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TRACES OF LIQUEFACTION UNDER THE SHINANO RIVER BANK DURING THE 1964 NIIGATA EARTHQUAKE

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ABSTRACT

Lateral ground spreading is a phenomenon caused by liquefaction during earthquakes. During the 1964 Niigata earthquake, the Shinano River bank moved several metres towards the river centre because of lateral spreading. To explore evidence of this lateral spreading, in 2005, 41 years after the earthquake, we conducted a soil investigation of the left upstream riverside of the Showa Bridge using a pile-type soil sampler called the Geoslicer. The Geoslicer consists of a sample tray and a shutter plate that are driven into the ground sequentially using a weighted vibrator. This progressive technique was developed in Japan to allow a cross-section of the underground soil profile to be visualized. At the investigation site, the lengths of the driven sheet piles were 7.5 m; in all, 10 piles were used, including 2 longitudinal pieces and 8 transverse pieces. Detailed observations of the peeled sample showed typical traces of liquefaction, such as dikes of fluidized sand, water-escape structures, and deformation structures of the lower part of alternating strata of clay and silt overlying a liquefaction sand layer. A cyclic triaxial test of the undisturbed sand specimen sampled by this technique proved that the sampling technique was effective in that it maintained the in-situ mechanical properties of sand deposits.

Keywords: Liquefaction evidence, 1964 Niigata earthquake, Field investigation, Lateral spreading

INTRODUCTION

The Niigata earthquake is famous for the tremendous amount of damage caused by liquefaction phenomena. It raised awareness among geotechnical engineers of earthquake-induced liquefaction. Among the types of liquefaction damage, lateral spreading is recognized as a phenomenon in which large ground deformation continues after the earthquake. Residual deformation during the earthquake is sometimes called “permanent displacement”. The permanent displacement caused by lateral spreading was determined through a comparison of aerial photographs taken before and after the earthquake (Hamada et al., 1986, 1992).

In recent years, it has also become known that the foundation piles of bridge were affected by lateral spreading. However, because the lateral spreading mechanism remains unclear, pile foundation design incorporating countermeasures against lateral spreading remains problematic (JGS, 1998). One major obstacle is that the lateral deformation distribution under the ground, which is indispensable information for practical earthquake-proof design of foundation piles, has yet to be clarified.

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Uncertainty also clouds the issue of whether ground deformation occurs mainly during earthquake motion or after the motion terminates because permanent displacement caused by flow failure has been generally recognized through a comparison of aerial photographs taken before and after the earthquake. However, past damage experience has shown that ground deformation caused by liquefaction sometimes occurs after the earthquake motion terminates. For example, apartment houses near the Shinano River continued tilting for 10–20 min in the aftermath of the Niigata earthquake (Kawakami & Asada, 1966). It is impossible to explain this kind of progressive failure as an inertial effect of seismic shaking.

Recently, several researchers have suggested the possibility of shear failure (including the water film effect) caused by the seepage of pore water after an earthquake (Fiegel et al., 1994; Dobry et al., 1995; Boulanger et al., 1996; Kokusho, 1999; Tokimatsu, et al., 2001; Sento et al., 2004). These studies showed, experimentally, that pore-water inflow causes shear failure of soil that is subjected to constant shear stress.

As described above, uncertainties remain about lateral spreading phenomena. Where and when does the ground move? In this study, the authors attempted to find traces of liquefaction, especially lateral spreading, which have remained under the Shinano River banks since the 1964 Niigata earthquake four decades ago.

INVESTIGATION SITE

Location of the investigation site and outline of the damage around there

Figure 1 shows the investigation site location and a photograph of the collapsed Showa Bridge. The Showa Bridge is located at the Shinano River mouth in Niigata city. Damage to the bridge was especially concentrated on the left-bank side, affecting both its superstructure and substructure: the five span simple girders collapsed and plastic deformation of the pier piles was apparent (JSCE report, 1966). According to an eyewitness account, the collapse of girders occurred one to two minutes after the end of the main shock. The impression of the witness was that the seismic motion might have caused the toppling of the first collapsed girder, but there was a marked time delay before the other girders collapsed. The photo is believed to have been taken from the left bank of the river, near the investigation site.

Figure 1. Showa Bridge collapsed at the 1994 Niigata earthquake and the location (taken by Emeritus Prof. Kuranishi, Tohoku University, Japan)

Figure 2 shows the permanent deformation along the river near the site, as determined by Hamada et al. (1986). Around the investigation site, about 8 m displacement towards the river center was observed. Consequently, it can be inferred that the pile sustained severe damage from lateral spreading.

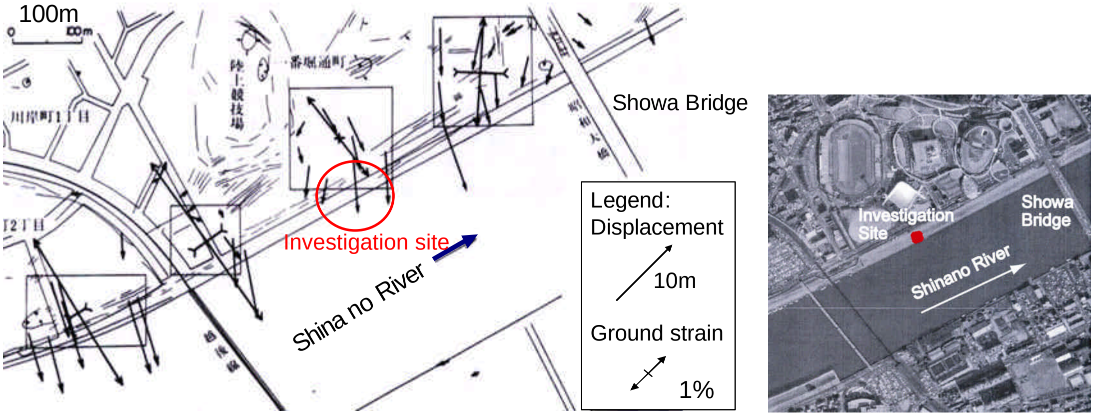

Figure 2. Permanent ground deformation measured after the earthquake near the site (after Hamada, et al. ,1986, 1992)

History of the investigation area

Before the soil investigation, the authors examined old geographical maps that had been compiled as early as in 1912. Figure 3 shows four of those maps. According to the historical records, the area is a typical lowland area in the Niigata alluvial plain and has suffered flooding repeatedly from ancient times. The Ohkouzu Diversion Channel was planned in the 19th century and completed in 1922 to channel flood waters rapidly to the Sea of Japan. Consequently, the Shinano River basin is rich and fertile, and this has contributed to the region's development. In the 1912 map, a small sand bar was visible in the river around investigation site. In those times, the river width was over two times what it is at present. In addition, Kawagishi-cho, where the tilted apartment building once stood, was apparently a river area in those times. A comparison of the 1912 maps and the 1931 map shows that the sand bar was developed and that the river narrowed in width during that period. The 1968 map, produced four years subsequent to the 1964 earthquake, is almost the same as the 1997 map, except for the Sekiya Diversion Channel, completed in 1912 (visible on the left side of the 1997 map). What is now the left riverbank was riverine until about 70 years ago. The investigation site is a reclaimed area.

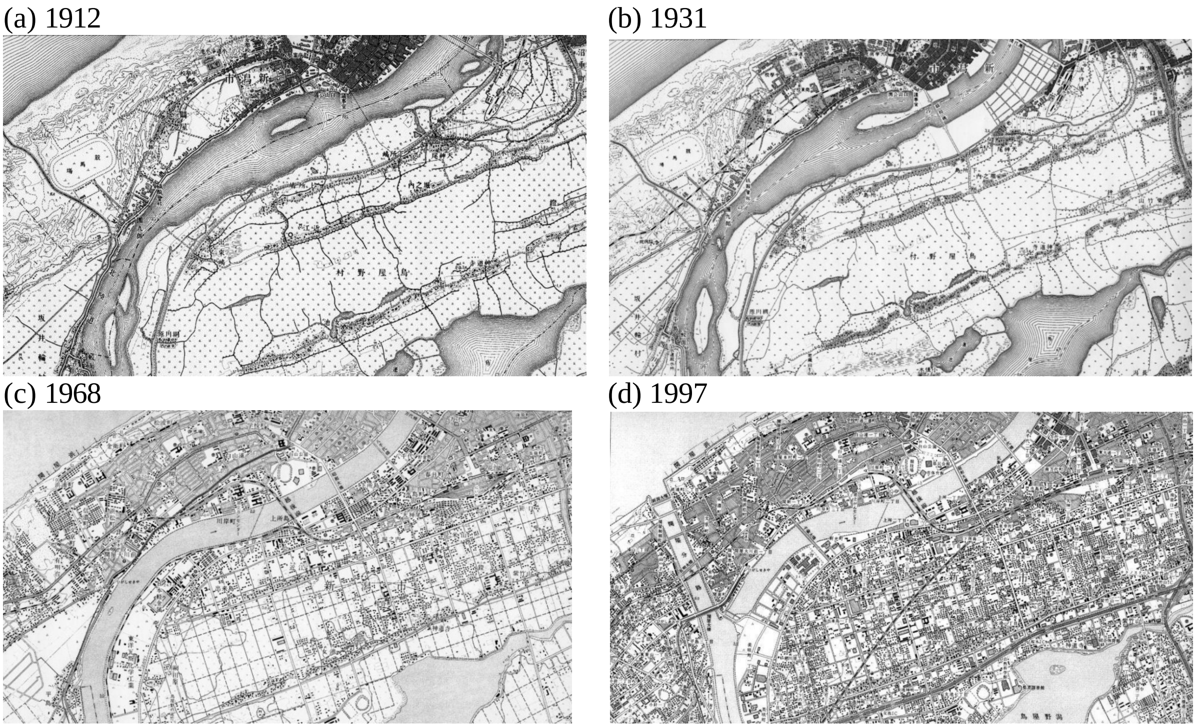

Figure 3. Ground history of the investigation site around the Showa Bridge (1/25000 map of southern Niigata published by the Japanese Geographical Survey Institute)

SOIL INVESTIGATION METHOD

Soil investigation method – Geoslicer

Figure 4 shows photographs of the soil investigation device, called the Geoslicer. This technique was developed in Japan and has been used for geological investigations of landslides, faults, and liquefaction identification (e.g., Nakata and Shimazaki, 1997, Haraguchi et al., 1998, Takada and Atwater, 2004). An outline of the procedure is as follows:

1) A steel sheet pile is inserted into the ground using a weighted vibrator, as shown in the left panel of the figure. Figure 5 shows that this sheet pile plays a role as a sample tray after it is pulled out. Generally, all the sheet piles are driven in first.
2) A shutter plate is then driven in to cover the sample soils, as shown in the right panel. The dimensions of the sheet pile used in this study are shown in the figure.
3) Figure 5 shows that the sheet pile and shutter plate are pulled out together from the ground and that the shutter plate is removed after being placed on the ground surface.
4) After removing the disturbed surface of the soil sample, the soil profile can be observed directly. A peel can be also made in order to keep the samples, if necessary.

Figure 4. Photographs of sheet pile driving and a schematic diagram of the sampling system

Figure 5. Pulled out sheet piles

Arrangement of inserted steel sheet piles for soil sampling

Figure 6 shows a cross-section of the investigated bank. After the earthquake, the riverbank was restored and is open now to the public as an amusement area. In the restoration and construction process, the bank was filled with dredged soil from the riverbed, as shown in Fig. 6. Therefore, there was a depth of several metres of fill material from the surface at that time. In this investigation, the driven sheet pile was about 7.5 m long and there were 10 piles in total, consisting of 8 transverse pieces from GS-1 to GS-8, and 2 longitudinal pieces of GS-9 and GS-10. Ordinary boring and Swedish cone tests were also carried out around the Geoslicer. Figure 6 shows that the additional boring was carried out about 20 m away on the downstream side.

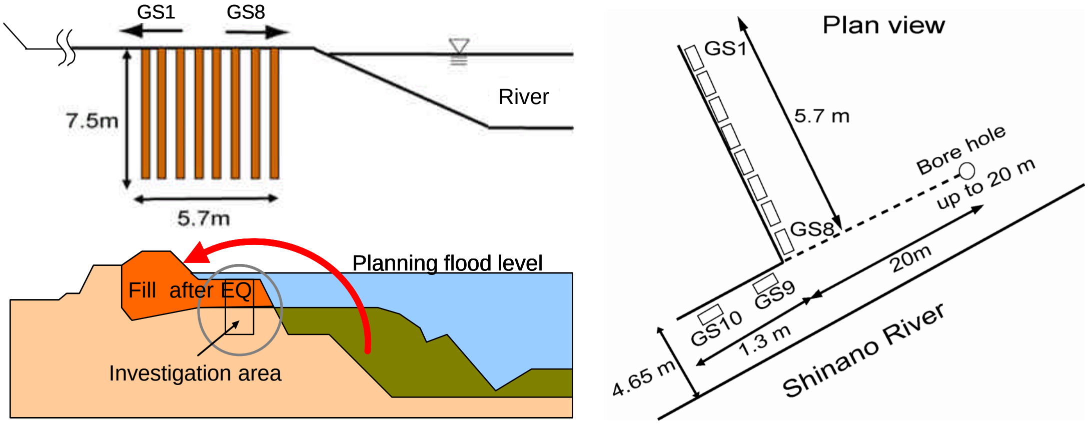

Figure 6. Cross section and plane view of ground investigation

RESULTS OF THE INVESTIGATION

Summary of strata in Geoslices

Figure 7 shows an overall cross-section of the investigation area. Generally, the ground from the surface to G.L.-7.5 m is divisible into three strata. The first stratum is artificial fill from the surface, to -3 m or -4 m. This stratum comprises dredged earth material that was put in place when the present riverbank was constructed. No depositional structure was apparent in this region. The boundary line to its underlying stratum is clear in appearance of round stones and gravel.

The second stratum, from -3 or -4 m to -6 m, displayed alternating clay, silt, and sand layers. That alternation indicates repeated flooding when it had been river. The alternating stratum is comprised of about 25 layers. This stratum is considered to be alluvial because there are no remains of oceanic organisms. According to dating by the isotope carbon on the organic matter sampled from G.L.-6.0 m to -6.1 m in GS-8 of silt layer, its age was estimated at 1833±116 A.D. Therefore, this alternating stratum is young and might include sediments that were deposited after the Ohkouzu Diversion Channel was constructed. Furthermore, it is noteworthy the only large earthquake event this stratum had experienced was the 1964 Niigata earthquake: no other historical large earthquake event has struck Niigata City in the last 200 years.

The third stratum is sandy soil. According to conventionally obtained boring data, this stratum continues for more than 20 m, sometimes containing coarse and medium-coarse sand, and with organic silt from G.L. -16.5 m to -16.8 m. The SPT-N values of this stratum were 5–20. In the geoslices, especially in GS-10, many mud clasts were observed in the sand layer. The age of the mud clast was judged as 1733±49 B.C. by dating. The mud clast differs from the overlying clay and silt. In the following section, as a matter of course, the authors specifically examine the bottom two strata.

Distribution of soil particle size in the depth direction

Figure 8 shows the soil classification in the depth direction. In the left figure from -3 m to -5 m of GS-1 and the middle figure from -4 m to -5 m, the clay fraction was identified using a micro-track analyzer. In strata deeper than -6 m, an ordinary grain size distribution analysis with a sieve was used. One feature is the high amount of silt, despite it being sandy soil.

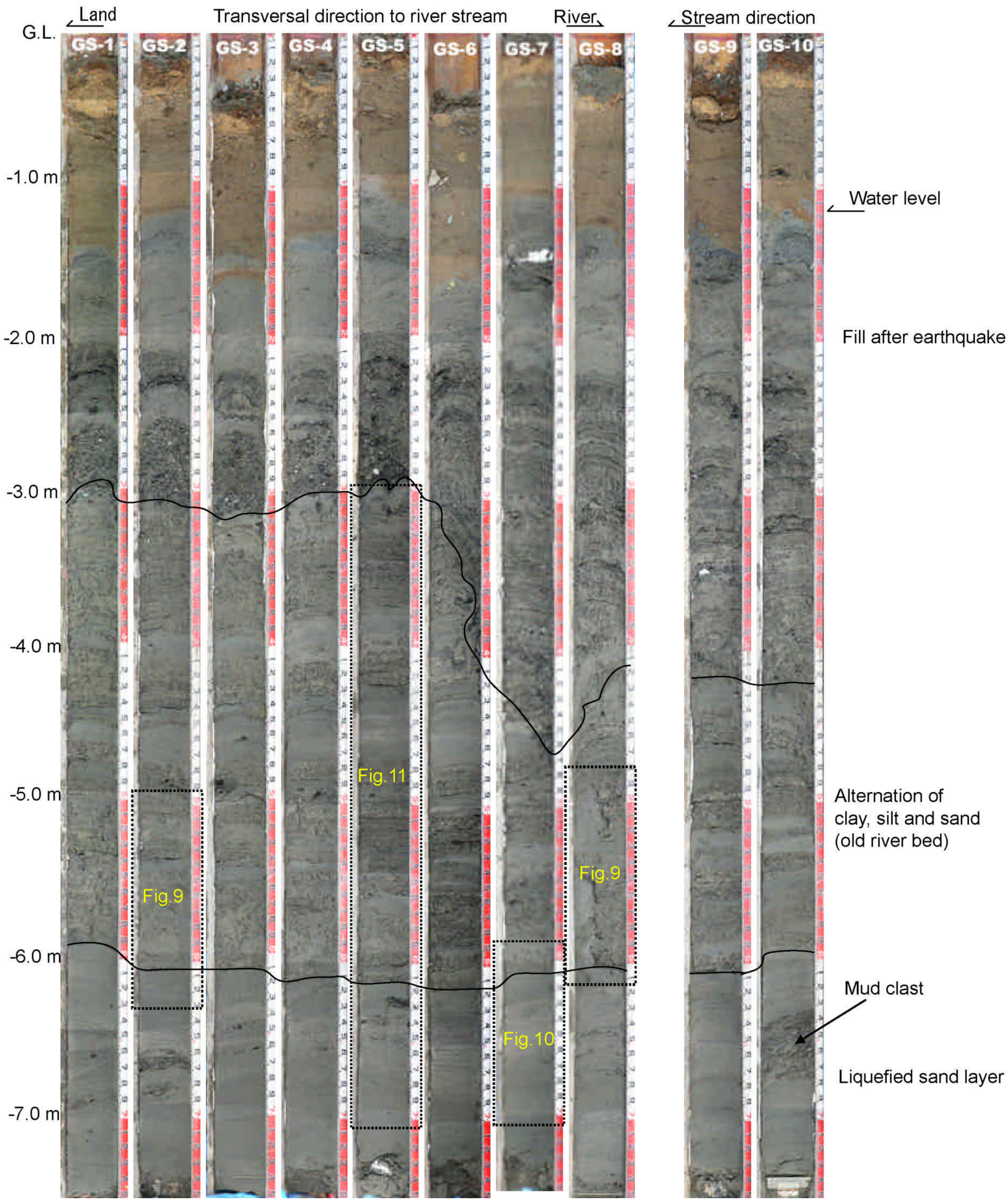

Figure 7. Overall cross section of investigation area; the detailed photograph can be seen in the following web page; http://soil1.civil.tohoku.ac.jp/shinanogawa

Typical soil structure observed in the Geoslices

Dike of fluidized sand

Dikes of fluidized sand (injected sand from the underlying liquefied sand layer) were observed in several Geoslices. Figure 9 shows examples of GS-2 and GS-8. In addition to the actual photograph, a figure with adjusted colour tone is also shown on the left side. These are traces of liquefaction of the underlying sand layer. It is also apparent that no depositional structure exists in the sand intrusion. As an example of GS-2, the fine silt layer around -5.3 m impeded the upward flow of liquefied sand. The initial deposition structure of the alternation of clay, silt, and sand in the sand injection zone is strongly disturbed.

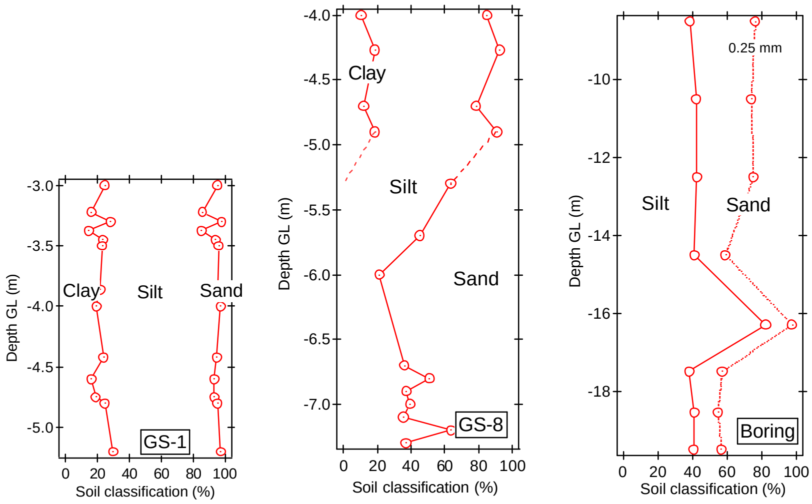

Figure 8. Distribution of soil particle size in depth direction

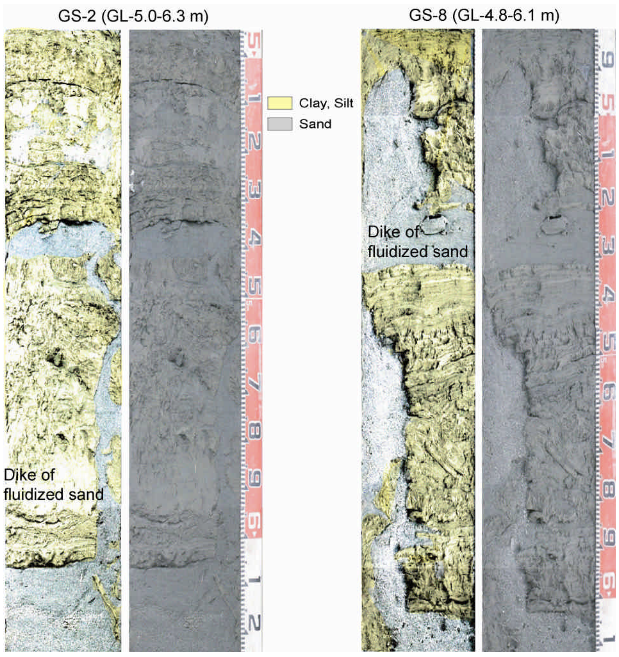

Figure 9. Example of the dike of fluidized sand observed in GS-2 and GS-8

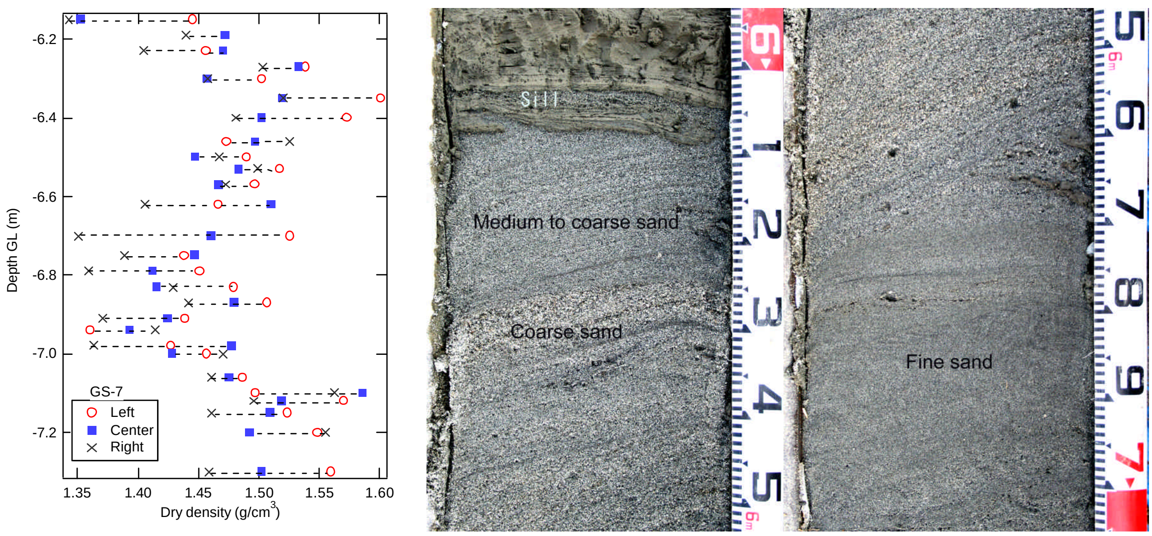

Figure 10. Deviation of dry density at one metre, from 6.2 m to 7.2m in GS-7

Dry density of the sand layer immediately beneath the silt layer

Several experiments have shown that a water layer might form beneath a bed of a low permeability layer that traps fluid expelled from the liquefaction of underlying sand (Liu and Qiao, 1984; Anegawa and Miyata, 2001; Kokusho, 1999). Therefore, the authors specifically examined the interface between the bottom silt layer and the liquefied sand layer. Figure 10 shows a section of the GS-7 slice and the dry density of sand. The sand layer includes several kinds of sand composed of different-sized grain particles. The dry density was measured at the site from the undisturbed soil sampling from three points extending from left to right. The dry densities were scattered: varying from 1.35–1.50 within one metre. The dry density at the point immediately beneath the silt layer around -6.1 m and that of fine sand around -6.8 m was low compared to that at other points containing coarse sand. Careful examination of the interface between the bottom silt layer and liquefied sand layer revealed a sill that was injected into the silt laminar at a low angle. In the sill and the portion immediately under the bottom silt layer, no bedding structure was found in comparison to that in the deeper zone. This kind of structure might result from the water formation trapped by the low-permeability layer.

Water escape structure

The left photographs show the water-escape structures observed in GS-5. This kind of structure is known to be formed during the upward migration processes of water. It might be formed in cases where the sediment structure is strong.

Deformation structure of the lower part of the alternating stratum overlying the liquefied sand layer

The photograph shown at the bottom right depicts the deformation structure of the lower alternating stratum. The initial horizontal deposition structure is disturbed greatly by folding. This zone might have been deformed horizontally during the Niigata earthquake, engendering lateral spreading. In contrast, in the upper part of the alternating stratum, the initial deposition structure remained, as shown in the upper right photograph.

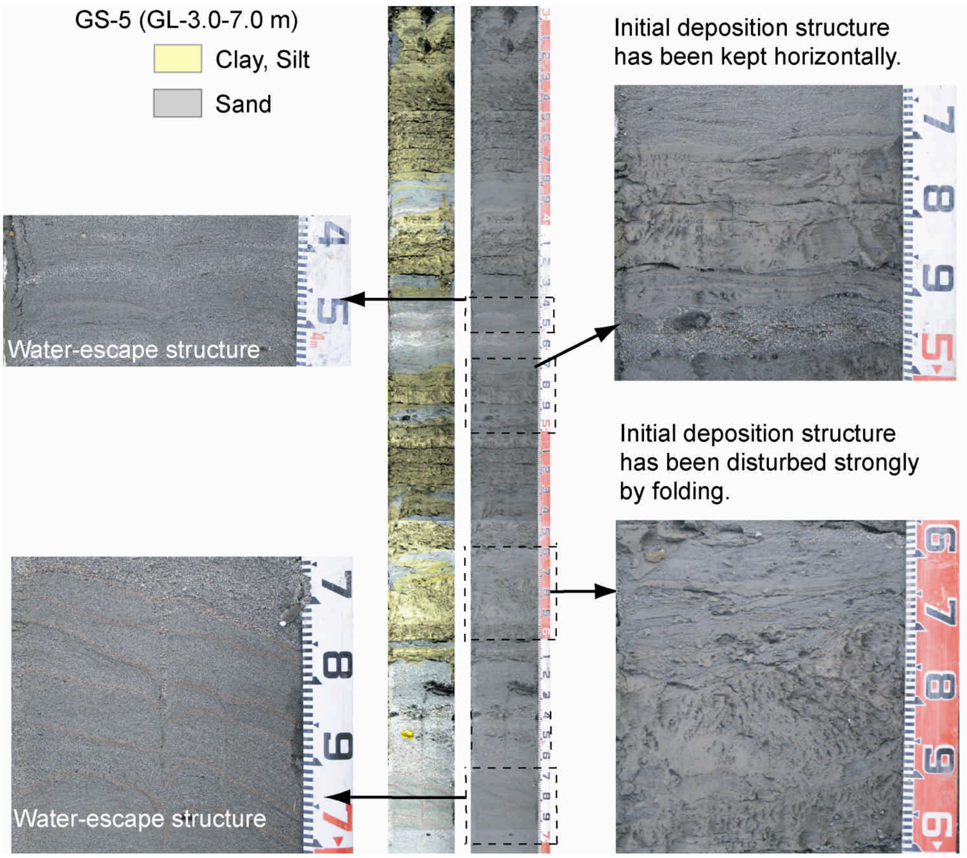

Figure 11. Typical deformation structures found in the GS-5

Cyclic triaxial tests for the Geoslicer sand sample

Cyclic triaxial tests were conducted for both undisturbed sand samples from Geoslices and the reconstituted sand specimens equalized to the same density as undisturbed sand areas to elucidate the cyclic shear strength of the liquefied sand layer. The undisturbed sand was sampled manually from the soil sampler, as shown in Fig. 12, and was frozen at the site. The test was a cyclic triaxial strain-controlled type test (detailed procedures and concepts are described in the literature {Kazama et al., 2000}). On the right side of Fig. 12, the applied cyclic shear strain history is shown.

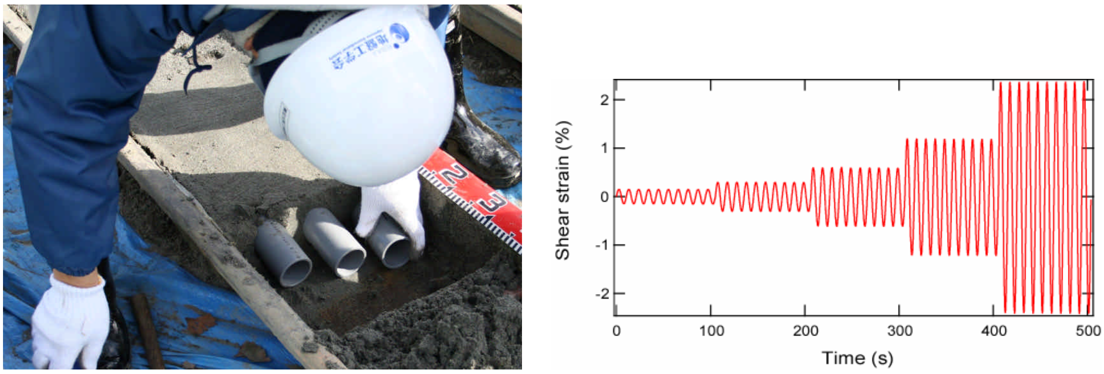

Figure 12. Sampling method and applied cyclic shear strain of triaxial test

Figure 13 shows a comparison of the results for the undisturbed and reconstituted specimen. The shear stress response of the reconstituted sand decreased more rapidly than that of undisturbed sand when the same shear strain was applied under the undrained condition. The excess pore water pressure of reconstituted sand also developed more rapidly than the undisturbed one. These performances show that reconstituted sand was weaker than undisturbed sand against cyclic shear. From this result, undisturbed sand samples are considered to retain the soil particle structure formed under in-situ conditions (i.e. aging effects). The Geoslicer seems to be an effective sampling method that imparts minimal disturbance to loose sand deposits.

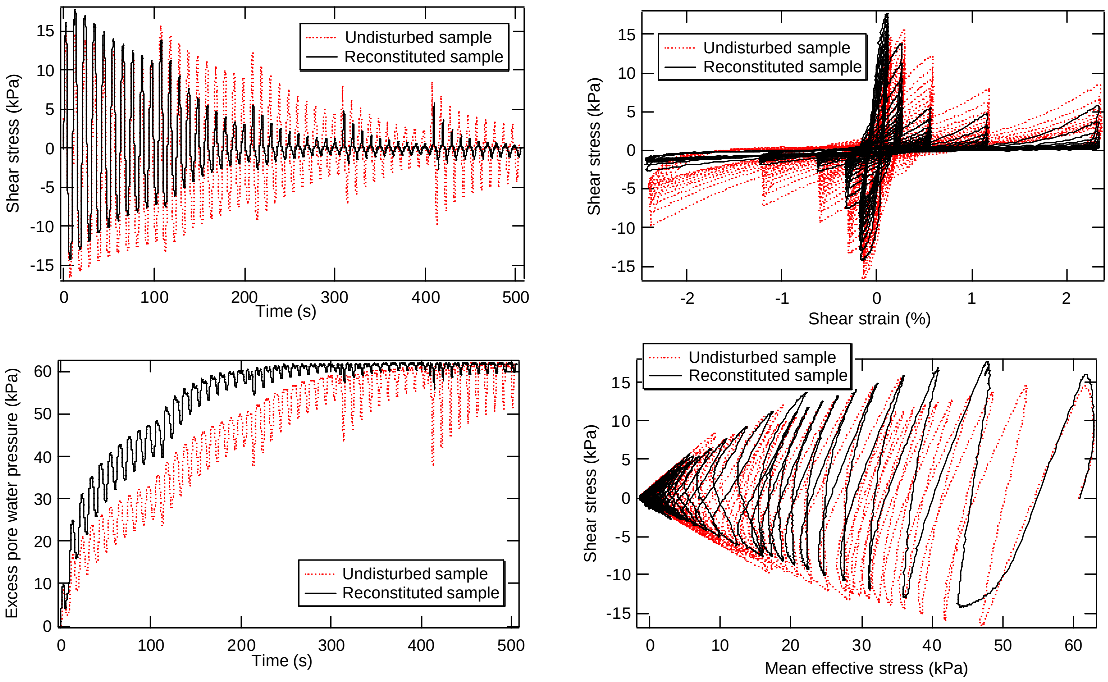

Figure 13. Comparison of the results of cyclic triaxial test between undisturbed and reconstituted sand

CONCLUSIONS

The authors conducted a field soil investigation using a Geoslicer at the left bank of the Shinano River to explore traces of liquefaction-induced lateral spreading during the 1964 Niigata earthquake. The salient conclusions obtained from this study are the following.

1. The investigation site ground consists of three strata: fill material when the present bank was constructed from G.L. to G.L. -3 or -4 m; a stratum of alternating clay, silt, and sand from G.L. -3 or -4 m to 6 m; and the sand stratum from G.L. -6 m to at least -20 m. The sand layer was identified as a liquefied layer because of evidence of a sand dike of fluidized sand.

2. In addition to the dike of fluidized sand, typical deformation structures caused by liquefaction, such as the water escape structure, a sill at the interface between the bottom silt layer and the liquefied sand layer, and deformation of the silt layer overlying the liquefied sand layer were apparent in the geoslices. Considering the land history of the investigation site, the natural disaster history of the Niigata City, and the dating of deposit organic matter, it is implied that these deformation structures were formed during the 1964 Niigata earthquake.

3. A comparison of the results of the cyclic triaxial test show that the undisturbed sand has higher resistance to cyclic shear than reconstituted sand. The Geoslicer was found be an effective sampling method that imparts little disturbance on loose sand deposits.

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