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CHARACTERISATION OF SLOPE FAILURES DURING THE 2004 NIIGATA-KEN CHUETSU AND THE 2007 NIIGATA-KEN CHUETSU-OKI EARTHQUAKE

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ABSTRACT :

Slope failures mainly occurred in costal terraces during the 2007 Niigata-ken Chuetsu-oki Earthquake because the earthquake centre was on coastal region in the north of Kashiwazaki City and Kariwa Village. On the other hand, hilly and mountainous areas suffered heavy damage from the 2004 Niigata-ken Chuetsu Earthquake although the distance of epicentre between those two earthquakes was only about 40 km. Topographical and geological characteristics of Chuetsu area were discussed comparing the damaged areas of both earthquakes in the paper. Typical slope failures during the Chuetsu-oki Earthquake including liquefaction in sand dune were reported in detail. In addition, soil samples were obtained from the sites of the slope failures in both earthquakes. Using the samples, physical and shear tests were conducted to elucidate the soils' strength properties.

KEYWORDS: geology, landslide, site investigation, topography, triaxial test, unsaturated soil

1. INTRODUCTION

At 17:56 on 23 October 2004, the Niigata-ken Chuetsu Earthquake whose main tremor was magnitude of 6.8 struck a mid part of Niigata-ken (Chuetsu area) and seriously damaged infrastructures of hilly and mountain area which are Kawaguchi town, Ojiya city, Nagaoka city, etc. (Fig. 1). This earthquake is an epicentral earthquake of thrust fault with hypocentre of about 10 km depth and characterised that frequent strong aftershocks led to increasing damage. After just three years, at 10:30 on 16 July 2007, the Niigata-ken Chuetsu-oki Earthquake whose main tremor was magnitude of 6.8 occurred on the offshore about 30 km northwest of epicentre of the Niigata-ken Chuetsu Earthquake. This earthquake is an epicentral earthquake of thrust fault with hypocentre of about 10 km depth and JMA Seismic Intensity was recorded "6 upper" in Kashiwazaki city, Nagaoka city and Kariwa village (Fig. 1).

Chuetsu area has been compressed in northwest-southeast directions due to the crustal movement and constituted folded mountains formed by quite young tertiary deposits (Fig. 2). During the Chuetu earthquake, numerous landslides occurred in Yamakoshi of Nagaoka city (formerly Yamakoshi village). Social problems developed when many towns became isolated because landslides cut off traffic and public service lifelines. Soil from landslides closed river channels and formed natural dams along the Imo River, which flows north to south in Yamakoshi. The natural dams submerged some towns and emergency measures were promptly undertaken to prevent debris flows caused by natural dam breaks.

The number of landslides during the Chuetsu-oki Earthquake is small comparing with that of the Chuetsu Earthquake. Slope failures concentrated in coastal terrace, which is located in the south of epicentre, because the earthquake occurred not under mountainous area but under offshore and the fault moved from the epicentre to the south direction. Other comparisons of both earthquakes are arranged in Table 1. The both earthquakes are very similar each other except for frequency of the aftershock. Figure 3 shows the number of aftershocks over M4.0 against elapsed days after the mainshock in recent Japanese epicentral earthquakes. The data used in Fig.3

were obtained from the Japan Meteorological Agency. The large difference between the both earthquakes is frequency of aftershocks. Although the aftershocks are very frequent in the Chuetsu Earthquake, they were extremely inactive. As many evacuees who escape from the fear of repeated large aftershocks had forced to live in inconvenient evacuation space, some of them suffered from phlebothrombosis referred as to "economy class syndrome" in the Chuetsu Earthquake.

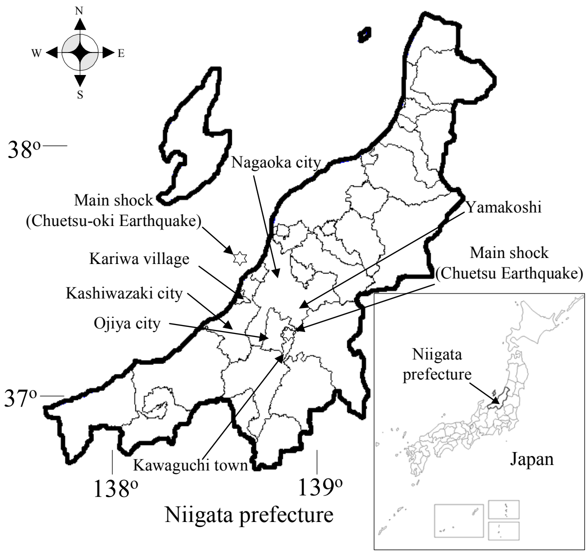


Figure 1 Map of Niigata prefecture

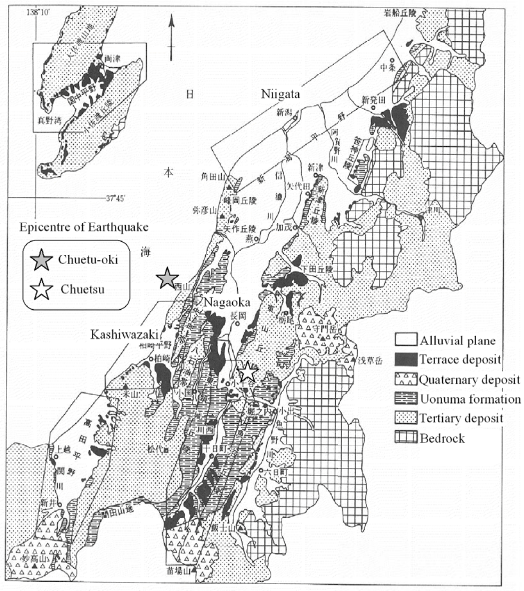


Figure 2 Geological feature (Niigata prefecture, 1989)

Table 1 Comparisons of the earthquakes (on Sep. 2007)

	Chuetsu Eq.	Chuetsu-oki Eq.
Date	23 Oct. 2004	16 July 2007
Epicentre	Chuetsu area	Chuetsu offshore
Depth	13 km depth	10 km depth
Cause	Thrust fault	Thrust fault
Magnitude	M6.8	M6.8
JMA Intensity	7	6 upper
Death	67	11
Damage	3 trillion Yen	1.5 trillion Yen
Aftershock	Frequent	Rare

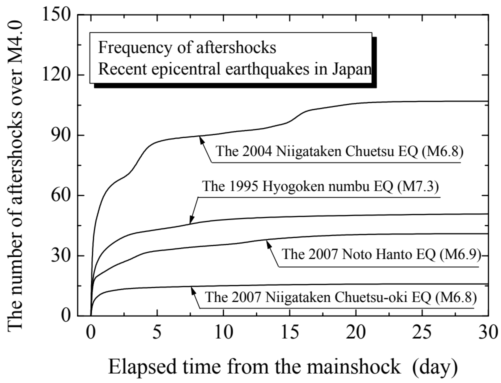


Figure 3 The number of aftershocks over M4.0 (Data from JMA)

2. CHARACTERISTICS OF SLOPE FAILURE

The locations of landslides during the Chuetsu Earthquake are shown in Toyota et al. (2006). It is understood that enormous number of landslides occurred during the earthquake, especially along the Imo River in Yamakoshi village. Some parts of the Imo River are submerged due to natural dams created by landslides. Several reasons of frequent landslides were reported in Toyota et al. (2006): 1. The unstable slops were created because the river had scoured the toe of the slope, 2. A complex topography in which synclinal axes and anticlinal axes are arranged with a short interval was formed and it is easily weathered, 3. Sandstone and sandy mudstone, which are soft and fragile, are distributed widely around this area.

Figure 4 shows the locations of landslides during the Chuetsu-oki Earthquake, based on the map provided by the Geographical Survey Institute. According to Ministry of Land, Infrastructure, Transport and Tourism as of 6 Aug. 2007, total number of slope failures is 108 during the Chuetsu-oki Earthquake. This number is considerable small comparing with 3,000 over during the Chuetsu Earthquake. The slope failures concentrated in the step slope of coastal terrace from Shiiya to Hijirigahana, which is quite long distance. Although almost of all slides were surface collapses, large mass movements rarely occurred in inland part such as Nagamine or Ohzumi. On the other hand, the landslides are hardly seen in inland part, which expands in the southwest of the Kashiwazaki plain and is formed by Yoneyama Formation.

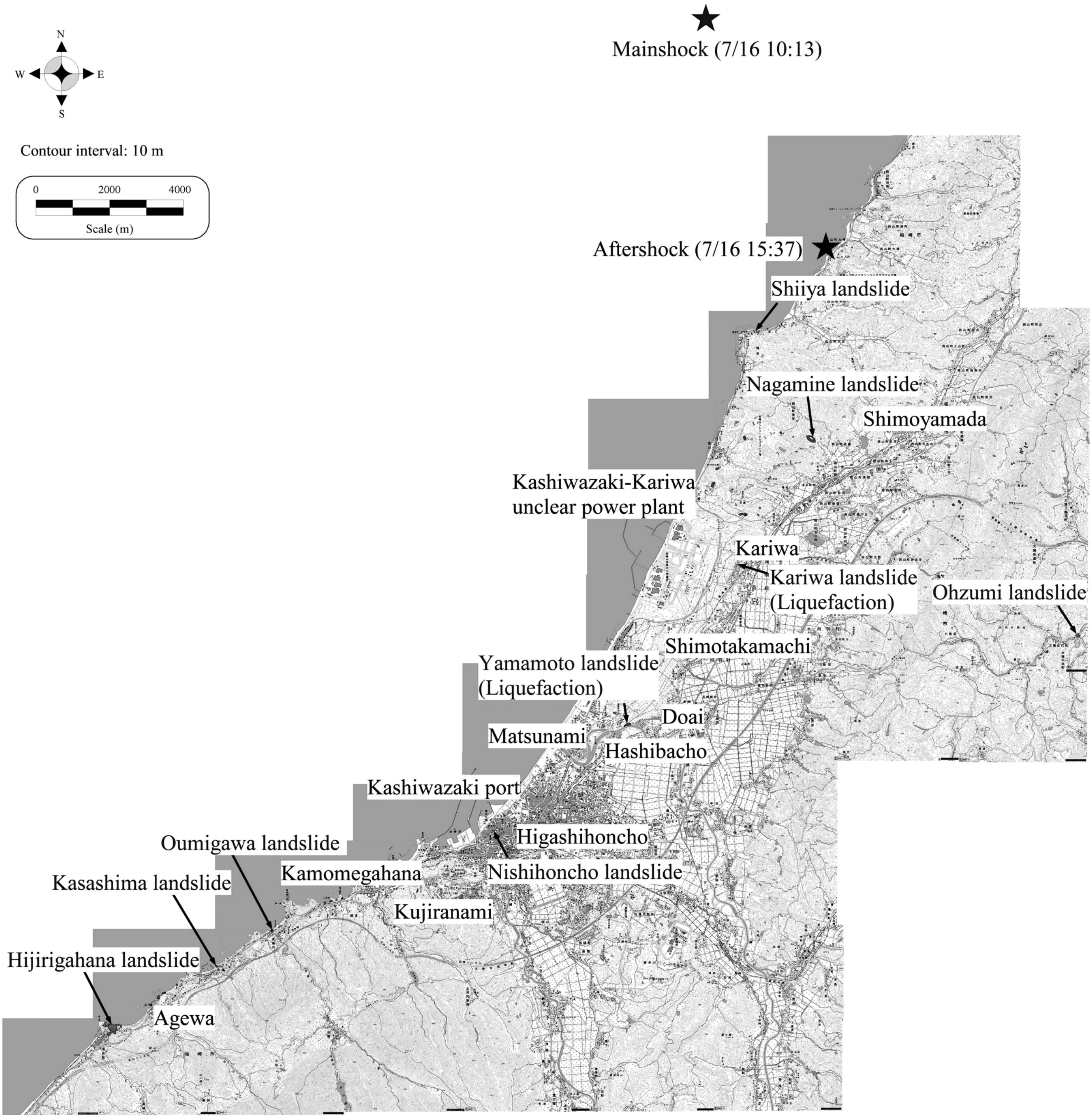
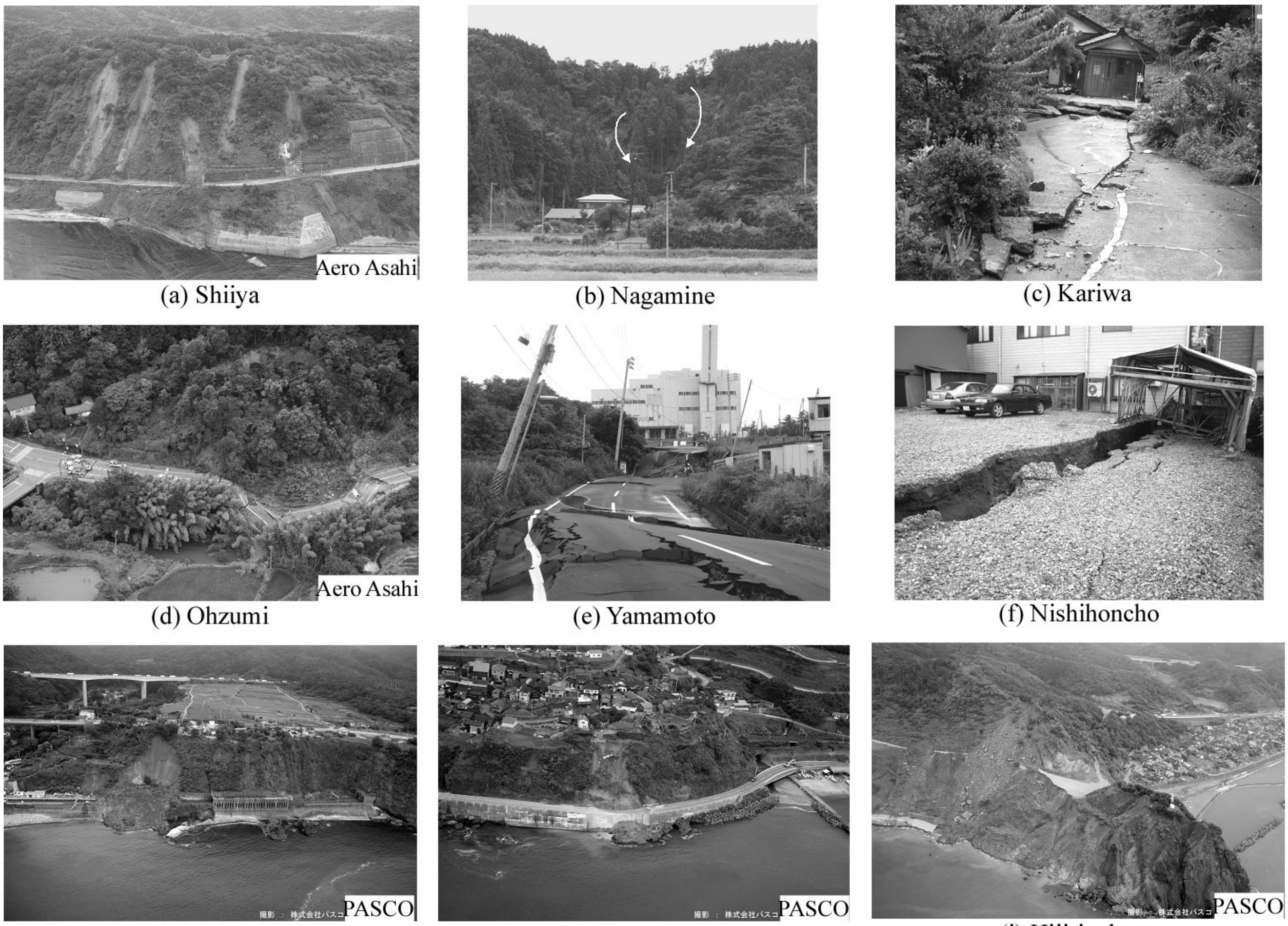


Figure 4 Landslide locations during the Chuetsu-oki Earthquake (provided by GSI)

Figure 5 shows the photographs of representative landslides during the Chuetsu-oki Earthquake. Several surface slope failures, which are about 10 m in width, about 3 m in thickness and 70 m in maximum length including sliding mass, occurred in Shiiya and the soil mass blocked the national road No. 352 as shown in Fig. 5 (a). This place is a cape that juts out into the sea and the steep slope of about 45 is a reverse-dip slope composed by alternation of sandstone and mudstone of the Shiiya Formation. Toyota et al., 2004 reported that similar slope failures in which weathering surface had collapsed in same geology and topography. It is understood that this type of slopes is in danger of earthquakes as well as heavy rainfall. Large scale of landslide occurred in Nagamine of Nagaoka city (Fig. 5 (b)). It is the only slide that broke out in a valley topography in all slides selected in the paper, whereas other slides occurred in convex topography. This place is designated specified as debris flow designated area. The slope is about 20° and the width is about 100 m and the length is about 210 m and the thickness is about 10 m. The dip slope is formed by alternation of sandstone and mudstone of the Nishiyama Formation. The slide occurred at the both side as shown using arrows in the Fig. 5 (b) and the smooth mud stone of about 30° and light grey colour appeared after the soil flew down. There is no apparent sign of movement in the soil mass remained in the centre. Lateral spreading due to liquefaction occurred at the edge of Arahama dune slope, where the dune is crossing with soft alluvial deposits, in Kariwa of Kariwa village and houses were damaged as shown in Fig. 5 (c). This area also had the same damage during the Chuetsu Earthquake. Some houses that seismically reinforced after the Chuetsu Earthquake suffered slight damage. It is considered that the cause of this damage was problematic ground composed of loose sandy soil with high underwater level.



(a) Shiiya (b) Nagamine (c) Kariwa
(d) Ohzumi (e) Yamamoto (f) Nishihoncho
(g) Oumigawa (h) Kasashima (i) Hijirigahana

Figure 5 Representative landslides during the Chuetsu-oki Earthquake

Mass movement landslide occurred in Ohzumi of Nagaoka city (Fig. 5 (d)). The landslide broke out at inland area by East comparing other major slope failures (Fig. 4). The size of moving soil mass was about 10m thickness, about 100 m width and length. The soil mass moved down with cut of National highway, route No. 8, and temporarily closed Kuro River, which streams at the bottom of the slope. The dip slope structure that inclines with the slope of about 25° is composed from thin sand and silt layers of Uonuma Formation. There was no damage during the Chuetstu Earthquake in spite of large tremor as the same as the Chuetsu-oki Earthquake. It might be considered that degradation and formation of slip surface progressed during the Chuetsu Earthquake in this slope. The unstable surface of moving mass was cut and removed for emergency repairs. Then, the road was quickly opened to traffic with two-lane a week after the earthquake. More than 2 m difference in level due to slide occurred at Yamamoto of Kashiwazaki city (Fig. 5 (e)). As shown in the centre of figure, chimney of a waste incineration centre fractured by the strong earthquake shaking. This area is located in the edge of Arahama dune bounded on Sabaishi River. It is considered that this deformation was caused by the lateral spreading due to liquefaction because of high underwater level. Yamamoto estate near this area was also damaged by liquefaction. More than 50 cm subsidence whose width is more than 100 m was formed in Nishihoncho 2-chome of Kashiwazaki city (Fig. 5 (f)). This area was inside Arahama dune enclosed with U River and the sea. The sliding area looks large because apparent damage was not seen in the retaining wall constructed on the steep slope and some displacement appeared in the gentle slope area located at the bottom of the steep slope. Although it is considered that the slide was induced by liquefaction of bottom of the slope, there were not liquefaction traces nearby. The slope failure occurred at the place adjacent to JR Oumigawa station (Fig. 5 (g)). The railway was buried by collapsed soil mass. Cracks appeared at the top of the slope and threaten people who live on the top of the slope. Sea cliff of about 45°, which is formed in a convex topography in plane surrounded by Tanne River and the sea, crumbled down in the range of about 40 m in width, about 50 m in length and about 5 m in thickness. The bedrock is mud and silt stone of Yoneyama Formation covered by river-bed and literal deposits. This slope is designated specified as prevention area of slope failure. Water soaks out from boundary of strata in knick line of the slope. It is considered that the strongly weathered surface broke down because collapsed soil was very soft without rock blocks and included plenty of water. Figure 5 (h) shows a slope failure occurred at a sea cliff of about 35° in Kasashima of Kashiwazaki city. The road was buried by collapsed soil mass and some people who live near the top of the slope had to evacuate. The slope is designated specified as prevention area of slope failure and the geology and the topography of this area are also similar as those of Oumigawa. The size of the failure was about 30 m in width, about 30 m in length and about 3 m in thickness. Weathered upper part of knick line of the slope mainly collapsed as shown in the figure. The base rock had appeared after the failure in the lower part of the slope. Slope failures took place in Hijirigahana, which is a cape in Yoneyama of Kashiwazaki city. Several failures occurred in a dip slope side that faces the sea and a failure, which threatened inhabitants in the bottom of the slope, also occurred in a reverse-dip slope side that lies in opposite side over the

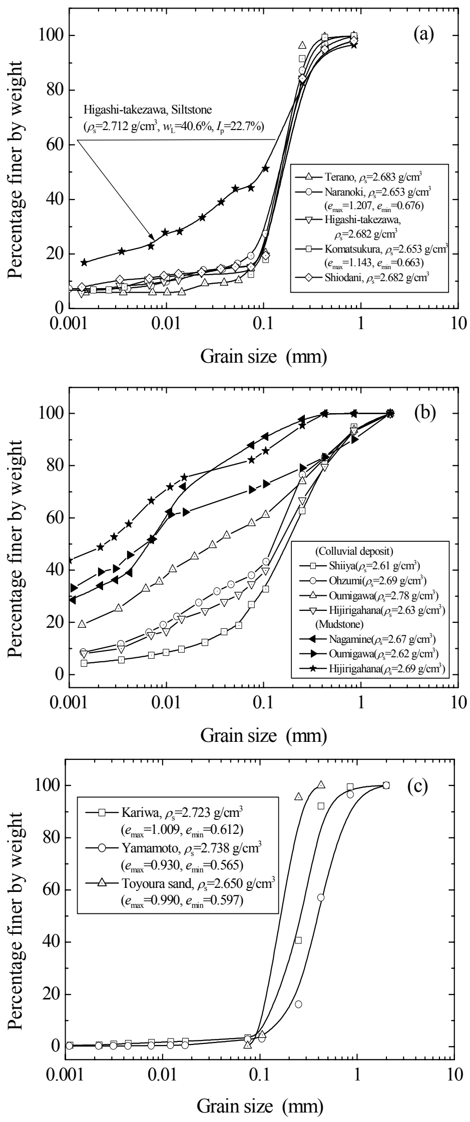


Figure 6 Grin size distributions obtained from failure sites: (a) Slopes (Chuetsu Earthquake), (b) Slopes (Chuetsu-oki Earthquake), (c) Arahana dune (Chuetsu-oki Earthquake)

ridge (Fig. 5 (i)). These failures are more than 30 km away from the epicentre. The size of the largest slide occurred in the dip slope was about 25° slope, 90 m wide, about 200 m long and about 10 m thick in upper part but thinner in lower part. Smooth sliding surface of grey mudstone that has about 28° inclination clearly appeared with striations, which present a frictional trace by sliding. According to Kashiwazaki city hall, in the same place, small slope failures had repeatedly occurred at every natural disaster such as heavy rainfall or the Chuetsu Earthquake. The same type of slope failure in Yokowatashi of Nagaoka city was reported by Onoue et al. (2006) during the Chuetsu Earthquake. Thus, rock sliding along smooth bedding plane and joint surface easily occurred during earthquakes.

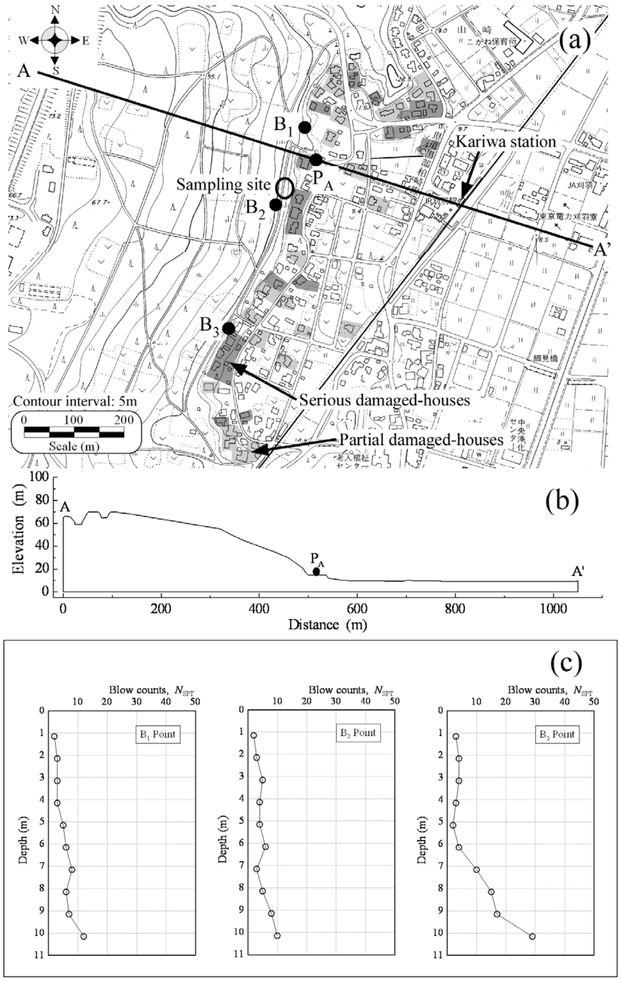


Figure 7 Topography map of Kariwa: (a) Plane figure, (b) Cross section, (c) Penetration resistance (Provided by Niigata Prefecture)

3. SOILS PROPERTIES OBTAINED FROM SLOPE FAILURE SITE

3.1. Grain size distributions of soils

Figures 6 (a), (b) and (c) show grain size distribution of the soil samples taken from slope failure sites in the Chuetsu and the Chuetsu-oki Earthquakes. All samples from the main scarps risen during the Chuetsu Earthquake are sand including less than 10% fines (Fig. 6 (a)). This means that sandy natural slopes are more fragile than clayey natural slopes during earthquakes. The exposed mudstone at Higashi-takezawa is composed mainly of silt; that is, siltstone. These results agree with information from the geological map, which shows alternation of sandstone and mudstone strata. The maximum and minimum void ratios based on Japanese industrial standards (JIS A 1224) are respectively 1.207 and 0.676 in Naranoki sand and 1.143 and 0.663 in Komatsukura sand. Figure 6 (b) shows grain size distribution of colluvial deposits and mudstones taken from natural slope failure sites in the Chuetsu-oki Earthquake. Mudstones contain much fine than colluvial deposits. Furthermore, the colluvial deposits have much fine content than those of Fig. 6 (a). This means that silty and clayey deposits were predominant in natural slope failure points during the Chuetsu-oki Earthquake comparing with the cases in the Chuetsu Earthquake. This aspect might be the reason why the number of failure sites in the Chuetsu-oki Earthquake is smaller than that in the Chuetsu Earthquake. Figure 6 (c) shows grain size distribution of soils in Kariwa and Yamamoto formed Arahama dune, which was damaged by liquefaction in the Chuetsu-oki Earthquake. For comparison, grain size distribution curve of Toyoura sand, which is Japanese standard sand, is also demonstrated in the figure. Those are pure sand whose fine content is less than 5 %. The maximum and minimum void ratios based on JIS A 1224 are respectively 1.009 and 0.612 in Kariwa sand and 0.930 and 0.565 in Yamamoto sand.

3.2. Mechanical properties of Kariwa soil

Mechanical properties of soils obtained from the residential area, Kariwa (Figs. 4 and 5 (c)), damaged by liquefaction were examined in detail. Topography map in plane and cross section of Kariwa and the *N*-values (N_{SPT}) of the ground are shown in Figs. 7 (a), (b) and (c), respectively. Point P_A in the figures show house that suffered a severe damage due to lateral ground displacement. An area of serious damaged-houses is coloured dark grey, while that of partial damaged-houses are light grey. Points B_1, B_2 and B_3 in the figures shows boring investigation point where the standard penetration test was conducted. This area is composed of Arahama dune, which formed a gentle slope of about 10% behind the residential area. From the result of the standard penetration test (Fig. 7 (c)), it is clear that Arahama dune is very soft as far as 10 m depth. Disturbed samples were obtained from the damaged site of Kariwa because the soil was too week to get block samples. Reconstituted specimens were made using the dry deposition method (Ishihara, 1993). Dry soil was filled in a cone-shaped slender funnel with a nozzle about 12 mm in diameter. This funnel was the same as that used for determining the maximum void ratio based on JIS A1224. The sand was accumulated in the mould with zero height of fall at a constant speed until the mould became filled with the sand. Then, the side of the mould was hit by hummer to make a given density of specimen. The dune was very loose because in-situ void ratios based on the core cutter method were 0.81 (D_r=50%) to 0.85 (D_r=40%). The grain size distribution curve, e_{max} and e_{min} of the soil are shown in Fig. 6 (c). Cyclic undrained triaxial tests of constant deviator stress amplitude were performed with constant axial strain rates of 0.1 %/min to examine the basic liquefaction behaviour of the soil. Furthermore, Cyclic constant volume direct (box) shear tests of constant deviator stress amplitude were also conducted with constant shear displacement rate of 0.1 mm/min to examine effects of initial shear due to slope on liquefaction. Specimen size and the testing procedures are the same as those in Komatsukura sand in triaxial tests. In direct (box) shear tests, specimens of d=60 mm in diameter and h=20 mm in height were used for testing in dry state without water saturation. After applying a certain vertical stress, cyclic constant volume direct (box) shear of constant deviator stress amplitude were performed with constant axial strain rates of 0.1 mm/min.

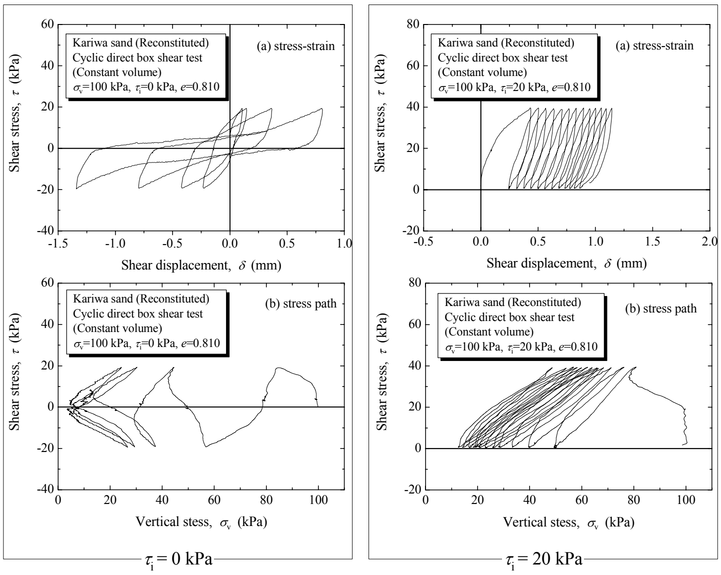


Figure 8 Effects of initial shear on cyclic shear behaviour in Kariwa sand

Figure 8 shows effects of initial shear on cyclic shear behaviour in Kariwa sand using direct (box) shear tests. In the case of no initial shear, similar cyclic behaviour with that of cyclic undrained triaxial tests is obtained in direct (box) shear tests. When the initial shear is applied, although amplitude of shear displacement does not exceed that without initial shear, large residual displacement occurred in the direction of initial shear. Important factor for estimating liquefaction damage is not only double amplitude of shear strain (displacement) but also residual shear strain (displacement). Figure 9 (a) shows the comparison of liquefaction resistance between Kariwa sand and Toyoura sand using the results of cyclic undrained triaxial tests. The relative density of Kariwa sand was set at about 46% that is close to the relative density of real ground. For liquefaction judgement, double amplitude of axial strain of 1% is used for cyclic undrained triaxial tests. It is understand that the ground composed from Kariwa sand is very liquefiable because the liquefaction resistance of D_r=46% Kariwa sand lies between those of D_r=44% Toyoura sand and D_r=55% Toyoura sand. Figure 9 (b) shows effects of initial shear on liquefaction resistance of Kariwa sand using the results of cyclic direct (box) shear tests under constant volume condition. The relative density of Kariwa sand was set to be close that of real ground. The relative density of Kariwa sand before shearing (D_r=49 - 52%) in the direct shear test was slightly higher than the average D_r=46% before shearing in the triaxial test. The slope behind the houses of Kariwa is about 10° (Fig. 7 (b)). The initial shear of 10 kPa and 20 kPa were applied to the specimen under vertical stress of 100 kPa. Occurrence of liquefaction is judged when double amplitude of shear or residual shear displacement reaches a certain value. Double amplitude of shear displacement or residual shear displacement of 0.5 mm is applied for liquefaction judgement in the case of cyclic constant volume direct (box) shear tests. Ishihara et al. (1977) demonstrated that liquefaction strength depended on the effective mean principal stress. Comparing Figs 9 (a) and (b), although the effective mean principal stress of the direct shear test is smaller than that of the triaxial test, cyclic strength of direct (box) shear tests is slightly higher than that of cyclic undrained triaxial tests. The reasons of this are that there may be the effects of the difference specimen's density and stress conditions. When the initial shear is high (τ=20kPa), liquefaction resistance is stronger than that of no initial shear. When the cyclic stress amplitude is small, liquefaction resistance is stronger than that of no initial shear in the case of initial shear of τ=10kPa. However, liquefaction resistance becomes weaker than that of no initial shear as the cyclic stress amplitude becomes larger. From this result, it will be necessary for softening and large deformation during cyclic loading that the cyclic shear stress develops to the reverse direction with the initial shear. This means that lateral displacement induced by liquefaction is increased in gentle slope comparing level ground when a strong shake due to earthquakes apply to the ground.

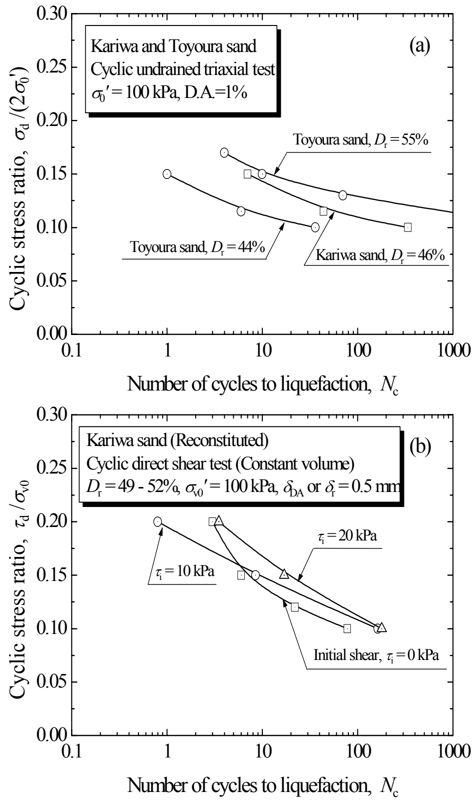


Figure 9 Effects of initial shear on liquefaction resistance in Kariwa sand: (a) Cyclic undraind triaxial test, (b) Cyclic direct shear test under constant volume

4. CONCLUSIONS

1. The magnitude, the mechanism and the place of the Chuetsu and the Chuetsu-oki Earthquakes are similar to each other except for frequency of the aftershock. The aftershock rarely occurred during the Chuetsu-oki Earthquake whereas that frequently occurred during the Chuetsu Earthquake.
2. The number of landslides during the Chuetsu-oki Earthquake is small comparing with that of the Chuetsu Earthquake. The reason might be that the earthquake occurred not under mountainous area but under offshore during the Chuetsu-oki Earthquake.
3. Silty and clayey deposits were predominant in natural slope failure points during the Chuetsu-oki Earthquake whereas sandy deposits were predominant during the Chuetsu Earthquake.
4. The dune of Kariwa is very loose and liquefiable deposit. The liquefaction damage due to lateral flow is amplified in gentle slope comparing level ground when the earthquake generates a strong shake.

REFERENCES

Niigata Prefecture (1989). Explanatory note of geological map in Niigata.
Ishihara, K. (1993). Liquefaction and flow failure during earthquakes, Géotechnique, Vol. 43, No. 3, pp. 351-415.
Ishihara, K., Iwamoto, S., Yasuda, S. and Takatsu, H. (1977). Liquefaction of anisotropically consolidated snad, Proc. 9th ICSMFE, Vol. 2, pp. 261-264.
Onoue, A., Wakai, A., Ugai, K., Higuchi, K., Fukutake, K., Hotta, H., Kuroda, S. and Nagai, H. (2006). Slope failures at Yokowatashi and Nagaoka College of Technology due to the 2004 Niigata-ken Chuetsu Earthquake and their analytical considerations, Soils and Foundations, Vol. 46, No. 6, pp. 751-764.
Toyota, H., Wang, J., Nakamura, K. and Sakai, N. (2006). Evaluation of natural slope failures induced by the 2004 Niigata-ken Chuetsu Earthquake, Soils and Foundations, Vol. 46, No. 6, pp. 727-738.
Toyota, H., Nakamura, K. and Sakai, N. (2004). Evaluation of dike and natural slope failure induced by heavy rainfall in Niigata on 13 July 2004, Soils and Foundations, Vol. 46, No. 1, pp. 83-98.