EVALUATION OF SITE AMPLIFICATION CHARACTERISTICS BASED ON STATION CORRECTION FACTORS OF ATTENUATION RELATIONSHIP OF RESPONSE SPECTRUM

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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. Ground motion records observed after the 32 events were employed to construct the attenuation relationship. 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 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 and average S-wave velocities using a geographic information system (GIS) dataset. Lastly, the site amplifications for specific periods were estimated throughout Japan.

Keywords: attenuation relationship, response spectrum, station correction factor, average shear wave velocity.

1. 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; Yamazaki et al. 2000) for specific geographical areas of Japan and the entire area of Japan 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

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Table 1: Summary of the 32 earthquake events used in this study

Number of events	32
Number of records	9,734
Number of recording stations	1,699
Recording period	March 26 , 1997 to April 12 , 2011
Magnitude range	4.8 to 9.0 (Moment magnitude)
Depth range	6 to 146 km

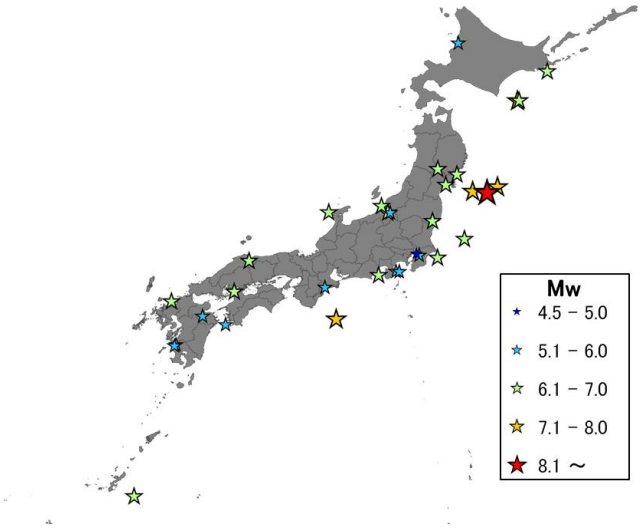

Figure 1: Locations of epicenters for the 32 earthquake events

used when estimating the seismic intensity distribution after damaging earthquakes (Maruyama et al. 2010).

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. Presently, the nationwide seismic observation networks K-NET and KiK-net are deployed in Japan 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.

Based on these backgrounds, 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 station correction factors were obtained from the attenuation relationships of the velocity response spectra with a damping ratio of 5%. Employing the JEGM, the site amplifications at specific periods are estimated throughout Japan.

2. ATTENUATION RELATIONSHIP OF RESPONSE SPECTRUM

This study compiled the ground motion records at K-NET and KiK-net stations observed during the 32 earthquake events. Table 1 summarizes the events, and Figure 1 shows the locations of

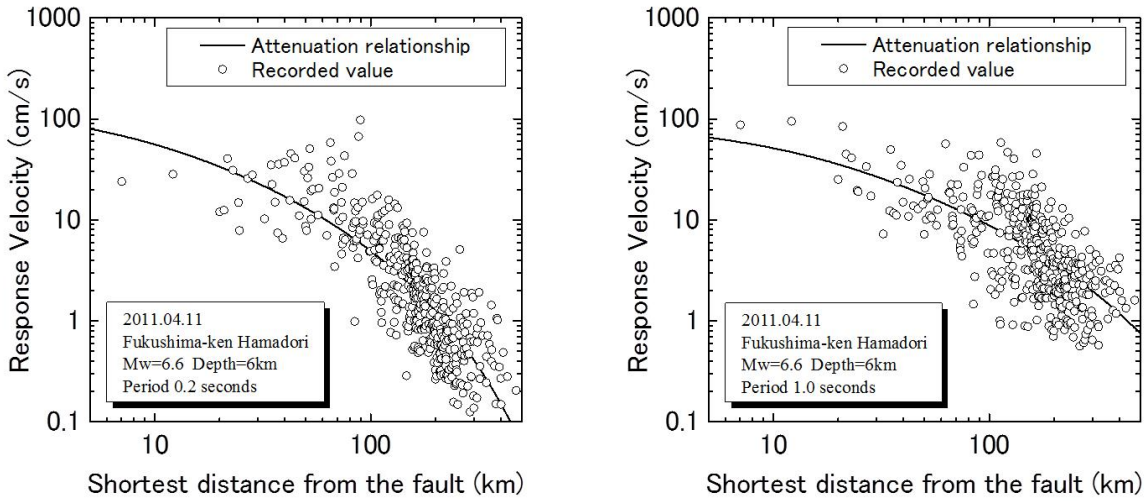

Figure 2: Attenuation relationship constructed by this study for a period of 0.2 s and 1.0 s

epicenters. The dataset consists of the events occurred from 1997 to 2011 including the 2011 Tohoku Earthquake with the moment magnitude (Mw) of 9.0.

To construct the attenuation relationship of response spectrum, regression analysis was performed assuming an equation of form,

$$\log_{10} y(T) = b_0(T) + b_1(T)Mw + b_2(T)r + b_3(T)\log_{10}(r + k(T)) + b_4(T)H + c_i(T) \quad (1)$$

where $y(T)$ is the amplitude of the response spectra in cm/s for the resultant of the two horizontal components, Mw 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. $k(T)$ is introduced accounting for the saturation of the amplitude of strong motion in the near-source area as a function of Mw (Si and Midorikawa 2000). $b_3(T)$ was assumed to be -1 (Molas and Yamazaki 1995). 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. Figure 2 shows the attenuation relationships for the period of 0.2 and 1.0 s. In the figure, the observed values during the earthquake occurred in Fukushima Prefecture on April 11, 2011 are also illustrated.

3. EVALUATION OF THE STATION CORRECTION FACTORS

3.1. Comparison with the transfer function

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,

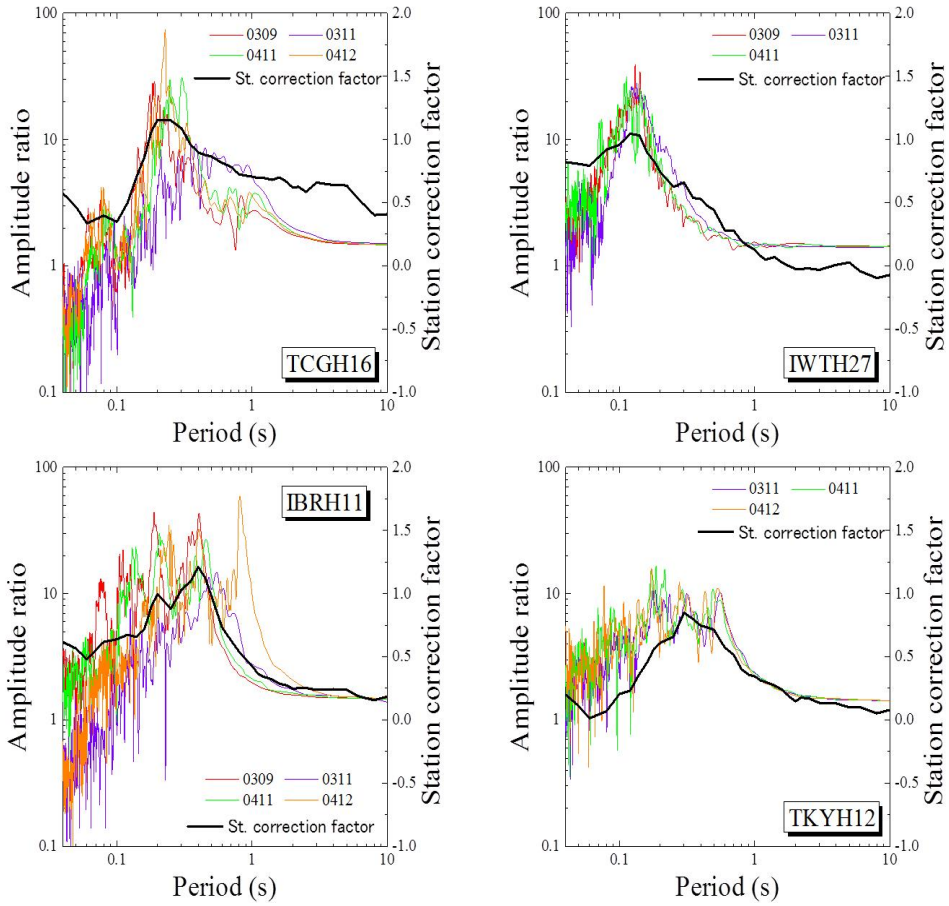

Figure 3: Comparison between the transfer functions for several dates (colored lines) and the station correction factor (black line) at KiK-net stations

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

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 Hz.

In the comparison with the transfer functions, the station correction factors were normalized with the reference of those at rock sites. The mean of the station correction factors were calculated among 10 sites whose shear wave velocity averaged over the upper 30 m (AVS30) is larger than 1000 m/s to be used as the reference, $c_r(T)$. Then, the station correction factors were normalized as,

$$c'(T) = c_i(T) - c_r(T) \tag{3}$$

Figure 3 compares between a site's transfer functions and its plot of station correction factors with the reference of rock site versus period. 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. According to the results, station correction factors are effective for evaluating site amplification versus period during ground shaking.

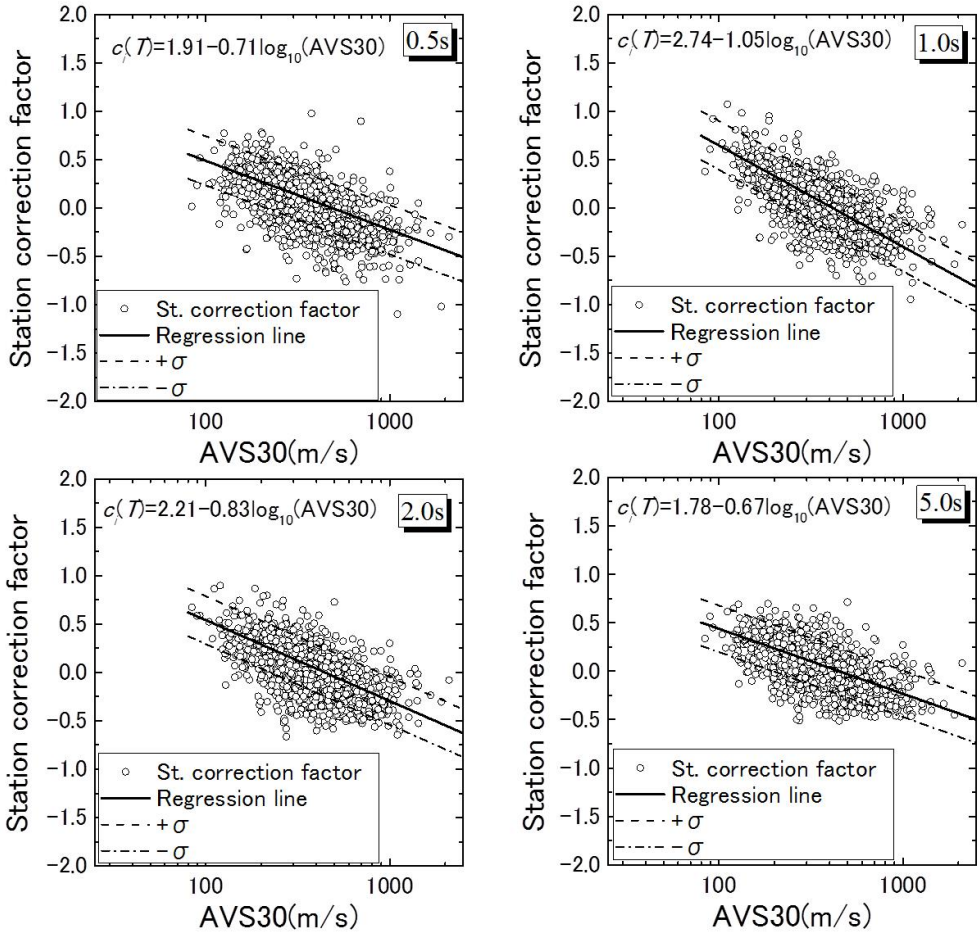

Figure 4: Relationship between the station correction factor and the AVS30 for a period of 0.5 s, 1.0 s, 2.0 s and 5.0 s

3.2. Relationship between the station correction factor and AVS30

Wakamatsu et al. (2004) developed the Japan Engineering Geomorphologic Classification Map (JEGM) based on a new engineering-based geomorphologic classification scheme. A nationwide AVS30 distribution map is created using the nationwide shear wave velocity datasets for Japan, which are available from K-NET and KiK-net survey sites, and the JEGM (Matsuoka et al. 2006). This study evaluates the relationship between the station correction factor and the AVS30. The AVS30 at the seismic observation station was calculated using the shear wave velocity profile based on the definition by Matsuoka et al. (2006).

Figure 4 shows the relationship between the station correction factor and the AVS30 for the specific periods. In the figure, the result of regression analysis assuming Eq.(4) is also illustrated.

$$c_i(T) = e_0(T) - e_1(T) \cdot \log_{10}(AVS30) \tag{4}$$

where $e_0(T)$ and $e_1(T)$ are the regression coefficients. According to the results, smaller station correction factors are observed under larger values of AVS30.

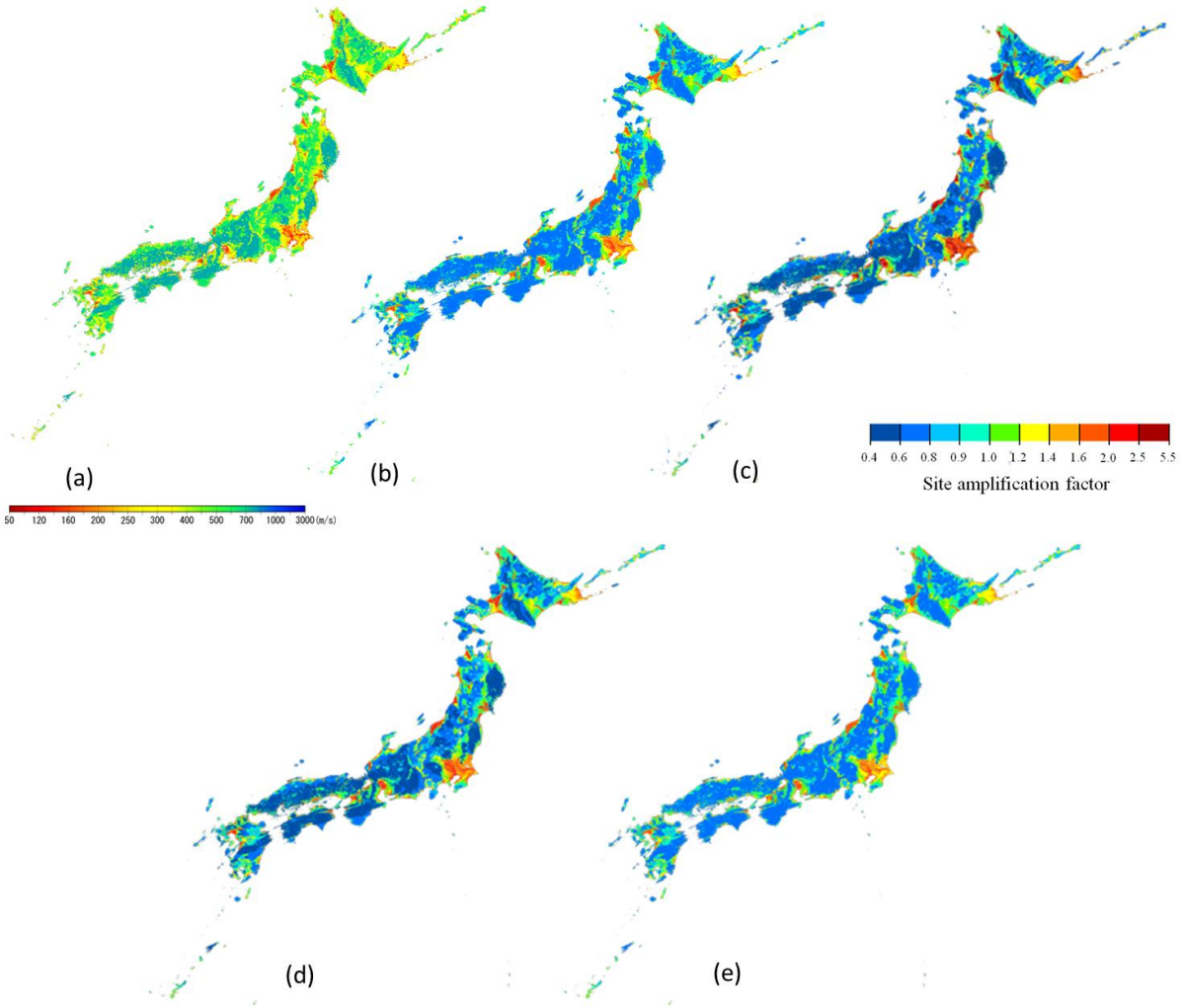

Figure 5: (a) Nationwide distribution of the AVS30 and those of the amplification factors of response spectrum for a period of (b) 0.5 s, (c) 1.0 s, (d) 2.0 s and (e) 5.0 s.

4. ILLUSTRATION OF AMPLIFICATION MAP THROUGHOUT JAPAN

The shear wave velocity averaged over the upper 30 m (AVS30) is used as an appropriate simplified site conditions term (Building Seismic Safety Council 2003). The nationwide AVS30 distribution map is also developed in Japan, and it can be downloaded at the website of the Japan Seismic Hazard Information Station (J-SHIS) operated by NIED (2013). The amplification factors of the peak ground velocity (PGV) are obtained based on the AVS30 distribution map (Fujimoto and Midorikawa 2006). The amplification factors, which are also available at the J-SHIS, are defined with respect to the outcrop base with a shear wave velocity of 400 m/s.

This study also employs the nationwide AVS30 distribution map to estimate the amplification factors of response spectrum for a given period. Assuming the linear relationship between the station correction factor and $\log_{10}$(AVS30) as shown in Fig. 4, the amplification factors were estimated for specific periods throughout Japan. Since the base outcrop is assumed to have a

uniform shear wave velocity of 400 m/s, Eq. (4) is adjusted such that $c_i(T) = 0$ when AVS30 = 400 m/s. Note that the amplification factor of the response spectrum with respect to the outcrop base is denoted as $10^{c_i(T)}$.

Figure 5 illustrates the nationwide distribution of the AVS30 compiled at the J-SHIS and those of estimated amplification factors of response spectrum for specific periods. The effects of periodic components of ground motions can be evaluated using these amplification maps.

5. CONCLUSIONS

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 station correction factors were compared with their respective transfer functions, which represent the amplification characteristics between 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 the shear wave velocity averaged over the upper 30 m (AVS30). Performing regression analyses, the linear relationships between the $\log_{10}$(AVS30) and the station correction factors for specific periods were constructed. Lastly, the nationwide distributions of amplification factors of response spectrum for specific periods were illustrated using the relationships.

The seismic intensity considering the effects of periodic components can be evaluated using the amplification factors estimated by this study. In a future study, earthquake induced damage to various structures will be evaluated with emphasis on periodic contents of ground shaking.

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