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Ground damage caused by 2007 Niigataken Chuetsu-oki Earthquake

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ABSTRACT

On 16 July 2007, an earthquake of magnitude 6.8 occurred with an epicentre off the west coast of Niigata Prefecture (Japan), causing widespread damage to buildings and other types of civil engineering structures due to ground shaking and earthquake-induced ground failures. This paper briefly presents the results of the post-earthquake damage investigation conducted in the affected area after the earthquake, with emphasis on the seismic-induced ground failures.

1 INTRODUCTION

A large earthquake, with magnitude M_{JMA}=6.8 (M_w=6.6) occurred at 10:13 AM on 16 July 2007 off the coast of Chuetsu Region, Niigata Prefecture. The earthquake, with focal depth of 17 km, had an epicentre located offshore, about 60km southwest of Niigata City. The earthquake registered a Japan Meteorological Agency (JMA) seismic intensity of 6+ (about IX in MMI scale) in Kariwa Village, Kashiwazaki City and Nagaoka City (all in Niigata Prefecture) and in Ohzuna Town (Nagano Prefecture). A seismic intensity of 6- was also registered in three other areas (Figure 1). At about 15:37 of the same day, a large aftershock, with magnitude M_{JMA}=5.6, also occurred with focal depth of 10 km.

As a result of the quake, 15 people were killed and 2315 people were injured. In addition, 1319 houses in Niigata Prefecture totally collapsed while another 857 houses suffered extensive damage (Niigata Prefecture, 2007). Major lifelines, such as gas, water and electricity, were affected and suspended for more than one day in several areas. In Kariwa Village, a large nuclear power plant was reportedly damaged due to the large ground shaking. More than fifty cases of landslides and other slope failures were reported, and liquefaction was observed in several areas near the coasts.

Note that another earthquake (officially called the 2004 Niigataken Chuetsu Earthquake) jolted the region on 23 October 2004, with epicentre about 30km from the present one. This earthquake caused large number of landslides in the mountainous region near the epicentre and forced local authorities to suspend operation in 233 segments of national and prefectural routes.

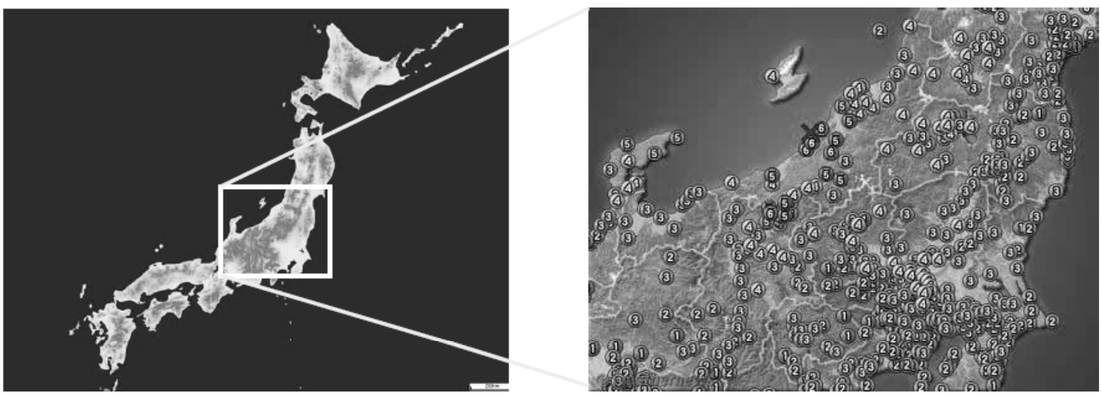

Figure 1: Location of earthquake epicentre and distribution of seismic intensities

This paper gives a brief summary of the post-earthquake investigation results performed in the area a week after the disaster, with emphasis on the geotechnical features of the earthquake.

2 GEOLOGY AND TOPOGRAPHY

The topography of the Chuetsu Region is characterized by rivers and ridges of hill extending from north-northeast to south-southwest. This region is well-known to be one of major landslide areas in Japan. Sedimentary rocks after the Neocene are distributed thickly. They are classified as "soft rocks" and are intercalated by unconsolidated mudstone and tuff layers, making them susceptible to earthquake-induced landslides.

Kashiwazaki City is located in a flat river valley at the centre of the coastline in Niigata Prefecture and in the Kariwa Plain. The city is surrounded by mountains and spreads over a set of sand dunes, which has been elongated along the coast in such a way that the mouths of both Ugawa River and Sabaishigawa River (two major rivers flowing into Japan Sea) are bent southwest. Sand, silt, mud and other suspended matters that have been carried by these two rivers over centuries have been deposited southeast behind the sand dunes. The urban areas of Kashiwazaki City were built over these soft alluvial deposits.

3 STRONG MOTION RECORDS

The earthquake triggered many strong motion recorders installed throughout the affected area. Figure 2 shows the records obtained by K-Net in Kashiwazaki City, where a JMA seismic intensity of 6+ was recorded. It can be observed from the records that the horizontal components show spiky response, which is typically observed in dense sands undergoing a state of cyclic mobility due to liquefaction. Peak accelerations are observed in the time period between 25-28 sec when the spikes are predominant. The maximum values recorded in this site were 667, 514 and 369 cm/sec^2 in the NS, EW and UD directions, respectively. The duration of shaking lasted for about 10 sec. A check on the soil profile at the site revealed dense sandy soil (SPT *N*-value > 20) between GL-3m to -13m. Near the station, large cracks were observed on the asphalt roads, indicating the occurrence of lateral spreading in the downslope direction.

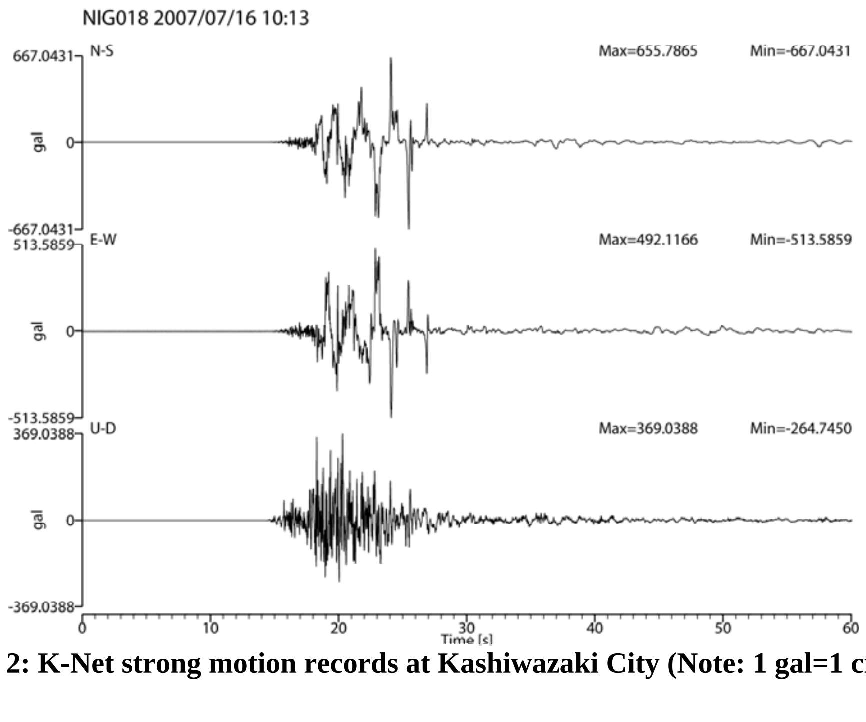

Figure 2: K-Net strong motion records at Kashiwazaki City (Note: 1 gal=1 cm/sec^2)

Table 1 compares the maximum PGAs recorded during this earthquake and those registered during other recent earthquakes in Japan. It can be observed that with the exception of those recorded during the 2004 Niigataken Chuetsu Earthquake, the PGAs during this earthquake are remarkably of the same level as those observed in other recent large-scale earthquakes.

Table 1: Comparison of peak ground accelerations recorded during this earthquake and other recent earthquakes in Japan.

Earthquake	Seismic Station	Maximum Acceleration (cm/sec^2)		
		N-S	E-W	U-D
2007 Niigataken Chuetsu oki Earthquake	K-Net Kashiwazaki	667	514	369
	K-Net Ojiya	391	455	116
2007 Noto Hanto oki Earthquake	K-Net Anamizu	473	782	556
	K-Net Togi	717	849	462
2004 Niigataken Chuetsu Earthquake	JMA Kawaguchi	1142	1676	870
	K-Net Ojiya	1144	1308	820
2003 Tokachi Oki Earthquake	K-Net Hiroo	810	970	461
1995 Hyogoken Nambu Earthquake	Kobe Marine Observatory	818	617	332
	JR Tottori Station	608	645	280

4 GROUND FAILURES CAUSED BY THE EARTHQUAKE

4.1 Slope failures

The slope failures caused by this earthquake consisted of shallow translational slides, debris slumps and deep-seated rotational slides. Although Typhoon No. 4 passed through the area a few days before the earthquake, the soils were generally not sufficiently wet to cause debris flows; however, the resulting saturation of the slopes may have intensified the damage.

One major landslide occurred in the vicinity of JR Shin-etsu Mainline's Omigawa station (see Figure 3a) where the debris covered part of the railway line. Fortunately, no one was injured due to the landslide. The slope was fairly steep and the slide involved a volume of soil about 100m high, 50m wide and 10m deep. The resulting scar had almost vertical face. Because of the steep hills in the vicinity of the station, other landslides were observed in the area as well. Note from the figure the presence of railway tunnel protection structure immediately to the right of the landslide, indicating slope instability problems in the area.

Figure 3: Examples of slope failures during the earthquake: (a) near JR Omigawa station (photo by Kokusai Kogyo Co. Ltd); and (b) along National Route No. 8 in Senbon, Nagaoka City (photo by Prof. Inoue).

Another large-scale landslide occurred along National Route No. 8, which connects Kashiwazaki to Nagaoka. The landslide, which occurred in the foothills of Senbon (east of Kashiwazaki), started at about 60m above the road pavement (see Figure 3b). The slide pushed the highway into the Kurokawa River which runs parallel to the road (on the left lower portion of the photo). The debris covered about 80m section of the road, causing the suspension of traffic operation along this major road.

Several embankment failures were observed in road fills along the coast. In Kasashima off Route No. 8, a 60m-portion of an embankment underwent more than 1m of vertical displacement, resulting in road closure (see Figure 4a). The slope appeared to have undergone previous stabilization using slope grading and gabion baskets to support the toe, as shown in Figure 4b.

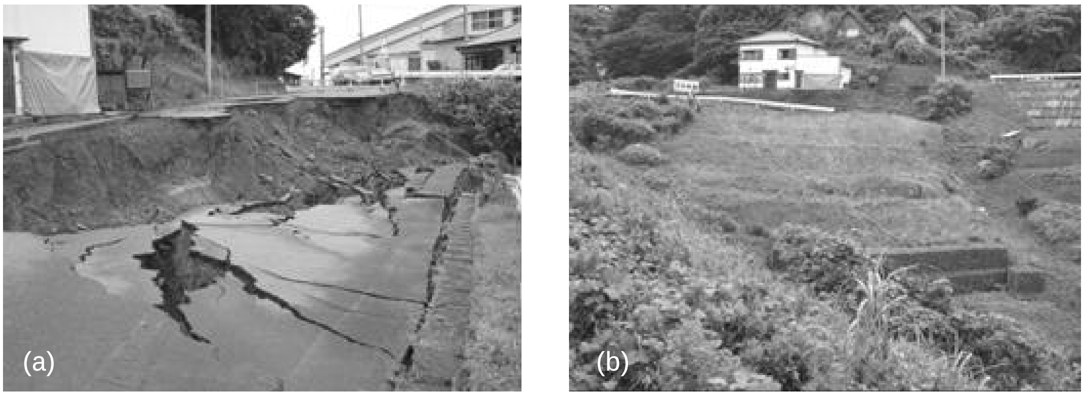

Figure 4: Collapse of man-made embankment in Kasashima.

4.2 Soil liquefaction

Evidences of soil liquefaction were observed in many locations in Kashiwazaki City and Kariwa Village, particularly in riverbank deposits, beach deposits, dune sands and placed fills. Ground cracks, uplifted manholes, and sand boils were observed in many areas. As mentioned earlier, the Kashiwazaki urban area contains alluvial soils where the sand deposits have flowed from the rivers over the soft alluvial formation. These soil profiles were the main reasons why liquefaction occurred in many locations during this earthquake.

The road parallel to the Sabaishi River which leads to the Kashiwazaki City's Garbage Incinerator Plant underwent extensive liquefaction. The road spread laterally towards the river, resulting in massive embankment failure (See Figure 5a). The vertical displacement of the head

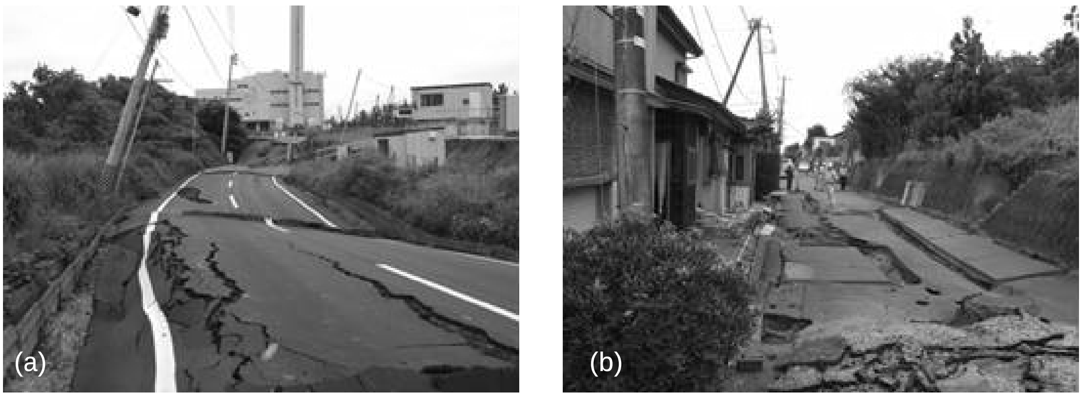

Figure 5: Liquefaction-induced ground deformations: (a) Road leading to Kashiwazaki Incinerator Plant; (b) at Yamamoto Danchi, Yamamoto Town

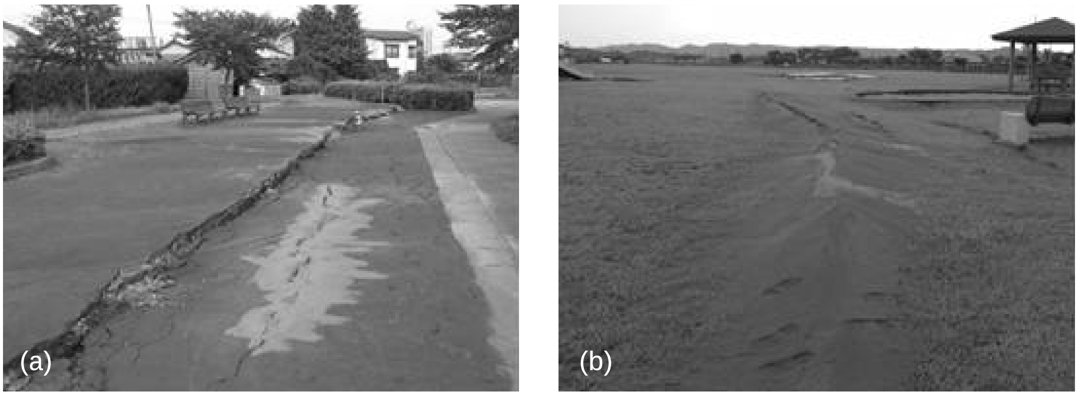

Figure 6: Sand boils induced by soil liquefaction: (a) Suidobashi Park; and (b) Sabaishigawa Park

scarp was about 3m (maximum), with the lateral spread movement occurring from the sand quarry area towards the river. Sand boils were also observed near the river. This site may have been a former river channel of the Sabaishi River which was buried when the road was constructed. Also seen in the background of the photo is the damaged exhaust chimney of the plant. The reinforced concrete chimney, measuring 58m high by 4.6m wide, was broken at the lapped reinforcing joint slightly below the centre of the chimney.

Another area of extensive damage was observed in Yamamoto Danchi, Yamamoto Town adjacent to the incinerator plant (Figure 5b). Cracked pavements, uplifted manholes, lateral spreading and uneven settlements were observed in many parts of the area. Considerable liquefaction was also observed at the Suidobashi Park in Nishimoto, Kashiwazaki City (Figure 6a). This area has been transformed into a park when flood mitigation efforts were implemented in 1984 at the time the Ugawa River system was straightened. Sand boils and ground cracks were also observed in Sabaishigawa Park (Figure 6b).

5 DAMAGE TO OTHER CIVIL ENGINEERING STRUCTURES

5.1 Port, harbour and coastal structures

The earthquake affected several coastal structures in Niigata Prefecture. Among these, the Kashiwazaki Port, the largest facility in the affected region with approximately 1.25km of waterfront berths, suffered extensive damage due to liquefaction-induced ground deformations. At the West Wharf, settlement and displacement of the quay walls opened joints in the aprons and deformed the ground in the yard area (see Figure 7a). At the Fishing Port, the apron settled

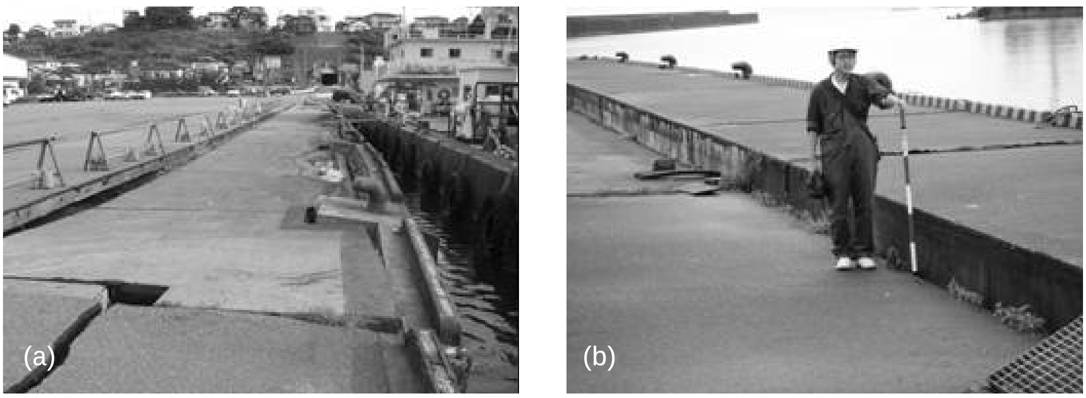

Figure 7: Damage to port and harbour facilities: (a) lateral spreading; and (b) apron settlement in Kashiwazaki Port.

by as much as 20 cm due to the lateral displacement of the quay wall toward the sea (see Figure 7b). Similar types of damage were observed at the Central Wharf, where cracked pavements, deformed quay walls and uneven surfaces were noted. In addition, the remains of blown-out sands caused by liquefaction were observed in many places around the harbour. The Eastern Berth, which was being used by the Japan Coast Guard and Japan Self-Defence Forces as staging area for recovery and rebuilding efforts, suffered minor liquefaction effects, with lateral displacements in the order of <5cm and apron settlements ranging from 2-7cm.

5.2 Railway facilities

Damage to railway lines were also evident, although highly localized. Between Arahama Station and Nishiyama Station on the JR Echigo Line, the rail track buckled at locations where the railway embankment moved laterally during the earthquake (Figure 8a). Moreover, the Arahama Station platform was completely damaged, together with the powerlines and signalling equipment, as a result of liquefaction-induced settlement and lateral spreading (Figure 8b).

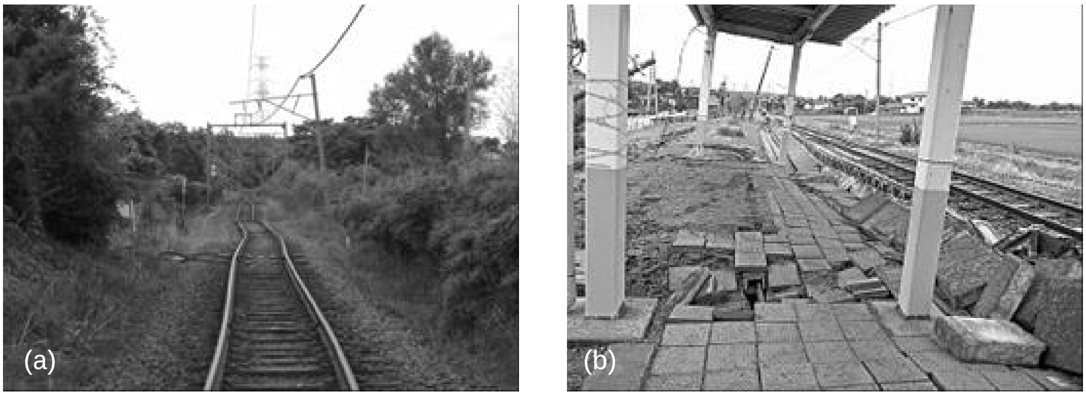

Figure 8: Damage to railway facilities: (a) buckled railway track; and (b) damaged platform of Arahama train station.

6 CONCLUDING REMARKS

Although considered not as catastrophic, extensive ground failures, such as landsliding and liquefaction-induced ground deformations, occurred as a results of the earthquake. Due to its geologic nature, liquefaction was one of the main causes of damage observed in Kashiwazaki City. Lateral spreading and ground settlements resulted in damage to port structures and the amplified ground motion in the liquefied area caused serious damage to buildings. The typhoon that passed through the affected site days before the earthquake may have compounded the damage since the saturated ground resulted in numerous landslides.

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REFERENCE

Niigata Prefecture (2007). *Damage condition caused by the 16 July 2007 Nigataken Chuetsu oki Earthquake (as of 14 December 2007),* Report No. 212 (in Japanese).