Earthquake News (continued)

Geotechnical Damage due to the 2011 Christchurch, New Zealand

On the other hand, a more pronounced liquefaction was observed in residential houses/properties in North Kaiapoi, although relatively minor compared to those after the 2010 Darfield earthquake. Two examples of damage to residential properties are described below.

Figure 22 is comparative photos of settlement of a two-story house due to liquefaction. The slope in front of the garage was originally uphill, but it became a downhill after 2010 Darfield earthquake as a result of more than 50 cm of ground subsidence. This house suffered additional 15 cm of subsidence from the 2011 earthquake. The narrowing gap between the roof and the head of a member of the research team can be recognized from the figure. Although the investigators appearing in the photos are actually different, their heights are almost the same.

Figure 22. Further subsidence in two-story house neighboring the stop bank. (North Kaiapoi)

Massive amount of sand ejecta, about 400 mm in thickness, was observed in a property following the September 2010 event (Figure 23). The ejected sand covered a deck in front of the entrance, with thickness of about 10 cm. The observed thickness of sand ejecta after the 2011 earthquake was around 20 cm.

Figure 23. Repeated liquefaction in a residential property in North Kaiapoi.

As mentioned above, liquefaction-induced damage comparable to September 2010 was observed at few residential properties in North Kaiapoi. However, the areas affected by liquefaction in this earthquake were more localized than during the previous one. The areas where evidence of liquefaction were observed during the 2011 earthquake are indicated as red colored areas in the liquefaction map of 2010 Darfield earthquake (Figure 24; Cubrinovski et al., 2010). Note that liquefied area shown in the figure is based on the view observation conducted on 27 February and 4 March 2011. The indicated area may be extended as a result of further investigations.

Earthquake News (continued)

Geotechnical Damage due to the 2011 Christchurch, New Zealand

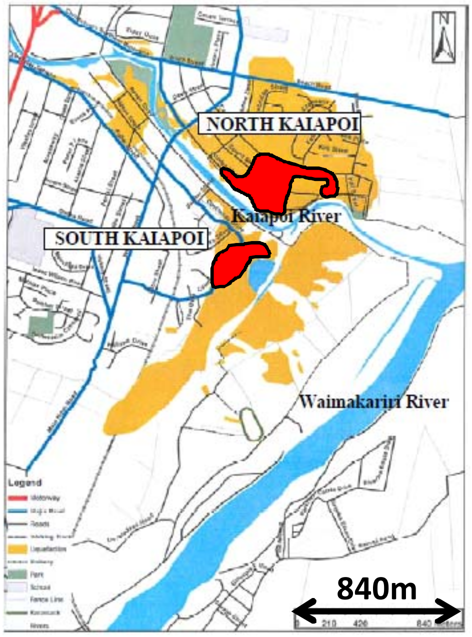

Figure 24. Comparison of liquefied area in Kaiapoi between 2010 Darfield and 2011 Christchurch earthquakes (Modified from Cubrinovski et al., 2010).

After the 2010 Darfield earthquake, SWS tests were conducted at a residential property shown in Figure 23 (Cubrinovski et al., 2010 and JGS, 2010). The profiles of converted N-value from SWS tests are shown in Figure 25. The upper portion of the ground consists of very loose sand, with depth more than 7 m and the ground water table was very shallow. Figure 26 shows the grain size distribution curves of sand ejecta collected in Kaiapoi. The solid curve with red color in the figure indicates the grain size distribution of soil collected after this earthquake, while the other dashed curves correspond to soils taken after the 2010 Darfield earthquake. The sands ejected in both earthquakes have generally similar grain size distribution. Moreover, they have similar grain size distributions as the sand ejecta in Christchurch, which are shown in Figure 10.

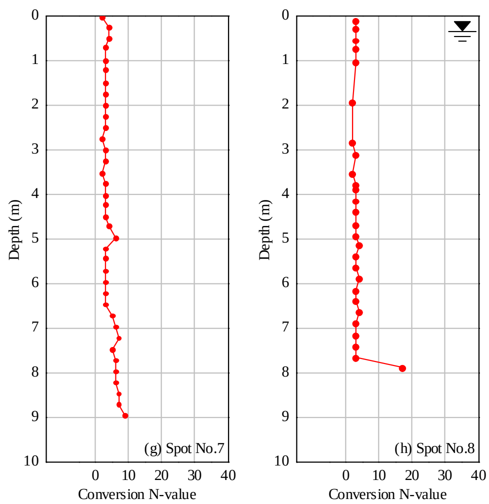

Figure 25. Converted SPT N-value profile in North Kaiapoi. Ground survey was conducted by University of Canterbury and JGS Reconnaissance team on September 2010 (JGS, 2010).

Earthquake News (continued)

Geotechnical Damage due to the 2011 Christchurch, New Zealand

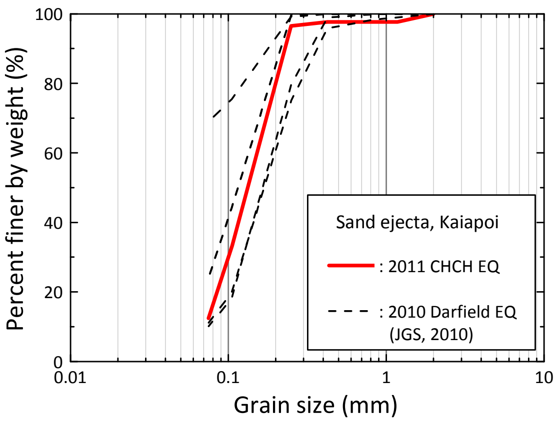

Figure 26. Grain size distribution curves of sand ejecta collected at Kaiapoi.

EFFECT ON SLOPE (CLIFF) STABILITY

During the Christchurch earthquake, numerous slopes and cliffs suffered shallow land slides and rock falls. One of the most severe damages to a cliff was observed in Sumner, located at the north end of Port Hills in the Banks Peninsula, about 12 km south-east of Christchurch. The cliffs in this area were formed by slope erosion of an ancient volcano. Residential houses were constructed on the cliffs as well as on the flat ground underneath. Many residential houses were built at the edge of the cliff.

Figure 27 shows a landscape of the affected cliff located at the west side of Wakefield Avenue in Sumner. This cliff is approximately 70 m high and 500 m long in north-south direction. The cliff surface was previously covered with vegetation, but became bare due to earthquake disturbance.

Figure 28 shows a rock fall near a building. The fallen rock is about 4.8 m wide, 6.6 m high and 15.8 m long. Numerous rock falls occurred in other hilly areas adjacent to the epicenter and residential houses and traffic were severely affected.

Figure 27. Panoramic view of a disturbed cliff (Sumner).

Earthquake News (continued)

Geotechnical Damage due to the 2011 Christchurch, New Zealand

Figure 28. Huge rock fall adjacent to a building (Sumner).

CONCLUDING REMARKS

Although the collapse of many commercial buildings led to the greatest casualties in the M 6.3 Christchurch earthquake, by far the most significant damage to residential buildings and lifelines was the result of liquefaction and associated ground deformations. Although the M 7.1 Darfield earthquake caused liquefaction in Christchurch and adjacent areas, the M 6.3 Christchurch earthquake induced more widespread liquefaction and caused more serious damage to infrastructure. Experiences from case histories all over the world have highlighted the effect of liquefaction to buildings and buried structures, but the scale of damage experienced in Christchurch following the 2011 event was unprecedented and may be the greatest ever observed in an urban area. Moreover, the short time interval between two large events has presented a very rare opportunity to investigate liquefaction in natural deposits.

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Earthquake News

On Gigantic Tohoku Pacific Earthquake in Japan

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INTRODUCTION

At 2:46 PM local time on March 11th, 2011, a gigantic earthquake of magnitude Mw=9.0 occurred and affected the eastern half of Japan. Because the seismological aspects of this earthquake have been reported at many web sites and publications, the present report puts emphasis on the damage aspects that have so far been revealed by the post-earthquake investigations. This report is a contribution made by many members of the Japanese Geotechnical Society.

The causative fault of this earthquake is located in the Pacific Ocean off east Japan where an oceanic tectonic plate has been subsiding under the archipelago (Fig. 1). In the area of Sendai City, that is one of the biggest cities in the eastern part of Japan, there had been warning about a possible big earthquake in the coming years. It was anticipated that a part of the plate subduction to the east of Japan would cause this extreme event. The reality was, however, more than anticipated, the size of the causative mechanism being 500 km in length in the NS direction and the width being 200 km.

In modern times, two gigantic earthquakes have been reported in this part of subduction. The one in 1896 registered the seismic magnitude (M) of 8.2 to 8.5 and the associating tsunami killed 21,915 victims together with 44 missing. The other one in 1933 was of M=8.1 (Mw=8.4) and claimed 1522 victims with 1542 missing. Both earthquakes caused minor intensity of shaking. Another tsunami disaster in the same area was caused by the 1960 Chile earthquake of Mw=9.5 and 142 people were killed. Those experiences encouraged both public and private sectors to be prepared for future tsunami disasters by constructing high sea walls and conducting tsunami evacuation drills, in which the height of future tsunami was decided on the basis of previous tsunamis. Despite those efforts, the present earthquake produced much bigger tsunami over the entire coast of east Japan (Fig. 1). It is often said that the 2011 earthquake is of similar size and effect as the *Jogan* earthquake in AD 869 that hit the same area and produced huge tsunami damage.

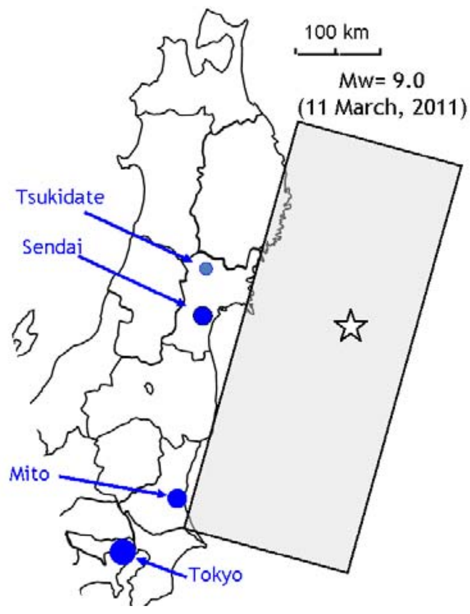

Fig. 1 Location of causative mechanism and major damage areas (Fault model by National Research Institute for Earth Science and Disaster Prevention)

Earthquake News (continued)

On Gigantic Tohoku Pacific Earthquake in Japan

Geospatial Information Authority of Japan announced that the coseismic displacement of the earth crust in the coastal area was at maximum 5.3 m in the horizontal direction towards the Pacific Ocean and 1.2m in subsidence. Thus, many areas along the affected coastal area got under water, the tsunami effect was made more serious, and the tsunami water remained in the area for a longer time, making the rescue very difficult. Fig. 2 illustrates the coseismic subduction in Sendai area. Note that similar subsidence occurred at many places in the world during past gigantic earthquakes: Kohchi of Japan in 1946 and at several more times in the history, Valdivia and surrounding area in Chile in 1960, South Alaska in 1964, and Izmit Bay of Turkey in 1999. Kohchi and Valdivia came upwards again after the quakes.

(a) Natori City, south of Sendai (b) Gamo of Miyagino Ward, Sendai

Fig. 2 Coseismic subsidence in Sendai (Photographs by Daiken Suzuki, former student of University of Tokyo)

EARTHQUAKE GROUND MOTION

Figures 3 and 4 show the distribution of peak ground acceleration (PGA) and peak ground velocity (PGV) of horizontal components, respectively. PGA values do not simply attenuate from the east coast, but major two clusters are recognized in 1) Miyagi Prefecture (around N38.5° E141.0°), and 2) Tochigi and Ibaraki Prefectures (around N36.5° E140.5°). This implies that the rupture process during the earthquake was not uniform, and contained several asperities radiating strong ground motions. Another point to note is that Tokyo and its surrounding area near the bottom of the figures were subjected to strong shaking. Therefore, damage occurred at many places therein. Fig. 5 illustrates the acceleration records at K-NET Ishinomaki station to the east of Sendai City in Miyagi. It is evident here that there are at least two strong earthquake events that are superimposed on each other. Thus, it is reasonable to assume several asperities in the source mechanism. Another important issue is the long duration time of strong shaking. Increasing the number of seismic loading cycles, this long duration time made the extent of subsoil liquefaction more serious.

Earthquake News (continued)

On Gigantic Tohoku Pacific Earthquake in Japan

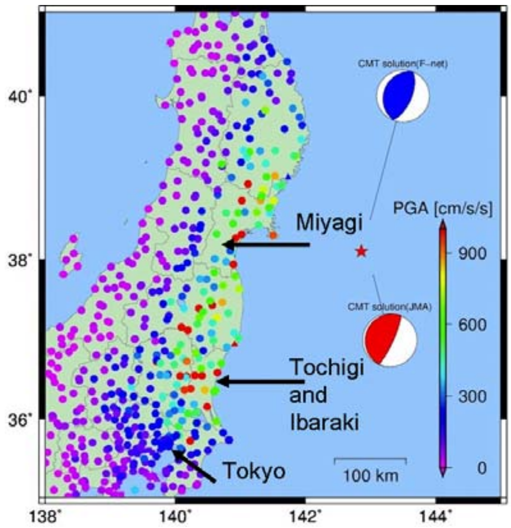

Fig. 3 Distribution of peak ground acceleration provided by NIED, ERI (the University of Tokyo), AIST, and PARI

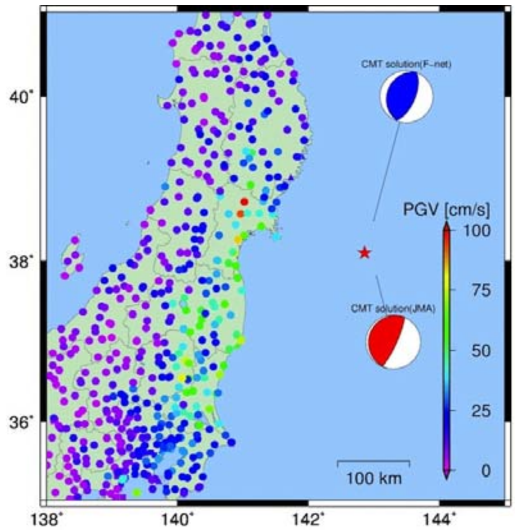

Fig. 4 Distribution of peak ground velocity provided by NIED, ERI (the University of Tokyo), AIST, and PARI

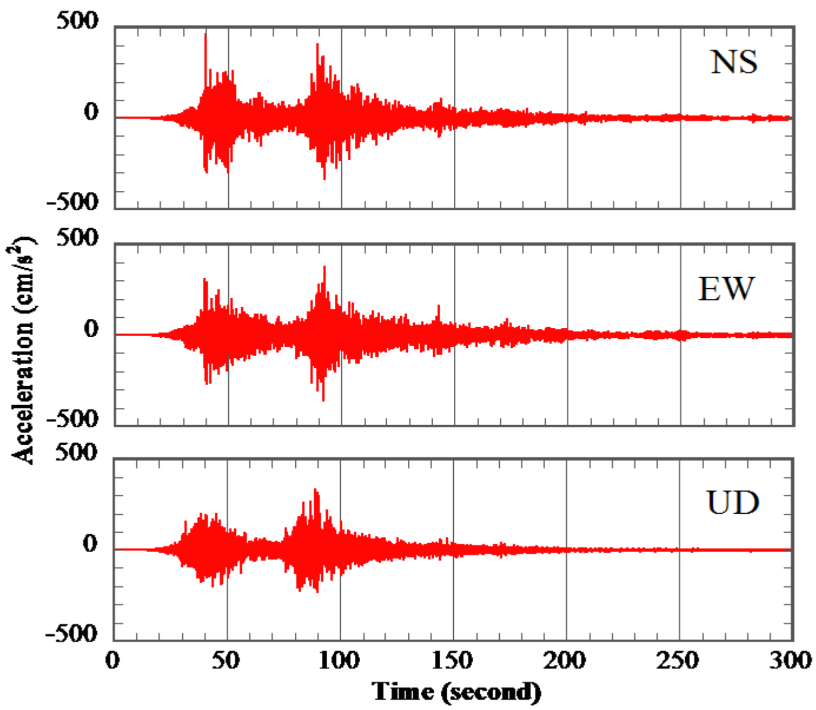

Fig. 5 Strong earthquake motion record at Ishinomaki to the east of Sendai City, Miyagi Prefecture (K-NET MYG010)

Earthquake News (continued)

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DISTRIBUTION OF DAMAGE

Many kinds of damage were caused by the earthquake over a large area in the eastern part of Japan (Fig. 6), ranging over 500 km in NS direction. The number of victims is not yet finalized in the middle of April because tsunami brought many people into sea and also debris of destroyed houses have made searching very difficult. It is anticipated that the total number of victims would be more than 25,000, most of which were killed by tsunami, while the total amount of debris is 26.7 million tons.

The major induced damages are classified into tsunami-related ones, liquefaction of sandy ground, and instability of slope and embankment. It is noteworthy that structural damage was not so significant as in the cases in previous gigantic earthquakes in the concerned region. Fig. 7(a) indicates the central part of Sendai City where many high-rise buildings survived the earthquake without problems. Of particular interest is illustrated in Fig. 7(b) in which Tsukidate Township survived the quake without structural damage despite that the Meteorological Agency issued the highest seismic intensity scale of 7 here. A local dentist was interviewed to mention that the shaking was long and strong, he could not keep standing up, but his old wooden house survived this event without structural damage. Information about lifeline damage is not yet available.

Earthquake News (continued)

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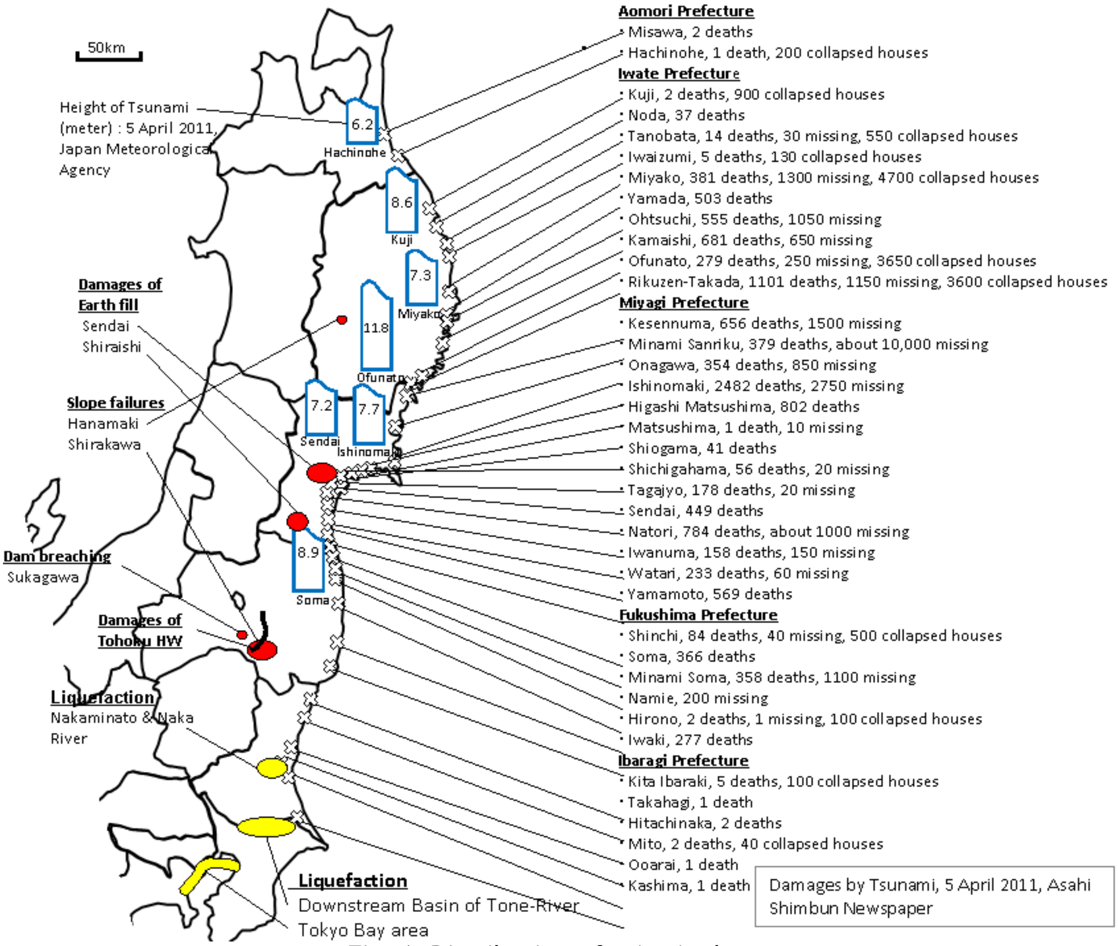

Fig. 6 Distribution of seismic damage

(a) Intact buildings in central Sendai City (b) Houses and shops without damage in Tsukidate Township

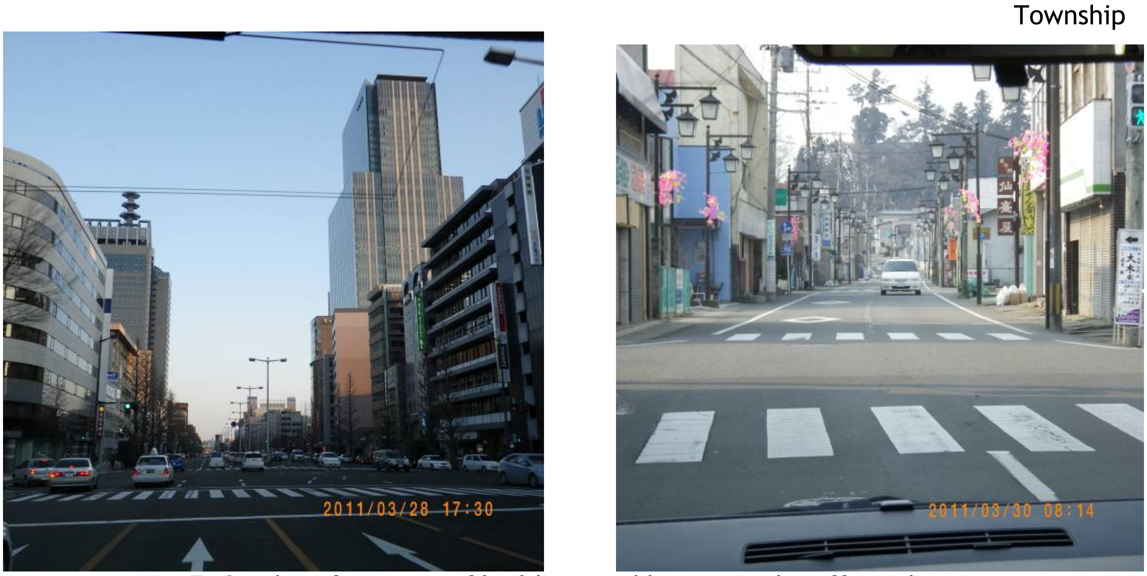

Fig. 7 Good performance of buildings and houses in the affected region

Earthquake News (continued)

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TSUNAMI DISASTER

Tsunami was the most serious type of damage. Because of the sympathy to tsunami victims and their families, engineering societies decided to postpone damage reconnaissance in the affected area unless very necessary. There is, however, minimum information available. First, the height of tsunami was investigated to find that the height was more than 15 m and easily overtopped sea walls that had been constructed against the previously known tsunami height. The destructive power of high tsunami was substantial and removed nearly all the structures in the attacked areas (Fig. 8). This photograph reminds us of Banda Aceh after tsunami disaster in 2004. In this flat land, there is no place for people to evacuate, even if a tsunami alert is issued properly. In some tsunami-affected areas, the sea water remained on shore for many hours and evacuation was made impossible. Prof. Nozomu Yoshida of Tohoku Gakuin University had to take refugee on a pedestrian bridge crossing a street for 12 hours without food and warm overcoat, because the street was inundated until 1 AM. There was a huge amount of debris after tsunami attack (Fig. 9). This debris has to be disposed in an appropriate way, which is a very difficult task.

Fig. 8 Yuriage township near Natori River mouth to the south of Sendai (Photo by Daiken Suzuki)

Fig. 9 Tsunami debris in Tagajo Municipality

(a) Intact quay wall (b) Erosion in building foundation

Fig. 10 Post-tsunami situation in Ishinomaki Harbor to the east of Sendai

Earthquake News (continued)

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Fig. 11 Erosion of embankment at bridge abutment after tsunami Strike (Iwanuma in Miyagi Prefecture)

Fig. 12 Resuming business of fish restaurants after tsunami strike (Nakaminato Harbor, Ibaraki)

Fig. 13 Destroyed sea wall near Abukuma River mouth

Figure 10(a) shows that the quay wall of Ishinomaki Harbor was intact, although the retreating tsunami water was so powerful to erode sand in building foundation (Fig. 10b). Despite this good seismic performance of the quay wall, the operation of the harbor was stopped for many weeks because facilities for cargo handling were destroyed. Hence, rescue stuffs could not rely on mass transportation by ship. Fig. 11 demonstrates tsunami erosion in bridge abutment. There are local people who have been working hard to reestablish previous life conditions. Fig. 12 shows recovery of fish restaurants in Nakaminato Harbor in Ibaraki Prefecture, 100 km NE of Tokyo, where the tsunami height was 4.2 m, being 1.0 m above the ground surface. The loss of backfill soil behind a coastal levee near the mouth of Abukuma River (Fig. 13) suggests that erosion by the arrival of tsunami was the main cause of the damage, which was more serious than the effect of retreating tsunami.

Earthquake News (continued)

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LIQUEFACTION PROBLEMS

Example of Liquefaction

Liquefaction risk is high in sandy ground that is loose, water-saturated, and young in age. This liquefaction-prone situation is found in recent artificial islands, abandoned river channels, and backfill of sewage pipelines. Liquefaction occurred at many places of such environment during the present earthquake.

Many artificial islands have been constructed along the coast of Tokyo Bay since 1960s mostly by using dredged seabed sand. Because the risk of liquefaction in such islands has been known for many years, big factories and business buildings have improved subsoil by densification and other methods. During the present earthquake, consequently, most liquefaction problems occurred in the unimproved residential areas where people did not have much knowledge about liquefaction risk.

Figure 14 illustrates sand boiling, which is an evidence of subsurface liquefaction, in a sports facility in Urayasu City in the east suburb of Tokyo. Land reclamation took place in 1980s in this area. Fig. 15 shows the consolidation settlement of liquefied sand in the same area. Because the building was supported by a pile foundation, no structural damage occurred therein and this shopping mall was able to start business within a few weeks after the quake. It is possible, however, that the differential settlement between the building and the ground destroyed many lifeline connections. Fig. 16 indicates road pavement that distorted substantially because of liquefaction. One important feature of the liquefaction problem is the damage in private properties. Overall liquefaction in residential development in manmade islands caused subsidence and tilting of many houses (Fig. 17). Lack of liquefaction mitigation measure in private lands and houses and their restoration at reasonable cost are now attracting public concern. Moreover, damage to lifeline, which is in particular sewage pipeline, is important. Figs. 18 and 19 demonstrate floating of manholes in Urayasu and another northern city of Sukagawa. Floating and surface subsidence imply need for more efficient compaction of backfill sand. Noteworthy is that quay walls around the manmade islands were maintained stable, being different from those in Niigata (1964) and Port Island in Kobe (1995), and lateral flow of liquefied subsoil did not occur.

Fig. 14 Liquefaction in Urayasu City of Chiba

Fig. 15 45-cm subsidence of ground surface in front of a shopping center (Urayasu City)

Earthquake News (continued)

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Fig. 16 Distortion of road pavement in residential area (Mihama of Chiba)

Fig. 17 Tilting of house (Mihama of Chiba)

Fig. 18 Uplifting of manhole of 2 meter In Urayasu of Chiba

Fig. 19 Uplifting of manhole and surface subsidence in Sukagawa of Fukushima

Liquefaction occurred in other areas as well. One part of the sheet piles quay wall at Nakaminato Fishermen's Harbor in Ibaraki Prefecture was distorted as illustrated in Fig. 20. Because this particular place is probably situated upon a small river channel, liquefaction occurred and allowed profound outward displacement of the quay wall and subsidence of the backfill where a later tsunami strike eroded the soil. Figs. 21 and 22 indicate distortion and subsidence of a road embankment and associating uplift at the foot of the slope. Boiled sand obviously verifies the occurrence of liquefaction. It seems that the higher embankment subsided and the lower ground surface came up because of volumetric balance during soil movement. It is noteworthy that the industrial site next to this place did not liquefy probably because of soil improvement.

Fig. 20 Damaged quay wall in Nakaminato Harbor

Earthquake News (continued)

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Urbanization and development of residential area have been conducted out of Tokyo area as well. Fig. 23 indicates house damage in Abiko City of Ibaraki. Liquefaction was concentrated in a small area which used to be a small pond that was filled with sand in 1950s for urban expansion. Liquefaction damage occurred in a residential area in Kuki City (Fig. 24) to the north of Tokyo where originally swampy topography was converted to a residential area.

Fig. 21 Distortion of road embankment in Nakaminato of Ibaraki Pref.

Fig. 22 Uplift near the toe of distorted slope in the previous figure

Fig. 23 Liquefaction in residential area of Abiko City (Fusa area)

Fig. 24 Liquefaction-induced tilting of house in Kuki City of Saitama Prefecture

Earthquake News (continued)

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Fig. 25 Liquefaction-induced lateral spread of Naka River levee

River levee was damaged by liquefaction at many places in Tokyo and Sendai areas as well. Because the number of damage is substantial and the rainy season is going to start soon in early June, quick and efficient restoration work is needed. Many river channels have been made straight from the original meandering shape and consequently levees are now resting upon liquefaction-prone subsoil. Boiling sand from the levee body was also observed as well during the reconnaissance, suggesting that levees may be partially loose and that water content is high. Fig. 25 shows subsidence and lateral spreading of Naka River levee in Ibaraki Prefecture (near the site of Nakaminato Harbor). This part of levee is situated upon an abandoned river channel.

(a) Crack on the crest (covered for protection) (b) Sliding in slope on river side

Fig. 26 Distortion of Naruse River levee on right bank near 40.0 km post

Earthquake News (continued)

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Fig. 27 Flattened Levee of Hinuma Lake near Mito City (Pechanko!)

Fig. 28 Repeated liquefaction behind Eai River levee at Kita Wabuchi site

Figure 26 illustrates significantly distorted levee of Naruse River to the north of Sendai City. Longitudinal deep cracks and sliding of slope towards the toe are remarkable. Liquefaction was found as well on the river side. A very significant subsidence and lateral motion occurred at a levee of Hinuma Lake near Mito (Fig. 27). The entire body of the levee became almost level because of liquefaction at the bottom.

Liquefaction in an abandoned river channel in Fig. 28 indicates repeated liquefaction during the main and after-shocks in 1978, another earthquake in 2003 and finally in 2011. In spite of liquefaction, the levee was maintained intact.

Roles to Be Played by Geotechnical Engineering

It is desired by people living on liquefaction-prone land that geotechnical engineering serves them with protections from future risks. However, there are two problems to be overcome. First, restoration of tilting and subsidence of houses are urgently needed. In the example damage of Fig. 29 (Hinode area of Itako City, Ibaraki, that used to be a small lake), there seems to be no structural damage in a house, and its restoration is possible. However, the risk of repeated liquefaction and damage during aftershocks after expensive restoration has to be taken into account. It is feared that aftershocks may continue for months or years after this gigantic earthquake. On the other hand, residents are annoyed by such tilting problems as headache and dizziness that are caused by as small as 1% or less of floor inclination. Thus, despite the risk of repeated liquefaction, house restoration is still desired. It is noteworthy that conventional liquefaction mitigation such as shown in Fig. 30 was successful. Now such measures as are possible under existing houses are sought so that liquefiable subsoil is improved and tilting is restored. Because private houses are structurally less strong than RC buildings, special care and experience are indispensable.

The second problem is the meaning of liquefaction hazard maps. Many local governments had assessed liquefaction risk and published hazard maps. However, there are claims now that liquefaction occurred in areas where the hazard map did not warn liquefaction risk. This situation was caused by the following reasons:

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- Liquefaction risk was assessed against a future earthquake that was most likely to affect the concerned municipality and the 2011 earthquake of Mw=9.0 and many number of shaking cycles has been out of concern.
- Old topography and surface geology should be more carefully studied because the size of artificial land reclamation may be very small.
- Location of available borehole investigation may have a large interval and very local soil condition may be overlooked. This risk is particularly high if liquefaction risk is evaluated on the basis of averaged borehole data in a square grid of, for example, 50m*50m.
- It should be widely understood that existing methodologies for liquefaction risk assessment employ many empirical correlations that are subject to data scattering and are not so accurate as those formulae in electrical engineering and material science.
- Because of many uncertainties, published liquefaction risk is rather overestimation in order to avoid future troubles on responsibility.

Fig. 29 Liquefaction-induced house damage in Hinode area of Itako City, Ibaraki

Fig. 30 Successful soil improvement in Irifune-Kita area of Urayasu residential area

Many problems have to be overcome in order to successfully help people from geotechnical earthquake problems. It is easy to point out how difficult the problems are. However, such an attitude does not produce anything good for future. This is the time for geotechnical engineers to work hard so that people will recognize the importance of out discipline.

INSTABILITY OF SLOPE AND EMBANKMENT

Shear failure of slopes and embankments occurred at many places. As far as natural slopes are concerned, the size of failures is not very large. Fig. 31 indicates an example in Ibaraki, north of Tokyo. A bigger slope failure occurred in Shirakawa City of Fukushima Prefecture (Fig. 32). This failure developed within a layer of weathered welded tuff and claimed 13 victims. Noteworthy is the long distance of run-out that suggests the apparent friction angle of 5 degrees approximately. It is necessary to further watch the slope behavior during aftershocks to come and the rainy season.

Earthquake News (continued)

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Fig. 31 Rock fall at Ohgo of Ibaraki

Fig. 32 Failure of natural slope at Hanokodaira of Shirakawa City

Fig. 33 Distortion of Shida Bridge approach Naruse River, north of Sendai

Fig. 34 Distortion of railway embankment (Joban Line of Japanese Railway East, near Mito, Ibaraki)

Distortion of embankment occurred at many places and hindered operation of transportation. Fig. 33 is a distorted road embankment. Fig. 34 shows ongoing restoration of railway truck resting on distorted embankment. Although railway service was stopped for many weeks, the earthquake did not kill any passenger in trains. It is particularly remarkable that the bullet trains (Shinkansen) successfully stopped at the onset of earthquake when they were running at a velocity greater than 200 km/h. This success was achieved by combination of many safety technologies.

On the contrary, many problems were detected in artificial earth fills for residential land development in hill areas. Fig. 35 demonstrates a slope failure at Midorigaoka area of Shiroishi City, south of Sendai. Formerly known as Kotobuki-Yama, this development slope failed during the 1978 Miyagiken-Oki earthquake when the earth filling was going on. It appears that engineers in those days judged that the slope would not be perfectly stabilized, and the land was converted to a green park instead of selling it for residence. That decision was right because the upper part of the slope failed once more (Fig. 35a). Note that part of the lower half of the slope has been stabilized by drainage of ground water (see drainage well in Fig. 35b) and was stable during the 2011 earthquake.

Earthquake News (continued)

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(a) At the top of slope (b) Drainage wells near the bottom of slope

Fig. 35 Slope failure at Midorigaoka of Shiroishi City of Miyagi Prefecture, south of Sendai

Fig. 36 Failure of residential development slope in Midorigaoka of Sendai City

Fig. 37 Compressive distortion of ground surface near bottom of unstable slope (Midorigaoka of Sendai)

Slope failure was repeated similarly in a land development area in Sendai City. Fig. 36 shows that the slope failure during a future earthquake was feared and this area has been left vacant until the slope failed once more in 2011. This right decision, however, was not made in a nearby area of Fig. 37. This figure indicates that ground was subjected to compressive distortion at the bottom of a moving slope. Fig. 38 shows soil liquefaction in a hilly area of Sendai City. A local person said that there used to be a small stream here and that it was backfilled at the time of land development. Therefore, the mechanism of this liquefaction is similar to what has happened in larger artificial islands near Tokyo.

Oritate area in the western part of Sendai City is a new residential development in hills. Cut-and-fill construction was practiced here and Fig. 39 indicates significant damage in a fill part. In contrast, the cut part was free of damage. Thus, the recent fear about seismic stability of residential fill was verified. Note, however, that there are stable fill as well because of the good quality of construction.

Earthquake News (continued)

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Fig. 38 Soil liquefaction in Asahigaoka 2 of Sendai City

Fig. 39 Damage that was limited to filled part of residential development in hilly area (Oritate 4 of Sendai)

Fig. 40 Empty reservoir of Fujinuma Dam in Sukagawa City of Fukushima Prefecture

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Fujinuma earth dam (Fig. 40) in Sukagawa City was constructed from 1937 to 1949. Its height was 17.5 m and the slope gradient was 1:2.5 on the downstream side, while 1:2.8 on the reservoir side. Being of uniform cross section, this dam was probably not well compacted because modern compaction machine was not available in those days. There were two dams here and No. 1 Dam was eroded and breached (Fig. 41a) and caused flooding of 1.5 million cubic meters of water. No. 2 Dam failed towards the reservoir but did not breach (Fig. 41b). The flooding torrent rushed downstream from No. 1 Dam through a narrow small valley (Fig. 42) and attacked a village (Fig. 43) to destroy houses where 8 people were killed.

(a) No. 1 Dam after erosion and breaching

(b) No. 2 Dam without breaching

Fig. 41 Seismically breached Fujinuma Dam

Fig. 42 Valley after torrent

Fig. 43 Village attacked by flood

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Fig. 44 Intact shape of municipal waste landfill at Yumenoshima of Tokyo

Concern was addressed to the behavior of a solid municipal waste landfill at Yumenoshima in Tokyo. As shown in Fig. 44, no subsidence or instability was triggered therein by the earthquake motion.

NUCLEAR POWER PLANTS

There are several nuclear power plants along the Pacific Coast of Honshu Island in the earthquake affected region. While most reactors were in operation, some were out of operation for scheduled inspection / maintenance. Although all operating reactors safely shut down when the earthquake occurred, the ones of Fukushima I Power Plant caused serious problems. Because detailed information about this accident has been supplied to the public through media, the present article limits its scope to essential aspects and related environmental effects.

The Fukushima Nuclear Power Plant I was constructed and has been operated by the Tokyo Electric Power Company (TEPCO) since 1970. The strong shaking during the present earthquake did not damage the facilities. Conversely, the design tsunami height was 5.7 m as suggested by experiences in modern times and concerns about more serious height started in the 21st Century. Because the facilities were not fully designed against tsunami problems, the real tsunami height of 14 m washed away emergency water pumping machines and inundated the diesel power generators in the seismically safe basement. Thus, all the electric power sources were lost, emergency cooling became difficult, and many radioactive problems resulted.

Fukushima II Power Plant that is located at 11.5 km South of Fukushima I successfully shut down. In this plant, protection from tsunami was better than in Fukushima I. Two people were injured during the earthquake. Cooling problem and escape of smoke have been reported but no serious consequence has been known.

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Onagawa Power Plant that is situated to the east of Sendai has been operated by Tohoku Electric Power. Reactors successfully shut down at the time of the earthquake and were well protected from tsunami strike. Before the quake, there were concerns about seismic instability of a high reinforced cliff behind this power plant. However, no instability problem was found after the earthquake.

There were six reactors in the Fukushima I plant and three of them, Nos. 1 to 3, were in operation while Nos. 4 to 6 had shut down for a scheduled inspection, when the earthquake occurred. When the plant was first designed, the design peak ground acceleration was 1.74 m/s^2 but was later raised to 4.12 or 4.52 m/s^2. Although there are fears that the real earthquake acceleration of more than 5 m/s^2 is greater than the real value, it should be recalled that modern earthquake resistant design relies more on response spectra and such a fear on acceleration is not reasonable. The tsunami effect was more serious than shaking. High waves destroyed and inundated electric facilities, and tsunami debris in the power plant made emergency activities more difficult.

During the days after the quake, the temperature in the reactors and connected facilities went up and even hydrogen explosions occurred. It appears that many cracks occurred either during the earthquake or upon explosions. Hence, the radioactivity in the air, in soil, in ground water, and in the sea increased. Damage to local farming and fishing is very significant. Leakage of hydrogen gas from the reactors caused explosions in the reactor buildings and destroyed their concrete walls. Another problem was the leakage of radioactive water into soil. Grouting was practiced to solve this problem.
Social effects of the nuclear accident will be stated in the next chapter.

SOCIAL IMPACTS

Because the earthquake source mechanism was remarkably large (Fig. 1), damage occurred over a huge area. Thus, the total number of damage was substantial. This fact made the impact of the damage to the entire nation extremely profound. This mass effect of damage is very important and was hardly experienced during past earthquakes. In contrast, the significance of individual (geotechnical) damage is not so serious as compared with what has happened during past big earthquakes. The large number of damage delayed the initiation of direct railway service by more than one month between Tokyo and Sendai. Road transportation was made difficult as well and the earthquake-hit Sendai area suffered from shortage of food, fuel, and other emergency materials. The industrial activities in the affected Tohoku region decreased substantially, causing very negative effects to both national and international economies. It is still unclear how to manage the assembled effect of many small damages.

The radioactivity discharged from Fukushima I nuclear power plant caused contamination of air, soil, and sea water. Near the power plant, cleaning of contaminated soil will be a very important issue. Similarly, salt contamination of soils in tsunami-hit areas and areas of coseismic subsidence (Fig. 2) will be very important for re-initiation of agriculture. Hopefully, the high rate of annual precipitation will naturally clean up the soil in a short period.

More problems are pointed out in the field of geoenvironmental engineering. Soil was contaminated by oil in tsunami-affected areas. Cleaning of those soils is urgently needed. Removal of debris and, in particular, tsunami debris (Fig. 9) is another important issue. The total amount of the debris will be as much as 26.7 million tons.

Earthquake News (continued)

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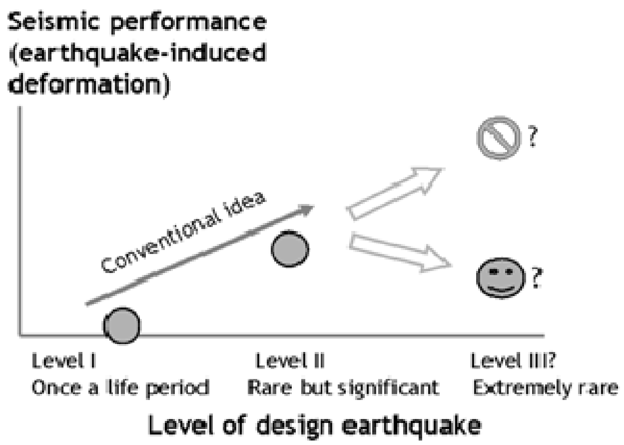

Fig. 45 Contradictory ideas in seismic performance-based design principle

These experiences raise a question to the principle of seismic performance-based design. The recent trend towards the seismic performance-based design stated that more damage (deformation) should be allowed for less frequent and stronger earthquake action. In this regard, in Fig. 45, Level I design earthquake that may occur once during a life time of a structure allows nearly no residual deformation, while Level II earthquake, that is considered rare, allows some but not fatal damage. Because the 2011 earthquake, which was extremely rare after the previous Jogan earthquake in 869, made a very significant impact on the national and international community, it may be felt that the allowable damage caused by this very rare Level III (?) earthquake should be made smaller than so far considered. Then a question arises why deformation has to be made smaller for less frequent (Level III) earthquake.

The contradiction between two opposite opinions arises because the engineering community is not accustomed to the cumulative effects made by a mass of damages. Individual damage may not be significant but, if the number of damage is 1000, the total impact is extremely bad. One of the most important lessons that are learnt from the 2011 earthquake is the lack of our suitable response to the mass effect of damages.

The accident of the nuclear power plant is still making many problems. During the first 4 weeks after the quake, many people in Tokyo were scared by the possibility of catastrophic explosion of the reactors. Accordingly, they escaped from Tokyo and took refugee in the western part of the country or in other countries. Although the feared catastrophe has not happened till the end of April, some leakage of radioactivity still continues. Agricultural and fishing products may be contaminated and life of local farmers and fishermen are becoming difficult. Local people around Fukushima I Plant have to be evacuated from their home land and have to live in remote areas without knowing when they can return home.

There are fears that Tokyo and even the entire Japan are subject to radioactive pollution. It should be recalled that this article was written in Tokyo without health problem.

Earthquake News (continued)
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CONCLUSIONS

The gigantic earthquake of M_w=9.0 on March 11th caused many damages and problems including tsunami tragedies and nuclear accidents. Geotechnical problems are made up of liquefaction in house foundation and river levees. It seems that the significant impact on the community caused by the problems, excluding tsunami and nuclear ones, was not the consequence of significant individual damage but the result of the number of damage and spatially wide distribution. Due to this mass damage effect, the post-earthquake response and restoration works have been made difficult and delayed. These features have not been considered in the conventional design philosophy and should be discussed from now on. Another important point is the damage caused in people's properties; house subsidence due to subsoil liquefaction and slope instability in residential developments in hilly area. People are now well aware of the problems under the ground surface and seeking for advice and help. Therefore, it should be stressed that this is the time for geotechnical engineers to work hard and demonstrate people the importance of our discipline. Geotechnical engineering of the People, by the People, for the People has to be constructed now.

ACKNOWLEDGEMENT

This report is supposed to be one of the earliest and comprehensive international reports on geotechnical damages caused by the gigantic earthquake in Japan. It is aimed by publishing this report in this bulletin to help ISSMGE members receive important information earlier than others. The authors conducted damage reconnaissance studies at many places for many days. They deeply appreciate supports provided by the Japanese Geotechnical Society, the Japan Society of Civil Engineers, and the Ministry of Land, Infrastructure, Transport and Tourism, together with the aid given by local communities that were indispensable in the success of the study.