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Model experimental study of landslides based on combined optical fiber transducer and different types of boreholes

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ABSTRACT

Using a model box for laboratory model experiments on a slope is one of the most effective and acceptable methods for studying the occurrence and development of landslides. However, there have been no studies involving model experiments in which different types of combined optical fiber transducer (COFT) materials are buried in boreholes with different sizes and forms. Moreover, there have been no previous reports on the mechanism of a landslide being determined using the COFT we designed. Based on our previous studies, we designed a new model experimental box (with an interior space size of 4.5 × 2 × 1.7 m). A sliding bed was constructed of brick, with sliding surfaces made by layering cement mortar and stainless steel plates. The friction coefficients of these sliding surfaces were 0.63 and 0.27, respectively. Three loading schemes were designed: a stack load, jack, and jack and stack load combination. A landslide model experiment with two types of boreholes (inclined and vertical) was designed, and two laboratory model experiments were successfully conducted under the same soil conditions. During the test, the model slopes were cut, the COFTs were broken, and the corresponding data were collected, thus verifying the accuracy of the established experimental model. The results showed that the COFT measurements of the load movement direction were identical to previous research results. The friction coefficient of the sliding surface was a critical factor for the imposed load. The jack and stack load combination is recommended for this type of experiment. An inclined borehole model with a small inclination angle is not recommended for use in the model experiment, and an appropriate COFT material and borehole size should be selected according to the actual circumstances. The four stages of the land-sliding mechanism (compaction, gradual sliding, slightly faster sliding, and rapid sliding) could be determined from the tests.

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1. Introduction

The main research methods for landslides include field surveying and monitoring (Zhou et al., 2009), laboratory and outdoor model experiments (Jia et al., 2009; Guglielmi and Cappa, 2010), and numerical simulation analysis (Chemenda et al., 2009). Comparatively, field surveys are the most accurate method, but if the researchers must travel a long distance to reach the survey site, such surveys are difficult to conduct and are an inconvenient means to collect data. Field surveys require significant amounts of labor, material resources, and time. Numerical simulation analyses of landslides are simple to perform. Simulations require the least labor, material resources, and time, but simplified models need to be established, and many ideal parameters are supposed. These result in some differences from the actual slope, which may lead to incorrect results. A laboratory model experiment can simulate field rock and earth mass parameters fairly well. The implementation is less difficult, and it requires less labor, materials, and cost than afield survey. The experimental data are easy to collect, and the experiment results are reliable. Hence, model experiments are widely used in landslide research by researchers, engineers, and technicians (Li et al., 2008; Yan et al., 2010; Zhu et al., 2015).

A model box is indispensable in conducting a model experiment, and various studies have been conducted using them. However, many of these model boxes are small: 1.5 × 0.25 × 1 m (Li et al., 2016), 3 × 2 × 1.5 m (Li et al., 2008), or 3 × 1.5 × 1.5 m (Zhu et al., 2015). In one case, the cross-section of the test pile was only 2.5 × 3.5 cm (Li et al., 2016). The volumes of experimental soil used with two other models were also small (Li et al., 2008; Zhu et al., 2015). However, a relatively larger model box is better when conducting this type of experiment. Thus, a large-scale model box should be utilized in the model tests.

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A decade or two ago, optical fiber technology was introduced into landslide monitoring, including optical time domain reflectometry (OTDR) (Tang et al., 2009; Zhu et al., 2011), Brillouin optical time domain reflectometry (BOTDR) (Wang et al., 2009), Brillouin optical time domain analysis (BOTDA) (Zeni et al., 2015), and the fiber Bragg grating(FBG) (Li et al., 2008; Hong et al., 2016) and FBG combined with inclinometers (Pei et al., 2012). Optical fibers have a strong resistance to electromagnetic interference and can be used to realize long-distance and real-time detection, giving this technology broad application prospects.

The landslide monitoring method based on boreholes is one of the most effective methods to monitor landslides. Clinometers (Sargent, 2004), time domain reflectometry (TDR) technology based on coaxial cables (Dennis et al., 2006), and the combined optical fiber transducer (COFT) monitoring method (Zhu et al., 2011, 2014a, 2014b) are all monitoring methods based on boreholes. Vertical and inclined layouts are used for boreholes based on conditions of the site. A vertical borehole is nearly vertical to the sliding surface, while an inclined borehole has an inclination angle between the borehole and the sliding surface. Model experiments with a self-designed model box were conducted to verify the accuracy correctness of the model box and its corresponding loading and detection devices, compare the effectiveness of these two types of boreholes and the friction coefficients in the model tests, and study the landslide mechanism using the COFT that we designed. Soil samples with the same attributes were used in these experiments. Meanwhile, we conducted a contrast test study by burying COFTs constructed with different materials in boreholes with different sizes, to investigate the monitoring effectiveness of the COFT in slope models.

2. Test model design

2.1. Sliding bed and sliding surface

To ensure that the boreholes and sliding surfaces were in the form of inclined or vertical boreholes, we built a landslide model with an artificial sliding bed and sliding surface. An arc-shaped curve was used for the sliding surface, based on the slice method. The sliding bed was constructed with MU20 shale bricks and M5 cement mortar. Cement mortar with a ratio of 1:1 (cement to sand) was used on the surface of the sliding bed to form a sliding surface by plastering, smoothing, and press polishing.

The sliding surfaces were treated with different methods according to experimental requirements to compare the test results of different sliding surfaces. To decrease the friction coefficient, we used 1.5-mm-thick stainless steel plates to pave the sliding surface made of cement mortar. The friction coefficients were tested and the values were 0.63 and 0.27, the mortar and steel plates, respectively.

2.2. Model box design

A. Determination of size of model box. During the occurrence and development processes of a landslide, the model soil mass can deform or cut off the monitoring transducer within a borehole, providing better monitoring effectiveness. The soil mass in front (or on top) of the borehole should be as massive as possible to increase its load on the borehole. Thus, it is beneficial to increase the size of the experimental model box. To satisfy the experimental requirements, the height of the model box was made as small as possible to decrease the quantity of soil and make the implementation of the experiment easier.

To ensure that sliding could occur on the slope of the model box, but exert as little influence as possible, 30 cm and 50 cm spaces were reserved in the model box, in front of and behind the sliding surface, respectively, at the slope crest and slope toe.

To set multiple boreholes simultaneously, the net length, width, and height of the model box we designed were 4.5 m, 2 m, and 1.7 m, respectively. Considering the reuse of the model experiment box, we purchased a 100 × 100 × 4 mm galvanized steel pipe for its main frame, and a 100 × 50 × 4 mm galvanized steel pipe for its other component.

B. Design of reaction frame with safety rail. A 1 m tall reaction frame was designed and fabricated after calculation to ensure the safety of the stack load and the convenience of jack loading. The space between the pillars of the reaction frame was deduced by adding another pillar. The reaction frame could be used as a rail to ensure the safety of the stack load and dowel steel used to disperse the jack load. The cladding of model box was 8 + 8 double-layer tempered glass.

A photograph of the model box is shown in Fig. 1.

2.3. Loading system

In accordance with the loading schemes, the loading system was composed of bearing plates (no. 1 and no. 2), stack blocks, jacks, and reaction trusses, as shown in Fig. 2.

2.3.1. Bearing plates

To ensure that the stack block load was uniformly transferred to the model soil mass and prevent the stack blocks from piercing this mass, a 1 cm-thick steel plate (the no. 1 bearing plate) was laid down between the soil mass and stack blocks.

To ensure that the jack load could be uniformly transferred to the stack blocks, a 1 cm-thick steel plate (the no. 2 bearing plate), was laid down between the stack blocks and jacks. Because the local stress of the jack stand was concentrated on the no. 2 bearing plate, 50 × 50 × 4 mm steel pipes were laid onto this bearing plate, and a piece of 25 × 10 × 1 cm reinforced steel plate was soldered onto each jack stand. The no. 1 and no. 2 bearing plates had a width of 1 m, and lengths of 193 cm and 196 cm, respectively.

2.3.2. Stack blocks

The height of a stack block was calculated to be 52 cm based on the height of the reaction frame, and minus the height of two bearing plates, jacks, and reaction trusses. Based on the size of a bearing plate, the width of the stack blocks was calculated to be 50 cm, which allowed them to be placed on the bearing plates side by side in two rows. Based on the width of the model box, the thicknesses of the stack blocks were 20 cm and 18 cm, and we used 18 of the former and 4 of the latter. These dimensions made the blocks convenient to transport and easy to load.

The stack blocks were pre-fabricated using C40 concrete. According to the structural requirements, steel bars were placed in the stack blocks to ensure long-term use, while lifting rings were set on the outside to facilitate transport.

2.3.3. Reaction trusses

Because a reaction truss could be made of steel pipes and the load imposed by the jack was large and concentrated, a reaction truss was

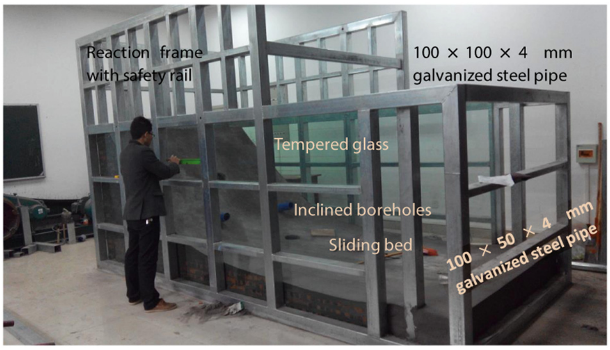

Fig. 1. Photo of the model box.

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