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PRELIMINARY EVALUATION OF SITE AMPLIFICATION FROM STRONG MOTION RECORDS OF THE 2011 TOHOKU, JAPAN EARTHQUAKE

S. Midorikawa[(1)], Y. Nogi[(2)], and H. Miura[(3)]

[(1)] *Professor, Tokyo Institute of Technology, smidorik@enveng.titech.ac.jp*
[(2)] *Formerly Graduate Student, Tokyo Institute of Technology, ngyshr@gmail.com*
[(3)] *Associate Professor, Hiroshima University, hmiura@hiroshima-u.ac.jp*

Abstract

The 2011 Tohoku, Japan earthquake of Mw9.0 produced many strong motion records. The records provide a unique opportunity to examine site amplifications in strong shaking level. The available site data for the records, however, are limited. To strengthen the site data, microtremor measurements are conducted at 467 strong motion sites in the high seismic intensity area of the earthquake where the peak accelerations on rock sites are averagely as high as 0.45 g. As the H/V spectral ratios of microtremors show different shapes for each NEHRP site class, the criteria are determined for the NEHRP site classification from the H/V spectral ratio. By using the criteria, the strong motion sites in the high intensity area are classified into site classes B, C, D and E sites. As the standard deviation of the peak accelerations on rock sites in the area is relatively small, the shaking level inputted to the bedrock in the area may not have large difference. Therefore, the site amplification at strong shaking level is preliminarily evaluated from the ratio of the average spectrum at site class C, D or E with respect to that at class B. The amplifications of site classes C and D to B are almost two, and rather similar to each other. The amplification of site class E to B, however, is larger at longer periods and smaller at short periods, showing stronger site effects. The amplifications are compared with those derived from weak motion records. The difference in both amplifications indicates effects of nonlinear soil response at strong shaking level.

Keywords: Site Amplification, NEHRP Site Class, Strong Motion Record, The 2011 Tohoku Earthquake, Microtremor

1. Introduction

Earthquake ground motion is often affected by soil conditions at the site. Therefore evaluation of the site effects is important for specifying input ground motion in seismic design of structures. Ground classification has been used as an index for the site effects in seismic design codes. In the U. S. building code, the NEHRP site class based on the average shear wave velocity of ground in the upper 30 m, V_{s30}, is used to define site factors for the design spectrum. The site factors depend on intensity of motion on reference rock and are defined based on the nonlinear soil response analyses [1]. The validity of the nonlinear analyses, however, have not fully examined by observed strong motion records.

The 2011 Off the Pacific Coast of Tohoku earthquake (hereafter Tohoku earthquake) of M_w9.0 produced many strong motion records [2]. The records provide a unique opportunity to examine site amplifications in strong shaking level. The available site data for the records, however, are limited. This makes difficult to examine the correlation between site classification and amplification. Microtremors have been used as a convenient measure to evaluate the site characteristics. Kanai [3] has presented proposals to determine ground classification by periods and amplitudes of microtremors. In order to reduce effects of time variation of microtremors. Nakamura [4] has proposed the horizontal-to-vertical (H/V) spectral ratio of microtremors for site characterization. The H/V ratio of microtremors will be a potential tool for more reliable ground classification.

In this paper, we investigate the method for ground classification using the H/V spectral ratio of microtremors, and classify the strong motion sites into the NEHRP site class from microtremors. Then we evaluate preliminarily the site amplification for each site class from high-intensity strong motion records of the Tohoku earthquake.

2. Strong Motion Records of the Tohoku Earthquake

The Tohoku earthquake of Mw9.0 widely shook the northeastern part of Japan. From the earthquake, several thousands of strong motion records were obtained owing to dense strong motion observation networks in Japan. We collected and compiled the records on the ground from the networks by National Research Institute for Earth Science and Disaster Prevention, Japan Meteorological Agency, the prefectures of Japan, Ministry of Land Infrastructure and Transportation, Building Research Institute, Port and Airport Research Institute, East Nippon Expressway Company, East Japan Railway Company, Tohoku Institute of Technology and Tohoku University [2]. The total number of the records is about 3,000.

Figures 1 show distributions of peak horizontal acceleration and velocity, respectively. In the figures, the larger of the two horizontal components is used. Peak horizontal accelerations higher than 700 cm/s^2 are observed at 103 sites and those higher than 1000 cm/s^2 at 36 sites, respectively. The peak horizontal velocities higher than 50 cm/s are observed at 140 sites and those higher than 100 cm/s at 5 sites, respectively. Higher accelerations and velocities are found in areas parallel to the central and southern parts of the fault plane.

Regarding the site data, at K-NET sites, the shear-wave velocity profile is available to 20 m in depth or less. The average shear-wave velocity to 30m depth, V_{s30}, is estimated from shallower data by using the procedure shown in Midorikawa and Nogi [5]. At KiK-net sites and some other sites where the deeper profile is available, V_{s30} is directly calculated from the profile. For about 800 sites, V_{s30} is determined from the velocity profile. For the other 2,200 sites where velocity profile data are not available, V_{s30} has been estimated based on geomorphological categories [6]. The geomorphological category at each site is simply read from the 250m-mesh digital map by Wakamatsu and Matsuoka [7], and broad relationships are used to estimate V_{s30} from the geomorphological category. Therefore the estimated V_{s30} values are less reliable than those from the velocity profile.

We selected strong motion sites in high-intensity areas as the target sites in this study, as shown in Fig. 2. The number of the sites is 467. The distribution of the sites is almost parallel to the coastline of Iwate, Miyagi, Fukushima and Ibaraki prefectures. The distances from the earthquake fault plane to the sites are similar.

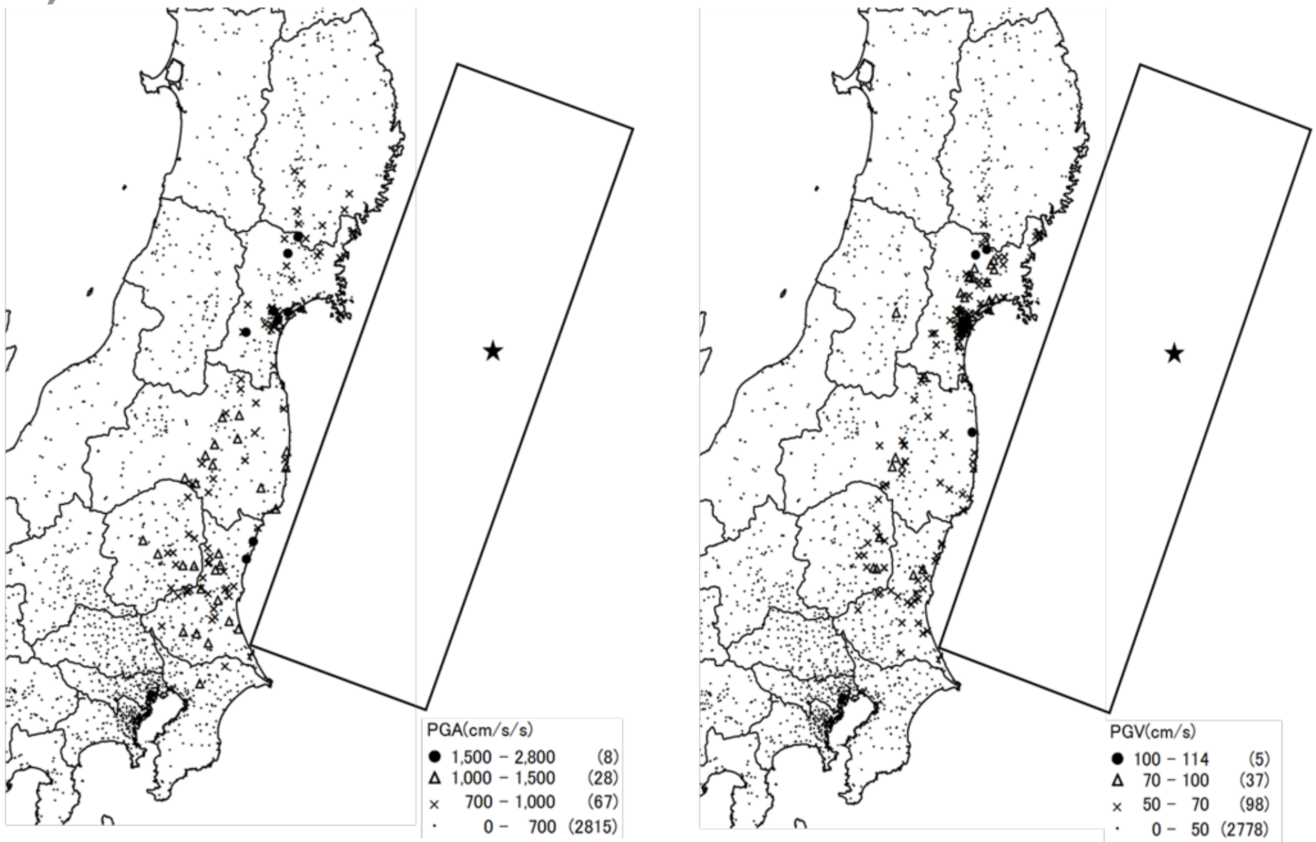

Fig. 1 - Distribution of peak horizontal acceleration and velocity

Among the 467 target sites, the soil profile data is available at only 92 sites. For the other sites, the additional site information will be needed to examine site effects on strong motion records.

3. Microtremor Measurements for Site Classification

To strengthen the site data, microtremor measurements are conducted at 467 sites in the high intensity area mentioned before. In the measurement, we use the system whose overall response is almost constant with ground velocity up to 2 seconds, as shown in Fig. 3. When analyzing microteremors, we selected three noise-free portions with duration of 20.48 seconds from the recordings. For each portion, the mean of the spectra of two horizontal components is computed as the horizontal spectrum, and the horizontal to vertical spectral ratio (H/V spectrum) is computed. The Parzen window of 0.3 Hz is used in calculation of the spectrum. Then, the H/V spectrum at a site is defined as the average of the H/V spectra for three portions. Figure 4 shows an example of the H/V spectrum at K-NET Kakuta site.

Among the 467 sites where microtremors were measured, the NERHP site class is determined at 92 sites where the soil profile data is available. The definition of the NEHRP site class is shown in Table 1. The sites are classified into 9 class B sites, 28 class C sites, 44 class D sites and 11 class

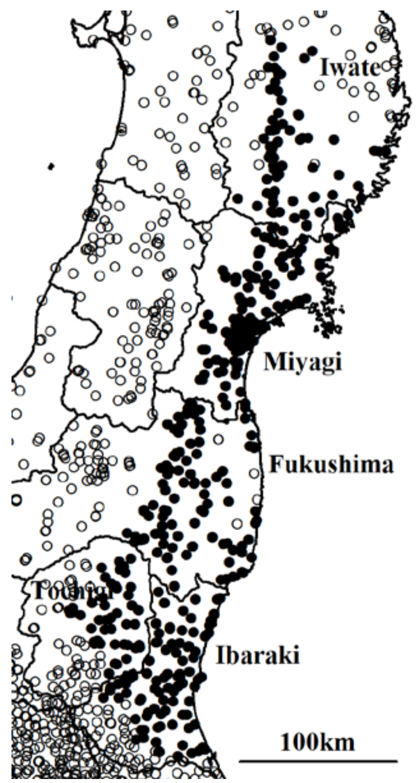

Fig. 2 – Location of target sites (solid circles)

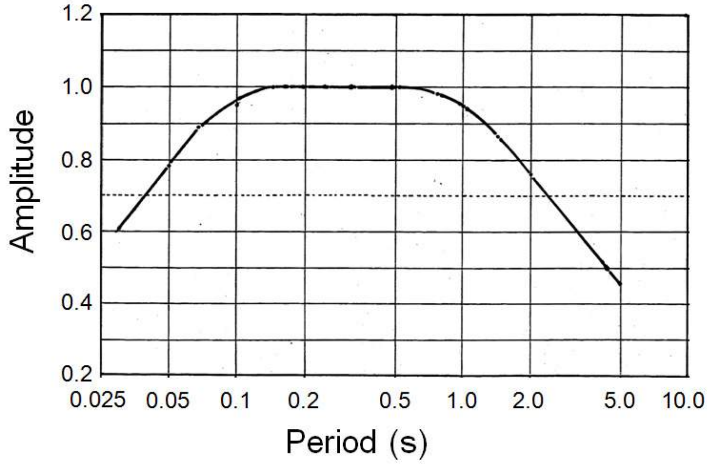

Fig. 3 – Overall response curve of microtremor measurement system

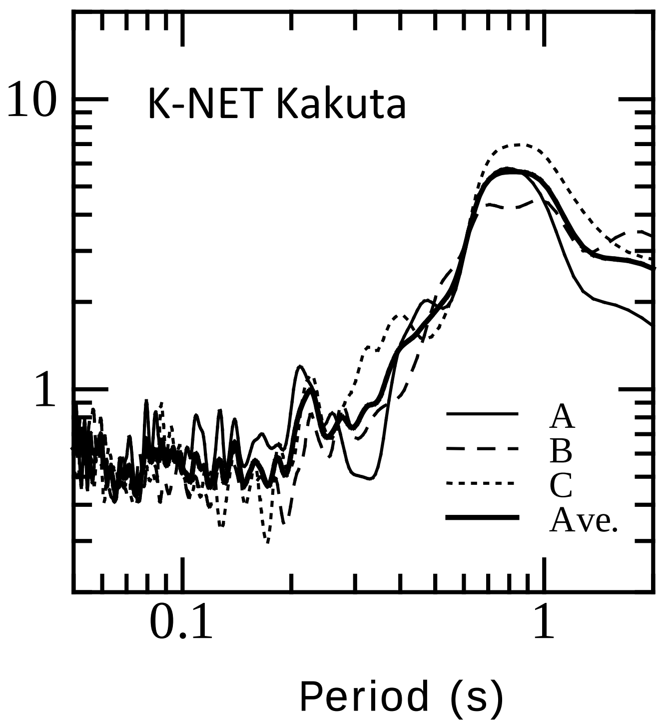

Fig. 4 – Example of H/V spectrum of microtremors

Table 1 – NEHRP site class

Site Class	V_{s30} (m/s)
A	$1500 < V_{s30}$
B	$760 < V_{s30} \leqq 1500$
C	$360 < V_{s30} \leqq 760$
D	$180 < V_{s30} \leqq 360$
E	$V_{s30} \leqq 180$

E sites. The mean and standard deviation of the H/V spectral ratios of microtremors for different NEHRP site classes are shown in Fig. 5. In the figure, we added the microtremor data at 12 sites of class E in Yokohama area because of smaller number of the class E sites. The H/V spectral ratios of microtremors show different shapes for each NEHRP site class. At site class B, the H/V spectra tend to be constant with period and the amplitudes are almost smaller than two. At site class C, the H/V spectra become larger and have peaks at periods of around 0.2 sec. At site class D, the peak period is longer than that at site class C, but the spectral shape does not show large difference with that at site class C. At site class E, the spectral shape is much different from those at the other site classes, and the ratios show larger values at periods of 0.6 to 1.2 sec.

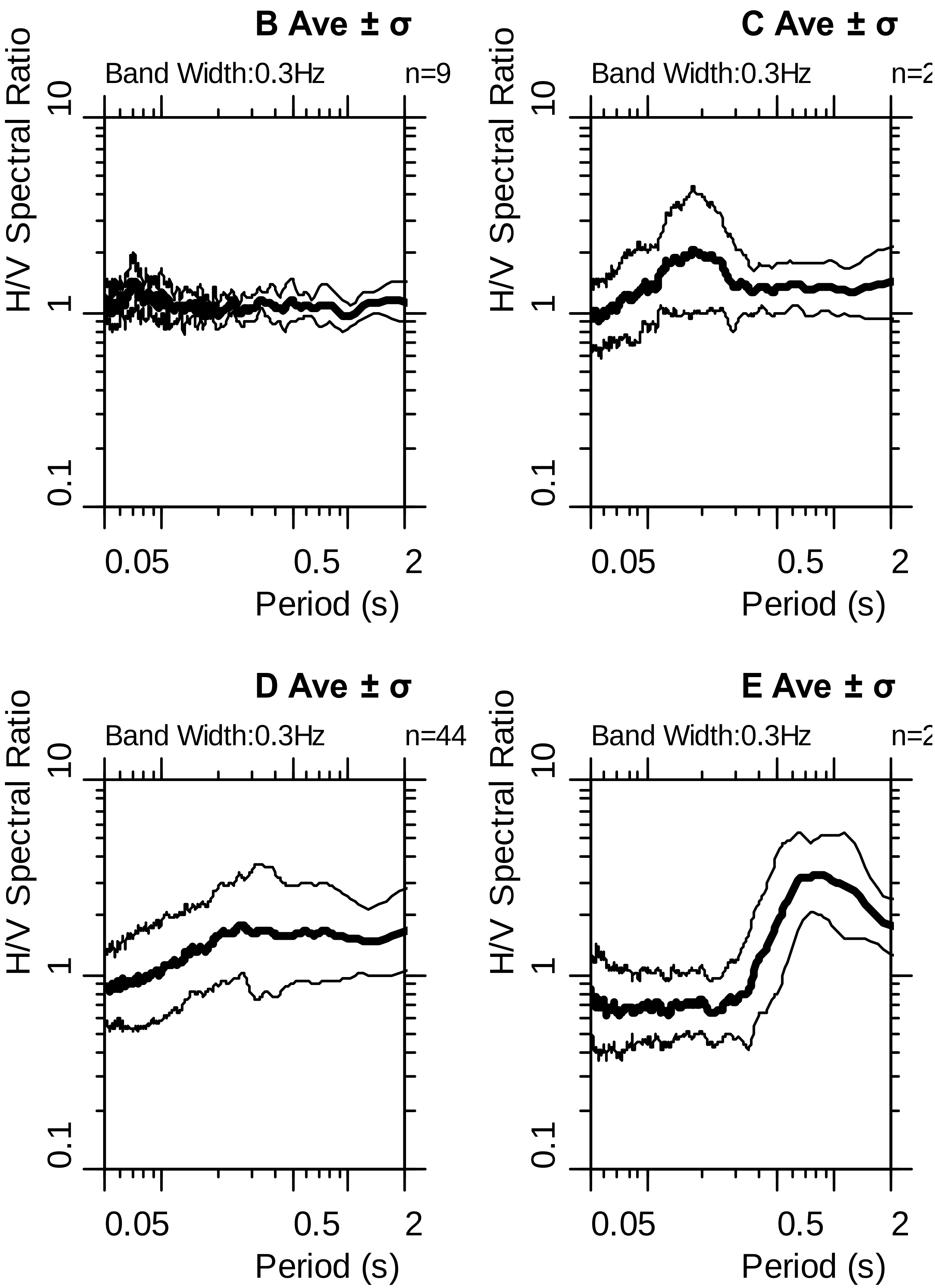

Fig. 5 - Average and standard deviation of H/V spectra of microtremors

From the characteristics of the H/V spectra at each site class, the criteria are examined to define the NEHRP site classification from the H/V spectral ratio. Finally, the following criteria are determined for site classification from the H/V spectral ratio: 1) the site having the H/V spectral ratio with higher values at periods of 0.6 to 1.2 sec. with respect to those at periods of 0.1 to 0.3 sec. is the class E, as shown in Fig, 6, 2) the site having smaller variance of the H/V spectral ratio at periods of 0.1 to 2 sec. is the class B, as shown in Fig. 7, and 3) the sites having the H/V spectral ratios with larger and smaller values at periods of 0.3 to 0.8 sec. with respect to those at periods of 0.1 to 0.2 sec. are the classes D and C, respectively, and the site having the intermediate ones is the class C or D referring the geomorphologic information, as shown in Fig. 8.

To check the accuracy of the proposed method, we compare the classification results by microtremors with those by the PS-logging data at 73 sites where the site data is not used in constructing the proposed method. As shown in Table 2, the total accuracy is 77 %. For the comparison, the results by geomorphologic data are checked, and the total accuracy is 51 % as shown in Table 3. It is confirmed that the proposed method has better accuracy than the existing method.

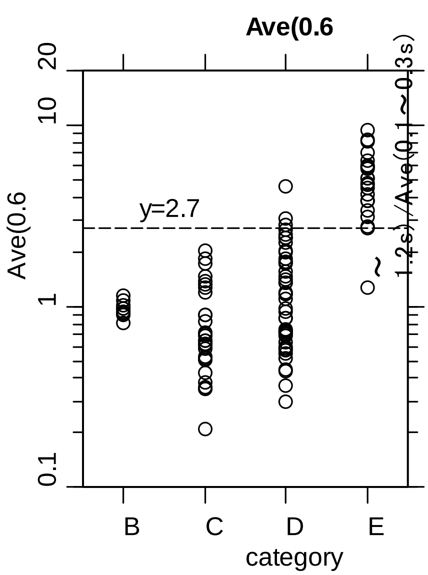

Fig. 6 - Criterion to classify class E

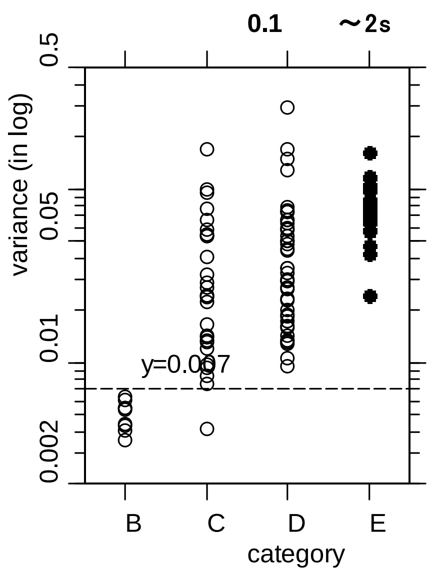

Fig. 7 - Criterion to classify class B

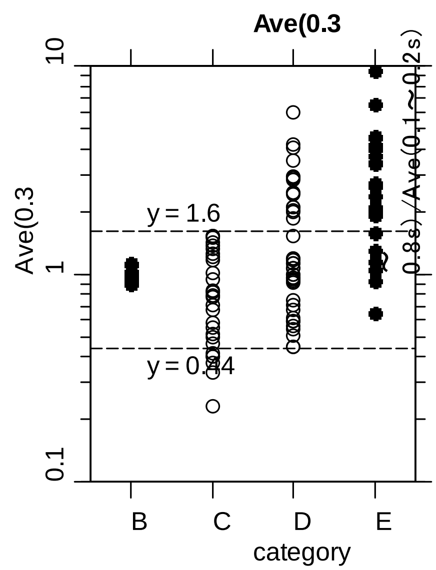

Fig. 8 - Criterion to classify classes C and D

Table 2 - Comparison of classifications by microtermors and by PS-logging data

PS-logging

Microtremor	B	C	D	E	sum
B	3	2	0	0	**5**
C	0	17	5	0	**22**
D	0	4	18	2	**24**
E	0	0	4	18	**22**
sum	**3**	**23**	**27**	**20**	**73**

Total Accuracy
77%

Table 3 - Comparison of classifications by geo-morphologic data and by PS-logging data

PS-logging

Geomorphologic Classification	B	C	D	E	sum
B	1	5	0	0	**6**
C	2	14	6	0	**22**
D	0	4	20	18	**42**
E	0	0	1	2	**3**
sum	**3**	**23**	**27**	**20**	**73**

Total Accuracy
51%

4. Site Effects on Response Spectra

By using the criteria for site classification, the target strong motion sites are classified into 30 class B sites, 153 class C sites, 207 class D sites and 77 class E sites. As shown in Fig. 9, the spatial distribution of sites with each site class is almost uniform. The peak accelerations and velocities at site class B which is considered to be a reference site are about 0.45 g and 25 cm/s in average, respectively. This indicates that the records at target sites have strong motion level. To discuss site effects on the strong motion records, the average spectrum for each site class is calculated and shown in Fig.10. The velocity response spectra tend to be constant with period at class B. The spectral amplitudes become larger at softer site classes. At site class E, the amplitudes tend to be larger at around 1 second.

The average and standard deviation of the peak horizontal accelerations at site class B are 0.45 g and 0.19 g, respectively. The relatively smaller deviation suggests that the shaking level inputted to the bedrock in the area may not have large difference. Therefore, the ratio of the average spectrum at class C, D or E with respect to that at class B is considered to be an approximate of site amplification. The spectral ratios are shown by thick lines in Fig. 11. The amplifications of site classes C and D to B are almost two, and rather similar to each other. The amplification of site class E to B, however, is larger at longer periods and smaller at short periods, showing stronger site effects.

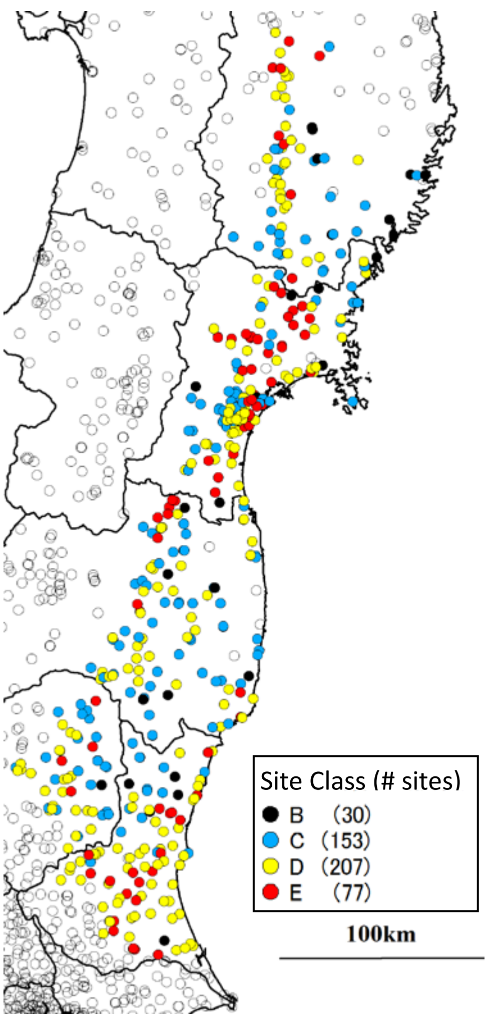

Fig.9 – Distribution of site class

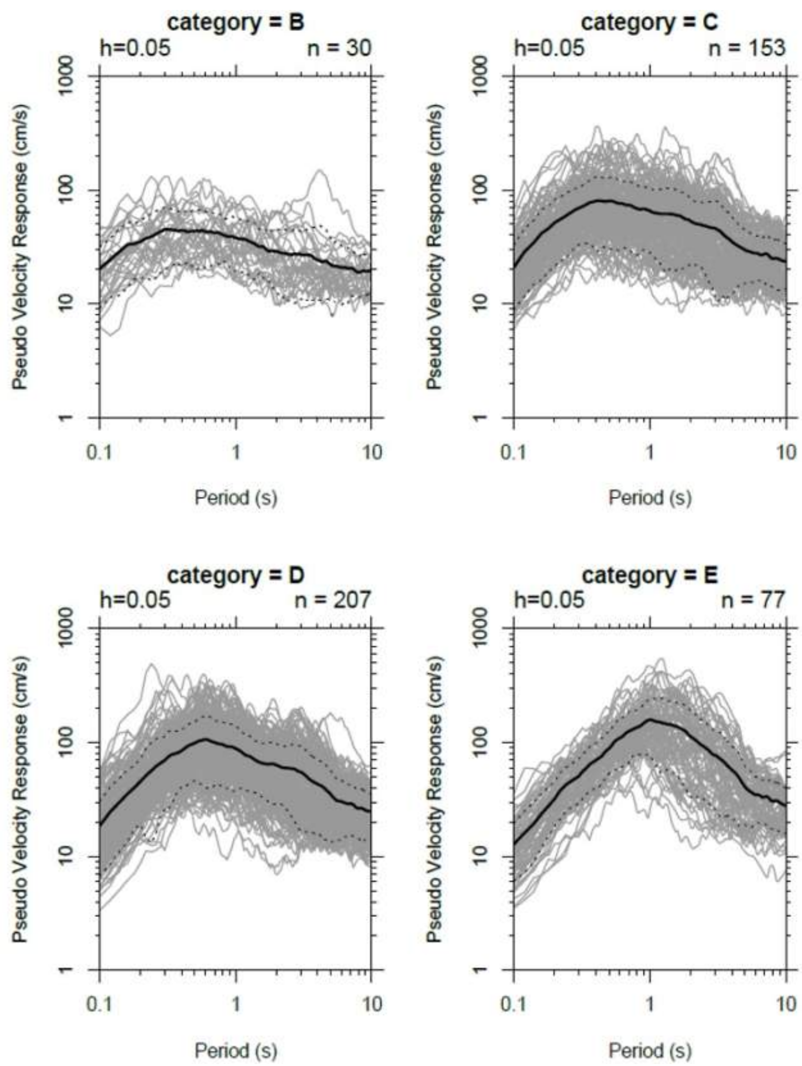

Fig. 10 – Average velocity response spectra and standard deviation

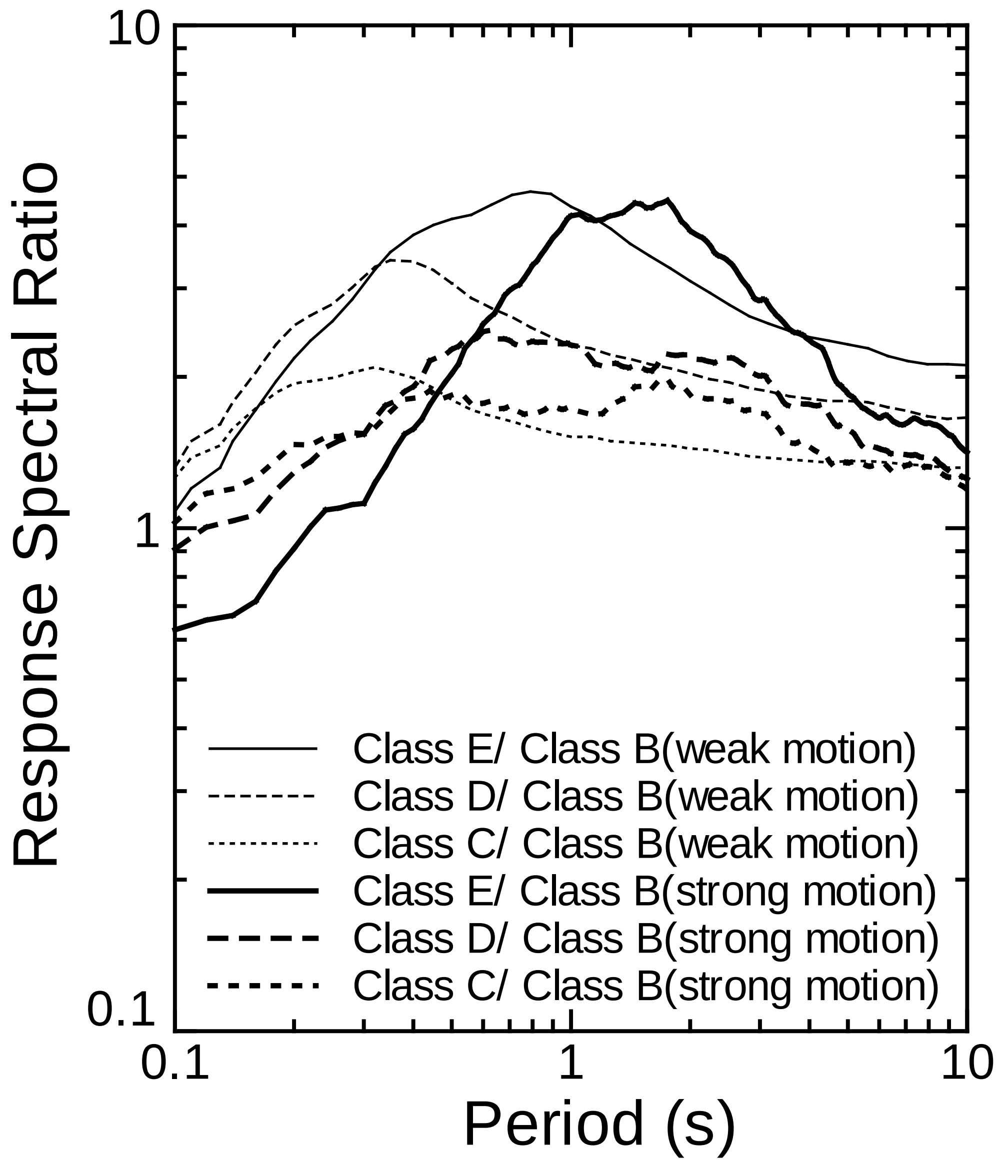

Fig. 11 – Comparison of site amplification from strong motion with that from weak motion

The amplification is considered to be in strong motion level at which the peak acceleration at site class B is approximately 0.5 g. The amplification in weak motion level has been derived with respect to V_{s30} from weak motion records whose the peak accelerations are smaller than 0.1 g [8]. Assuming the V_{s30} corresponding to site classes B, C, D and E are 900, 450, 270 and 140 m/s, respectively, the amplification of site classes C, D and E to B are calculated for weak motion and shown by thin lines in the figure. In general, the amplification for strong motion is much smaller at short periods and slightly larger at longer periods that that for weak motion. The difference in both amplifications is smaller at site class C (stiff site) and larger at site class E (soft site). The results are consistent with previous observations at soft soil sites in which the amplification factors become smaller and the predominant periods of ground become longer with increase of amplitude level of ground motion [9-12]. The amplification for strong motion shown in this study is preliminary one, and the further study will promise to quantify nonlinear site factor from strong motion records.

5. Conclusions

The strong motion records in the high seismic intensity area of the 2011 Tohoku, Japan earthquake are used to discuss site effects at strong shaking level. The strong motion sites in the high intensity area are classified into classes B, C, D and E sites from the results of microtremor measurements. The site amplification is preliminarily evaluated from the ratio of the average spectrum at class C, D or E with respect to that at class B. The amplifications of site classes C and D to B are almost two, and rather similar to each other. The amplification of site class E to B, however, is larger at longer periods and smaller at short periods, showing stronger site effect. The amplification is compared with the site amplification derived from weak motion records. The difference in both amplifications indicates effects of nonlinear soil response at strong shaking level.

Acknowledgements

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