Down-hole seismometer arrays near liquefied Tokyo Bay Area and Landslides in the Upper-stream Reach of Abukuma River

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1. Overview

Underground motions within a hard diluvial stratum were obtained at Toyocho (35.669286,139.812055) and Shinkiba (35.645681,139.824562). Observations at both sites have started in 1976 in commission from Tokyo Metro Subway. They are the closest to the Tokyo Bay Area, which has suffered serious liquefactions in the March 11th 2011 quake.

Fig. 1 Locations of seismometers and times of landfilling (after “the history of Tokyo Port, MLIT”[1)])

1.1 Toyocho site

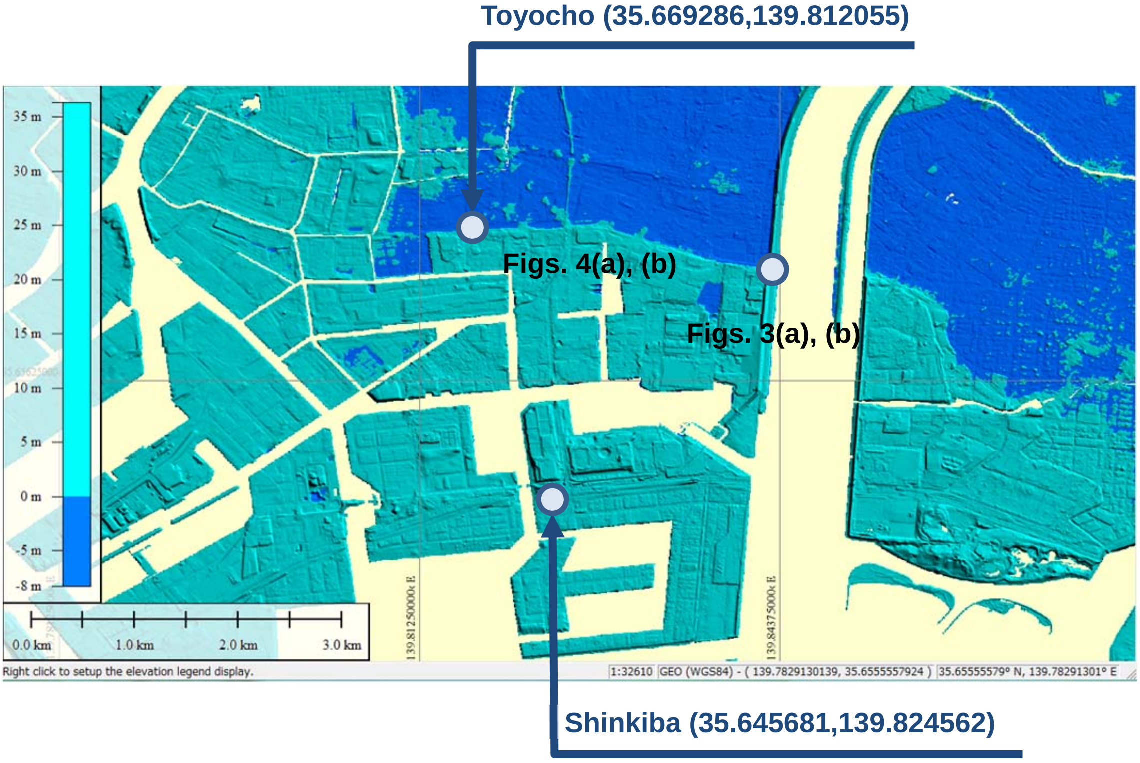


Fig. 2 Locations of seismometers: Blue area north behind coastal landfills are below sea level. (after Digital Map 5m-grid, Geospatial Information Authority of Japan[2)])

Fig. 3(a) Upstream view of low-lying area near Arakawa Bridge of the subway Tozai line (35.665856,139.842868, Location is shown in Fig. 2): The area has been suffering from a serious land subsidence problem.

Fig. 3(b) Tsunami marks along the right bank of Arakawa River
（Photo taken at 17:30, 2011/04/10, at 35.665856,139.842868）

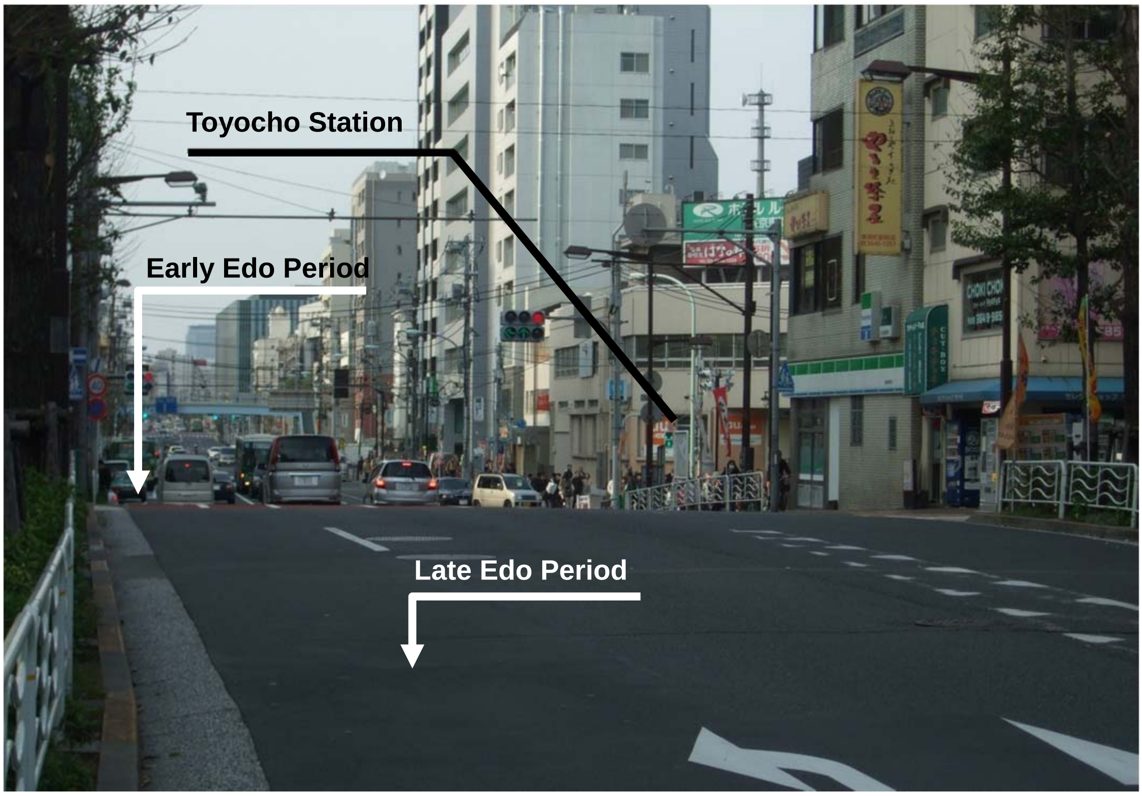


Fig.4(a) Sudden elevation change shows the presence of boundary between earlier landfill (the other side), and later landfill. (35.668763,139.816437)

Fig. 4(b) Raised entrance of Toyocho Subway Station at 35.669469,139.816766: The entrance has a watertight door.

A 124km^2 area behind the sea-frontal reclaimed lands had been suffering from serious ground subsidence due to overuse of ground water and gas. Subsidence finally stopped immediately after a set of lows for limiting excessive use of underground water was enacted in 1970th. However, the area remained several meters below sea level without any clear sign of rebound and thus a serious concern of inhabitants of the area. This earthquake with its epicenter 380km northeast of Tokyo has caused little damage to the low-lying areas. it was fortunate that no damage to river and sea banks, drainage pump stations was reported. However there were clear marks of tsunami surge along river banks (see Fig. 3b), and inhabitants need to remain careful for a possible near-field earthquake.

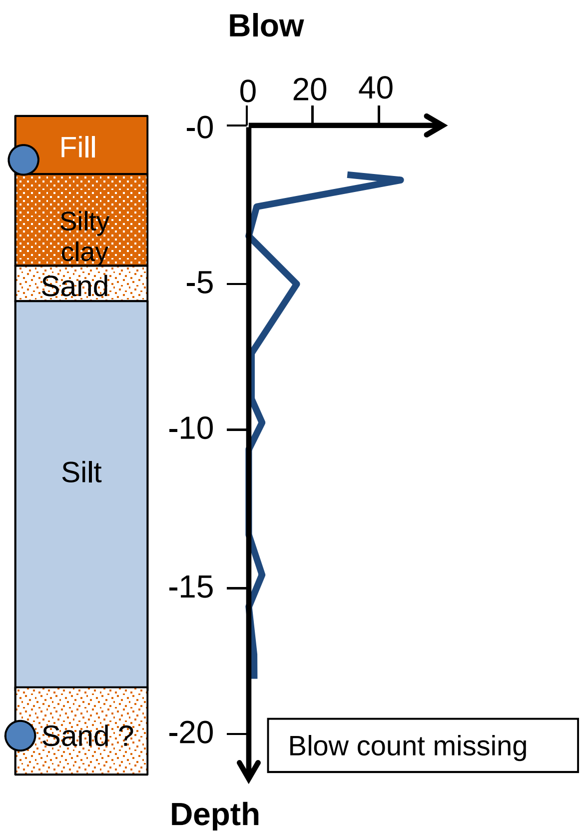


Fig. 5 Soil profile at Toyocho site and locations of seismometers (dark-blue circles)

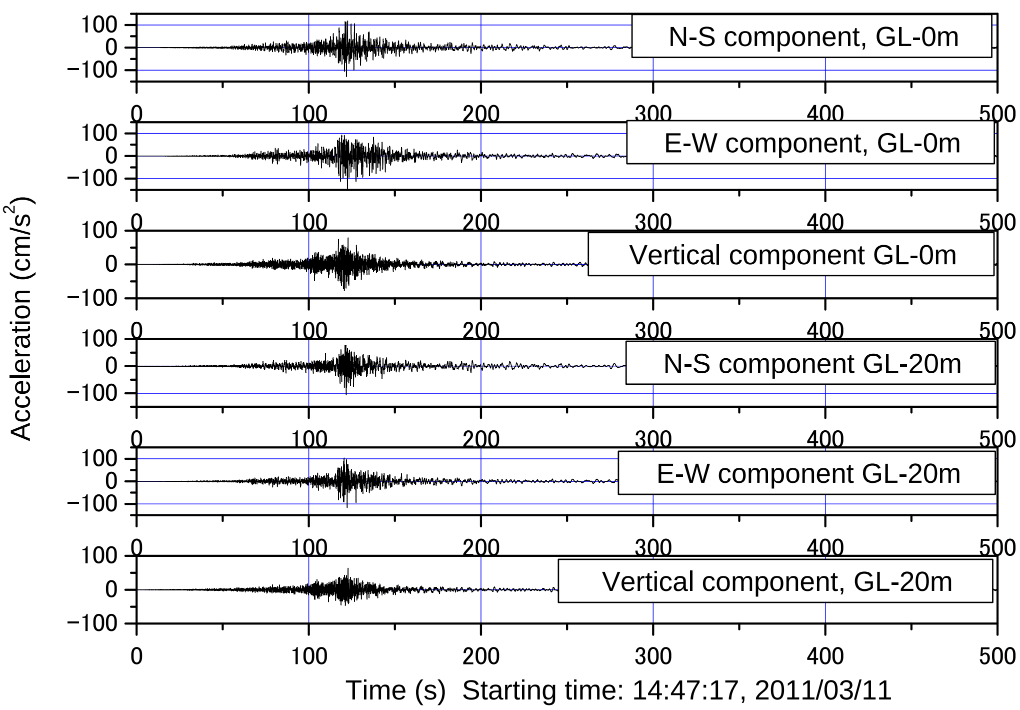
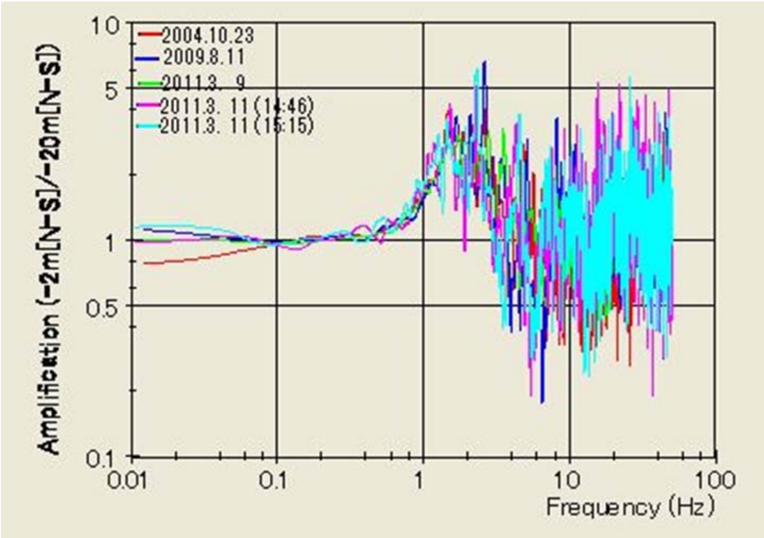
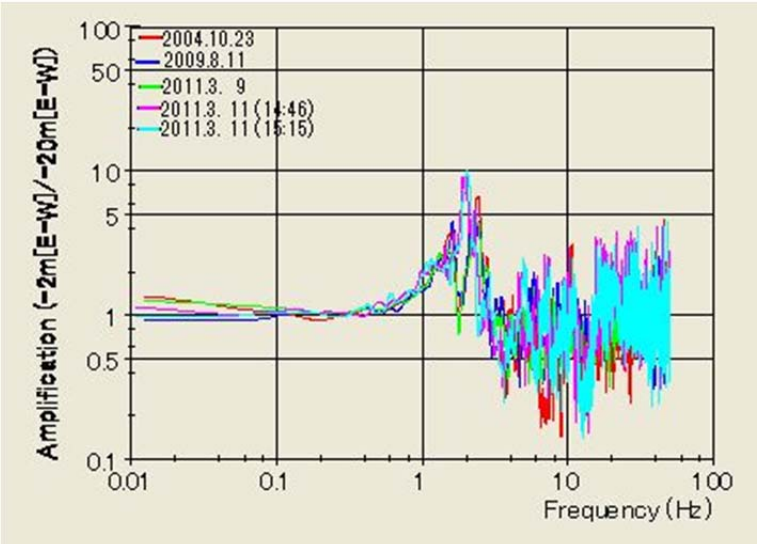


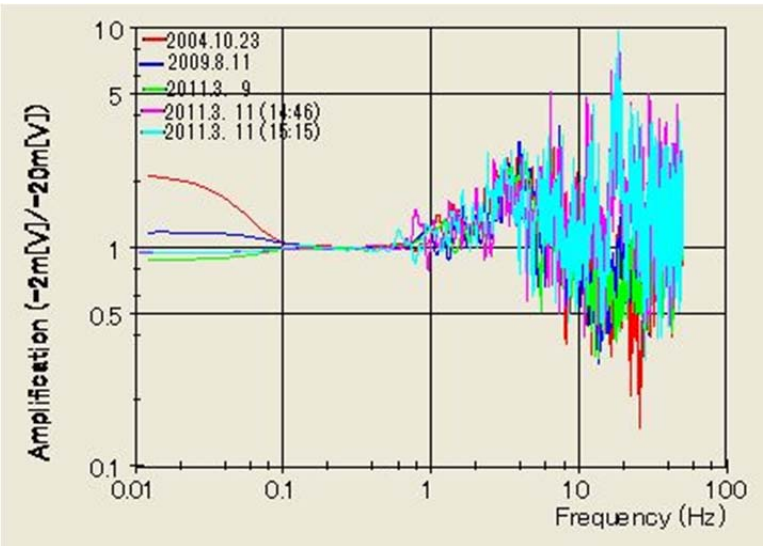
Fig. 6 Accelerograms st Toyocho from the main event (Unit: cm/s^2)
-20m (NS: 116.7, EW 63.7, UD: 80.2), -0m (NS: 128.7, EW 155.5, UD: 77.7)
Note that PGAs appeared about a minute after the first arrival of S wave. The duration of the strong ground motion was very long.



In NS direction



In EW direction



in UD direction

Fig. 7. Frequency-domain amplifications for 6 major ground motions observed at Toyocho: The first peak appears at around 1,7Hz and 5Hz for lateral and vertical motions, respectively and there is no clear difference among 6 records including the one from the March 11th quake.

1.2 Shinkiba site

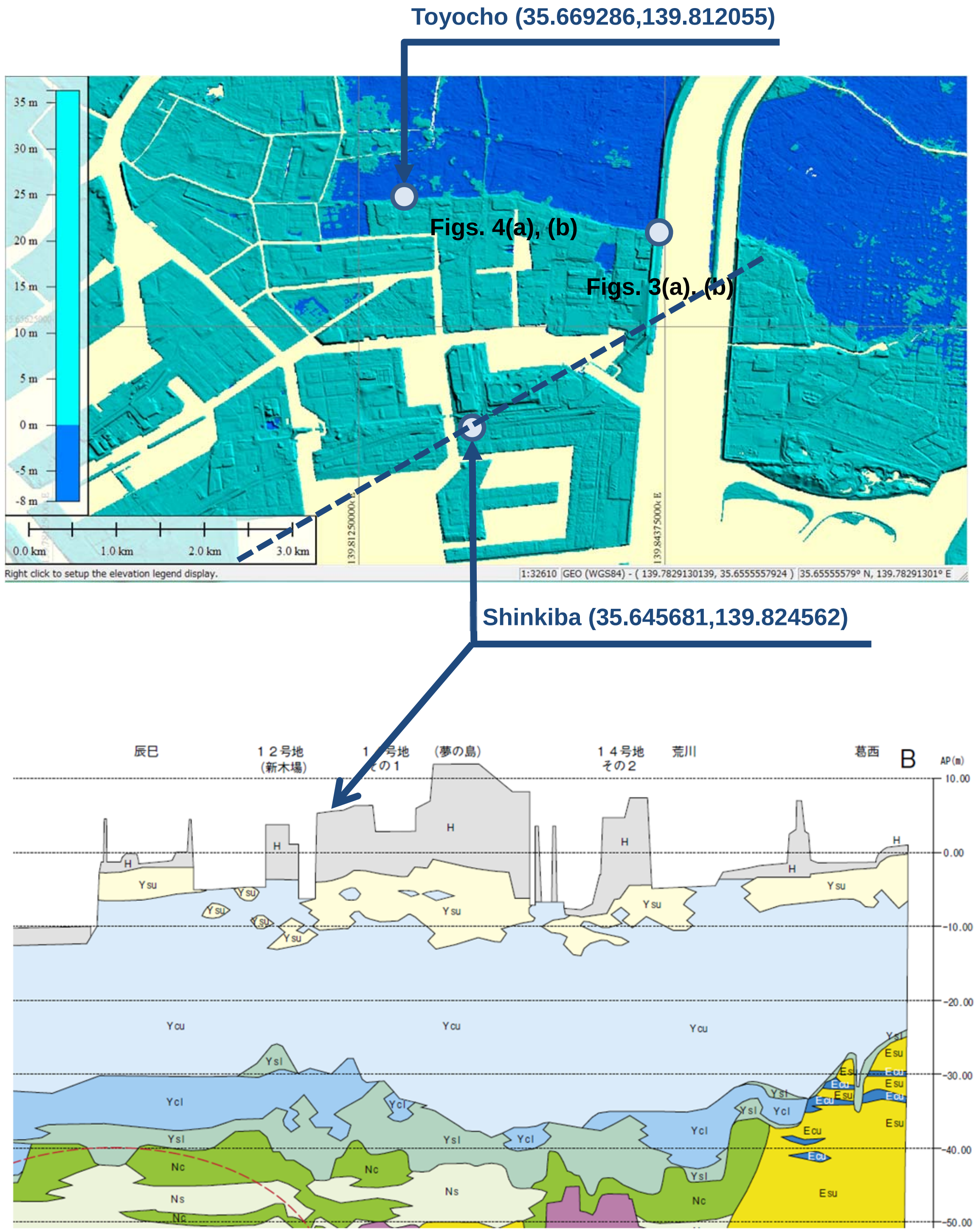


Fig. 8. Locations of seismometers and soil profile at Shinkiba (Soil profile after Technical Note No. 37, Tokyo Geotechnical Consultant Association[3]) Soils from the top follow: H= landfill, Y_{su}=sand, Ycu=Clay (upper Yurakucho layer), Y_{cl}= Clay (Lower Yurakucho layer), Y_{sl} =sand (Lower Yurakucho layer), N_c, N_s= Sand and clay from late Pleistocene epoch spreading above diluvial sandy and gravely layer of Tokyo. Seismometers are located at -2m and -76m.

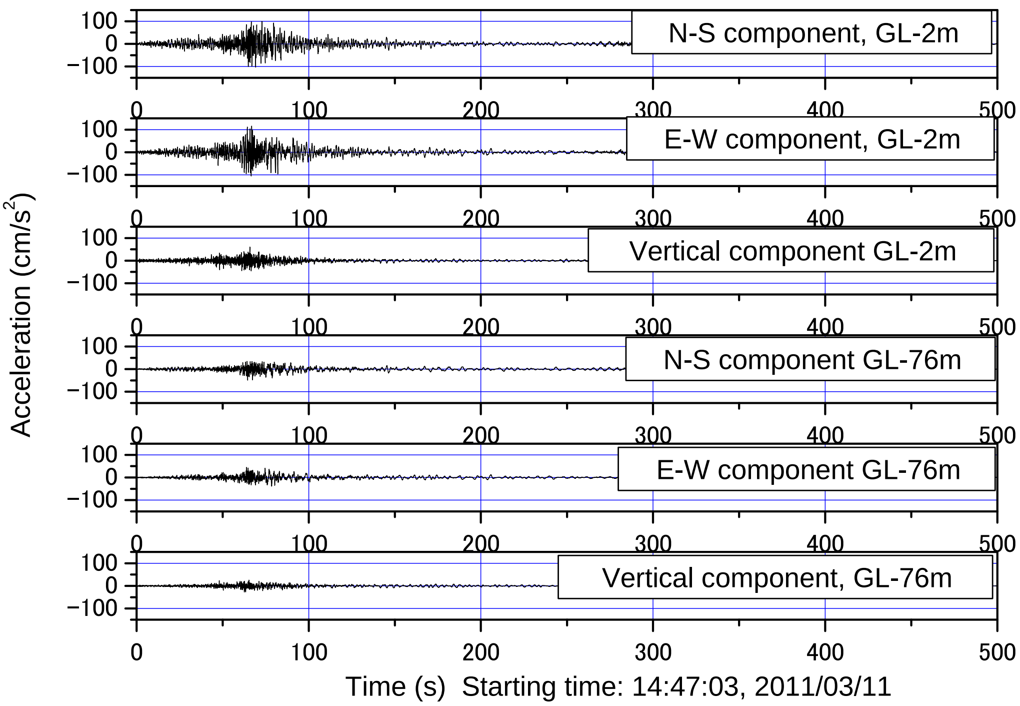
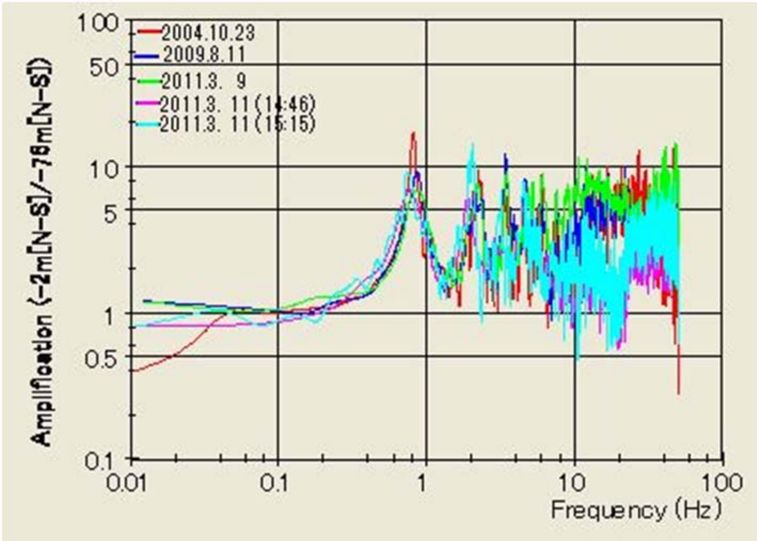
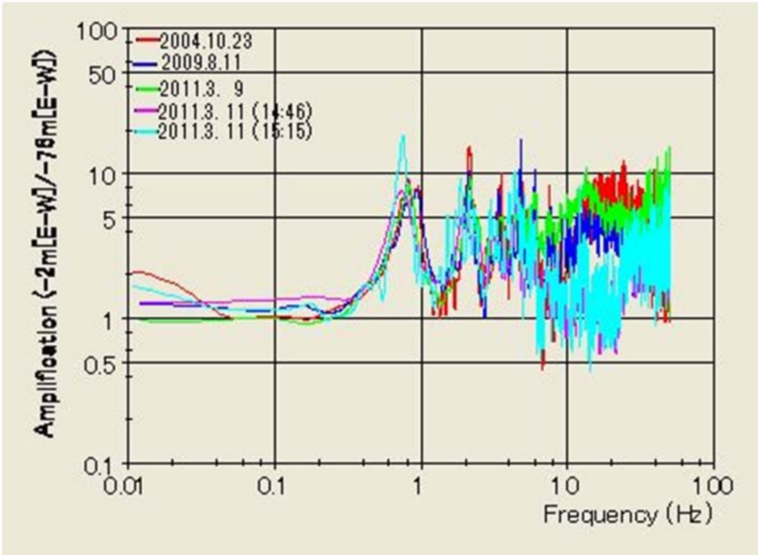


Fig. 9 Accelerograms at Shinkiba from main event (Unit: cm/s^2)
-76m (NS: 48.6, EW 44.8, UD: 27.3), -2m (NS: 102.7, EW 115.7, UD: 60.4), No clear sign of cyclic mobility though liquefactions were found near the station (see the photo below).

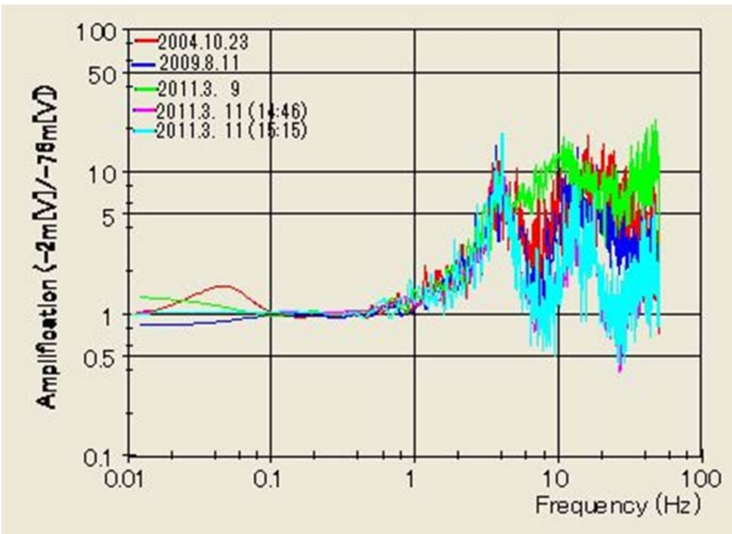
Fig. 10 Liquefied sand near Shinkiba subway station (photo on 2011/03/15 by T. Kiyota. Location: 35.644812,139.828148）



In NS direction



In EW direction

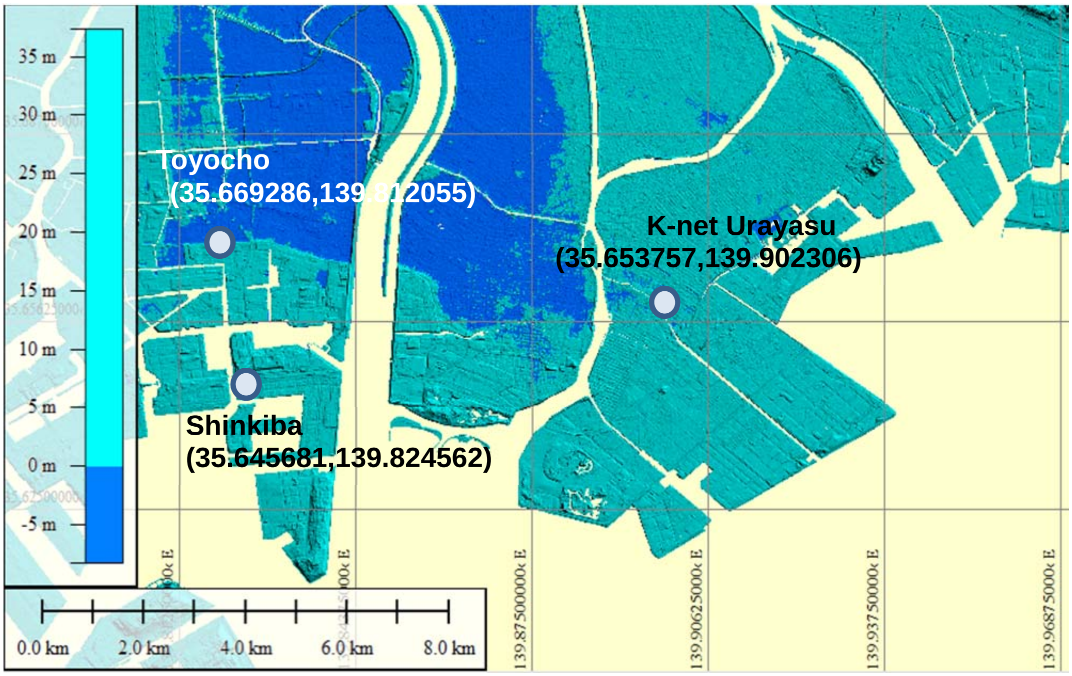


In UD direction

Fig. 11. Frequency-domain amplifications for 6 major ground motions observed at Shinkiba: The first peak appears at around 0,8Hz and 4Hz for lateral and vertical motions, respectively. Differing from those at Toyocho (Fig. 7), amplification curves for the March 11th quake and its aftershock at 15:15 on the same day deviate from the others as the frequency increases above 4 to 5 Hz.

Liquefactions in Tokyo Bay Area

Remarkable liquefactions were found in Maihama and Urayasu areas about 6km east of Shinkiba.



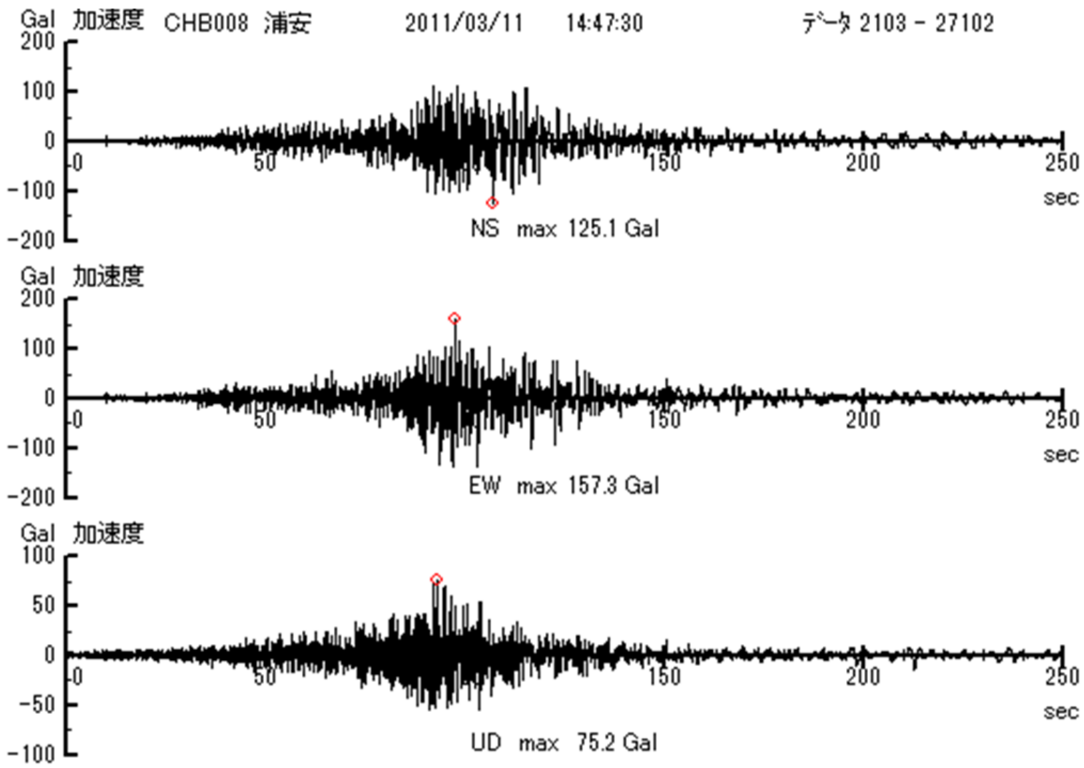


図 12 Recorded time histories of acceleration at K-net Urayasu (CHB008, 35.653757,139.902306)[4]: When compared with those from surface sesmographs at Shinkiba and Toyocho, they are all similar with each other in terms of PGAs and duration times.

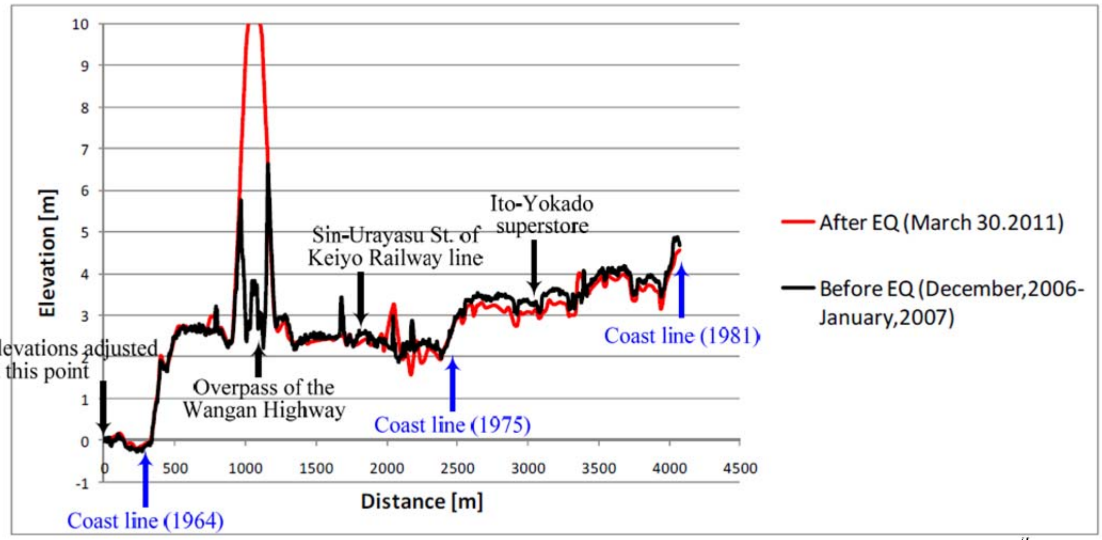


図 13 Elevations along Line-01 in Urayasu city before and after the quake of March 11th 2011

A dual-frequency DGPS survey was conducted on March 30, 2011 in Urayashu Coastal Area. Two lines (Line-01.kmz and Line-02.kmz) were taken. Elevations along Line-01 (Fig. 13(a)) were compared with those from a 1m-resolution DEM for the same area (December 2006 to January 2006).

Some points with GDOP values larger than 3, representing lower GPS positional precision, were discarded, and yet there are some points of low positional precision. Moreover the earthquake have caused serious nation-wide misalignments of triangulation points. Therefore, the figures are just a rough-and-ready indication of subsidence.

Fig. 13(b) shows the stepped configuration along Line-01 indicating there have been twice large landfilling activities since 1964. It may be premature, before taking many lines, to say something with confidence from this figure but some noticeable subsidence (about 0.3 to

0.4m) can be seen within an about 1km wide brush along the boundary between the first and second landfills. This wide brush may extend in east-west direction as shown in both Fig. 14(a) and 14(b).

Fig. 14(a) Locations of temporary water supply valves[5)]
Blue place marks: Temporary water supply valves, Colored areas: purple= it will take a long time to restore water supply systems, orange= water supply restored, red= sewage system cannot be used (as of April 10th, 2011).

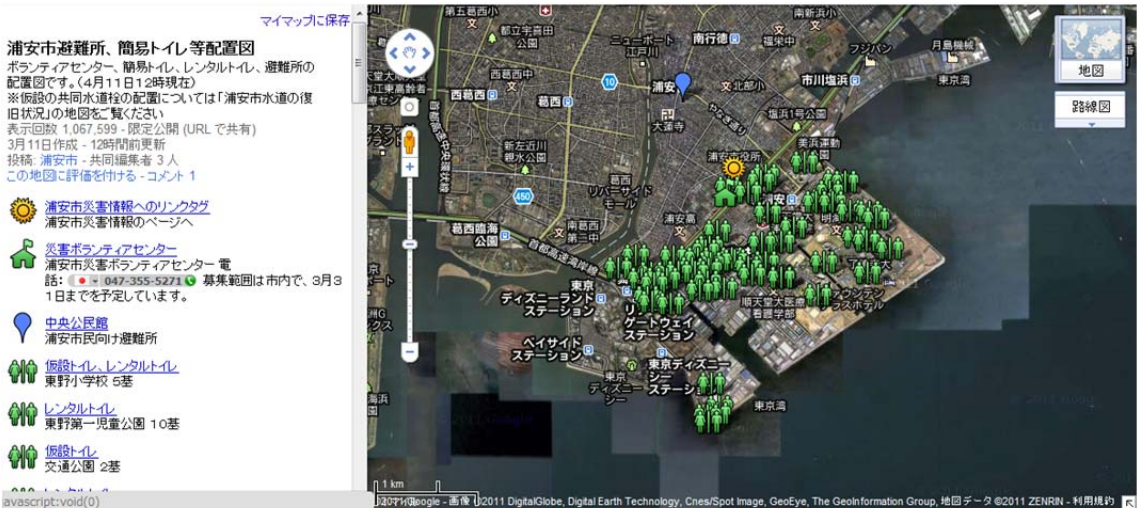


Fig. 14(b) Locations of temporary toilets as of April 11th 2011. (Urayasu City)[6)]

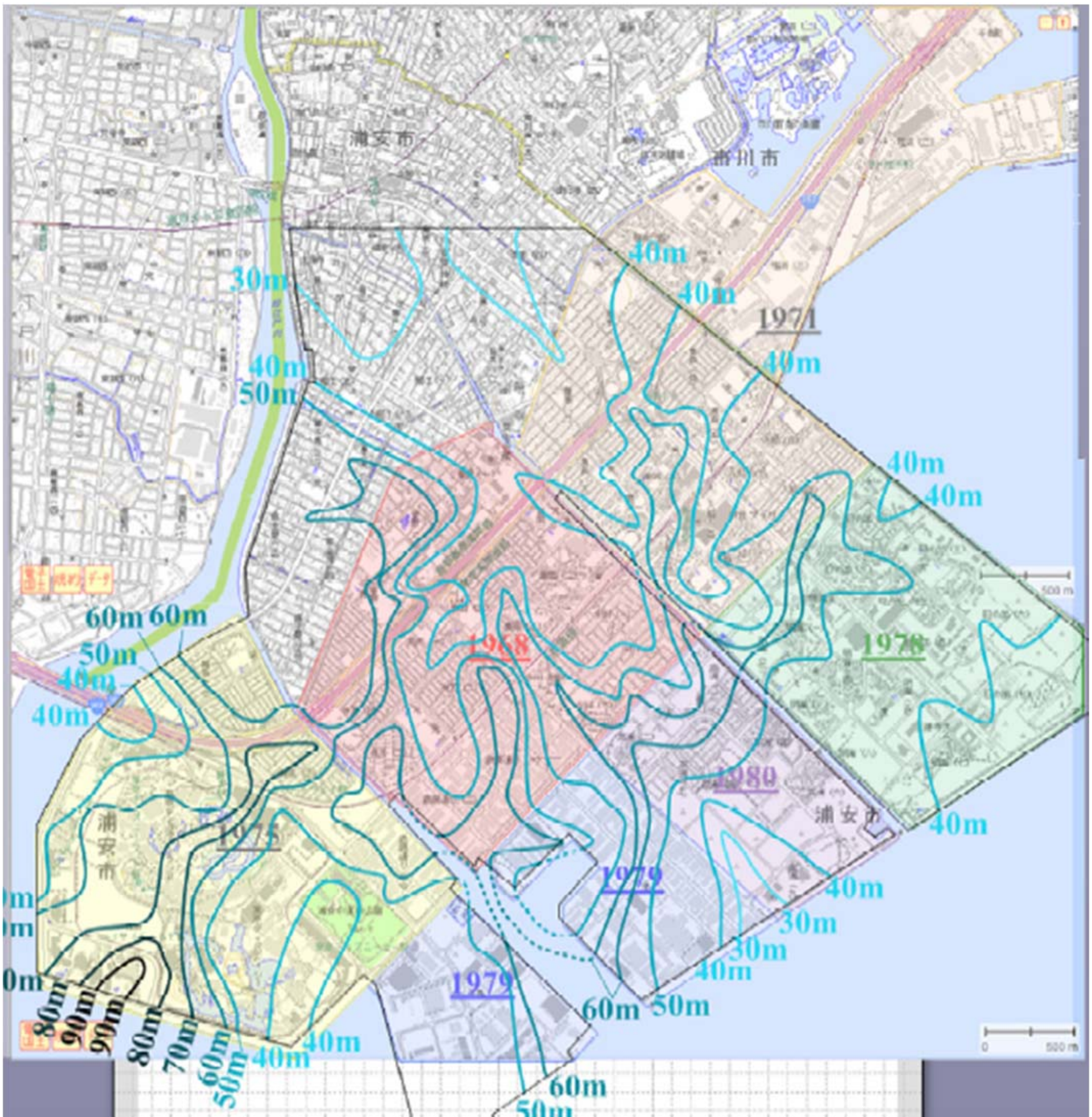
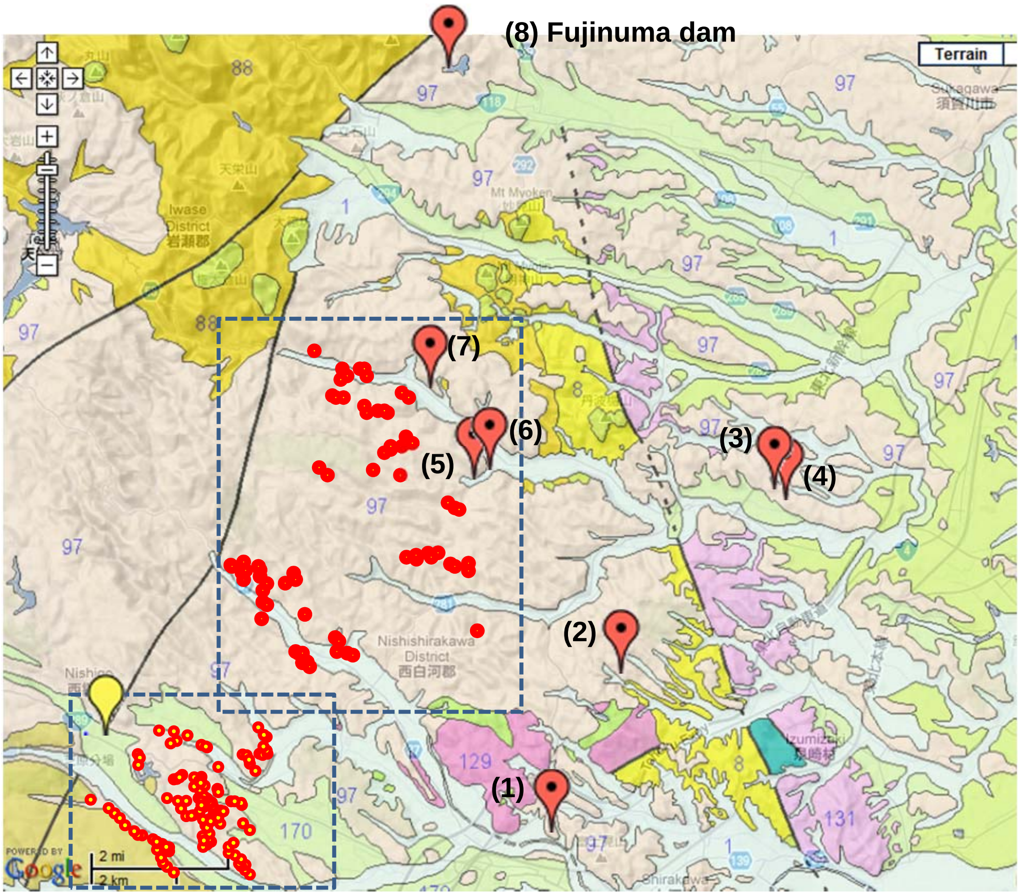


Fig. 15 Depths of diluvial sandy/ gravely stratum (Urayasu City)[7)]: Wide brushes of serious liquefaction (soil subsidence) seem to be found where the diluvial stratum is deep.

3. Landslides in Shirakawa city

Landslide problems are hard to spot in the shadows of those for tsunami and the Fukushima Daiichi nuclear power plant. However not a few people have been killed by landslides in the upper stream reach of Abukuma River. Back in Aug. 27, 1998, this area, an upstream reach of Abukuma River, was ravaged by a torrential rain. The rain was reportedly responsible for more than 1000 slope failures in this 10km-by-10km area of low-raised mountain terrain (see red circles in this figure). They are mostly found in Early Pleistocene non-alkaline pyroclastic flow volcanic rocks.



Kik net NJSHIGO (37.1585, 140.0963)

Slope failures caused by the EQ of March 11th 2011.

Slope failures caused by the heavy rain of Aug. 27th 1998 (after Inokuchi[8])

97 Early Pleistocene non-alkaline pyroclastic flow volcanic rocks

78: Late Miocene to Holocene volcanic debris
97: Early Pleistocene non-alkaline pyroclastic flow volcanic rocks

Fig. 16 Distribution of earthquake-inflicted landslides in the upper stream reach of Abukuma River, north of Shirakawa City, Fukushima Prefecture. (after "Seamless Geological Map of Japan"[9])

Fig. 17 Landslide #1 in Fig. 16: 13 people were killed in the debris. Exposed slip surface; 110m wide, 205m long, 31m high. Location of Photo point: 37.138253,140.217605

Fig. 18 Landslide #2 in Fig. 16. Soil mass slid around the south mouth of a Shinkansen railway tunnel. 50m wide, 300m long, 60m high. Photo location: 37.174611,140.238848

Fig. 19 Landslide #3 in Fig. 16. 60m wide, 99m long, 15.6m high. Photo location: 37.213788,140.276721

Fig. 20 Rock fall #7 in Fig. 16. Photo location: 37.230448,140.185461

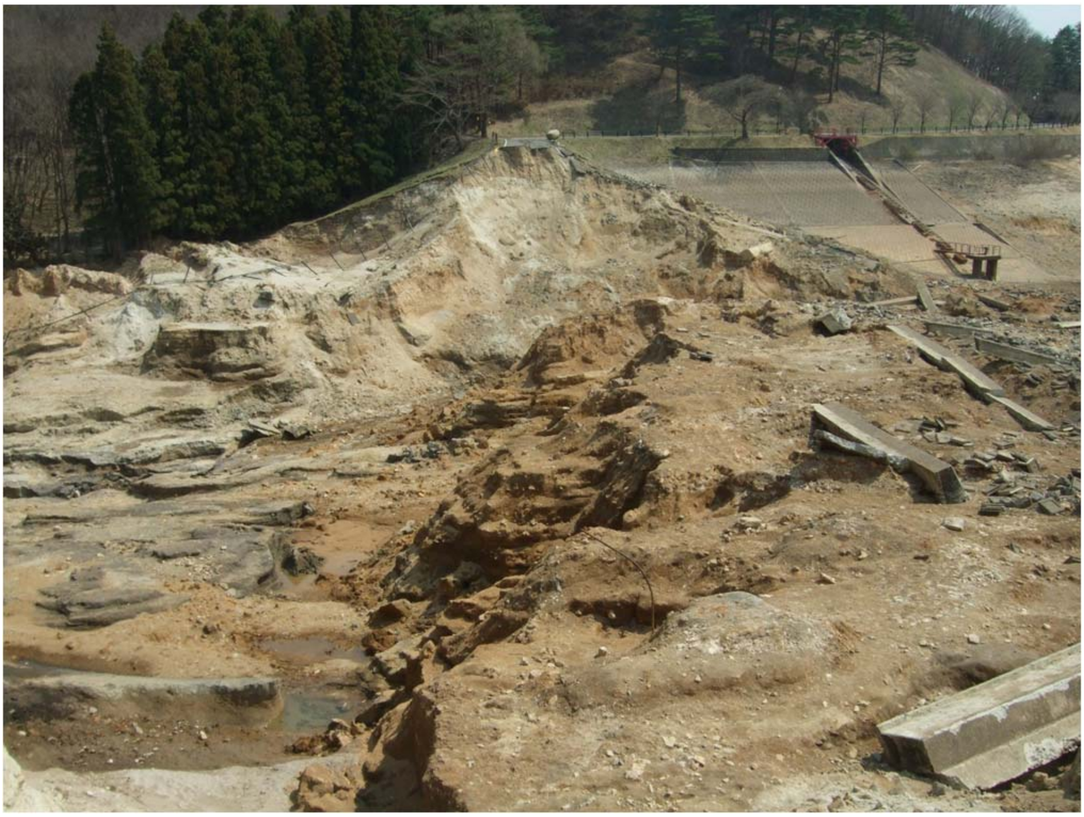
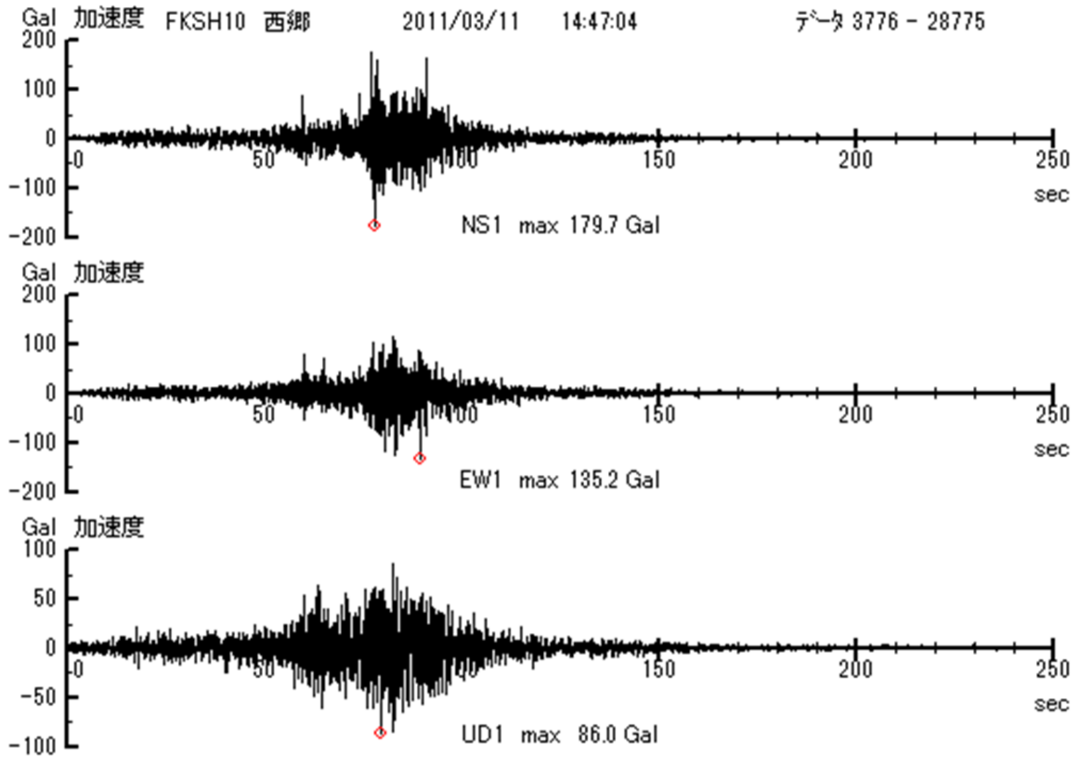
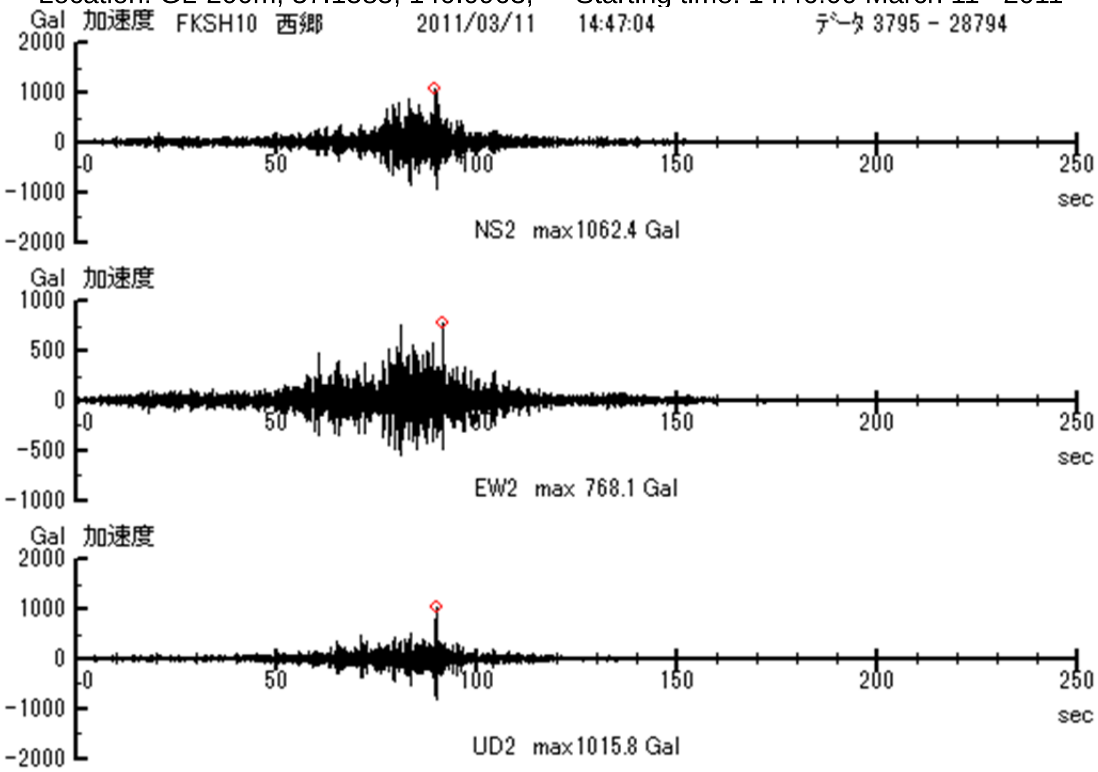


Fig. 21 Breached Fujinuma Dam (Placemark #8 in Fig. 16). Photos above and below show respectively breached dam body from left and right abutments. There is a subsided/slid soil mass of the upstream slope spreading over the lake bottom; the slide may have been followed by the subsidence of the entire dam body and thus water-overtopping.



Location: GL-200m, 37.1585, 140.0963, Starting time: 14:46:00 March 11th 2011



Location: GL-0m, 37.1585, 140.0963, Starting time: 14:46:00 March 11th 2011

Fig. 22 Time histories of acceleration at Kik-net Nishigo (37.1585, 140.0963). See yellow place mark on Fig. 16.

4. Summary

Underground motions within a hard diluvial stratum were obtained at Toyocho (35.669286,139.812055) and Shinkiba (35.645681,139.824562); both are down-hole observation sites near the Tokyo Bay area which suffered liquefactions in the March 11th 2011 quake.

1. At Toyocho site, there was no clear difference in terms of the frequency-domain amplifications among 6 records including the one from the March 11th quake. No serious damage was reportedly found in the vicinity of the site, which area remained several meters below sea level due to the overuse of underground water and gas until 1970's and thus has been a serious concern of inhabitants of the area.
2. At Shinkiba site, frequency-domain amplifications for 6 major ground motions show the first peak appearing at around 0,8Hz and 4Hz for lateral and vertical motions, respectively. Differing from those at Toyocho, amplification curves for the March 11th quake and its aftershock at 15:15 on the same day deviate from the others as the frequency increases above 4 to 5 Hz. Liquefactions were found around the observation site.
3. At Shin-urayasu area, Liquefactions were serious. The result of a dual-frequency DGPS survey, which was conducted on March 30, 2011, showed some noticeable subsidence (about 0.3 to 0.4m) within an about 1km wide brush along the boundary between the first and second landfills. This wide brush may extend in east-west direction.
4. Not a few people have been killed by landslides in the upper stream reach of Abukuma River. Back in Aug. 27, 1998, this area, an upstream reach of Abukuma River, was ravaged by a torrential rain. The rain was reportedly responsible for more than 1000 slope failures in this 10km-by-10km area of low-raised mountain terrain. Both landslides induced by the March 11th 2011 Earthquake and the heavy rain in 1998 are mostly found in Early Pleistocene non-alkaline pyroclastic flow volcanic rocks.

References:

1) "History of Tokyo Port, Ministry of Land, Infrastructure and Transport. http://www.pa.ktr.mlit.go.jp/tokyo/rekishi/pdf/e-do01.pdf.
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3) Tokyo Bay, Technical Note No. 37, Tokyo Geotechnical Consultant Association http://www.tokyo-geo.or.jp/html/frameset3.htm
4) digital strong-motion seismograph (KiK-net), http://www.kik.bosai.go.jp/kik/index_en.shtml.
5) Locations of temporary water supply valves, http://maps.google.com/maps/ms?ie=UTF8&oe=UTF8&msa=0&msid=203270978399365323165.00049eac879db30aab2c7
6) Locations of temporary toilets as of April 11th 2011, Urayasu City, http://maps.google.co.jp/maps/ms?ie=UTF8&brcurrent=3,0x34674e0fd77f192f:0xf54275d47c665244,1&hl=ja&msa=0&msid=203270978399365323165.00049e42f95b035ea5d4c&ll=35.660783,139.911232&spn=0.07908,0.132008&z=13&iwloc=00049e438ab7f56e5205f
7) Depths of diluvial sandy/ gravely stratum (Urayasu City), http://www.city.urayasu.chiba.jp/menu3185.html
8) Takashi Inokuchi (1998): Report on the Landslide Disaster in the Upper Part of the Abukuma River, Fukushima Prefecture due to Heavy Rainfall in August 1998, National Institute of Earth Science and Disaster Prevention, http://dil.bosai.go.jp/library/pub/natural_disaster/natural_disaster.htm.
9) Seamless Geological Map of Japan, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, http://riodb02.ibase.aist.go.jp/db084/maps.html