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GEOLOGICAL CONDITIONS AND SOIL DEFORMATIONS IN THE JULY 17, 2007, CHUETSU OFF-SHORE EARTHQUAKE

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ABSTRACT :

Dwellings collapsed and water, gas and electricity supplies were cut by a powerful earthquake of M=6.7 on July 17th, 2007, which also caused a small radiation leak and fire at the world's biggest nuclear plant. Greater part of Kashiwazaki central area and the nuclear power plant cover sand dunes that have been developed along the shoreline. Cracks that appeared on road pavements show that the steep slopes of these sand dunes have subsided towards wet flatlands, and many dwellings were flattened near these "slip faces".

KEYWORDS: Chuetsu Offshore Earthquake, sand dunes, crack patterns, infrared images

1. INTRODUCTION

A powerful earthquake of M=6.7 occurred off the west coast of Kashiwazaki, Niigata Prefecture at 10:13 a.m. local time on July 17, 2007. The epicentral area is in a zone of slow and steady compressive tectonic movement. This movement has formed NNE-SSW-trending folds of sand, silt and mud rocks of tertiary geological time in areas spreading several tens kilometers east of Kashiwazaki. It was about three years ago, on Oct. 23, 2004, the Chuetsu Earthquake (Mid-Niigata Prefecture Earthquake) jolted one of these areas of active folding. In this earthquake of 2004, an abundant number of landslides in the epicentral mountain region forced the local authorities to suspend the operation of totally 233 segments of several prefecture routes and the national route No. 249. Though the July 17, 2007, Chuetsu Off-shore Earthquake, has a similar tectonic mechanism in the active folding zone, geotechnical aspects of damage to houses and civil-infrastructures are largely different from those in the 2004 earthquake. Among many case examples of damage reported, a shut-down of Kashiwazaki-Kariwa Nuclear Power Plant got a front-page coverage of newspapers. Though the damage to the reactors was not fatal at all and all reactors automatically powered down safely in response to the quake, rather secondary damage to pipes have caused a cut in water supply for fire hydrant, etc. Since foundations of the plant buildings go through an unstable layer of sand down to a sturdy layer of sedimentary bedrock, and thus relative displacements between plant buildings and the surrounding soils were quite large enough to dislocate and cut underground facilities such as pipes. This case example symbolizes the damage in this earthquake, and it is needed to discuss cause-and-effect relationships for many infrastructures and dwellings taking into account the geological conditions in this area.

2. SAND DUNES IN KASHIWAZAKI AND DAMAGE TO DWELLINGS

On the Sea of Japan side, northerly winter winds off the Eurasian continent have been developing over centuries sand dunes. The dunes are longer on the windward (north) side where the sand is pushed up the dune, and a shorter "slip face" in the lee of the wind. Fig. 1 compares the present satellite imagery in 2007 of Kashiwazaki (taken from Google Earth) and a topographical map of the same area in 1912. Kashiwazaki city spreads over a set of sand dunes, which has been elongated along the coast in such a way that it would bend mouths of both Ugawa and Sabaishi rivers southwest, two major rivers flowing into the Japan Sea. Sand, silt, mud and other suspended matters that waters of these two rivers have carried over centuries have been deposited south-east behind the sand dunes. Fig. 1 shows that the old river trace of Ugawa had a meander near the south end of the sand dune and a lagoon at its mouth.

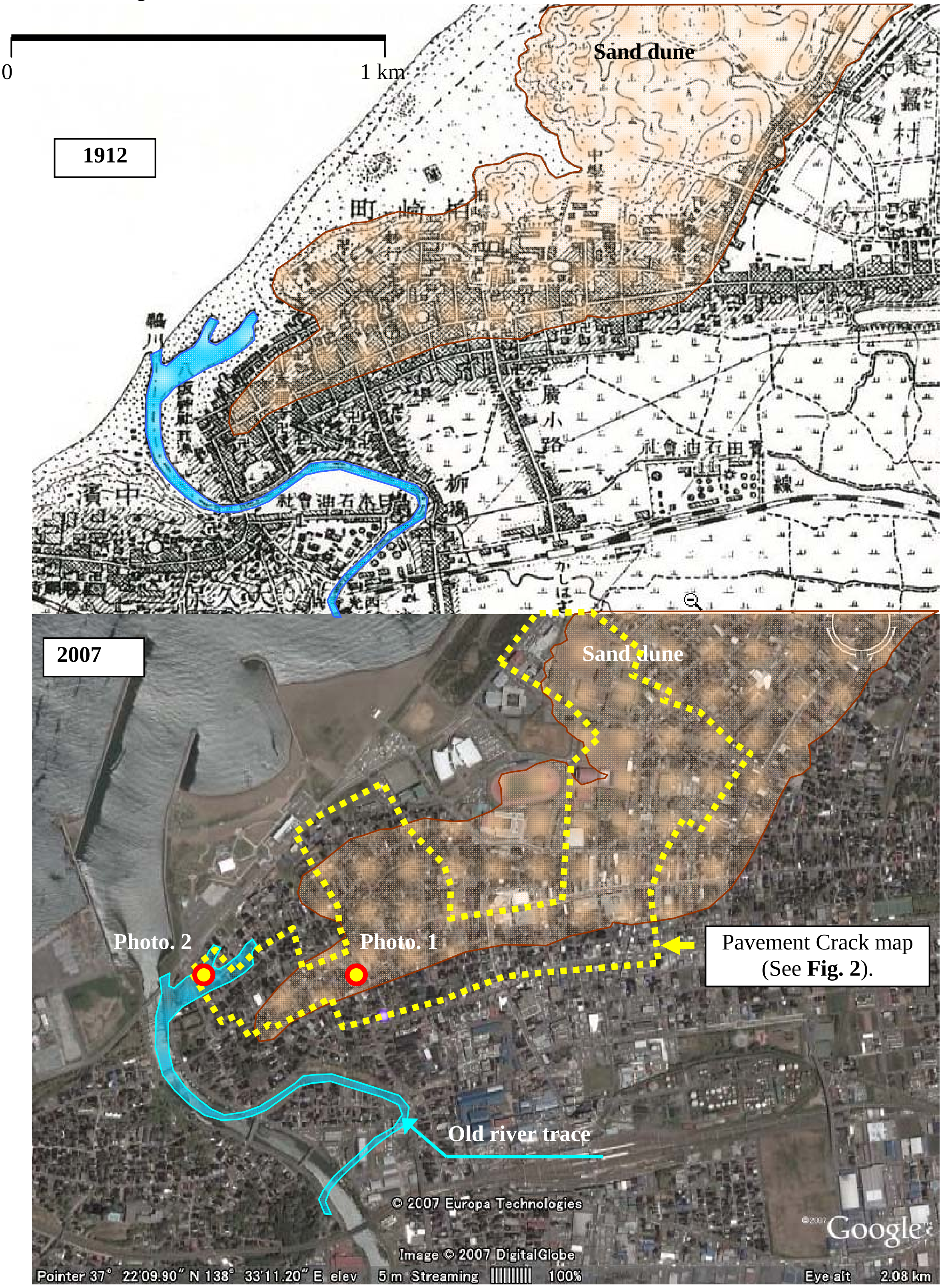

Figure 1. Satellite imagery in 2007 of Kashiwazaki (Google Earth) and a topographical map of the same area in 1912. Location of lower left corner of the satellite imagery: 37°21’38.87”N, 138°32’22.29”E

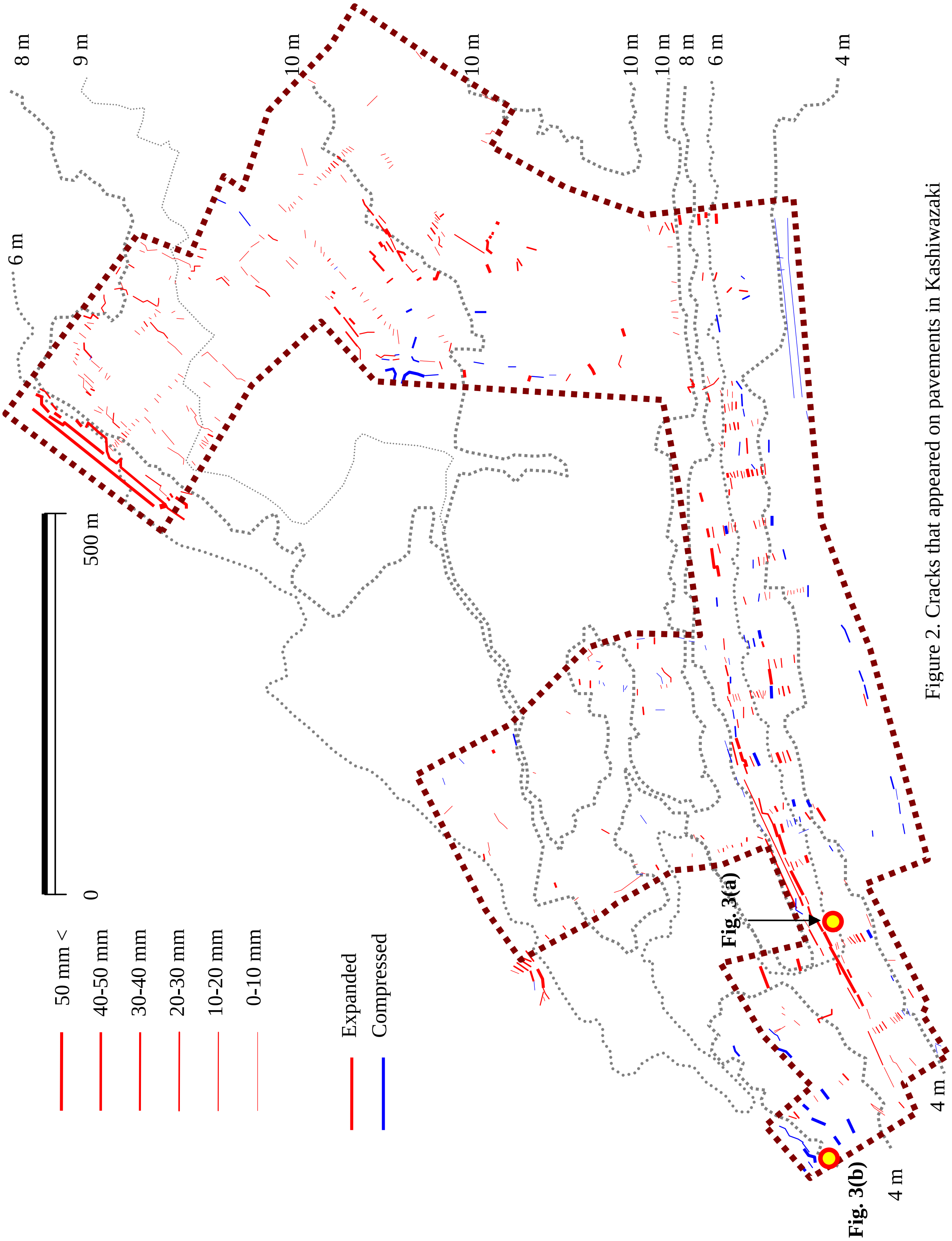

Figure 2. Cracks that appeared on pavements in Kashiwazaki

(a) Crack opened along ridge of sand dune

(b) Pavement buckled up along the toe of sand dune

Figure 3. Cracks and buckled marks of pavements in Kashiwazaki

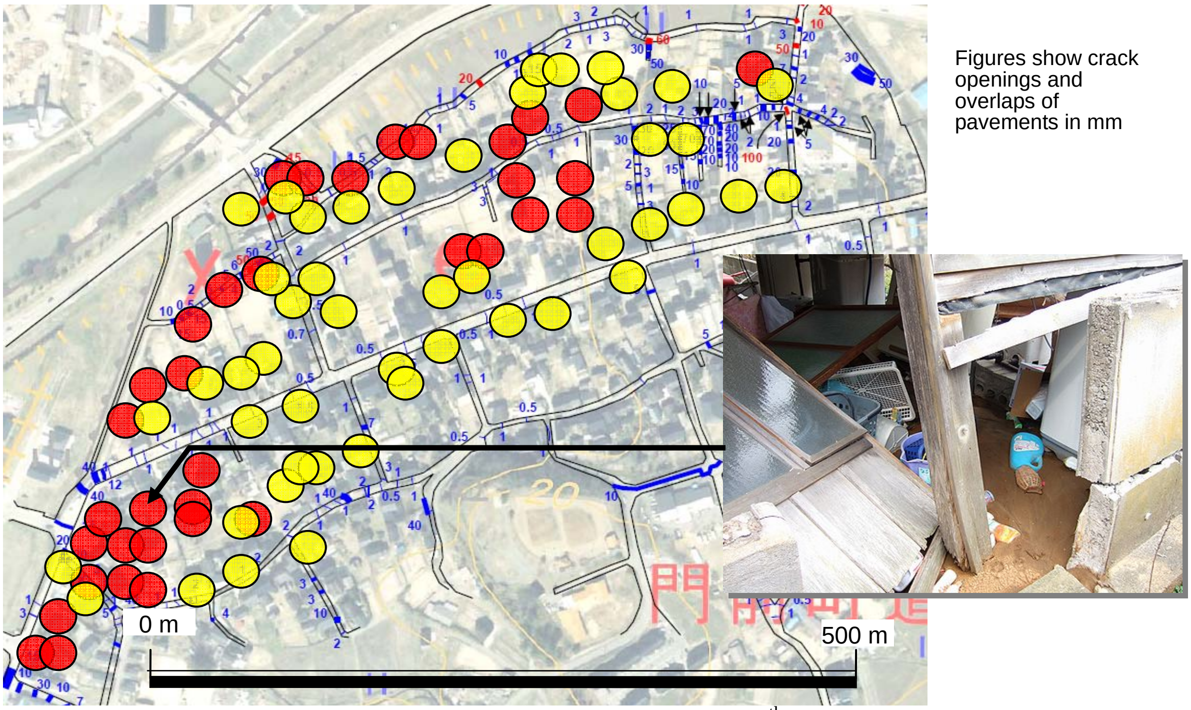

Figure 4. Dwellings in Toge, Wajima City, destroyed in the March 25th 2007, Noto Earthquake. Yellow circles are severely damaged houses, while red circles are completely flattened.

Location of lower left corner of the satellite imagery: 37°17’13.70”N, 136°44’24.91”E

Fig. 2 is a map of cracks that appeared on pavements in the area enclosed with broken line in Fig. 1. Red and blue lines show respectively open cracks (Fig. 3(a)) and compressed marks (including those colliding over the others, buckled up; see Fig. 3(b)). Most clusters of open cracks are found along ridges of the sand dunes while many compressed marks were found along toes of the dunes and some were found along an S-shaped sagged zone among the sand dunes. These cracks and compressed marks show that the steep slopes of these sand dunes have subsided towards wet flatlands and sagged zones, and many dwellings were flattened near these “slip faces”.

This case example is remarkably similar to the damage to dwellings due to the March 25th 2007, Noto Earthquake. The earthquake shook Toge, a remote habitation of Wajima city. Though damage to houses was all severe, those completely flattened were only found within an about 100m-wide brush as shown in Fig. 4. Within this wide brush, both open cracks and compressed marks of road pavements were densely found. Though either the crack openings or overlaps of the pavements are small, they may have been large enough to dislocate houses off their foundations (Photo in Fig. 4).

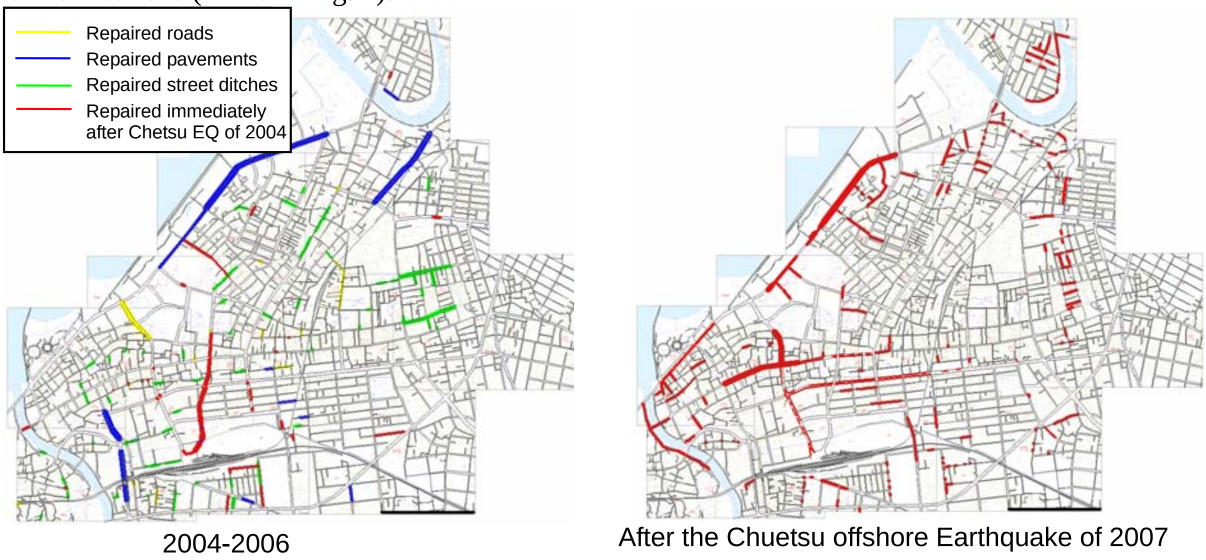

Figure 5. Repair works before and after the 2007 Chuetsu offshore earthquake
Location of lower left corner of the satellite imagery: 37°21’37.48”N, 138°32’34.43”E

It is also noted that the crack pattern that appeared on the pavements in Kashiwazaki overlaps the locations of ordinarily occurring repair works in the city (see Fig. 5). In other words, ordinary geotechnical problems may hint possible damage to lifeline facilities. A further study will be needed to supply the scenario with more quantitative underpinning.

3. TUNNEL THROUGH A SAND DUNE

Kariwa Tunnel (South mouth at 37°26’15.61”N, 138°36’42.79”E) goes through a sand dune at a height of about 100m rising immediately behind the Kashiwazaki-Kariwa Nuclear Power Plant. This 500m-long tunnel goes straight north for the first 300m distance from the south mouth, and takes a gentle turn to west. The traffic through the tunnel was once suspended for a quick inspection, but it was called off immediately after confirming that there was no serious crack which could affect the serviceability. Though the cracks looked like nothing much to worry about, they can show how the surrounding sands have been displaced in the intense shake. Figs. 6(a), (b) and (c) show the development of the tunnel lining with its outer wall outside and the western side up, longitudinal section along the tunnel alignment, and cracks that have appeared on pavements, respectively. Most cracks were found within a 100m-long segment near the north mouth of the tunnel, and openings of these cracks were generally larger on the west wall than those on the east wall, indicating that the north end of the tunnel was bent northeast-wards, namely towards the toe of the sand dune. Fig. 7 shows the northern 100m segment of the tunnel. This part of the tunnel wall was covered up with a carbon-fiber sheet when the inner wall was first repaired in 2001, six years before the earthquake. It is noted that the sheet came obliquely off along the two thirds height of the west tunnel wall. This flaking of the sheet and diagonal cracks that appeared on the concrete north entrance of the tunnel indicates that the tunnel cross-section was diagonally deformed in oval probably due to soil pressure behind the west wall of the tunnel. Water leaks were more visible on the west wall of the tunnel than those on the east wall, suggesting that the tunnel is blocking underground water behind its west wall. Fig. 8 shows infra-red image of the carbon-fiber sheet that has flaked off in the earthquake. Behind the sheet, which has been stapled to the tunnel wall before the 2007 earthquake, there clearly appear cracks of the concrete wall. This shows that the damage to tunnel was severe where ordinary repair works were needed.

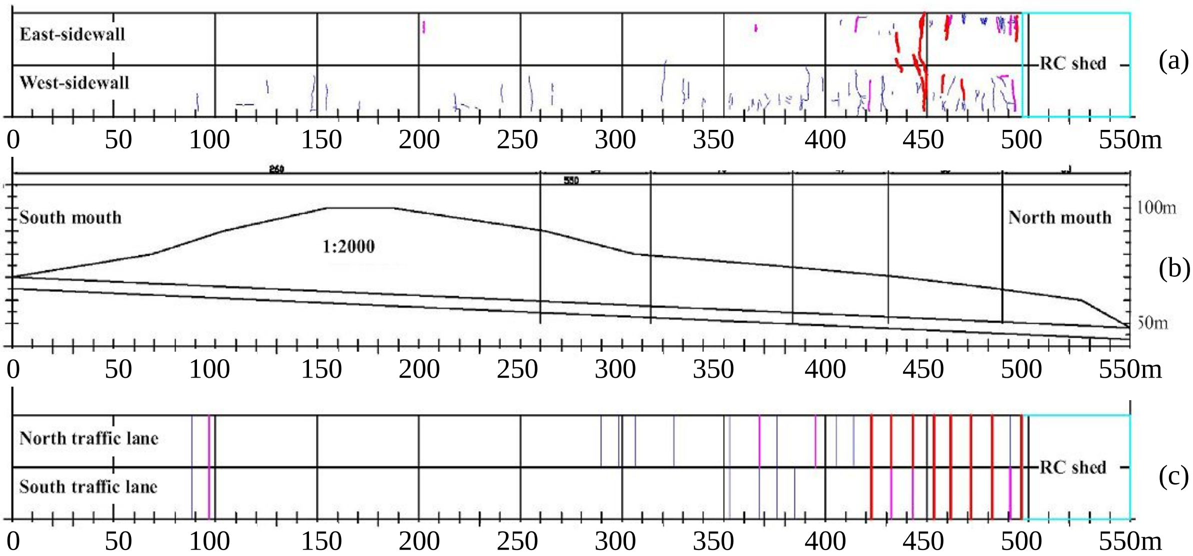

Figure 6. (a) Development of the tunnel lining, (b) longitudinal section along the tunnel alignment, and (c) cracks that have appeared on pavements

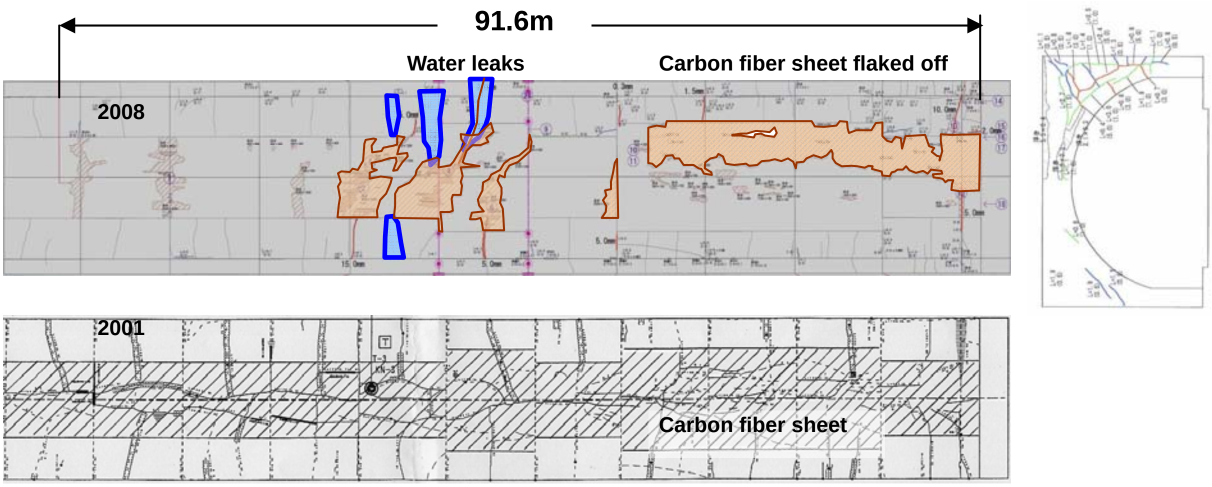

Figure 7. Northern 100m-long segment of Kariwa Tunnel

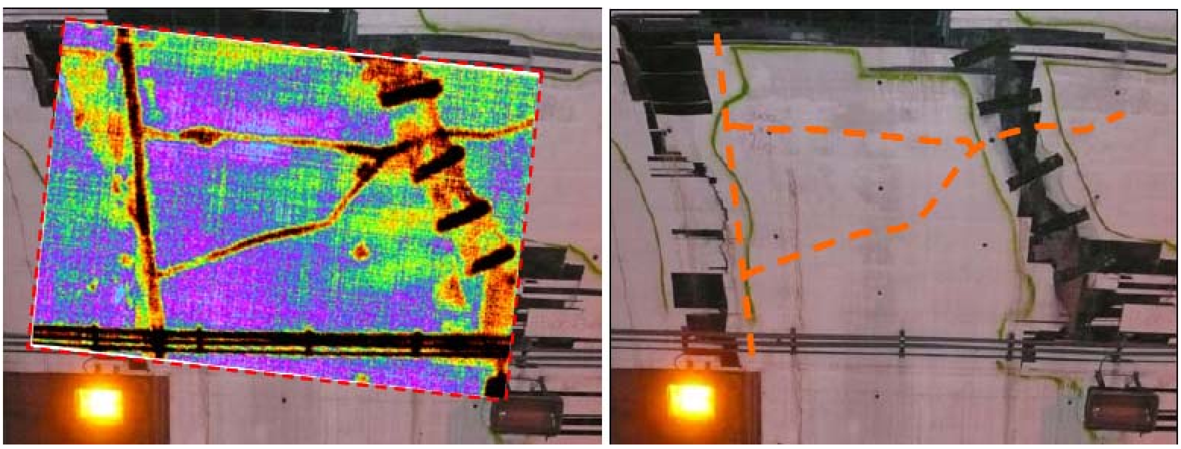

Figure 8. (left) Infrared image of cracks hidden behind carbon-fiber sheet covering the tunnel wall.

4. LANDSLIDE MASS THAT HAS BLOCKED JR HOKURIKU RAILWAY

A slope failure occurred at Oumigawa station (37°20’46.24”N, 138°29’10.00”E) of the JR Hokuriku railway, and the soil mass covered its western approach (Fig. 9). Water is seeping out along a layer boundary slightly dipping west across the entire terrace (see yellow arrows in Fig. 9). At the time of our group’s third visit to Oumigawa station on July 30, some recovery works have started and the soil mass covering the railway had been partially removed. The geological stratification was inferred from a close-up of the failure surface that appeared south behind the station. There are three major geological formations exposed on the failure surface: (a) sand and gravel terrace deposit, (b) inter-bedding formation of volcanic conglomerates and mudstones, and (c) mudstone, from the top.

(a) Sand and gravel terrace deposit

This terrace deposits dates back to the geological time of about 0.11Ma (Kobayashi et al, 1995). Streaks from layer boundaries show that ground water is seeping out from the boundaries among the exposed geological formations. Yoneyama formation ((b) and (c) in Fig. 9), immediately below the (a) terrace deposits, is inferred as a base rock of Pliocene period. It has a strike in nearly E-W direction and dips about 8 degrees to north (Kobayashi et al, 1995).

(b) Inter-bedding formation of volcanic conglomerates and mudstones

This inter-bedding formation consists mainly of volcanic conglomerate. Thin lenses of mudstone are found bedding in at some locations along the boundary between two formations (a) and (b). These lenses are weathered, and are more compact than the overlying terrace deposit.

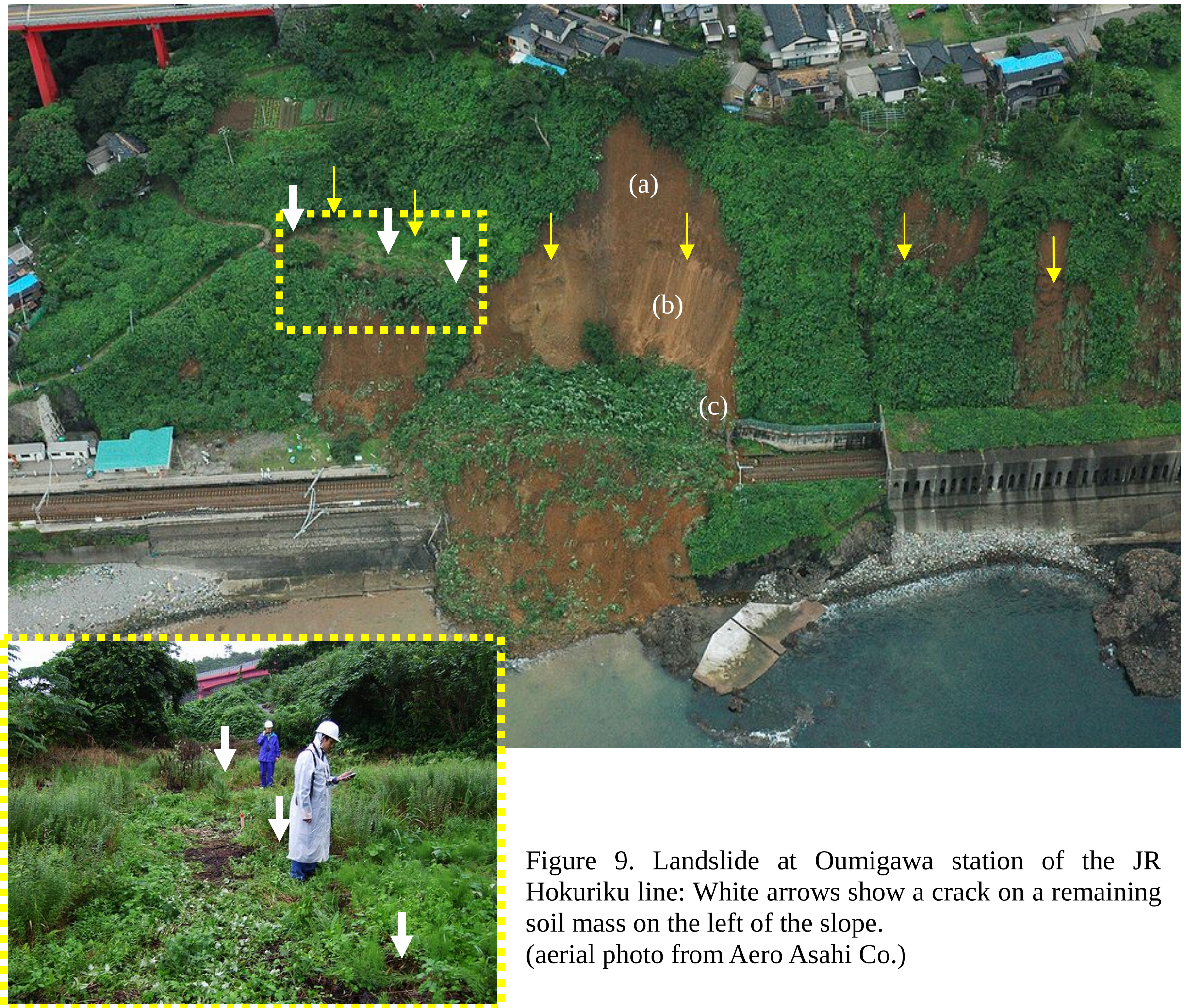

Figure 9. Landslide at Oumigawa station of the JR Hokuriku line: White arrows show a crack on a remaining soil mass on the left of the slope.
(aerial photo from Aero Asahi Co.)

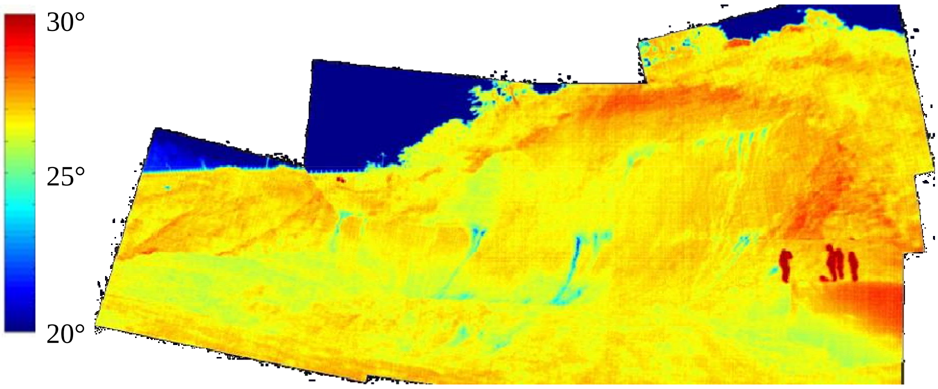

Figure 10. Infrared image of slope surface. Color scale shows “degrees” on Celsius temperature scale.

(c) Mudstone

The lower gray part is rather intact, but upper light-brown part is weathered. This mudstone is compact, and no clear bed is seen. According to cores taken from borings performed after the earthquake, there is volcanic conglomerate spreading beneath this mudstone formation, at about the same level as the railway elevation. This can also be inferred from the geological map.

With an infrared camera (NEC SanEi TH702MV), we took images of the whole failure surface. Blue to green streaks of underground water (20-25 degrees on Celsius scale) are found seeping out at some locations along two major boundaries among the geological formations. This information together with the geological information can be useful for the recovery works. E.g. drainage installations can be concentrated in areas where waters are seeping out.

5. CONCLUSIONS

Greater part of Kashiwazaki central area and the nuclear power plant area cover sand dunes that have been developed along the shoreline. Cracks that appeared on road pavements and Kariwa Tunnel show that the steep slopes of these sand dunes have subsided towards wet flatlands. It is also noted that the crack patterns that appeared on the pavements in Kashiwazaki and the inner concrete wall of Kariwa Tunnel overlap the locations of ordinarily occurring repair works. In other words, ordinary geotechnical problems may hint possible damage to lifeline facilities.

At Oumigawa station of the JR Hokuriku railway, where a landslide mass has covered its western approach, a infrared image of the escarpment clearly showed streaks of underground water seeping out at some locations along two major boundaries among the geological formations. The Infrared camera also allowed to detect cracks hidden behind the carbon-fiber sheet covering inner wall of Kariwa Tunnel. These pieces of information can be useful for quick recovery works.

ACKNOWLEDGEMENT

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