Learning from Earthquakes

Preliminary Observations on the Niigata-Chuetsu Oki, Japan, Earthquake of July 16, 2007

Three days after the Niigata-Chuetsu Oki earthquake, EERI and GEER (Geo-Engineering Earthquake Reconnaissance) deployed a joint team of engineers and emergency management experts to document geotechnical effects; the performance of the Kashiwazaki-Kariwa nuclear power plant; the performance of other structures, bridges, ports and harbors, and lifelines; and the response and recovery. The EERI-GEER team, with the assistance of the Japanese Association for Earthquake Engineering (JAEE), was led by Robert Kayen of the U.S. Geological Survey and Santiago Pujol of Purdue University, and included Brian Collins of the USGS; Scott Ashford, Stephen Dickenson, and Yohsuke Kawamata of Oregon State University (with partial support from the Pacific Earthquake Engineering Research Center); Scott J. Brandenberg of UCLA; Norm Abrahamson, Lloyd Cluff, Joseph Sun, and Ben Tsai of PG&E; Haruo Hayashi, Norio Maki, and Laurie Johnson of Kyoto University; Mark Yashinsky of Caltrans; with contributions from Peter Yanev; Renee Lee of Arup; Kit Miyamoto of Miyamoto International; Yasuo Tanaka and Hidetaka Koumoto of Kobe University; Kohji Tokimatsu of Tokyo Institute of Technology; Toshimi Kabeyasawa, Kim Yousok, Kazuo Konagai, Toshikazu Kabeyasawa, and Toshinori Kabeyasawa of Tokyo University; Nanako Marubashi and Toshikatsu Ichinose of the Nagoya Institute of Technology; Keiko Tamura of Niigata University; and the staff of the Research Center for Urban Safety and Security (RCUSS). The team also coordinated lifelines investigations with a team from the American Society of Civil Engineers (ASCE) Technical Council on Lifeline Earthquake Engineering (TCLEE), in-cluding Mark Yashinsky (also with EERI), Stephen Dickenson (also with GEER), Curt Edwards, Anshel Schiff, Alex Tang, and Yumei Wang. The ASCE team received assistance from the Japanese Society of Civil Engineers (JSCE). The JSCE team members included Jorgen Johansson and Hiroyuki Yanagawa.

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Introduction

The M6.6 Niigata-Chuetsu Oki earthquake struck at 10:13 am local time on July 16, 2007, along the west coast of Honshu Island, Japan. It was followed by a sequence of aftershocks that were felt during the entire time of the reconnaissance effort. The event had a shallow focal depth of 10 km and struck in the Japan Sea immediately offshore from Kariwa (see Figure 1). The quake affected an approximately 100 km-wide area along the coastal areas of southwestern Niigata prefecture and triggered numerous ground failures as far away as the Unouma Hills, located approximately 50 km inland.

In Niigata prefecture, the JMA seismic intensity was 6+ (IX in MMI) in Kariwacho, Kashiwazaki City, and Nagaoka City; it was the same in Ohzuna-machi in Nagano prefecture. The downtown Kashiwazaki City K-NET site recorded a PGA of 0.67g. The earthquake resulted in 11 fatalities and nearly 2,000 injuries. Close to 1,100 residential structures collapsed — almost exclusively old bamboo and stuccoed post-and-lintel structures with heavy kawara tile roofs. Many of these collapses were associated with displacements on the slopes of sand dune deposits or with liquefied ground. There was damage to gas, water, and electricity infrastructure and to the world's largest nuclear power plant, the Kashiwazaki-Kariwa facility. The power plant was in a region of high isoseismal intensity, as inferred from the observed damage patterns in the area.

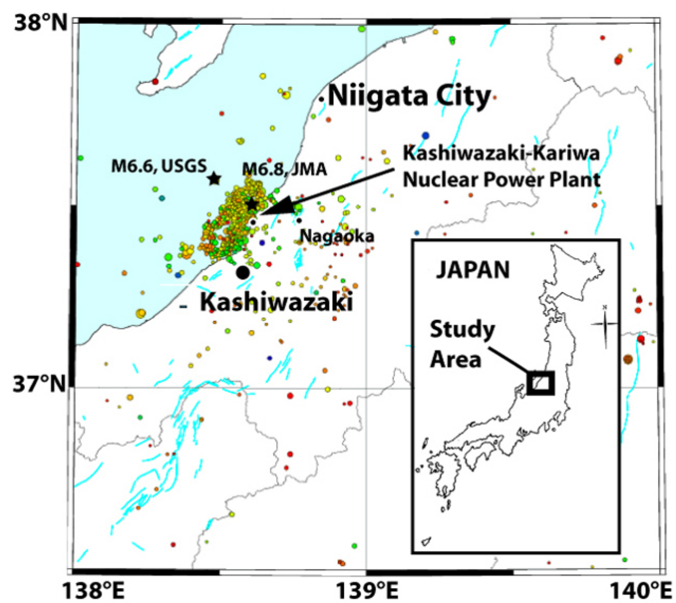

***Figure 1:** Location and aftershock map of Niigata Chuetsu Oki event.*

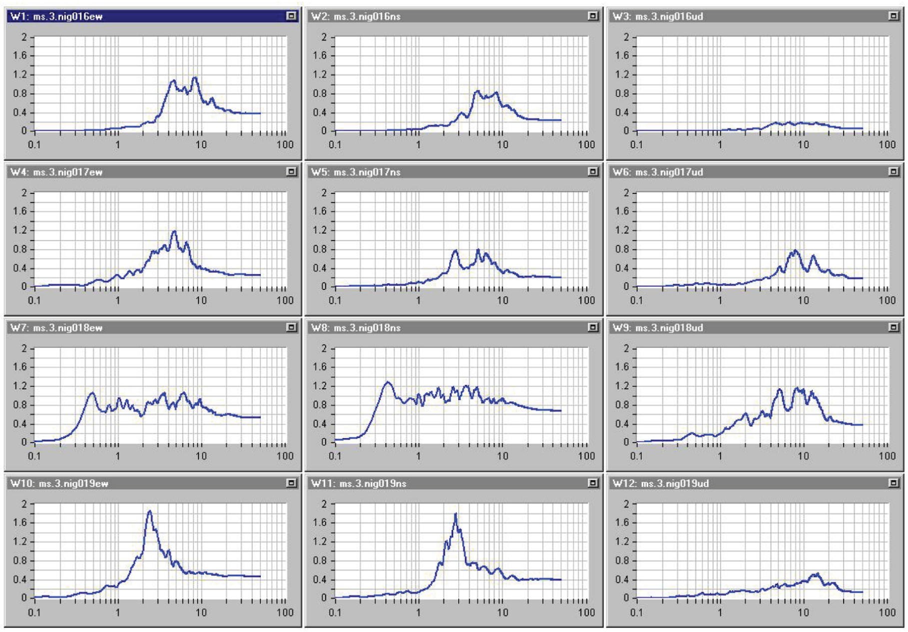

Figure 2: *Acceleration response spectra for a damping coefficient of 5%. From top to bottom: NIG016, NIG017, NIG018, NIG019. The left panel is the EW component, the middle panel is the NS component, the right panel is the Z component. The horizontal axes represent frequency, in Hz, and the vertical axes represent absolute acceleration as a fraction of the acceleration of gravity.*

The team recorded the spatial position and severity of ground failure and structural damage using digital mapping techniques. GPS data, site logs, and digital pictures are archived in a Google Earth database mentioned in the preface; it contains a comprehensive explanation of each site for use as a supplement to this newsletter insert. The database was constructed as the reconnaissance progressed, and proved useful for planning visits to unexplored areas. Niigata Prefecture has built a 3D buildings layer for Kashiwazaki City in Google Earth that was useful for identifying critical facilities. High-resolution laser-mapped data sets of the most significant structural and geotechnical damage features were also collected for preservation using the USGS's terrestrial LiDAR (light detection and ranging) system.

Seismological Aspects

Niigata is located in a subduction zone near the boundary between the Amur plate and the Okhotsk plate (two relatively small plates that lie between the larger Eurasia and Pacific plates). The moment magnitude of the mainshock of this event was estimated to be 6.6 using teleseismic data (USGS) and 6.7 using regional data. The Japan Meteorological Agency assigned a magnitude of 6.8 to the mainshock.

The Niigata earthquake was a buried reverse-slip earthquake, with a hypocenter estimated at a depth of 8 km (NRI ESDP, 2007). Two potential planes of faulting are unresolved, as aftershock locations fell on both planes. The rupture length is estimated to be 30 km and the down-dip fault width is estimated to be 22 km for both planes. The inferred location of the hypocenter is at the northeast end of both planes, and the rupture is inferred to have progressed from the northeast toward the southwest. Slip models for both rupture planes show a single strong asperity in the western end of the rupture. The maximum computed slip is 3.5m.

The Japanese nationwide strong motion network, K-NET, recorded the earthquake at 390 stations, 20 of which were within 50 km. The accelerograms obtained at station NIG018 (close to the fault plane and within the area where damage was more severe) show low-frequency content, suggesting features associated with liquefaction in foundation soils below the instrument. Whereas there was no observed sign of liquefaction at the ground surface, the spiky trace of the acceleration record is consistent with the known behavior of sandy soils undergoing cyclic mobility in undrained loading. Acceleration response spectra computed for a damping coefficient of 5% are shown in Figure 2.

The seven-unit Kashiwazaki-Kariwa Nuclear Power Plant is located about 16 km from the epicenter determined by the Japan Meteorological Agency (JMA) for this event and was instrumented at 99 locations. The motions at 33 locations with a new sensor system were recorded, but the recordings at the other 66 older instrument locations, including two free-field down-hole arrays and most of the structural arrays, were lost with the exception of the peak values. The ground motion data on the old system could not automatically transmit due to communication congestion, and aftershocks triggered the recorders and overwrote the buffer containing the mainshock recordings. The 33 recordings of the new system included 27 from a majority of the reactor and turbine buildings and one 4-depth free-field array at the service hall (see Figure 3). The data indicate a large range in the foundation motions for the EW component, with PGA values ranging over a factor of two (322-680 gals). The NS component shows more similar values (267-311 gals). The large variation in the EW component values cannot be explained by simple 1-D site effect differences. Recordings from aftershocks show a large variation in the site response, with larger motions for the northern units (5,6,7) for some aftershocks and larger motions for the southern units (1, 2, 3, 4) for other aftershocks.

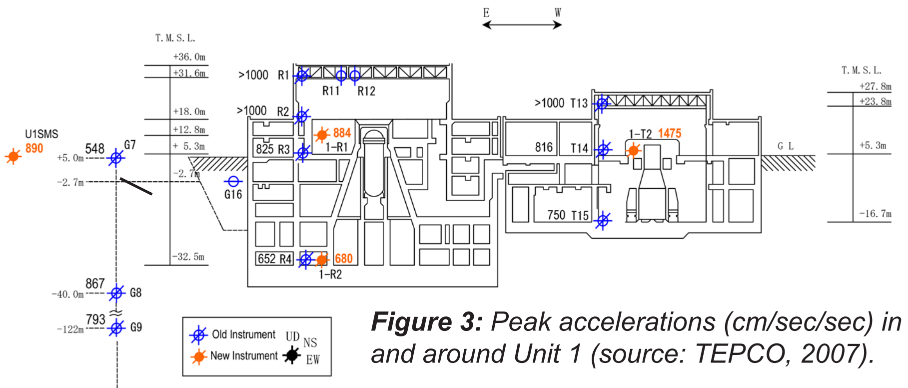

Figure 3: *Peak accelerations (cm/sec/sec) in and around Unit 1 (source: TEPCO, 2007).*

The observed variation in the PGA amplification is correlated with epicentral azimuth, indicating that strong 3-D wave propagation effects are contributing the large variability of the ground motions over short distances. The large range of PGA values on the EW component shows the need for multiple recordings at NPP sites to reliably determine the input ground motions for the structures.

Liquefaction

Liquefaction was observed from the southern port of Kasashima village, south of Kashiwazaki City, to Shiya village north of the Kashiwazaki-Kawira nuclear power plant. Liquefaction evidence was seen in four general settings: riverbank deposits, beach deposits, dune sand, and placed fill. Along the Sabaishi River, liquefaction and lateral spreading features were observed over approximately 5 km from the river mouth. River deposits near the sea liquefied and settled severely at the Kashiwazaki wastewater treatment facility separating two plant buildings (Figure 4). Upriver, liquefaction resulted in settlement of the levee embankment near the Kai-Un Bridge, a large water main pipe separation, and a large lateral spread along the river bank immediately east of the municipal incinerator (Figure 5).

The U River, located in the southwestern portion of Kashiwazaki City, was farther from the epicentral region and exhibited less liquefaction damage, all of it within one kilometer of the mouth of the river.

Figure 4: *Pipe breaks due to separation of two halves of Kashiwazaki Wastewater Treatment Plant.*

A long, coast-parallel, surficial unit of dune sand within and north of Kashiwazaki City was the source of numerous liquefaction failures, particularly along the edge of the modern flood plain. The sand was typically very soft under foot, and may have been reworked in areas by the ancient, meandering Sabaishi and U Rivers. At one site, liquefaction-

Figure 5: *Lateral Spread on north side of Kai-Un Bridge area of the Sabaishi River (site RK6).*

Figure 6: *Settlement of ground adjacent to the grade beam between footings of a high voltage transmission line tower (site RK40).*

Figure 7: *Landslide at the Oumigawa Train Station on the Shin-etsu Line (sites RK20, YT16/SA9).*

induced settlement was observed around the foundation pile cap of a large high-voltage power transmission tower leading from the nuclear power plant. Though the soil pulled away from the cap, the pile cap and tower had no indication of deformation (Figure 6).

Sandy fill deposits used for backfill for the wastewater and stormwater drain network performed poorly throughout the epicentral region, causing hundreds of separated and uplifted manholes that incapacitated the drains and impeded traffic. Ports and harbors suffered only moderate levels of settlement and liquefaction-related lateral spreading.

Landslides

Landslides caused by the earthquake consisted of shallow translational slides, debris slumps, and deep-seated rotational slides. In general, landslide activity was focused near the coast, with many steep (>50°) slopes experiencing shallow landsliding of overlying colluvial debris and residual soils. Shallow coastal landslides were observed to be 0.5 to several meters deep in colluvial and residual soils, and ranged from 5 m^3 to several thousand cubic meters in volume. Typical slope surface and failure plane inclinations were between 50° and 70°, failing in translation as debris slides and slumps. There were also additional landslides some distance away from the main damaged areas (~10 km northeast of Kashiwazaki and 7 km east of the Kashiwazaki-Kariwa Nuclear Power Plant) in an upland, mountainous region. These slides also generally consisted of shallow translational slides.

Where transportation lines crossed areas of steep terrain, landslides blocked or destroyed whole sections of roadways and railways. Three major transportation routes were blocked by landsliding in the region: the coastal road (Route 353) to the north of the Kashiwazaki-Kariwa Nuclear Power Plant; the railway to the south of Kashiwazaki, at the Oumigawa train station on the Shin-etsu Line (Figure 7); and Highway 8, north of the intersection with Route 252 located inland from the coast.

An area of dense landslide activity not investigated by the field reconnaissance team, but identified through helicopter reconnaissance by the Japanese Public Works Research Institute (PWRI), was identified approximately 20 km to the southeast of Kashiwazaki, in the Takayanagi-Machi region. Because this area is located a significant dis-

Figure 8: *Road embankment failure off Route 8 on the way to Kasashima (site YT18).*

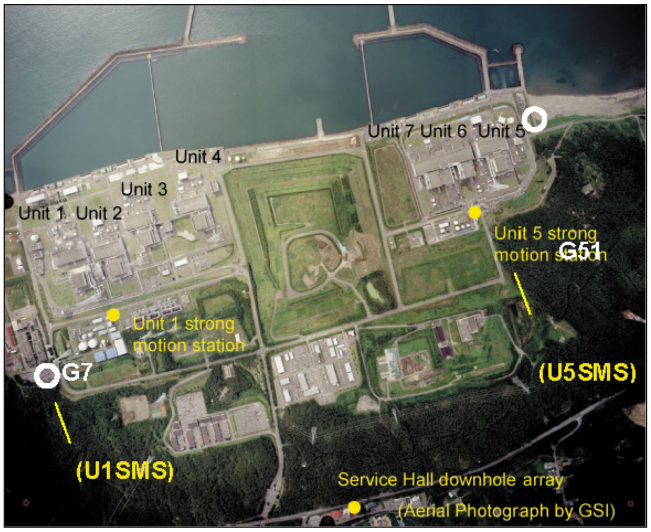

Figure 9: *Aerial photograph of Kashiwazaki-Kariwa Nuclear Power Plant area (GSI, 2007).*

Figure 10: *Ground settlement around buildings at the nuclear power plant was a major cause of damage to foundations and footings.*

tance away from other observed landslides caused by the earthquake, it is anomalous to the general pattern of observed geotechnical and structural damage and should be investigated more thoroughly.

Embankment failures were typical in road fills both along the coast, and were also observed at three sites located further inland (Figure 8). Embankments underwent from 10 cm to 1 m of vertical displacement, extending 10-60 m in length. Three embankment failures required full closures of roads or protection with tarps to reduce rainfall infiltration and the associated potential for additional movement. Among these was a 15-m-high, 97.5-m-wide earth-fill dam located to the east of the region, where cracking through the midpoint of the crest was observed. The water level at the time was well below the crest.

At a water supply dam located southwest of Kashiwazaki City, cracking of the crest was also observed, along with minor concrete cracking and spalling on the upstream side. Here, the reservoir water level was within several meters of the dam crest at the time of observation.

Structures

The Kashiwazaki-Kariwa Nuclear Power Plant: The world's largest nuclear power plant, owned by Tokyo Electric Power Corporation (TEPCO), was located 10-20 km above the southeast-dipping fault plane and 3 km above the northwest-dipping plane (Figure 9). The performance of the facility was mixed. The emergency shutdown system — which had been set to be triggered by horizontal accelerations exceeding 120 gals or vertical accelerations exceeding 100 gals — operated successfully. The main structures did not suffer significant damage. In structures surrounding the primary facilities of the plant, a fire broke out in an electrical transformer. Radiation leaks were caused by spilling of water from spent fuel pools, failure of joints in exhaust pipes, and the falling of drums containing low-radiation nuclear waste.

Observed damage was related to problems with foundation soils (Figure 10). Joints of piping resting on isolated footings and expansion joints in covered pathways failed, and underground pipes supplying fire retardant to reactors broke because of the relative movement between soils and the foundations. In a two-story steel building used for plant administration, drop ceilings fell and windows broke. Access through doors was impaired by ground settlements of up to 40 cm. The plant was closed after the earthquake and is expected to remain closed for months.

Hara Sake Plant: The Hara Sake Plant, located near the Kashiwazaki Station, consisted of both new structures and older ones (50+ years). Five buildings belonging to the sake plant collapsed, all in the southward direction. All of the collapsed structures were two-story timber structures. Two were used for storage and the other three for manufacturing and operations (Figure 11).

One timber structure housed a large machine frame of heavy steel construction. The steel frame and any ground-level equipment were bolted to the ground. Pipes and air ducts were fastened to the steel frame with steel ties. All brewing equipment was fastened and bolted to the frame. During the earthquake, the machine frame provided additional support to the timber structure. That structure was able to withstand seismic loading with little damage, while

Figure 11. *Hara Sake Plant tank storage area. Two-story timber structure collapsed around storage tanks, Kashiwazaki City, Niigata.*

Table 1. Distribution of fatalities and damage reported by the local press

Town	Impact on Population		Impact on Housing		
	Fatalities	Injuries	Total Collapse	Partial Collapse	Other Damage
Niigata		12		1	28
Nagaoka		243	8	281	2694
Sanzyo		32			347
Kashiwazaki	10	1339	908	1912	20198
Oziya		40			99
Tokamachi		8		5	58
Tsubame		10	2	4	628
Myoko		0		2	26
Zyoetsu		132	13	43	2220
Uonuma		6			2
Minamiuonuma		4			4
Izumosaki		10	17	84	719
Kariwa	1	105	148	347	436
Kamo		0			
Yuzawa		1			
Mitsuke		14			341
Sado		0			
Agano		0			1
Itoigawa		1			6
TOTAL	11	1957	1096	2679	27807

other timber structures on the premises collapsed. The only reported damage in the structure was two detached pipes.

Residential Structures: The earthquake caused the collapse of nearly 1,100 houses in the Niigata prefecture. Damage to 1- to 3-story wood buildings was observed along the 30-kilometer long coastal region between Hatsusaki, to the south, and Shiya, to the north. Damage extended inland to western Nagaoka, 12 km east of the coast. Kashiwazaki City reported the largest number of collapses in the region. Table 1 provides information on the distribution of fatalities and damage reported by the local press.

To our knowledge, all of the structures that collapsed were wooden structures and unreinforced masonry fences. Preliminary estimates of collapse rate ranged between 5-7% for buildings and houses in the vicinity of the K-NET instrument in Kashiwazaki. The team documented more than 200 collapses of houses, fences, sheds, and canopies. No clear trend is visible regarding displacement direction. Photos of all of the sites visited are linked to the Google Earth map available at the USGS website.

Both ground shaking and ground failure problems affected residential houses in the area. A large percentage of the houses affected by ground

Figure 12: *Collapse of house with heavy tile roof.*

Figure 13: *Traditional Japanese tsuchi-kabe ("soil wall") construction technique (site SP13).*

Figure 14: *Failure of reinforced concrete stack (site SP31).*

Figure 15: *Details of failure of reinforced concrete stack (site SP31).*

Figure 16: *Shear failures of reinforced concrete columns (site NIT-81).*

shaking had at least one of three features: a soft story; heavy clay-tile roofs (Figure 12); or walls constructed from a combination of wood and clay (Figure 13). This traditional Japanese construction technique is commonly known as tsuchi-kabe or “soil wall” and consists of tied bamboo framework filled with clay. Many of the houses that had damage associated with ground failure (soil liquefaction, vertical settlement, and dynamic displacements of structures) were built on either reclaimed alluvial sandy deposits or sand dune slopes

Reinforced Concrete Structures: The reinforced concrete stack at the Kashiwazaki Municipal Recycling Plant failed (see Figure 14). The 59-m-tall stack was one of the tallest reinforced concrete structures in the area. It had a square cross section with 4.6 m sides and walls that varied in thickness from 18 cm at the top to 36.6 cm at the bottom. The failure took place at a height of approximately 17 m, where the longitudinal reinforcing bars were lap spliced Figure 15). According to the plant manager, this was also the location where rebar quantity was reduced. The failure caused the upper part of the stack to fall 6-7 m. Some transverse reinforcing bars, which also had lap splices, were observed to have ruptured. It has been reported that the stack was designed in accordance with modern design standards, which require lap splices to have a length equal to 40 times the diameter of the largest bar spliced. Splice failures in similar conditions have been reported to have caused the collapse of a stack during the 1999 Kocaeli, Turkey earthquake (Kilic and Sozen, 2003).

Damage in the other reinforced concrete buildings that were visited ranged from structures with limited cracks not exceeding 1-2.5 mm to several buildings with severe distress (Figures 16 and 17). A three-story building used as a karaoke parlor in downtown Kashiwazaki and a two-story seaside hotel suffered shear failures of columns in its first story. It appears that the spacing of

Figure 17: *Karaoke parlor in downtown Kashiwazaki.*

ties exceeded the specified maximum of 10 cm, though a maximum spacing of ties of 10 cm has been mandatory in Japan since 1972.

Most concrete buildings that were studied in detail featured large reinforced concrete spandrels (1-2 m deep, 12-30 cm wide) built integrally with girders and columns. These spandrels are common in Japanese buildings constructed before 1982. The combination of large spandrels, large columns, and tightly spaced ties results in structures with large base shear capacities.

Steel Building Structures: In Kashiwazaki, steel structures were not as common as concrete structures. At

Figure 18: *Buckling of steel braces (site SP7).*

a gymnasium located 430 m from a K-NET station, buckling of steel braces in the lower of the two stories in the structure was observed. The braces had T-shape cross sections with a thickness of 12 mm. The flange measured 150 mm and the stem 45 mm. The braces had a slope of 2/3 with respect to the horizontal. Four pairs of braces reinforced each story in the NS direction. The floor plan was approximately 20 m in the EW direction and 33 m in the NS direction (Figure 18).

The steel framing of the one-story Super Center Plant 5 building was damaged because of failure of the foundation. This is by far the largest building in the entire affected area. A fault-like mole track was observed across the entire width of the flat slab of the building (Figure 19). The slab and its reinforcing steel failed in tension. A gap of probably more than a foot opened up and then closed

Figure 19: *Damaged slab in Super Center Plant 5 (site RK 41).*

Figure 20: *Buckling of beam flanges (site RK41).*

during the motion (this may have happened several times), as evidenced by buckled rebar. This distortion of the foundation buckled many of the connections of the columns to roof beams (Figure 20).

Steel braces are commonly used in the area to strengthen reinforced concrete structures. In the structures visited that use this system, the steel-concrete marriage appeared adequate to resist lateral loading. Nevertheless, operations were disrupted in some of these structures by plaster and concrete spalling and by damage to architectural elements at construction joints.

Lifelines

Lifelines are designed to remain in service for small earthquakes and to prevent life-threatening damage during large ones. Based on these criteria, lifelines performed reasonably well during this earthquake. However, several lifelines remain closed a month after what was a moderate-sized offshore event.

Bridges and Highways: Damage to bridges crossing the Sabaishi River (north of Kashiwazaki) and the U River (south of Kashiwazaki) was caused by permanent deformation of embankments that run parallel to the rivers. Lateral and vertical deformations of embankments ranging from a few centimeters to about a meter were observed. Embankments cracked at their crests and, in some instances, sand boils flowed upward through these cracks, indicating liquefaction (Figure 21).

Bridges across the Sabaishi River were subjected to larger ground deformation, and therefore more damage, than were those on the U River.

The bridges along the Sabaishi River consisted of 15-100 m long continuous steel I-girder or reinforced concrete superstructures resting on elastomeric bearings supported by reinforced concrete piers and abutments. The thickness of the bearings ranged from 15-30 cm. Bearings deformed where embankment slumping pushed abutments toward the river. Deformations of bearings ranged from 7-17 cm. Cracks up to 1 cm wide were observed in reentrant corners of abutments. Spalling of pavement and concrete was observed at expansion joints.

Vertical offsets at bridge approaches caused by soil settlement ranged from 5 cm to 1 m (Figure 22). Asphalt or gravel fill was placed to permit cars to cross bridges. Utility lines attached to bridges where approaches settled were damaged. Settlement of approaches was observed at bridges crossing the Sabaishi and U rivers, and at bridges along the Hokoriku Expressway.

There were several long-span bridges on National Highway 8 and on the Hokuriku Expressway south of Kashiwazaki that suffered damage to fixed steel bearings and to structural members. Since these structures were very stiff, the bearing damage acted like a fuse to limit the force on the structures.

In many cases, roadways were blocked by landslide debris, in others the roadfill and foundation failed and required extensive repair. The Nippon Expressway had so much settlement, especially at bridge approaches, that it was closed for several days after the earthquake and still had traffic restrictions in early August. Landslides also closed roads along the coast both north and south of Kashiwazaki.

Figure 21: *Embankment cracking near river crossing.*

Figure 22: *Abutment settlement at a bridge crossing the Sabashi River.*

***Figure 23:** The Ozumi Senbon Landslide, located along Highway 8 just north of the intersection with Route 252, closed both lanes of traffic (site RK1).*

***Figure 24:** Wastewater treatment plant damaged due to ground settlement and shaking.*

In one location, located inland from the coast, both lanes of a busy regional highway were moved down slope by about 10 m as a result of a deep-seated slope movement (Figure 23). The road was reopened less than seven days after the earthquake. A large lateral spread affected a road near the Kashiwazaki municipal waste incinerator, forming a headscarp with a vertical offset of 2.5 meters that transected the road. The pavement was heavily damaged for a length of over 200 m in the lateral spread region.

Three tunnels were visited for further inspection. The 1,610-m-long Yoneyama expressway tunnel had 15 to 20-m-long longitudinal cracks at midheight of the lining of the northbound tube. The cracks on each side of the line were offset by some 20 meters, possibly indicating that some geological feature crossed the tunnel at an approximately 60-degree angle.

The second longest tunnel inspected, the 530-m-long Kariwa Tunnel, bores through an 80-meter-high sand dune just to the north of the nuclear power plant; it suffered extensive cracking in its northern end, where water leakage was observed. The curve of the tunnel and downward grade of 1.4% towards the north could hypothetically stop groundwater flowing down from the high sand dune behind it and force this groundwater to run along the tunnel towards the north.

The 150-m-long Banjin Tunnel suffered extensive cracking at its western portal due to movement of surrounding ground. Older repaired cracks were found in the middle one-third of the Banjin Tunnel, possibly indicating some change in the geological structure and mechanical properties of the surrounding ground.

Water Systems: Water for the region is provided by reservoirs in the mountains north of Kashiwazaki City. There were three pipes carrying water into the city, and two of them broke during the earthquake. If the third waterline had broken, there were still large cisterns throughout the city that could have been used to fight fires. Most of the pipe breaks were the result of problem soils. Waterlines were broken by landslides, lateral spreading, liquefaction, and soil settlement. For instance, a water line was broken when the concrete cover at the end of a pipe bridge subsided towards the Sabaishi River due to lateral spreading of the surrounding soil.

The co-location of roads, bridges, water, sewer, and communication lines sometimes compounded these problems. For instance, at one location on Route 8, a highway embankment failed, which broke a water main and a fiber optic conduit. In addition, manhole risers blocked many roads when pipes rose due to soil liquefaction.

The Kashiwazaki City water treatment plant suffered minor damage during the earthquake, but the wastewater treatment plant had major damage. Although wastewater continues to be treated, it is no longer possible to remove sludge from the system, which will become critical at some point. Pipes, clarifiers, sludge digesters, and other essential equipment were damaged due to the ground shaking, soil displacement, and differential settlement at the plant (Figure 24).

Power Systems: The Tokyo Electric Power Company (TEPCO) maintains the Kashiwazaki-Kariwa Nuclear Power Plant (7965 MW), which is the main source of electricity for the City of Tokyo. Tohoku Electric maintains the transmission lines, distribution lines, and substations in the area affected by the earthquake.

The nuclear power plant (NPP) was shut down by the government after the earthquake and will remain closed for at least a year, resulting in over $US 1 billion in lost revenue. At the time of the TCLEE visit (August 3-6), the NPP was being inspected by the International Atomic Energy Agency (IAEA). More information on the performance of the NPP will come out of their investigation.

There was also some damage to the transmission system maintained by Tohoku Electric. Towers, transformers, and other equipment were slightly damaged due to lateral spreading, soil settlement, and ground shaking. Generally, there was about a five-minute power disruption caused by this earthquake.

Natural Gas Systems: The natural gas system was the most heavily damaged of the lifelines, due to the many breaks in the transmission and distribution lines caused by liquefaction and settlement of poor soils in the region. Moreover, pressurized natural gas tanks in the region sustained damage, fortunately without causing any fires. At the time of the TCLEE visit (August 3-6), restoration of service was ongoing.

Communication Systems: NTT provides landline telephone and internet services for the region. The high volume of calls following the earthquake and the damage to underground optical cables conduits in five locations impaired services. About 5% of the fiber conductors in these cables were cut. NTT data showed that the phone system was back to normal three days after the earthquake.

Cellular phone services are provided by four companies in the region. Power interruption longer than ten hours affected cell site operation.

The 119 emergency service system worked well during the earthquake, although delays of up to 20 minutes were reported at the Kashiwazaki fire station because there were only five answering stations.

Ports and Airports: The coastal location of this earthquake resulted in moderate damage to port and coastal infrastructure from the small village of Kasashima, in the southwest, to the town of Kariwa in the north. The Kasashima Harbor exhibited negligible to very minor evidence of ground deformation and seismic effects to coastal infrastructure (e.g., quay walls, seawalls, breakwaters).

Trace remnants of very small, localized ground deformations were observed, and it appears that the ground motions in this area were just strong enough for incipient lateral deformation of the ground and waterfront earth retention structures.

The westernmost section of the Port of Kashiwazaki was subjected to the effects of widespread liquefaction, lateral spreading, and settlement exceeding 30 cm in many areas (Figure 25), and a pronounced graben formed between a port building and the waterfront quay wall. A pile-supported structure performed very well, but two pedestrian-accessible roof areas on either side of the main structure were distressed by ground settlement and lateral spreading. Fortunately, the damage did not keep the port from being a major staging area for relief supplies following the earthquake.

Along the waterfront to the southwest of the Sabaishi River and transverse to the riverfront sheet pile wall is a seawall that extends southwest roughly 2.0 km towards the Minatomachi Seaside Park. On the north end of the seawall, the lateral wall movement was roughly 0.6 m and exhibited an increased seaward tilt to the southwest with lateral deformation of approximately 1.5-2.0 m.

There are no commercial airports in the earthquake-affected region.

Rail Systems: Damage to railways was caused by landslides (for example, at the Oumigawa Train Station south of Kashiwazaki), settlement of foundation soils, and spreading and slumping of railway embankments. In some cases, damage was observed at sites without apparent ground failure, presumably due to transient ground shaking. Horizontal track offsets up to 30 cm were observed.

Figure 25: *Kashiwazaki Harbor — Liquefaction induced lateral spreading and settlement of soil beneath a harbor-front caisson resulted in rotation toward the harbor and lateral displacement of the soil behind it.*

Some trains carrying passengers at the time of the earthquake were damaged; news reports immediately following the earthquake indicated that a stationary train derailed at Kashiwazaki Station, but that no one was injured.

Fire Following Earthquake

There were three reported fires during this earthquake. One of the fires, at the nuclear power plant, was a direct cause of this earthquake, while the other two were one day and three days after the event. The lack of fires following this earthquake can be attributed to the gas shutoff valves that were used widely in the damaged area.

Figure 26: *Construction of temporary housing.*

Table 2. Projected damage costs in Niigata Prefecture for 2007 earthquake, compared with estimated damage costs for the 2004 earthquake

	2007 Earthquake Projected Damage Costs	**2004 Earthquake Estimated Damage Costs**
Buildings	200 billion yen	700 billion yen
Infrastructure	70 billion yen	1,200 billion yen
Businesses and Factories	300 billion yen	300 billion yen
Agriculture, Forestry, Fishing	40 billion yen	400 billion yen
Utilities	10 billion yen	100 billion yen
Other	880 billion yen	300 billion yen
TOTAL	1,500 billion yen	3,000 billion yen

- *"Other" includes business interruption costs, which in the case of the nuclear power plant may be comparable to all other direct losses.*
- *Source: Policy Division, Governor's Policy Bureau, Niigata Prefecture, July 23, 2007.*

Response and Recovery

The earthquake struck on a national holiday, but essential government personnel reported for work soon after, as required when an earthquake registers JMA Intensity 6 or greater. Niigata Prefecture activated its emergency task force (ETF) headquarters within the first hour, and the more heavily damaged cities and towns in the prefecture also activated their ETFs over the course of the first day. Heeding lessons from the 2004 earthquake, the prefecture has a two-tier staffing structure in its ETF, with current department representatives as well as those who held those positions in 2004.

During the first 72 hours, the prefecture and its local governments focused on rescue operations, sheltering, and provision of food and water. In the immediate aftermath, there were 124 sites in the prefecture serving more than 11,000 evacuees. As of August 8, 55 sites were still in operation serving 974 evacuees. Over 100 locations throughout the prefecture provided free shower and bathing facilities to disaster victims, including many "onsen" hot spring spas and hotels. Niigata Prefecture plans to construct more than 1,200 temporary housing units and, by July 26 several sites were already under construction (Figure 26).

Japan's Prime Minister officially declared this to be a "very severe" disaster and established a cabinet-level ETF to coordinate with the prefecture and affected local governments. Self Defense Forces (SDF) supported various rescue operations, and prefectures and local governments across Japan assisted through mutual aid agreements. The SDF and Coast Guard also sent ships to Kashiwazaki to provide drinking water by using desalination systems.

Teams of engineers and architects inspected and posted buildings throughout the prefecture with red, yellow, and green tags related to the building's safety for occupancy. Unlike the practice in the United States, this tagging system is not tied directly to local occupancy regulations; however, local governments do conduct another five-scale damage survey that is often led by local tax assessor's offices. These surveys result in the issuance of certificates to disaster victims as evidence of their losses. Local governments have based the apportionment of monetary donations, allotment of temporary housing, and other recovery-related benefits on these certificates. Kashiwazaki City and supporting academic institutions are developing a GIS-based damage certification database and plan to survey 62,000 structures by August 10.

On July 23, Niigata Prefecture's governor released projected costs for the 2007 earthquake totaling 1.5 trillion yen (US$12.77 billion). The prefecture's costs for the 2004 earthquake were approximately twice as much (Table 2). The 2007 costs include an 880 billion yen (US$7.5 billion) estimate associated, in part, with indirect costs of the closure of the nuclear power plant and decreased tourism.

In 2004, Japan's government had a significant role in financing the recovery of damaged roads, tunnels, and other public infrastructure. In 2007, houses and businesses are the heaviest hit, and public dollars cannot be used for private property repairs in Japan. Niigata Prefecture also has one of the lowest earthquake insurance penetration rates in the country. Consequently, there will be challenges in raising the necessary recovery dollars.

References

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