APPLICATION OF ON-SITE EARTHQUAKE EARLY WARNING BASED ON S-WAVE/P-WAVE RATIO TO KANTO BASIN, JAPAN

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Abstract

In a railway field of Japan, seismic stations have been installed at an interval distance of 10 kilometers to dozens of kilometers along a railway line. To stop moving trains immediately after an earthquake occurs, two types of earthquake early warnings (EEWs), which are based on the threshold of earthquake ground motions (on-site type) and the prediction of earthquake ground motions using initial P-wave (remote sensing type), are adopted. The on-site earthquake early warning for the threshold of earthquake ground motions are generally applied to S-wave dominated in seismic waves; therefore, Tsuno and Miyakoshi (2018) developed the method using the threshold of P-wave to issue EEW more rapidly than the method using the threshold of S-wave. In this study, we applyed the conventional method based on S-wave/P-wave ratio to data observed in the Kanto basin, Japan.

East Japan Railway Company has installed seismic stations of around 100 along railway lines spread in the Kanto basin. At first, we estimated the site amplification factors at the seismic stations, using both the seismic data on the surface by East Japan Railway Company and the seismic data on the borehole by KiK-net (National Research Institute for Earth Science and Disaster Resilience). We, then, estimated the site amplification factors for a frequency range of 0.2 to 10 Hz, which explain the deep sedimentary deposits in the Kanto basin.

To issue the on-site earthquake early warning for the threshold of earthquake ground motions earlier, we investigated the accuracy of the conventional method based on S-wave/P-wave ratio at the seismic stations. As the results in the frequency domain, the predicted S-waves by multiplying P-waves by S-wave/P-wave ratios at the seismic stations were in good agreements with the observations, reflecting both the site amplification factors of P-waves and S-waves in the Kanto basin. Therefore, we concluded that this conventinal method can potentially issue the on-site earthquake early warning earlier than the previous method.

Keywords: on-site earthquake early warning, S-wave/P-wave ratio, threshold of P-wave, Kanto basin, site amplification factor

1. Introduction

In a railway field of Japan, seismic stations have been installed at an interval distance of 10 kilometers to dozens of kilometers along a railway line. To stop moving trains immediately after an earthquake occurs, two types of earthquake early warnings (EEWs), which are based on the threshold of earthquake ground motions (on-site type) and the prediction of earthquake ground motions using initial P-wave (remote sensing type) [1], are adopted. The on-site earthquake early warning for the threshold of earthquake ground motions are generally applied to S-wave dominated in seismic waves; therefore, the previous studies [2] [3] [4] developed the method using the threshold of P-wave to issue EEW more rapidly than the method using the threshold of S-wave. In this study, we applyed the conventional method based on S-wave/P-wave ratio to data observed in the Kanto basin, Japan, where East Japan Railway Company has installed seismic stations of around 100 along railway lines [3].

2. Data used in and around the Kanto basin

To evaluate site amplification factors in the Kanto basin, we used seismic data on the surface by East Japan Railway Company and seismic data on borehole by KiK-net (National Research Institute for Earth Science and Disaster Resilience: NIED), as shown in Fig.1. Totally, the number of 121 earthquakes occured in the period of 29th October, 2011 to 14th October, 2013 are used in this study. Location of earthquakes is shown in Fig.2.

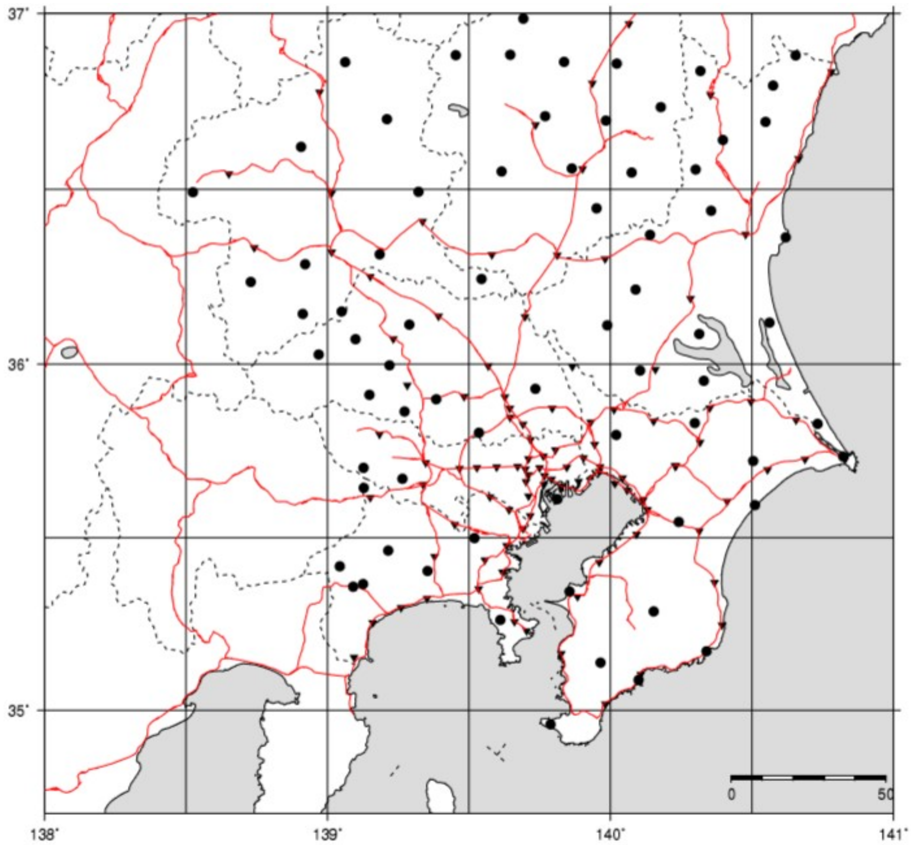


Fig. 1 – Location of seismic station used in this study

(▼: JRE, ●: KiK-net by NIED)

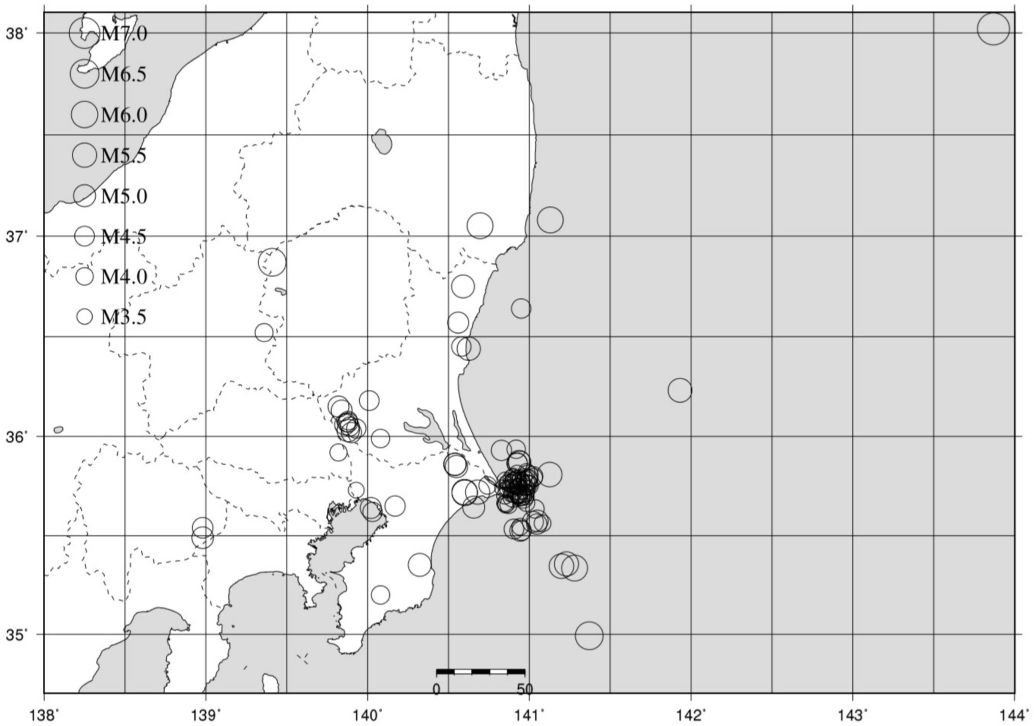
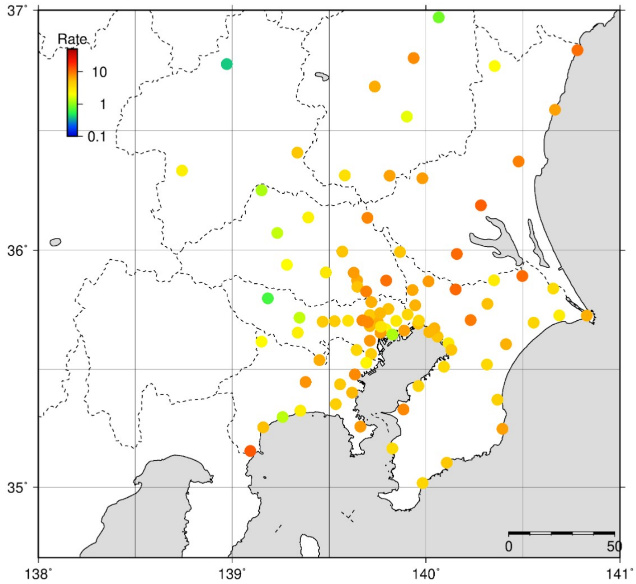


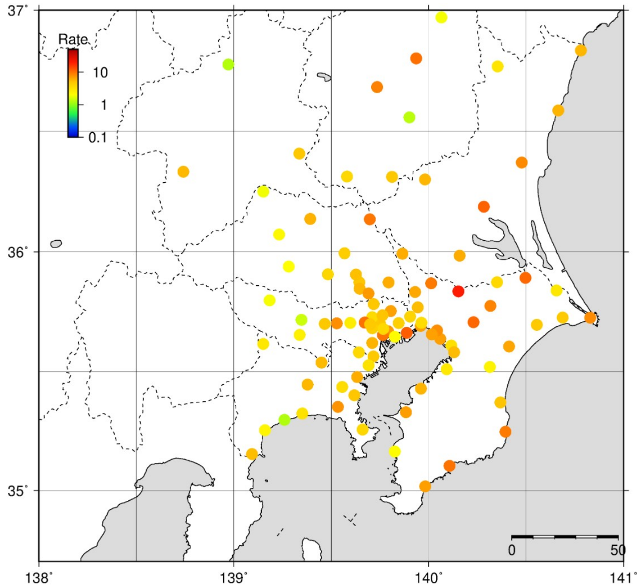
Fig. 2 – Location of earthquakes used in this study

3. Site amplification factors in the Kanto basin

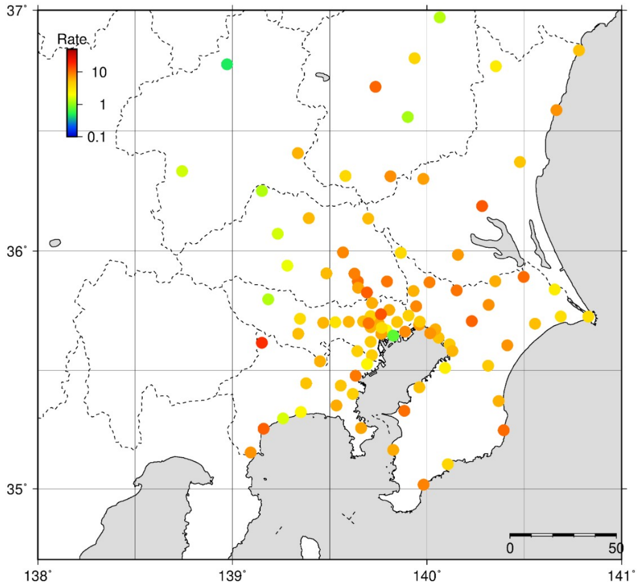
We estimated site amplification factors at the seismic stations, using both the seismic data on the surface by East Japan Railway Company (JRE) and the seismic data on the borehole by KiK-net (NIED). In this study, as the site amplification factors, spectral ratio of S-waves observed at the seismic stations of JRE on the surface to S-wave observed on the borehole at the seismic stations of NIED where are located at the most nearest stations of JRE were calculated. The time-window of 10.24 seconds for NS and EW components was used in the calculation of Fourier spectrum without the smoothing process. To calculate spectra ratio, we finally averaged Fourier spectrum for NS and EW components. Fig. 3 shows the spectral ratios at frequencies of 0.5, 1, 2, and 5 Hz at the seismic stations by JRE, in the Kanto basin. In this figures, the contrast of the spectral ratios increases as the frequency increase, indicating that the shallow subsurface structures has the characteristics of heterogeneity in the Kanto basin. On the other hands, the spectral ratios at a frequency of 0.5 Hz has even a certain value, due to a deep sedimentary deposits in the Kanto basin (e.g. Yamanaka and Yamada, 2003 [5]). To predict appropriately seismic ground motions excited by a deep sedimentary deposits in the Kanto basin, therefore, we need to estimate the site amplification factors for the wide range of frequency.



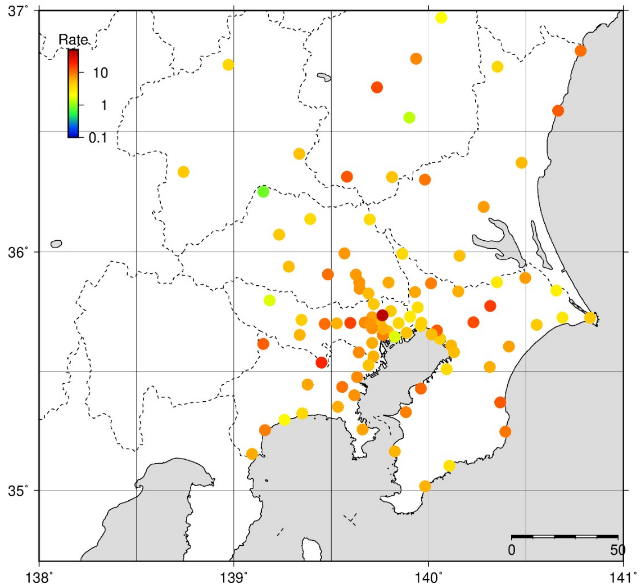
(a) Frequency of 0.5 Hz



(b) Frequency of 1 Hz



(c) Frequency of 2 Hz



(d) Frequency of 5 Hz

Fig. 3 – Spectral ratios at frequencies of 0.5, 1, 2, and 5 Hz at the seismic stations by JRE, in the Kanto basin

4. On-site earthquake early warning for the threshold of P-wave

4.1 Outline

Fig.4 shows a conceptual diagram of the proposed method for exceeding the threshold of the P-wave. As shown in Fig. 3, this method directly predicts the S-wave from the P-wave observed at the prediction site. Therefore, this simple method can potentially issue the earthquake early warning earlier than the previous method by the time of Ts-p.

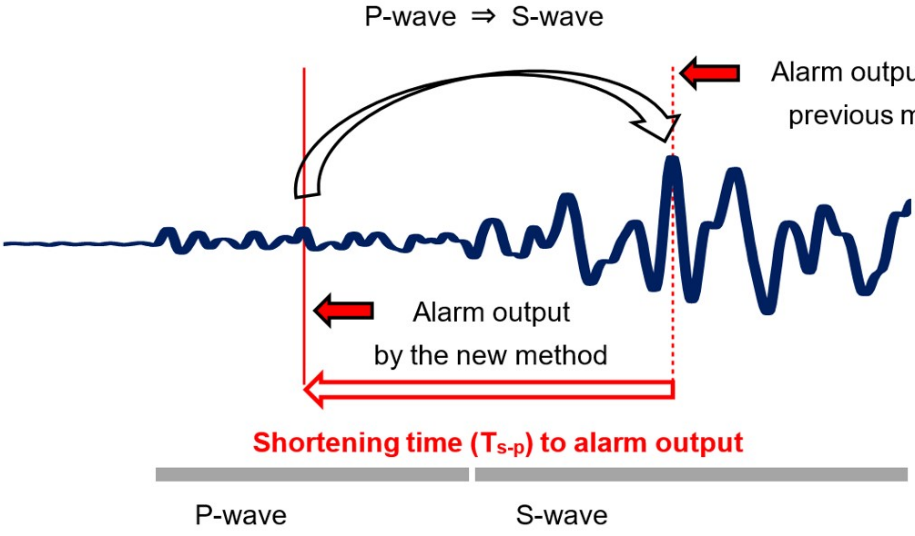


Fig. 4 – Conceptual diagram of the proposed method

4.2 Methodology

Assuming double couple of a point source, in the far-field earthquake, Fourier spectra of the P-waves and S-waves on the surface ground are expressed, as shown in the equation of (1) and (2) [4]. The relationship between P-wave and S-wave on the surface ground is influenced from the source effects, the path effects, and the site effects for both P-waves and S-waves.

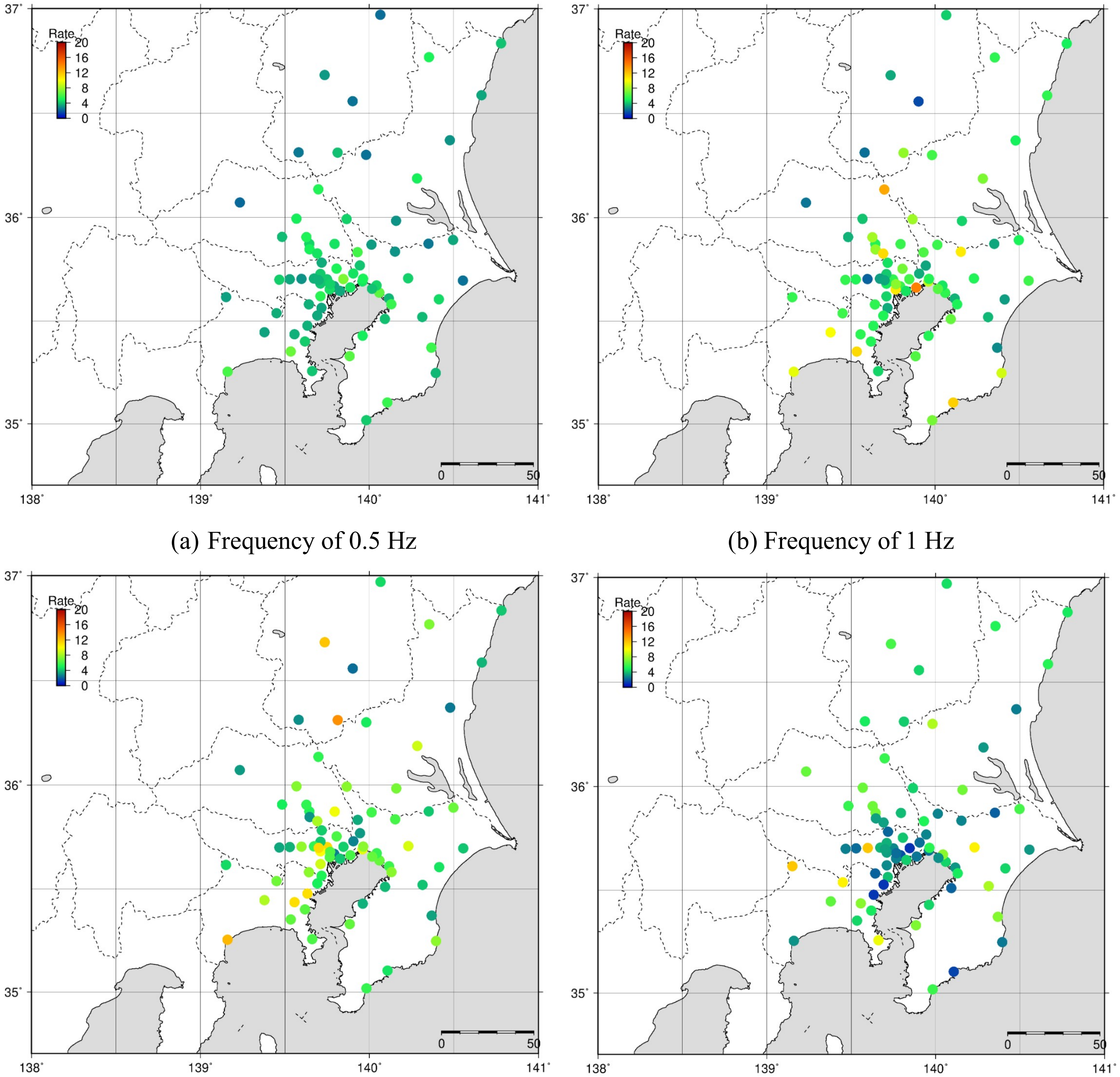
$$\log O_{\mathrm{s}}^{S}(\omega)=\log O_{\mathrm{s}}^{P}(\omega)+a_1(\omega)-a_2(\omega)+a_3(\omega) \tag{1}$$

$$a_1(\omega)=\log\frac{V_{\mathrm{P}}{}^3}{V_{\mathrm{S}}{}^3}+\log\frac{R_{\theta\phi}^{S}}{R_{\theta\phi}^{P}}+\log e^{\frac{r\omega}{2}\left(-\frac{1}{Q_{\mathrm{S}}V_{\mathrm{S}}'}+\frac{1}{Q_{\mathrm{P}}V_{\mathrm{P}}'}\right)},\quad a_2(\omega)=\log G^{P}(\omega),\quad a_3(\omega)=\log G^{S}(\omega) \tag{2}$$

Here, ω is an angular frequency, ρ and V are a density and a velocity of body waves around an earthquake source, r is the a source distance, $R_{\theta\phi}$ is a radiation coefficient, and Q is an internal attenuation at the crust. V' represents an average velocity of body waves in the crust. The upper suffixes of P and S indicate P-waves and S-waves and the lower suffix of s indicates the surface ground.

4.3 S-wave/P-wave ratios obtained in the Kanto basin

We estimated S-wave/P-wave ratios at the seismic stations, using the seismic data on the surface by East Japan Railway Company (JRE). In this study, as S-wave/P-wave ratios, spectral ratio of S-waves observed at the seismic stations of JRE on the surface to P-wave observed on the surface at the seismic stations of JRE. The time-window of 10.24 seconds was used in the calculation of Fourier spectrum without the smoothing process. Fig. 5 shows the S-wave/P-wave ratios (averaged for NS and EW components) at frequencies of 0.5, 1, 2, and 5 Hz at the seismic stations by JRE, in the Kanto basin. Compareing to the results for site amplification factors (Fig. 3), the results for S-wave/P-wave ratios has lower contrast for each frequency, due to the contribution of P-waves (See the equation of (1)).



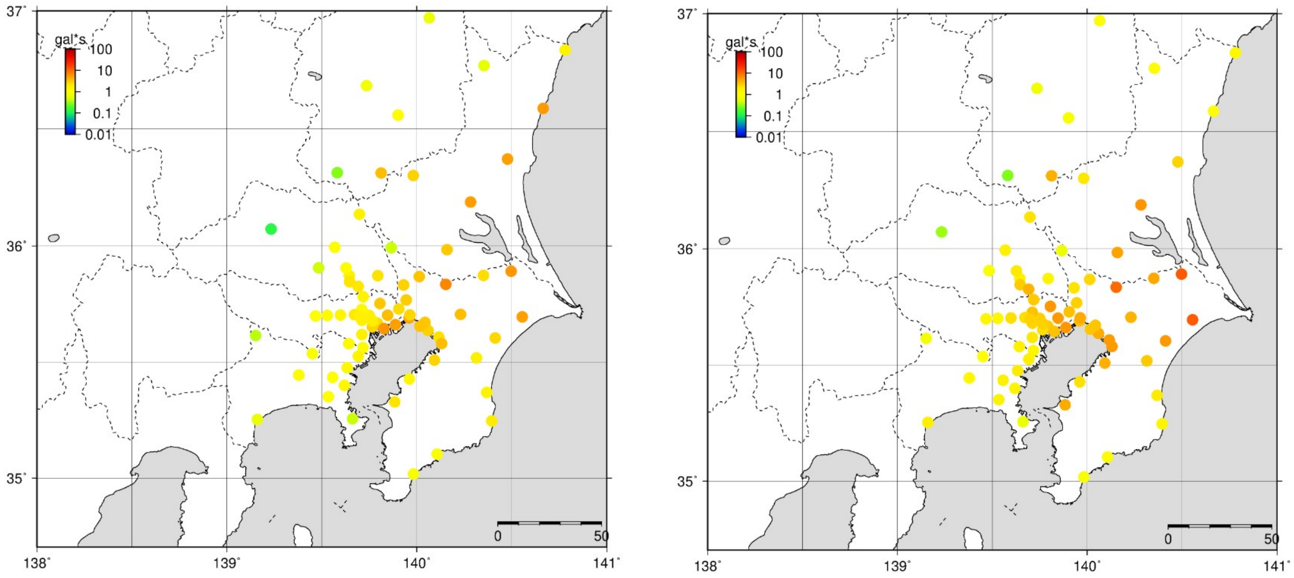
(a) Frequency of 0.5 Hz (b) Frequency of 1 Hz

(c) Frequency of 2 Hz (d) Frequency of 5 Hz

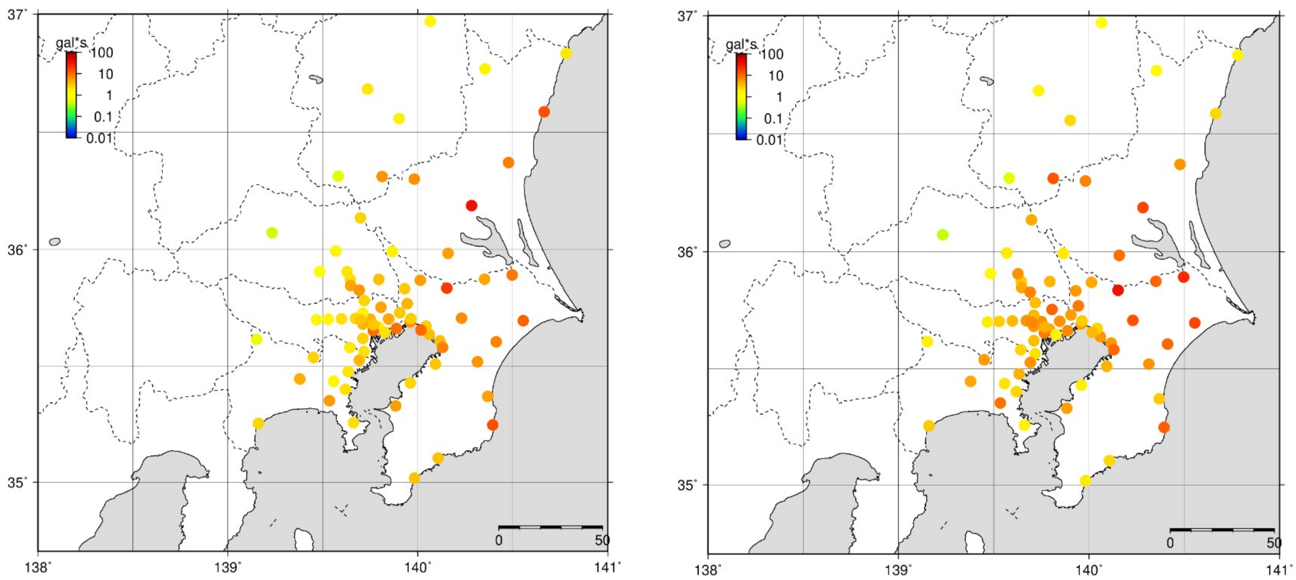
Fig. 5 – Spectral ratios of S-waves to P-waves at frequencies of 0.5, 1, 2, and 5 Hz on the surface of the seismic stations by JRE, in the Kanto basin

5. Accuracy of this method

We predicted S-wave in the frequency domain, multiplying S-wave/P-wave ratios prepared in advace (See Fig. 5) by P-wave observed at the seismic stations of JRE. Fig. 6 shows the accuray of this method by comparing of the predictions of S-wave to the observations of S-waves at frequencies of 1 to 2 Hz in the Kanto Basin. As the results in the frequency domain, S-waves predicted multiplying S-wave/P-wave ratios by P-waves at the seismic stations were in good agreements with the observations, reflecting both the site amplification factors of P-waves and S-waves in the Kanto basin.



(a) Observation (left) and prediction (right) at a frequency of 0.5 to 1 Hz



(b) Observation (left) and prediction (right) at a frequency of 1 to 2 Hz

Fig. 6 – Comparison of the predictions of S-wave to the observations of S-waves at frequencies 0.5 to 2 Hz

6. Conclusion

We estimated the site amplification factors for a frequency range of 0.1 to 10 Hz, which explain the deep sedimentary deposits in the Kanto basin, using both the seismic data on the surface by East Japan Railway Company and the seismic data on the borehole by KiK-net.

To issue the on-site earthquake early warning for the threshold of earthquake ground motions earlier, we investigated the accuracy of the conventional method based on S-wave/P-wave ratio at the seismic stations. As the results in the frequency domain, the predicted S-waves by multiplying P-waves by S-wave/P-wave ratios at the seismic stations were in good agreements with the observations, reflecting both the site amplification factors of P-waves and S-waves in the Kanto basin. Therefore, we concluded that this conventinal method can potentially issue the on-site earthquake early warning earlier than the previous method.

Acknowledgements

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