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ABSTRACT

Recently middle class earthquakes have occurred and caused various geotechnical damages every year in Japan. Among them geotechnical damages during five earthquakes from 2004 to 2008 are introduced. The 2004 Niigataken-chuetsu earthquake caused failure of expressway embankments and uplift of sewage manholes. Liquefaction-induced damage to quay walls and tanks occurred in artificially reclaimed lands during the 2005 Fukuokaken-seiho-oki earthquake. Liquefiable area had been predicted about 17 years before the earthquake. Liquefied zones were fairly coincided with the predicted liquefiable zones. Very severe slide of highway embankments occurred at 11 sites during the 2007 Notohanto earthquake. During the 2007 Niigataken-chuetsu-oki earthquake, liquefaction induced in old river channels and on gentle slopes of sand dunes, and caused settlement of houses and breakage of low pressure gas pipes. However, some houses, sewage manholes, gas pipes were survived. Huge landslides and serious debris flows occurred along the slopes of Kurikoma Volcano during the 2008 Iwate-Miyagi-nairiku earthquake. Many landslides and debris flows occurred.

INTRODUCTION

Japan is the narrow and long country with an area of 377,800 km^2 and a length of about 3000 km. About 70 % of the land is mountain area. The highest mountain, Mt. Fuji is 3,776 m. Huge numbers of natural and manmade steep slopes are existed. These slopes are easy to slide due to earthquakes and heavy rains. Along coastal lines, many artificially reclaimed lands have been formed. Liquefaction occurs in the reclaimed lands during earthquakes. Moreover activity of earthquake is very high. Therefore, geotechnical disasters due to earthquakes occur in almost every year. In this paper, geotechnical damages occurred in recent five years due to middle class of earthquakes, shown in Fig.1, are introduced.

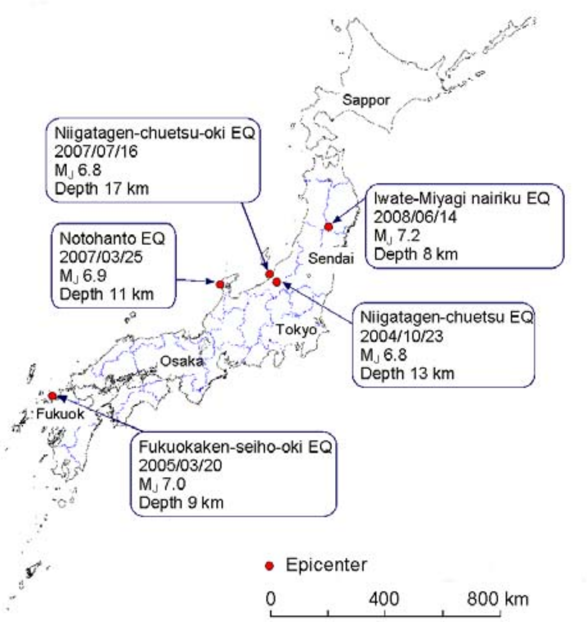


Fig.1. Recent five earthquakes introduced in this paper

THE 2004 NIIGATAKEN-CHUETSU EARTHQUAKE

On October 23, 2004, the Niigataken-chuetsu earthquake, of Mj=6.8, occurred. Fig.2 shows the epicenter of the earthquake and the distribution of the maximum surface acceleration recorded by K-NET (National Research Institute for Earth Science and Disaster Prevention, NIED). The maximum surface acceleration recorded at Kawaguchi Town was 1,722 Gals. Many railways including the Shinkansen, roads, houses,

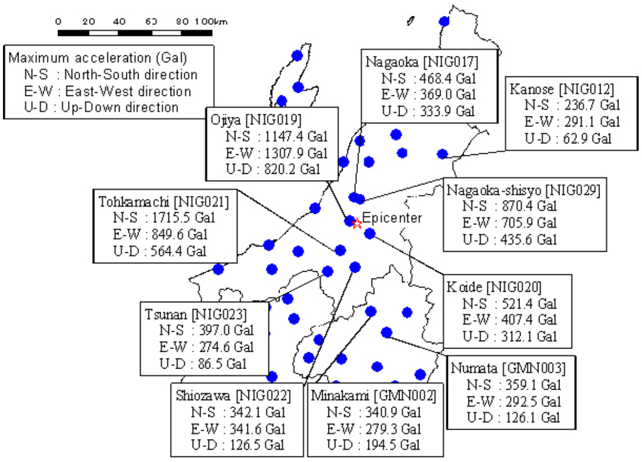


Fig.2. Epicenter and the distribution of the maximum surface acceleration recorded by K-NET

pipelines and other structures were severely damaged. Moreover, a huge number of landslides hit many towns and villages. The displaced soil dammed up rivers and made natural dams. Among them, damage to sewage facilities (Yasuda and Kiku, 2006) and expressway embankments (Yasuda and Fujioka, 2009) are introduced in this paper.

Sewage facilities were damaged in 22 cities and towns. The maximum distance from the epicenter to damaged towns was about 30 km. The total loss of sewage facilities was valued at 20.6 billion Yen. 152.1 km of pipes were damaged. 1,453 manholes and many buried sewage pipes were uplifted as shown in Photos 1 and 2. The maximum height of the uplifted manholes was about 1.5 m. A car collided with an uplifted manhole in Nagaoka City. Roads caved in at 5,908 sites. Photo 3 shows a road cave-in in Nagaoka City. The surface of the road settled by several tens of cm. Therefore, the damage to the sewage manholes and pipes not only prevented the disposal of waste water but also erected obstacles to traffic and restoration activities.

A technical committee was organized by the Ministry of Land Infrastructure and Transport, to investigate the mechanism of the damage and to select appropriate restoration work (Technical Committee on the Sewer Earthquake Countermeasures, 2005). Detailed soil investigations were carried out at sites of damage and undamaged sites in Nagaoka City, Ojiya City and Kawaguchi Town. Typical procedures for the construction of buried pipes and manholes, in Japan, are as follows: i) ground is excavated using sheet piles or other retaining walls, ii) pipes or manholes are placed at the bottom

Photo 1. Uplifted manhole in Ojiya City

Photo 2. Uplifted pipe found during restoration work in Nagaoka City

Photo 3. Road cave-in on sewage pipes in Nagaoka City

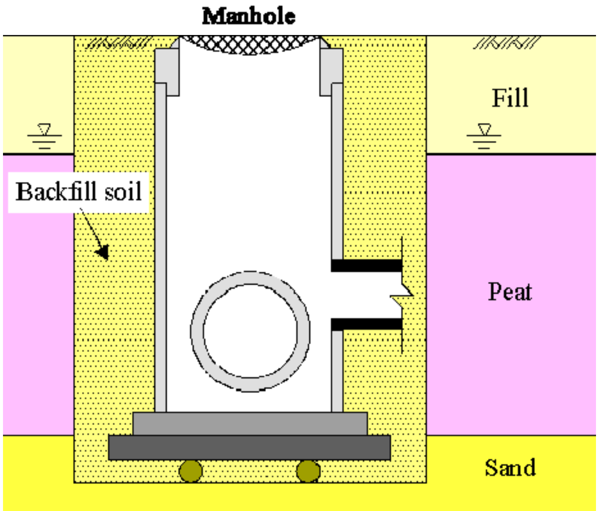


Fig. 3. Schematic diagram of the cross section of a sewage manhole

of the ditch or holes, and iii) the ditch or hole is filled with sand which is compacted as show in Fig.3. Soil fill in the damaged sites were sand with fines to sand with gravel. Water levels in the soil fill at the damaged sites were extremely shallow, such as GL.- 0.2 m to GL.- 1.1 m. The density of the soil fill at the damaged sites was very low, with degree of compaction D_C of 74% to 81% or relative density Dr of 38 % to 41%. Therefore, it is certain that the soil fill liquefied and caused the uplift of manholes. Water tables at the undamaged sites were slightly deeper than those at the damaged sites. This may be the reason why manholes were not uplifted at these sites. The following relationships were found:

a) Damage increased with a decrease in the depth of the water table in clayey ground.

b) The damage to newly constructed pipes was substantial. This implies the resistance to liquefaction of sand fill increased with age.

Based on these investigations, appropriate restoration methods were proposed to prevent damage during future earthquakes. The proposed methods were as follows:

(1) compact the sand fill to more than 90 % of degree of compaction (Dc>90 %),

(2) fill ditches with gravel instead sand,

(3) mix the sand fill with cement.

In the restoration work, the manholes that uplifted more than about 5 cm and the pipes that uplifted more than 1/4 of the diameter of the pipes had to be replaced in Nagaoka City.

The Niigataken-chuetsu earthquake caused serious damage to expressways. 580 km along six national expressways were closed due to the earthquake. Damaged expressway embankments were filled with banking materials and all expressways were able to open for emergency vehicles about 19 hours after the earthquake because expressway bridges and tunnels were not seriously damaged. About 13 days after the earthquake all expressways were opened to normal traffic.

The most serious damage occurred in the following sections:

a) between Horinouchi IC and Echigokawaguchi IC (8.8 km), and between Yamamotoyama Tunnel and Yamaya PA (5.5 km) of Kan-etsu Expressway as shown in Fig.4, and

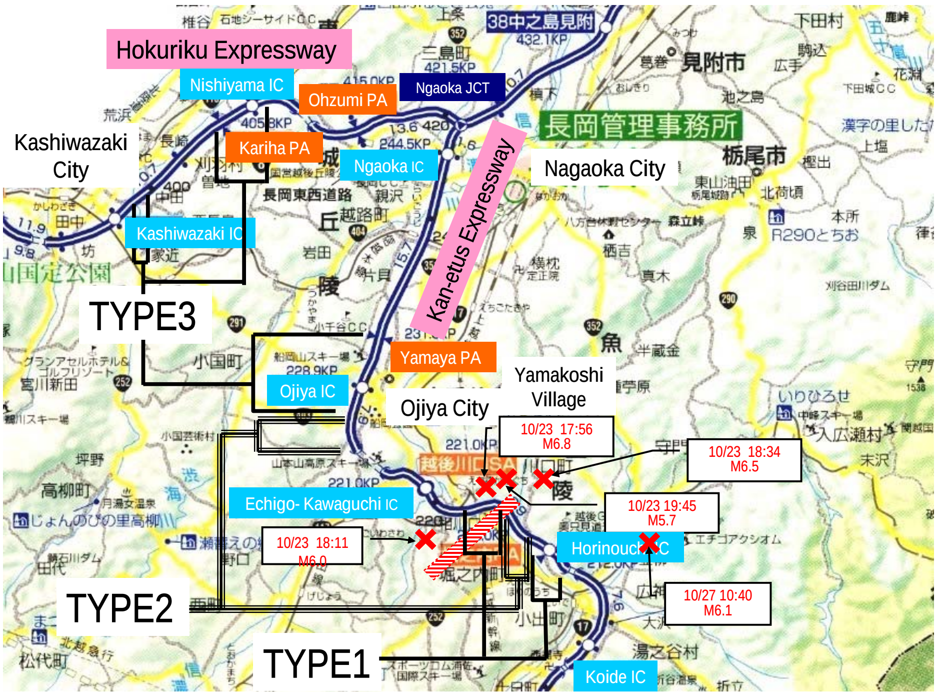


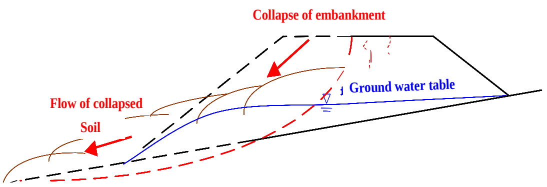
Fig. 4. Route map of Kan-etsu and Hokuriku Expressways and zones damaged during the Niigataken-chuestu and Niigataken-chuetsu-oki earthquakes (Yasuda and Fujioka,2009)

b) between Ohzumi PA and Nagaoka JCT (6.0 km) of Hokuriku Expressway.

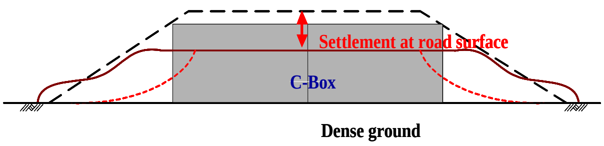
This was the first time that an earthquake caused severe damage to the embankments of national expressways. The section between Horinouchi IC and Echigokawaguchi IC of Kan-etsu Expressway was constructed on the slopes of hills. The embankments were constructed mainly by cut and filling. Sliding of the filled embankments occurred at several sites during the 2004 Niigataken-chuetsu earthquake. The section between Yamamotoyama Tunnel and Yamaya PA was constructed on level grounds and the embankments were constructed by filling soils. Large settlement of the embankments occurred in this section.

Several seismic records were obtained for these severely damaged zones. The recorded maximum surface accelerations were 489 cm/s^2 at Horinouchi Town, 1722 cm/s^2 at Kawaguchi Station, 1502 cm/s^2 at K-net Ojiya site and 1008 cm/s^2 at Ojiya Castle. Therefore, the seismic motion in the severely damaged zones was very strong.

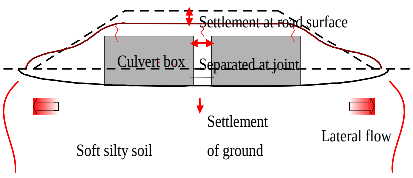
According to the mechanism of failure of embankments, the damage of the Kan-etsu Expressway can be classified into three types as follows:
(1) Type 1: Serious slide of the embankment on the sloping ground as schematically shown in Fig.5 (a);



(a) Type 1: Serious slide of the embankment on the sloping ground



(b) Type 2: Settlement of the embankment on the level ground without the deformation of the ground



(c) Type 3: Settlement of the embankment and the culvert on the level ground with the deformation of the ground

Fig. 5. Classification of the damage to the embankment of Kan-etsu Expressway according to the mechanism of failure (Yasuda and Fujioka,2009)

(2) Type 2: Settlement of the embankment on the level ground without obvious deformation of the ground as schematically shown in Fig.5 (b);
(3) Type3: Settlement of the embankment and the culvert on level ground with deformation of the ground, as schematically shown in Fig.5 (c).
Sections where these types of failures occurred are shown in Fig.4.

Type 1 failure was serious slides of the embankment on the sloping ground. Type 2 failure was settlement of the embankment on level ground without the deformation of the ground. Type 3 failure was settlement of the embankment on level ground with deformation of the ground. In Types 2 and 3, settlement of the embankment seemed to have been induced due to the reduction of shear modulus of the fill materials. A reduction of the shear modulus of soils in the foundation ground also seemed to influence Type 3 failure.

Figure 6 shows the soil cross section from Yamamotoyama Tunnel to Yamaya PA. The surface soil is gravel near Yamamotoyama Tunnel, then, gradually changes to soft clayey soil or loose sandy soil towards Yamaya PA. Type 2 and Type 3 failures occurred near Yamamotoyama Tunnel and around Ojiya IC, respectively. Large differential settlement of 70 cm occurred between the embankment and the culvert box at C-Box Kawaguchi 11, as shown in Photo 4. The subsurface soil of the foundation ground is dense gravel with the an SPT *N*-value of more than 50. The height of the embankment is about 10 m. Fill materials are sandy silt with gravel, gravel with cobbles and clayey silt with gravel. The fines content of these soils was 50 to 60%. The measured water level was about 3 m higher than the bottom of the embankment. However, it is not clear whether the water was perched.

The differential settlements between embankments and culverts, and the settlements of culverts themselves between Yamamotoyama Tunnel and Yamaya PA, were measured. The differential settlement was about 50 to 70 cm near Yamamotoyama Tunnel and the settlements of culverts were about 10 to 20 cm. On the contrary, culverts near Ojiya IC

Photo 4. Differential settlement between embankment and culvert at C-Box Kawaguchi 11 (Yasuda and Fujioka,2009)

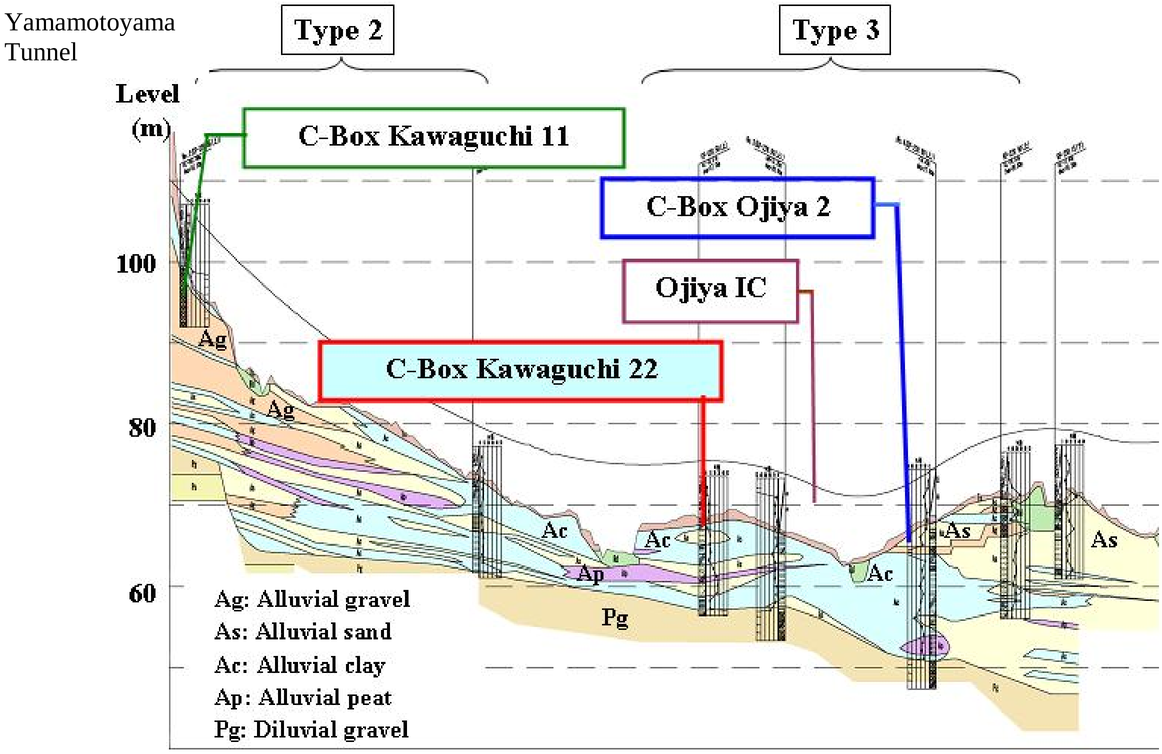


Fig. 6. Soil cross section between Yamamotoyama Tunnel and Yamaya PA (Yasuda and Fujioka,2009)

settled much more than this. Around Ojiya IC, differential settlement of several tens cms occurred between embankments and culverts as shown in Photo 5. Moreover, culverts settled several tens cms and stretched as shown in Photo 6 and 7. Embankment soil fell through the opened joints. The deformation of embankments, culvert boxes and ground are schematically shown in Fig.5 (c). Both toes of the embankments spread in a lateral direction and caused the lateral displacement of adjacent ground as shown in Photo 8. The embankment soils at the two sites are clayey soils with 70% to 80% of fines. The SPT *N*-values of the embankment soils are 5 to 10. The heights of the embankments at the two sites were 5.6 to 6.8 m and 5.3 to 5.6 m, respectively. The water levels at the sites were about 3 m higher than the bottom of the embankments, though the embankments were constructed on level ground. At C-Box Kawaguchi 22, thick soft silty layers, with the SPT *N*-values of about 5 are deposited from the ground surface to a depth of 16 m. A thin soft, silt, layer 2 m thick is deposited under the embankment at C-Box Ojiya 2. Then, silty sand, silt, sandy silt and silt layers, with SPT *N*-values of 10 to 20, are deposited to a depth of 24 m.

As mentioned above, differential settlements between embankments and culverts, and the settlements of culverts themselves were measured after the earthquake. Moreover, differential settlements between embankments and bridges,

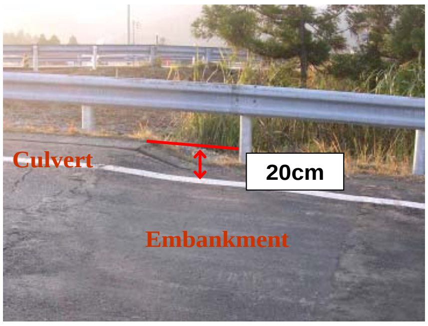


Photo 5. Differential settlement at C-Box Kawaguchi 22(Yasuda and Fujioka, 2009)

Photo 6. Settlement of culvert at C-Box Kawaguchi 22

Photo 7. Separation of culvert joint at C-Box Ojiya 2 (Yasuda and Fujioka, 2009)

Photo 8. Moved ground adjacent to C-Box Ojiya 2

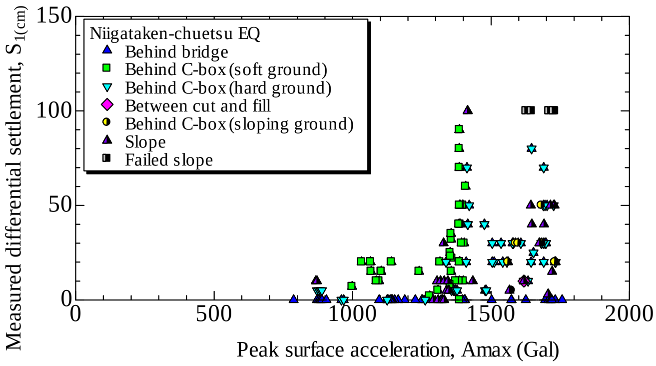


Fig. 7. Relationship between differential settlement and maximum surface acceleration (Yasuda and Fujioka,2009)

and differential settlements between fill and cut zones were measured. The relationships between these differential settlements and peak surface accelerations are plotted in Fig.7. The peak surface acceleration was estimated based on the relationship between the epicentral distance and the peak surface accelerations recorded by K-net. Differential settlements increased with the peak acceleration as shown in Fig.7.

THE 2005 FUKUOKAKEN-SEIHO-OKI EARTHQUAKE

The Fukuokaken-seiho-oki earthquake, with a magnitude of 7.0 (Mj), occurred in Japan on March 20, 2005. Fig. 8 shows the epicenter of the earthquake and the distribution of the

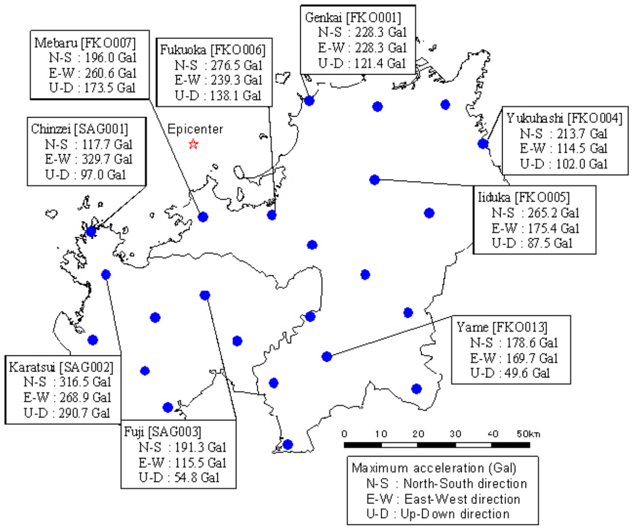


Fig.8. Epicenter and the distribution of the maximum surface acceleration recorded by K-NET

maximum surface acceleration recorded by K-NET (NIED). Epicenter of the earthquake was about 30 km northwest from downtown of Fukuoka City. Direction of a fault is estimated as NW-SW. Maximum horizontal surface acceleration recorded in the center of Fukuoka City was 277 Gals. Seismic intensity by JMA scale in Fukuoka City was 5 to 6. The earthquake caused severe damage to houses due to the failure of retaining walls in a tiny island named Genkai-jima which is only about 10 km from the epicenter. . A lot of tiled roofs of timber houses were damaged due to shaking in wide area. Several buildings suffered damages in the central area of Fukuoka City. Liquefaction occurred in many reclaimed lands and caused damages to quay walls, tanks and sheds. Slope failures occurred at several sites in Shikano-shima island that are located about 20 km from the epicenter.

Close circles plotted on Fig.9 show liquefied sites (Yasuda and Tanoue, 2006). Almost all sites are located in reclaimed lands along Hakata Bay. No liquefaction occurred in alluvial low land. One site in Uminonakamichi sand sprit liquefied. However the liquefied site was a newly filled land on a pond. Therefore, it can be said liquefaction occurred in only artificially reclaimed lands.

Among the reclaimed lands, Oki-hama, Nanotsu, Higashi-hama Aratsu and Hakozaki, Momochi-hama were constructed before 1990. These reclaimed lands were filled mainly with sandy soil. Other reclaimed lands, Meino-hama, Odo, Atago-hama, Kashii-hama and Island City were newly filled with clayey soil. Therefore, only few or no boiled sands were observed in the latter newly reclaimed lands. On the contrary, in the former reclaimed, liquefaction occurred at comparatively many sites. In Oki-hama, a quay wall tilted as shown in Photo 9. Horizontal displacement of the quay wall was about 2 m. The ground behind the quay wall flow toward bay and subsided. Flowed zone extended about 10 m behind the quay wall. Several quay walls tilted a little in Nanotsu, Higashi-hama and Aratsu. Two small tanks settled about 20

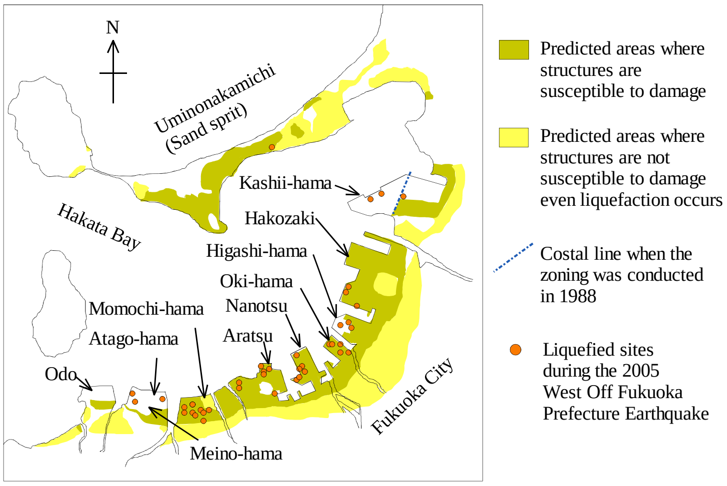


Fig.9. Hazard map for liquefaction and liquefied sites during the Fukuokaken-seiho-oki earthquake

Photo 9. Displacement of a quay wall and subsidence of the ground in Oki-hama

Photo 10. Boiled sand in Momochi-hama

Photo 11. Liquefaction-induced flow at Uminonakamichi Seaside Park

cm due to liquefaction in Aratsu. In Momochi-hama, sand boils were observed at many sites as shown in Photo 10. However, no damage to buildings and timber houses occurred. Obvious ground subsidence did not occurred at the liquefied sites. Therefore, it is estimated that liquefied layer was thin.

Many boiled sands were observed at Uminonakamichi Seaside Park. This site was newly developed for a park by filling a part of a pond with sand. The filled ground behind a remaining pond has a gentle slope towards the remaining pond. Liquefaction-induced flow occurred on the sloping ground. Maximum horizontal displacement due to the flow was about 10 m. The flow extended to about 80 m. Cracks occurred on the ground surface due to the flow as shown in Photo 11. Simple piers and promenades were damaged due to the flow. A filled sand layer is deposited from ground surface to a depth of about 10 m. The fill was clean and very loose because its SPT *N*-value was very low as 2 to 7. Therefore, it is estimated the fill liquefied due to the earthquake.

By the way, seismicity around Fukuoka City is the lowest class in Japan. However, microzonation during earthquakes was needed because Fukuoka City is the biggest and most important city in southern Japan. Then microzonations for liquefaction, strong shaking, slope failure were conducted based on several analyses in 1988 (Yasuda and Matsumura, 1991). Shadowed zones in Fig.9 show the predicted areas where structures are susceptible to damage due to liquefaction. By comparing with the actual liquefied sites, validity of the microzonation is discussed as follows:

(1) Almost all liquefied sites are located in the predicted area where structures are susceptible to damage. Therefore, roughly speaking, the microzonation for liquefaction was fairly valid.

(2) Liquefaction occurred at three sites in Atago-hama, though it was predicted liquefaction does not occur because this land was filled with clayey soil. The liquefied sites are located along old shore protections. In general, sandy soil is filled just behind shore protections during reclamation work. So, sandy soil might be existed at the sites and liquefied during the earthquake.

(3) In Uminonakamichi sand sprit, liquefaction did not occur in natural ground though some areas at the toe of sand dune were predicted to liquefy. Boring data were few in this sand sprit because heavy structures were not existed. Therefore, in the microzoning, the ground at the toe of sand dune was judged to be liquefiable based on the experience during past earthquakes. For example liquefaction occurred in the ground at the toe of sand dune during the 1964 Niigata and 1983 Nihonkai-chubu earthquakes. Difference on ground conditions between at the liquefied sites and at Uminonakamichi is not clear. Future study is necessary.

THE 2007 NOTOHANTO EARTHQUAKE

On March 25, 2007, the Notohanto earthquake, of Mj=6.9, occurred. Fig.10 shows the epicenter of the earthquake and the distribution of maximum surface acceleration recorded by K-NET (NIED). Many timber houses collapsed due to strong shaking in Wajima City. Collapse of natural slopes along coast occurred also. Moreover, the highway embankments of the Noto-yuryo road were very seriously damaged. Huge slides occurred at 11 sites shown in Fig.11. Photos 12 and 13 show the slides at sites No.9 and No.32, respectively. A soil cross section and plan at site No.32, estimated after the earthquake, are shown in Fig.12 and 13. The height, thickness and length of the collapsed soil were about 30 m, 12 m and 80 m, respectively. The embankment soil was weathered tuff.

Sasaki et al. conducted detailed investigation at damaged and not damaged embankments and summarized that the groundwater level tended to be high near the slope toe of the damaged embankments (Sasaki et al., 2008). And the possibility that the existence of water within the embankment might have affected the level of damage, is pointed out.

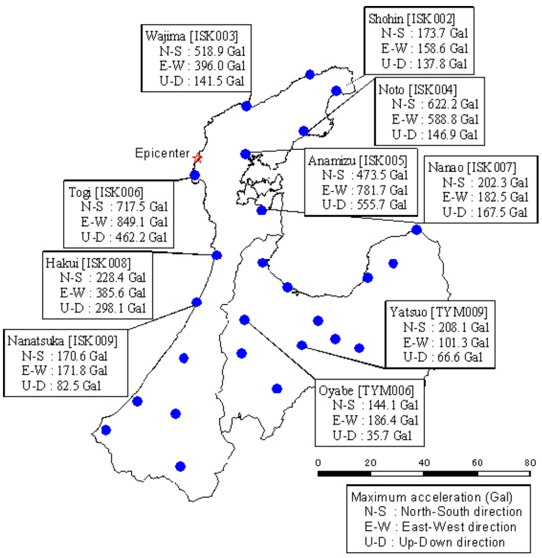


Fig.10. Epicenter and the distribution of the maximum surface acceleration recorded by K-NET

Fig.11. Map of sites along Noto-yuryo road seriously damaged during the 2007 Noto-hanto earthquake

Photo 12. Slide of the embankment of Noto-yuryo road at site No.9

Photo 13. Slide of the embankment of Noto-yuryo road at site No.32

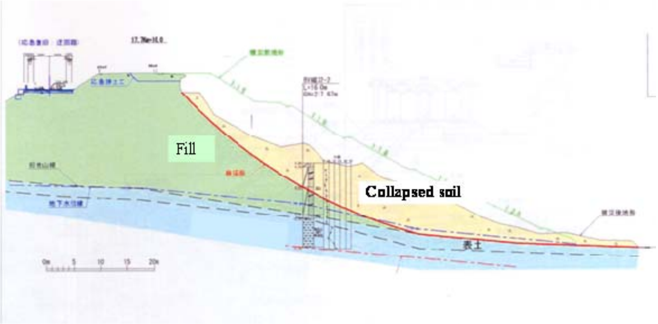


Fig.12. Cross section at site No.32 (by Ishikawa Pref.)

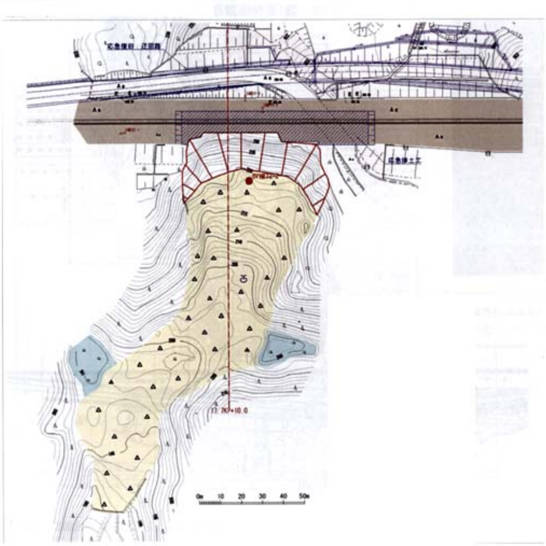


Fig.13. Plan at site No.32 (by Ishikawa Pref.)

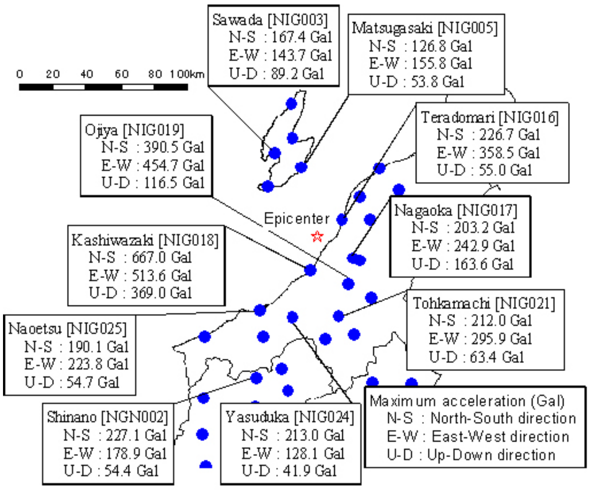


Fig.14. Epicenter and the distribution of the maximum surface acceleration recorded by K-NET

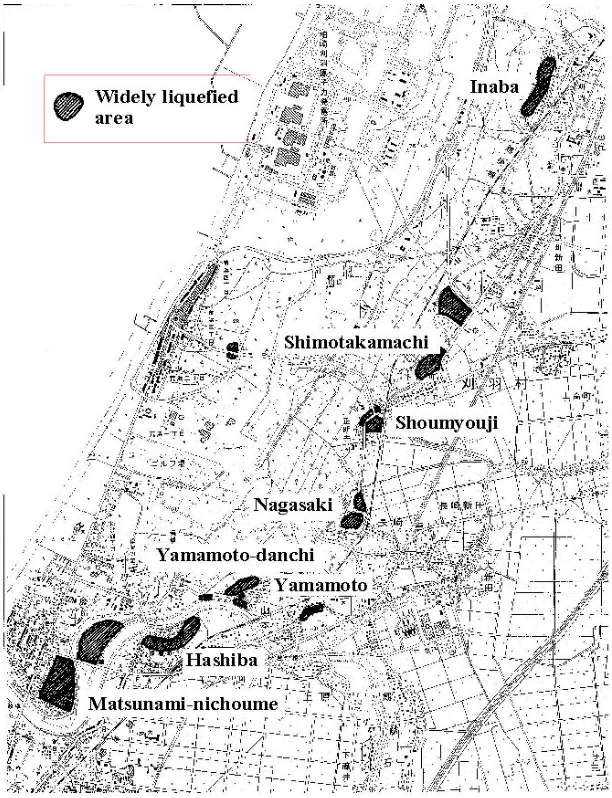


Fig.15. Widely liquefied areas

THE 2007 NIIGATAKEN-CHUETSU-OKI EARTHQUAKE

On July 16, 2007, the Niigataken-chuetsu-oki earthquake, of Mj=6.8 occurred in Japan. Fig.14 shows the epicenter and the distribution of the maximum surface acceleration recorded by K-NET (NIED). The maximum surface acceleration recorded at K-NET Kashiwazaki which is located in the center of Kashiwazaki City was 667 Gals. Many houses, pipelines and other structures were severely damaged (Yasuda, 2009). Moreover, landslides occurred at several sites. A nuclear electric power plant shut off immediately. During the 2004 Niigataken-chuetsu earthquake, several houses and sewage pipes and manholes had suffered damage in this area also. Some of the damaged houses and sewage pipes were not damaged due to the new earthquake because appropriate countermeasures had been applied during the restoration works. In this paper, damages to houses, sewage facilities and gas pipes are introduced.

Liquefaction occurred at many sites in and around Kashiwazaki City. Among them, widely liquefied areas are shown in Fig.15 In geomorphological condition, liquefied areas are divided into two groups: i) Matsunami and Hashiba district where liquefaction occurred in old river channels, and ii) other areas where liquefaction and associated ground flow induced on the gentle slopes of sand dunes.

Photo 14. A settled house in Hashiba district

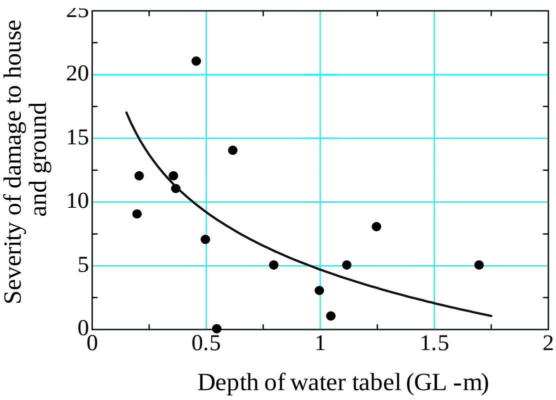


Fig.16. Relationship between grade of severity and depth of ground water table

Photo 15. Erupted sand and a settled electric pole in Matsunami district

Among the first group, about 20 houses settled due to liquefaction in Hashiba district as shown in Photo 14. The author and his colleagues conducted detailed survey on the damage to houses and grounds. Then, severity of the damage to houses and grounds were graded. Figure 16shows the relationship between the grade of severity of the damage and depth of ground water table. Severity of damage decreased

Photo 16. Damaged house due to liquefaction-induced flow in Yamamotodanchi district

with the increase of the depth of water table. If the ground water table was deeper than about 1.5 m, no sever damage was observed. Photo 15 shows boiled sand and settled an electric light pole in Matunami district. Huge amount of water and sand erupted in Matunami district due to liquefaction. However, only few houses which were located on sloping grounds were damaged. Measured ground water tables at several sites were about GL-2 m to -3 m. Therefore it can be judged that no severe damage to houses occurred because surface unliquefiable layer was thicker than about 1.5 m, though liquefaction induces in the layers below ground water table. This phenomenon is similar as the previous experience during the 2000 Tottoriken-seibu-oki earthquake (Yasuda, et al., 2004).

In the second group, very severe damage to houses occurred as shown in Photo 16 because not only liquefaction but also liquefaction-induced ground flow occurred at sloping grounds of sand dunes. In Inaba district, liquefaction had occurred during previous two earthquakes: the 1964 Niigata earthquake and the 2004 Niigataken-chuetu earthquake. Several houses settled during the 2004 earthquake were restored by two types of countermeasures. The first type of the measure was to install long steel piles with 5 to 6 m long, then build new houses. No severe damage occurred to the houses though surrounding ground liquefied and subsided about 20 cm. The second type was underpinning of existing houses by short steel piles. The depth of piles were about GL-2 m. Severe damage to the houses with the settlement of about 30 cm occurred as shown in Photo 17. The depth of the piles must be not enough to support the houses because liquefied depth was about 6 to 7 m.

In the liquefied areas, uplifted manholes were few though surrounding grounds liquefied. Relationships between the depth of the bottom of sewage manholes and the depth of ground water table in Hashiba and Matsunami districts are plotted on Fig.17. The depths of the bottoms of the manholes were almost same or shallower compare with the depths of ground water tables. This may be the reason why sewage manholes were not uplifted.

Photo 17. A settled house due to liquefaction though restored by short steel piles after the previous

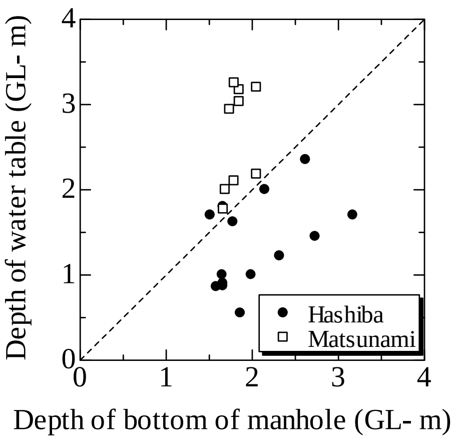


Fig.17. Relationships between the depth of the bottom of sewage manholes and the depth of ground water table in Hashiba and Matsunami districts

In case of low pressure gas pipes, very severe damage occurred in Matsunami district because the gas pipes were mainly screw type connected steel pipes which are not strong to deformation. On the contrary, almost no damage occurred in Hashiba district though liquefaction occurred because new and stronger gas pipes were used.

Moreover it was remarkable that high and middle pressure gas pipes which are strong steel pipes with diameters of 50 cm to 300 cm, were damaged at 28 sites as show in Fig.18. Main type of the damages was buckling of pipes occurred at the boundary between a wide valley plain and surrounding hills or sand dunes. In and around Kashiwazaki City, the wide valley plain with about 15 km long and 3 to 5 km wide is formed. Figure 19 shows a soil cross section along 17-17' line. Soft clayey alluvial layers, Ac in Fig.19, are deposited in the valley plain. Maximum depth of the alluvial layers is about 50 m as shown in Fig.19. However the thickness of the soft clayey layers is quite irregular inside the plain. About 20,000 years ago during ice age, several valleys existed and formed very

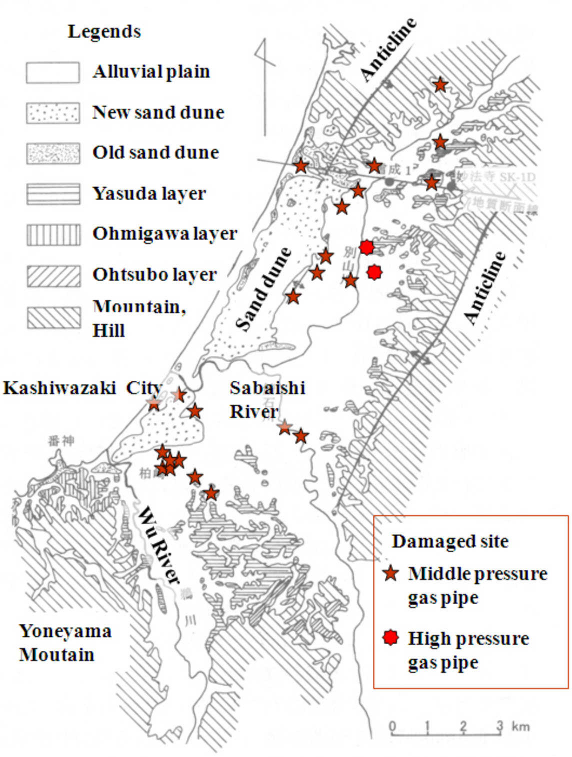


Fig.18. Topographical map and damaged sites to high and middle pressure gas pipes

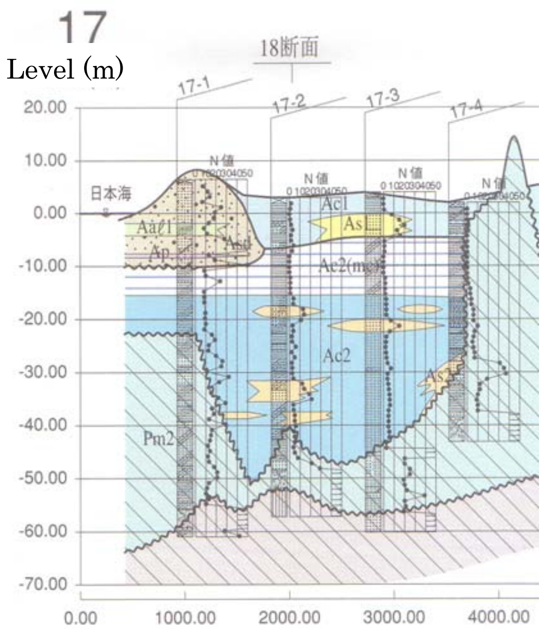


Fig.19 Soil cross section along 17-17' line (Niigata Prefecture Geotechnical Consultants Association, 2002)

irregular ground surface in this area. Then the alluvial clayey layers were deposited on the irregular ground surface and formed a wide valley plain. Between the valley plain and the Japan Sea sand dunes are formed along the coast. Other sides

Photo 18. One site where middle pressure gas pipe was damaged due to buckling at the boundary between a valley plain and a surrounding hill

of the plain are surrounded by hills and mountains. As mentioned above, the surface soil in the valley plain is very soft. Moreover, epicenter of the earthquake is fairly close. Then it is estimated that very large compressive strain induced at the boundary between the valley plain and surrounding hills or sand dunes and caused the buckling of the middle and high pressure gas pipes. Photo 18 shows topographical condition of a damaged site.

THE 2008 IWATE-MIYAGI-NAIRIKU EARTHQUAKE

The 2008 Iwate-Miyagi-nairiku earthquake, with a magnitude of Mj=7.2, occurred on June 14, 2007. Fig.20 shows the epicenter of the earthquake and the distribution of the maximum surface acceleration recorded by K-NET (NIED). As many active volcanoes are existed in the epicentral area, huge landslides occurred on the slopes consisted by volcanic soils. Slid soils blocked river flow at several rivers and formed quake lakes.

The biggest slide occurred on the slope at the lake of Aratozawa Dam as show in Photo 19. Volume, width, length and average thickness of the slid mass are estimated as 67 million m^3, 900 m, 1300 m, and 100 m respectively. Slide occurred though slip surface was almost flat as 1 to 2 degree. According the investigation conducted after the earthquake, sandstone and siltstone layers are existed at the depth of the slip surface.

Remarkable damage due to the combination of slide and debris flow occurred on the southeast slope of Mt. Kurikoma which is volcano. There was a hot spring inn named "Komanoyu" on the right side terrace of Dozou Valley as schematically shown in Fig,21 and photo 20. A slope at left side of the Dozou Valley slid due to the earthquake and blocked the flow of Dozou Valley. At the time Komanoyu Inn had no damage. Due to the earthquake, a slope at the top of Dozouzawa Valley slid also as shown in Photo 21 and caused debris flow by including snow and river water. The volume,

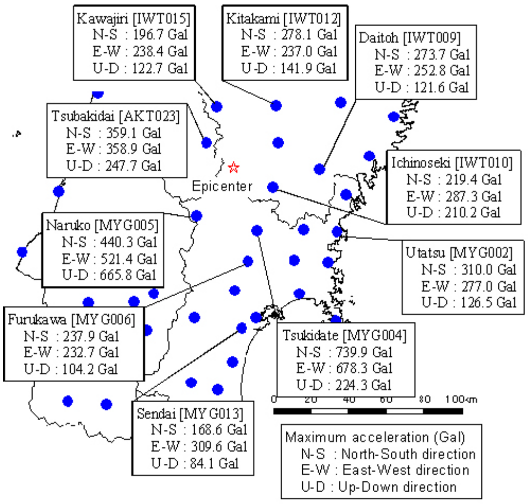


Fig.20. Epicenter and the distribution of the maximum surface acceleration recorded by K-NET

Photo 19. *Biggest landslide at Aratozawa*

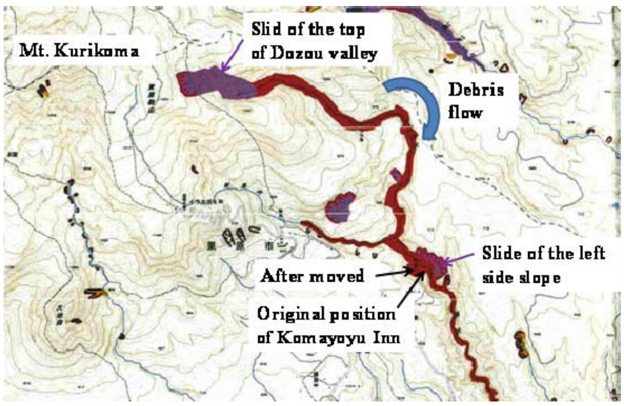


Fig.21. Komayoyu Inn, slide at two sites and debris flow

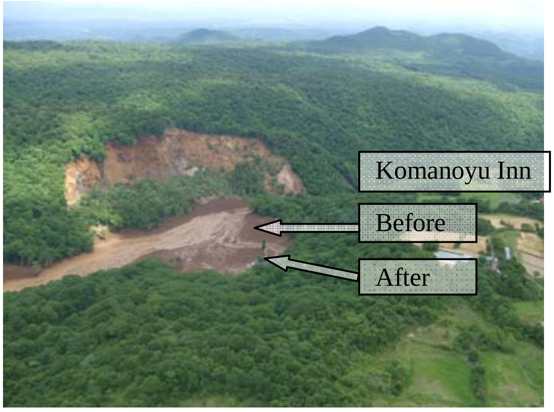


Photo 20. *Komanoyu Inn and slide of left slope after the damage by debris flow*

Photo 21. *Lanndslide at the top of Dozou Vally and associated debris flow*

Photo 22. *Collapse of Matsurube Bridge*

width, length of the slid mass was about 0.55 million m^3, 250 m, 100 m, respectively. The debris flow reached to Komanoyu site about 9 minutes after the earthquake and turned the direction to the right because the slid mass from the left slope blocked the flow. And the right-turned debris flow hit and pushed the Komanoyu Inn about 50 m as shown in Photo 20. Peoples stayed in the inn were buried in the debris.

One more surprising damage occurred at Matsurube Bridge. The bridge fell down due to the lateral force from right side bank as shown in Photo 23. It is estimated that the right slope of the river slide due to inertia force and pushed the abutment of the bridge.

CONCLUSIONS

Geotechnical damages during recent five earthquakes in Japan from 2004 to 2008 are introduced. The following features are found.
1. The 2004 Niigataken-chuetsu earthquake caused three types of failure of expressway embankments. Uplift of about 1400 sewage manholes and many pipes occurred due to the liquefaction of replaced soil.
2. Liquefaction occurred in Fukuoka City during the 2005 Fukuokaken-seiho-oki earthquake. Liquefiable area in the city had been predicted about 17 years before the earthquake. Liquefied zones were fairly coincided with predicted liquefiable zones.
3. Very severe slide of highway embankments occurred at 11 sites during the 2007 Notohanto earthquake.
4. During the 2007 Niigataken-chuetsu-oki earthquake, liquefaction induced at old river channels and gentle slopes of sand dunes, and caused settlement of houses and breakage of low pressure gas pipes. However, some houses and sewage manholes were survived because ground water levels were low. Low pressure gas pipes in some districts were survived because new and stronger gas pipes were used in the districts. High and middle pressure gas pipes were damaged at 28 sites. Main type of the damages was buckling of pipes occurred at the boundary between a wide valley plain and surrounding hills or sand dunes.
5. Huge landslides and serious debris flows occurred along the slopes of Kurikoma Volcano during the 2008 Iwate-Miyagi-nairiku earthquake. Many roads were closed due to the landslides and debris flows.

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