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DAMAGE INDUCED BY THE 2007 NIIGATAKEN CHUETSU-OKI, EARTHQUAKE

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ABSTRACT :

The 2007 Niigataken Chuetsu-oki (Off Mid-Niigata) earthquake centered around Kashiwazaki City and Kariwa Village along the coast of the Sea of Japan in Niigata Prefecture, Japan, on July 16, 2007. Liquefaction of old river channels and dune sand hinterlands, a deep seated lateral flow of sand dune deposits, landslides of banking that buried valleys and damage to houses and infrastructures accompanied by the failure of natural slopes were remarkable. Moreover, the land subsidence of the world's largest nuclear power plant site was excessive. Subsequent surveys revealed that the floor on post footings of almost all residences heaved up in the shape of a convex by soil liquefaction.

KEYWORDS: Damage, Landslide, Liquefaction, Dune, The 2007 Off-Mid Niigata Earthquake

1. INTRODUCTION

The July 16，2007 Off Shore Central Niigata Earthquake (estimated magnitude of 6.8 on the JMA (Japan Meteorological Agency) scale) occurred at around 10:13 in 17 km offing seabed of Central Niigata shown in Figure 1. The JMA maximum seismic intensity of over 6 (MSI of 6+) was observed in Nagaoka, Kashiwazaki and Kariwa, on the coast of the Japan Sea in Niigata prefecture, and Iizuna, Nagano prefecture, which is located approximately 100 km south from the hypocenter. A MSI of 6- was observed in Joetsu, Izumozaki, and Ojiya city which is very near the source area of the 2004 Central Niigata Earthquake. In addition, a M5.8 (estimate) and a MSI of 6- aftershock occurred around 15:37, the same day. According to the Fire Defense Agency, the earthquake resulted in 11 deaths, 1804 injuries, and 1086 complete collapses, 3790 partial destruction and 34469 partially damaged houses.

2. GEOGRAPHICAL FEATURE AND GEOLOGY OF STRICKEN AREA

As seen in Figure 1, the Oguni/Kawanishi hills, Hachigoku Anticline, Central Hill, and Teradomari/ Nishiyama Hills form parallel anticlinal axes, and the Shibumi River, the Sabaishi River and the Simazaki River / the Betsuyama River / Kashiwazaki Plain form the synclinal axes. The Shibumi, the Sabaishi and the U River markedly meander while punching both banks.

Kashiwazaki Plain and its circumference Quaternary Formations are shown in Figure 2. The Kasajima, Yasuda, Omigawa and Otsubo Formations of Pleistocene form marine terrace and hill-like geographical features at the peripheral of Kashiwazaki Plain. The Yasuda Formation which alternately consists of silt, sand, and sandy gravel forms the terrace of medium height having a relative height of 10-30 m in comparison with the alluvial soil surface were markedly dissected, and forms numerous valleys at the foot of Central Hill. The Arahama Dune is a loose new Holocene sand dune distributed along the seashore zone from northern Miyagawa to southern Kujiranami. A Stiff Banjin Sand Dune of Pleistocene partially underlies the Arahama Dune. The Kashiwazaki layer consisting of alternations of clay, silt, and sand (in part stone) strata is a deep weak alluvium of 100 m or more thick. The SPT-N values are less than 5 in the upper part and 10-20 in the lower part.

3. EARTHQUAKE MOTION

A part of K-net (Japanese nationwide strong motion network) acceleration record observed at Kashiwazaki, Ojiya, and Teradomari is shown in Figure 3. In the Kashiwazaki NS wave, long period-ization begins about 3 seconds after the beginning of the record and cyclic mobility phenomena are seen, suggesting that soils under the observation point liquefied. The spectra of Ibayashi et.al. (2001)'s unit earthquake input energy were compared in Figure 4. According to this figure, the predominant period of the Kashiwazaki NS wave was as long as 2.4 seconds. Since the input energy in terms of the velocity dimension regarding this period at Kashiwazaki is 15.2 times that at Teradomari which was located closer to the epicenter and 230 times in terms of energy dimension, the destructive power of the earthquake was particularly large in the Kashiwazaki area. The destructive power to the structure having a predominant period of about 2 seconds at Kashiwazaki brought by this earthquake was equal to that at Ojiya brought by the previous earthquake.

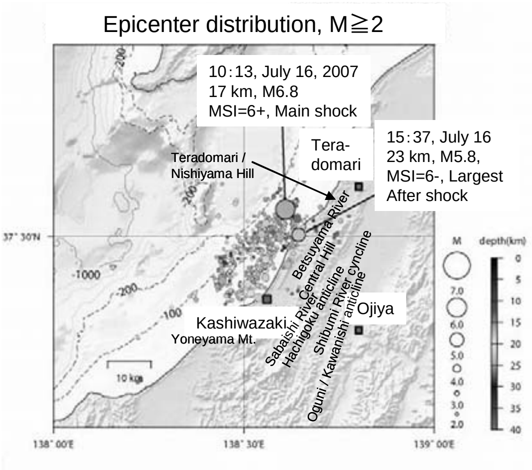


Fig.1 Epicenters of main and after shocks
(Corrected to JMA Home Page (2007))

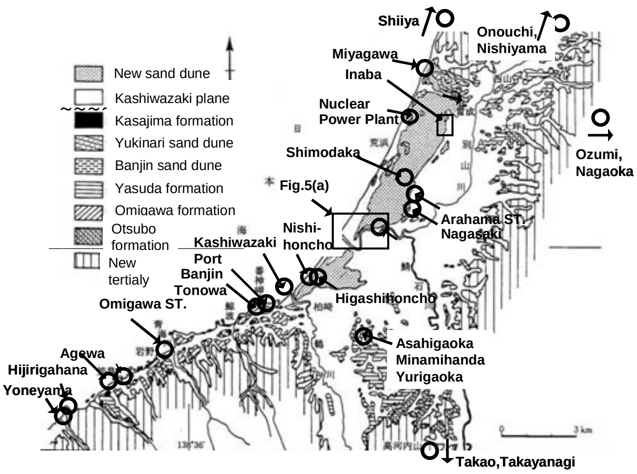


Fig.2 Quaternary formations of Kashiwazaki Plane
(Corrected to Geology of Kashiwazaki (1983))

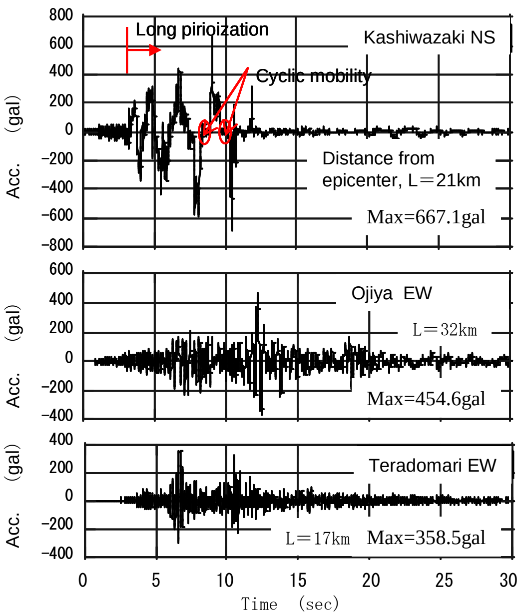


Fig.3 Examples of acceleration wave (K-net)

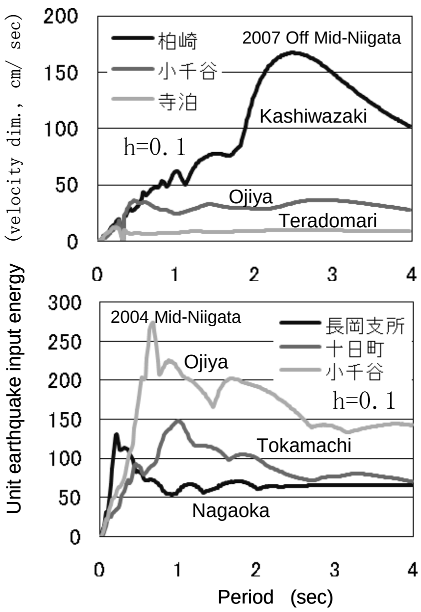


Fig.4 Spectra of unit earthquake input energy

4. DAMAGE AND FOUNDATION

4.1. Structures

4.1.1 Road

As shown in Photo 1, the strongly weathered soil slid almost along the dip slope of stiff sand and silt rocks at Ozumi Sembom-cho, Nagaoka-city, resulting in the collapse of National Route No.8 for a length of 140 m and blockage of the Kuro river at the toe of the slope for a length of over 50 m. The road shoulder of Route No.116 sank at various places in Nishiyama-cho, Kashiwazaki city. Photo 2 (a) shows a horizontal gap of the roadbed in a transverse direction, and level difference in the run direction at the boundary of the high banking section on alluvium and the natural ground section of diluvium. Photo 2 (b) shows a landslide depositing on Route 352 at Shiiya-shore, Kashiwazaki. The slope with a system of fissures dipping backward of Siiya Formation is an abrasion cliff of about 60° inclination. Photo 2 (c) shows a liquefaction induced slope failure including a sand quarry and its front road at Yamamoto, Kashiwazaki. Photo 2 (d) shows subsidence and lateral spreading of Arahama-Nakada Route at Shimodaka, Kariwa Village. The roadbed is new dune sand. According to Ministry of Land, Infrastructure, Transport and Tourism Hokuriku Regional Development Bureau (MLITTHRDB, 2007), serious damage occurred at 44 places within major transportation routes.

4.1.2 Railroad

As seen in Photo 3, the sand gravel terrace at the top of a sea cliff slid with collapse of strongly weathered volcanic rock surface below the middle part of the steep slope at the Omigawa Railroad Station on the Shinetsu Line, spilling debris on the station and tracks. At the Omigawa Railroad Bridge, the abutment backfill subsided and the rails hung (Photo 4 (a)).

With respect to Echigo Line, lateral and vertical deformations in train tracks (Photo 4 (b)) were observed throughout this region. Joint bars dispersed and the tracks were separated on the railroad embankment to the west of the Sabaishi River Bridge (Photo 4 (c)). The railroad bed in this region is considered to be banked with sand. The platform at Arahama Station caved in below the level of track due to liquefaction of subsoil (Photo 4 (d)).

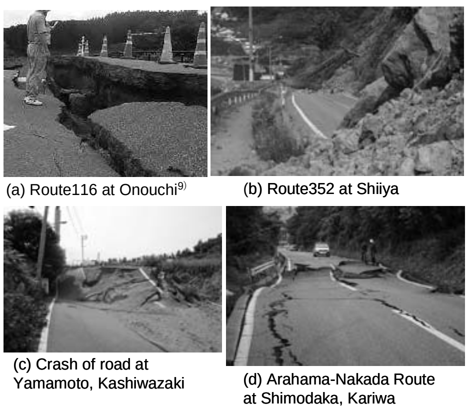
4.1.3 Port

The east quay of the central wharf at Kashiwazaki Port inclined forward (Photo 5), and the aprons of the central and west quays settled due to liquefaction of sandy backfill. No. 3 quay of the Nakahama wharf also inclined forward at its east end. Displacement and rotation of caisson were confirmed at other quays, too, of this port.

4.1.4 River

The left bank of the Sabaishi River subsided approximately 1 m over a distance of 50 m associated with lateral spreading at Hashiba-cho, Kashiwazaki (Photo 6). Since this place is one where the old channel was coffered by new bank for river training, the underlying loose sandy soil liquefied. Lots of liquefaction induced long crest cracking were observed at other new banks crossing the old channel near and adjacent to the Kaiun Bridge. Judging from a significant longitudinal gradient with height difference along the crest

Photo 1 Ozumi, Nagaoka: Landslide at Route No.8



(a) Route116 at Onouchi[9)]
(b) Route352 at Shiiya
(c) Crash of road at Yamamoto, Kashiwazaki
(d) Arahama-Nakada Route at Shimodaka, Kariwa

Photo 2 Damage of roads

of the bank, subsidence of the road surrounding a pump pit nearby (Photo 7(a)), and ejection height of a water pipeline supported by piles in the embankment (Photo 7(b)), elevation of the river bank is considered to have decreased by 20 cm to 1 m or more from place to place in this region.

A crack of 5 m deep and 100 m long (Photo 7(c)) was found in the left bank of the Shinano River at Machikarui, Teradomari town. Deep longitudinal cracks at other sections of the bank, sand boils and cracks parallel to the river at various places of high water channel (Photo 7(d)) along this river occurred. According to Shinanogawa River Office of MLITTHRDB (2007), totally 18 damage were caused in the Shinano River System. The Jorakuji River was blocked at Jorakuji, Izumozaki.

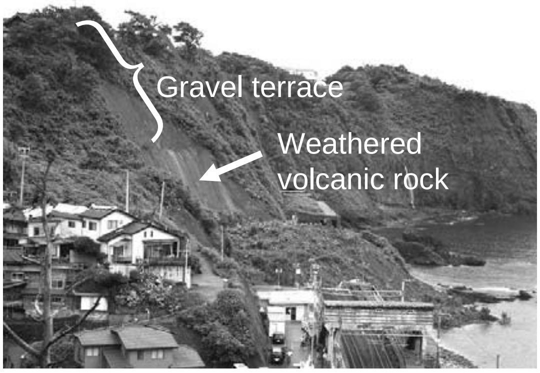
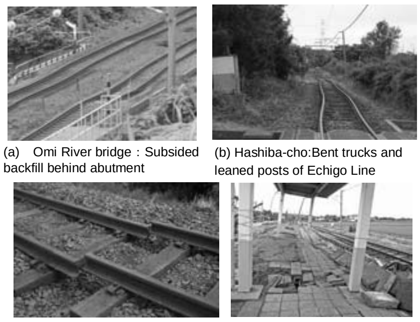


Photo 3 Omigawa Station, Kashiwazaki: Collapse of sea cliff and berried railroad station of Shinetsu Line

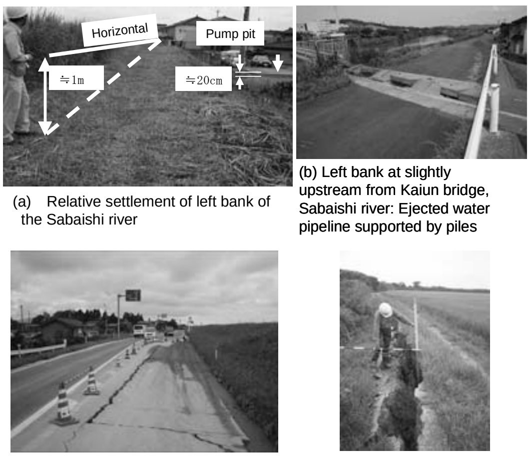


(a) Omi River bridge : Subsided backfill behind abutment
(b) Hashiba-cho:Bent trucks and leaned posts of Echigo Line
(c) West of Sabaishi River Bridge : Separated trucks of Echigo Line
(d) Arahama Station:Caved-in platform(Photo: By Yoshinori Hosaka)

Photo 4 Damage of railroads

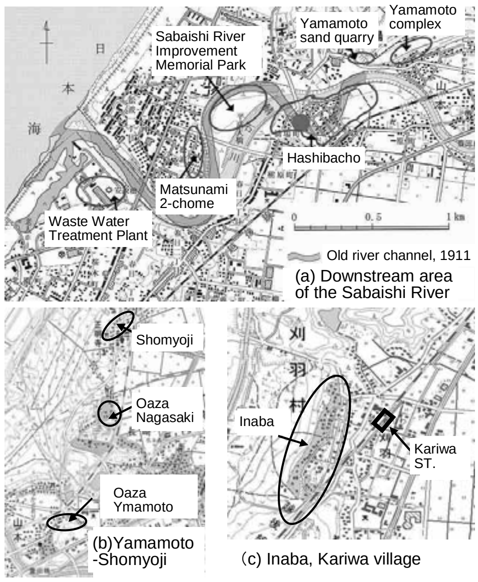
Photo 5 Inclination of caisson quay and trace of sand pumping at Kashiwazaki Port

Photo 6 Subsided bank of Sabaishi River



(a) Relative settlement of left bank of the Sabaishi river
(b) Left bank at slightly upstream from Kaiun bridge, Sabaishi river: Ejected water pipeline supported by piles
(c) Machikarui, Teradomari:Crack in left bank of the Shinano River (Photo: By Shinanogawa River Office, MLITT)
(d) Machikarui, Teradomari:Crack at high water channel of the Shinano River (Photo:BY Shinanogawa River Office, MLITT)

Photo 7 Damage of river



(a) Downstream area of the Sabaishi River
(b)Yamamoto -Shomyoji
（c) Inaba, Kariwa village

Fig. 5 Locations suffered damage by Liquefaction

4.2. Residential land

4.2.1 Liquefaction induced damage

Liquefaction of soil occurred at various places shown in Figure 5(a)-5(c). Photo 8 shows a street at Matsunami 2-chome which was developed during 1973-1976 by filling dune sand on former flood plane of the Sabaishi River. The vicinity streets were thoroughly covered with sand and water. Photo 9 shows a crater appeared at a street in Hashiba-town. The house in this photo straddles the old river channel and riverside reclaimed in 1974, and was severely damaged with the crack and level difference along this boundary. River deposits under the topsoil at Kashiwazaki Wastewater Treatment Plant underwent settlement about 35 cm on the whole. The Sabaishi River Improvement Memorial Park suffered from long distance cave ins with ejecta of underlying sand in the green space, and cracks, folds of pavement and jetting of sand in the parking lot. Yamamoto housing complex is a terrace type residential section on a hinterland slope of the new sand dune. Liquefaction induced slope failure caused a large-scale collapse of housing sites at the middle terrace involving serious damage at the lower one.

Damage due to liquefaction of sand fill and/or landslide of river deposits toward the old Betsuyama river channel was severe along the old riverside at Oaza Yamamoto. Tilting, bending and twisting of houses through subsidence of foundations and garden mountains with reverse uplift of floor posts (as mentioned later) and housing sites were remarkable on the edge of the new sand dune at Oaza Nagasaki. Such heave of floor is a common feature of the damage induced by the liquefaction of soil. Several houses fell down due to liquefaction between the foot of the sand dune and Kurobe-Kashiwazaki Local Roote at Shomyoji, Kariwa-village shown. The elevation of ground water is almost the same as that of the roadbed here. Many houses which was rebuilt or repaired after suffering heavy damage brought by the previous earthquake were seriously damaged again due to liquefaction-induced landslide of the sand dune at Inaba, Kariwa-village. Photo 10 shows an example which moved a couple of meters and tilted by around 10° only half a year after the reconstruction.

4.2.2 Landslide at steep slope high-land

Banjin 2-chome, Kashiwazaki-city is located on a highland of the Banjin layer of 12-13 m thick underlain by Omigawa formation. The north side steep cliff with a height of abut 20m was retained by a huge strong wall. Several houses behind the top of the retaining wall were hit by the strong motion. Many houses at the terrace shape residential land facing south were damaged due to the landslide of strongly weathered loose surface sand which was 2-3 m thick. At a block of this housing complex, the earth retaining wall of 50 cm thick and 4.5 m tall separated from the back ground for over a distance of 50 m. It rotated to stand straight with the strong motion of the main shock, resulting in a cave-in of the road on the backfill. Furthermore, a part of this wall with a mass of approximately 150 t fell frontward and collided with the back of three houses destroying them due to an aftershock (Photo 11(a)). The north side slope slid at Tonowa to the west of this highland, resulting in a long scarp running along the center line of the road (Photo 11(b)).

4.2.3 Damage at filling ground in dissected valleys

At a hilly residential area developed by cutting terrace and filling dissected valleys of the Yasuda formation, lots of landslides occurred at the filling ground. Figure 6(a) shows long cracks appearing at Asahigaoka complex. As compared in Figure 6(b), the strength of the fill material at Spot Q is approximately one half that of the intact soil at Spot P. Lots of houses were damaged mainly along the clacks (Photo 12(a)). Although there was also much crack related damage at Minamihanda (Photo 12(b)) and Yurigaoka sections of the east-, west-ward next area, respectively, almost no damage were identified on the cutting or natural ground.

4.2.4 Damage due to landslide in downtown Kashiwazaki on the new sand dune

Downtown central of Kashiwazaki city where the new sand dune covers most of the area has a ridge in the east-west direction. Landslides with long distance occurred at both the north and the south slopes. The broken line in Photo 13 shows the scarp of the north landslide along the border of Nishi-Honmachi and Nishi-Minatomachi. The scarp appeared at the shoulder of steep slope and just behind the top of cliff for a distance of approximately 200 m. This slide partially includes caves in of backfill behind retaining walls. Collapses of houses, temples are identified in the photo. The broken line in Photo 14 shows cracks and remarkable level differences appeared in the south slope with an inclination of around 5 % at Higashi-Honcho. The ground slid and spread toward the south. Many houses and buildings straddling this line were heavily damaged and some of them collapsed. The two transverse cracks are clear in the pavement of the east street end. The crack of the roof marked with the star symbol caused partially because bending fracture of the building itself due to collapse of pillars on the ground floor which is open to the street without any wall as well as lateral flow of ground associated with the liquefaction related landslide.

4.3 Others

4.3.1 Landslide and collapse of slope

A large translational landslide occurred at Higirigahana, Kashiwazaki, as shown in Photo 15. The slip surface is about 100 m wide at maximum, the sliding distance is over 200 m and the height difference is about 100 m. The surface consists of several bedding planes which constitutes thin alternating beds of sandstone and mudstone. Although the total number of slope failure exceeds 400, it is around 1/10 compared with over 4400 caused by the previous Central Niigata Earthquake because of offshore type events.

4.3.2 Damage to Nuclear Power Plant

Kashiwazaki Kariwa Nuclear Power Plant was located approximately 16 km south of the epicenter and

Photo 8 Street covered by spouted sand

Photo 9 Crater in the street and damaged house

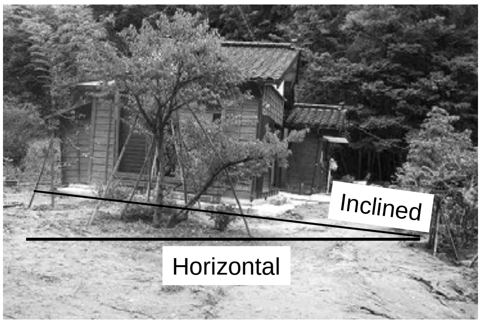
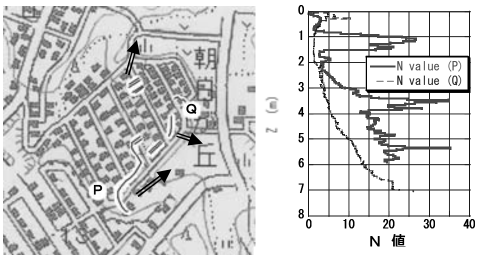


Photo 10 Tilted house due to liquefaction

(a) Banjin 2-chome:Retaining wall bumped against front houses (Photo: By Niigata Local Government)

(b) Tonowa：Crack and scarp due to landslide of steep slope

Photo 11 Damage to high-land with steep slope



(a) Cracks of ground at Asahigaoka complex

(b) Converted Sweden Weight Sounding Test results at point P (Intact) and Q (Fill)

Fig.6 Landslide at filling ground

(a) Asahigaoka: Crack in the garden of a house

(b) Minamihanda：Crack In the ground of a park

Photo 12 Cracks appeared in filling ground was affected in various features including liquefaction-induced excessive settlement of the ground (Photo 16). A fire occurred at the in-house electrical transformer of Unit No. 3 (Photo 17) due to the settlement of the duct supported by footing foundations. Although many other damage were caused to non-nuclear structures systems and facilities, all reactors in operation at the main event were shut down automatically and no abnormality that could impact the functional or structural integrity was found in the equipment in the reactors.

4.3.3 Sewer manholes

Since numerous sewer manholes uplifted due to liquefaction of soil at the 2004 Central Niigata earthquake were back placed by using cement or lime mixed sand, the number of uplifted manhole is not so much this time. Marked uplifts were, however, identified here and there where no countermeasures have been applied because of non damage last time (Photo 18).

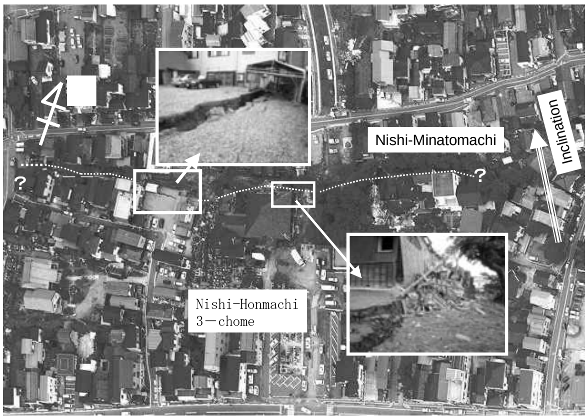


Photo 13 Scarp appeared at north slope of Downtown Kashiwazaki

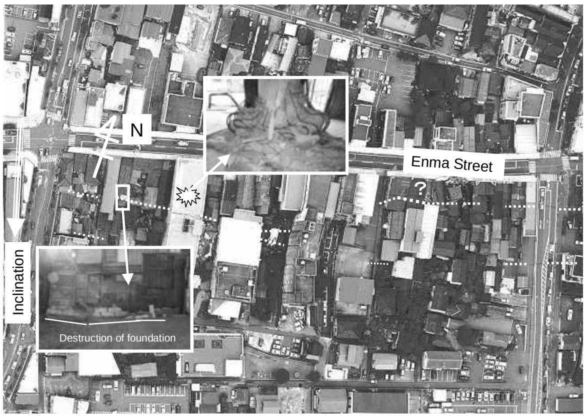


Photo 14 Marked level difference and crack appeared in gentle slope of dune at Downtown Kashiwazaki

Photo 15 Slope failures along the multiple dip surfaces at Hijirigahana (Photo:By Pasco Co.)

Photo 16 Settlement and apouted sand at Kashiwazaki Kariwa Nuclear Power Plant

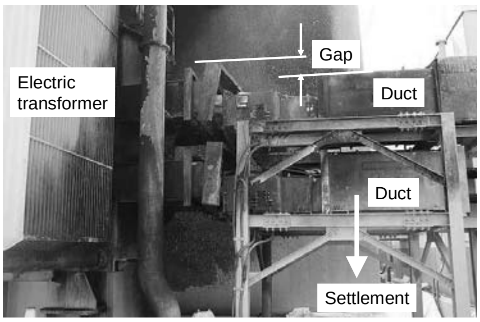


Photo 17 Differential settlement-induced gap which caused fire of the electrical transformer

Photo 18 Uplifted sever manhole (Photo: By Hiroyoshi Kiku)

5. HEAVE OF FLOOR INDUCED BY LIQUEFACTION

The floor of room in a house is usually supported by several floor posts with an individual footing in Japan, whereas columns and walls are generally supported by continuous footings. In the process of reconnaissance and subsequent investigation, it was made clear as aforementioned that the floor heaves up due to uplift of the floor posts caused by liquefaction of soil. Figure 7 shows examples of survey result regarding floors of damaged houses at various areas shown in Figure 5. Each figure shows single room or multiple rooms. The arrow shows the summit in each room and broken lines show edges of the relevant room. As seen in this figure, the elevation of the floor is the maximum near the center of each room besides inclination and twist of the house itself.

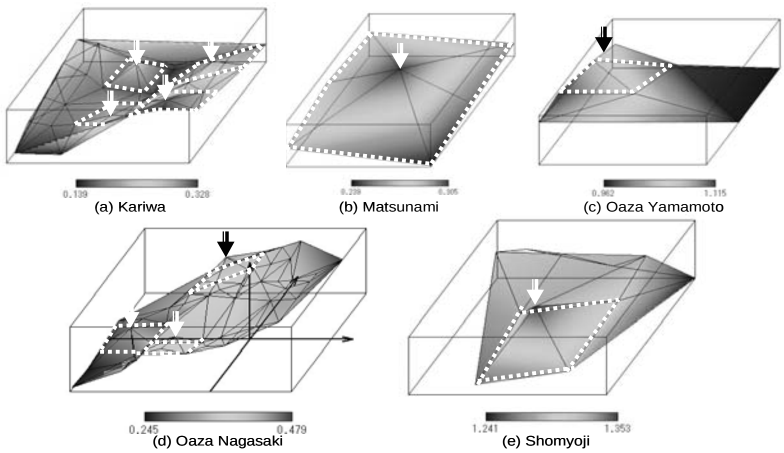


Fig. 7 Heaved up floor of houses damaged due to liquefaction
(Broken line: Edge of room, Arrow: Top of the floor in elevation)

6. SUMMARY

The damage caused by the 2007Niigataken Chuetsu-oki Earthquake is summarized as follows:

(1) Liquefaction-induced damage to residential lands, roads and rails is remarkable at the hinterland of sand dune and flood planes. Liquefaction-related landslides and spreading of gently slanting ground deteriorated the situation.
(2) Collapses of slope are conspicuous at sea cliffs.
(3) The Nuclear power plant was hit by a strong motion of an approximately twice the magnitude as expected in the design code.
(4) Many landslides occurred at housing land newly developed by filling soil in dissected old valleys.
(5) The floor of houses heaved up due to uplift of the floor posts caused by liquefaction of soil.

REFERENCES

Japan Meteorological Agency. http://www.seisvol.kishou.go.jp/eq/2007_07_16_ chuetu-oki/index.html
Fire Defense Agency. http: //www.fdma.go.jp/detail/751.htm4
National Research Institute for Earth Science and Disaster Prevention.http: //www.k-net.bosai.go.jp/ k-net/
Hokuriku Regional Development Bureau, MLITT: http://www. A hrr.mlit.go.jp/
Shinanogawa River Office, MLITTHRDB. http: //www.hrr.mlit.go.jp/shinano/0to24/index.htm
History compilation committee of Kashiwazaki. (1983). Geology of Kashiwazaki, Volume on Geology, The history data of Kashiwazak, Kashiwazaki-municipal Press, Japan
Ibayashi, K., Nakazawa, M., Ozaka,Y. and Suzuki M. (2001). Damage evaluation method based on total earthquake input energy and unit earthquake input energy in reinforced concrete pier. *Journal of the Japan Society of Civil Engineers*, No.676/V-51, 1-11.