京 都 大 学 防 災 研 究 所 年 報 第48号 B 平成17年4月
Annuals of Disas. Prev. Res. Inst., Kyoto Univ., No. 48 B, 2005

Landslides in Kisawa area, Tokushima Prefecture during the 2004 Typhoon Namtheun

Gonghui WANG, Akira SUEMINE, Gen FURUYA,
Masahiro KAIBORI*, and Kyoji SASSA

* Faculty of Integrated Arts and Sciences, Hiroshima University

Synopsis

During Typhoon Namtheun, heavy rainstorm fell on Shikoku area, and triggered numerous landslides in Nakagawa basin of Tokushima Prefecture, Japan in August 1, 2004. Among them four large landslides were triggered in Kisawa village, causing great damage to properties and leading the missing of two persons. Preliminary investigation on them revealed that these landslides experienced rapid long runout movement. Ring shear tests on the samples from different landslides showed that shear resistance could be reduced greatly due to the build-up of high excess pore-water pressure after the shear failure was triggered by the increase in ground water table during the rain.

Keywords: Rainstorm; Landslide; Typhoon Namtheun; Ring-shear test; Mechanism

1. Introduction

Typhoon Namtheun (the 10th tropical storm in the western Pacific in 2004) originated west of Minamitorishima Island of Japan on July 25, 2004. It made landfall on Shikoku island on July 31, then passed through the Seto Inland Sea and Hiroshima Prefecture, and moved toward the eastern part of the Korean Peninsula, losing energy to become a tropical depression (Fig. 1a). Accompanying this typhoon, heavy rain fell on the Shikoku area of Japan (Fig.1b), especially in the Nakagawa District (on the southwest part) of Tokushima Prefecture, setting a new Japanese daily precipitation record (Fig. 2).

Many landslides were triggered by the storm; the most catastrophic among them were four giant landsides occurring on Kisawa village of Nakagawa District, Tokushima Prefecture. These were at the Oyochi, Kashu, Azue, and Kamagatani areas of Kisawa village (Fig. 3), and we call them the Oyochi, Kashu, Azue, and Kamagatani landslides, respectively. The Oyochi, Kashu, and Azue landslides all are within a small area (Photo 1); the Kamagatani landslide is little further from the others. These landslides destroyed houses, forests and farms and severed roads. Two people were caught in one of the landslides, and their bodies were never recovered. This report gives a brief, preliminary account of the larger landslides in Kisawa area.

2. Rainfall Characteristics

Torrential rain in Tokushima and Kochi Prefectures accompanied the slow approach and passing of Typhoon Namtheun. At Kaminaka town (about 10 km far away from these four landslides) of Nakagawa District, Tokushima Prefecture, the total precipitation from July 30 to August 2 was more than 2,000 mm (Fig. 2). This is several times the normal precipitation for the months of July and August in this area. Hourly precipitation reached more than 120 mm (Fig. 2). The highest daily precipitation of 1,317 mm was recorded on 1 August (Fig. 2); this value exceeds the previous Japanese daily precipitation record of 1,114 mm, recorded at Kito village (about 16 km southwest of Kisawa village) on September 11, 1976 accompanying Typhoon Fran.

The area where precipitation exceeded 1,500mm for the storm was centered on Kisawa village and Kaminaka town, as a very narrow area of 5-6 km in the east-west direction, and 10-20 km in the south-north direction (Fig. 1b). Within this area, many landslides were triggered.

3. Geological background

The area where the landslides occurred is characterized by deep river valleys with steep slopes, and many of the mountain slopes have steep chutes.

Most of the settlements are located on gentle slopes formed by past landslides, or on narrow streamside terraces. According to the subsurface geological map of Tokushima Prefecture (Tokushima Prefecture, 1983), the area is mainly underlain by Paleozoic greenstone, Paleozoic and Mesozoic pelite and greywacke, and serpentinite of the Mesozoic Kurosegawa terrane, as well as limestone and chert.

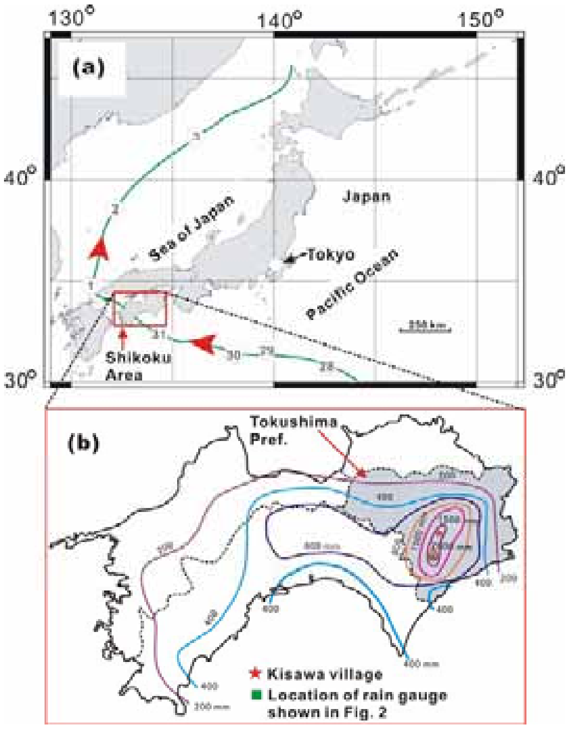

Fig. 1 (a) Path of Typhoon Namtheun (after National Institute of Informatics, 2004). (b) Rainfall distribution in the Shikoku area from July 30 to August 2 (after Nakagawa River Office, Shikoku Development Bureau, Ministry of Land, Infrastructure and Transport (MLIT), Japan, 2004)

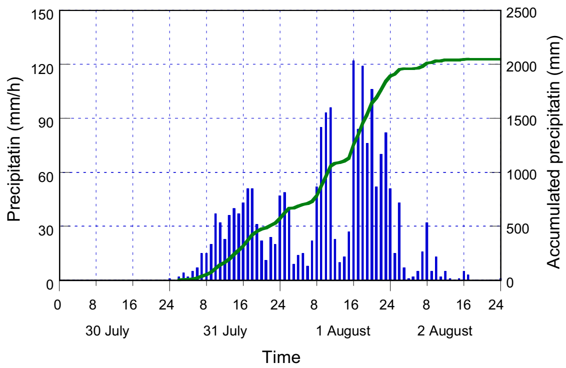

Fig. 2 Hyetograph of the heavy rainfall (data courtesy of Shikoku Electric Power Co., Inc.)

4. Landslides in Kisawa area

4.1 Oyochi landslide and Kashu landslide

The Oyochi and Kashu landslides occurred on the same ridge and side of the mountain (Photo 1). Oyochi landslide was triggered mid-slope on the mountainside, about 1 km from the Oyochi settlement (Photo 2) at approximately 20:30 hr, August 1. Two people were caught up in this landslide, and their bodies have not been found. The head scarp is situated at an altitude of about 1000 m, while the join of the slope to the Oyochi valley is about 560 m. The slope angle averaged 34 degrees. The displaced materials of about 0.5~1×10^6 m^3 from the cover and weathered bedrock moved downslope to the river, and hit the opposite side of the channel. A part of the displaced mass crossed a ridge on the opposite slope (area ① in Photo 2), and transformed into a large debris flow, traveling a further 2 km along the valley (area ② in Photo 2). In this area, the bedrock is mainly composed of greenstone and serpentinite with visible cracks. Immediately below the source area, the displaced mass is meters thick, and contains some huge boulders (Photo 3). The deposited mass could be liquefied by stamping feet, indicating the highly liquefiable character of the landslide materials.

Fig. 3 Location of Oyochi, Kashu, Azue and Kamagatani landslides

Photo 1 Oblique aerial view of the Oyochi, Kashu, and Azue landslides (photo by Shikoku Development Bureau, MLIT, Japan)

Photo 2 Oblique aerial view of Oyochi landslide (photo by Shikoku Regional Development Bureau, MLIT, Japan)

Photo 3 Deposits of landslide mass at Oyochi

Photo 4 Oblique aerial view of Kashu landslide (photo by Shikoku Regional Development Bureau, MLIT, Japan)

Photo 5 Oblique aerial view of Azue landslide and the unstable blocks after the August 1, 2004 event (photo by Nakanihon Sky Service Station, Japan). The broken brown line outlines the area of the ancient landslide

Photo 6 Oblique aerial view of the Fudono area after the landslide (photo by Shikoku Regional Development Bureau, MLIT, Japan)

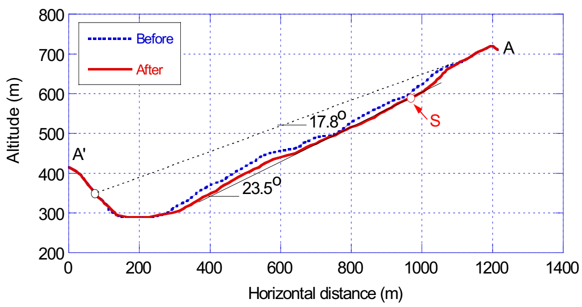

Fig. 4 Longitudinal section of the Azue landslide (A-A' in Photo 5; S is sample point for grain size analysis and ring-shear test)

Photo 7 Subsidence on the left hand side of the landslide locating on the upper part of the Azue landslide scarp (yellow dashed region in Photo 5)

Kashu landslide (Photo 4) occurred on the same slope near the Oyochi landslide, and almost at the same time as the Oyochi event. The head scarp is situated at an altitude of about 910 m, while the altitude of river floor is about 300 m. The slope angle averaged 27 degrees. According to a local resident, Kashu landslide started on the lower valley slope near Kashu settlement (below A-A' in Photo 4), and was followed by another two failures, finally retrogressing almost to the ridgeline of the mountain on August 2.

4.2 Azue landslide

Azue landslide is located on the left side of Sakashu-Kito River, in front of the Kashu landslide (Photo 5). A remarkable scar indicating an ancient landslide is also visible at the same site (Photo 5 outlined approximately by the brown broken line). We also found a small-scale linear depression on the mountain top during our survey. The new landslide occurred near the southern boundary of the old landslide scar within the weathered bedrock layer. Azue landslide has a width of about 130 m, a horizontal length of about 1 km, and a depth ranging from 10 to 20 m. The volume of the displaced material was estimated to be about $1\sim2\times10^6$ m^3. The displaced material slid down the slope, crossed the river, and rose up the opposite mountain slope to about 30 m (immediately below the Fudono area), destroying and carrying away the Fudono bridge, which was built on the national road (Photo 6).

A longitudinal section of the landslide (Fig. 4), was plotted using data from an airborne laser scanner after the failure (performed by Aero Asahi Corporation), and the pre-failure topography was obtained from a forest map with 2-m contour. The landslide originated on a slope of approximate 23.5 degrees with an apparent friction angle of about 17.8 degrees (Fig. 4). From the travel distance and the height reached on the opposite slope, the speed of the displaced landslide material was estimated to be very fast (>20 m/s, Hiura, et al, 2004).

Photo 8 Exposure of the sliding surface beneath the old landslide. The materials above/below the sliding surface are weathered green stone

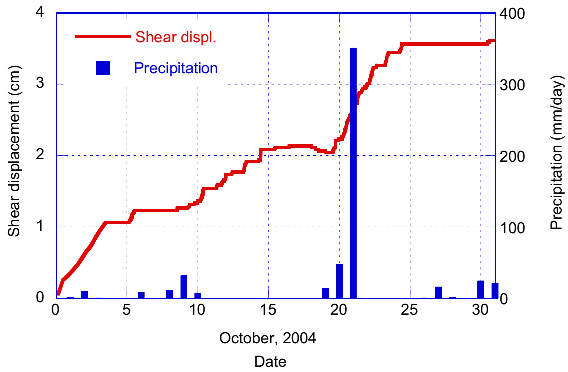

Fig. 5 Observed shear displacement and daily precipitation on October 2004 for the unstable block above the Azue landslide

The main failure of Azue landslide occurred at approximately 23:00 hr on August 1, a little later than the Oyochi and Kashu landslides. Afterwards, loud crashing noises continued for several hours, probably due to retrogressive failures. On the upper parts of the slope near the scarp, landsliding of the unstable regions of the displaced mass on a small scale is still continuing, and some places has been covered by thick displaced material. Light green and light red/purple bedrock (green stone) is exposed on the right hand side of the landslide.

We were told that a landslide occurred 5 years ago on the area below the curve of F-F' shown in Photo 5, also during heavy rain. We noticed that a smooth surface of relatively hard bedrock crops out (below F-F' on Photo 5), which strikes N45ºE and dips north (Hiura, et al, 2004). We infer that this surface formed an impermeable or less permeable layer, which facilitated a rapid rise in the local ground-water table during the storm, which in turn triggered the slope failure.

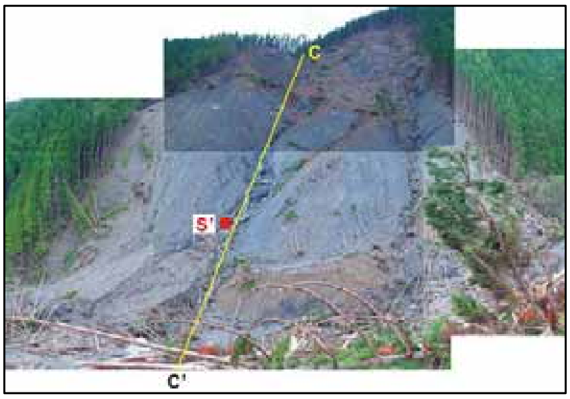

Photo 9 A general view of Kamagatani landslide. S' marks the sample site, and the red dashed cycle marks the site of Photo 10

Photo 10 A close view of the location marked by the red dot in Photo 9. This is the location of the cool ground-water resurgence

Photo 11 A displaced concrete block from the soil-conservation (check) dam (Black area outlined by the broken white line) on the slope opposite the landslide source (Red arrow: downstream of the valley; White curved arrow: move direction of the block)

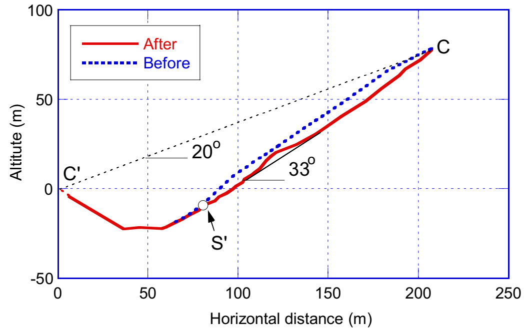

Fig. 6 Longitude section of the Kamagatani landslide (S' is sample point; the pre-failure topography was obtained from neighboring slope)

Above the main scarp of Azue landslide, another huge block moved slightly. After the landslide, numerous cracks with significant displacements were found on the slope above the main scarp (and along the scarp of the old landslide). The white dashed lines that were made basing on the observed cracks outline the boundary of each landsliding sub-block. The road on the left hand side of the old landslide scar was severed by a crack, where there was subsidence of about 2.0 m (Photo 7). The subsidence increased to 2.5m over about two weeks. It exposed a well-consolidated sliding surface of the old landslide (see Photo 8), which originated in the bedrocks and strikes N44ºW and dips 48ºW.

Preliminary bore-hole data indicate that the unstable block ranges from 20–50 m in thickness. Therefore, the unstable landslide mass was estimated to be in the order of 10^6 m^3. This landslide mass is still deforming, and measured displacements by the installed extensometers show that its movement is very sensitive to rainfall. This can be seen from Fig. 5, where the monitored shear displacement on October 2004 by means of an extensometer located on point E in Photo 5 is plotted together with the daily precipitation. A detailed account the deformation of this landslide mass is beyond the scope of this report and will be presented elsewhere.

4.3 Kamagatani landslide

Kamagatani landslide (Photo 9) is located on the right slope of the valley of Kamagatani River, the upper tributary of Sakashu-Kito River. This landslide is about 7 km north of the three landslides discussed above.

The landslide originated on a slope of about 33 degrees. It has a width of 120 m, a length of 200 m, and a depth of 10–15 m. The displaced landslide mass was estimated to be about 2×10^5 m^3. The source area consists of mudstone, which is overlain by sandstone and ancient colluvial deposits. The failure occurred within the outer layers of these strata. In the middle part of the source area, a ridge-shaped roll existed, suggesting the presence of hard rock. A large amount of groundwater discharges near the mudstone-sandstone boundary (Photo 10). The landslide carried away a soil-conservation (check) dam that previously stood on the toe of the slope. A large block of concrete from the dam is now on the top of the slope ridge on the opposite slope across the valley (Photo 11). This is where we placed the total-station measurement system to measure the landslide's longitudinal profile (point C' on Fig. 6). The displaced soil mass reached and dammed Kamagatani River. The landslide dam had been eroded by the river before our investigation, but we have inferred from the deposit profile remaining on the river banks that the displaced material was deposited with a final slope angle of about 9 degrees. From the height of the concrete block and elevation of deposits on the slope opposite to the landslide, the displaced landslide material was estimated to have had a speed greater than 17 m/s when it reached the valley bottom.

5. Possible mechanisms for these landslides

As mentioned previously, the Oyochi, Kashu, and Azue landslides have very similar geological backgrounds, while the Kamagatani landslide is different. Nevertheless, they all were rapid to some extent. To understand the triggering, as well as the possible movement mechanism, it is important to understand the shear behavior of these materials before and after the failure, and how these are affected by rainfall. Therefore, samples were take from the source area of Azue landslide (S in Photo 5) and from the Kamagatani landslide (S' in Photo 9), for laboratory examination, and testing in a ring-shear apparatus described in Sassa et al. (2004a). Due to a size limitation imposed by the shear box, gravel greater than 2 mm in diameter was removed by sieving before testing. The grain size distribution of the samples used in the tests is presented in Fig. 7.

The landslides were obviously triggered by heavy rain, and so to simulate the rising ground-water table due to rainfall, shear tests were performed with slowly increasing pore-water pressure. For the test, the oven-dried sample was first deposited dry in the shear box, and then saturated with the aid of carbon dioxide and de-aired water. After the sample had been saturated and consolidated to the initial stress state, pore-water pressure was increased slowly until shear failure was triggered. Note that the saturation degree was checked for each sample by measuring the B_D value, which is a parameter proposed by Sassa (1988) for the saturation degree in the direct shear state.

For Azue landslide, the sample had a specific gravity of 2.94 in the field, and dry density of 2.08 g/cm^3. Because the test aim was to examine the shear behavior of the landslide material before and after failure, a soil element was selected from the sliding surface where the overlying soil was 25-m thick. The initial normal stress and shear stress acting on the soil element were calculated to have been 488 kPa and 212 kPa, respectively. The test results are presented in the form of time-series data (Fig. 8a) and effective stress path (Fig. 8b). Shear failure was triggered when the pore-water pressure was increased to a certain value (Fig. 8a). The monitored pore-water pressure after failure showed a brief reduction and thereafter increased with further shearing. During this period, shear resistance was greatly reduced. The effective stress path fluctuated widely (Fig. 8b), probably due to problems in measuring pore pressure (as detailed in Sassa et al 2004b). The final apparent friction angle was very small, about 5.4 degrees.

A similar test was performed on a sample from the Kamagatani landslide. Time-series data (Fig. 9) show that shear failure was triggered when the pore-water pressure was increased to point "P". After failure, pore-water pressure showed a sharp increase and then decreased. To measure the pore-water pressure within the shear zone, the shear box was switched to an undrained condition after point "SUD". The pore-water pressure increased with progress of shearing. The shear resistance showed almost no change in the final shear stage, indicating no further build up in excess pore-water pressure within the shear zone. The apparent friction angle was about 8.3 degrees (Fig. 9b). Although the final shear resistance shown in Fig. 9 is smaller than that in Fig. 8; the greater apparent friction angle in Fig. 9b is considered to be due to the smaller initial normal stress. The initial consolidated normal stress usually does not affect the shear resistance at steady state when a sample is subjected to undrained shearing, if other test conditions are the same (Castro & Poulos 1977; Kramer 1988).

6. Summary

A field investigation was made of the larger landslides triggered at Kisawa village by an unprecedented rainstorm accompanying typhoon Namtheun in 2004. Basic characteristics of these landslides were described and some laboratory ring-shear experiments were performed to examine possible triggering and movement mechanisms.

(1) The Oyochi, Azue, and Kamagatani landslides moved rapidly over long distances. No evidence was found from which to determine the speed of the Kashu landslide.

(2) The Azue landslide originated on the gentle slope on an ancient landslide. Due to the occurrence of the new landslide, the old landslide was reactivated and continues to move.

(3) Impermeable hard bedrock (or a layer of lower permeability) enabled the ground-water table to rise, which caused an increase in pore-water pressure within the overlying soil, and triggered the landslides.

(4) Results of ring-shear tests on samples from Azue and Kamagatani landslides showed that high excess pore-water pressure could be built up such that shear resistance lowered to very small values, indicating that both samples are highly liquefiable.

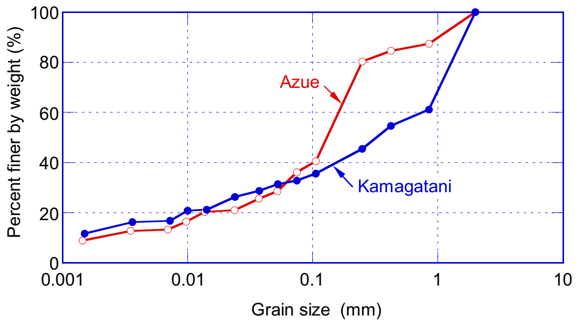

Fig. 7 Grain-size distributions of samples from the Azue and Kamagatani landslides (after removal of the >2 mm size fraction)

Finally, it is noted that further studies of the sliding characteristics of the unstable landslide block above Azue landslide during rainfall are needed and are being planned.

Acknowledgment

Prof. Okabe of Tokushima University, Prof. Hiura of Kochi University, Dr. Satofuka and Dr. Tsutsumi of Kyoto University, are thanked for their help and discussions in the field survey. Thanks also go to the Aioi Civil Office of Tokushima Prefecture and to the Kisawa Village office for their help in the field.

References

Castro, G. and Poulos, S.J. (1977): Factors affecting liquefaction and cyclic mobility. Journal of Geotechnical Engineering Division, ASCE, Vol. 103, pp. 501-516.

Hiura, H., Kaibori, M., Suemine, A., Satofuka, Y. and Tsutsumi, D. (2004): Sediment-related disasters in Kisawa-Village and Kaminaka-Town in Tokushima Prefecture, Japan, induced by the heavy rainfall of the Typhoon Namtheun in 2004 (prompt report). Journal of the Japan Society of Erosion Control Engineering, Vol. 57, No. 4, pp. 39-47.

Kramer, S.L. and Seed, H.B. (1988): Initiation of soil liquefaction under static loading conditions. Journal of Geotechnical Engineering, ASCE, Vol. 114, pp. 412-430.

Nakagawa River Office, Shikoku Development Bureau, Ministry of Land, Infrastructure and Transport, Japan (2004) The flood situation on the downstream of Nakagawa river due to the 2004 Typhoon No. 10 (Namtheum) (in Japanese). at website: http://www.skr.mlit.go.jp/nakagawa/nakagawa_topics/H16_10gou/mokuji.html.

National Institute of Informatics (2004): Digital Typhoon: Typhoon 200410 (Namtheun). http://agora.ex.nii.ac.jp/digital-typhoon/news/2004/TC0410/index.html.en.

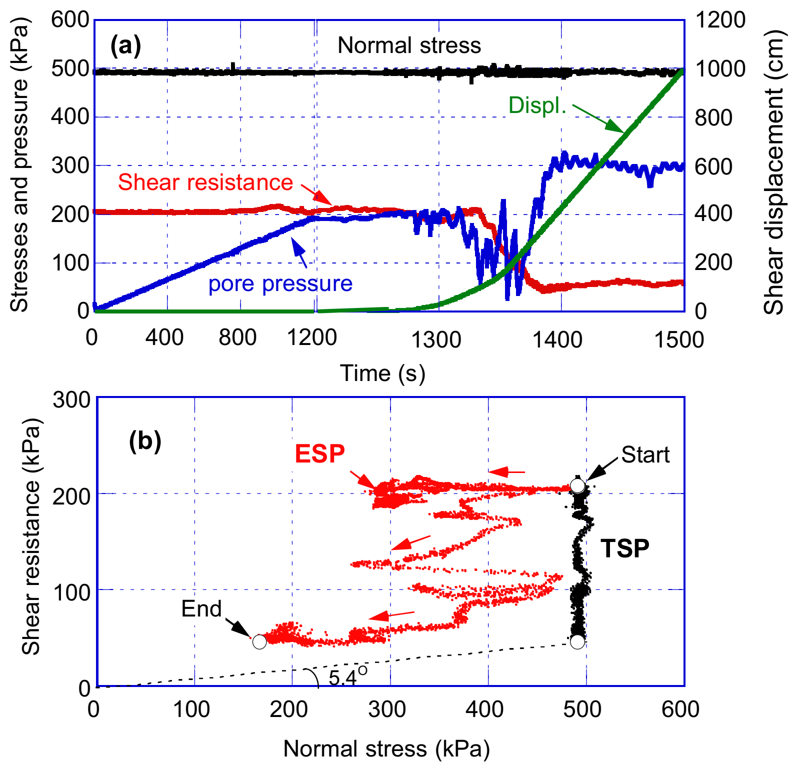

Fig. 8 Results of a ring-shear test on a sample from the Azue landslide. (a) Time-series data for normal stress, shear resistance, pore-water pressure and shear displacement; (b) stress path (ESP: Effective Stress Path; TSP: Total Stress Path) (Pore-pressure parameter, B_D= 0.96, e = 0.425)

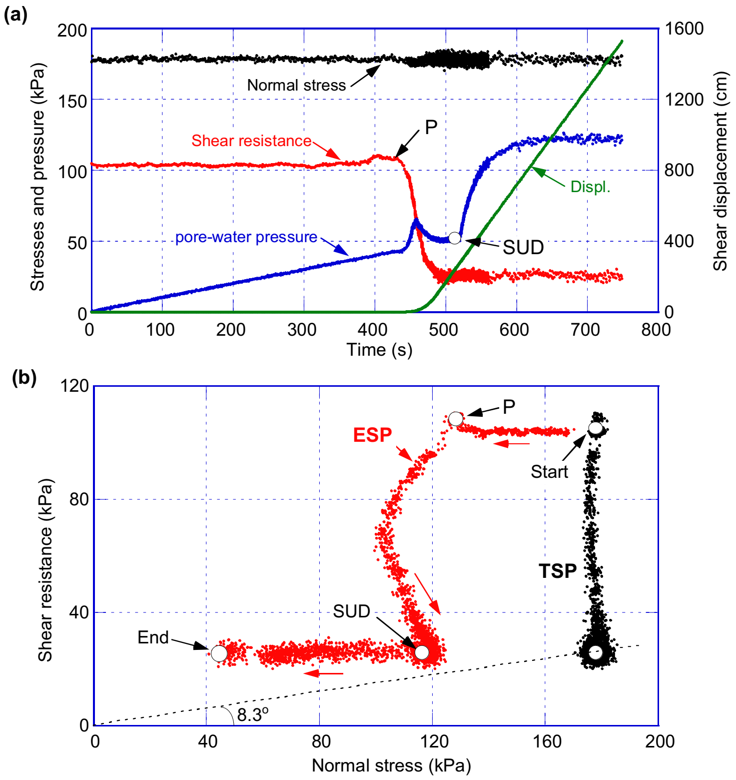

Fig. 9 Results of a ring shear test on a sample from the Kamagatani landslide. (a) Time-series data for normal stress, shear resistance, pore-water pressure and shear displacement; (b) stress path ($B_D = 0.97$, $e = 0.513$)

Sassa, K. (1988): Geotechnical model for the motion of landslides. Special Lecture of 5th Int'l. Symp. on Landslides, "Landslides", Rotterdam: Balkema, Vol. 1, pp. 37-55.

Sassa, K., Fukuoka, H., Wang, G., and Ishikawa, N. (2004a): Undrained dynamic-loading ring-shear apparatus and its application to landslide dynamics. Landslides, Vol. 1, No. 1, pp.7-20.

Sassa, K., Wang, G., Fukuoka, H., Wang, F., Ochiai, T., Sugiyama, M. and Sekiguchi, T. (2004b): Landslide risk evaluation and hazard zoning for rapid and long-travel landslides in urban development areas. Landslides, Vol.1, No.3, pp. 221-235.

Suemine, A., Kaibori, M., Wang, G., and Furuya, G. (2004): Preliminary investigation report on the landslide hazards on the upstream basin of Naka River, Tokushima Prefecture, triggered by the Typhoon No. 10, 2004. Landslide: Journal of the Japan Landslide Soc, Vol. 41, No. 3, pp. 87-89 (in Japanese).

Tokushima Prefecture (1983): Subsurface geological map: Kumosoyama. Naigai Map Co. Ltd., 33p.

平成 16 年台風 10 号による徳島県木沢村の土砂災害

王功輝・末峯章・古谷元・海堀正博*・佐々恭二

*広島大学総合科学部

要　旨

平成 16 年 7 月 25 日に発生した台風 10 号に伴って，徳島県南部地域では 7 月 30 日から 8 月 2 日までの 4 日間で連続降雨量が 2,000mm を超過する記録的な豪雨が発生した。この豪雨により，徳島県木沢村の大用知，加州，阿津江及び釜ケ谷地区で大規模な斜面崩壊が発生した。現地調査，計測を行った結果，これらの斜面崩壊が高速長距離運動となったと考えられる。また，阿津江地区の崩壊により崩壊地の背後に再滑動を始めた大規模な地すべりが生じたことが判明された。さらに，リングせん断試験機を用い，阿津江と釜ケ谷崩壊地から採取した試料に対して降雨による斜面崩壊の再現実験を実施した。その結果，地下水位が降雨により一定の値まで上昇することによって，崩壊が発生し，その後せん断に伴って水圧が急速に増加し，せん断抵抗が低い値まで低下したことが分かった。

キーワード：土砂災害，豪雨，台風 10 号，リングせん断，メカニズム