INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering
© 2005–2006 Millpress Science Publishers/IOS Press.
Published with Open Access under the Creative Commons BY-NC Licence by IOS Press.
doi:10.3233/978-1-61499-656-9-2607

Fluidization mechanisms of flowslides triggered by earthquake and rainfall

Mécanismes de liquéfaction des coulées boueuses déclenchées par tremblement de terre et fortes précipitations

F.W. Wang
Research Centre on Landslides, Disaster Prevention Research Institute, Kyoto University, Uji, Gokasho, Kyoto 611-0011, Japan

Y. Tanaka & K. Nakamura
Department of Civil Engineering, Kanazawa University, Kanazawa 920-8667, Japan

ABSTRACT
The difference between the fluidization mechanisms of the Tsukidate flowslide triggered by earthquake and the Yamashina flowslides induced by rainfall was examined through field investigations, soil tests and numerical simulations. In the case of the Tsukidate flowslide, after a liquefaction of sliding mass, the combination effect of grain crushing and rapid shearing rate of the pyroclastic material on the excess pore pressure generation was concluded as the main reason. While, in the case of the Yamashina flowslides, the low shear strength mobilized in the fully saturated weathered mudstone debris with a very low permeability was attributed to the high mobility of the flowslides.

RÉSUMÉ
Les principales différences observées et quantifiées entre les mécanismes de liquéfaction de la coulée de boue de Tsukidate déclenchée par tremblement de terre et les coulées de boues Yamashina induits par de fortes précipitations ont été examinées lors des campagnes de terrain, des essais mécaniques et des simulations numériques. Les processus rupturels mises en causes dans le cas de la coulée de boue de Tsukidate, ainsi que les fortes surpressions interstitielles sont associés à la liquéfaction de l’ensemble de la masse en mouvement, combiné au broyage des grains et une vitesse de cisaillement rapide du matériel pyroclastique. Par contre, dans le cas des coulées de boue de Yamashina, la grande mobilité des matériaux est associée à la faible résistance au cisaillement des argilites altérées et entièrement saturés et à leur très faible perméabilité.

1 INTRODUCTION

Fluidization is a process of landslide changing from solid-like landslide block to liquid-like flowslide (Wang & Sassa, 2002). It can be distinguished from debris flow that generally moves in a narrow channel and has water supply. Fluidization generally results in flowslide that moves for a long distance at high speed, even on a gentle slope (Sassa et al., 2001). This makes the evacuation from the flowslide very difficult. In recent years, a lot of flowslides occurred in Japan and brought economic losses and live losses. However, the fluidization mechanism of a landslide transferring into flowslide is not fully understood (Wang & Sassa, 2000; Okada et al., 2001). In this paper, through studies on two flowslide cases, one is Tsukidate flowslide triggered by earthquake, and the other is the Yamashina flowslides triggered by rainfall through field investigations, laboratory tests, and numerical simulations, the fluidization mechanism of flowslide was studied. The site locations were shown in Fig.1.

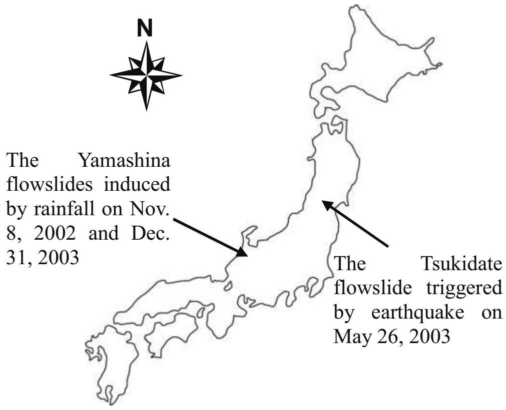
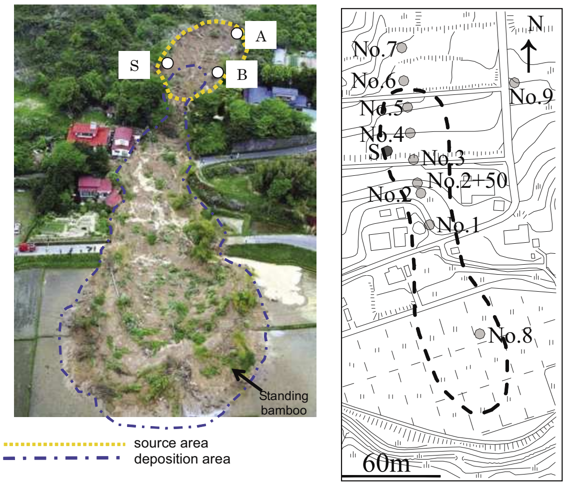


Figure 1. Site locations of the Tsukidate flowslide and Yamashina flowslides

2 CASE STUDY ON THE TSUKIDATE FLOWSLIDE



(a) air photo (Yomiuri, 2003) (b) location of the penetration tests

Figure 2. The Tsukidate flowslide

Tsukidate flowslide was triggered by Sanriku-minami earthquake in Miyagi, near Sendai City on May 26, 2003. Fig. 2a is an air-photo taken on the next day after the flowslide occurred (Yomiuri, 2003). After a rapid and long runout sliding, it deposited in a rice paddy. Formerly this site was a valley, and it was refilled with pyroclastic refill for house construction purpose. The water trace on the surface of the debris deposit after failure indicated a fully saturated condition of the sliding mass during motion. The bamboo standing at the front of the deposit indicates a very rapid movement of the flowslide. Portable penetration tests were conducted at the flowslide and nearby area to investigate the strength properties of the refill materials, triaxial consolidated-undrained shear tests were performed to investigate the effect of grain crushing and rapid loading rate, and landslide motion simulations were carried out to reproduce the sliding process.

2.1 *Field investigation and portable penetration tests*

Fig.2b shows the locations of the portable penetration tests. Points No.1 to No.5 were conducted at the source area. Point No. 8 was at the deposit area in rice paddy. Point No. 6 and No.7 were at the main scarp where is also the refilled area. It is of interesting to mention that there was a step between No.6 and No.7 formed by a sliding induced by rainfall in 2002. It means that, in the last time, landslide triggered by rainfall, but did not fluidize. Difference between the rainfall trigger and earthquake trigger must exist.

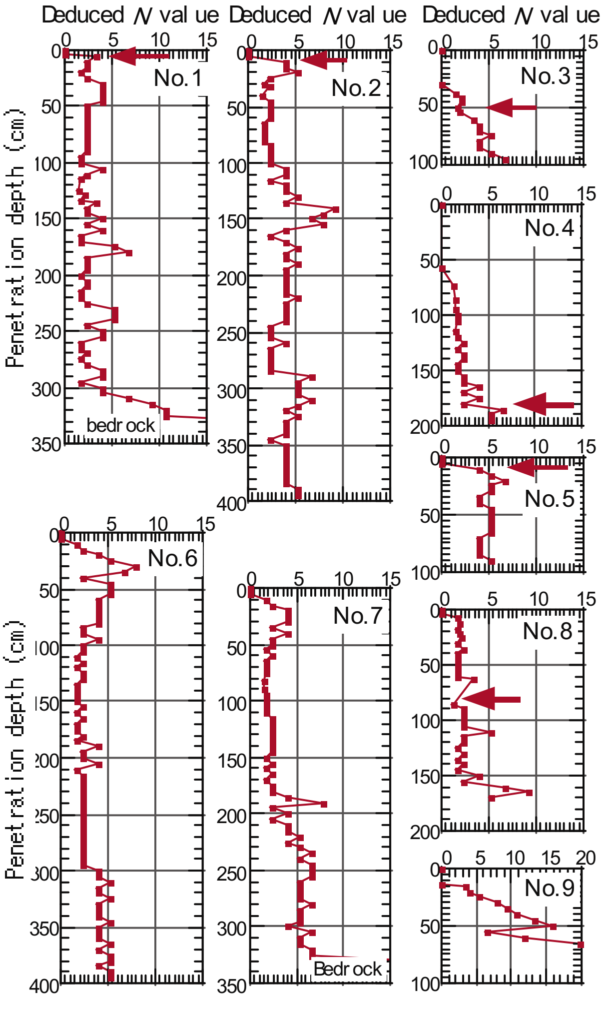


Figure 3. Reduced *N* value from the portable penetration tests at the Tsukidate landslide and nearby area (arrow shows the possible sliding surface. No.9 is located outside the refill area.)

Based on the blow numbers of the portable penetration tests, the deduced *N* values used in the standard penetration tests were calculated (Fig.3). In field investigation, the following findings were obtained. (1) Penetration strength of the displaced debris became to near zero indicating a fluidization phenomenon; (2) Penetration strength of the pyroclastic refill outside the source area of the flowslide was very weak, indicating a loose structure of the refill slope; (3) deoxidization color of the soil in sliding surface indicating that groundwater existed in the slope regularly.

According to the field investigation, the maximum thickness of the sliding mass was about 5 m. Apparent friction angle of the flowslide, which is the slope of the line from the top of the source area to the toe area of the deposits, was as low as 7.3 degrees (Inspection committee of the Japan Landslide Society et al., 2003), showing a high mobility of the flowslide.

2.2 *Consolidated undrained triaxial tests on the pyroclastic materials*

Consolidated undrained (CU) triaxial tests were conducted on the soil samples taken from the flowslide in two series. One series is to investigate the possible stress level of the refill soil for grain crushing, and how the excess pore pressure affected by the grain crushing through changing the consolidation stress. The applied consolidation stress ranged from 24 kPa to 195 kPa. Skempton's pore pressure coefficient *A* was used to evaluate the excess pore pressure generation. The result shows that the maximum *A* value and its average value increased along with the increase of the consolidation stress (Fig.4). Through the comparison of the grain size distribution of the soil sample before and after tested, it is confirmed that grain crushing occurred during the undrained shear at all of the tests (Fig.5). By the way, the effective normal stress at the sliding surface of the Tsukidate flowslide ranged from 20 to 50 kPa.

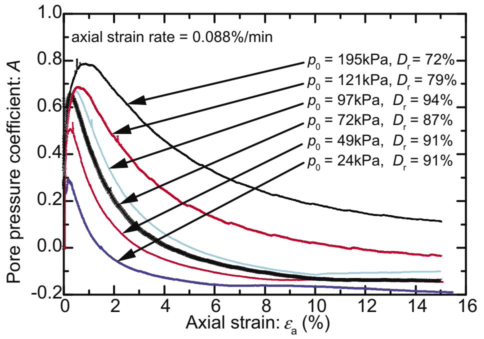


Figure 4. Pore pressure coefficient *A* versus axial strain of the pyroclastic materials in the CU tests at different consolidation stresses

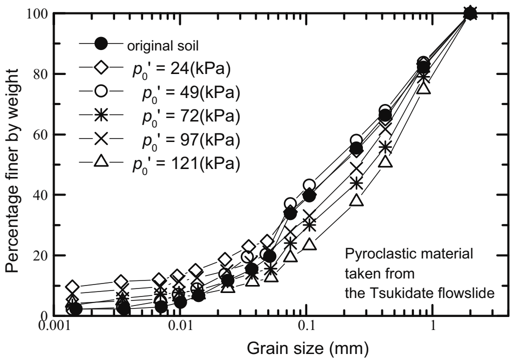


Figure 5. Grain size distributions of the original and tested soil samples in the CU tests

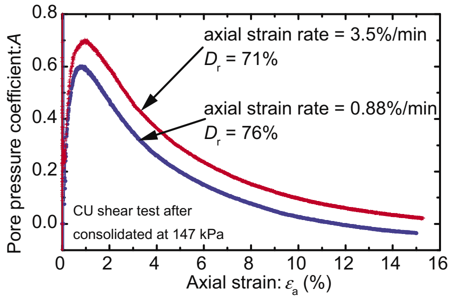
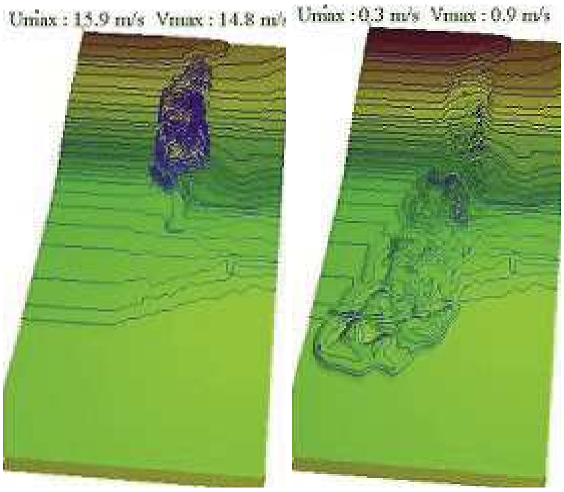


Figure 6. Excess pore pressure versus axial strain of the pyroclastic materials tested in different axial strain rates

The other series is to investigate the effect of the quick loading rate caused by earthquake on the pore pressure generation behavior. CU tests were conducted at two different axial strain rates, 0.88%/min and 3.5%/min, respectively after consolidated at 147 kPa. The results show that high excess pore pressure generated at high loading rate (Fig.6). Moreover, higher excess pore pressure was kept higher during the whole shearing process.

2.3 *Landslide motion simulations on the Tsukidate flowslide*

Motion of the Tsukidate flowslide was reproduced by means of the geotechnical model of landslide motion proposed by Sassa (1988) with adopting the changing model of apparent friction coefficient (Wang & Sassa, 2002). Back analysis was performed through adjusting the affected area with the actual deposit distribution (Fig.7), and the shear resistance mobilized in the landslide motion was estimated as 2.5 kPa. The result shows that the landslide should be nearly fully liquefied during the whole sliding process.



(a)
Step: 550 Time: 5.591 sec
$U_{\max}$: 15.9 m/s $V_{\max}$: 14.8 m/s

(b)
Step: 3950 Time: 35.004 sec
$U_{\max}$: 0.3 m/s $V_{\max}$: 0.9m/s

Figure 7. Landslide motion simulation on the Tsukidate flowslide (thickness of the sliding mass was enlarged by 5 times)

Based on the above investigation, the following scenario could be estimated. The refilled pyroclastic material in the former valley regularly existed at a fully saturated condition. With the rapid seismic loading, liquefaction must have occurred during the earthquake. The combination effect of grain crushing and high shear rate on the excess pore pressure generation during the motion process promoted the fluidization process.

3 CASE STUDY ON THE YAMASHINA FLOWSLIDES

The Yamashina flowslides occurred two times until now at Yamashina area, Kanazawa City. After the first occurrence of the flowslide, field investigations including boring exploration, portable penetration tests, trench excavation to check the deposit structure, and deformation monitoring to warn further failure were conducted. Fig.8 shows the plan of the landslide. The bedrock in the landslide site and nearby area was the Saikawa group consisting of block mudstone in Miocene epoch, Tertiary period. At the first time on November 8, 2002, it was induced by a continual rainfall for over one week. At the second time on December 31, 2003, slope failure triggered by snowmelt and heavy rainfall again at the former main scarp. The following gives a summary for the two failure occurrences.

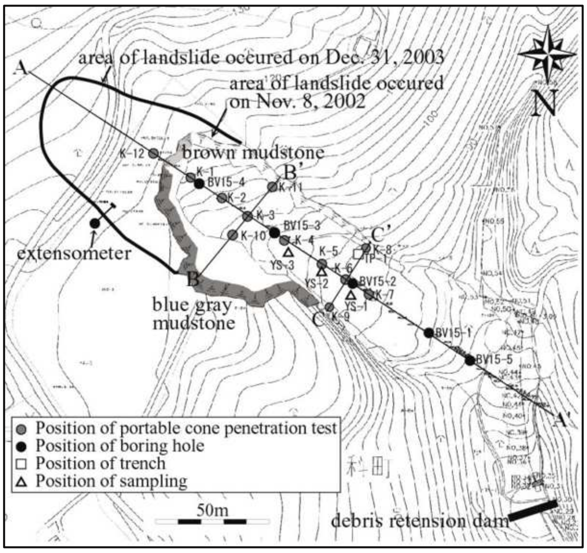


Figure 8. Plan of the Yamashina flowslides including two failure occurrences

3.1 *Flowslide occurred on November 8, 2002*

Fig.9 is the longitudinal section of the first flowslide. The original topography is based on the topography map before landslide occurred. The current topography was measured by Total Station equipment. The sliding surface was estimated by portable penetration tests. The average thickness of the sliding mass at the rear part was about 15 m, and the width was about 100 m. Because of a one-week continual rainfall, the sliding mass was fully saturated. A part of deposits of the flowslide was so soft and weak that it is even impossible to access. However, at the part of the former slope surface, there were cracks and showing a mass movement features. The apparent friction angle of the landslide was about 10 degrees showing a high mobility.

It is of interesting to mention that, at the toe part of the deposits, bamboo grove which distributed in the front part of the slope formerly stopped the flowslide and shortened the possible sliding distance of the slide. Through back-analysis on the flowslide with the landslide motion model, the shear strength after long shear distance (i.e., steady state) of the soil at the passing area and the mixture of soil and bamboo at the toe-near area

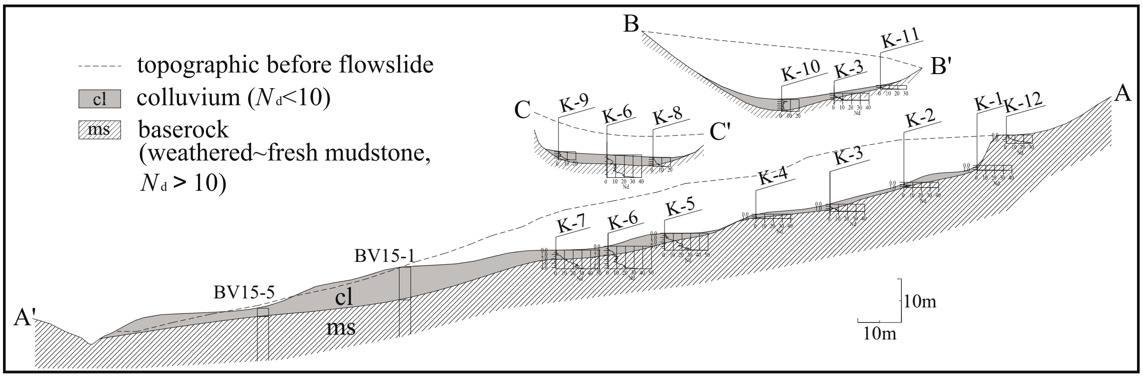
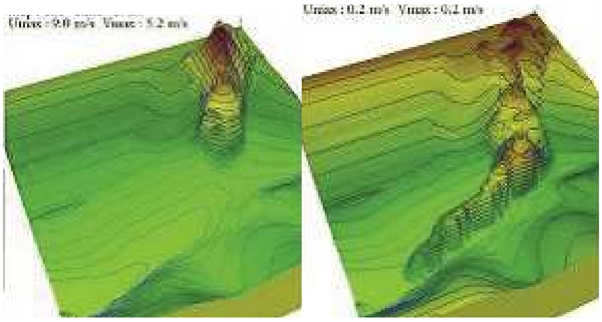


Figure 9. Longitudinal section of the Yamashina flowslide after the first event occurred on Nov. 8, 2002

were estimated as 10 kPa and 50 kPa, respectively. Fig.10 shows a part of the simulation results.



(a) t = 6.5 sec
U_{max}: 9.0 m/s V_{max}: 5.2 m/s

(b) t = 35.9 sec
U_{max}: 0.2 m/s V_{max}: 0.2m/s

Figure 10. Landslide motion simulation on the first occurrence of the Yamashina flowslide (Thickness of the sliding mass was enlarged by 5 times)

3.2 *Flowslide occurred on December 31, 2003*

Before the final failure at the second failure occurrence, a continual main crack appeared at the main scarp of the first occurrence. Fig.11 shows the monitored displacement results by means of an extensometer crossing the main crack, and the meteorological data including snowfall, rainfall and temperature. Companying with the snowmelt from Dec. 28, a rainfall event on Dec. 29 accelerated slope deformation, and another rainfall event on Dec. 31 triggered the failure.

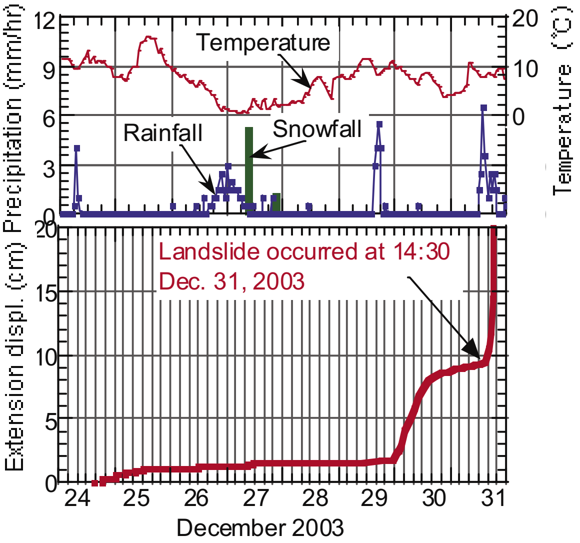


Figure 11. Monitored displacement by extensometer crossing the main crack, and meteorological data

At the second time, the displaced soil mass at the main scarp was estimated about 50,000 m^3 (Fig.8). Field investigation showed that the displaced weathered mudstone loaded on the debris deposits of the first time sliding, and moved for a long distance. Influenced by the sliding, even the toe part of the first time sliding deposits moved down for about 3 m.

The regression failure of the mudstone is under researching now. However, the following scenario is clear. After snowmelt and two times intense rainfall, the mudstone debris deposits of the first time were fully saturated. A sudden failure from the main scarp induced a quick loading behavior on the fully saturated debris. The shear strength of the saturated weathered mudstone debris must be very low during the quick loading because of its low permeability. This might be the reason of the second flowslide occurred and enlarged through affecting the first time debris deposits.

4 CONCLUSIONS

Through two case studies on the flowslides triggered by earthquake and rainfall respectively, the difference between the two types of flowslide triggered by different factors was examined. After a slope failure, whether it can fluidize or not, must affected by lots of factors such as slope geometry condition, soil grain contents and so on. However, the saturated condition is the most controlling factor. The common feature of the Tsukidate flowslide and the Yamashina flowslide is that the fluidized debris was under a fully saturated condition. For the two cases, the following conclusions were obtained.

(1) In the case of Tsukidate flowslide, liquefaction was triggered by earthquake at first, and during the sliding process, excess pore pressure generations caused by grain crushing and rapid shear rate are the main reason for the fluidization.

(2) In the case of Yamashina flowslides, low shear strength mobilized in the fully saturated weathered mudstone debris was attributed to the flowslides.

From this comparison study on the flowslides triggered by different factors, a basic knowledge of the flowslide could be extracted. Whether a flowslide can be developed depends on the accumulation of the excess pore pressure that will reduce the shear strength of the soil. A comparison between the dissipation rate and generation rate of the excess pore pressure is the vital factor for flowslides, in spite of that the triggering factor is earthquake or rainfall.

REFERENCES

Inspection Committee of the Japan Landslide Society, Inspection committee of the APERIF, 2003. A report of the landslide disaster activated at Tsukidate Miyagi prefecture by the Sanriku-minami earthquake, 26 May, 2003. *Journal of the Japan Landslide Society*, Vol.40, No.2, pp.45-46.

Okada, Y., Sassa, K., Fukuoka, H. 2000. Liquefaction and the steady state of weathered granitic sands obtained by undrained ring shear tests: a fundamental study of the mechanism of liquidized landslides. *Journal of Natural Disaster Science*, Vol. 22, No. 2, pp.75-85.

Sassa, K. 1988. Geotechnical model for the motion of landslides. *Proc. 5th International Symposium on Landslides*, 1, 37-56. Rotterdam: Balkema.

Sassa, K., Wang, G., Fukuoka, H. 2001. Mechanism of transition from slide to flow in granular soils. *Proc. ISSMGE TC-11 (Landslides) & ATC-9*, Trabzon, Turkey, pp.1-19.

Wang, F.W., Sassa, K. 2000. Relationship between grain crushing and excess pore pressure generation by sandy soils in ring-shear tests. *Journal of Natural Disaster Science*, Vol. 22, No. 2, pp.87-96.

Wang, F.W., Sassa, K. 2002. A modified geotechnical simulation model for the areal prediction of landslide motion. *Proc. 1st European Conf. on Landslides*, Prague, 735-740.

Wang, G.H., Sassa, K. 2001. Factors affecting rainfall-induced flowslides in laboratory flume tests. *Geotechnique*, Vol.51, No.7, pp. 587-599.

http://www.yomiuri.co.jp/national/news/20030527it04.htm