

Reconnaissance Report of July 16, 2007 Niigata-Ken Chuetsu-Oki, Japan, Earthquake

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ABSTRACT: *The damage survey of the Niigata-ken Chuetsu-Oki, Japan earthquake ($M_{JMA} = 6.8$) of July 16, 2007 was conducted by the reconnaissance team of Disaster Prevention Research Institute (DPRI), Kyoto university. The area with dimension of 24 km x 19 km is investigated by the reconnaissance team. This paper reports the seismological aspects and observed geotechnical and structural damage during the damage survey in the area. The landslides, liquefaction and ground settlements were the most important geotechnical features that caused serious damage to the lifelines and buildings. Especially, landslides caused major damage to the railways and roads. The building damage survey was conducted around Kashiwazaki city hall where the K-net strong motion station was located. The damage to the buildings was classified as D2 or D3 within 100m around the city hall. Meanwhile, the collapsed wooden houses (D6 Grade) were mostly concentrated in Higashi Honmachi street situated in 280 m south of city hall. Most of the wooden house, concrete block fences and tomb stones seem to have collapsed in the northwest-southeast direction falling to the east as to the west. This direction was found to be in the direction of slip on the fault.*

Keywords: Damage survey; Niigata-Ken Chuetsu-Oki of July 16, 2007; Directional damage; Geotechnical and structural damage

1. Introduction

On July 17, 2007 at 10:13 (local time), an earthquake (Niigata-ken Chuetsu-Oki) with magnitude of $M_{JMA} = 6.8$ (Japan Metrological Agency Magnitude) in depth of 15km occurred at Chuetsu region (37.50N, 138.60E) in Niigata prefecture, Japan, see Figure (1). The epicenter was located in off shore of Kariwa village and Kashiwazaki city. The Niigata-ken Chuetsu-Oki was the most important earthquake after 1995 Kobe and 2004 Niigata-ken earthquakes. The Niigata-ken Chuetsu (2004) earthquake occurred just three years before Niigata-ken Chuetsu-Oki (2007) earthquake with epicenter located at about 50km east side of the recent earthquake. The instrumental *JMA* seismic intensity of 6+ comparable to IX in *MMI* scale was estimated at Kariwa village, Kashiwazaki city, Nagaoka city in Niigata prefecture,

and Ohzuna-machi in Nagano prefecture. Eleven people were killed, about 1284 were injured, and more than 10,000 were evacuated as of July 20, 2007. In a preliminary estimate of financial losses caused by the July 16 earthquake, the Niigata prefectural government put the damage at 1.5 trillion yen as of July 24. The number of totally collapsed houses were 949 in Niigata prefecture. The earthquake halted gas service to about 35,000 and disrupted the water supply to all Kashiwazaki, a city with a population of around 95,000 whose economy relies on nuclear power generation and fishing. Major lifelines have been damaged and suspended for more than a day. While electricity was recovered after a day in most of the area, water supply has not been recovered for four days (as of July 20, 2007). The Kashiwazaki nuclear

power plant, which is one of the world largest nuclear power plant including 7 reactors, suffered serious damage to auxiliary facilities because of unexpectedly large strong shaking. To investigate the earthquake damage, a reconnaissance team from Geotechnical group of Geohazard division, Disaster Prevention

Research Institute (DPRI), Kyoto University, was dispatched to the earthquake stricken area just after the earthquake. The area with dimension of 24km x 19km is investigated by reconnaissance team, see Figure (2). In this paper, the seismological and geotechnical aspects as well as building damage observed during the damage survey in the area is summarized.

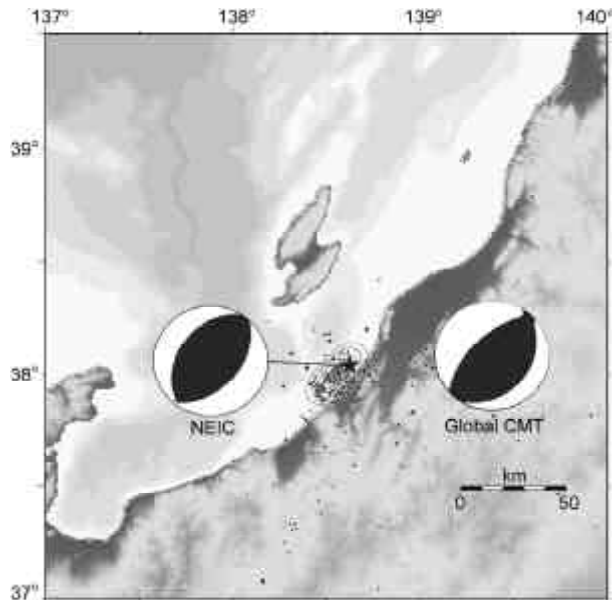


Figure 1. Location of the Niigata-ken Chuetsu-Oki (2007) earthquake and focal mechanism of the mainshock given by NEIC.

2. Geological and Seismological Aspects of the Earthquake

The earthquake epicentre was located in off shore of Kariwa village and Kashiwazaki city in west of Japan. The anticline and syncline together with parallel faulting are the main tectonic features in the area, see Figure (3). The kashiwazaki city and Kariwa village are located on the middle of a big syncline with axis in the NE-SW direction extended into the Japan Sea. The syncline is compressed in SE direction and experienced repeated faulting with strike parallel to the syncline axis and mostly dipping to the east, especially in off shore area. The CMT solution for the 2007 Niigata-Ken Chuetsu-Oki earthquake shows a reverse fault with the strike in NE-SW direction, see Figure (1). Figure (4) shows the epicenter distribution of the aftershocks in the area. Horizontal length of the distribution is

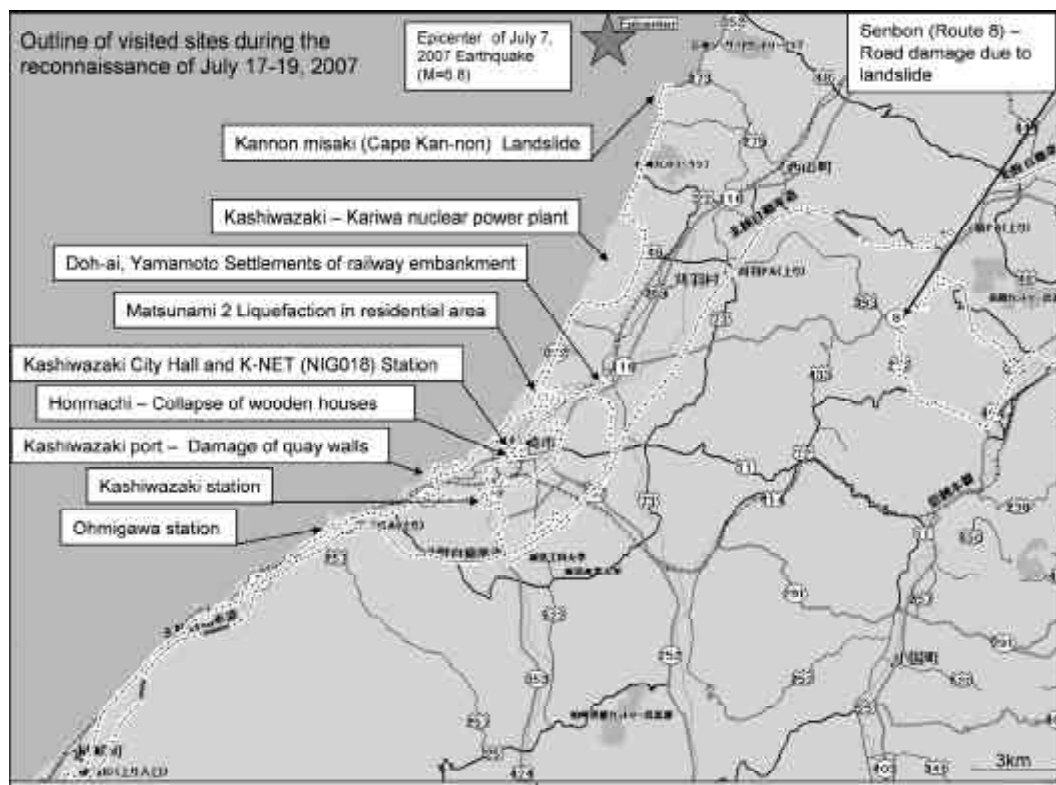


Figure 2. Map of the investigated area during reconnaissance of July 17-19 and the location of important features observed in the area.

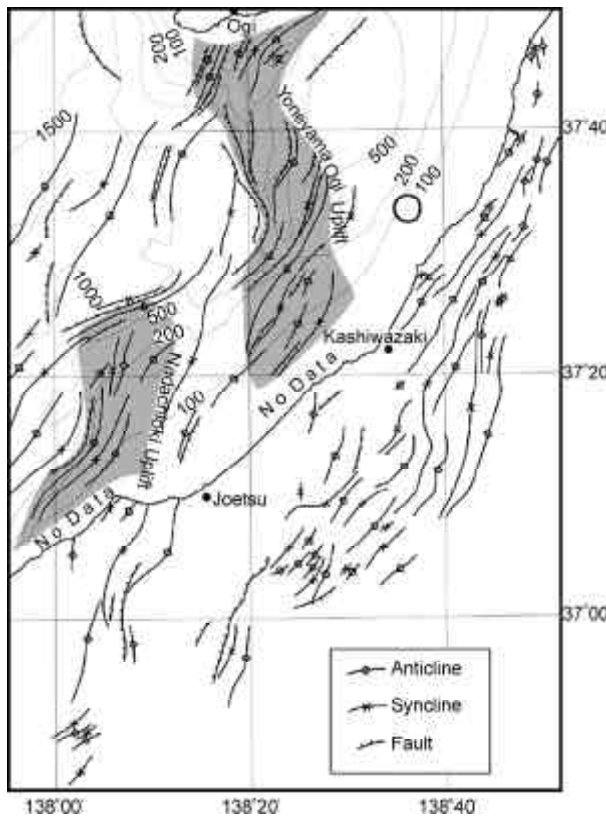


Figure 3. Tectonic map of the area (<http://www.jishin.go.jp/main/chousa/07jul-chuetsu-oki/p11.htm>).

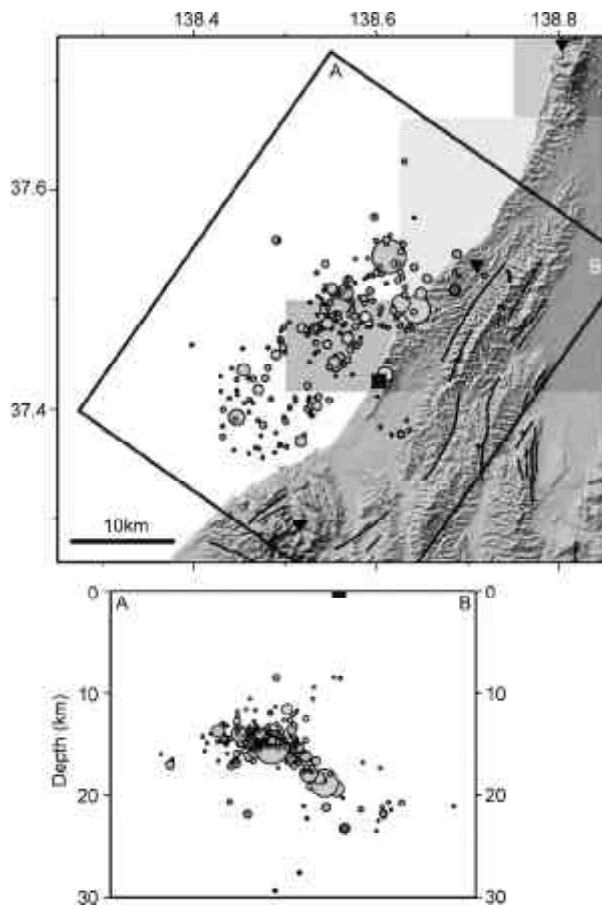


Figure 4. Epicentral distribution of aftershocks and the cross-section projected along AB line.

about 28km with a depth range from 0 to 20km. As seen on the vertical cross-section in Figure (4), the dip angle of hypocenter distribution shows a clear inclination toward the SE direction. The trends of epicentral and hypocentral distribution coincide with the source parameters estimated by Yagi [3] and ERI [4] using inversion analysis of teleseismic data. The results of Yagi's source inversion reveal a shallow asperity with a maximum slip of 70cm moving in upward direction, see Figure (5).

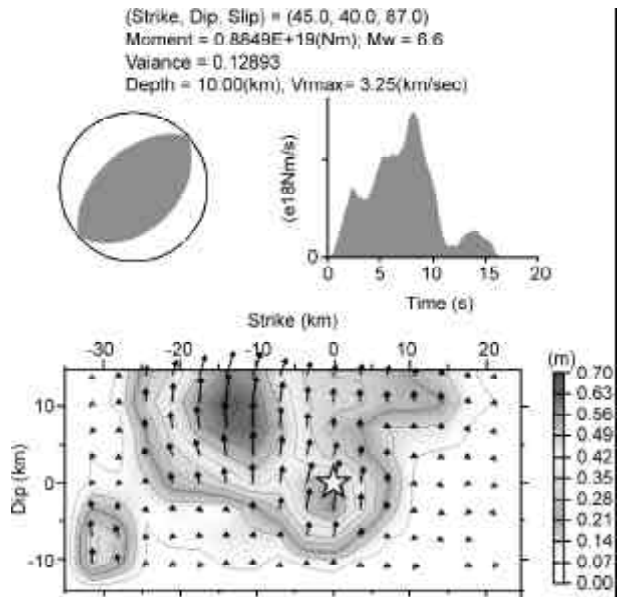


Figure 5. Source parameters and slip distribution on the fault based on waveform inversion of teleseismic data [3].

3. Strong Ground Motion

391 K-net strong motion stations in epicentral distance range of 15km to 440km were triggered by the mainshock. Figure (6) shows the distribution of observed peak ground acceleration (PGA) based on K-net free-field strong motion stations. The maximum peak ground acceleration (PGA) of about 667cm/s^2 was recorded in NS component at Kashiwazaki station, which was the nearest station to the epicenter (15km), see Figure (4). Figure (7) shows the recorded acceleration time histories together with the calculated velocity time histories for different components of ground motion at Kashiwazaki station. The interesting feature in the horizontal components of ground motion can be seen as a low-frequency motion modulated by the spiky shape motion. This type of motion is typically seen for dense sands under the state of cyclic mobility caused by liquefaction. The PGA of 667cm/s^2 and 512cm/s^2 for NS and EW components, respectively, were observed when the

spiky motions are dominant at 25s to 28s. The soil profile at Kashiwazaki site also indicates the dominance of dense sands at shallower depth (<5m), see Figure (8a). The site effect is also estimated using horizontal to vertical spectral ratio (HVSr) at Kashiwazaki site as shown in Figure (8b). The predominant frequency found to be 0.55Hz, which means that the subsoil condition in the Kashiwazaki city is soft, and might be categorized as D type in

2003 UBC. This type of soils usually associated with much seismic damage, especially when dominated by sand at surface.

4. Geotechnical Damage

The big landslides, liquefactions, and ground settlements were the main geotechnical features that caused the big damage to the lifelines, infrastructures, industrial facilities, and buildings. Figure (9) shows

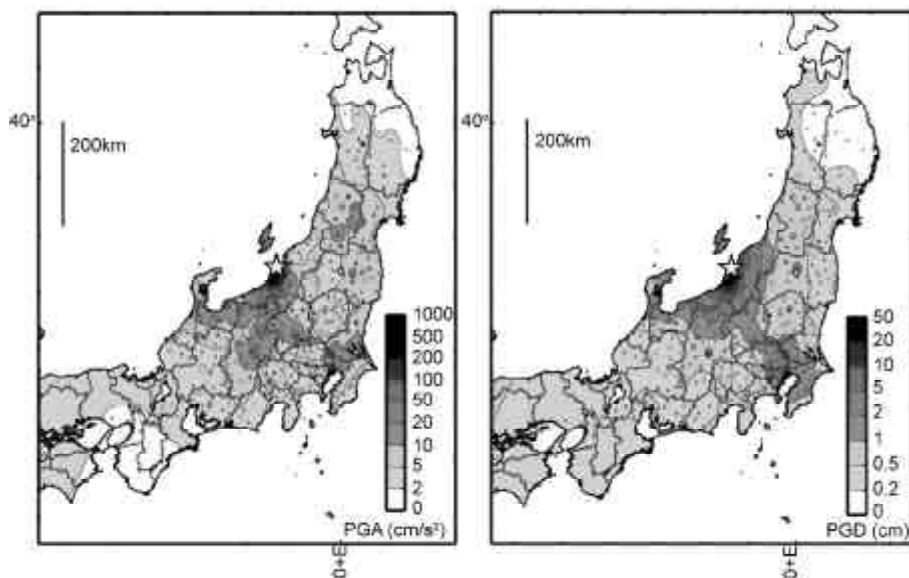


Figure 6. The distribution of peak ground acceleration and displacement based on K-net strong motion stations (<http://eoc.eri.u-tokyo.ac.jp/furumura/07chuetsu/index.htm>).

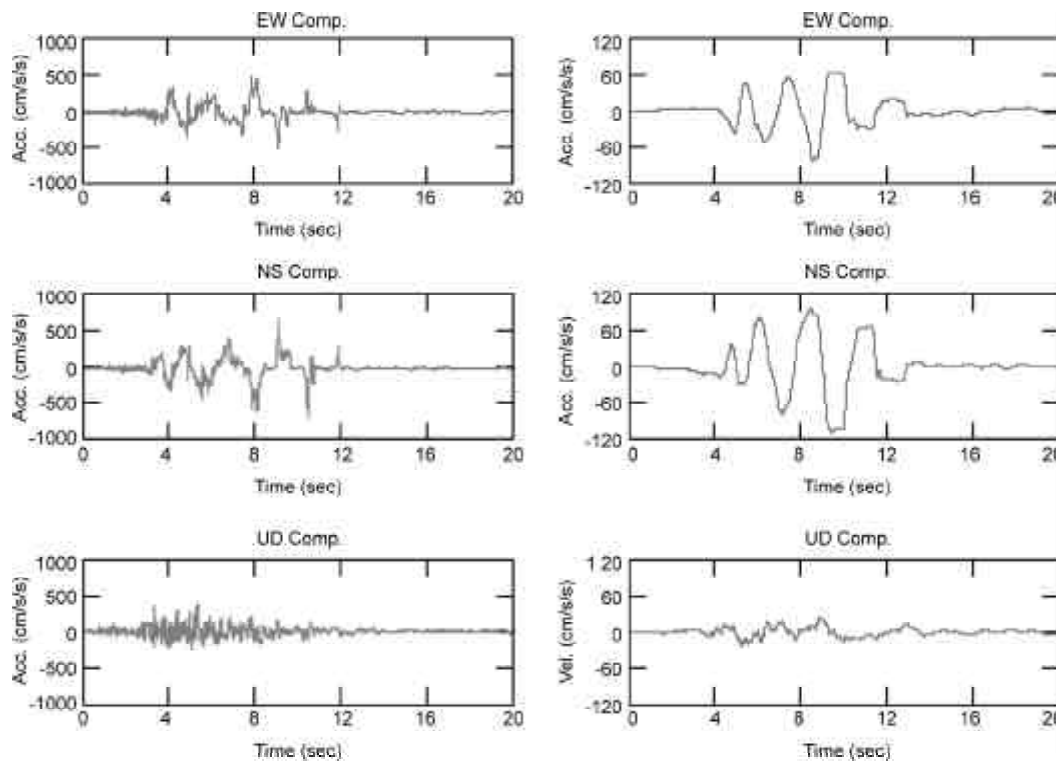


Figure 7. Strong motions recorded in Kashiwazaki K-net station and calculated velocity time histories (high passed filter of 0.08 Hz).

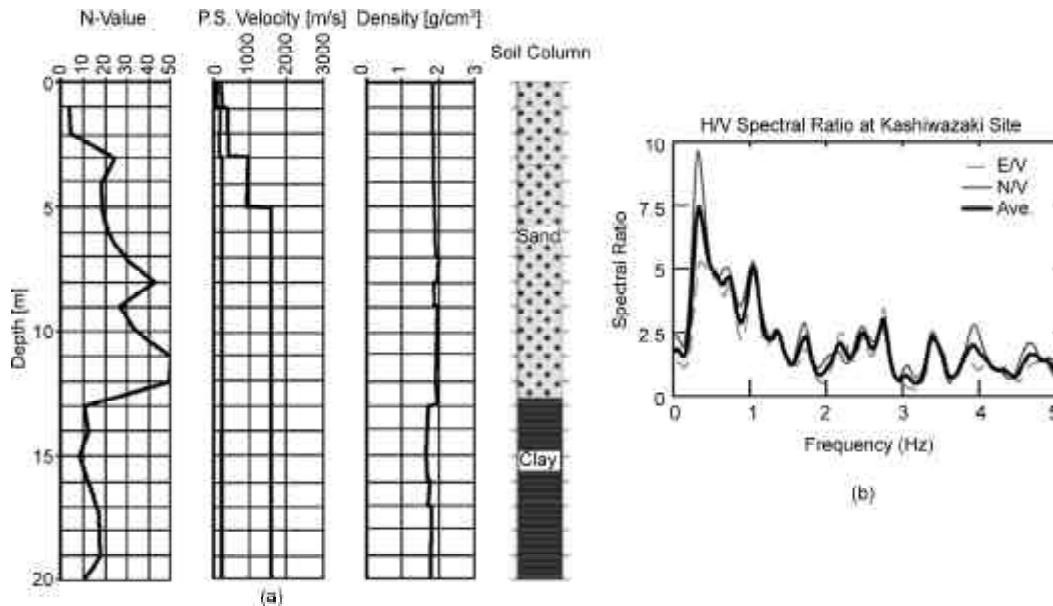


Figure 8. (a) Soil profile in Kashiwazaki strong motion station; (b) the horizontal to vertical spectral ratio (HVSr) for different directions and the average in Kashiwazaki strong motion station.

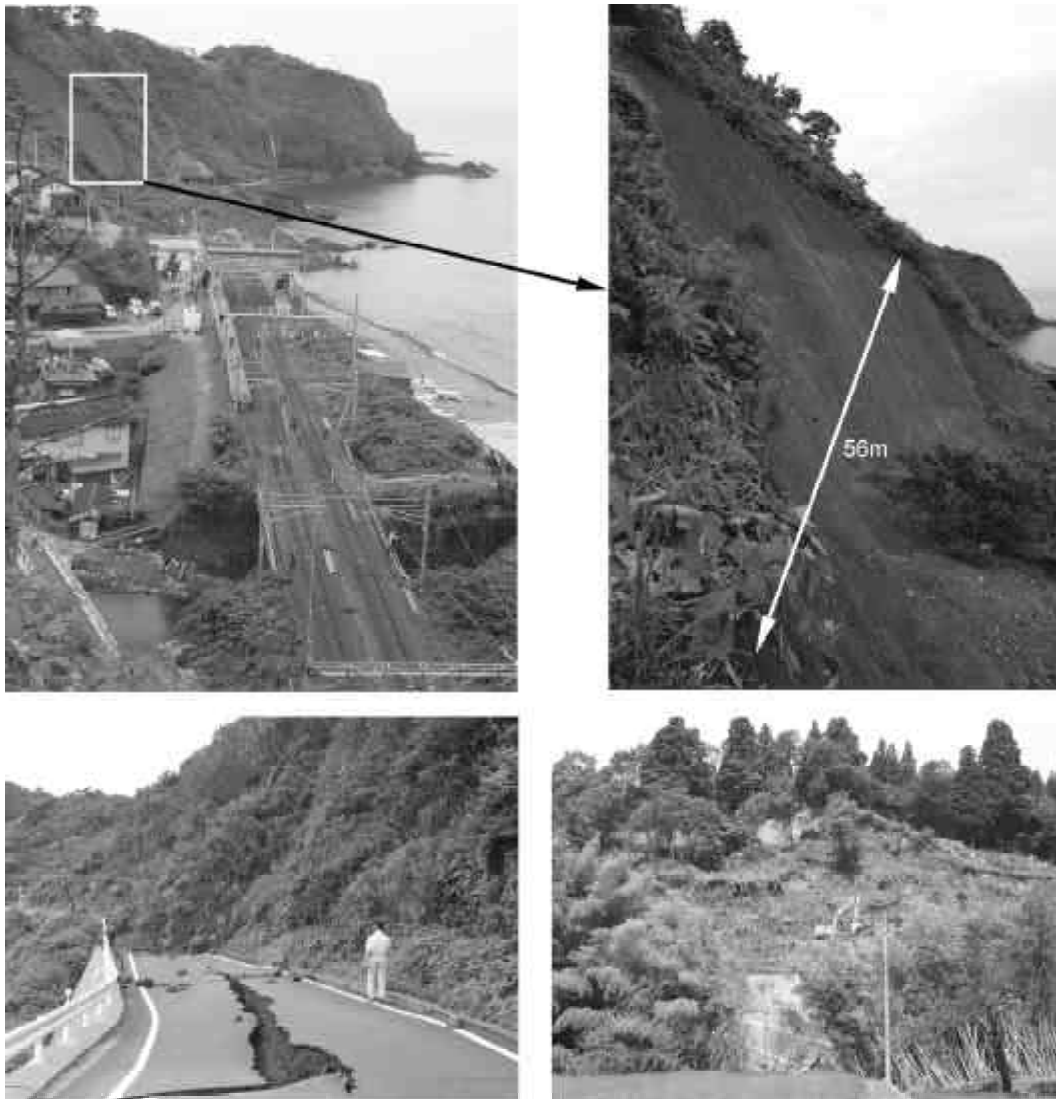


Figure 9. The landslides observed near the Ohmigawa station of JR Shin-Etsu line, Kan-non misaki (Cape Kan-non), and near the route 8 at Senbon that connects Kashiwazaki to Nagaoka.

the observed landslides where their locations in the area can be seen in Figure (2). Damage due to liquefaction to the utility poles, roads and buildings were mostly observed in Kashiwazaki fishery port and Matsunami 2 in Kashiwazaki city. The Matsunami 2 was originally farm lands and sand dunes that gradually changed to a residential area from 1973 to 1976. The area is 14 ha and east part of the developed

land suffered heavy damage due to liquefaction. The occurrence of liquefaction after the large shaking with an eruption of muddy water at 2m height is described by eye witnesses, see Figure (10). Settlement of a railway embankment due to the loss of the bearing capacity of its base ground was found in Doh-Ai with no evidence for liquefaction, see Figure (11). Cross-sectional dimension of the



Figure 10. The liquefaction observed at Matsunami 2 in Kashiwazaki city that cause damage to utility poles, asphalt roads and foundation of houses.



Figure 11. Settlement of the railway embankment in Doh-Ai and damaged road pavements near the railway.

embankment after deformation is 6.8m at the crest, and 16m at the toe. Its height after deformation is 1.2m. Road pavements near the railway settlement were damaged possibly due to liquefaction of filled material that is used for construction of swage pipes and manholes, see Figure (11). This may indicate that major soil type in this area is cohesive and contains low permeable material. In Kashiwazaki

fishery port, the settlement of apron near 0.5m was observed. Furthermore, the sheet pile type quay wall with tie rods deformed around 1m toward the sea, see Figure (12). Large ground fissures due to liquefaction were found in the Sabaishigawa Kaishu-Kinen park, Makhara, and Kashiwazaki. The Kaishu-Kinen park was constructed on a sandbar along the Sabaishi river, see Figure (13).



Figure 12. Damage to sheet pile type quay wall with tie rods in Kashiwazaki fishery port due to settlement where the evidence for liquefaction was also found.



Figure 13. Large ground fissures due to liquefaction at the Sabaishigawa Kaishu-Kinen Park in Makhara-Kashiwazaki. The park was constructed on a sandbar along the Sabaishi river.

5. Damage to the Buildings and Industrial Facilities

The building damage was mostly concentrated in Kashiwazaki city and Kariwa village. A building damage survey in Kashiwazaki city around Kashiwazaki city hall was performed, see Figure (14).

We also measured the direction of collapsed buildings in the area. The damage grade of buildings was evaluated using Okada and Takai [2] classification of wooden houses, as shown in Figure (15) [2]. In this classification, building damage is categorized into 7 grades from D0 (no damage) to D6 (very heavy

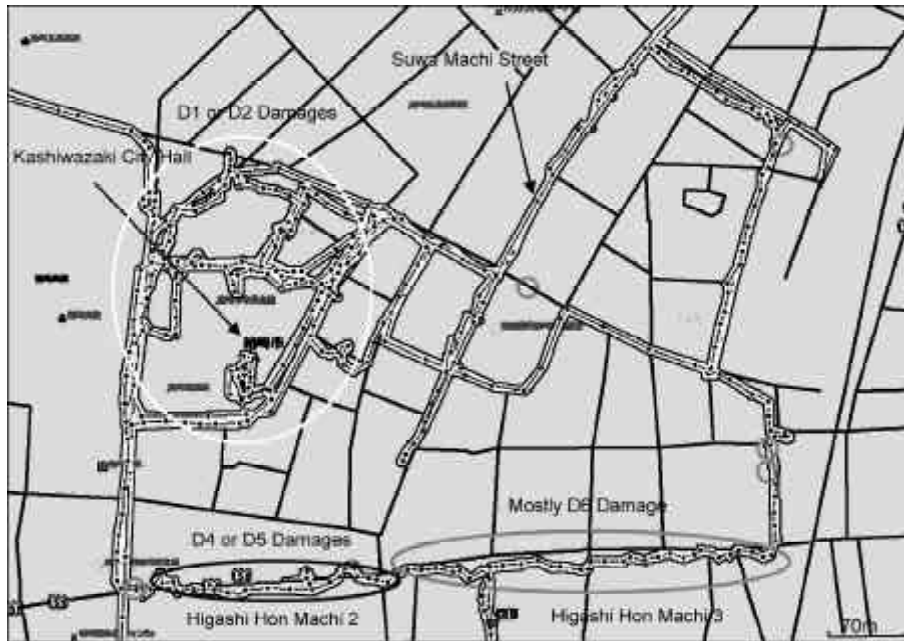


Figure 14. The area around Kashiwazaki city hall where the building damage survey was performed. The damage type and their distribution are also shown in the figure.

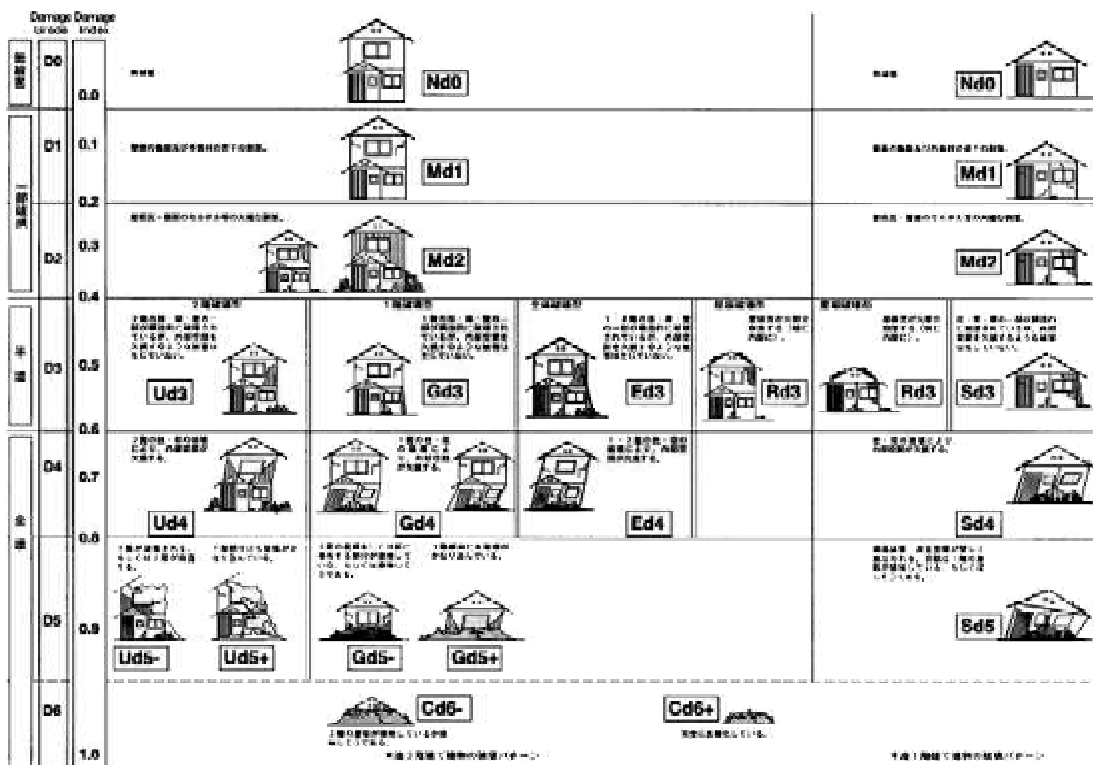


Figure 15. Damage grade and classification for wooden houses in Okada and Takai [2].

structural damage or collapsed). Most of the building damage is classified as *D1* and *D2* near the Kashiwazaki city hall. However, many wooden houses with Grade 5 and 6 damage were observed along the Higashi Hon Machi street (regions 2 and 3). Figure (16) shows typical collapse of wooden houses together with their collapse direction observed in this street. The Highashi Hon Machi street was almost directed along *EW* direction with a lenient slop in its south side. Besides this observation, the scares damage along the other streets was found that is mostly categorized as a *D2* or *D3* types. The place that damage *D6* was observed is shown in the map in Figure (14). Although it was not possible to visit all the damaged buildings, the ntensity based on collapsed buildings seems to be lower than the one announced based on instrumental *JMA* seismic intensity (6+ comparable to *IX* in *MMI* scale).

Due to the security problems, it was not possible to visit two important industrial facilities in the area which are Kashiwazaki nuclear power plants and Riken company. However, we relied on some information about these facilities based on provided information by local authorities and mass media. The Kashiwazaki nuclear power plant is the largest nuclear power plant in Japan, which located near the Kariwa Village. This nuclear power plant consists of 7

reactors that generate 8,200,000kw power for Tokyo area. It suffered serious damage in auxiliary facilities only during earthquake, see Figure (17). An electrical transformer at the plant fired and it could not be quickly extinguished due to the broken water pipes, Figure (18). Meanwhile, a small amount of water containing radioactive materials had leaked from a unit at its Kashiwazaki-Kariwa nuclear power plant. The contaminated water was also released into the ocean, but officials said it had produced no effect on the environment. The *PGA* of 680cm/s^2 was recorded at the nuclear power plant site. This was 2.5 times stronger than those its reactors had been designed to withstand. According to the Tokyo Electrical Power Company (*TEPCO*) website, the responsible company of Kashiwazaki nuclear power plant, the units were constructed on engineering bedrock for design *PGA* of 270cm/s^2 . A report by the Niigata prefectural government has stated that about 700 billion yen would be lost from the suspension of operations at Kashiwazaki-Kariwa nuclear power plant. Furthermore, prefectural authorities also estimated that Niigata farmers would lose between 100 billion and 200 billion yen due to consumer fears about radioactive fallout from the nuclear power plant. The Riken company, which manufactures ring piston for most automobile companies such as Toyota and Nissan,



Figure 16. Observed damaged to the wooden houses in Highashi Hon Machi street together with their direction of collapsing.

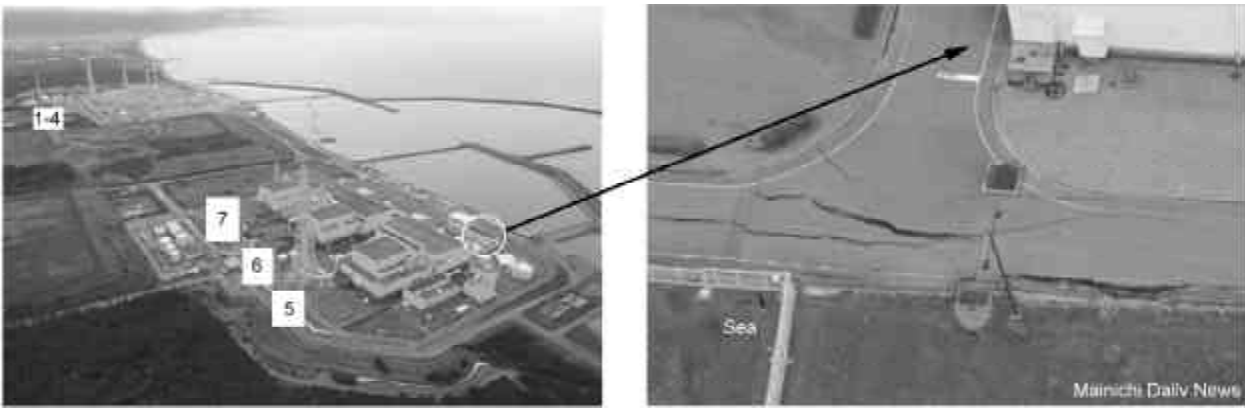


Figure 17. The Kashiwazaki nuclear power plants consist of 7 reactors showing the damage due to liquefaction and ground settlement.



Figure 18. Fire in an electrical transformer at the nuclear power plant and displaced barrel of nuclear waste. The radioactive materials were also leaked to the ocean and contaminated the environment.

was out of line for about one week. These caused a produce line of these automobile companies being stopped for two days.

6. Motion Directionality and Directional Damage

An investigation of damage to the buildings revealed that most of the collapsed wooden houses are directed in *EW* directions fallen to the west. This indicates that the motion may polarize in especial direction due to either deep geological irregularity or near-source effects [1]. To provide more facts, the velocity and displacement time histories are calculated from the recorded acceleration time histories in the Kashiwazaki station. Then, the particle motion in horizontal plane is investigated as shown in Figure (19). This figure reveals a strong polarization of motion in *NW-SE* direction that is in accordance with the observed direction of collapsed buildings.

Masonry and concrete block fences are nearly unique constructions for study of strong motion directionality since they have seismically weak and strong directions. For instance, fences oriented in the *EW* direction are more likely to be toppled by

motions directed north-south than by motions directed east-west. Therefore, we investigated the damage concrete block fences and measured their toppling directions. The falling direction of tombstones and electrical poles was also measured. These are good objects to investigate ground motion directionality due to their unified constructions and no preferable structural directions. Figure (20a) shows an example of directional damage observed in Matsunami 2. The electrical poles directed along the *EW* displaced more than those directed in the *NS* direction. Furthermore, some examples of fallen concrete block fences and tombstone are shown in Figure (20b). Figure (21) summarized the estimated toppling direction of concrete block fences or tomb stones in the investigated area. Furthermore, the overturning ratio of tomb stones is calculated as a ratio of the number of overturning tombs to the total number of tombs in each investigation point. It is interesting to note that this direction is almost parallel to the fault normal and slip direction on the fault plain. Then, it might be attributed to the near-source effect. However, the deep geological structure may also affect the strong

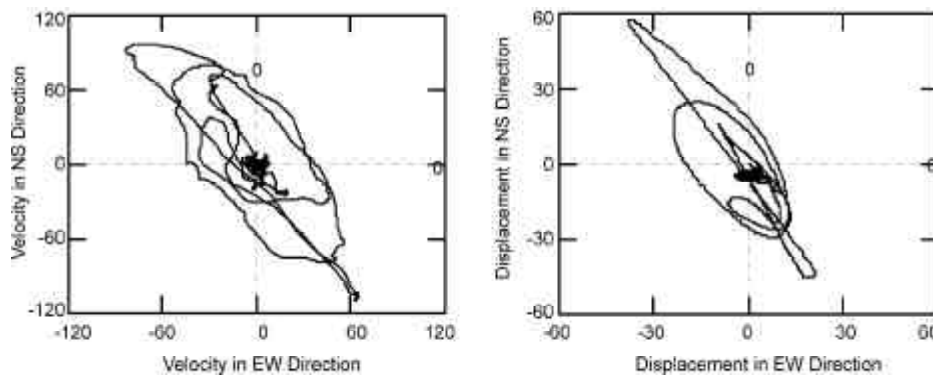


Figure 19. 2-D particle motion of calculated velocity (cm/s) and displacement (cm) time histories for the mainshock recorded at Kasiwazaki K-net station (high passed filter of 0.08 Hz).



Figure 20. Evidence for directional damage (the arrows show the north side); (a) electrical poles directed in EW direction displaced more in comparison with those directed almost in NS direction at Matsunami 2; (b) The toppling direction of the concrete block fences and tomb stones in Kashiwazaki area, see Figure (21).

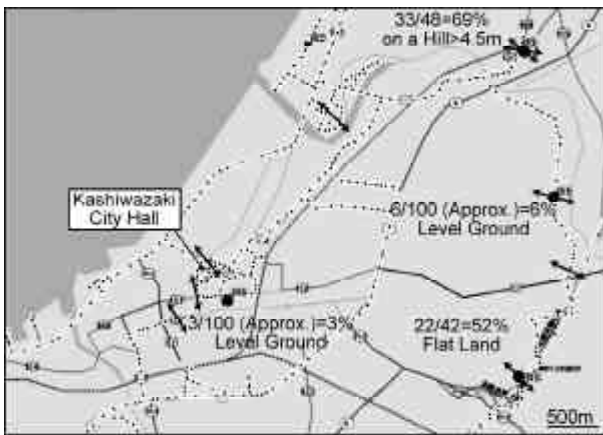


Figure 21. The outline of the area where the toppling direction of the concrete block fences and tomb stones were measured. The toppling direction is also shown together with overturning tomb stone ratios in graveyards.

motion directionality. Hence, more detailed investigations need to clarify the actual reason for the observed phenomenon in the region.

7. Conclusions

We conducted the damage survey soon after the Niigata-ken Chuetsu-Oki ($M_{JMA} = 6.8$), Japan earthquake of July 16, 2007 as a reconnaissance team of Disaster Prevention Research Institute (DPRI), Kyoto University. The seismological data reveal a causative fault of the earthquake to be a reverse fault with $N45E$ strike, dipping 40 degree to the east. However, forward directivity pulse in velocity of recorded ground motions in K-net stations can not be predicted by such a dip direction. The recent investigation on variation of aftershocks distribution with time revealed that the aftershocks were distributed toward the west and after a big aftershock with magnitude close to mainshock their distribution was changed to the east. The acceleration waveform of the mainshock at the Kashiwazaki station, located 15km from the epicenter, was analyzed to derive several characteristics of strong ground motion. The effect of cyclic mobility due to liquefaction produced a spiky long period motion that caused a PGA of $667cm/s^2$ and $512cm/s^2$ in NS and EW directions, respectively. Furthermore, the particle motion of calculated velocity and displacement time histories reveal a strong directionality of motion in $EW-SE$ direction. This direction found to be parallel with fault-normal and slip direction on the causative fault. In addition, the three distinct pulses can be observed on calculated velocity ground motions at K-net and JMA Stations as well as those recorded in

Kashiwazaki nuclear power plant. This may indicate the existence of three asperities (The area with large slip on the fault) on the causative fault.

The geotechnical features such as landslides, liquefaction, and ground settlements were the main cause of damage to the lifelines, roads, railways and buildings. While the landslides made a big damage to the roads and railways, liquefaction and ground settlement were the main reason of damage to the ports and foundation of buildings. The site amplification characteristics were investigated using $HVSR$ in Kashiwazaki station site. The predominant frequency found to be lower than $1Hz$, which means the subsoil condition in the Kashiwazaki city is soft, and might be categorized as D type according to 2003 UBC . The building damage survey was also conducted around Kashiwazaki city hall. The wooden houses mostly suffered $D2$ to $D3$ damage, except for Highashi Hon Machi street that was dominated with the collapsed buildings with $D6$ type damage. Based on the damage to the buildings, the intensity seems to be overestimated by the one announced based on instrumental JMA seismic intensity (6+ comparable to IX in MMI scale). During the damage survey, the direction of collapsed houses, concrete block fences, and tomb stones were measured. It was found that almost 90% of them collapsed in the $NW-SE$ direction falling to the east. This direction was in accordance with the estimated particle motion in Kashiwazaki strong motion station and reveals the possible effect of near-source in observed directional damage. However, due to the complex sub-surface geological irregularity in the area, more detailed investigation is needed to clarify the main reason.

References

1. Ghayamghamian, M.R. (2007). "Directional Damage Due to Near-Fault and Site Effects in the $M6.4$ Changureh-Avaj Earthquake of 22 June 2002", *Journal of Seismology*, **11**, 39-57.
2. Okada, S. and Takai, N. (2000). "Classification for Structural Types and Damage Patterns of Buildings for Earthquake Field Investigation", *Proc. of the 12th World Conference on Earthquake Engineering*, Paper No. 705.
3. Yagi, (2007). http://iisee.kenken.go.jp/press_HP/yagi/EQ/2007niigata/.
4. ERI (Earthquake Research Institute) (2007). <http://taro.eri.u-tokyo.ac.jp/saigai/chuetsuoki/>.