J. SE Asian Appl. Geol., Sep–Dec 2010, Vol. 2(3), pp. 208–216

THE MECHANISM OF INITIATION AND MOTION OF THE RAPID AND LONG RUNOUT LANDSLIDES TRIGGERED BY THE 2008 WENCHUAN EARTHQUAKE

Wang, F.W.*, Sun, P., Cheng, Q.G., and Fukuoka, H.

Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto 611-0011, Japan

Abstract

The 2008 Wenchuan earthquake triggered many rapid and long runout landslides, which made great loss of property and human lives directly. It is very important to understand the mechanism of initiation and motion of the rapid and long runout landslides. In this paper, field investigations on some typical landslides are introduced at first, and then the ring shear tests for simulating the initiation and motion of the Donghekou landslide are presented in details. The real seismic wave monitored in Shifang station was applied in the simulation test for the landslide initiation, while three different conditions of water content (dry, partially saturated, and fully saturated) were applied for the samples in the simulation tests to simulate landslide motion. It was found that the valley water and groundwater played a key role in the long runout and rapid landslide motion process during the great earthquake. This makes the difference for where landslide occurred but stopped soon and where landslides moved for long distance with high speed and killed many people. For the purpose of disaster mitigation, we strongly suggest that:(a) Avoid locating village in the landslide motion path, because the same event will occur in the future; (b) Avoid locating village and people on the landslide, because the landslide will deform easily with the seismic activity; (c) The attention should also be paid for landslide and debris flow during the reconstruction process for disaster mitigation in long period.

Keywords: *Wenchuan Earthquake, rapid and long runout landslides, ring shear tests, initiation, motion*

1 Introduction

The 2008 Wenchuan earthquake caused heavy damages in Sichuan Province and the nearby areas in China. According to the official statistics (as of 6 July 2008), the earthquake caused 69,197 death, and 18,340 missing. Among them, about one third was caused by landslides directly and indirectly. As the typical examples, the rapid and long runout Wangjiayan landslides caused the devastating damages in old town of Beichuan county town, the Donghekou landslide in Qingchuan County and the Jiufeng-cun landslide in Pengzhou City that killed all of the people and destroyed all of the villages in their traveling paths. Almost nobody survived the rapid and long runout landslides. Thus, understanding the mechanism of the initiation and motion of the rapid and long runout landslides is extremely important for the disaster mitigation for the next seismic activity cycle in the land-use planning. In this presentation, the field investigation results for this purpose are introduced at first, and then the experimental results with ring-shear apparatus to simulate landslide initiation and motion are presented. Finally, some suggestions

*Corresponding author: F.W. WANG, Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto 611-0011, Japan. E-mail: wangfw@landslide.dpri.kyoto-u.ac.jp

are made to the local people for land-use in the reconstruction process.

2 Field investigation results on some typical landslides

2.1 Rockfall occurred in Hongyan Resort Village

Hongyan Resort Village in Qingcheng-Houshan is located on an old landslide. Because the slope was relatively gentler than nearby area, large scale development was conducted and a large resort village was formed here. During the Wenchuan earthquake, rockfalls occurred at the roadside, killed about 40 people, and totally cut the transportation (Figure 1). From the field observation, the road was built along the erosion path of a torrent which passed through the old landslide (or we can call it as old landslide dam). Moreover, the buildings in this village were almost heavily damaged and no building can be used further. From this site, it is very clear that old landslide (especially those moved for long distance like this one in Hongyan Resort Village) is very fragile to earthquake and easy to displace when it is affected by large earthquake.

Figure 1: The rockfall occurred in Hongyan Resort Village, in an old landslide dam.

2.2 Rock sliding – rock flow in Jiufeng-cun Village

In Jiufeng-cun Village, rock sliding occurred at the source area at first and turned into rock flow in the sliding down process because of the topography of water collecting of the source area and distribution of many loose debris along the flowing path (Figure 2). From the old map before the earthquake, it can be estimated that a similar slope failure had occurred previously and the event this time is just a repeat of the previous event, hence it will occur again at the same valley in the future.

Figure 3: The rock sliding – debris flow in Donghekou Village. The flowing path was considered fully saturated.

2.3 Rock sliding – debris flow in Donghekou Village

A large scale rock sliding occurred in the back mountain at Donghekou Village because of the earthquake and moved down as a debris flow when the sliding mass entered the valley bottom and where the deposit was estimated to be in a fully saturated state, based on the photo showing the village before the earthquake and the post-earthquake investigation (Figure 3). Soil samples were taken from the site and simulation tests on the initiation and motion mechanism on this landslide were conducted; the results are presented in the following section.

2.4 Wangjiayan earth fall – sliding and Jingjiashan rockslide in Beichuan county town

The damages caused by landslides triggered by the Wenchuan earthquake in Beichuan County town are the most severe ones in the whole dis-

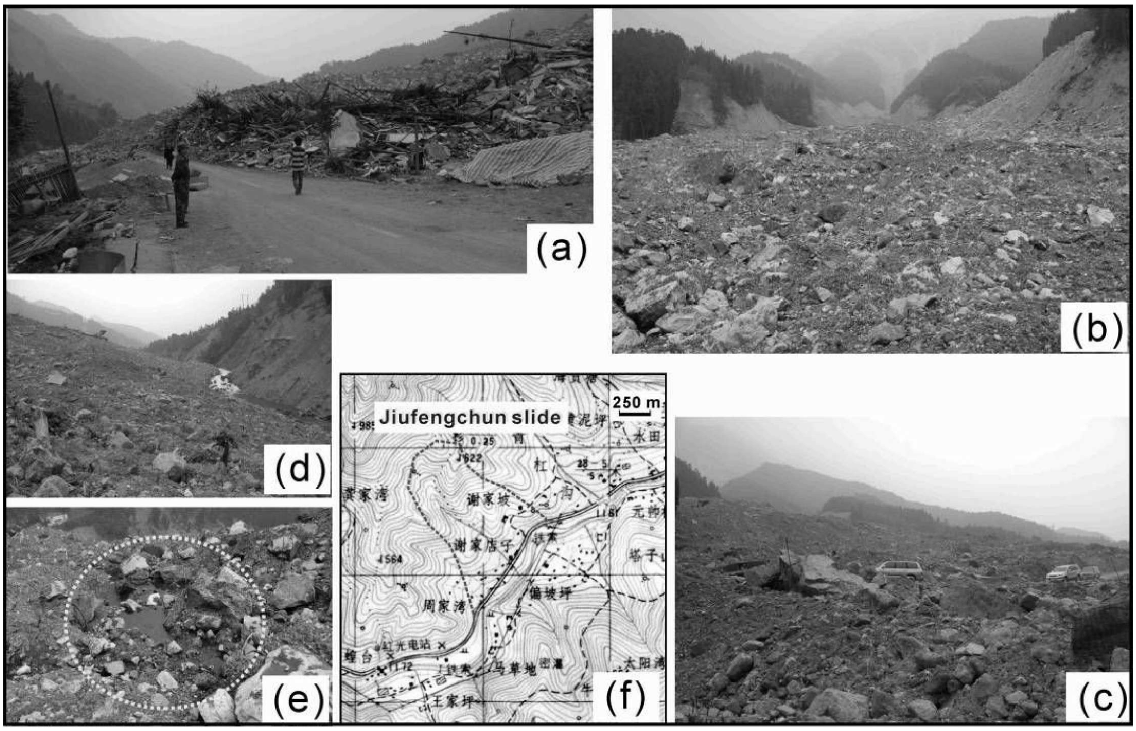

Figure 2: The rock sliding-rock flow in Jiufeng-cun Village. (a) Toe part, (b) Flowing path, (c) Oblique view, (d) Dammed river, (e) water in the sliding mass, (f) Old map showing a valley located along the flowing path

aster (Figure 4). At Wangjiayan, earth fall occurred in the weathered shale and sandstone, and it became to a long runout and rapid landslide at the toe of the slope. This landslide destroyed the old town and caused 1600 deaths. The shallow groundwater table and the low permeability of the sliding mass are considered to have played key roles in the landslide motion. While the Jingjiashan rockslide occurred in dolomite/limestone, and also because the displaced rock mass was almost dry, it posed and stopped at about 25 degrees. The Maoba Senior High School was destroyed and about 400 students and teachers were killed, because the school was located too near the toe of the slope, and the seismic fault just passed by this site.

3 Simulation tests for the initiation and motion mechanism of the Donghekou slide as a case study

Using the undrained ring shear apparatus developed in Kyoto University, Japan, two types of simulation tests were conducted. They are: (a) Simulation test to clarify the initiation mechanism of landslide triggered by the Wenchuan earthquake; (b) Test to simulate the moment when the failed sliding mass loaded onto the valley deposits, and to clarify the motion mechanism for long runout and high speed.

3.1 The simulation test for landslide triggered by the real seismic wave

In this test, the initial stress condition was set according to the longitudinal section of the Donghekou landslide (Figures 5-7). The real wave of the Wenchuan earthquake monitored at Bajiao Town in Shifang City by Seismic Monitoring Network, China Earthquake Administration was used. Through transforming the three components of the seismic wave to two components along the sliding surface (increment of shear stress) and perpendicular to the sliding surface (increment of normal stress), the input signals were formed (Figure 8) (Wang et al. 2000) and loaded to the sample (sample A from

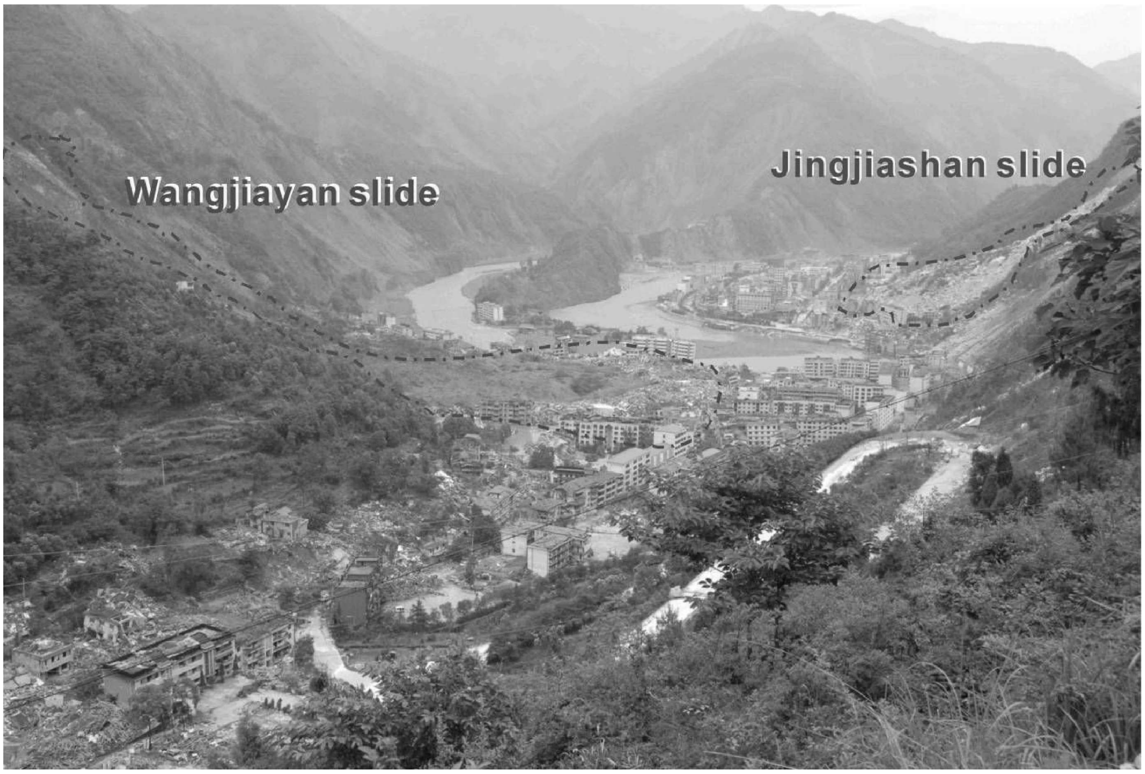

Figure 4: Wangjiayan earth fall-sliding (left) and Jingjiashan rockfall (right) in Beichuan county town. The Wangjiayan landslide killed 1600 persons and the Jingjiashan landslide killed 400 persons

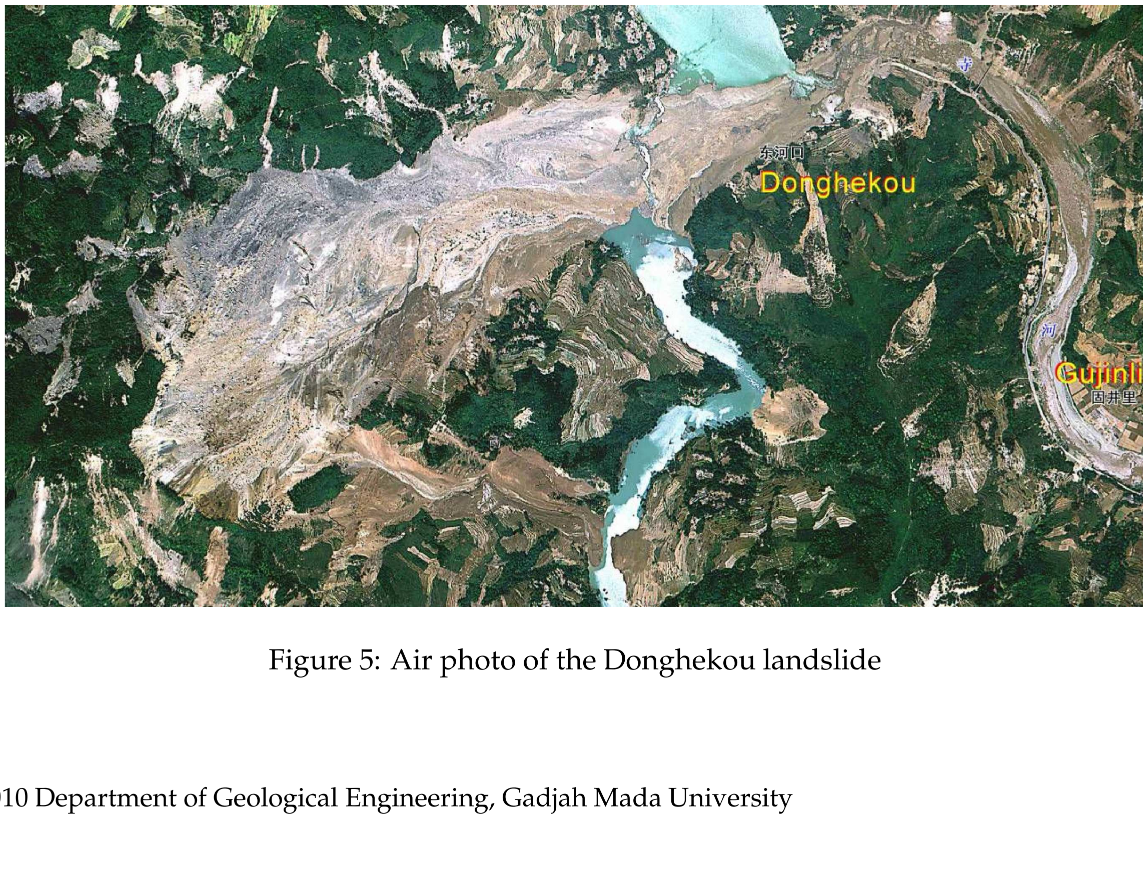

Figure 5: Air photo of the Donghekou landslide

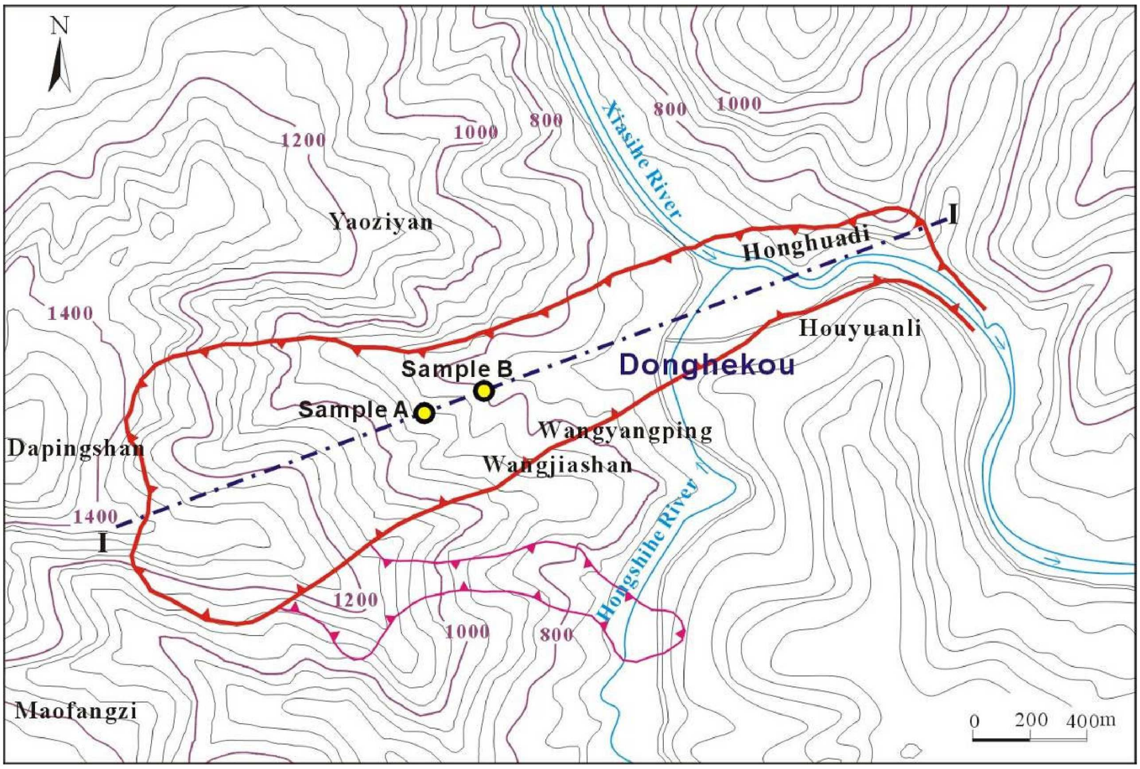

Figure 6: Map of the Donghekou landslide

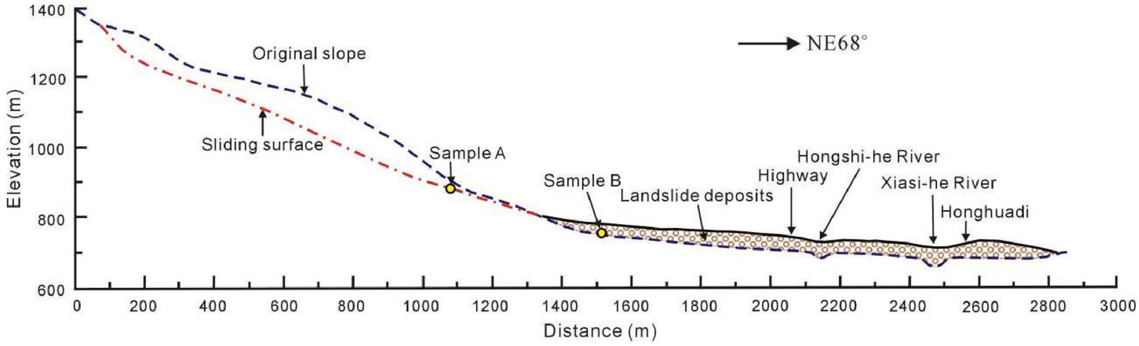

Figure 7: Longitudinal section of the Donghekou landslide

the source area of the Donghekou slide) taken from the Donghekou landslide.

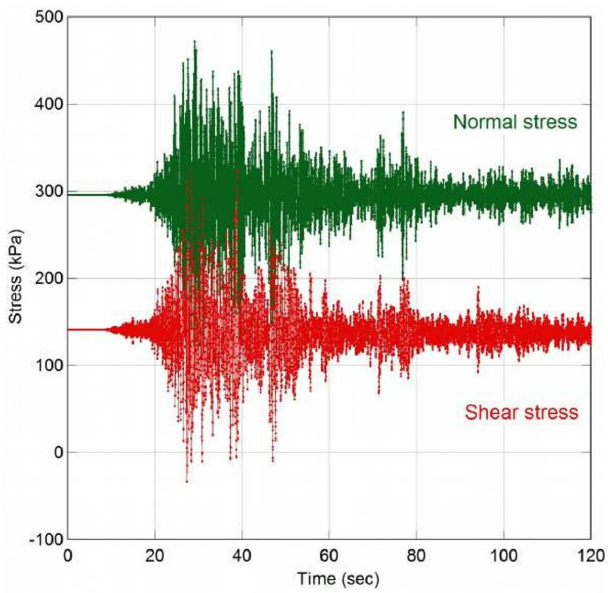

Figure 8: Real seismic wave, which was recorded by China Administration of Earthquake, was transferred to the input signal for the simulation test.

Figure 9 is the whole series data for the geo-simulation test on the Donghekou slide. While, Fig.10 is the zoom-up of the first period of the data from 18 to 30 seconds. From the two figures, it can be seen that the sample failed at about 10 seconds (20 second at the Figs.9-10) from the beginning of the earthquake (10 second in Figuger 9), and the shear displacement accelerated at about 25 seconds. At the same time (from 20 seconds), the pore-water pressure shows a rapid increasing, and reached the same value with the normal stress at about 45 seconds. It means a fully liquefaction. Corresponding to the rapid increasing of the pore-water pressure, the shear resistance decreased rapidly, and reached a very low value about 15 kPa. At the end of the seismic loading, the shear displacement reached about 35 m with high speed (the maximum speed of the apparatus at the selected gear).

After the undrained shearing for 35 m, the sample in the shear box were taken out, and the grain size distributions were analyzed (Figure 11). Comparing with the original sample, it is obvious that grain crushing occurred in the

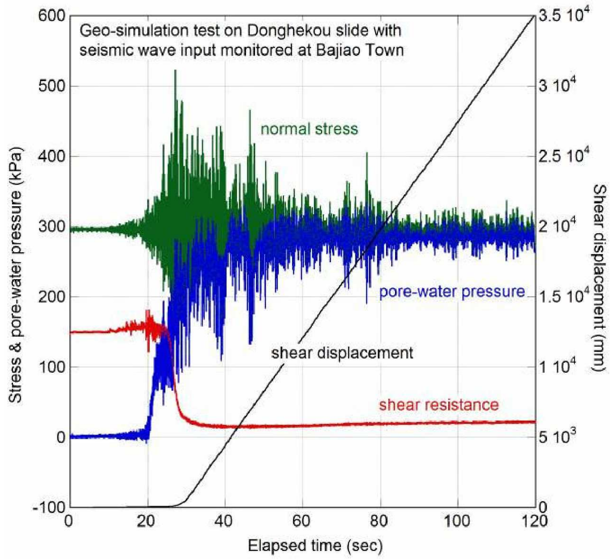

Figure 9: Geo-simulation test results of the Donghekou landslide with real seismic wave.

whole samples, and those at the shear zone is finer. It is evident that grain crushing can occurred at undrained condition and it may contribute to the liquefaction of the soil during shearing.

3.2 The simulation test to show the process when the failed sliding mass loaded on the valley deposit

In this series test, three kinds of condition for the valley deposit were considered. They are (i) day condition, (ii) unsaturated, and (iii) fully saturated. Sample B was used in this series tests. Figures 12 are the results for the three cases. When the failed sliding mass fell down to the valley deposits in dry condition (case i), only very limited shear displacement occured, whereas when the valley deposit is fully saturated (case iii), large distance and high speed motion occurred. The high pore-water pressure was measured, and the shear resistance was very small (about 45 kPa). This should be a possible reason for the long runout motion for more than 2 km of the Donghekou landslide. Figure 13 shows the total stress path and effective stress path of the test with fully saturated soil sample. The apparent friction angle (the inclination of the line connecting the end of TSP and the original point) is only 5.4 degree, it means

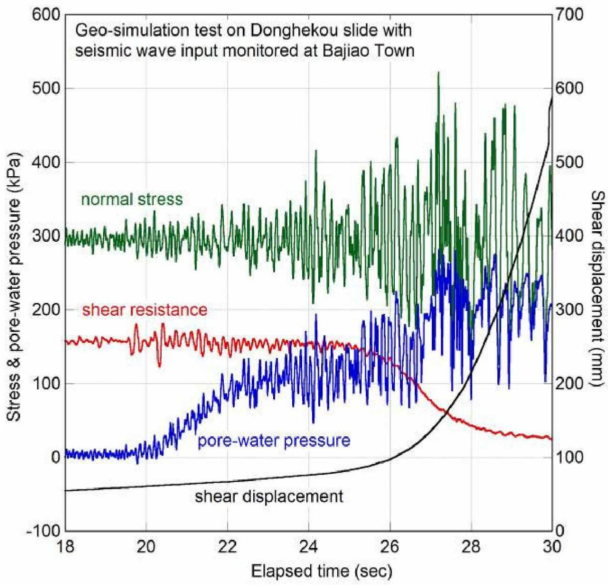

Figure 10: Zoom-up of the Geo-simulation test on the Donghekou slide.

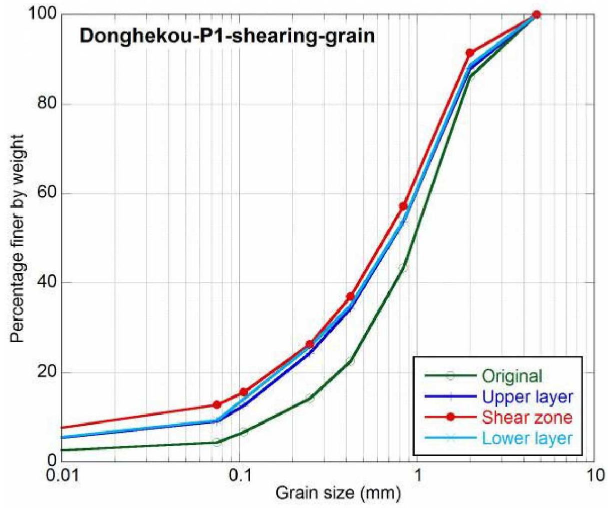

Figure 11: Grain size distribution of the source area sample from Donghekou slide. The original sample, soils from upper layer of the shear box, lower layer of the shear box, and shear zone are shown.

the landslide can keep moving until a position where the angle to the source area smaller than this value.

Actually, the angle from the toe of the Donghekou landslide and the source area is about 11 degree. Considering the energy dissipation caused by hitting each other, some parts may not be in fully saturated condition, and so on, this result is quite accepted to explain the actual situation. This test shows that the existence of the water is a very important factor for the rapid and long traveling motion.

4 Conclusion and suggestion for landuse in the reconstruction process

Through field investigation on the long runout landslides triggered by the Wenchuan earthquake, and experimental study on the Donghekou landslide, it is found that the valley water and groundwater played a key role in the long runout and rapid landslide motion process during the great earthquake. This makes the difference for where landslide occurred but stopped soon and where landslides moved for long distance with high speed and killed many people.

For the purpose of disaster mitigation, we strongly suggest that:

1. Avoid locating village in the landslide motion path, because the same event will occur in the future;
2. Avoid locating village and people on the landslide, because the landslide will deform easily with the seismic activity;
3. The attention should also be paid for landslide and debris flow during the reconstruction process for disaster mitigation in long period. We found that some new villages were located in debris flow prone area such as the Qian-tribe minority village in Beichuan shown in Figure 14.

Acknowledgement

The field investigation and sampling was partially supported by Chinese State Key fundamental Research Program project (2008 CB425802, representative: P. Cui). The first author acknowledges financial support from MEXT of Japan (No. 18403003, representative: F.W. Wang) for the first two investigations in the disaster area caused by the 2008 Sichuan earthquake. On 26 July to 3 August 2008, he made a third investigation with financial support from a scientific research fund for the

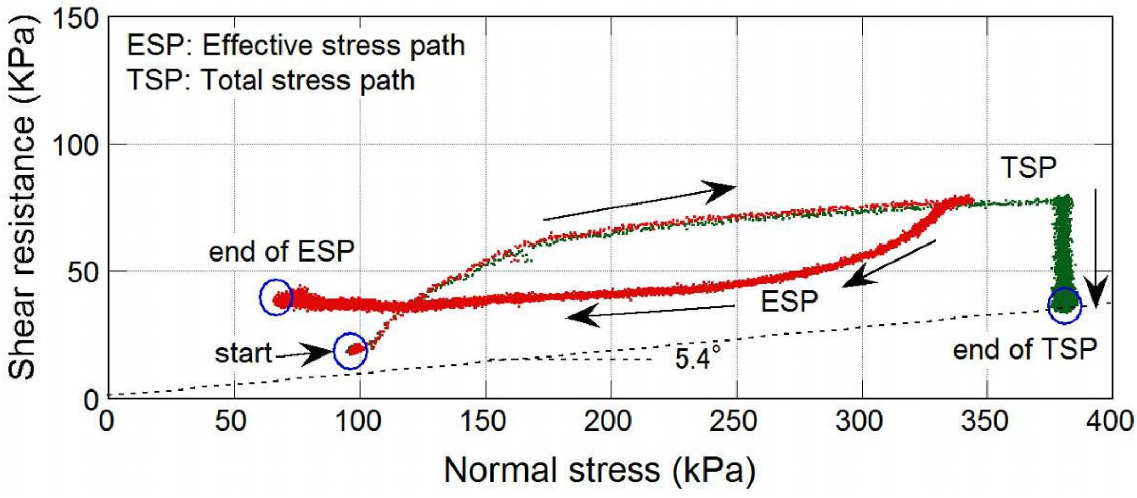

Figure 13: Total stress path and effective stress path of the simulation test with fully saturated sample B

Sudden-disaster investigation (Representative: K. Konagai) from MEXT of Japan. The authors deeply appreciated the discussions with Prof. K. Konagai of University of Tokyo, Prof. S. Tsuchiya of Shizuoka University, Japan in the field investigation.

References

Wang, F.W., Sassa, K., Fukuoka, H. (2000) Geotechnical simulation test for the Nikawa landslide induced by 1995.1.17 Hyogoken-Nambu earthquake. Soils and Foundations, Vol.40, No.1, pp.35-46.

Wang, F.W., Cheng, Q. G., Highland, L., Miyajima M., Wang, H.B., Yan, C.G. (2009). "Preliminary investigations of some large- scale landslides triggered by the 2008 Sichuan earthquake", Landslides, Vol.6, No.1, pp.47-54.

Yin, Y.P., Wang, F.W., Sun, P. (2009) Landslide hazards triggered by the 2008 Wenchuan earthquake, Sichuan, China. Landslides, Vol.6, No.2, pp.139-152.

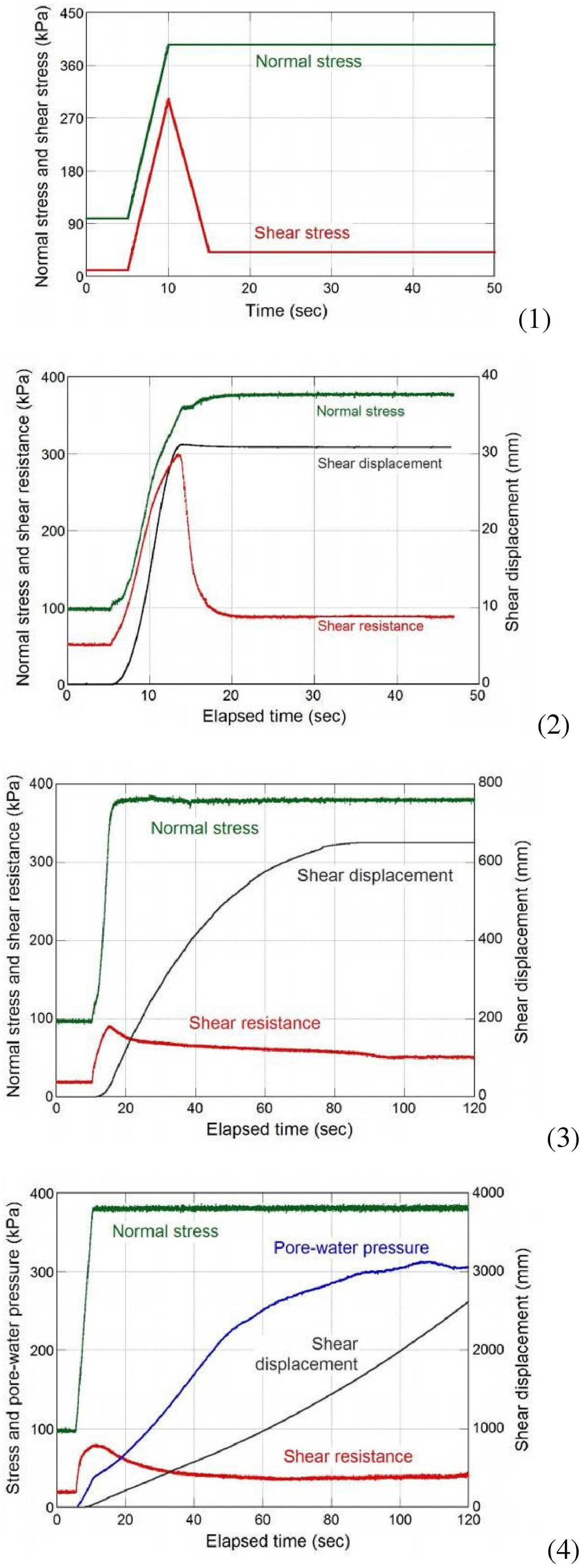

Figure 12: Loaded stress signals (1) and results of the Donghekou landslide motion simulation test with day sample (case I, ii, iii) (2-4).

Figure 14: Secondary disaster such as debris flow should be considered in the reconstruction process. The photo was taken in February 2009 in Beichuan County

