Learning from Earthquakes

Preliminary Observations on the Niigata Ken Chuetsu, Japan, Earthquake of October 23, 2004

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The EERI team arrived on October 30, and was in the field through November 4. The GEER team was in the field November 15-19. The research of both teams and the publication of this report are funded by EERI's Learning from Earthquakes Program, under National Science Foundation grant #CMS-0347055.

Introduction

The M_w 6.6 earthquake that struck Niigata Prefecture on the evening of October 23, 2004, was the most significant earthquake to affect Japan since the 1995 Kobe earthquake. Forty people were killed, almost 3,000 were injured, and numerous landslides destroyed entire upland villages. Landslides were of all types; some dammed streams, creating new lakes likely to overtop their new embankments at any moment and cause flash floods and mudslides. Landslides and permanent ground deformations damaged roads, rail lines and other lifelines, resulting in major economic disruption. The numerous landslides resulted, in part, from heavy rain associated with Typhoon Tokage. At Nagaoka City, there had been 100 mm (4 inches) on October 20 and 13 mm (.5 inch) on October 21. The earthquake forced more than 100,000 people into temporary shelters, and as many as 10,000 will be displaced from their upland homes for several years, if not permanently. Total damages are estimated by Japanese authorities at US$40 billion, making this the second most costly disaster in history, after the 1995 Kobe earthquake.

The epicenter was in northwestern Honshu, about 80 km south of Niigata City (population 500,000), well-known as the place liquefaction was first systematically studied following the 1964 M7.5 earthquake. The epicenter was beneath the Uonuma Hills along the Shinanogawa Lowland (Figure 1), an

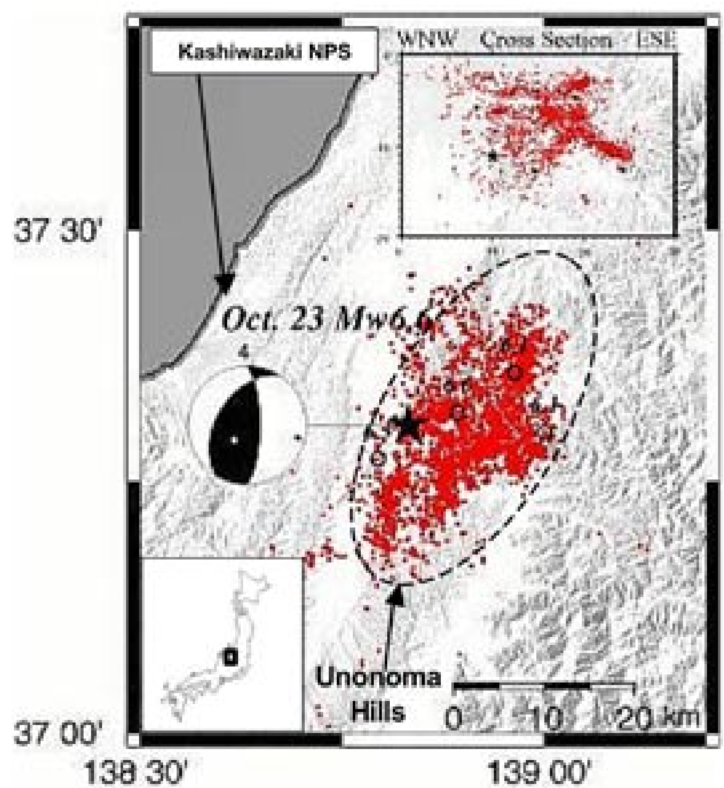

***Figure 1.** Aftershock pattern and mechanism. The Unonoma Hills are approximately outlined by dashed ellipse, and the Shinanogawa Lowland is the white area to the west (adapted from original figure by Group for Joint Observation, Kyoto and Kyushu Universities).*

alluvial plain that is bisected by the Shinano River as it flows toward the Sea of Japan. While the 2004 earthquake was felt in Niigata, neither significant effects nor liquefaction was observed there. South (or upriver) of Niigata, toward the epicentral area, there are a number of smaller cities and towns on the plain and some industrial sites; the remainder of the plain is covered by wet rice farmland (i.e. rice paddies). Nagaoka (population 194,000) was the largest city significantly affected by the earthquake. It suffered minimal damage, but had highway and train service disruptions, school closures, and an influx of refugees from surrounding areas. More seriously damaged areas were the city of Ojiya (population 41,000) and surrounding rural areas, most notably the village of Yamakoshi (population 2,222) and the town of Kawaguchi (2000 population 5,748), which sustained JMA intensity 7, the maximum on that scale (approximately equivalent to MMI XI-XII).

The Joetsu Shinkansen crosses this region in a north/south direction and terminates in Niigata. One of its trains was derailed by the earthquake.

Seismology and Strong Ground Motion

The mainshock at 17:56:00 Japan time (08:56:00 UT) on October 23 had a moment magnitude M_w 6.6. The epicenter (lat. 37.30, long. 138.84) was located 4 km east of the city of Ojiya (Figures 1 and 3). The mainshock was followed by an aftershock sequence with four events of JMA magnitude 6 or larger, and 12 events of magnitude 5 to 5.9 (as of November 28), far more than usual for an event of this magnitude. There was no surface rupture observed with the earthquake, and the mainshock is currently not associated with any mapped fault. The focal mechanism of the main shock shows almost pure reverse faulting on a fault striking 30 degrees east of north, dipping down to the northwest at 54 degrees. The source area is 20-30 km long, with down-dip widths of about 14 to 25 km.

The earthquake occurred near the Sea of Japan in an area of relatively high seismicity. Within 100 km, there have been five other earthquakes greater than M_{jma}6 since 1941, including the 1964 M_{jma}7.5 Niigata earthquake. All the large earthquakes of the present sequence occurred beneath the mountainous region east of Ojiya, where there are mapped Neocene-Quaternary folds. Across the region, there are many mapped short lineaments (1-10 km) trending northeast-southwest, along with the recognized Muika-Machi-Bonchi-Seien fault (Geological Survey of Japan).

The hypocenter was in the central or lower region of the fault, so the rupture propagated updip toward the east and along strike in the northeast and southwest directions, with a duration of about 10-15 sec. The largest amount of slip was in an area about 10 km x 10 km in the region of the hypocenter. Strong hanging wall effects were manifested in the large peak accelerations recorded above and to the west of the fault at locations such as Ojiya, where 1.33 g PGA and 128.7 cm/sec PGV were recorded 4 km west of the hypocenter (Figure 2). The largest recorded peak acceleration, 1.75 g (and 53.1 cm/sec PGV), was recorded at Tohkamachi (NIG021), located about 20 km south-southwest of the epicenter. Peak accelerations of 0.48 g and 0.89 g were recorded at Nagaoka and Nagaoka-Shisho, respectively, located 16 km north of the epicenter. The peak acceleration recorded at Niigata City, at an epicentral distance of 70 km, was 0.11 g. For comparison, the M_w 7.5 1964 Niigata earthquake, which caused the extensive liquefaction, was located offshore at an epicentral distance of about 55 km north of the city, and had a peak value of 0.16 g, with a longer duration in Niigata City.

Aftershock hypocenters are distributed over a region that is about 30 x 20 km at depths ranging from 15 km to the surface, which roughly coincides with the area of the mainshock and larger aftershock rupture

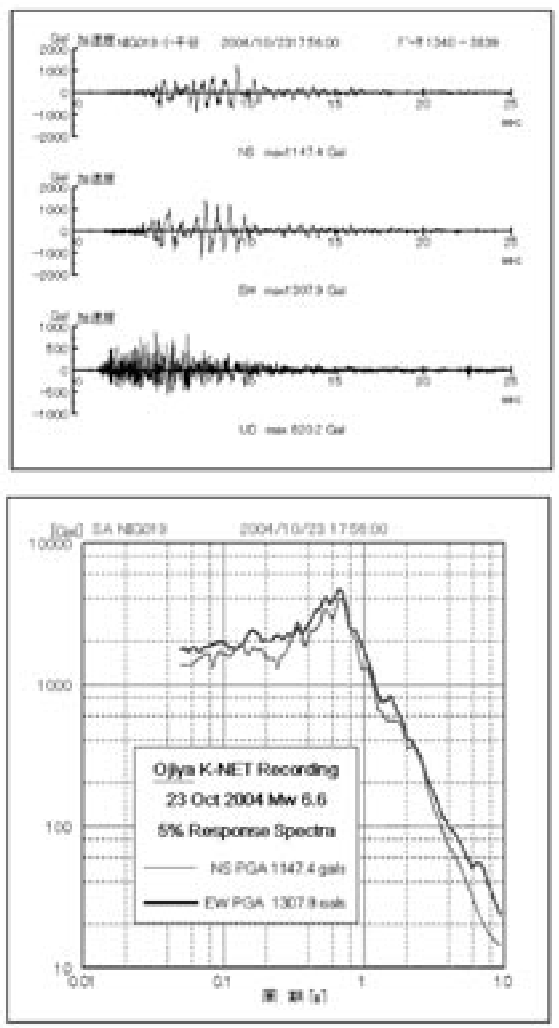

Figure 2. *Ojiya K-NET Seismograph NIG019. (top) PGA 1.33 g EW, 1.17 g NS, and 0.83 g UD, and (bottom) 5% damped response spectra for two horizontal directions (source: NIED).*

areas. The locations show a complex pattern of westward and eastward dipping structures that are associated with the mainshock and larger after-shocks.

Geotechnical Aspects

Landslides, liquefaction, and permanent ground displacements accounted for most of the physical and economic effects of the earthquake. Figure 3 shows the distribution of landslides caused by the earthquake, as well as areas where liquefaction was generally observed. The map also shows other effects discussed below.

Landslides: Niigata Prefecture documents 442 individual landslides in this earthquake, although on the ground the number appeared even larger. Heavy rainfall in the days prior to the earthquake likely had a fundamental impact on the distribution and scale of landsliding. Bedrock throughout the area of major landsliding consists of a folded sequence of very weak and friable claystone and siltstone that is fairly nondurable, with interbedded sandstone and minor conglomerate. For the argillaceous bedrock materials, high antecedent moisture would tend to cause softening and strength reduction, as well as elevated pore or joint water pressures and seepage forces.

Observed modes of slope failure included translational soil slips, deep-seated rotational slumps, debris flows, slump-flow complexes, and large block slides. In some cases, the failures were clearly controlled by bedrock structure, while other deep-seated bedrock failures did not have an apparent relation to the bedrock structure. The limited scope of the reconnaissance mission did not allow for the team to determine how many of the landslides were reactivated movements versus first-time movements. However, preliminary observations indicate that some pre-existing (ancient) deep-seated landslides were not remobilized during the earthquake.

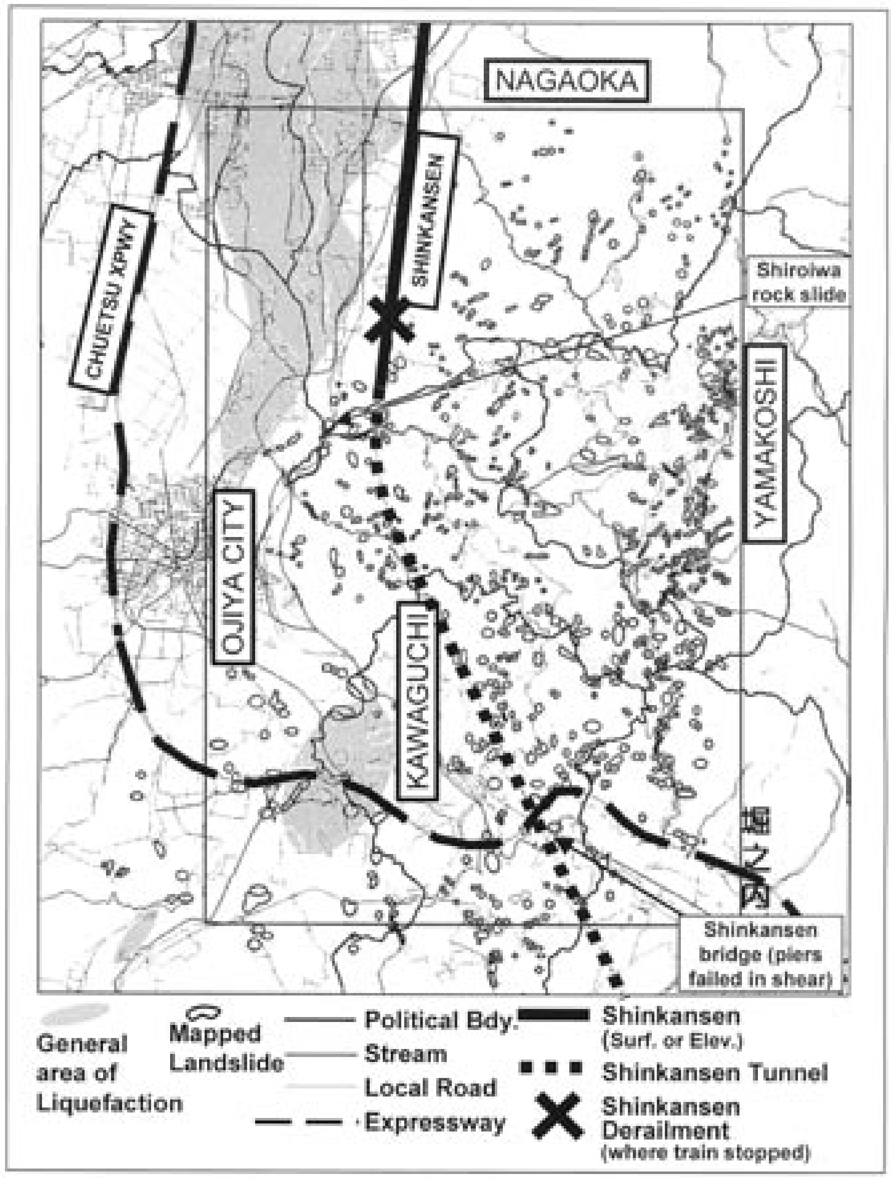

Figure 3. Map of affected area showing main effects of mainshock (adapted from KKC aerial photos).

The most widespread type of observed failure consisted of translational slip of the regolith and highly weathered bedrock materials on very steep slopes flanking floodplains and along incised river and creek channels. This type of failure generally involves the upper 5-10 feet of soil, and slip appears generally to be concentrated along the interface between significant root growth and underlying highly weathered bedrock. Examples of this type of failure are shown in Figure 4.

Another commonly observed failure mode was slump-flow complexes within colluvium-filled swales and in areas of deep regolith. If antecedent moisture conditions had not been so severe, it is probable that the significant flow characteristics commonly exhibited by these failures would not have been so prominent. Many debris flows with significant runout distances were triggered by the earthquake, as shown in Figure 5. In several cases, massive debris flows blocked natural drainage courses, forming landslide dams.

Figure 4. *North-facing valley wall with extensive translational soil sliding into valley bottom, Yamakoshi epicentral area (photo: K. Kelson).*

These events have already resulted in the flooding of villages and infrastructure (Figure 6), and there is potential for large sudden floods to initiate if the landslide dams are breached in an uncontrolled manner.

An earthquake-triggered landslide dammed a river about 1 km west of Komatsugura. The landslide was a block slide that formed on a dip slope dipping about 15-20^{o} west. As the block moved downslope, a large graben formed at the head of the landslide; the landslide moved across the canyon and completely blocked the drainage. A reservoir several kilometers long formed behind the dam and, at the time of the team's visit (November 19, 2004), the reservoir was rising 15-20 cm/day despite efforts to pump water over the dam. Several roads and structures had been inundated upstream. An emergency spillway was being constructed to prevent uncontrolled overtopping and catastrophic failure of the dam, which could inundate downstream communities in ten minutes. The landslide material consisted of weakly cemented Pliocene and Pleistocene sandstone and mudstone that is easily erodible.

A classic example of a block slide can be seen in Figure 7. The mould (negative impression) of the block is defined by a bedding surface dipping at about 30^{0} toward the free face of the slope, along with vertical joint release surfaces intersecting the right side of the bedding plane. The overlying block of bedrock traveled on the order of 100-150 feet, riding over the valley floor. This failure occurred along a hogback ridge, and bedding plane slides of similar or larger size were observed at several locations along the hogback.

A major landslide at Shiroiwa (White Rock) drew international attention because a mother and two young children were buried in their car. They were discovered about four days after the quake, with only the four-year old boy surviving.

As the bedrock throughout the area of major landsliding is judged to be sufficiently weak under saturated conditions to permit development of continuous shear on curved surfaces, it is not surprising that deep-seated rotational slides occurred, much like classical soil slumping.

Figure 5. *Typical debris flow, exhibiting a narrow path and long runout (photo: S. Kieffer).*

Figure 8 shows a deep rotational slide, as evidenced by a block of back-rotated trees and agricultural land bordering an approximately 100-foot high headscarp to the left. Farther downslope, similar back-rotated blocks were observed, and the estimated maximum depth of the sliding surface is on the order of several hundred feet.

A major question remains regarding the influence of prior rainfall on slope stability. The extent of landsliding is very large, and the authors are not aware of other earthquakes of similar magnitude that have caused slope instability to this extent. If the earthquake had struck under normal soil moisture conditions, or relatively dry conditions, it is likely that the extent of landsliding would have been significantly less.

This emphasizes that risk of prior rainfall should be considered in any evaluation of seismically induced slope instability. Due to the sparse population in the mountainous epicentral region, the number of resultant casualties was surprisingly small. However, seismically induced landslides under saturated ground conditions in areas of the San Francisco Bay and Los Angeles would cause similar damages and many more casualties.

Figure 7. *Block slide formed by bedding plane (sliding surface) and two sets of vertical joint release surfaces (photo: S. Kieffer).*

Liquefaction: Clear evidence of liquefaction was widespread but sporadic, and was primarily confined to rice fields along the Shinano River and to backfill around sewer pipelines. Some sand boils were observed under the Shinkansen viaduct (Figure 9) near the site of the derailment, and under a few bridges. However, there was much indirect evidence of liquefaction. Liquefaction may have contributed to the many ground failures, particularly near Kawaguchi, though no sand boils were observed. Ground settlement on the order of tens of centimeters along the Uono and Shinano rivers, along with levee slumping, could have resulted from liquefaction. Ultimately, the amount of liquefaction and associated ground failure was less than that anticipated by members of the EERI reconnaissance team.

Figure 6. *Inundation of homes upstream of landslide dam (photo: K. Kelson).*

Hillside fills: The hillside residential area of Takamashi, located on the eastern edge of Nagaoka, experienced significant slope failures during the earthquake. Takamachi is located on a natural hill at the edge of the Shinano valley and the native soil consists of early Pleistocene sand and silt. It is assumed that the area was constructed by cutting the top of the hillside and using this material as fill along the edges. In most places, the fill was confined by a 4-m high rigid, concrete retaining wall. Four large sections of retaining wall failed catastrophically, with the soil sliding a significant distance downslope. Figure 10 shows one of the large failures, extending across the road and close to the adjacent homes. Four segments of the concrete retaining wall translated significantly during the earthquake,

Figure 8. *Deep rotational slump, indicated by a block of back-rotated trees and agricultural land, beneath an approximately 100 foot high headscarp (photo: S. Kieffer).*

including one that came to rest within the trees downhill.

In addition to the catastrophic failures, severe cracking due to slope and retaining wall deformations was observed in many areas along the edge of the hill. As much as 1 m of downslope movement was observed, and these deformations caused significant damage to structures. No failures or ground cracking were observed in areas that did not have a retaining structure.

The yellow and red-tagged structures within the Takamachi area were almost completely concentrated in areas with adjacent slope failures and ground cracking.

Figure 9. *Sand boils at the derailing site of the Johetsu Shinkansen (Oct. 25) (photo: K. Kiyono).*

Within the interior of the hillside area, only green-tagged structures were encountered. It appears that all of the structural damage in Takamachi can be attributed to the deformations and failures of the hillside slopes.

Buildings

As a generalization, building damage in this earthquake was surprisingly light given the high apparent ground motions. Traditional single-family Japanese houses are one- and two-story wood post and lintel with bamboo reinforced mud infill and heavy fired clay tile roofing. They perform very poorly in earthquakes, being prone to pancake collapse, as seen in the 1995 Kobe earthquake. In the Niigata region, houses tend to have larger and more numerous interior columns and heavier roof beams, due to the heavy snows (up to 3 m) every winter. A substantial number of these buildings collapsed in Kawaguchi, although the effects of shaking and PGD were hard to differentiate. Damage in Ojiya was lighter, although there were still some collapses and heavily damaged houses. There was very little to no damage to houses of this type in Nagaoka.

Within the last two decades, a newer type of residential construction has been increasingly built in the region, presumably due to the snow accumulations, in which the entire ground floor exterior wall is of reinforced concrete, with second and third stories of more traditional wooden construction. These buildings are significantly taller and larger than more traditional housing, and are more like U.S. housing in that they have shingle roofing rather than heavy clay tile. They fared very well in the earthquake, having benefited from more modern building codes and construction practices.

Figure 10. *Failure of hillside fill in Takamachi residential area (photo: E. Rathje).*

Commercial and institutional buildings generally performed well, with some exceptions. A surprising success was a three-story 1960s vintage RC frame school building in Ojiya about 100 yards from the 1.33 g PGA seismograph recording. The building was completely undamaged, with the exception of a cracked brick chimney. Another success story was a large three-story hotel complex situated on the ridge directly above Kawaguchi. Despite having a landslide immediately adjacent, the building sustained no damage, with the exception of some minor pounding at a seismic joint between two parts.

Large "big-box" stores are increasingly prevalent in Japan, and two were observed in Ojiya with precast cladding having fallen away from steel frames. Entry was denied, but extensive salvage and repair operations were observed. A ten-story concrete-clad building was observed to have classic shear cracking of columns, and an electronic chip fab plant was reported to have sustained heavy nonstructural damage.

Lifelines

After landslides, damage to lifelines was the most notable result of this earthquake. Roads and highways were damaged at numerous locations, with similar damage to rail lines. An historic first was the derailment at full speed of a Shinkansen (bullet) train. With that exception, transportation structures performed generally well in this series of earthquakes. There were no collapses; damages appeared to be limited and repairable, and not surprising given the level of ground motions. The EERI team visited every bridge structure crossing the Uono and Shinano Rivers in the epicentral region. All but two of the highway bridges were open for at least limited traffic; the two that were closed appeared to be open for emergency vehicles.

An unusual aspect of this earthquake was damage to transportation tunnels. Water and power systems sustained some damage, but were back in service within hours, except in the hardest hit areas.

Roads and Highways: Landslides and permanent ground displacements of varying magnitudes seriously damaged roads at over 6,000 locations throughout the region. Virtually all roads in the Uonoma Hills were cut by landslides (Figure 11) and many pavements in the lowland areas were disrupted by floating manholes, settlements at culverts and bridge abutments, and general disruption of the paved surface.

Highway bridge structures generally performed well in the earthquake series, with the exception that significant settlement of approach fills was observed on many bridges. Most had been repaired with asphalt by the time the EERI team arrived in the area. Several highway bridges suffered damage to piers and bearings, but closure of the bridge was not required. A unique feature of the region are pipes, carrying water at 13° C, embedded in concrete along many streets and roads; the water is sprayed on snow in the winter to melt it. Over 600 km of such piping exists in the region, and much of it was damaged. Since that damaged the pavement, the

Figure 11. *Damage to road in Uonoma Hills. Note abandoned car in distance (photo: J.P. Bardet).*

Figure 12. *Derailed Shinkansen (Oct. 31) (photo: C. Scawthorn).*

town of Kawaguchi removed it and put down gravel. However, snowplows cannot operate on such roads, so considerable disruption is expected this winter when the deep snows come.

Railroads: There was extensive damage to roadbeds caused by ground failures. Significant damage was observed on the Shinkansen elevated viaduct, as well as on some local railway lines, but all appeared to be repairable. The Joetsu Shinkansen line carries 360,000 passengers per day, and was scheduled to restore service on December 28, 2004. A northbound Shinkansen train derailed just south of Nagaoka City (Figure 12). As the train traveling over 200 km/hr was exiting a tunnel, the driver felt the earthquake and applied the brakes. The train passed under a 300-m-long covered section, and began to derail along a viaduct, approximately 500 m from the exit of the tunnel. The train engine came to rest approximately 1.9 km from the tunnel exit, taking over 1.5 km to stop. There were no reported injuries as a result of the derailment, which occurred entirely along a straight section of elevated, level viaduct through rice farms. The viaduct, constructed in the 1970s, is composed of several different types of segments with varying heights and section design, some of which were damaged in the earthquake. Ground cracking, ground settlement, and signs of significant soil softening were observed at many locations along the viaduct (Figure 9).

In the town of Kawaguchi, the Joetsu Shinkansen railway bridge was damaged. Piers supporting the Wanazu Bridge over the Uono River suffered a flexural failure due to a reinforcement discontinuity, as shown in Figure 13. Several columns of a viaduct section just south of the bridge also failed. Repairs were underway at both locations by the end of the team's time in the area. Tracks of the JR Joetsu Line were also damaged due to minor fill settlement in the Wanazu area. In Kawaguchi, rails were buckled in numerous locations, and several plain concrete piers of the JR Iiyama Line were damaged, while the superstructure remained intact.

Tunnels: Several tunnels were damaged in this event, including the 8.6 km Shinkansen tunnel, which had fallen lining at about mid-length, and buckled track. Spalled lining occurred in the Wanatsu Tunnel of National Route 17.

Utilities: The earthquake cut off all power, gas, water, and telephone service to Ojiya city. Upwards of 300,000 households in the region

Figure 13. *Damaged piers of Joetsu Shinkansen Wanazu Bridge (Nov. 1) (photo: S. Ashford).*

lost electric power. As of Sunday evening, the day after the earthquake, 98,000 homes in Ojiya and Nagaoka still lacked electric power. Water supplies were cut through most of the affected area, and the lack of telephone service added to the isolation of the mountain areas cut off by landslides. Many areas received water from tank trucks, dispatched from neighboring areas.

Electric power was restored steadily, but as of October 26, 34,000 households were still without power, mostly in Nagaoka and Ojiya. Tohoku Power employed 1,900 repair workers, but they were impeded in some places by damaged roads. Water and gas service took longer to restore, and as of October 26, 108,000 households still remained without running water and 56,000 without gas. Access was impeded by all the road closures. By November 3, power was restored to all but 2,300 households, mostly in evacuated parts of Yamakoshi and Ojiya.

Nagaoka City receives its water from the Shinano River, upstream of the city. Water level in the river is raised by lowering gates across the river, and water is diverted into a pipe that carries the water to a treatment plant downstream of the gates. The earthquake disrupted power to the gates and also caused some damage to the wire rope machinery used to raise the gates, so the gates could not be lowered and the treatment plant received no water. As a result, the plant had to resort to emergency drafting from the Shinano River (Figure 14).

Damage was more extensive at the Ojiya water treatment plant, which also draws its water from the Shinano via an intake structure and over the levee on an approximately 70-m long steel truss bridge. Differential displacements of the supports damaged the bridge, but did not cause collapse. In the plant, there were obvious signs of ground settlements, and the plant had sustained piping damage and was installing temporary piping. The plant was back in operation in hours. From the plant, water is pumped to two large hilltop reservoirs, one on each side of the Shinano. The EERI team visited the reservoir on the west bank, which is a circular concrete partially embedded tank, approximately 25 m in diameter. Some ground settlements had occurred around the tank, and entry structures had collapsed, but the tank was largely undamaged and in operation. The hilltop location is within 1 km of the 1.33 g PGA recording in Ojiya, and the hilltop had sustained landsliding and damage to nearby houses, and clearly had undergone very strong shaking.

Approximately 23 km from the epicenter is the Kashiwazaki-Kariwa Nuclear Power Station, at 8,300 MW (7 units) the world's largest NPS. The October 23 mainshock reportedly had no effect on the NPS, but a magnitude 5.2 on November 4 caused Unit 7 to shut down automatically (other units operated at the rated thermal power). In Kawaguchi, the Shinkansen has a substation stepping power down from 63kv to 1500 volts (the service voltage for the Shinkansen catenaries). Transformers in the substation were significantly tilted due to liquefaction, but still operating, and otherwise the substation was undamaged.

Social Impacts

The most seriously affected areas were small towns and villages near Nagaoka, especially the village of Yamakoshi, the town of Kawaguchi, and the city of Tokamachi. As is true in rural areas throughout much of Japan, the population has been in decline, with Yamakoshi and Kawaguchi declining by 11.9% and 5.9%, respectively, from 1995 to 2000. Nearly 40% of Yamkoshi residents and 25% of Kawaguchi residents are elderly. Although the earthquake occurred in mid-autumn, winter was rapidly approaching, and Niigata Prefecture is known to receive some of the heaviest snowfall in Japan.

Because landslides cut off transportation and communication to many areas, it took some time for emergency services to identify damage

Figure 14. *Emergency drafting of water from Shinano River for Nagaoka City Water Treatment Plant (photo: C. Scawthorn).*

and assess needs. There were reports of family and neighbors rescuing people from collapsed homes. By the morning after the Saturday evening earthquake, the Self-Defense Forces (SDF) opened a disaster headquarters in Ojiya to coordinate relief efforts, and used 300 personnel, 21 helicopters, and 65 vehicles to transport food and water to evacuation sites. They also evacuated tens of thousands of residents to emergency shelters, and used helicopters to airlift stranded villagers from the hamlet of Shiotani.

More difficult was reaching the isolated towns of Kawaguchi and Yamakoshi, which initially depended on airlifted food and water until they could be rescued the following day. In Kawaguchi, about 300 people took refuge in an elementary school and awaited assistance. By Monday evening, relief supplies were coming in over the roads, but still with not enough food for the population. In Yamakoshi, 250 residents spent two nights in a gymnasium without power or water before being evacuated. All but six of Yamakoshi's 2,200 residents were evacuated and taken to three sites in Nagaoka. The national government applied the disaster relief law to 29 localities, which meant that government would cover the cost of relief and shelter.

Many people spent the first night in their cars, but by the day after the earthquake, 82,000 were staying in emergency shelters. In Ojiya, 14,500 people took refuge at 93 different evacuation centers, mostly school gymnasiums and public halls. Even in lightly damaged Nagaoka, more than 34,000 people were evacuated to temporary shelters (Figure 15). On Monday, October 25, thousands were airlifted from about 60 mountainous communities, which remained closed to road access. Thirty police and SDF helicopters were needed to evacuate residents of seven municipalities. By Tuesday, October 26, about 320 people were still stranded in five hamlets.

Aftershocks and landslide dams posed continuing problems. A M5.2 aftershock on November 4 halted the bullet train line between Niigata and Nagaoka. It also closed down a section of the bullet train tracks that had just reopened. A M5.9 aftershock on November 8 again stopped the bullet train and closed a portion of the expressway to Tokyo. Continued rain during the ten days following the earthquake raised concerns about water behind the landslide dams in Ojiya and Yamakoshi. The Japan Meteorological Agency set up alarm units and surveillance cameras at five landslide dams, the prefecture prepared pumps to lower the water levels, and the prefecture recommended evacuation of 101 households containing 439 residents.

As of November 28, authorities attributed 40 deaths to the earthquake. Although most died from building collapses, approximately 14 deaths were from stress-related illnesses following the earthquake. One hospital patient died when an artificial respirator detached during the earthquake. Five died from complications due to living in their cars, including blood clots from inactivity. As a result, the prefecture encouraged people to move into SDF tents or to stay in accommodations farther away. Elderly residents were especially susceptible to exposure and stress-related illnesses.

Figure 15. *Interior of shelter in Nagaoka City (Nov. 6) (photo: C. Scawthorn).*

Economic Effects

Agricultural activities in Yamakoshi were disrupted by the earthquake, and residents fear permanent consequences. The village's main industry is the raising of carp, which it provides to decorative ponds throughout Japan. The cattle industry is another concern. Residents had to leave behind 1,000 cattle. In order to save his business, the largest cattle owner began ten days after the earthquake to airlift 700 cattle out of the village by helicopter, at considerable expense.

Area industries were also affected. Hokuetsu Paper Mills plant in Nagaoka shut down for several days, as did Matsushita Electric's chip production center. The Niigata Sanyo Electric Plant in Ojiya, which employs 1,500 workers and is Ojiya's largest employer, is closed indefinitely. An auto parts plant has been unable to resume its speedometer assembly line, which caused Honda Motor Company to halt auto production at four plants elsewhere in Japan. Other plants shut down for approximately one week, including Panasonic Communications, and Alps Electric Company.

The Tokyo Stock Exchange fell on the Monday following the earthquake, with the largest losses to Japan Rail East, companies with production facilities in the area, and insurers. On the positive side, the *Japan Times* reported that shares of construction-related companies increased sharply November 1 on the Tokyo Exchange, because investors anticipated a supplementary national budget to pay for reconstruction following the earthquake and recent typhoons. However, reconstruction will be a challenge to homeowners, since only 11.2 % of households in Niigata Prefecture have earthquake insurance, compared to 17.2 % nationally.

IT/GIS/GPS aspects

This earthquake reconnaissance effort provided an opportunity to apply new IT/GIS/GPS tools. Both teams used such high-tech tools as GPS, satellite imagery, and LiDAR (**Li**ght **D**etection **A**nd **R**anging).

For the first time, the EERI team utilized LiDAR, a 3-D scanning-laser that can create high-resolution, three-dimensional, digital terrain models of any surface, including earthquake-related ground, structural, and lifeline deformations. Approximately 30 laser scans of damaged roadways, structures, and displaced ground were taken with a tripod-mounted LiDAR apparatus, a portable device that models surfaces to a measurement accuracy of 1-2 cm.

An example of structural damage captured by the USGS LiDAR unit is presented in Figure 16, collected in the damaged portal of the Juetsu railroad tunnel, north of Horinouchi town. The portal is founded on a poorly compacted embankment fill that failed during the earthquake. The portal pulled away from the tunnel, settling vertically, sliding downslope, and rotating. In the photograph, the offset in the portal can be seen along the left wall of the tunnel, and the rotation can be seen in the ceiling. An oblique view of the LiDAR point-cloud data can be seen on the right. The left-lateral offset in the portal is clearly visible in the LiDAR model. In the LiDAR imagery, precise centimeter-scale measurements can be made of the three-dimensional deformation of the structure.

GPS also played an important role in this reconnaissance. Figure 17 shows the VIEWS (*Visualizing Impacts of Earthquakes With Satellites*) system, which allows full cataloging of ground video and still imagery geo-referenced to aerial photographs. A user can switch from the aerial photo to a close-up video or to still images. VIEWS is developed by ImageCat Inc., and its use is gratefully acknowledged.

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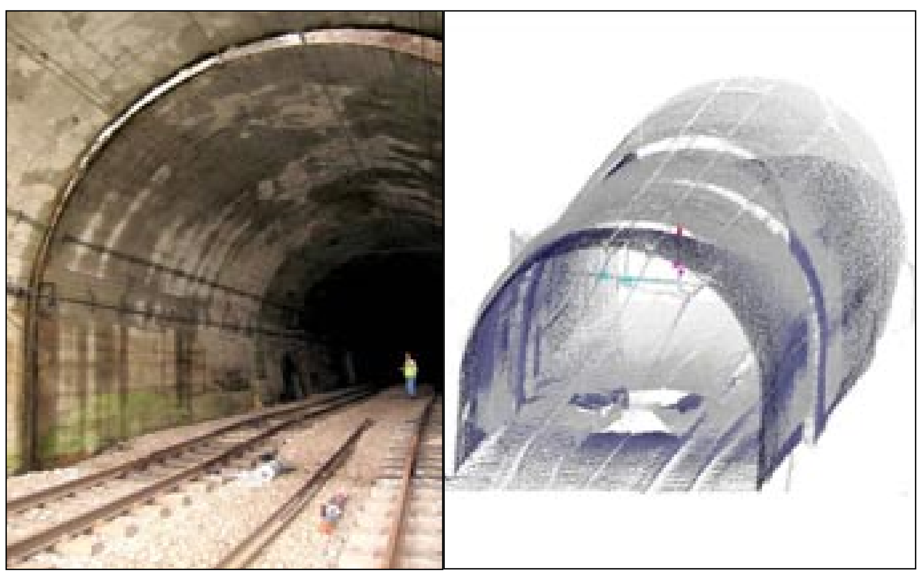
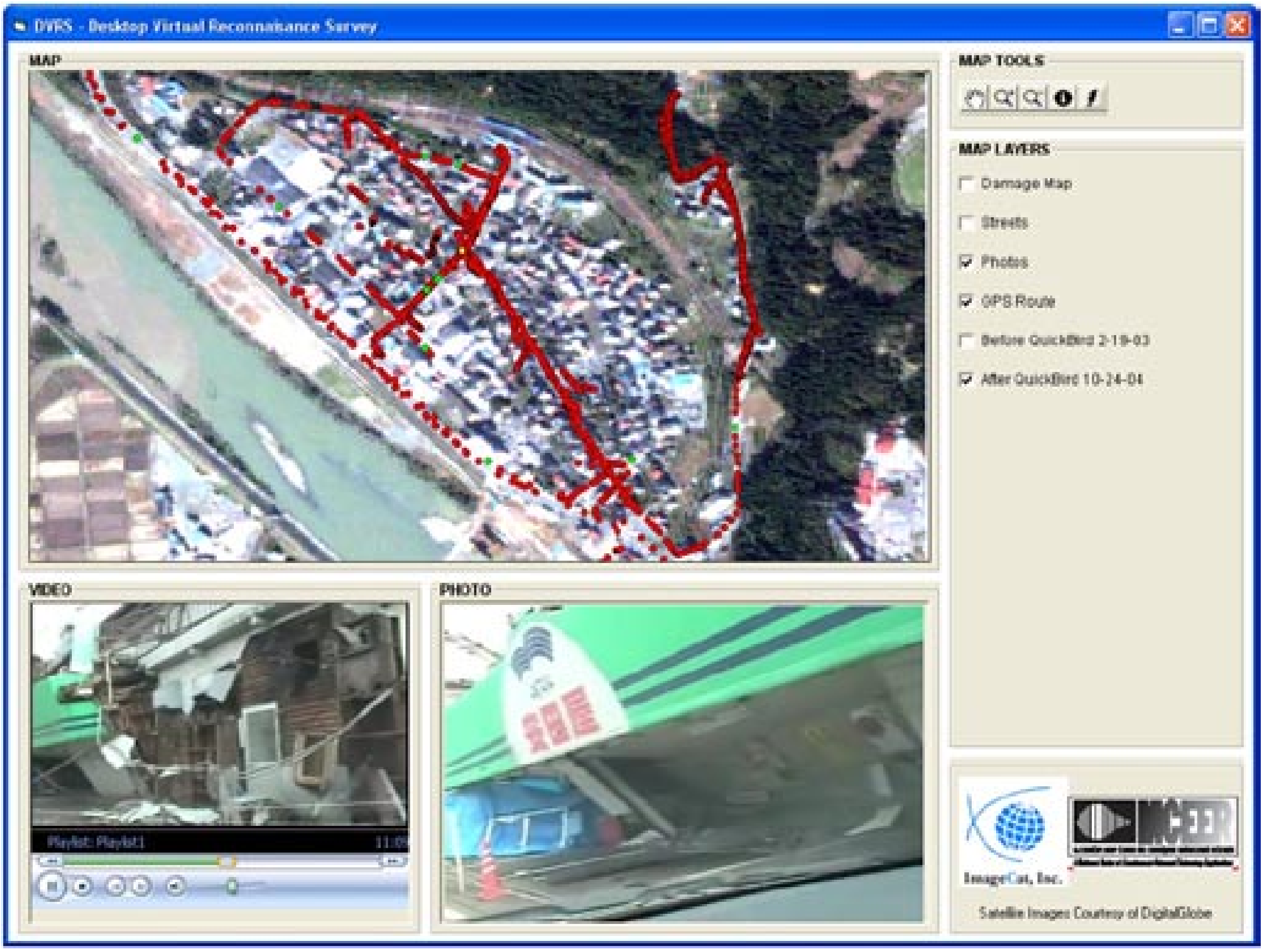
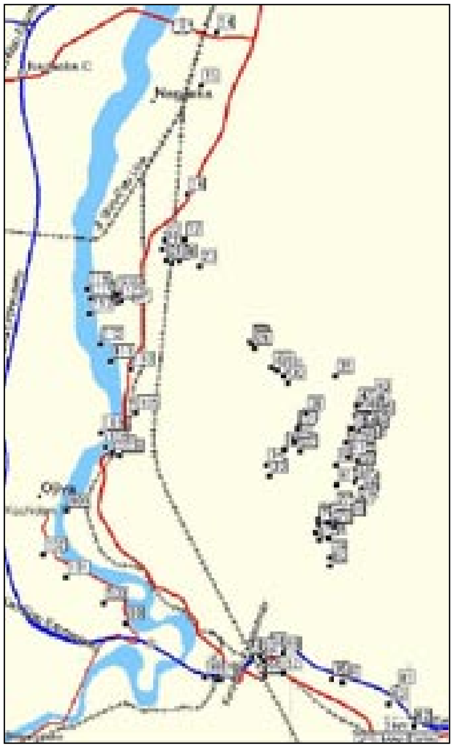


Figure 16. *Photograph (left) and LiDAR image (right) of damage to the Juetsu Railroad portal at Kita-Horinouchi from the portal entrance. Lateral displacement of the portal in the photo is visible and measurable in the LiDAR scan. (Source: R. Kayen)*





▲ ***Figure 17.***
(a) Screen shot from VIEWS, showing aerial-photo-referenced ground shots (VIEWS: C. Huyck).

◄
(b) Map with GPS-referenced photos (GPS: J. P. Bardet).