DOWN-HOLE SEISMOMETER ARRAYS NEAR LIQUEFIED TOKYO BAY AREA

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ABSTRACT: The East Japan earthquake on Mach 11th, 2011 was responsible for extensive damage to not only the Tohoku-Pacific coast region but also south Kanto region including Tokyo Bay area. Tokyo Bay area, especially Urayasu city, has suffered serious ground liquefaction. The authors have been conducting down-hole seismometer array observations in commission from Tokyo Metro Subway, and seismic records were obtained at two observatories, which eventually turned to be the closest to the liquefied Tokyo Bay area. This report introduces these records and the ground subsidence in Urayasu, observed through Differential GPS surveys.

Key Words: East Japan earthquake, Liquefaction, Down-hole seismometer arrays,

INTRODUCTION

The first author's laboratory has started observing seismic motions at several down-hole seismometer arrays since 1976 in commission from Tokyo Metro Subway, and underground motions were obtained at Toyocho (35.669286,139.812055) and Shinkiba (35.645681,139.824562), which arrays eventually turned to be the closest to the liquefied Tokyo Bay area, because Kik-net, Nationwide seismic observation network operated by the National Institute of Earth Science and Disaster Prevention (NIED) had no down-hole record available near the Tokyo Bay Area. This report briefly summarizes the observed underground motions and findings obtained through the authors' reconnaissance in the Tokyo bay area, highlighting liquefaction-induced ground subsidence in Urayasu.

AROUND TOKYO BAY AREA

Figure 1 shows locations of seismometers at Toyocho and Shinkiba, and times of landfilling. 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 Figure 3(b)), and inhabitants need to remain careful for a possible near-field earthquake.

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Figure 1 Locations of seismometers and times of landfilling (after “the history of Tokyo Port, MLIT”)

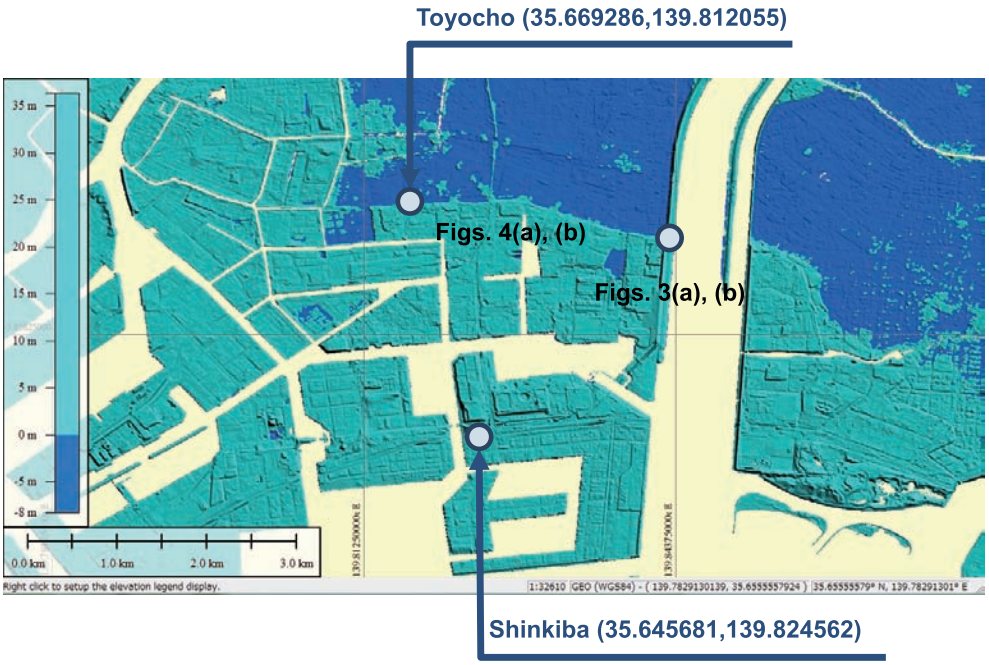


Figure 2　Locations of seismometers: Blue area north behind coastal landfills are below sea level.

Figure 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.

Figure 3(b) Tsunami marks along the right bank of Arakawa River

(Photo taken at 17:30, 2011/04/10, at 35.665856, 139.842868)

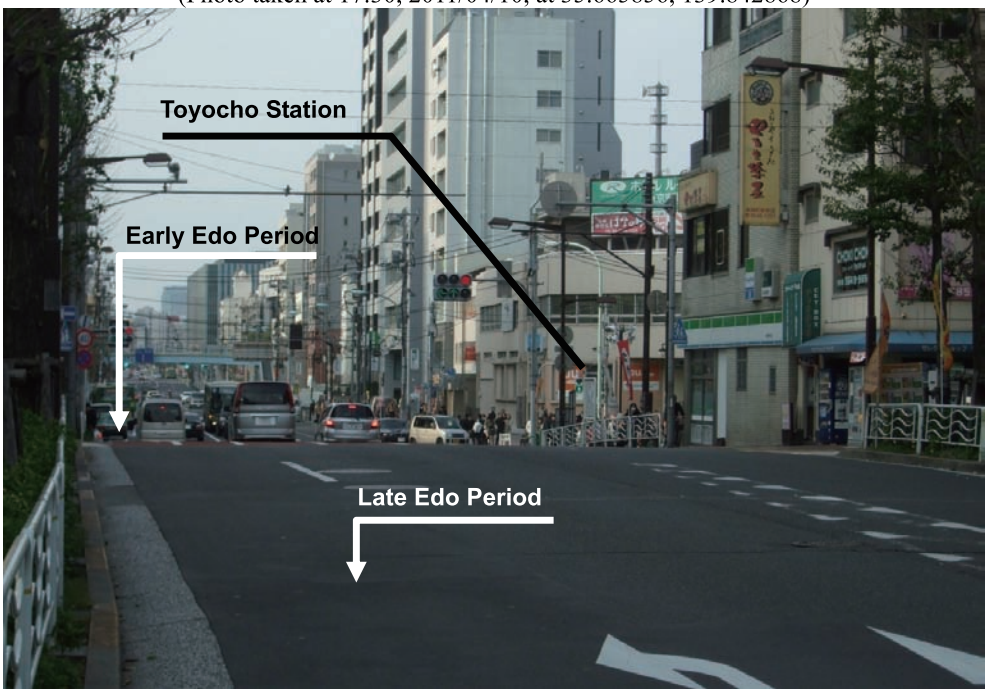


Fig.4(a) Sudden elevation change shows the presence of boundary between earlier landfill (the other side), and later landfill. (35.668763, 139.816437)

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

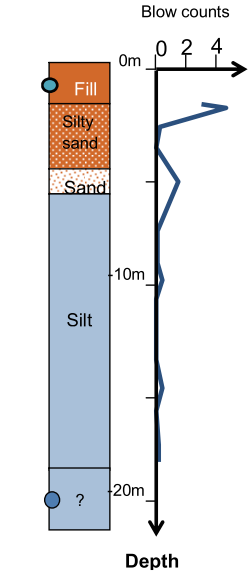


Figure 5 Soil profile at Toyocho site and locations of seismometers (dark-blue circles)

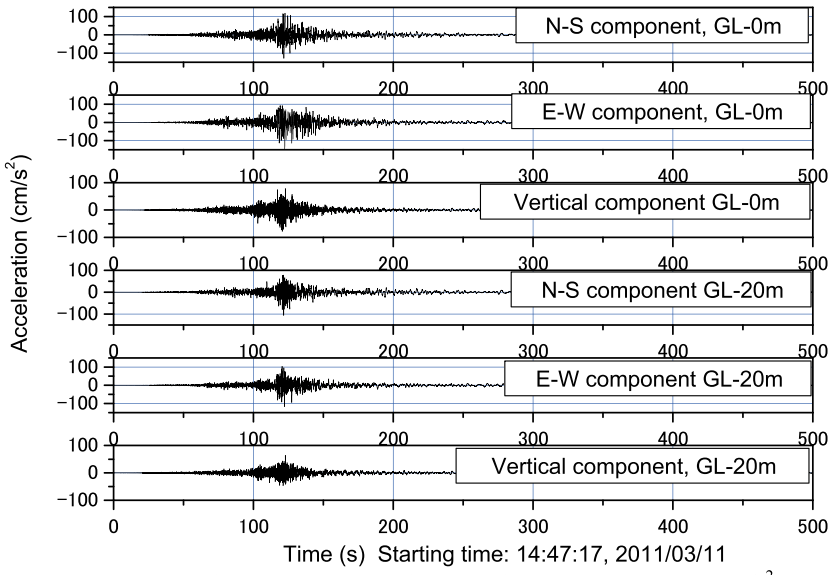
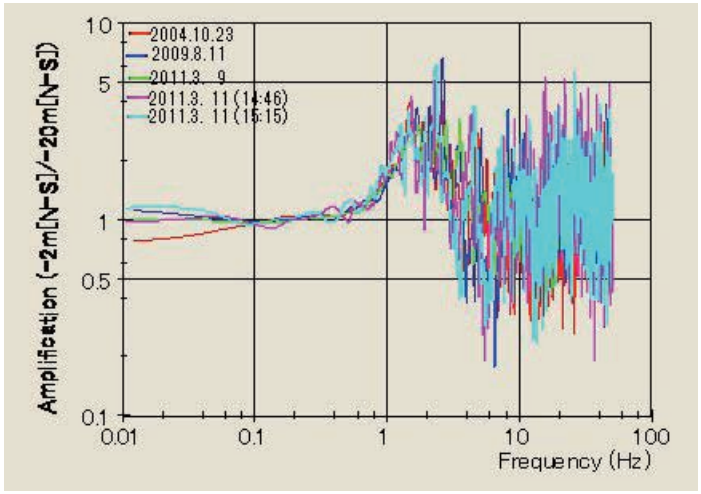


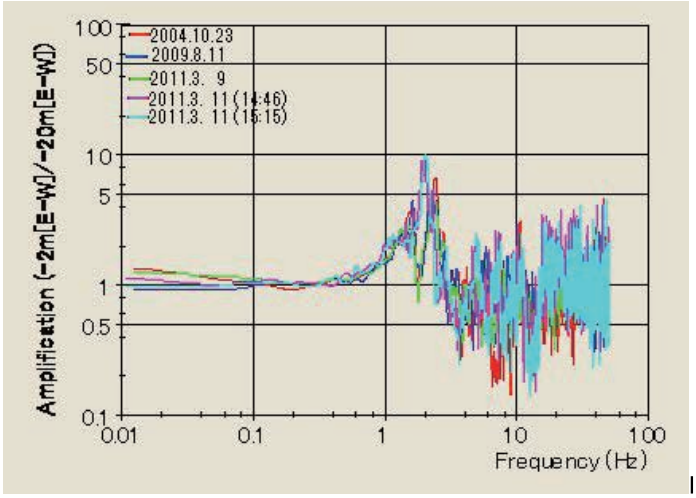
Figure 6 Accelerograms at Toyocho from the main event (Unit: cm/s^2)
(-20m (NS: 116.7, EW 63.7, UD: 80.2), -0m (NS: 128.7, EW 155.5, UD: 77.7))

TOYOCHO SITE

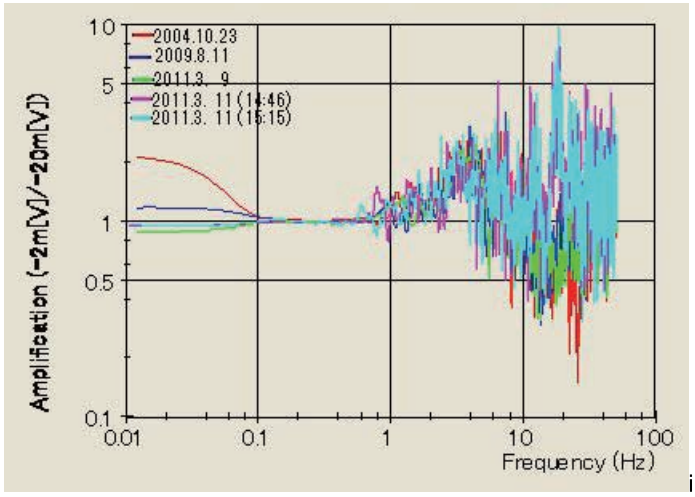
Figure 5 shows the soil profile at Toyocho site and locations of seismometers. And Figure 6 shows the accelerogrames at Toyocho from the main event. Note that PGAs appeared about a minute after the first arrival of S wave. The duration of the strong ground motion was very long. Figure 7 shows the frequency-domain 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.



In NS direction



In EW direction



in UD direction

Figure 7 Frequency-domain amplifications for 6 major ground motions observed at Toyocho

SHINKIBA SITE

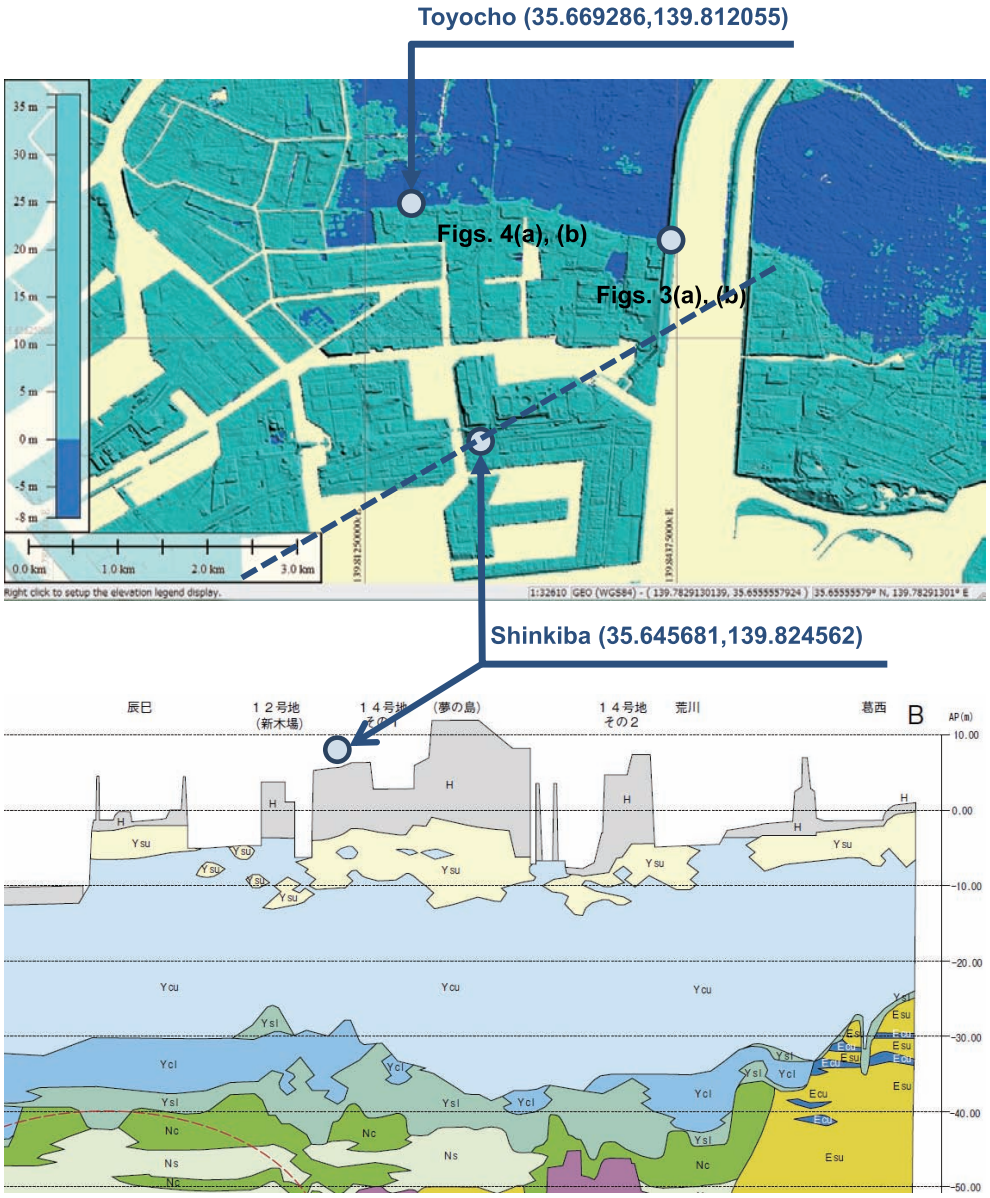


Figure 8　Locations of seismometers and soil profile at Shinkiba (Soil profile after Technical Note No. 37, Tokyo Geotechnical Consultant Association) Soils from the top follow: H= landfill, Ysu=sand, Ycu=Clay (upper Yurakucho layer), Ycl= Clay (Lower Yurakucho layer), Ysl =sand (Lower Yurakucho layer), Nc, Ns= Sand and clay from late Pleistocene epoch spreading above diluvial sandy and gravely layer of Tokyo. Seismometers are located at -2m and -76m.

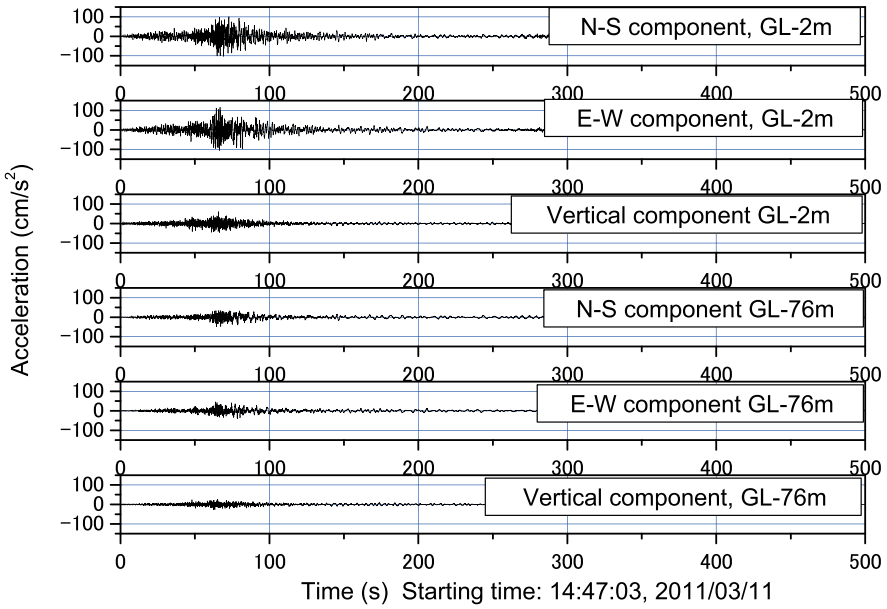
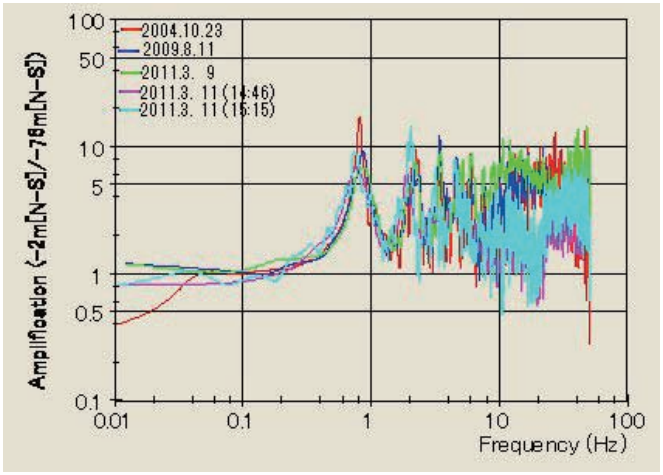
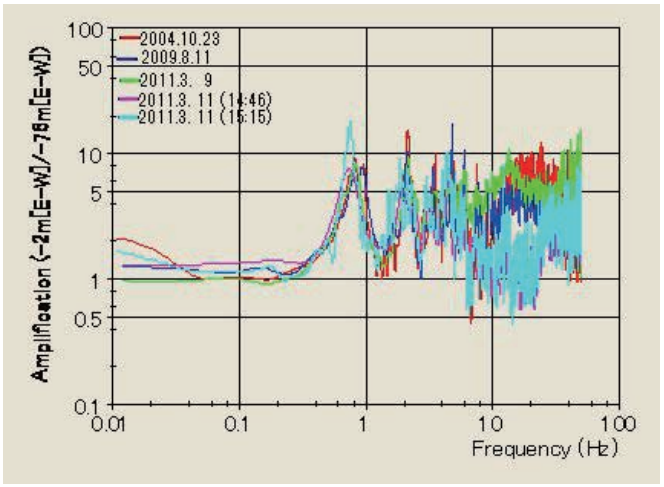


Figure 9 Accelerograms at Shinkiba from main event (Unit: cm/s^2): -76m (NS: 48.6, EW 44.8, UD: 27.3), -2m (NS: 102.7, EW 115.7, UD: 60.4), No clear sign of cyclic mobility though liquefactions were found near the station (see the photo below).

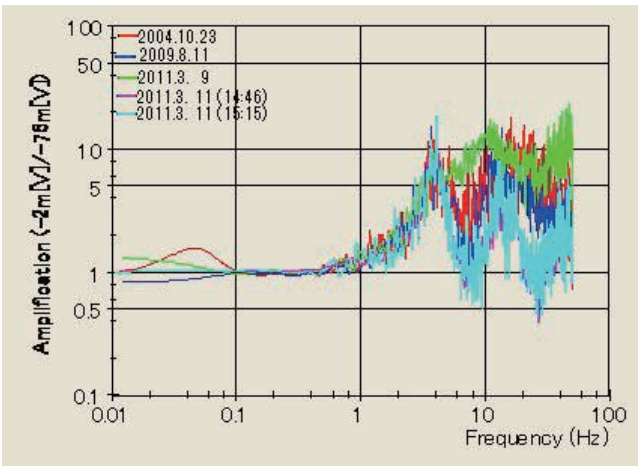
Figure 10 Liquefied sand near Shinkiba subway station (photo on 2011/03/15 by T. Kiyota. Location: 35.644812,139.828148）



In NS direction



In EW direction



In UD direction

Figure 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.

LIQUEFACTIOS IN TOKYO BAY AREA

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

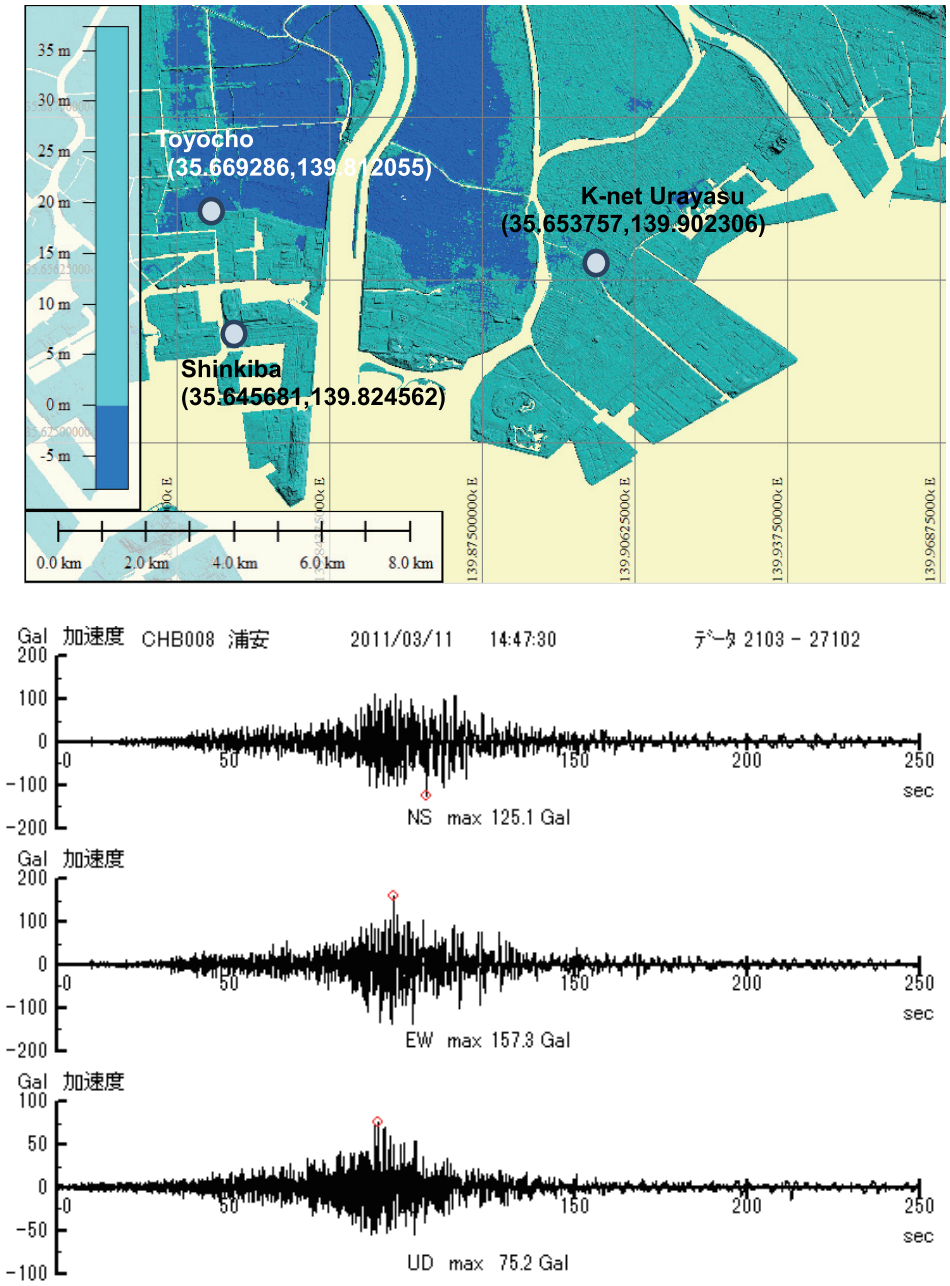


Figure 12 Recorded time histories of acceleration at K-net Urayasu (CHB008, 35.653757,139.902306): When compared with those from surface sesmographs at Shinkiba and Toyocho, they are all similar with each other in terms of PGAs and duration times.

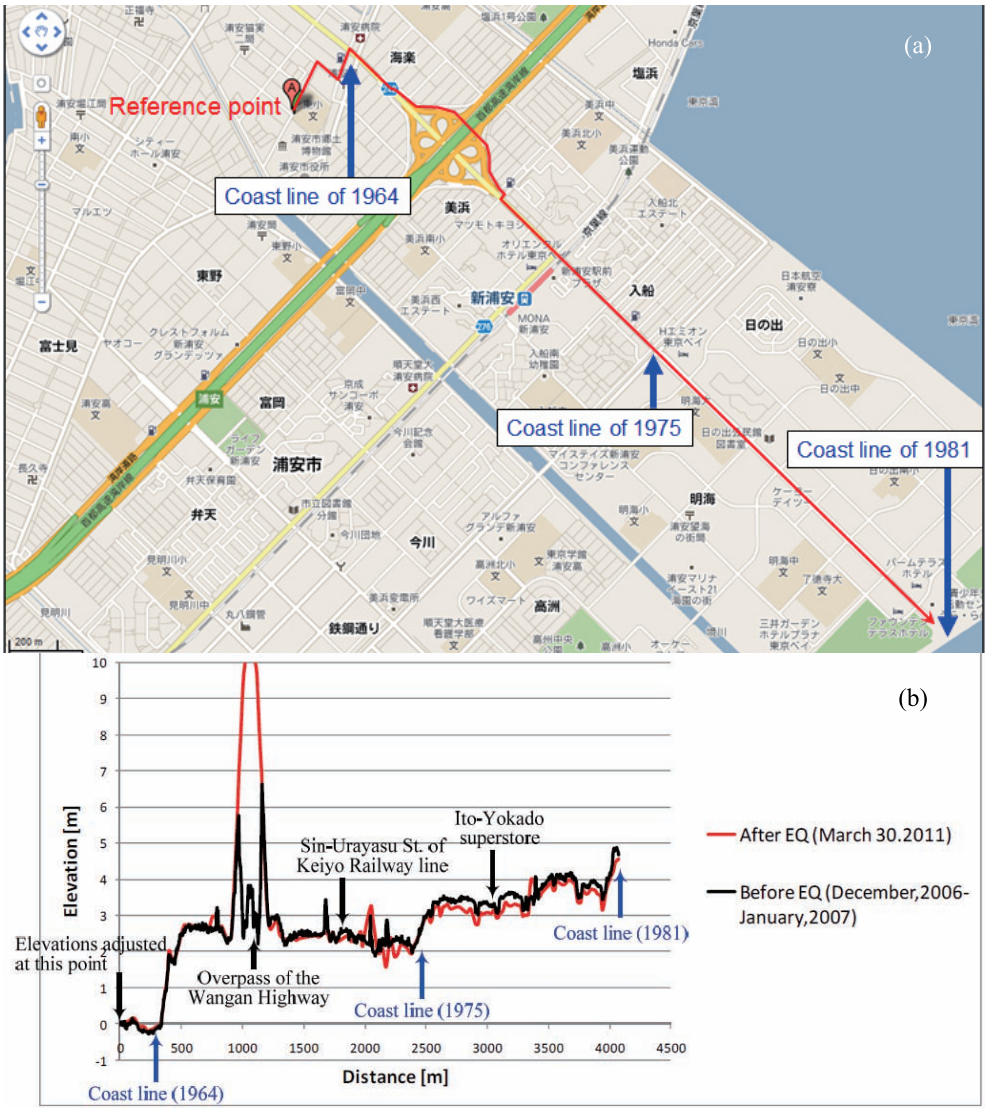


Figure 13 (a), (b) Elevations along Line-01 in Urayasu city before and after the quake of March 11th 2011

A dual-frequency DGPS survey was conducted on March 30, 2011 in Urayasu Coastal Area. Two lines (Line-01.kmz and Line-02.kmz) were taken. Elevations along Line-01 (Figure 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 has caused serious nation-wide misalignments of triangulation points. Therefore, the figures are just a rough-and-ready indication of subsidence.

Figure 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 Figures 14(a) and 14(b).

Figure 14(a) Locations of temporary water supply valves (Urayasu city)
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).

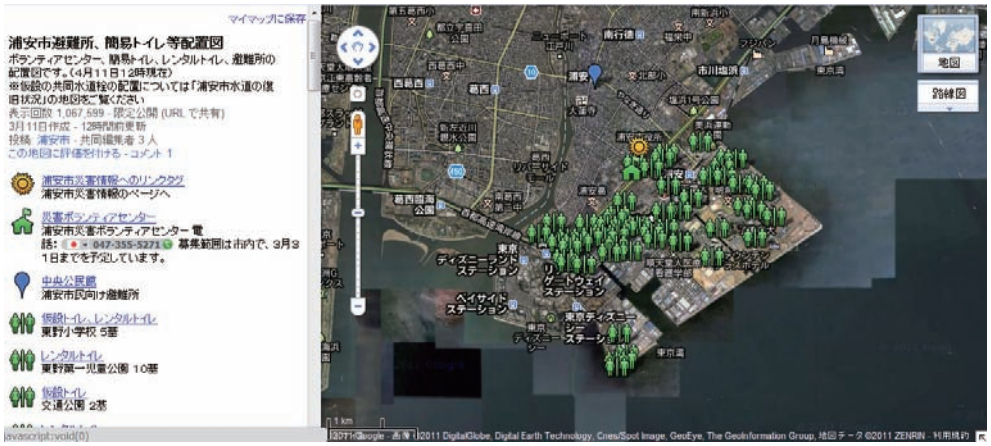


Figure 14(b) Locations of temporary toilets as of April 11th 2011. (Urayasu City)

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

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.

ACKNOWLEDGEMENT

Observations of seismic motions at Toyoch and Shinkiba sites have started in 1976 in commission from Tokyo Metro Subway. The authors are indebted to all personnel of Tokyo Metro Subway who have supported this long-term observation.

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.
2) Digital Map 5m-grid, Geospatial Information Authority of Japan, http://www.gsi.go.jp/ENGLISH/page_e30231.html.
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