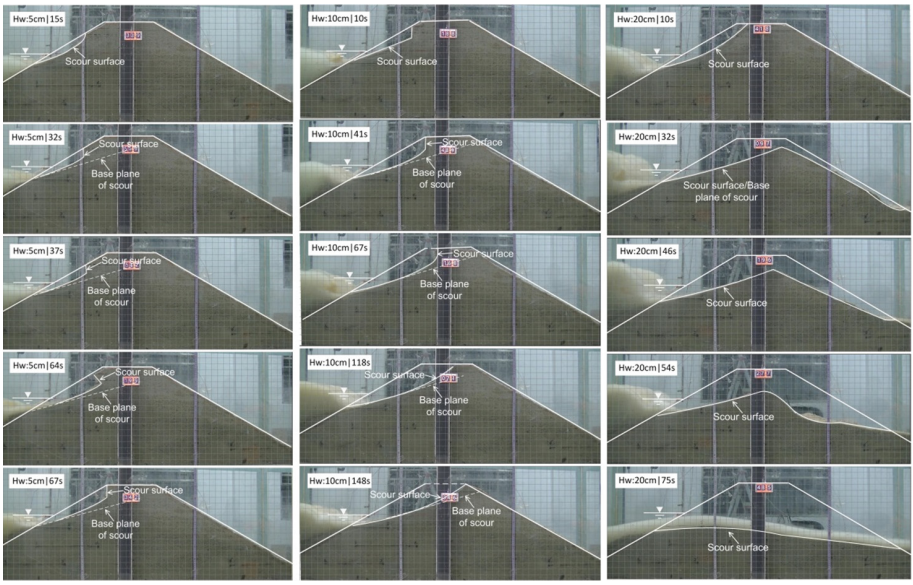
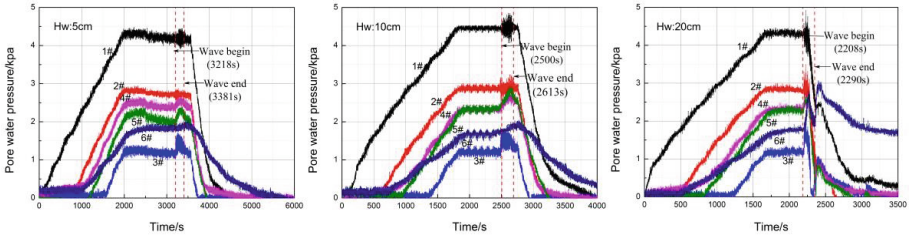


Fig. 4. The dam failure process

3.2 Pore Water Pressure Analysis

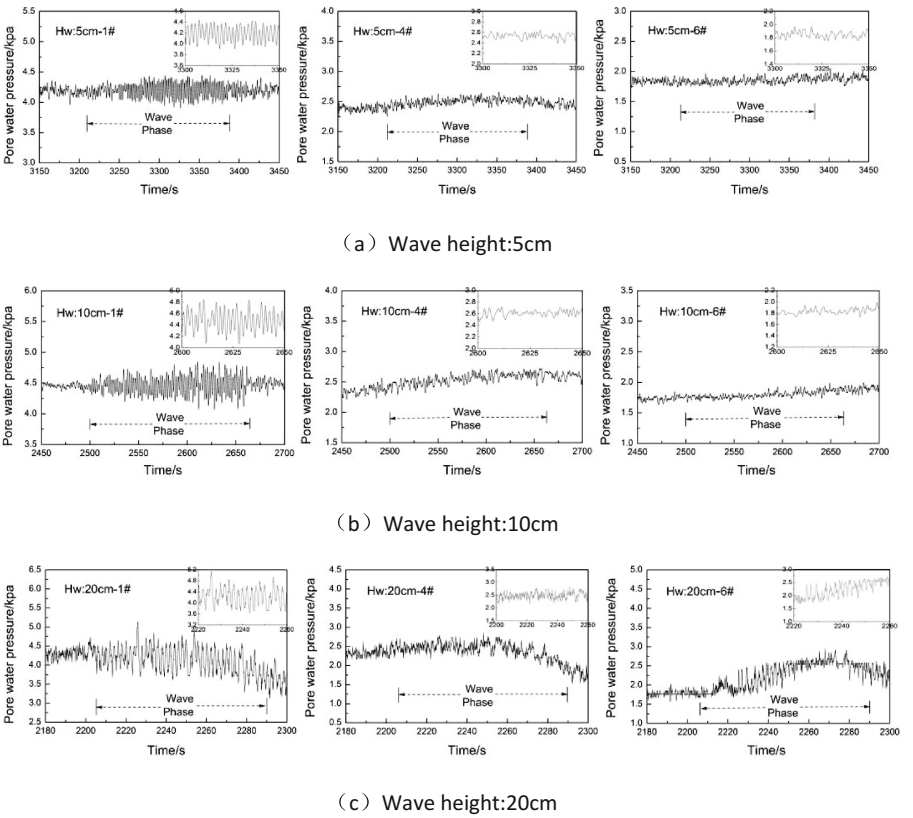
In scenario 1, the change of pore water pressure is shown in Figs. 5(a) and 6(a). In the water storage stage, the growth rate of 1-5# pore pressure is the same during the rising of water level and the growth rate of 6# pore water pressure is obviously smaller. In the static stage, the pore water pressure at each measuring point is relatively stable, and the pore pressure value is related to the location of each measuring point. By Fig. 6(a), it can be seen that in the wave making stage, the 1-3# pore pressure varies periodically with the wave, and the magnitude is basically the same as the height of wave. However, the pore pressure at 4-6# monitoring point has weak response to the wave. In the stage



（a） （b） （c）

Fig. 5. Pore water pressure response in the dam

of water releasing, the pore pressure at each measuring point of the dam decreases gradually. The decrease rate of pore pressure of 1-5# is the same, but the rate of 6# is obviously smaller, as shown in Fig. 5(a).



（a）Wave height:5cm

（b）Wave height:10cm

（c）Wave height:20cm

Fig. 6. Pore water pressure response in the wave making process

In scenario 2, the change of pore water pressure in dam is similar to that of scenario 1 in the process of water storage, static installation and drainage, as shown in Fig. 5(b). In the process of wave making, the amplitude of pore pressure in the dam increases further (see Fig. 6(b)).

In scenario 3, the variation law of pore water pressure in the dam is similar to the above two scenarios in the storage and static stage, as shown in Fig. 5(c). In the process of wave making, the amplitude of pore pressure in dam continues to increase. When the dam burst, the pore water pressure inside the dam would decline rapidly in the process of wave making (see Fig. 6(c)).

4 Conclusion

The stability of landslide dams under the action of landslide surge is studied in wave flume model tests with different wave heights. The following conclusions can be drawn.

The surge wave would cause erosion and sliding on the upstream slope. A steady and flat slope would remain when the wave height is low. The erosion became larger and the finally steady slope became flatter with the increase of the wave height. When the surge wave surpasses the dam crest, significant erosion would occur in the downstream slope, leading to overtopping failure.

The pore water pressure periodically varied with the wave and the magnitude is basically the same as the height of wave. The area far from the upstream slope has a delayed and weak response to the pore pressure of the wave. When the dam burst, the pore water pressure will decline rapidly.

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