EVALUATION OF SITE AMPLIFICATIONS IN JAPAN USING SEISMIC MOTION RECORDS AND A GEOMORPHOLOGIC MAP

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Abstract: In this study, the characteristics of site amplification at seismic observation stations in Japan were estimated using the attenuation relationship of each station's response spectrum after the 2011 off the Pacific coast of Tohoku earthquake. At KiK-net stations, the station correction factor at each station was compared to the transfer functions between the base rock and the surface. For each station, the plot of the station correction factor versus period was similar in shape to the graphs of the transfer function (amplitude ratio versus period). Therefore, the station correction factors at KiK-net stations are effective for evaluating site amplifications considering the period of ground shaking. In addition, the station correction factors were evaluated with respect to geomorphologic classifications using a geographic information system (GIS) dataset, allowing further analysis of site amplification characteristics.

INTRODUCTION

Ground motion observed at the surface is dominated by different influences such as the source characteristics, the propagation path, and the amplification characteristics of the ground surface. The amplification characteristics of the ground surface were estimated in several studies (e.g., Matsuoka and Midorikawa, 1995; Fukuwa *et al.*, 1998) for specific geographical areas of Japan and the entire area of Japan using using GIS datasets based on land classifications from digital national land information. Wakamatsu *et al.* (2004) proposed the Japan Engineering Geomorphologic Classification Map (JEGM) based on a new engineering-based geomorphologic classification scheme. A nationwide map of amplification factors is created using the shear wave velocity datasets for Japan (Matsuoka *et al.*, 2006; Fujimoto and Midorikawa, 2006) and is published by the Japan Seismic Hazard Information Station (J-SHIS). This map is widely used when estimating the seismic intensity distribution after damaging earthquakes (Maruyama *et al.*, 2010; Shoji and Sakurai, 2011).

The seismic intensity distribution is commonly estimated using site amplification factors for the peak ground acceleration (PGA) and the peak ground velocity (PGV). However, it is difficult to consider the effects of periodic components using only these amplification factors. Yamauchi *et al.* (2001) estimated the site amplification characteristics at seismic observation stations in Japan using the attenuation relationship of each site's response spectrum and determined the site amplification factors for each period of ground shaking. However, that study examines only 77 seismic observation stations.

Presently, the nationwide seismic observation networks K-NET and KiK-net are deployed by the National Research Institute for Earth Science and Disaster Prevention (NIED). During the 2011 Tohoku Earthquake, these networks recorded ground motion with a moment magnitude of 9.0. In this study, the site amplification characteristics at seismic observation stations are estimated based on the attenuation relationship of the response spectra using the K-NET and KiK-net ground motion records. The measurements of each site's station correction factor are compared with the results of Shabestari and Yamazaki (2000).

The specifications of the earthquake events used in this study are described in Table 1. Fig. 1 shows the locations of the earthquake source faults and the seismic observation stations used in this study. The fault models were developed by the Geospatial Information Authority of Japan (GSI; 2011a, 2011b, 2011c, 2011d). The station correction factors were obtained from the attenuation relationships of the velocity response spectra with a damping ratio of 5%.

ATTENUATION RELATIONSHIP OF THE RESPONSE SPECTRUM

This study used 1,870 seismic motion records that each had a maximum acceleration greater than 5 cm/s^2. These records were recorded by K-NET and KiK-net observation stations at 941 free field sites. Regression analysis was performed assuming an equation of form,

$$\log_{10} y(T) = b_0(T) + b_1(T)M_W + b_2(T)r + b_3(T)\log_{10} r + b_4(T)H + c_i(T), \tag{1}$$

where $y(T)$ is the maximum amplitude of the response spectra for the two horizontal components, M_W is the moment magnitude, r is the shortest distance from the fault in kilometers, h is the source depth of earthquake in kilometers, and the coefficients $b_i(T)$ are determined for each structural period T. The term $b_2(T)r$ represents anelastic attenuation, and the term $b_3(T)\log_{10}$ r represents geometric spreading. The geometric constant b_3 is assumed to be -1 (Molas and Yamazaki, 1995). The term $b_4(T)$ represents the effects of the focal depth for each period. The term $c_i(T)$ is the station correction factor, which adjusts for site-specific amplification characteristics for a given period, assuming a mean of zero for all stations. Comparisons between the attenuation relationships found in this study and those found in Shabestari and Yamazaki (2000) are shown in Fig. 2.

When the minimum distance between the fault and the station is less than 200 km, the attenuation relationship for a period of 0.2 s is significantly larger in this study than in Shabestari and Yamazaki (2000). For a period of 1.0 s, the attenuation relationship has no significant differences in comparison to Shabestari and Yamazaki (2000). These characteristics of the attenuation relationships were a result of the periodic components of the ground motion. Because the ground motion records in the district of Tohoku during the 2011 Tohoku Earthquake consisted mainly of the short period components, the attenuation relationship for a period of 0.2 s in this study is much larger than that of Shabestari and Yamazaki (2000).

EVALUATION OF THE STATION CORRECTION FACTORS

Comparison with the transfer function

Station correction factors represent site-specific amplification characteristics at seismic observation stations (Yamauchi *et al.*, 2001; Molas and Yamazaki, 1995). At each KiK-net station used in this study, the station correction factor plot was compared to the site's transfer functions. The transfer function between the base rock and the ground surface is expressed in the form,

$$H(f) = \frac{S_{xy}(f)}{S_{xx}(f)} \ , \tag{2}$$

where $S_{xx}(f)$ is the power spectrum of the acceleration at the base rock and $S_{xy}(f)$ is the cross spectrum of the acceleration between the base rock and the ground surface. A smoothing technique was employed using a Parzen window with a bandwidth of 0.2. An example comparison between a site's transfer functions and its plot of station correction factors versus period is shown in Fig. 3b.

A ground motion record with a PGA of 1,169 cm/s^2 was observed at the KiK-net Haga station (TCGH16) during the main shock. As shown in Fig. 3, the plot of station correction factor versus period is similar in shape to that of the transfer functions (amplitude ratio versus period) at that site. Figure 4 compares transfer function plots with the respective plots of station correction factor versus period at other sites. Similarly, the shape of station correction factor plot is similar to that of the transfer functions. According to the results, station correction factors are effective for evaluating site amplification versus period during ground shaking.

Illustration of station correction factors for different periods

The station correction factors obtained in this study were compared spatially to GIS data using regression analysis. In the regression analysis, the average value of the station correction factor was set equal to 0 so that a positive or negative station correction factor corresponded to sites that were more or less sensitive to ground shaking, respectively.

Figure 5 illustrates the distribution of the station correction factors for periods of 0.2 s, 1.0 s, and 5.0 s. In the Kanto district, a higher number of sites with positive station correction factors are observed at longer periods. However, in the eastern Tohoku district, seismic observation stations are found to be more sensitive to short period components of ground motion.

Station correction factors with respect to geomorphologic classification

The station correction factors estimated in this study were compiled with respect to geomorphologic classifications from GIS measurements, which consist of 250 × 250 m grid cells throughout Japan. The geomorphologic classifications are published on the J-SHIS website (Fig. 6). The grid cells are categorized by geomorphologic characteristics into 24 classes.

Figure 7 shows the station correction factors with respect to geomorphologic classification. The red lines indicate the mean values. The station correction factors at sites classified as mountain, hill, and gravel terrace show positive values at periods shorter than 0.5 s. However, factors at sites classified as back marsh, delta and coastal lowland, reclaimed land, and filled land have larger values at periods of approximately 1.0 s and show positive values when the period is longer than 0.5 s. The station correction factors in other geomorphologic classifications such as alluvial fan, natural levee, and valley bottom lowland show peak values at periods of 0.5–1.0 s. These results coincide with the characteristics observed in ground motion records, showing the effects of geomorphologic conditions on ground motion records.

CONCLUSIONS

In this study, the site amplification characteristics at seismic observation stations in Japan were estimated based on the attenuation relationships of response spectra after the 2011 Tohoku Earthquake. The station correction factors were compared with their respective transfer functions, which represent the amplification characteristics the base rock and the surface at KiK-net seismic observation stations. According to the results, for each station the plot of station correction factor versus period is similar in shape to the plotted transfer functions for that station. Therefore, the station correction factors are an effective tool for evaluating site amplification versus period during ground shaking.

Furthermore, the station correction factors were evaluated with respect to geomorphologic classification using GIS. Based on these results, sites classified as mountain, hill, and gravel terrace, which are associated with hard soil conditions, are sensitive to the short period components of ground motion. Sites associated with soft soil conditions are sensitive to the long period components of ground motion. These results are congruent with known tendencies of ground motion characteristics that reflect the effects of geomorphologic conditions.

REFERENCES:

Fujimoto, K. and Midorikawa, S., 2006. Empirical estimates of site amplification factor from strong-motion records at nearby station pairs. Proceedings of the 1st European Conference on Earthquake Engineering and Seismology, Paper No. 251.

Fukuwa, N., Arakawa, M. and Nishizaka, R., 1998. Estimation of soil amplification factor using digital national land information. Journal of Structural Engineering, Vol. 44B, pp. 77-84 (in Japanese).

Geospatial Information Authority of Japan, 2011a. http://www.gsi.go.jp/common/000060189.pdf

Geospatial Information Authority of Japan, 2011b. The 2011 off the Pacific coast of Tohoku Earthquake: Crustal Deformation and Fault Model, http://www.gsi.go.jp/cais/topic110422-index.html.

Geospatial Information Authority of Japan, 2011c. http://www.gsi.go.jp/common/000060655.pdf

Geospatial Information Authority of Japan, 2011d. http://www.jishin.go.jp/main/chousa/11may/p26.htm

Japan Seismic Hazard Information Station (J-SHIS), 2012. http://www.j-shis.bosai.go.jp/

Maruyama, Y. Yamazaki, F., Mizuno, K., Tsuchiya, Y. and Yogai, H., 2010. Fragility curves for expressway embankments based on damage datasets after recent earthquakes in Japan. Soil Dynamics and Earthquake Engineering, Vol. 30, No. 11, pp. 1158-1167.

Matsuoka, M. and Midorikawa, S., 1995. GIS-based integrated seismic hazard mapping for a large metropolitan area. Proceedings of the 5th International Conference on Seismic Zonation, Vol. 2, pp. 1334-1341.

Matsuoka, M., Wakamatsu, K., Fujimoto, K. and Midorikawa, S., 2006. Average shear-wave velocity mapping using Japan Engineering Geomorphologic Classification Map. Journal of Structural Engineering and Earthquake Engineering, Japan Society of Civil Engineers, Vol.23, No.1, pp. 57s-68s.

Molas, G.L. and Yamazaki, F., 1995. Attenuation of earthquake ground motion indices in Japan including deep

focus event. Bulletin of the Seismological Society of America, Vol. 85, pp. 1343-1358.
Shabestari K.T., and Yamazaki, F., 2000. Attenuation relation of response spectra in Japan considering site-specific term. Proceedings of the 12th World Conference on Earthquake Engineering, ref. No. 1432.
Shoji, G. and Sakurai, T., 2011. Analysis on Failure Modes of Road Structures due to the Slope Failures in the 2008 Iwate-Miyagi Earthquake and Development of the Related Damage Function. Journal of Japan Association for Earthquake Engineering, Vol. 11, No. 5, pp. 94-106 (in Japanese).
Wakamatsu, K., Matsuoka, M., Hasegawa, K., Kubo, S. and Sugiura, M., 2004. GIS-based engineering geomorphologic map for nationwide hazard assessment. Proceedings of the 11th International Conference on Soil Dynamics & Earthquake Engineering and 3rd International Conference on Earthquake Geotechnical Engineering, Vol.1, pp. 879886.
Yamauchi, Y., Yamazaki, F., Wakamatsu, K. and Shabestari, K.T., 2001. Relationship between geomorphological land classification and spectrum amplification ratio derived from attenuation relations. Journal of Japan Society of Civil Engineers, No.682/I-56, pp.195-205 (in Japanese).

Table 1: Specifications of earthquake events used in this study.

Earthquake	Date and time of occurrence	Epicenter	Moment magnitude (M_W)	Focal depth (km)
Foreshock	2011/3/9 11:45	Off the coast of Sanriku	7.3	8
Mainshock	2011/3/11 14:45	Off the coast of Sanriku	9.0	24
Induced earthquake 1	2011/4/11 17:16	Inland Fukushima	6.6	6
Induced earthquake 2	2011/4/12 8:08	Off the coast of eastern Chiba	6.4	26

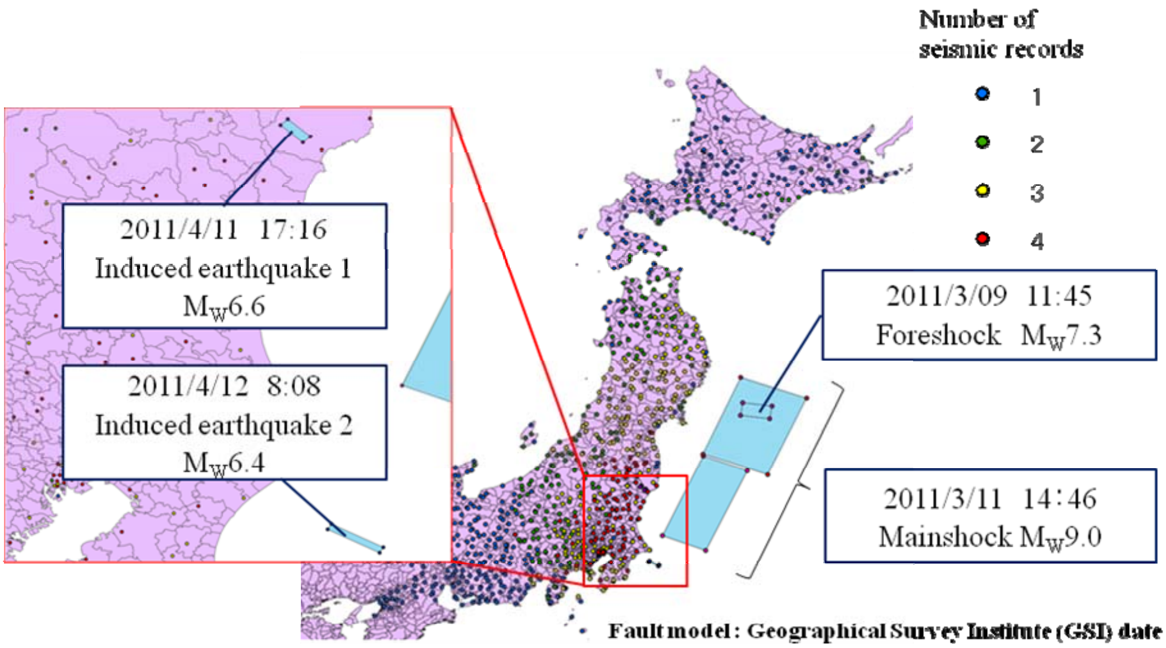

Figure 1: Earthquake source faults and the seismic observation stations used in this study.

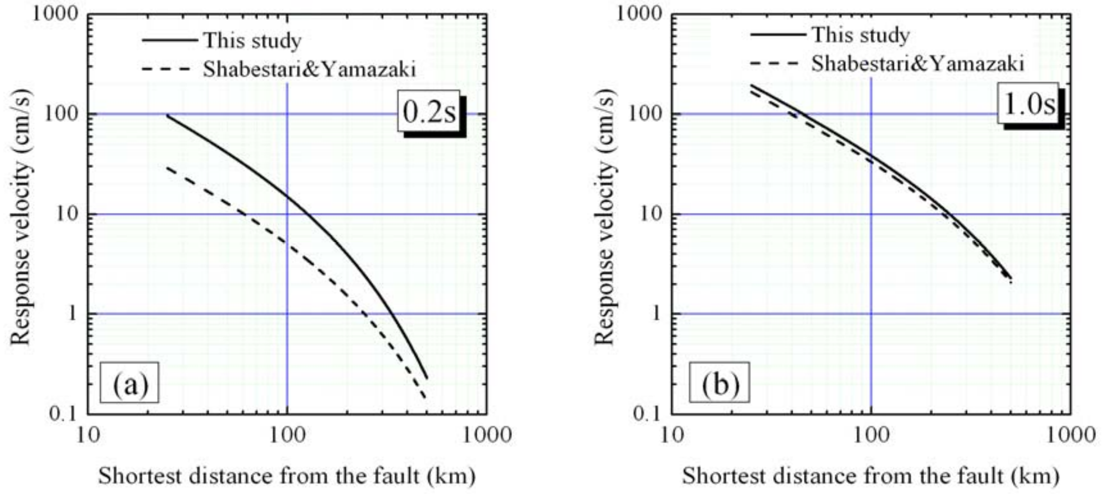

Figure 2: Comparison between the attenuation relationships constructed by this study and those by Shabestaria & Yamazaki (2000) for a period of (a) 0.2 s and (b) 1.0 s.

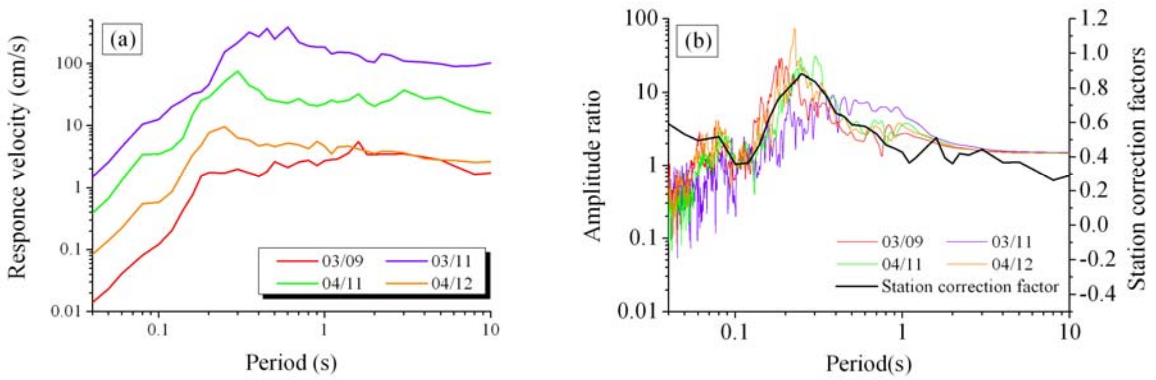

Figure 3: (a) Velocity response spectra with a damping ratio of 5% recorded at KiK-net Haga station. (b) Comparison between the transfer functions (colored lines) and the station correction factors (black line).

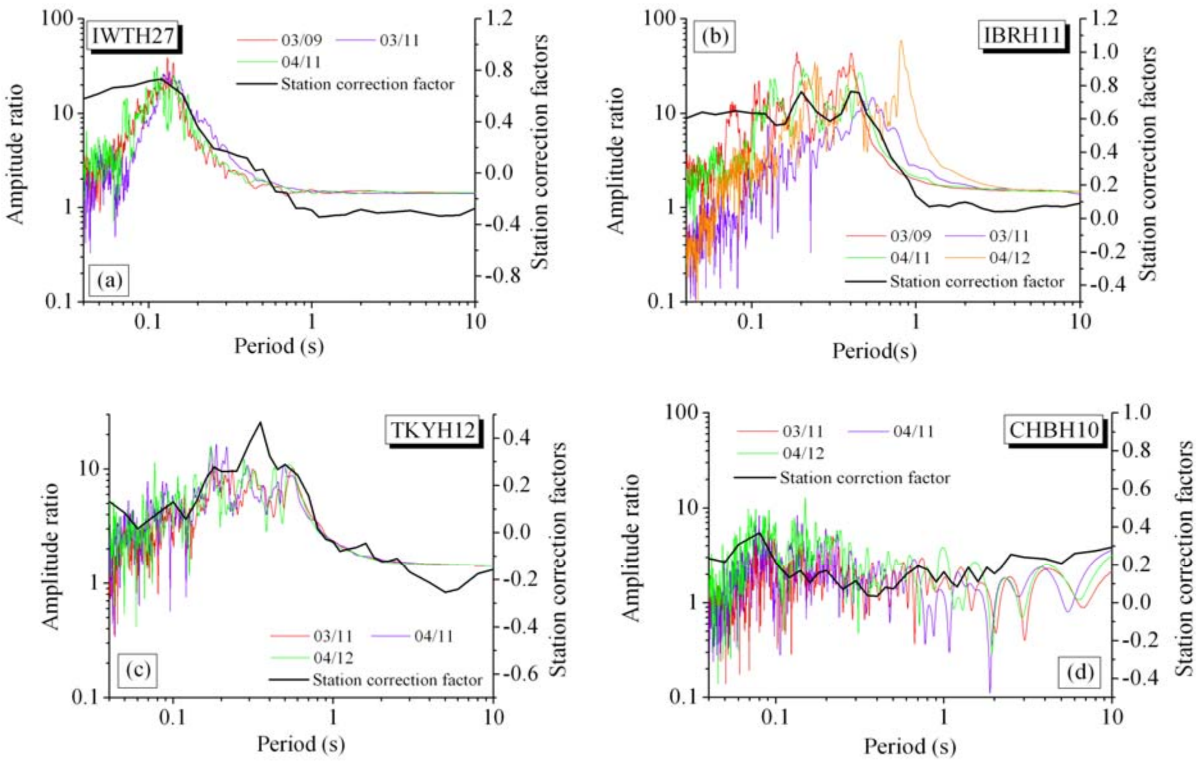

Figure 4: Comparison between the transfer functions for several dates (colored lines) and the station correction factor (black line) at (a) KiK-net Rikuzentakata (IWTH27), (b) KiK-net Iwase (IBRH11), (c) KiK-net Hachiohji (TKYH27), and (d) KiK-net Chiba (CHBH10) stations.

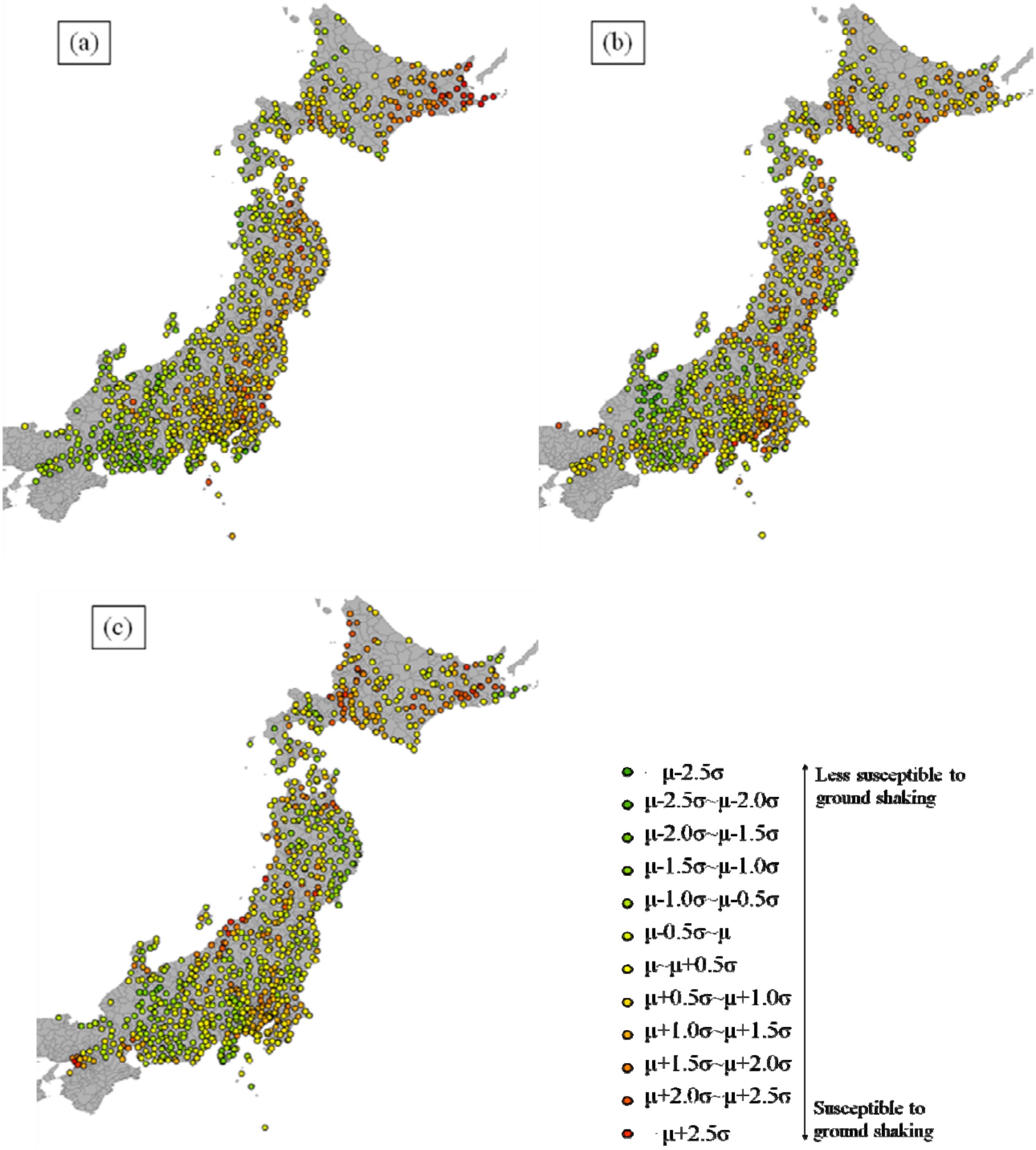

Figure 5: Illustration of station correction factors for the period of (a) 0.2 s, (b) 1.0 s, and (c) 5.0 s.

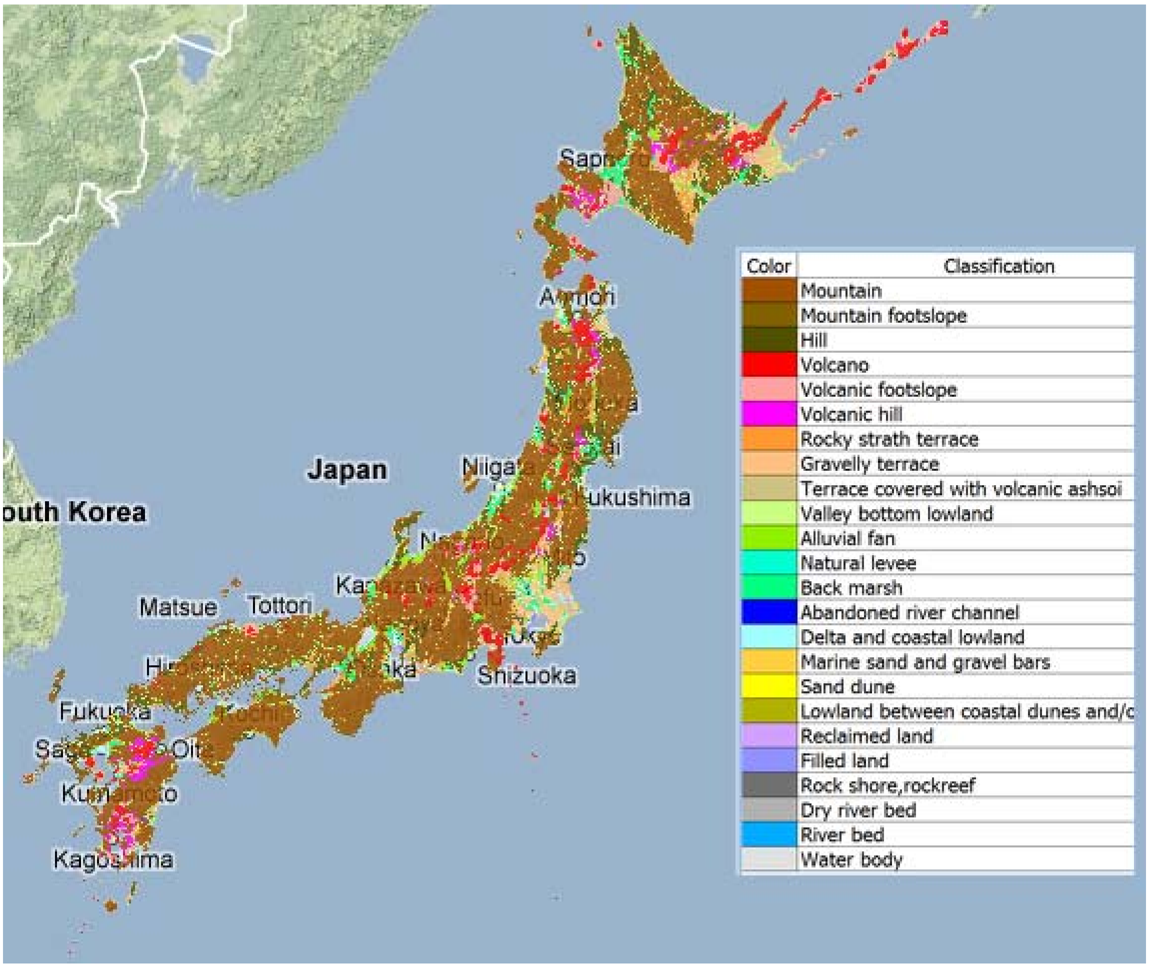

Figure 6: The geomorphologic classification map published on the website of Japan Seismic Hazard Information Station (J-SHIS, 2012)

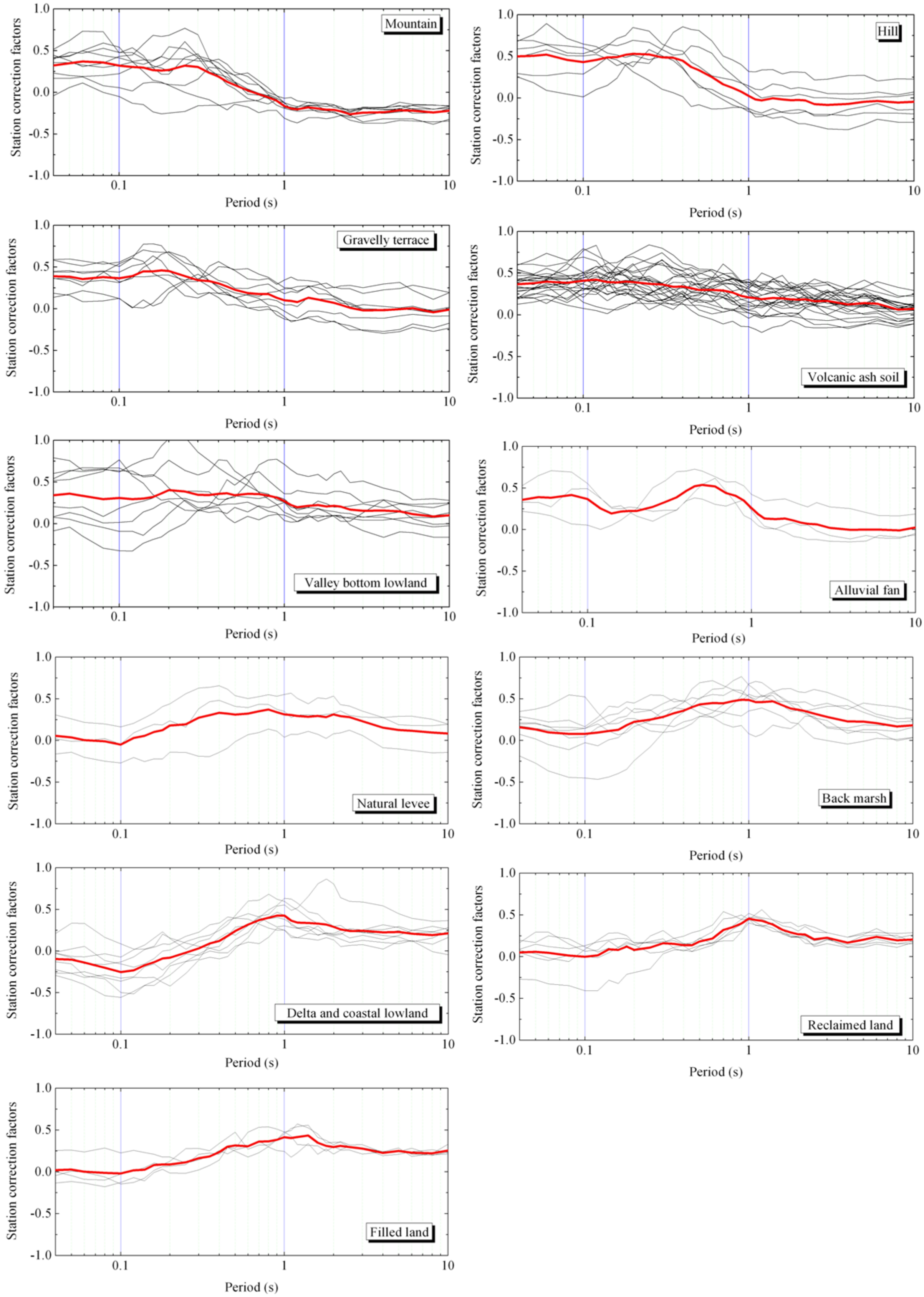

Figure 7: The station correction factors with respect to the geomorphologic classifications. The red line shows the average of the station correction factors.