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Change of Dynamic Properties of Ground Before and After the Great East Japan Earthquake

T. Mori[1], K. Matsushita[2], M. Kazama[3]

ABSTRACT

In this study, changes of seismic motion in a developed residential site in Sendai-City Japan before and after the Great East Japan Earthquake are mentioned. That is because the dynamic properties of fill ground may change before and after this large earthquake because of the fill ground damages. We observed earthquake records at the residential development which has numerous zones of cut and fill from the year 2007. The instrumental seismic intensity and the Fourier spectral ratio of acceleration were arranged using 33 earthquake records. As a result, the observed seismic intensity at the cut area was smaller than the fill area on the whole. After the Great East Japan Earthquake, the difference of instrumental seismic intensity against a base site (seismograph No.3) became larger, and the spectral ratio also became larger at frequency of 4.5 Hz to 6.0 Hz than that of before the earthquake.

Introduction

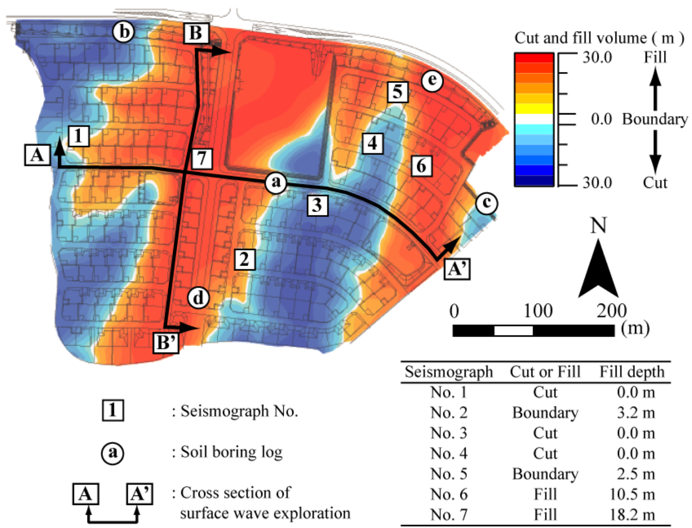
In recent years, the developed residential area which was made cutting and filling natural mountains and valleys is increasing with an increase of population and urbanization. It is generally thought that the fill ground has higher risk against seismic disaster than the natural ground or the cut ground. However, it is not indicated quantitatively how much danger increases in the fill ground. Seismic resistance of buildings has improved through the Japanese Building Standards Law revised in 1981. Therefore, most of seismic damages of buildings depend on the seismic character of ground. When discussing seismic damage of buildings, to grasp the seismic character of ground is important because there is an important interaction between the ground and the buildings. We had been observed earthquake records (Matsushita et al. (2010)) at the site, called "Minami-nakayama", located in Sendai City, Japan. At this site, the main shock of the Great East Japan Earthquake was not measured because of instrumental accident. However, plenty data of before and after the earthquake could be collected.

In this study, the arrangement of earthquake record based on 33 earthquake records, which were recorded before and after the earthquake, was performed because the seismic character of ground may have changed with the Great East Japan Earthquake. And the instrumental seismic intensity and the Fourier spectral ratio of acceleration are also mentioned in this manuscript.

[1] Department of Civil and Environmental Engineering, Maebashi Institute of Technology, Maebashi, Japan, mori@maebashi-it.ac.jp
[2] Misawa Homes Institute of Research and Development, Tokyo, Japan, Katsuya_Matsushita@home.misawa.co.jp
[3] Department of Civil Engineering, Tohoku University, Sendai, Japan, kazama_motok@civil.tohoku.ac.jp

Geotechnical characters of the study area

The study area places at hilly area in Miyagi Prefecture, and has a scale of about 500m (East-West direction) and 300m (North-South direction) respectively. The name of the study area is “Minami-nakayama”. Fig.1 shows the cut and fill map of Minami-nakayama drawn by combining an old topographical map (Nakajiri et al. (2008)) (scale of 1/2500, based on pictures taken by the U.S. Air Force in 1956) and a housing development map (scale of 1/500). The red and blue part indicate the filled part and the cut part respectively. The maximum fill thickness is more than 20m. This way referred to the "Description of the change forecasting survey guideline of large-scale reclaimed land" (Ministry of Land, Infrastructure, Transport and Tourism, Japan (2008)).



Seismograph	Cut or Fill	Fill depth
No. 1	Cut	0.0 m
No. 2	Boundary	3.2 m
No. 3	Cut	0.0 m
No. 4	Cut	0.0 m
No. 5	Boundary	2.5 m
No. 6	Fill	10.5 m
No. 7	Fill	18.2 m

Figure 1. Cut and fill map at Minami-nakayama

To obtain the soil material of the fill ground, the distribution of soil layer, and the compaction degree of soil, the Standard Penetration Tests and the Swedish Weighted Sounding Tests (SWS tests) were performed in 2009 (before the Great East Japan Earthquake). Soil boring logs, SPT *N*-values, and conversion *N*-value from SWS tests are shown in Fig.2. These test locations are indicated in Fig.1 as 1 - 7 and a - d. The base ground in this area consists of the tuffaceous sandstone in the pleistocene, and its SPT *N*-value is 50 or more. The fill is made from crashed tuffaceous sandstone, and its SPT *N*-value is 5 or less as a whole. The weathered tuffaceous sandstone which exists in the boundary between the fill and the base ground has small SPT *N*-value than that of the tuffaceous sandstone. The groundwater levels which were measured at the point “d” and “7” in Fig.1 were G.L. -0.8m to -1.1m through one year, and there were small influence of precipitation.

Next, the result of surface wave exploration along the line A-A' in the study area is shown in Fig. 3. The shear wave velocity of fill indicates 220 to 280 m/s. While, the shear wave velocity of base ground is 330 m/s or more. The shear wave velocity of weathered base ground is obscure, and the distribution of weathered base ground might not distinguish from only the surface wave exploration.

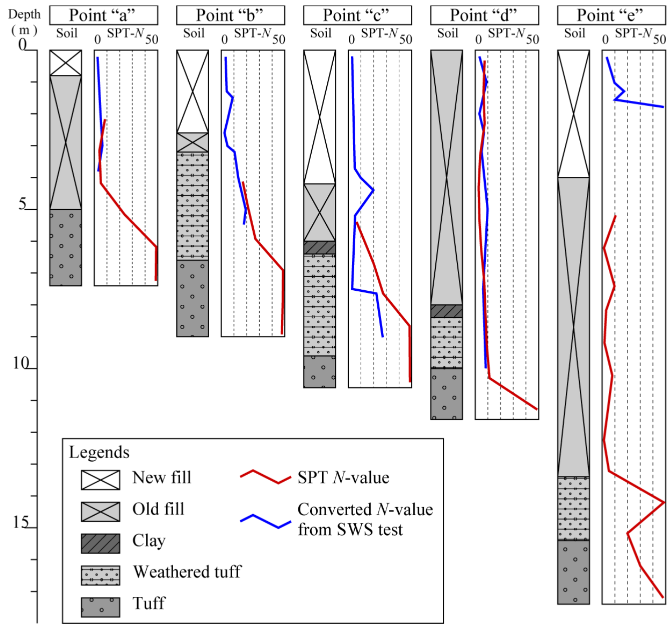


Figure 2. Soil boring logs, SPT *N*-value, and converted *N*-value from SWS test in the study area

Earthquake records

The observed earthquakes

The in-situ seismic observation was performed in Minami-nakayama area. The used seismographs were "E-catcher" (OYO Seismic Instrumentation Co.). The main shock of the Great East Japan Earthquake (March 11, 2011) was not measured because of instrumental accident (the seismic motion was too long time to record). However, plenty of data were measured before and after the earthquake.

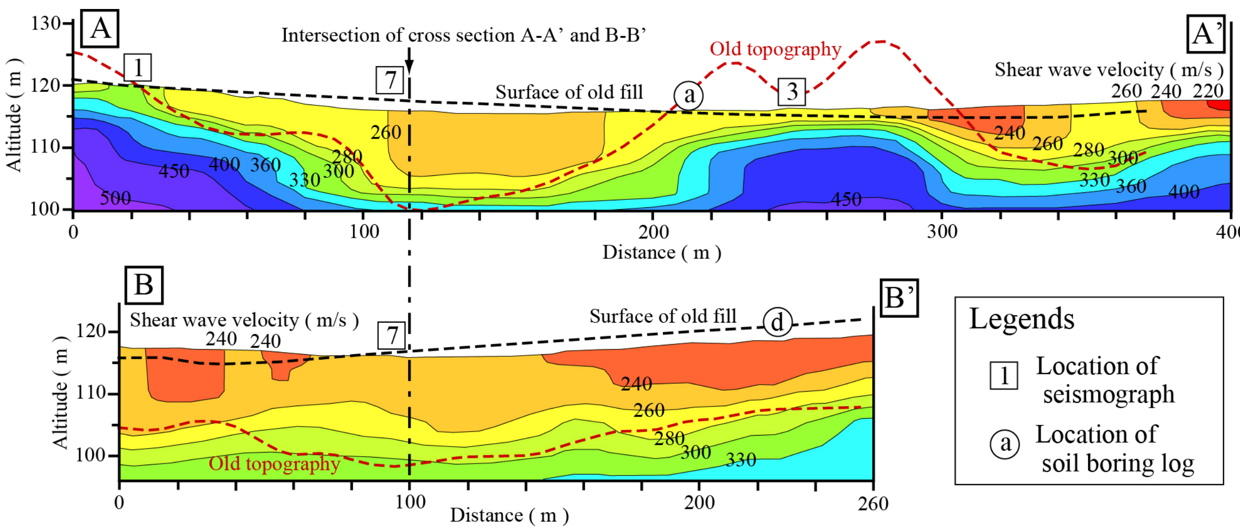


Figure 3. Cross section view of shear wave velocity along the line A-A' and B-B' in Figure 2

Table 1. The observed earthquake data

Earthquake record		Seismic Intensity							Difference of Seismic Intensity from ***No.3***					
No.	Date (y / m / d time)	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.1	No.2	No.4	No.5	No.6	No.7
1	2007/12/25 23:05	1.6	1.8	1.5	1.8	-	1.8	1.8	+0.1	+0.3	+0.3	-	+0.3	+0.3
2	2008/05/08 01:02	1.7	1.9	1.8	2.0	2.1	-	1.9	-0.1	+0.1	+0.2	+0.3	-	+0.1
3	2008/05/08 01:45	2.8	2.7	2.6	2.9	3.0	3.0	2.9	+0.2	+0.1	+0.3	+0.4	+0.4	+0.3
4	2008/06/14 08:43	4.0	4.1	3.8	4.1	4.0	4.0	4.2	+0.2	+0.3	+0.3	+0.2	+0.2	+0.4
5	2008/06/14 09:20	-	1.9	1.3	1.5	1.5	-	1.9	-	+0.6	+0.2	+0.2	-	+0.6
6	2008/06/16 23:14	-	1.9	1.3	1.6	1.5	1.6	1.9	-	+0.6	+0.3	+0.2	+0.3	+0.6
7	2008/10/30 00:49	2.5	2.5	2.2	2.4	2.7	2.6	2.9	+0.3	+0.3	+0.2	+0.5	+0.4	+0.7
8	2009/02/01 06:52	1.9	2.1	1.9	2.2	-	-	2.2	±0	+0.2	+0.3	-	-	+0.3
9	2009/02/17 09:13	1.2	1.5	1.1	-	-	-	-	+0.1	+0.4	-	-	-	-
10	2010/03/14 17:08	2.7	2.8	2.6	2.8	3.0	2.9	2.9	+0.1	+0.2	+0.2	+0.4	+0.3	+0.3
11	2011/03/09 11:45	3.2	3.3	3.2	-	3.4	3.3	3.4	±0	+0.1	-	+0.2	+0.1	+0.2
12	2011/03/10 03:16	2.3	2.4	2.3	-	2.5	-	2.4	±0	+0.1	-	+0.2	-	+0.1
	↑ Before the Great East Japan Earthquake													
	↓ After the Great East Japan Earthquake													
13	2011/03/15 22:31	2.7	2.9	2.6	-	2.9	2.8	2.9	+0.1	+0.3	-	+0.3	+0.2	+0.3
14	2011/03/16 04:01	2.2	2.4	2.0	-	2.4	-	2.4	+0.2	+0.4	-	+0.4	-	+0.4
15	2011/03/16 12:52	1.9	-	1.8	-	2.1	-	-	+0.1	-	-	+0.3	-	-
16	2011/03/17 21:55	2.3	2.5	2.2	-	2.6	-	2.5	+0.1	+0.3	-	+0.4	-	+0.3
17	2011/03/19 18:56	2.7	2.7	2.7	-	3.0	3.0	2.9	±0	±0	-	+0.3	+0.3	+0.2
18	2011/03/20 10:30	2.7	3.0	2.6	-	2.9	2.9	3.2	+0.1	+0.4	-	+0.3	+0.3	+0.6
19	2011/03/22 18:19	2.4	2.7	2.3	-	2.7	2.7	2.9	+0.1	+0.4	-	+0.4	+0.4	+0.6
20	2011/03/23 07:12	2.3	2.6	2.2	-	2.6	2.6	2.7	+0.1	+0.4	-	+0.4	+0.4	+0.5
21	2011/03/23 07:36	2.1	2.5	2.0	-	2.4	-	2.5	+0.1	+0.5	-	+0.4	-	+0.5
22	2011/03/24 17:21	3.0	3.3	2.9	3.0	-	3.1	3.3	+0.1	+0.4	+0.1	-	+0.2	+0.4
23	2011/03/25 20:36	2.2	2.3	2.0	2.3	2.3	-	2.4	+0.2	+0.3	+0.3	+0.3	-	+0.4
24	2011/03/29 19:54	2.5	2.5	2.5	2.7	2.8	2.7	2.7	±0	±0	+0.2	+0.3	+0.2	+0.2
25	2011/04/03 16:38	2.2	2.3	1.9	-	2.4	-	2.4	+0.3	+0.4	-	+0.5	-	+0.5
26	2011/04/06 22:55	2.1	2.3	2.0	2.2	2.3	-	2.3	+0.1	+0.3	+0.2	+0.3	-	+0.3
27	2011/04/07 23:32	-	5.2	4.8	5.1	5.2	5.1	-	-	+0.4	+0.3	+0.4	+0.3	-
28	2011/04/09 18:42	2.7	2.9	2.6	2.7	2.8	2.9	2.9	+0.1	+0.3	+0.1	+0.2	+0.3	+0.3
29	2011/04/11 17:16	3.8	4.2	3.9	4.1	4.3	4.2	4.2	-0.1	+0.3	+0.2	+0.4	+0.3	+0.3
30	2011/04/11 17:17	2.1	2.1	2.0	2.3	2.4	-	-	+0.1	+0.1	+0.3	+0.4	-	-
31	2011/04/11 18:05	-	-	1.8	2.0	2.3	-	2.2	-	-	+0.2	+0.5	-	+0.4
32	2011/04/11 20:42	2.5	2.8	2.4	2.7	2.8	2.8	2.8	+0.1	+0.4	+0.3	+0.4	+0.4	+0.4
33	2011/04/12 14:07	2.9	3.1	2.8	3.0	3.2	3.1	3.2	+0.1	+0.3	+0.2	+0.4	+0.3	+0.4

Table 1 shows the earthquake data which observed at Minami-nakayama. In this study, 33 earthquake records were used. This table shows the date of these earthquakes, the seismic intensity of each seismographs, and the difference of seismic intensity from No.3 at each site. The earthquakes indicated in No.1-No.12 occurred before the Great East Japan Earthquake and earthquakes, and the earthquakes indicated in No.13-No.33 occurred after the Great East Japan Earthquake. In this study, the data of seismograph No.3 was used as the reference data because the seismograph No.3 is located at a cut area and observed the smallest seismic intensity in almost all earthquakes. On the other hand, the data of seismograph No.4 were large overall, though this seismograph was installed at the cut area. As a reason, it is thought that the earthquake motion concentrated or was amplified because the seismograph No.4 had been located at the ridge of cut ground. The typical earthquakes, which observed at June 14, 2008 (The Iwate-Miyagi Nairiku Earthquake in 2008), April 7, 2011 (after shock of The Great East Japan Earthquake), and April 11, 2011 (after shock of The Great East Japan Earthquake), are indicated in Table 1 as gray hatching. At the earthquake at April 7, 2011, the seismograph No.1

and No.7 were not able to measure. As the tables show, Even if it is same earth-quake, there is a difference in seismic intensity about 0.4 at the maximum (For example, No. 3 vs. No. 7 in the earthquake at June 14, 2008). Thus, even if in the same developed housing site, it can be said that seismic response characters are different because the geographical structures are different.

Table 2 shows the differences of averaged instrumental seismic intensity from No.3 before and after the Great East Japan Earthquake. When No.5 is made an example, the difference is 0.29 before the earthquake, and is 0.37 after the earthquake. The difference of averaged instrumental seismic intensity after the Great East Japan Earthquake became larger than that before the Great East Japan Earthquake.

Table 2. Average difference of seismic intensity from the seismograph No.3

	Seismograph No.					
	No.1	No.2	No.4	No.5	No.6	No.7
Before the Great East Japan Eathquake (Number of data)	+0.09 (10)	+0.28 (12)	+0.26 (9)	+0.29 (9)	+0.29 (7)	+0.35 (11)
After the Great East Japan Eathquake (Number of data)	+0.10 (19)	+0.31 (19)	+0.22 (11)	+0.37 (20)	+0.30 (12)	+0.39 (18)

Comparison of seismic intensity

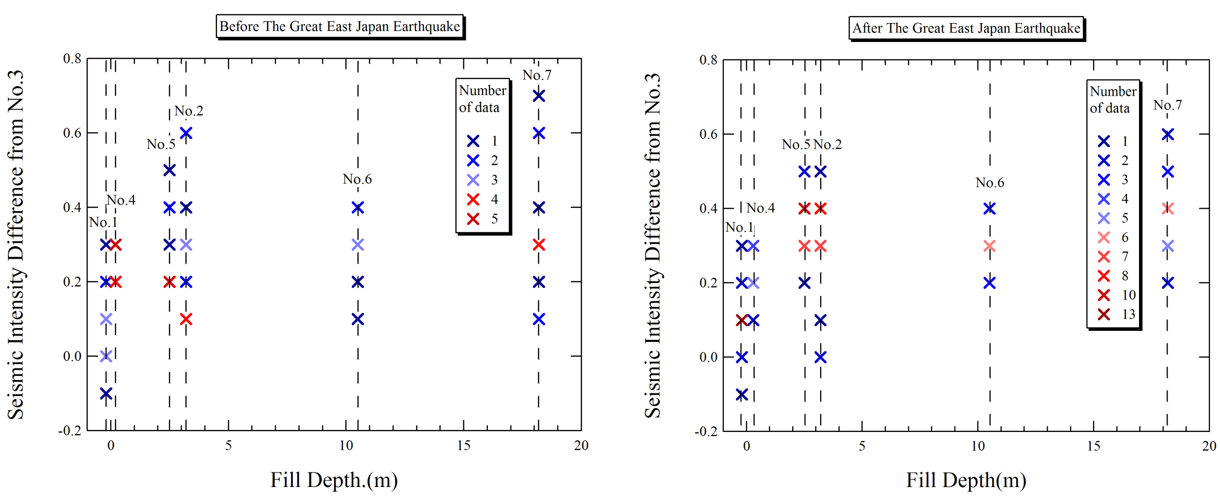


Figure 4. The difference of seismic intensity from the seismograph No.3

In Fig.4, the relationship between the difference of instrumental seismic intensity against No.3 and the fill depth at the position which the seismograph was installed is shown. Here, No.1 and No.4, which have fill depth of 0 m, are displayed side by side. The blue plots means small number of data, and the red plots means large number of data, because there were many data of the same value. Overall, the larger the thickness of fill becomes, the larger the difference of instrumental seismic intensity becomes. Fig.5 shows the instrumental seismic intensity of No.3 and the maximum and minimum instrumental seismic intensity observed except No.3. As this figure shows, the differences of instrumental seismic intensity against No.3 indicates inconstant tendency. This means that the differences of instrumental seismic intensity against No.3 were affected by many factors like fill depth, geological location and so on.

The instrumental seismic intensity has been defined as the following formula by the Japan Meteorological Agency (Japan Meteorological Agency, 2011).

$$I = 2\log_{10} a + 0.94 \quad (1)$$

Where, "I" means instrumental seismic intensity, and "a" (cm/s^2) means the calculated value from synthetic acceleration of three components (NS, EW and UD) and acceleration Fourier spectrum. The detailed calculating method of the value "a" is introduced to the Japan Meteorological Agency.

The next equation is defined for calculating the variation of value "a", when the difference of instrumental seismic intensity "I" becomes constant as Fig. 5.

$$I = 2\log_{10}(a \times x) + 0.94 \quad (2)$$

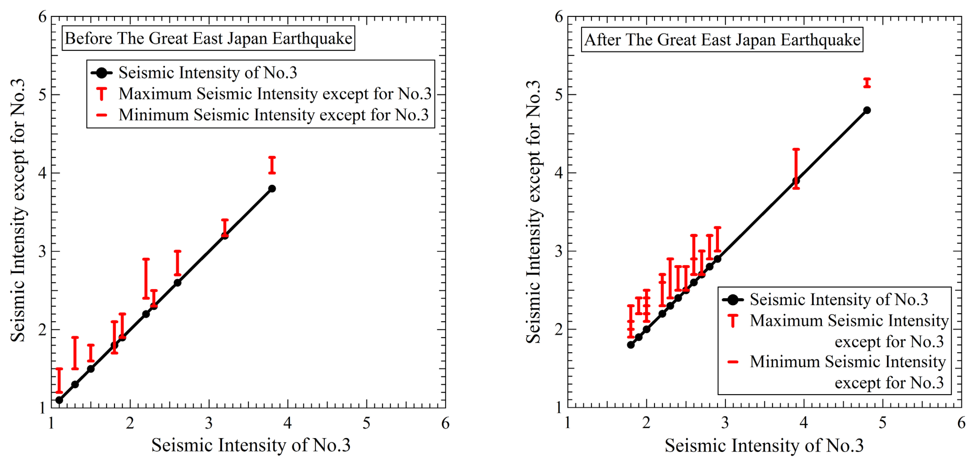


Figure 5. Seismic intensity of No.3, and max. and min. seismic intensity except for No.3

According to eq. (2), the difference of instrumental seismic intensity is expressed as the magnification of value "a". The value "x" indicates the magnification of the instrumental seismic intensity against the seismograph No. 3. The value "x" is obtained from the regression curve of "a" vs. "I". The example case about No. 3 vs. No. 5 is shown in Fig. 6. The ways of the process are shown as follows (the case of No.5 is used as an example).

(i) Plot the instrumental seismic intensity "I" and "a" about No.3 (green circles) and No.5 (blue squares) by using eq. (1). "I" is the observed value, and "a" is the calculated value.
(ii) Plot the points by using "a" of No.3 as the acceleration, and "I" of No.5 as the seismic intensity (red triangles).
(iii) Calculate the regression curve against the plots by using the process (ii).
(iv) The value of "x" in eq. (2) can be found in a regression curve. The value of "x" is 1.39 in the case of No.5, before The Great East Japan Earthquake.

Table 3. The value of "x" in the equation (2)

The value of " x " $I = 2\log_{10}(a \times x) + 0.94$	Seismograph No. (Fill depth (m))					
	No.1 (0.0 m)	No.2 (3.2 m)	No.4 (0.0 m)	No.5 (2.5 m)	No.6 (10.5 m)	No.7 (18.2 m)
Before the Great East Japan Earthquake	1.11	1.37	1.34	1.39	1.39	1.50
After the Great East Japan Earthquake	1.12	1.43	1.29	1.52	1.41	1.56
After / Before	1.01	1.04	0.96	1.09	1.01	1.04

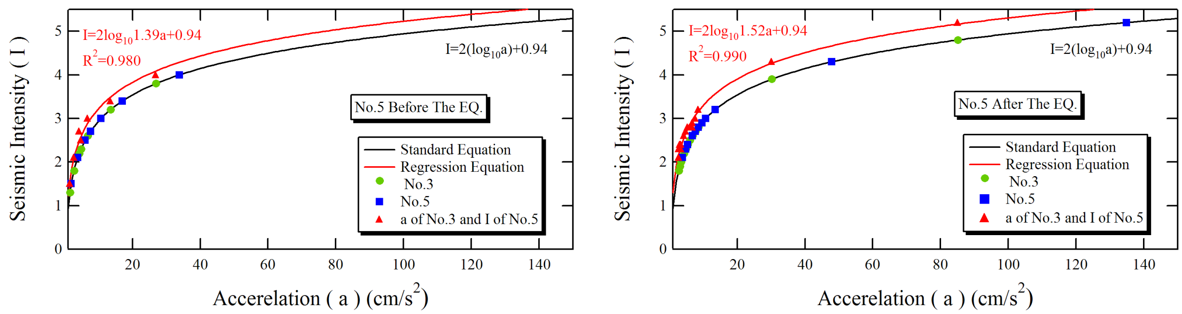


Figure 6. The relation between the value "a" and "I"

In Table 3, the value of "x" and the fill depth are summarized. The value of "x" expressed the magnification of the value "a" at each seismograph with different instrumental seismic intensity "I". The value "x" increased at most 9% after the earthquake except for No.4. The value of "x" increased after the Great East Tohoku Earthquake at the seismograph No. 2, No. 5 and No. 7. The largest rise amount was observed at the No.5, however this location had not large fill depth. And the fill depth of No.2 and No.7 was also difference. Therefore, it was thought that the influence of the fill depth upon the change of value "x" was small. When the locations of seismograph in Fig.1 is seen again, the seismograph No. 5 was installed at the shoulder of fill slope, and the seismograph No. 2 was installed at the boundary of cut and fill. From these things, it was guessed that the main influence of the change of value "x" was the ground damage due to the strong seismic motion.

Comparison of spectral ratio of acceleration

Difference of amplification ratio on each site

The Fast Fourier transform (FFT) analyses were performed to evaluate seismic motion on each site where seismograph was installed. The spectrum were smoothed by a Parzen-window with band width of 0.8 Hz. Then, the amplification ratio was calculated relative to the base site No.3. The seismograph No.3 was located a cut area, and the most of measured seismic intensity was smaller than the other points. As an example of this process, Fig.7 shows the spectral ratio of the acceleration in the EW (East-West) component on June 14, 2008 (The Iwate-Miyagi Nairiku Earthquake in 2008) and April 11, 2011 (after shock of the Great East Japan Earthquake). The spectral ratio is different at each site. For example, No.2 and No.7 have the large peak in about 3 Hz, and differ from the other seismographs. No. 1, 4, 5, and 6 have the peak frequency of 4.5 to

5.5 Hz. These differences may be affected on soil-structures by a site (No.2 and No.7 are in the place whose original geographical feature was a valley).

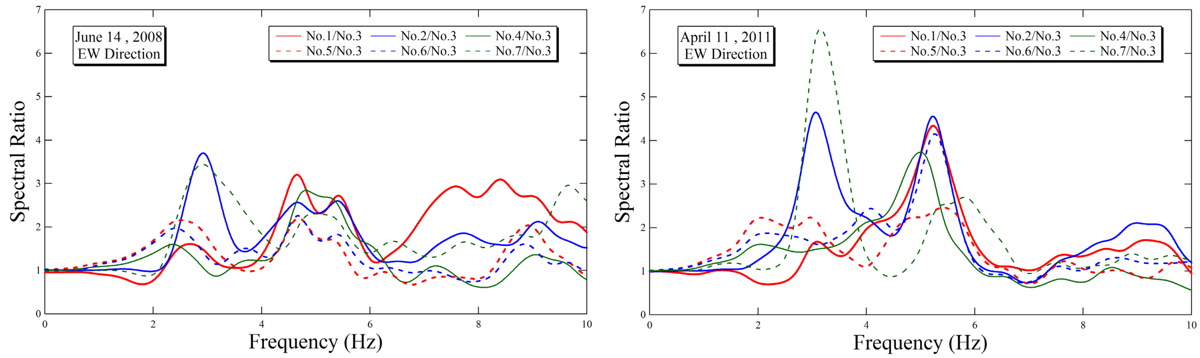


Figure 7. Spectral Ratio of acceleration (June 14, 2008 and April 11, 2011, EW direction)

Difference of amplification ratio before and after the Great East Japan Earthquake

For evaluating the difference of seismic characters before and after the earthquake, the amplification ratio was calculated relative to the base site No.3. Fig.8 shows the data at sites of No.5 and No.6. Here, the red lines indicate the data before the Great East Japan Earthquake (earthquake records of No.1 to No.12) and the blue lines indicate the data after the Great East Japan Earthquake (earthquake records of No.13 to No.33), respectively. As a whole, at peaks in higher frequency (about 4.5 to 6.0 Hz), the spectral ratio after the earthquake are larger than that one before the earthquake data. This means that the seismic character of the fill ground may have changed because the fill ground had been damaged from the earthquake.

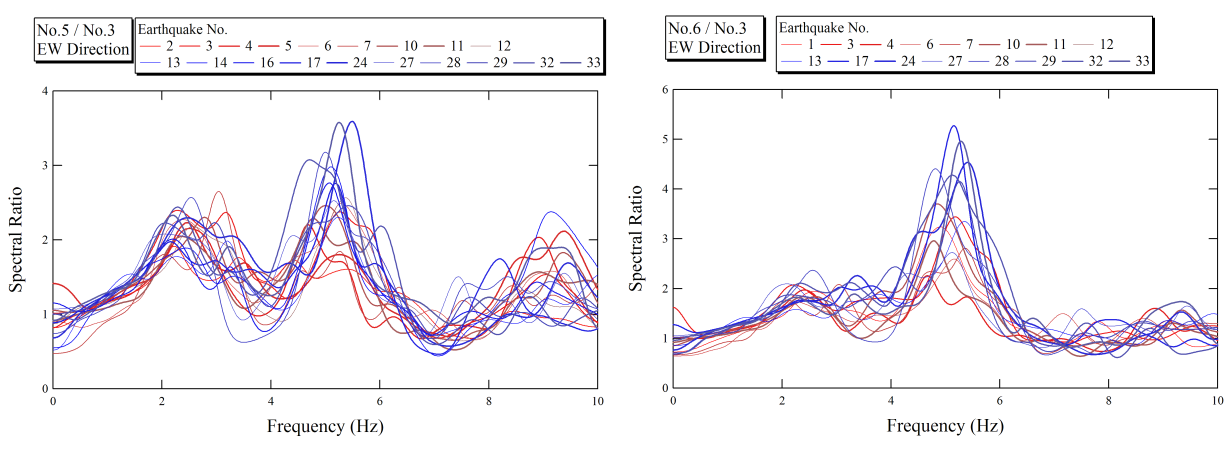


Figure 8. Change of Spectral Ratio of acceleration before and after the Great East Japan

Conclusions

The consideration about the change of seismic character before and after the Great East Japan Earthquake was performed based on a lot of in-situ earthquake records. As a result, following knowledge was found.

(1) The cut site (No.3) indicated lower instrumental seismic intensity compared with the other sites. Even if in the same development housing site, it can be said that seismic response characters are different because the geographical structures are different. As a whole, the observed seismic intensity at the cut area were smaller than that of the fill area.
(2) The difference of instrumental seismic intensity at each site against No.3 became larger except No.4, after the Great East Japan Earthquake. The maximum increase ratio was 9%.
(3) The influence of the fill depth upon the rise rate of instrumental seismic intensity was small. It was guessed that the main factor was the ground damage by strong seismic motion.
(4) At the sites of No.5 and No.6, as a whole, the spectral ratio after the earthquake became larger than that one before the earthquake at frequency of 4.5 Hz to 6.0 Hz. This means that the seismic character of the fill ground may have changed due to the damage by the earthquake.

Although the changes of ground seismic character before and after the earthquake were observed, further research is necessary why these changes have occurred.

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