AN EXPERIMANTAL STUDY OF THE IMPACT SLIDING PROCESS OF DONGHEKOU ROCKSLIDE-FRAGMENT FLOW TRIGGERED BY GREAT WENCHUAN EARTHQUAKE

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ABSTRACT

Donghekou rockslide, a typical rapid and long run-out rockslide located in Qingchuan County triggered by the 2008 Great Wenchuan earthquake, by which more than 780 people were killed. After the earthquake, we investigated this rockslide and collected representative valley deposits for tests. By using the advanced DPRI ring shear apparatus, a series of ring shear tests had been carried out to study the impact sliding process of Donghekou rockslide and significant conclusions were drawn. The test results showed that when the earthquake occurred, if avalanche could be taken place and the sliding mass could slide downward, the physical and mechanical property of the valley deposits on sliding route, especially the degree of saturation, played an important role for the further development of rapid and long run-out rockslide. When the valley deposits was dried, only a small displacement (0.005 m) was generated, which couldn't form a rapid and long run-out rockslide; while when the valley deposits was partially saturated or fully saturated, a large displacement (0.58 m and 0.82 m during 60 s, respectively) could be generated and a high velocity could be reached for the sliding mass, which made it possible for the generation of rapid and long run-out rockslide-fragment flow.

Key Words: Great Wenchuan earthquake, Rapid and long run-out rockslide, Ring shear test, Impact sliding process, Degree of saturation, Valley deposits

INTRODUCTION

On May 12, 2008, the Wenchuan earthquake (Ms=8.0; Epicenter located at 31.0°N, 103.4°E) with a focal depth of 14.0 km occurred in the Longmenshan tectonic belt in Sichuan Province, China. It caused more than 15,000 geo-hazards in the form of rockslides, rock-falls and fragment flows, and resulting in approximately 20,000 people were killed.

Regarding studies of earthquake-induced landslides, quite a few research reports or papers have been published by experts using data from events found all over the world (Shreve, 1968; Keefer, 1984; Wang, 1989; Hu, 1995; Wang, 1999; Papadopoulos and Plessa, 2000; Sassa, 2004; Cheng, *et al.*, 2007; *et al.*). After the great Wenchuan earthquake, a large

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number of researchers have visited the disaster area to investigate the geo-hazards, and various research publication have been written (Yin, *et al.*, 2009; Huang, 2009; Sun, *et al.*, 2009; Hu, *et al.*,2009; *et al.*).

Based on our long-term field investigations on many rapid and long run-out rockslides triggered by the 2008 great Wenchuan earthquake, it is found that most of the rockslides have a complex impact sliding process. In order to analyze this dynamic process, the Donghekou rockslide-fragment flow is presented as an example in this paper, and its impact sliding process is here analyzed with the help of ring shear testing apparatus.

GEOLOGICAL SETTING

The Donghekou rockslide-fragment flow presented in Figure 1, located in Donghekou village, Qingchuan County, Sichuan, is a typical rapid, long run-out, compound rockslide with the height difference between the toe and main scarp of 700 m, a sliding distance of more than 2400 m, and a volume of 10 million m^3. After the long run-out sliding occurred, it then transformed into a fragment flow, which scoured the banks of the Hongshihe River and the Xiasihe River successively, and formed two rockslide dams consisting of loose fragment and large rocks, which blocked the flows of the two rivers. In addition, this rockslide-fragment flow buried 7 villages, including, Donghekou (notably, the Donghekou Elementary School), Houyuanli, and Honghaudi villages (and others) resulting in a total of 780 people killed.

Fig. 1 General view of the Donghekou rockslide-fragment flow

Rocks of the Cambrian System and two groups of Sinian System outcrop in the source area are shown in Figure 2. We can see that the slide mass of the Donghekou rockslide-fragment flow is mainly composed of dolomite limestone and siliceous limestone of Sinian system, together with carbon slate and phyllite of Cambrian.

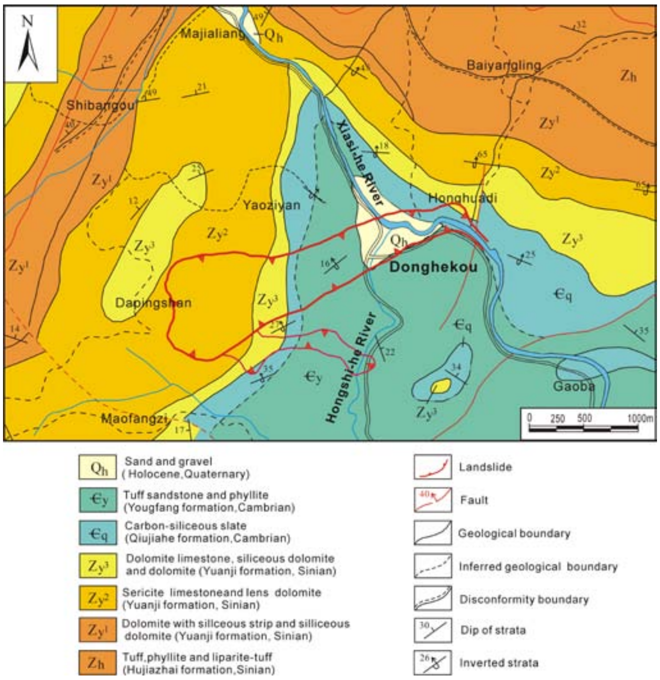

Fig. 2 Geological map of the Donghekou rockslide-fragment flow

RING SHEAR TESTING PROCEDURE

Ring shear testing apparatus

The impact sliding process of Donghekou rockslide-fragment flow is simulated by using the ring shear testing apparatus in the DPRI Landslide laboratory of Kyoto University, Japan. Figure 3 shows the newest type DPRI-7 within the DPRI ring-shear family, with the inner diamter of 27 cm, the outer diameter of 35 cm, the maximum height of sample of 11.5 cm, the shear area of 389.56 cm^2, the maximun normal stress of 500 kPa and the maximum shear speed of 300cm/s.


Fig.3 Ring shear testing apparatus DPRI-7 (Kyoto University, Japan)

Sample setting

The samples can be formed by means of both moist placement and dry deposition (Ishihara 1993), depending on test purposes. Generally, the dry deposition method was most commonly used. The overdried sample was allowed to fall into the shear box freely by layers. In order to generate a normally consolidated state, the layers were not tamped during the deposition process (Sassa, *et al.*, 2004).

Sample saturation and saturation degree checking

In most cases, samples must be partially saturated or fully saturated before test. Therefore, the samples were saturated by using the carbon dioxide and de-aired water. After a sample was packed in ring shear box, CO_2 was percolated through it to expel the air from the sample pores as slowly as possible. Usually, this process took 4–12 h. After hours of percolation of CO_2, de-aired water was infiltrated into the sample little by little. The degree of saturation was checked by using a pore-pressure parameter B_D, which was proposed by Sassa (1988), and is formulated as:

$$B_D = \Delta u / \Delta \sigma \quad (1)$$

where Δu and $\Delta \sigma$ are increments of pore water pressure and normal stress, respectively.

Sample consolidation and loading

To simulate the nature state of slope, samples taken from the rockslide sites must be consolidated before the test in most cases. Usually, the initial shear stress due to the weight of the soil mass above the sliding surface was applied step by step to reproduce an initial stress state same as field conditions. And then, the additional true loading based on the impact sliding process could be applied onto the sample.

IMPACT SLIDING PROCESS OF DONGHEKOU ROCKSLIDE-FRAGMENT FLOW

Simulation test for impact sliding process

In order to analyze the impact sliding process of Donghekou rockslide triggered by great Wenchuan earthquake, firstly, the initial stress condition must be set based on the longitudinal section of the Donghekou rockslide shown in Figure 4. Secondly, the real input wave of the impact sliding process was computed and used as the initial seismic wave according to Figure 5.

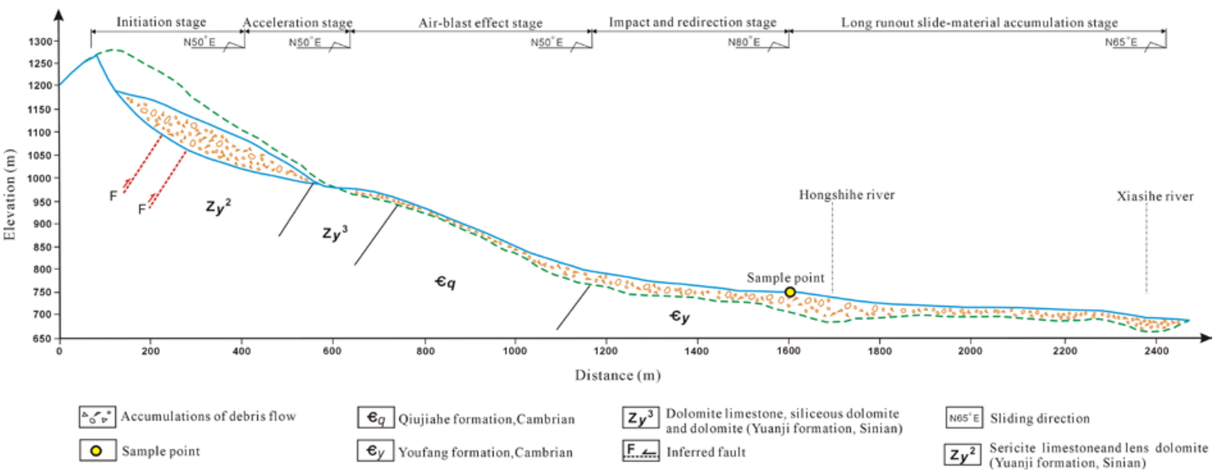

Fig. 4 Longitudinal section of the Donghekou rockslide-fragment flow

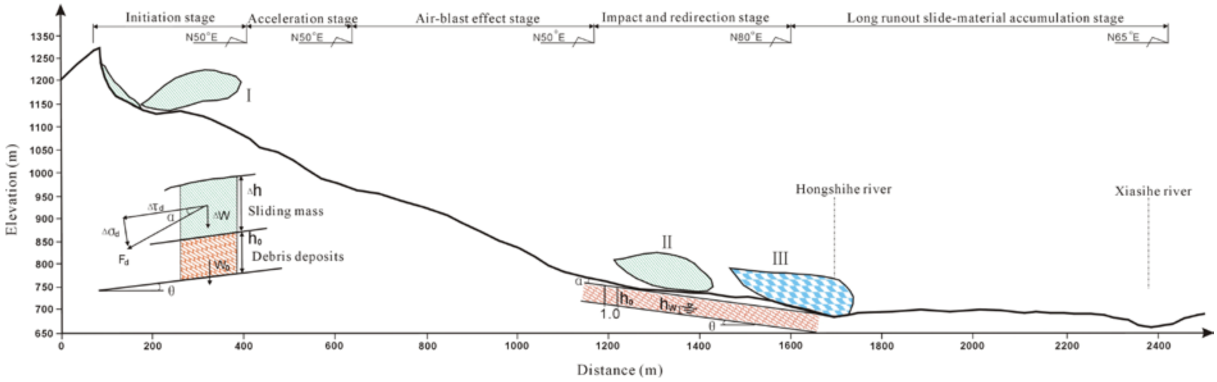

Fig. 5 Impact sliding process of Donghekou rockslide-fragment flow

Figure 5 indicates that the impact sliding process of Donghekou rockslide-fragment flow can be classified into three stages, here identified as initial stage Ⅰ, impact stage Ⅱ and sliding stage Ⅲ. Let us consider a column of unit width, which is a part of the debris deposit. At stge Ⅰ, the weight of the column was W_0. But when the sliding mass rode on to the fragment deposit (II) with a certain velocity, it will apply dynamic loading on the column. Here, we assume that the applied stress on the torrent deposits was as the sum of the static stress, ΔW, and the impact stress, F_d, working in the direction of motion of the sliding mass. In addition, θ is the slope angle, and α is the angle of thrust between the slope and the torrent bed. By analyzing the stresses state of the above three stages, the normal stress, shear stress and pore pressure at different stages were formulated as follows:

(1) Initial stage Ⅰ:

$$\begin{cases}\sigma_0 = \gamma_{sat} h_W \cos^2\theta + \gamma(h_0 - h_W)\cos^2\theta \\ \tau_0 = [\gamma(h_0 - h_W) + (\gamma_{sat} - \gamma_W)h_W]\sin\theta\cos\theta \\ \mu_0 = \gamma_W h_W \cos^2\theta\end{cases} \tag{2}$$

where σ_0, τ_0 and μ_0 are the initial normal stress, shear stress and pore pressure at stage Ⅰ; γ_{sat} and γ are the saturation bulk density and average bulk density of sliding mass; γ_W are the bulk density of water.

(2) Impact stage Ⅱ:

$$\begin{cases}\Delta\sigma_d = \gamma\Delta h \sin(\alpha - \theta)\cos\theta \\ \Delta\tau_d = \gamma\Delta h \cos(\alpha - \theta)\cos\theta\end{cases} \tag{3}$$

where $\Delta\sigma_d$ and $\Delta\tau_d$ are the normal stress and shear stress of stage Ⅱ, respectively.

(3) Sliding stage Ⅲ:

$$\begin{cases}\sigma_f = r[(h_0 - h_W) + \Delta h]\cos^2\theta + \gamma_{sat} h_W \cos^2\theta \\ \tau_f = \gamma[(h_0 - h_W) + \Delta h]\sin\theta\cos\theta + (\gamma_{sat} - \gamma_W)h_W \sin\theta\cos\theta\end{cases} \tag{4}$$

where σ_f and τ_f are the normal stress and shear stress of stage Ⅲ, respectively.

Based on the above formulas, the input wave of the impace sliding precess of Donghekou rockslide are given in Figure 6. And the endurance period is 60 s.

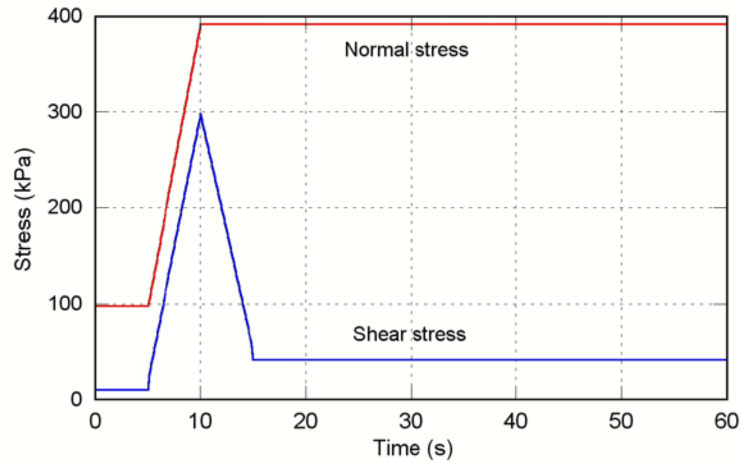

Fig.6 Input wave for impact sliding process of Donghekou rockslide-fragment flow

Analysis on the simulation test results

During the simulation test, three kinds of samples with different saturation degree were used so as to analyze the influence of saturation degree on the impact sliding process, e.g., the dried sample, the partially saturated sample and the fully saturated sample. The corresponding results of the above three kinds of samples were given in Figure 7, Figure 8 and Figure 9, respectively.

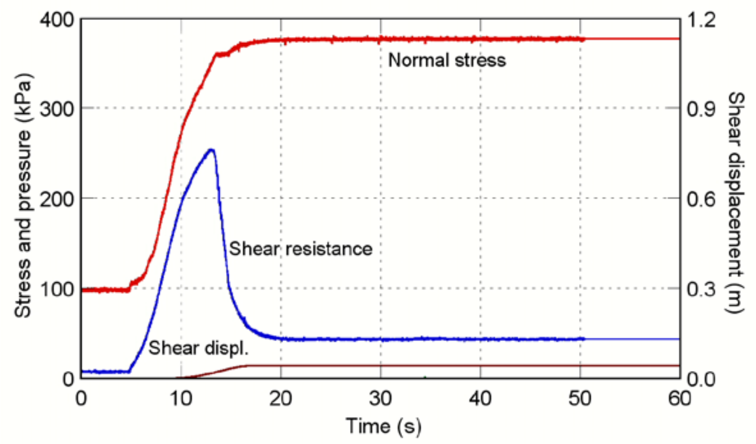

Fig. 7 Result of the impact sliding process of Donghekou rockslide-fragment flow (dried sample)

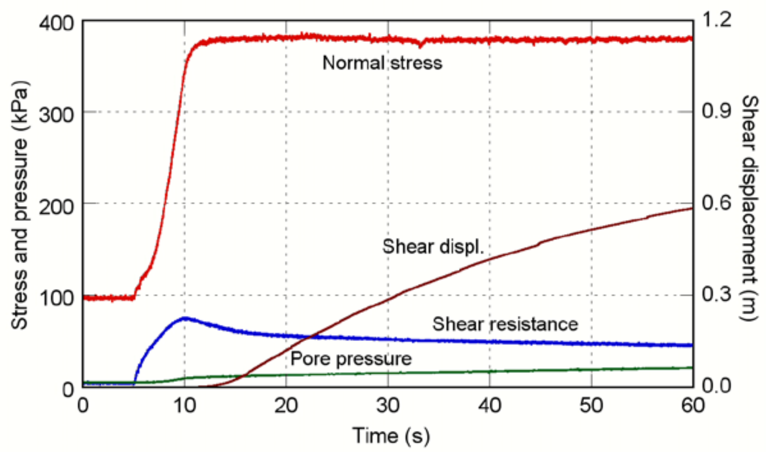

Fig. 8 Result of the impact sliding process of Donghekou rockslide-fragment flow (partialy saturated sample)

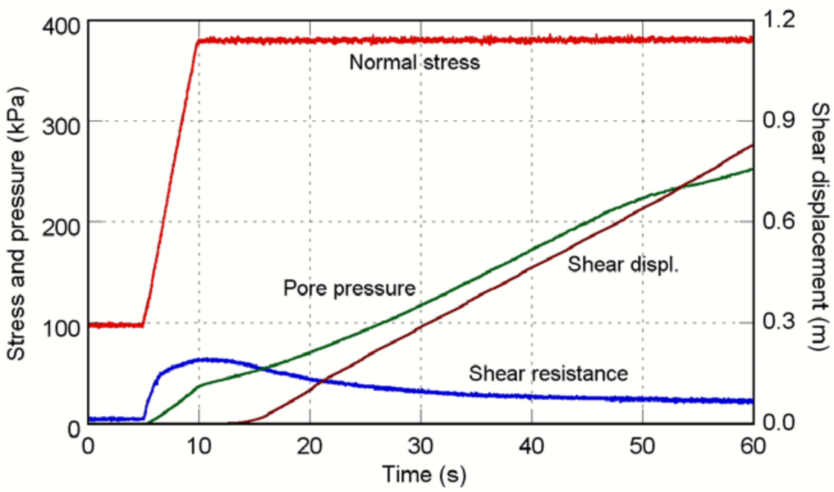

Fig. 9 Result of the impact sliding process of Donghekou rockslide-fragment flow (fully saturated sample)

From the impact sliding process results, we can see that when the sliding mass impacted on the valley deposits, different consequences could be obtained from different samples. When the valley deposits was dried, only a small shear displacement (0.005 m) was generated, which couldn't form a rapid and long run-out rockslide; while the valley deposits was partially saturated, a large displacement (0.58 m and 0.82 m during 60 s, respectively) could be generated and a high velocity of the sliding mass could be also obtained, consequently, it was made possible for the generation of rapid and long run-out rockslide-fragment flow.

CONCLUSIONS

This paper presents preliminary studies on the impact sliding process of Donghekou rockslides-fragment flow triggered by the great 2008 Wenchuan earthquake. It caused more than 15,000 geo-hazards in the form of rockslides, rock-falls and fragment flows causing approximately 20,000 people in total were killed by earthquake-related hazards. Based on our long-term field investigations on the long run-out rockslides triggered by the Wenchuan earthquake, and experimental study on impact sliding process of the Donghekou rockslide-fragment flow, it can be found that when the earthquake occurred, if avalanche or rockfall could take place and the sliding mass could slide downward, then the degree of saturation of valley deposits located along the sliding path will play a significant role for the further development of rapid and long run-out rockslide. As for the Donghekou rockslide-fragment flow, the partially saturated and fully saturated valley deposits distributed around the Hongshihe river and Xiasihe river played an important role for the rapid and long run-out process during the great Wenchuan earthquake.

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