

# The 2003 Tokachi-oki Earthquake of September 26

## 1. Summary

A severe earthquake struck Hokkaido, Japan, at 4:50 am on September 26, 2003. Epicenter of the earthquake was about 80km east-southeast of Erimo Cape, offshore of Tokachi. The depth of the epicenter was 42km, and its magnitude 8.0 ( $M_{JMA}$ ). This magnitude of the earthquake is 10 times as large as that of Kobe Earthquake.

We immediately set up an ABS Consulting investigation team in the Tokyo office, and dispatched three engineers to Hokkaido. The members of the team arrived at the Chitose airport in the evening of the day that the earthquake occurred and started the post-earthquake inspection next morning. Figure 1 shows the locations that we visited. The members of the investigation team and the route of this survey are as follows;

⌘ Team Member: Yuji Kobayashi (Principal Engineer), Shinji Yamada (Engineer), Tomohiro Kubo (Engineer)

⌘ Survey Route:

27 Sep. - Muroran-shi, Tomakomai-shi, Shizunai-cho, Miishi-cho, Urakawa-cho

28 Sep. - Obihiro-shi, Taiki-cho, Toyokoro-cho, Kushiro-shi

29 Sep. - Kushiro-shi, Kushiro-cho

30 Sep. - Sapporo-shi

Seismic intensities of these sites were 6- to 3.

In this earthquake, there was severe damage due to the Tsunami impact as well as the structure, port facilities and lifeline damage due to strong shaking. Crustal change and ground deformation were observed over southeast area (Southern Obihiro - Kushiro) of Hokkaido, since the platform of Hokkaido located on the North-America plate was kicked back together with the release of the seismic energy.

## 2. The Earthquake

The source of this earthquake was the plate-boundary or subduction zone, and caused by the release of the stress built up between the Pacific Ocean Plate and the North American Plate. Relative to North American Plate, Pacific Ocean Plate moves in northwest direction with an average velocity of 8 cm per year. Since the movement length between these plates is large, a major earthquake is likely to occur when the stress is released, and the return



period of M7 to 8 Earthquake is estimated to be several decades to centuries. This kind of earthquake is characterized by accompanying with Tsunami. The Committee of Earthquake Survey said in this March that they expected M8.1 earthquake would occur in this area "with 60% probability in another 30 years." According to the Japan Meteorological Agency (JMA), this earthquake may correspond to the expected earthquake by the committee. The National Research Institute for Earthquake Science and Disaster Prevention estimates that the overall rupture plate of the fault is 100km long and 50km wide, the displacement or slip length of the fault is 4 to 5 meters in the east-west direction, and the moment magnitude (Mw) is estimated to be 7.9. According to the Geographical Survey Institute of Japan, the observation stations in Erimo-cho and Hiroo-cho moved 95cm and 97cm respectively during the earthquake. That is, the Hokkaido Island extended in the south east direction due to the ground movement caused by the stress release at the subduction zone. This indicates that there was crustal change in the large area over Toyokoro-cho to Onbetsu-cho (please refer to the "Road" section).

In the past decade, three major earthquakes had hit this area; 1993 Kushiro-oki Earthquake (M7.5), 1993 Hokkaido Nansei-oki (M7.8), 1994 Hokkaido Eastern Offshore Earthquake (M8.2).

A series of Earthquakes occurred at 4:50 am and 6:08 am on September 26. Primal earthquake is M8.0, the depth of epicenter is 47km, and the next major one is M7.0 with the epicenter depth of 60km. The maximum seismic intensity recorded 6- for both of the major strikes. Table 1 provides the seismic intensity around Hokkaido Area for the primal earthquake (The data was obtained from the K-Net and local governments. The PGV values are calculated by band path filtering the acceleration records by FFT).



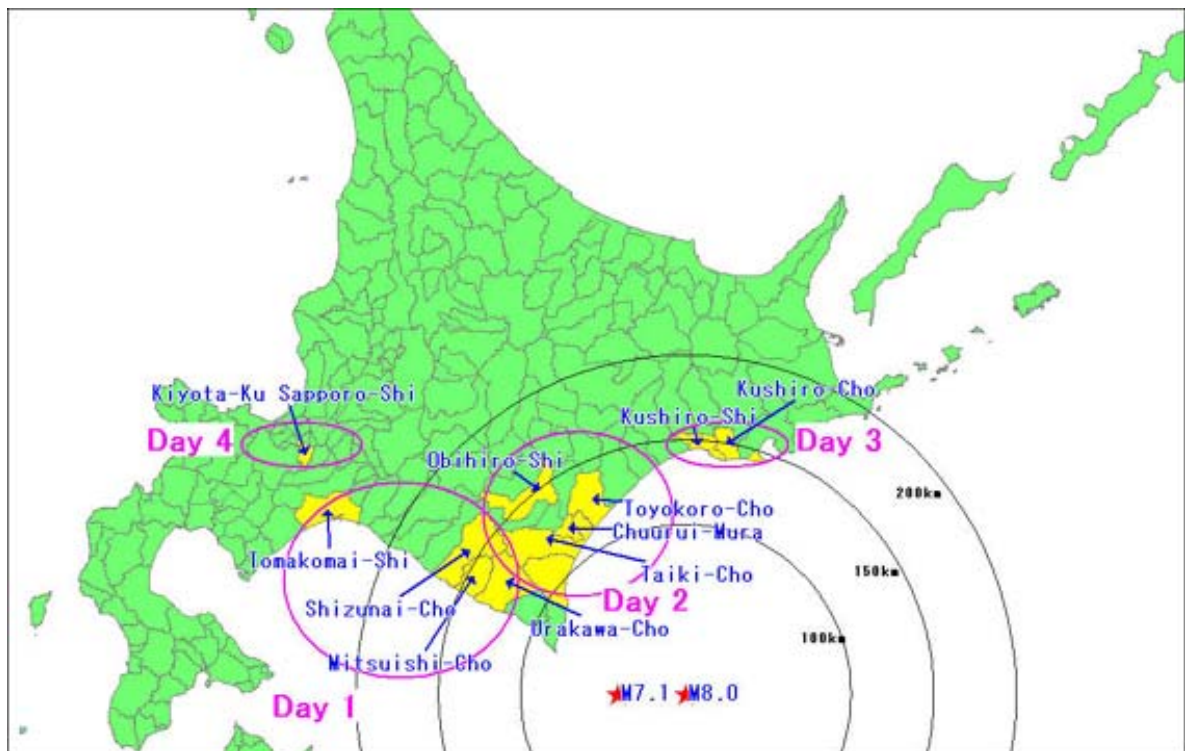


Figure 1: Site Maps

Table 1: Summary of Seismic Records

| Day     | Interview | Local Government       | Shaking Intensity | PGA [gal] (K-Net) | PGV [kine] (K-Net) | Structural Damage   | Water  | Gas              | Power   | Liquifaction       | Tsunami | Injured Person |
|---------|-----------|------------------------|-------------------|-------------------|--------------------|---|--|------------------|---|--------------------|---------|----------------|
| 27 Sep. |           | Muroran City           | 3                 | 106.6             | 14.8               |   |  |                  |   |                    |         |                |
|         |           | Tomakomai City         | 5-                | 96.7              | 23.2               | Nothing   | Disrupted water supply at 16 households  | No damage        | Recover in 2 to 3 hours                                       |                    |         |                |
|         |           | Shizunai-Cho           | 6-                | 187               | 38                 |   |  |                  |   |                    |         |                |
|         |           | Mitsuishi-Cho          |                   | 166.1             | 20                 |   |  |                  |   |                    |         |                |
|         |           | Urakawa-Cho            | 6-                | 240.8             | 36.4               | 1 Complete Collapse House<br>2 Half Collapse House<br>1 Complete Collapse Warehouse | On 12:00 of 27th, water supply was disrupted at 3000 households  |                  | Recover by 9:00 of 26th                                       |                    |         | 59             |
| 28 Sep. |           | Obihiro Shi            | 5+                | 192.7             | 30.2               |   |  |                  |   |                    |         |                |
|         |           | Taiki-Cho              |                   | 366.27            | 74.1               | Nothing   |  |                  |   |                    |         |                |
|         |           | Hiroo-Cho              | 5+                | 972.8             | 46.1               |   |  |                  |   |                    |         |                |
|         |           | Toyokoro-Cho           | 6-                |                   |                    | 70 to 80 houses were damaged.   | At the point of interview (15:00 of 28th), water supply was disrupted at most of the households in the town. | No damage        | Recover by 10:15 of 26th                                      | at Port and School |         |                |
|         |           | Kushiro Shi            | 5+                | 407.2             | 37.9               |   | Disrupted water supply at 201 households. Recover in a day   | Recover in a day | Power failure at 9100 households for a time, Recover in a day | at Port            |         | 148            |
| 29 Sep. |           | Kushiro Cho            | 6-                |                   |                    | 2 Half Collapse   | Sewage system damage   |                  |   |                    |         | 18             |
| 30 Sep. |           | Kiyota-ku Sapporo City | 4                 |                   |                    |   |  |                  |   |                    |         |                |



### 3. Structures

#### <Taiki-cho, Hiroo-gun>

The Taiki-cho Town Hall is a 3-story steel frame structure, and has a 2-story observation penthouse on the top of the building (PHOTO 01 and PHOTO 02). Although the roof of the penthouse appears to be very heavy due to the weight of the parapet with perfect waterproofing, it is only marginally supported by four columns. The strength of the columns appears to be insufficient to support such a heavy roof against strong shaking.



The school is located near the town hall described above. Much damage was observed the exterior walls, windows and columns of the gym (PHOTO 03) and school building (PHOTO 04). The school had been assigned as an evacuation center. Further considerations would be necessary if people had to evacuate to such a highly vulnerable or damaged building.





### <Kushiro-cho, Kushiro-gun>

The Kushiro Town Hall was recently built. There was localized damage at the appentice for the entrance. It had been entirely removed already, when the team arrived there. (PHOTO 05, The photo is provided photo by the Kushiro Town Office)



### <Urakawa-cho, Urakawa-gun>

The Urakawa elementary school is a 3-story RC structure, and has an "L"-shaped plan (PHOTO 06). The expansion joints between the entrance building (PHOTO 07) and classroom building (PHOTO 08), and the column foundation of the entrance building (PHOTO 09) were damaged. Reportedly, the school lessons would begin on Monday 29 in the classroom without damage.





In Urakawa-cho, there were some structures which were completely or half collapsed.

#### <Kushiro-shi>

The ceiling of the Departure Lobby in the Kushiro Airport fell down (PHOTO 10 and PHOTO 11). The operations of the Kushiro Airport were interrupted almost for a day due to the restoration. The repair work was completed at 4:55 pm on Sep. 26, and the airport was reopened at that time. Thirty-two flights out of the 36 regular flights had been cancelled as a result.



Liquefaction was observed in the Kushiro Fishing Port. There is a building that is separated by expansion joints into two structures (PHOTO 12 and PHOTO 13). One of the two structures settled down about 45cm at maximum due to liquefaction (PHOTO 14). When we arrived there, the building was being used as usual, even though it was damaged.



**<Toyokoro-cho, Nakagawa-gun>**

The ground around a building in the Otsu Fishing Port settled down about 30cm due to liquefaction. We observed evidence that this building was inundated with Tsunami waves (PHOTO 15 and PHOTO 16).





#### <Kiyota-ku, Sapporo-shi>

Ground settlement (30-40cm) due to liquefaction was observed on the road in Utsukushigaoka, which continues over 30 to 40m. More than 5 houses had been tilted due to the differential settlement (PHOTO 17).



## 4. Industrial Facilities

#### <Tomakomai-shi>

At 4:52 am on Sep. 26, fire following the earthquake burned down a crude oil tank (32,778kl) in the Hokkaido Refinery in Tomakomai (Idemitsu Kosan Co. Ltd.). Simultaneously, oil leaked from the piping in the refinery, and resulted in a fire, which was brought under control at 12:09pm on September 26 (PHOTO 18). The roof type of the tank caused fire is called a "floating roof," whose steel roof is floating on the stored oil in the tank and moves up and down depending on the quantity of the oil. According to the Fire Department, a fire may have initiated due to "sloshing" actions of the floating roof. The roof swung together with the oil in the tank that was shaken by the earthquake ("sloshing"), and then the oil spilled out onto the roof. The fire ignited the oil due to the friction between the roof and sidewall of the tank.

A Naphtha tank (26,000kl) in the same refinery initiated a fire at 10:36 on September 28. The floating roof had been tilted due to sloshing and the oil had spilled on the roof. It is thought that the spilled oil on the roof had caught a fire for some reason.

It is reported that, in the refinery, there were about 90 oil tanks out of which oil spilled onto the floating roof due to "sloshing."



## 5. Infrastructure

### <Taiki-cho, Hiroo-gun>

The center of the Rekifune Bridge sagged about 120mm at the joint section, since the ground under the bridge pier was deformed (PHOTO 19 and PHOTO 20).



## 6. Port Facilities

### <Hiroo-cho, Hiroo-gun>

The lateral spreading of the ground soil (15cm in lateral and 15 to 20cm in vertical) caused severe damage such as cracking in the quay walls (PHOTO 21 and PHOTO 22).



### <Toyokoro-cho, Nakagawa-gun>

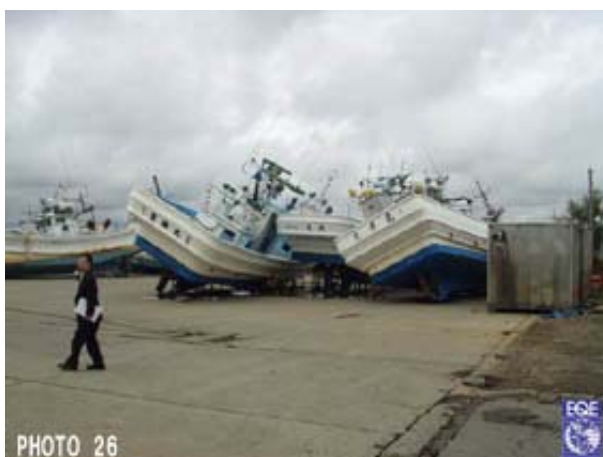
Movement of the quay walls was accompanied by lateral spreading of the ground soil (PHOTO 23). (20cm in lateral and 9-20cm in vertical)



There are many signs of boiling sand, indicating that liquefaction occurred in the port (PHOTO24 and PHOTO25).



Fishing boats were cast up onto the port by Tsunami (PHOTO 26). A large crane on the barge was hoisting these boat back into the sea (PHOTO 27).





### <Kushiro-shi>

The quay walls moved about 14cm laterally and 23cm in vertically due to liquefaction, and there are many signs of boiling sand in some places (PHOTO 28 and PHOTO 29). Due to the difference in the ground level caused by large-scale ground deformation, fork lifts were not able to be used at the ship-port interface during unloading from the ship. It significantly compromised the workability of the port.



## 7. Gravestones





### <Kushiro-cho, Kushiro-gun>

In general, there was no significant damage in the cemetery even where the intensity was 5+, since the gravestones in the surveyed area were anchored with sealing materials. In Shiundai Cemetery, however, there were some overturned or slid gravestones (PHOTO 30, PHOTO 31 and PHOTO 32).



### <Kushiro-shi>

The Itsukushima Shrine is located on the hill. One of the shrine gates at the foot of the hill overturned due to the earthquake shaking (PHOTO 33 and PHOTO 34). There was no damage to the shrine gate on the hill and the houses in the vicinity of the shrine (PHOTO 35).



## 8. Lifeline

### 8.1 Electric Power

High voltage electric cables and electric poles were significantly damaged in many places throughout Hokkaido. The #4 unit of the Tomato-Atsuma power plant was automatically shut down due to the strong shaking. As a result, no more than 370,000 houses across Hokkaido were temporarily blacked out. Most of them were recovered in several hours. According to the Hokkaido Electric Power Co., Inc. (HEPCO), the power supply in Hokkaido was completely recovered at 21:13 on September 26, after the restoration of the 53 houses in Toyokoro-cho. The major contributor to the power breakdown was the breaking of a power line, actuating automatic shutoff system of Tomashino-Atsuma power plant No.4. During the inspection, a number of power poles were observed to be tilted down in places (PHOTO 36). There was also a blackout in 1,340 houses in Inamura-mura, Aomori, and it was restored after one and a half hours.

In the Tomato-Atsuma power plant, problems were found in some devices during the

post-earthquake inspection. However, there was no heavy damage due to this earthquake. In the Tomari nuclear power plant, no damage has been reported so far. It was temporarily operated at low power of 55% right after the earthquake, and back to normal operation at 9:20 am on September 26.



## 8.2 Water System/Sewerage System

According to the Hokkaido prefecture government, water supply for 14 cities, 32 towns, and 2 villages (16,006 households) was cut off due to the electrical power failure or the pipe damage caused by ground deformation or liquefaction (PHOTO 37). Water contamination was also reported. As of 4:00 pm on the 28th of September, the water of 1640 households was cut off.

In the Shin-Toyo apartment block in Kushiro-cho, the pipes of the underground sewage system were floated up due to liquefaction, and outstanding manholes could be seen on the ground surface in many places (PHOTO 38). According to the Kushiro-cho office, such damage occurred along 80% of the overall piping length of 8km within the Shin-Toyo apartment block.



### **8.3 Gas**

Propane gas is used in most areas where strong ground shaking was recorded. According to the people in Toyokoro-cho, the shutoff device worked after the earthquake and the gas supply was temporarily cut off. The gas company staffs checked around each house and the gas supply was recovered soon. In Muroran-shi and Kushiro-shi, where city gas is supplied, no major damage was reported except the temporary interruption due to the seismic shutoff device.

### **8.4 Telecommunication**

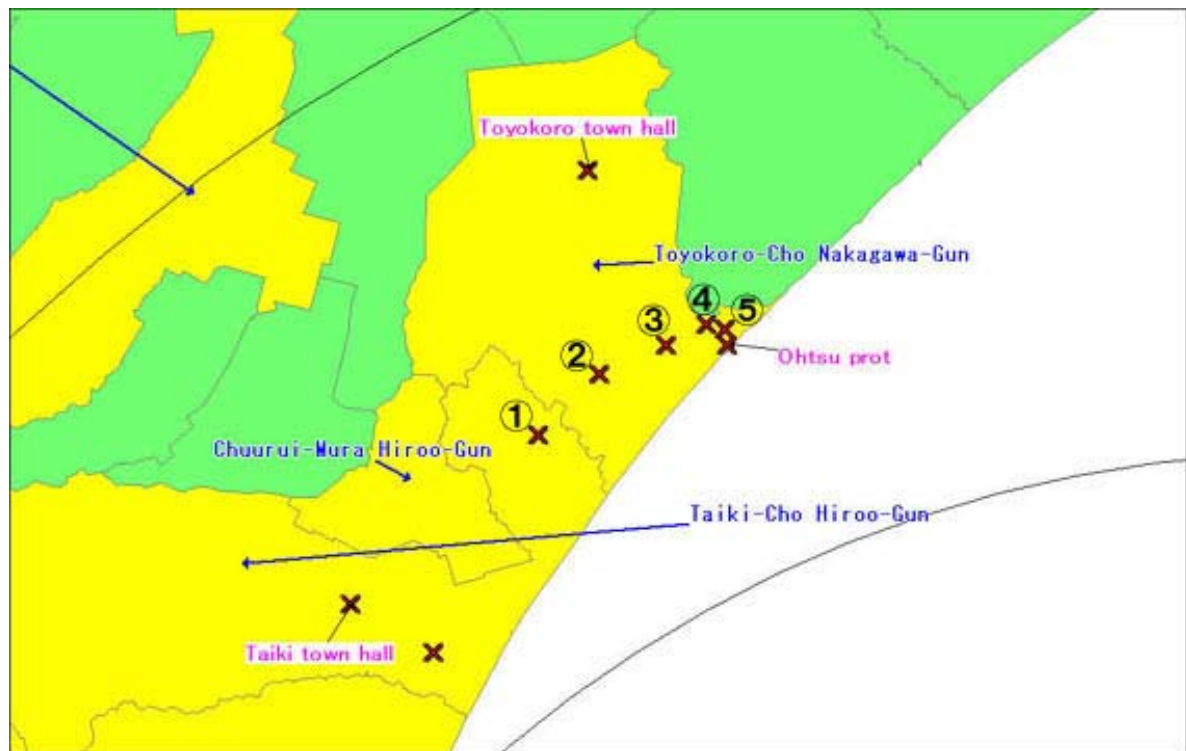
The cellular phone networks provided by two companies were not available until 7:00 pm on the 26th of September in some part of Mitsuishi-cho, since the backup power of the cellular phone station was shut down. No other major damage was reported.

### **8.5 Roads**

The earthquake caused ground rupture and settlement in the roads as well as the landslides, and traffic was closed or regulated in various regions. In Taiki-cho and Toyokoro-cho, circular slip occurred on Route 336 that runs through the slope, and the road moved 230mm horizontally and 170mm vertically at the location-1 in the figure below (PHOTO 39). Similarly, the slip recorded the horizontal and vertical movements of 700mm and 400mm respectively at the location-2 (PHOTO 40). At the location-3, on the same Route 336, there was ground settlement of 300mm supposedly along the underground wastewater piping (PHOTO 41). Ground settlement was also observed in another road running through the farmland due to the circular slide of the embankment (PHOTO 42).

The bank in the mouth of the Tokachi River was severely torn down (PHOTO 43 and PHOTO 44).







## 8.6 Railways

Almost a hundred damaged items (such as caved railways, bent rails and joint ruptures of the bridges) were reported throughout the railroads, and the railroad traffic was interrupted in many areas. The most significant damage was that the Express “Marimo” went off the rails near Naobetsu. There were some cracks caused by the earthquake in the concrete substructure at the railroad bridge near the Urakawa station (PHOTO 45 and PHOTO 46).



## **9. Conclusions**

### **1) Light structure damage**

In general, the structures performed well against strong shaking with light damage. This may be explained by several particular structural features in Hokkaido due to the cold weather and heavy snow:

- The roofs, where the snow falls and lies thick, are made of light and solid materials, such as steel plates and aluminum materials, in order to prevent freezing damage. This is also a good seismic design practice.
- The snow load is considered in the design loads for the roof. This also provides a good design margin as a result.
- In general, the foundation structure is embedded deep down below the ground surface in consideration of the freezing depth, which results in a stable foundation system.
- The wall opening such as a window is generally made smaller for thermal insulation, resulting in a good seismic performance with many walls.

### **2) Wide area of strong seismic intensities (5- and 6+)**

The huge earthquake magnitude (MJMA8.0) and the deep earthquake source (42km) resulted in a wide area of strong shaking intensities. The strong shaking was also observed in the Honshu Island, because of the activity of the volcanic mountains beneath the Hokkaido and Honshu.

### **3) Awareness and preparedness of the local communities**

The awareness and preparedness of the communities may have resulted in relatively slight damage without any death.

In the past decade, Hokkaido has been struck by several severe earthquakes, and also experienced significant Tsunami damage. Based on these experiences, the people in Hokkaido are highly aware of earthquake risk and well prepared for an earthquake. The local governments quickly guided the citizens for evacuation through the community wireless system, whenever a major earthquake that may cause Tsunami occurred, and provided the hazard maps and safety handbooks to them. There was an article saying that about 60% of the cities along the Pacific Ocean did not have any Tsunami hazard map. However, we found that every local government that we visited had made the hazard maps and delivered them to the citizens.

#### **4) Damage due to ground deformation**

Large-scale ground deformation was broadly observed from Obihiro to Kushiro. These significant lateral and vertical ground deformations interrupted the roads and caused severe damage in the piers of the bridges over the Tokachi River and the Rekifune River. The railways between Obihiro and Nemuro were also interrupted due to the damage caused the ground deformation. The interruption of the transportation system and the infrastructure severely impacted the daily life of the citizens.

#### **Acknowledgment**

We would like to thank all the local government staffs that we have visited for their kind and polite response to our inquiry, even though they were in the midst of the recovery work. We would also like to note that we use the information acquired from the K-net in this report, and express appreciation for it.