# Large ground deformations caused by the 2018 Hokkaido Eastern Iburi Earthquake

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Key Facts
- Hazard Type: Earthquake
- Date of disaster: Sept. 6th , 2018
- Location of Survey: Iburi and Sapporo, Hokkaido, Japan
- Date of the field survey: Oct. 9th to 10th, 2018
- Survey tools: GPS receivers and a laser ranger
- Key findings:
  1) Morphological features of a landslide mass north of Atsuma Town suggested that the activated frictional coefficient beneath this landslide mass was only 0.054 as much.
  2) Locations of the widespread liquefaction in residential areas of Sapporo's Kiyota Ward were found almost exclusively along old streams that ever existed there.

***Key Words :*** *Hokkaido Eastern Iburi Earthquake, volcanic ash and pumice, landslides, liquefaction*

## 1. INTRODUCTION

A $M_w$ 6.6 earthquake rocked the northern Japanese island of Hokkaido on September 6, 2018 at 3:08 a.m. JST. The Japan Meteorological Agency (JMA) has given it an official name "the 2018 Hokkaido Eastern Iburi Earthquake". The earthquake occurred just one day after the edge of a powerful typhoon Jebi left traces of destruction in the region. The intense tremor triggered more than 3,300 landslides confirmed over an about 20 km × 20 km area near Atsuma Town[1)], wiping out homes sparsely distributed along foots of mountains. There have been total 41 confirmed deaths that include 36 suffocated after being buried in landslide masses or crushed under falling houses in Atsuma[2)].

This calamity can largely be attributed to the geological features of the region. As shown in many reports of geological surveys, the region is covered thick with volcanic ash and crushable pumice from nearby volcano erruptions of Shikotsu (about 40,000 years ago)[3)], Eniwa (about 20,000 years ago)[4)] and Tarumae (about 9,000 years ago)[5)]. This report outlines some remarkable features of large ground deformations that appeared in this earthquake.


**Fig. 1** Aerial photograph of Atsuma north area (Sept. 6, 2018, with the map square grid 500 m on each side on Zone 12 of the Japan rectangular plane, contour lines from the digital surface model from Geospatial Information Authority, Japan on October 1, 2016).

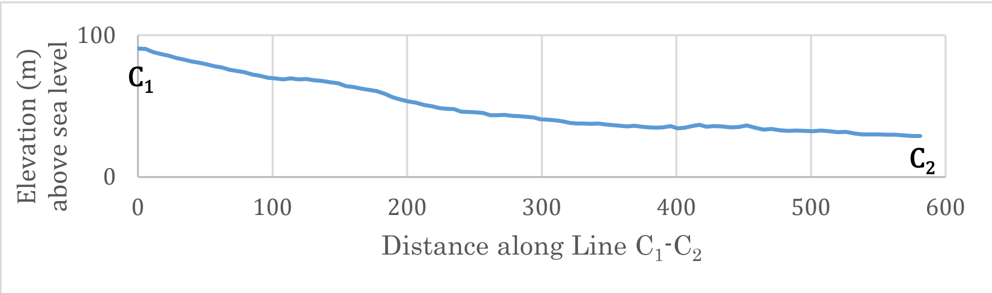


**Fig. 2** Cross-section of the slope along Line $C_1$-$C_2$ in Fig. 1: The digital terrain model was prepared by the Geospatial Information Authority, Japan on October 1, 2016. Locations of C1 and C2 are (N42.7518°, E141.8603°) and (N42.7538°, E141.8668°), respectively.

## 2. LANDSLIDES ALONG PREFECTURAL ROUTE NO. 10

The central part of the prefectural road No. 10 connecting Hayakita area of Abira Town and Atsuma Town goes through hilly terrain with low altitudes of about 100 to 150 m at highest. Hill slopes along this road are typically very gentle as shown in Fig. 1. The digital terrain model (DTM), which was used to prepare Fig. 1, was made by the Geospatial Information Authority of Japan (GSI, hereafter) on Oct. 1, 2016 before the area was severely shaken by the earthquake. It is therefore to be noted that the contour lines do not describe any morphological change caused by this earthquake. An aerial photograph of this area, which was also taken by GSI on September 6, 2018, was georeferenced and laid over the DTM with the recognized landslide traces marked with polygons of red broken lines. Landslide masses detached from hill slopes have traveled some ten to hundred meters long on gentle slopes and along existing shallow valleys. The cross-section $C_1$-$C_2$ in Fig. 1 along a shallow valley bottom is shown in Fig. 2. This cross-section shows that the landslide mass that have blocked the prefectural road No. 10 traveled along this extremely gentle valley with the average inclination of about 0.106, indicating that the mobilized frictional coefficient could have been as large as or smaller than this value, 0.106, with its toe part pressed against the opposite hill side. However, the scenario for the movement of this landslide mass is not that simple in that several soil masses detached from different locations on both walls of this valley have accumulated along the valley, and the toe part of the landslide mass may largely be from the nearest valley wall.

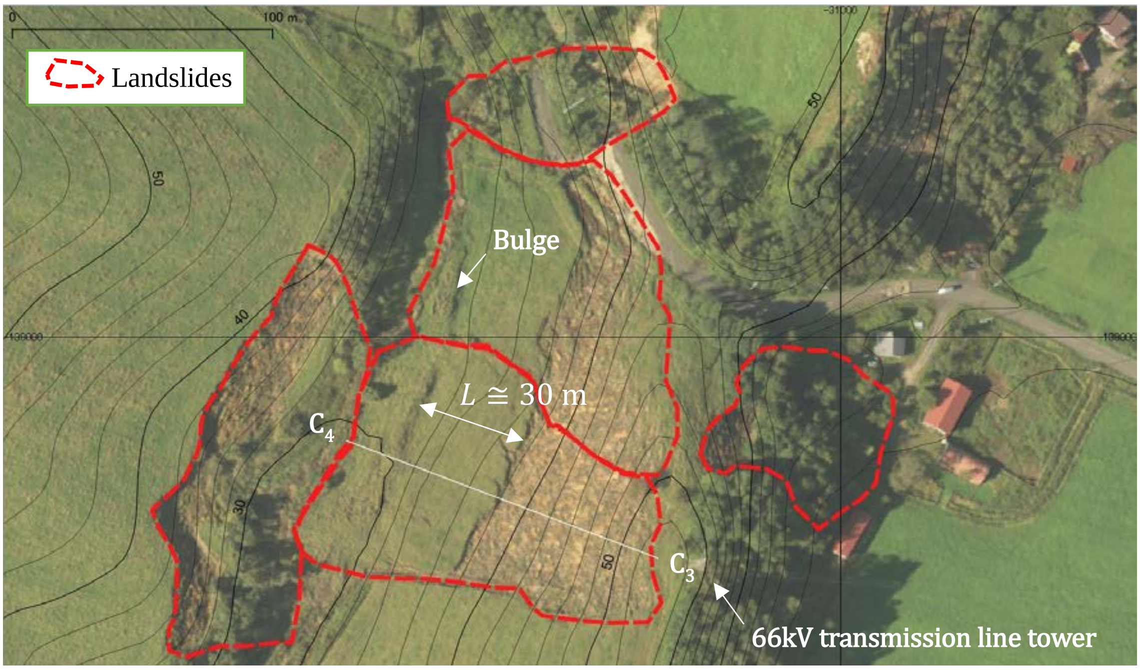


**Fig. 3** Coherent landslide mass compressed against the other side wall of valley

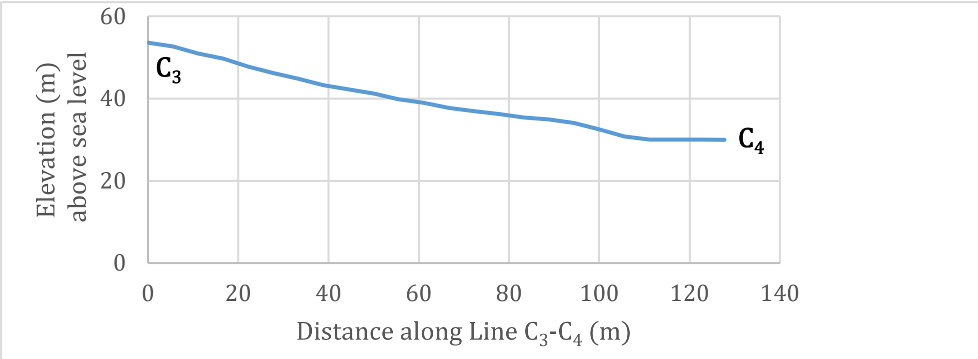


**Fig. 4** Cross-section of the slope along Line $C_3$-$C_4$ in Fig. 1: The digital terrain model was prepared by the Geospatial Information Authority, Japan on October 1, 2016. Locations of C3 and C4 are (N42.75636°, E 141.8704°) and (N 42.7568°, E 141.8690°), respectively.

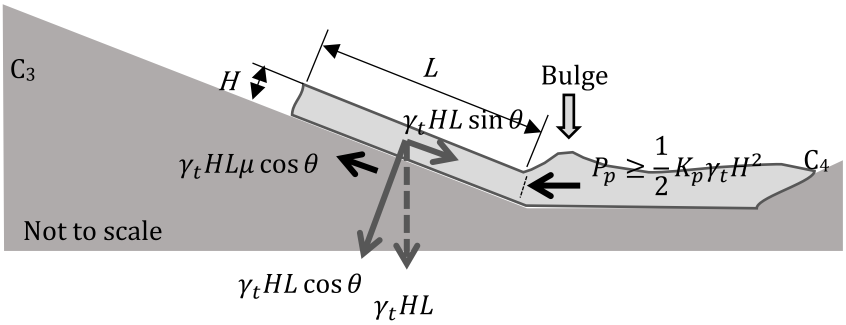


**Fig. 5** Cross-section of landslide mass that has stopped moving being compressed against the other side wall of valley (not to scale)

To examine the mobilized frictional coefficient in a more careful manner, the movement of a single planar and coherent landslide mass that has slid along Line $C_3$-$C_4$ (Figs. 1 and 3) is discussed herein. This planar landslide mass, after sliding on the very gentle slope with the average inclination of about 0.2 (Fig. 4), hit the opposite wall of the shallow valley and stopped forming a transverse bulge as illustrated in Fig. 5. This bulge is assumed to have developed where two-dimensional wedges of passive soil failure formed one after another at the boundary between the toe part pressed against the opposite valley wall and the slowing tail part with the uniform thickness $H$ as illustrated in Fig. 5. This tail part was gradually shortening until its final length of $L$ was reached.

Equation (1) shows the final equilibrium condition immediately before the final length $L$ of the tail part is reached:

$$(\gamma_t HL \sin\theta - \gamma_t HL\mu \cos\theta)\cos\theta \geq \frac{1}{2}K_p\gamma_t H^2 \quad (1)$$

where, an inequal sign is necessary because the bulge

**Fig. 6** Slightly exposed foundations of a 66kV transmission line tower
(Photo taken at N42.7563, E141.8704 near Point $C_3$ on Oct. 10, 2018 by Kazuo Konagai)

worked as a surcharge, $\gamma_t =$ unit weight of the wet landslide mass, and $K_p =$ coefficient of passive earth pressure, which is given by:

$$K_p = \tan^2\left(\frac{\pi}{4} + \frac{\phi}{2}\right) \tag{2}$$

with $\phi =$ internal friction angle of the landslide mass. Internal friction angle for the volcanic ash and pumice in Atsuma area have been examined by several researchers (Kitago et al., 1973[6]), Yagi et al., 2003[7]), etc). They have reported that values of $\phi$ for the samples they have taken from Atsuma and Monbetsu areas ranged from 42 to 48° under low effective confining pressures. Assuming that $\phi \cong 45°$, $H \cong 1.5$ m and $L \cong 30$ m for the Line $C_1$-$C_2$, $\cos\theta \cong 1$ and $\sin\theta \cong \theta$ given that $\theta \cong 0.2$, one obtains;

$$\begin{aligned} \mu &\leq \theta - \frac{1}{2} K_p \frac{H}{L} \\ &= 0.2 - \frac{5.83 \times 1.5}{2 \times 30} \cong 0.054 \end{aligned} \tag{3}$$

There are still much to examine to be sure, but this value suggests that the sliding surface beneath the landslide mass must have been very slippery like a banana peel. This landslide mass seems to have detached from the very top end of the slope just next to a 66kV transmission line tower. Though the both sides of this hill ridge have slid as shown in Fig. 3, the tower escaped from being taken away, though its foundations were exposed a little (Fig. 6).

## 3. LIQUEFACTION IN RESIDENTIAL AREA IN KIYOTA, SAPPORO

The intense shake of this earthquake has caused road subsidence in Sapporo's Kiyota Ward in association with tilts of many houses. Some cars were seen stuck in liquefied soil covering thick the sunken roads. These locations were found almost exclusively along old streams that underlie modern-era roads and were cutting the terrace of volcanic ash and clay 10 to 20 m down to lower elevations. These small valleys were filled with soils cut from the nearby terraces in the residential development from 1978 to 1980. Fig. 7 shows the change in elevation of the residential area. To make this map, a 1:25,000 scale terrain map of 1919 was first digitized, and then subtracted from the digital terrain model of Oct. 1, 2016. The severest swath of damage to houses associated with remarakable road subsidence was seen in the boxed area in Fig. 7. A pair of aerial photographs for this area shown in Fig. 8 were taken on September 13, 2018 by the GSI[8]). These photographs put side by side can be perceived as a single image in terms of depth by cross-eye viewing. Immediately east next to the park shown in the upper parts of these photos, water is seen stopped indicating that this is a part of the swath of ground subsidence (Fig. 9). The lower (eastern) parts of the photos show that muddy mixture covers a large portion of streets.

The swath continued further up along the old valleys as shown in Fig. 10 though the subsidence was getting less serious. Curiously enough, these swaths of ground subsidence are much narrower than widths of these old valleys. The swaths may have appeared above channels/ cavities that have developed underground through the filling of earthen material.

The name of "Kiyota" appeared over and over in reports of past earthquakes in Hokkaido that include the 1968 Earthquake off the Coast of Tokachi (May 16, 1968, $M_{JMA}$ 7.9), the 2003 Earthquake off the Coast of Tokachi (Sept. 26, 2003, $M_w$ 8.0) and an even much smaller and shallow earthquake of M4.6, which occurred on Dec. 2, 2010 immediately beneath Kiyota Ward and triggered landslides in a nearby golf course[9]). This fact may imply the difficult nature of the subsurface soil to deal with in the suburban development. In the 1968 Earthquake off the Coast of

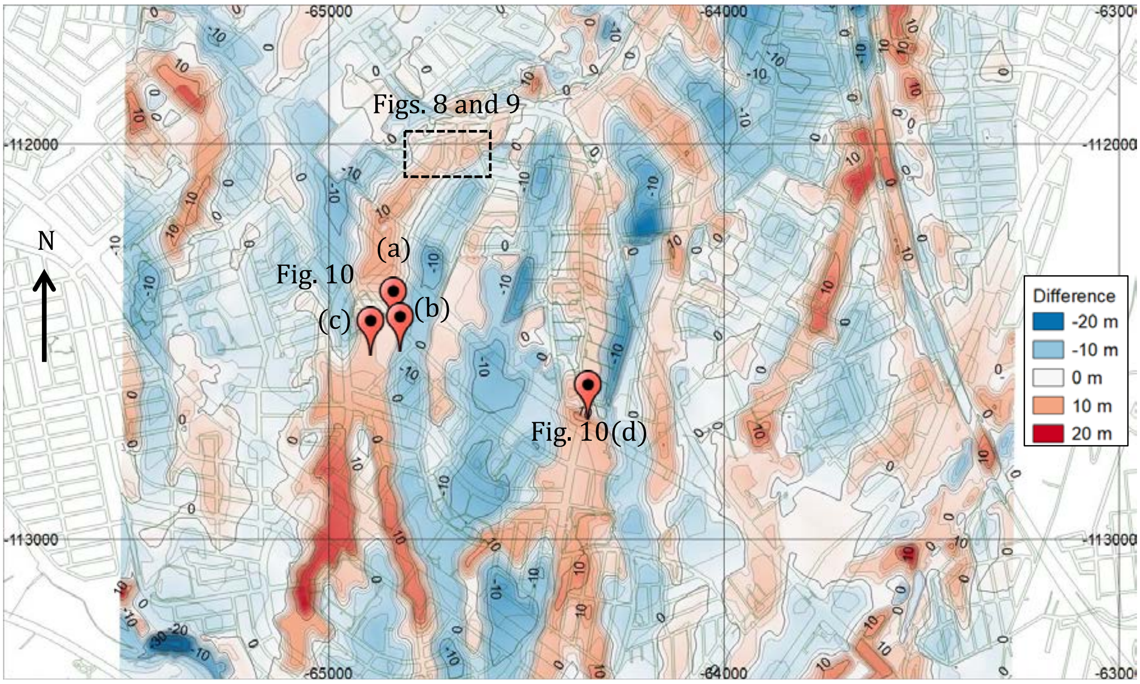


**Fig. 7** Change in elevation due to cut-and-fill: A 1:25,000 scale terrain map of 1919 was digitized, and subtracted from the digital terrain model of Oct. 1, 2016 (Zone 12 of the Japan rectangular plane). Damage to houses and ground subsidence were extremely serious in the broken-line boxed area.


**Fig. 8** A pair of aerial photographs of ground depression, Kiyota area, Sapporo: Photos were taken on September 13, 2018 by the Geospatial Information Agency, Japan.

Tokachi, the thorough cut-and-fill work of the area had not yet started, and the surface geological map shown in the general damage report of this earthquake (Fig. 11)[10] says that there were pumice-rich pyroclastic flow deposits and welded tuff exposed on the bottom of these valleys, which are now beneath filling earthen material. It is not clear yet how these soils (and maybe underground conduits

**Fig. 9** Swath of ground subsidence in the boxed area in Fig. 7 (Photo taken on Oct. 8, 2018 at N42.9890°, E141.4555° by Daiki Kodama)


**Fig. 10** Sunken roads in Sapporo's Kiyota Ward (Photos taken on Oct. 10, 2018 by Kazuo Konagai)

and pipes) interacted to cause the ground subsidence. In-depth investigations and analyses are to be done quickly.

## 4. SUMMARY

One of unique aspects of the damage caused by the 2018 Hokkaido Eastern Iburi Earthquake is that many of the calamities that took place in the landslide-prone hilly/mountainous areas and serious destructions in suburban areas of Sapporo can largely be attributed to the geologic features of the region, which is covered thick with crushable pumice and volcanic ash from erupptions of Shikotsu (about 40,000 years ago)[3], Eniwa (about 20,000 years ago)[4] and Tarumae (about 9,000 years ago)[5].

A planar and coherent landslide mass that has slipped on a gentle slope north of Atsuma Town suggested that the activated frictional coefficient beneath this landslide mass was only 0.054 as much, though there are still much to examine to discuss the slippery nature of the soil on surer grounds.

Locations of the widespread liquefaction in residential areas of Kiyota Ward were found almost exclusively along old streams that ever existed there, indicating that the liquefaction may have been caused by the use of volcanic ash-derived soil as filling earthen material. It is to be noted that the name of "Kiyota" appeared over and over in reports of past earthquakes in Hokkaido, and this fact may imply the

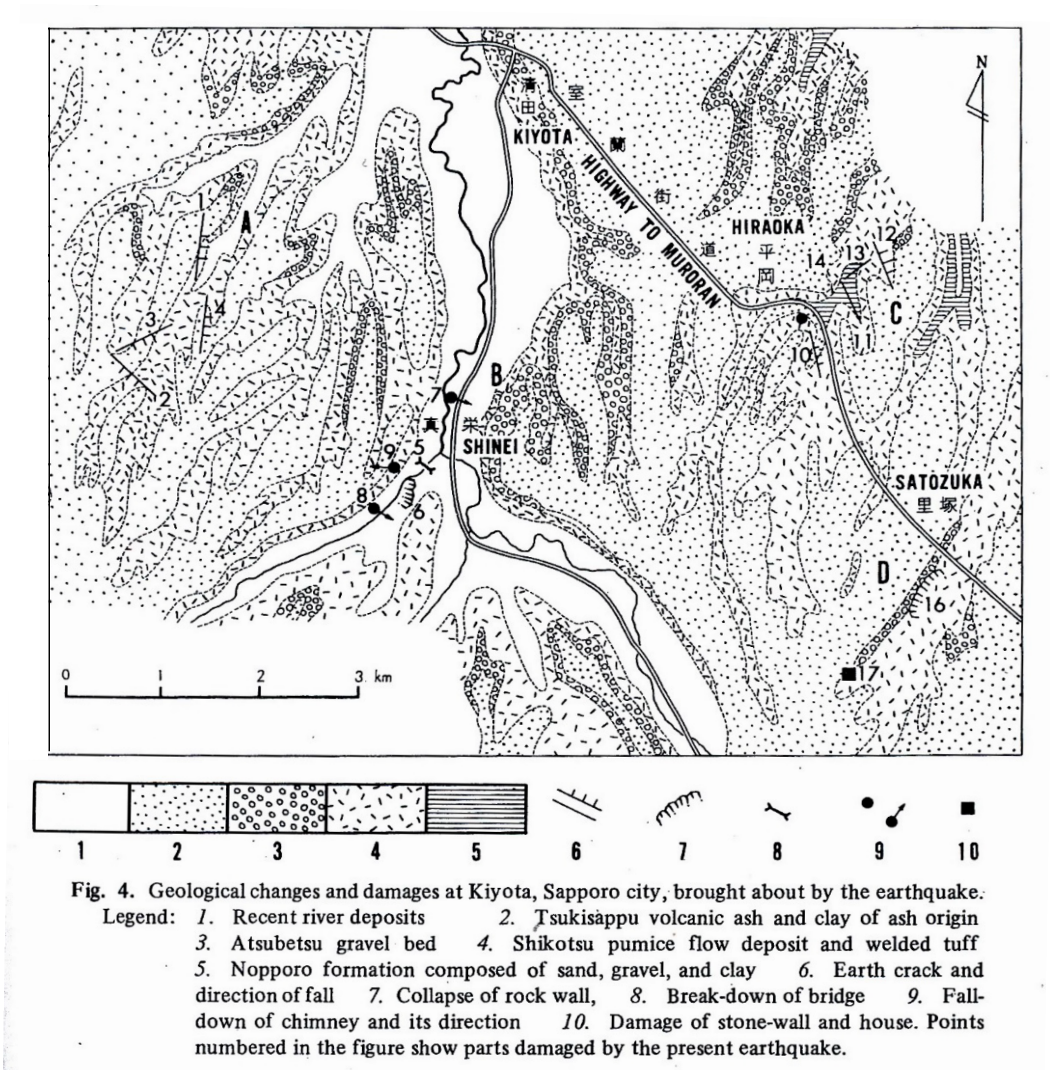


**Fig. 11** Locations of geotechnical disasters in Kiyota ward in the 1968 Tokachi-Oki Earthquake: The figure above is from the General Report on the Tokachi-Oki Eathquake of 1968[7]. When this earthquake occurred, cut-and-fill works had not yet started. This figure suggests that the landfills along valleys in this area underlay Shikotsu pumice flow deposits.

difficult nature of the subsurface soil to deal with in the suburban development. In-depth investigations and analyses are to be done quickly.

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