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Experimental study on the migration of fine grains with seepage in a soil layer

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ABSTRACT: A device for modeling the erosion and re-deposition of fine grains in the soil layer by artificial rainfall was designed. Through experiments, the effects of rainfall intensity and soil thickness on the migration of fine grains were investigated. The changes in grain size distribution with soil thickness under rainfall induced seepage were observed. It is shown that fine grains move downwards in the soil layer with rainfall induced seepage and re-deposit at the lower or middle part of the soil layer to form a thin layer of reduced permeability. Accordingly high pore water pressure forms, and the effective stress and the strength of the soil layer decrease, which can initiate debris flow or landslide.

1 INTRODUCTION

Landslides and debris flows, distributed broadly in nature, restrict the economic development and threaten the safety of towns, villages dams et al. A mass of debris flows and landslides were triggered by rainfall after the May 12th Wenchuan earthquake in Sichuan in 2008. Therefore, the forecast of landslides and debris flows is an important mission, especially in the earthquake affected area.

Although many studies on the forecast of landslides and debris flows have been carried out (Cui et al., 2000, Aleotro 2004), there is still no precise method of prediction which can be applied generally because of the limited understanding of the initiation mechanism. Experiments and in-situ measurements have been used in studying the initiation of debris flows in previous studies (Cui 1992, Iverson et al., 1997, Cui et al., 2009), while numerical simulations were used in a few studies (Lu et al., 2006, Lu & Cui 2010, Lu et al., 2010, 2011).

Seepage and surface flow during a rainstorm obviously changes the distribution of pore pressure and the mechanical properties of a slope. These changes alter the stresses and can cause deformation of a slope. Conversely, stress and deformation within the slope can affect the seepage process altering the hydraulic properties, such as the porosity, permeability and water storage capacity. Hence, the seepage and stress-deformation problems are strongly linked (Zhang et al., 2005, Wu & Zhang 2009). Duration is an important variable with which to forecast the initiation of debris flows, particularly for a real-time monitoring system (Chen et al., 2005).

It has been observed that the fine grains can migrate from the top to the lower part of the soil layer with the rainfall induced seepage, which can cause the blockage of pores and the increase of pore water pressure and the decrease in effective stress. As a result, a debris flow or landslide may occur (Jiao et al., 2005).

In order to study this phenomenon, a series experiments were carried out. The erosion and re-deposition of fine grains induced by seepage were studied. The effects of rainfall intensity and thickness of the soil layer were also investigated.

2 APPARATUS AND THE PREPARATION OF EXPERIMENTS

The soil was put in an organic glass cylinder with an inner diameter of 10 cm, an outer diameter of 15 cm and a height of 45 cm. A screen with the pore diameter 2 mm was glued to the bottom of the cylinder to allow the drainage of soil grains with diameters less than 2 mm. An apparatus of artificial rainfall was built consisting a water box, a flow-meter and a sprayer and could simulate a set of rainfall intensities. A container was placed below the cylinder to collect the drained water and eroded fine grains (Fig. 1).

The soil used in the experiments was sampled from the Weijia Gully in Beichuan, Sichuan Province, China. The soil was first dried and then wetted with a given water content. The thicknesses of the soil layer used in the experiment were 7 cm, 12 cm, 17 cm, 22 cm, 27 cm. The data including flow and time was recorded once the water drained from the bottom of the cylinder. When the drainage duration reached 240 s, the container was removed and the masses of the drained water and eroded fine grains were measured.

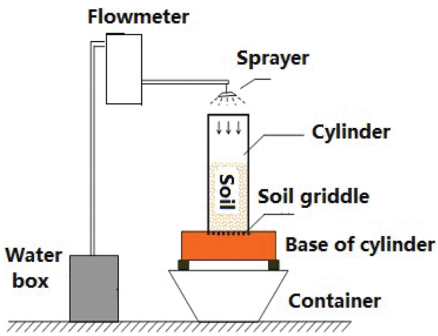

Figure 1. Sketch of experiment set-up.

3 RESULTS AND ANALYSIS

Figure 2 shows the changes in eroded fine grains mass with changing with soil thickness. For the same rainfall intensity, the eroded fine grains mass increases linearly with soil thickness. The increase rate with thickness is small when the rainfall intensity is small. This trend increases with rainfall intensity. Figure 3 shows the changes in the eroded soil-to-water mass ratio (SWMR, This ratio indicates the mass ratio between the eroded grains and the drained water which can reflects the eroded power of seepage) with the soil thickness. It can be seen that the SWMR increases with soil thickness in a linear relation under the same rainfall intensity. The eroded grains in unit drained water is more under the lowest rainfall intensity of 1.01×10^{-5}m/s than under rain intensity of 1.65×10^{-5}m/s and 2.38×10^{-5}m/s, Under the same soil thickness, the drained water increases fast with rainfall because the pores are not block by fine grains while the eroded fine grains increases slowly under small rainfall. However, the drained water increases slowly with rainfall maybe due to the blockage by fine grains. Thus the SWMR decreases first and then increases with rainfall under the same soil thickness.

Figure 4 shows the changes of eroded fine grains mass with rainfall intensity under the same soil thickness. The eroded fine grains mass has a positive exponential relation with rainfall intensity regardless of soil thickness.. This result is consistent with the characteristics of the initiation duration of debris flows with rainfall intensity (Ye 2011). In Ye's experiments, the duration from the beginning of rainfall to initiation (initiation time) of debris flow decreases exponentially with the rainfall intensity. Part of the reason is that the eroded fine grains block the pores fast with rainfall intensity to shorten the initiation time of debris flow Figure 5 shows the changes of the SWMR with rainfall intensity. The SWMR decreases first and then increases with the increasing rainfall intensity

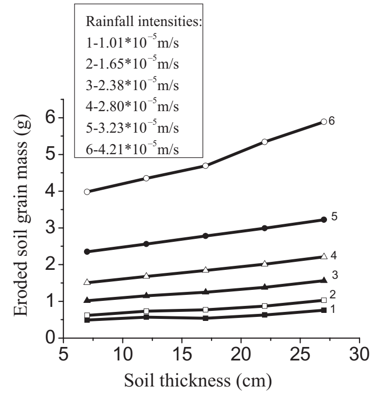

Figure 2. Eroded soil grain mass with soil thickness and rainfall intensity.

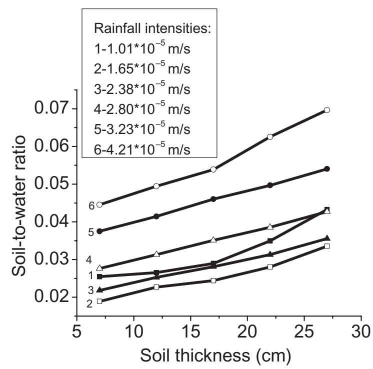

Figure 3. Soil -to- water ratio with soil thickness and rainfall intensity.

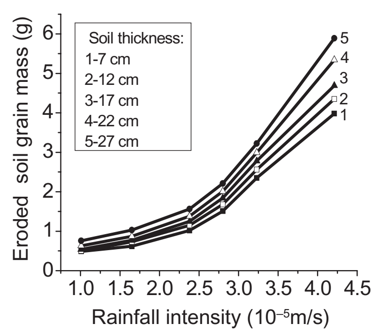

Figure 4. Eroded fine grain mass versus rainfall intensity and soil thickness.

under the same soil thickness. The reason is that the increase rate of the drained water is almost ta constant while the increase rate of the eroded fine grains increases slowly under small rainfall intensity and fast under large rainfall intensity.

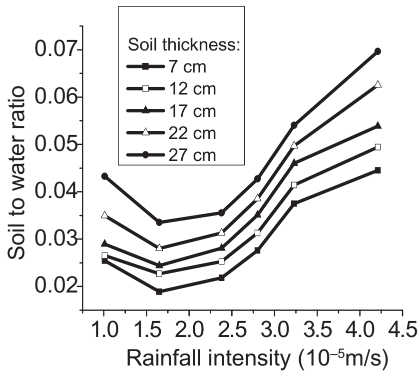

Figure 5. Soil to water ratio versus rainfall intensity and soil thickness.

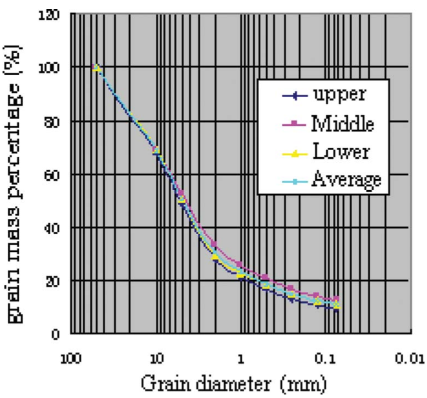

Figure 6. Grain size distribution in the upper, middle and lower parts of the soil sample.

4 GRAIN SIZE ANALYSIS

After the experiments, some of the fine grains were removed from the upper, middle and lower parts of the sample to conduct a grain size analysis.

The grain size in the middle was slightly larger than either the upper part or lower part in Fig. 6. This indicates that the fine grains transport downwards with seepage and re-deposit at the middle. At the lower part, some fine grains are taken away by seepage to the container. For an example, if the grains with grain diameters less than 0.25 mm are taken as t fine grains, the contents of fine grains at the upper part, middle part and lower part are 13.19%, 16.67% and 14.68%, respectively.

5 CONCLUSIONS

The main conclusions are as follows:

For the same rainfall intensity, the eroded fine soil mass increases with the soil thickness in a linear relation. The increase rate of eroded fine grains mass in unit drained water with thickness is small when the rainfall intensity is low.

Under the same soil thickness, the eroded finesoil grains mass increases with rainfall intensity and the increase rate rises also with the increase of rainfall intensity.

The content of fine grains at the middle is a little larger than either at the upper part or at the lower part. That means more grains are re-deposited at the middle to block the pores and decrease the porosity. Thus the permeability is the smallest at the middle, which may cause the block of pore water flow to increase the pore pressure and the decrease of the strength at the middle, As a result, a sliding surface is easy to form to excite landslide or debris flow.

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