

MICROTREMOR MEASUREMENTS FOR THE ESTIMATION OF SEISMIC MOTION ALONG EXPRESSWAYS

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ABSTRACT

In order to gather earthquake information at an early stage and to establish an efficient traffic control just after an earthquake, Japan Highway Public Corporation (JH) has been developing the new seismometer network along their expressways since the 1995 Kobe Earthquake. However variation of earthquake records was found, comparing with the records from the nearest stations of K-NET. In this study, the horizontal-to-vertical (H/V) Fourier spectrum ratios were calculated for microtremors observed at four JH seismic stations and four K-NET stations. The H/V ratios for the earthquake motions observed at these seismic stations were also calculated. It was observed that the H/V Fourier spectrum ratios for the microtremor and seismic motion are similar. Hence, using the H/V ratios for microtremor as quasi transfer functions, the earthquake records at the microtremor observation points can be predicted. This idea can be applied for the estimation of seismic motion along the expressway networks in Japan.

Introduction

Japan Highway Public Corporation (JH) owns expressway networks with a total length of 6,615 km (as of April, 2000). In order to gather earthquake information at an early stage and to establish an efficient traffic control just after an earthquake, JH had deployed 123 accelerometers along their expressways before the 1995 Kobe earthquake. Since the earthquake, JH has further deployed 202 new seismometers (Yamazaki et al., 2000). Currently, the average distance between adjacent seismometers is about 20 km together with the existing ones (Fig. 1). Using earthquake information from these instruments, JH closes their expressways if the peak ground acceleration (PGA) equal or larger than 80 cm/s^2 is recorded or reduces the maximum speed limit if the PGA equal or larger than 50 cm/s^2 is observed. However variation of earthquake records is often found in comparison with the records from neighboring seismic stations.

Figure 2 shows the acceleration response spectra of an earthquake recorded at JH Utsunomiya, K-NET Utsunomiya, and JMA (Japan Meteorological Agency) Utsunomiya stations. Note that 1,000 K-NET stations were deployed throughout in Japan by National Research Institute for Earth Science and Disaster Prevention (NIED), Science and Technology Agency. Although these three stations are located within a distance of 10 km, the spectral shape and amplitude of JH Utsunomiya station are quite different from those of the others. Because of the variation of earthquake records, the efficiency of traffic control after an earthquake is

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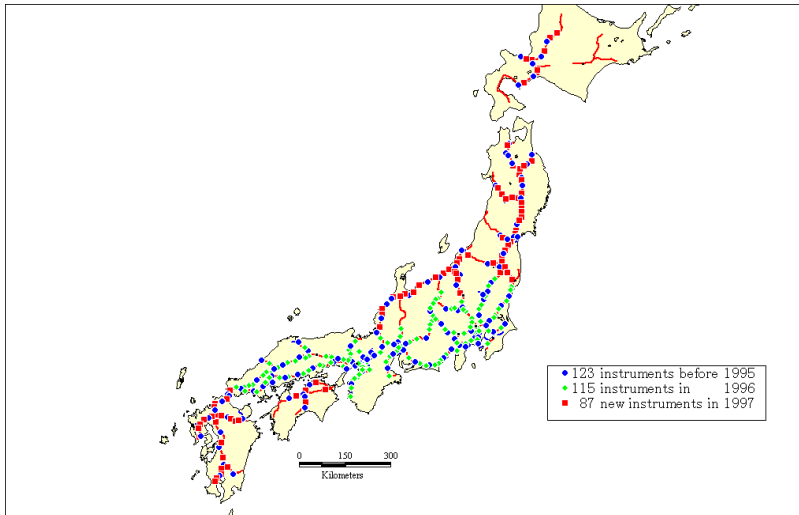


Figure 1. Location of accelerometers for expressways networks in Japan

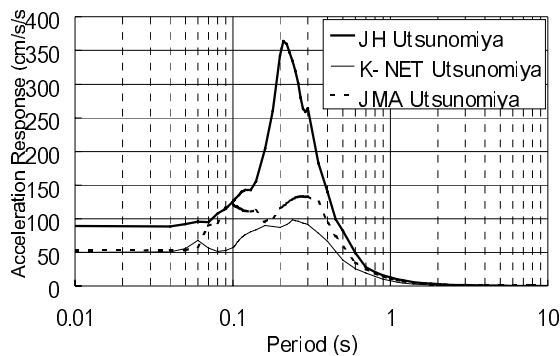


Figure 2. Acceleration response spectra around JH Utsunomiya station (EW component of June 24th, 1998 EQ)

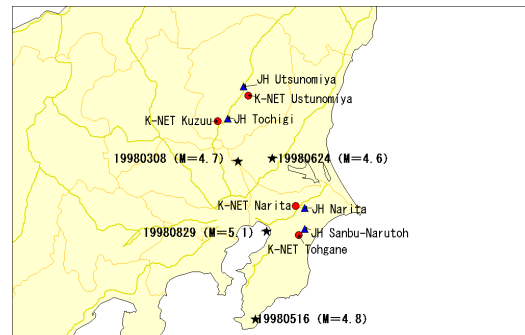


Figure 3. Location of seismic stations and epicenters of earthquakes used in this study

sometimes lost. Since the number of seismometers is not large enough to grasp the distribution of seismic motion along the expressway, the method to estimate the distribution based on sparsely deployed instruments is needed. In this study, using the horizontal- to-vertical (H/V) ratios of microtremors observed at JH seismic stations and the nearest K-NET stations, and using the earthquake records recorded at K-NET stations, the seismic motions at JH stations are predicted. Then the predicted seismic motions are compared with the recorded motions.

Comparison of H/V Spectrum Ratios of Microtremor and Earthquake Motion

Figure 3 shows the location of seismic stations and epicenters of earthquakes used in this study. Microtremor observation was conducted at four JH seismic stations and four K-NET stations. The distances between a JH station and its nearest K-NET station is equal or less than 10 km. Hence the effect of travel paths of seismic waves may be almost negligible to these pair stations.

The H/V Fourier spectrum ratios of earthquake motions recorded at the K-NET stations were calculated. Ten earthquake records were chosen at each station and the Fourier spectra smoothed by Parzen window with bandwidth 0.4 Hz were calculated. Then the H/V spectrum

ratios were calculated by

$$|R_{surface}(f)| = \sqrt{|F_{EW}(f)| |F_{NS}(f)|} / |F_{UD}(f)| \quad (1)$$

where $R_{surface}$ is the H/V spectrum ratio and F is the smoothed Fourier spectrum with suffix indicating two horizontal and vertical components.

Figure 4 shows the Fourier spectra for the EW and UD components at K-NET Utsunomiya and Figure 5 shows the corresponding H/V spectrum. Although the Fourier spectra for different events show wide variability in their amplitudes and some variability in their shapes, the H/V spectrum ratios fall in a narrow range of amplitude and shape. Yamazaki and Ansary (1997) explained this phenomenon by the attenuation relations of the velocity response spectra for the horizontal and vertical components.

The H/V spectrum ratios of microtremor were also calculated. Figure 6 compares the average H/V spectrum ratios of microtremor and earthquake motion at K-NET Utsunomiya station. The H/V ratio of microtremor is seen to be similar with that of earthquake motion. This similarity was also observed at all the other seismic stations in this study.

Nakamura (2000) explained the H/V spectrum ratio of microtremor using the wave propagation theory for the body waves. Based on this, the similarity of the H/V spectrum ratios for microtremor and earthquake motion can be easily explained because earthquake motions consist mostly of body waves. On the other hand, Konno and Ohmachi (1998) explained the similarity based on the fact that the peak period of H/V amplitude ratio for the fundamental mode of Rayleigh waves is almost the same as that of the transfer function for S-wave propagation, if the impedance ratio between the surface and base layers is large. In this study, the agreement among the peaks of the H/V spectral ratio of microtremor, transfer function for the S-wave, and H/V ratio of the fundamental mode Rayleigh wave was also observed.

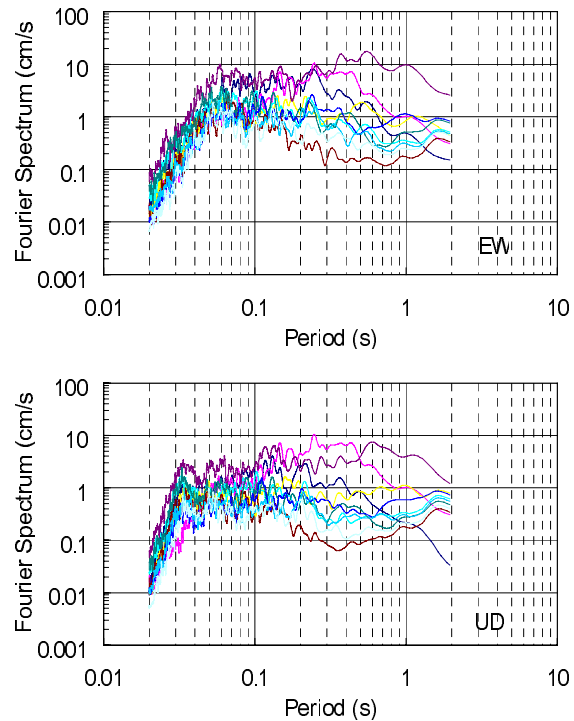


Figure 4. Horizontal (EW) and vertical Fourier spectra at K-NET Utsunomiya station

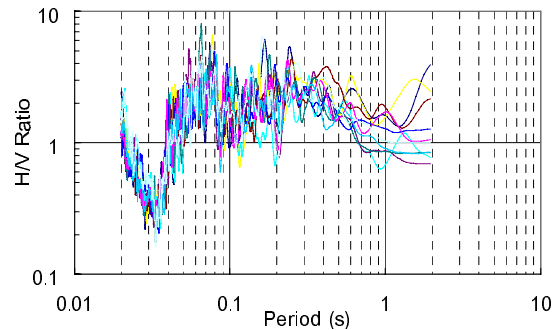


Figure 5. H/V spectrum ratios for 10 earthquakes at K-NET Utsunomiya station

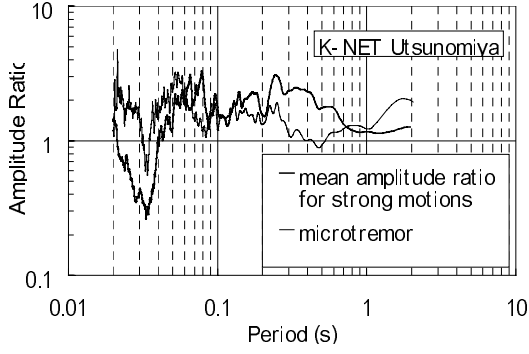


Figure 6. Comparison of average H/V spectrum ratios of earthquake motion and microtremor

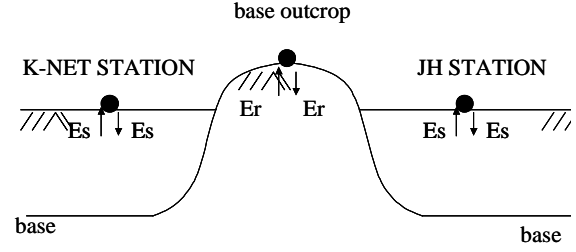


Figure 7. The soil structure models for two stations

Estimation of Seismic Motion Using Microtremor

Based on the similarity of the H/V spectrum ratio of earthquake motion and that of microtremor, the seismic motion at a JH seismic station is estimated by using an earthquake record at the nearest K-NET station and the H/V ratios of microtremor observed at the two stations.

We assume the soil structure shown in Fig. 7, in which the two seismic stations have the common baserock because the two stations are closely located. The (complex) H/V spectrum ratio of the earthquake motion at the surface of the K-NET station is written as follows:

$$R_{surface}^{K-NET} = (A_H^{K-NET} / A_V^{K-NET}) R_{reference} \quad (2)$$

where A_H and A_V are the (complex) transfer functions (between the surface and the rock outcrop) for the horizontal and vertical components, respectively and $R_{reference}$ is the (complex) H/V spectrum ratio of the base outcrop motion. Due to the similarity of the H/V spectrum ratios for earthquakes and microtremors, $R_{surface}$ is approximated by

$$|R_{surface}^{K-NET}| \approx r_{H/V}^{J/K} \quad (3)$$

where $r_{H/V}$ is the H/V amplitude ratio of microtremors. The similar relationship among $R_{surface}$, A_H , A_V , and $r_{H/V}$ can be assumed for a JH station.

Then we take the ratio of the H/V spectrum ratios of the microtremor observed at the JH and K-NET stations, written as follows:

$$r_{H/V}^{J/K} = \frac{r_{H/V}^{JH}}{r_{H/V}^{K-NET}} \approx \frac{|R_{surface}^{JH}|}{|R_{surface}^{K-NET}|} = \frac{|A_H^{JH}|}{|A_H^{K-NET}|} \left/ \frac{|A_V^{JH}|}{|A_V^{K-NET}|} \right. = \frac{|E_S^{JH}|}{|E_S^{K-NET}|} \left/ \frac{|E_P^{JH}|}{|E_P^{K-NET}|} \right. \quad (4)$$

where E_S and E_P are the (complex) Fourier spectra for the horizontal and vertical components, respectively. In this equation $R_{reference}$ is eliminated because of the assumption of the soil structure shown in Fig. 7. Figure 8 compares the ratios of the transfer functions between the two stations for the horizontal (S-wave) and vertical (P-wave) components. These transfer functions were calculated using the soil column models for JH Utsunomiya and K-NET Utsunomiya stations,

where PS-logging data exist. In the figure, at the predominant period of the transfer function ratio of the horizontal component, the transfer function ratio of the vertical component is almost equal to 1. Hence, around the predominant period of the transfer function ratio of the horizontal component, Equation 4 can be approximated by

$$r_{H/V}^{J/K} \approx \left| \frac{E_S^{JH}}{E_S^{K-NET}} \right| \quad (5)$$

According to Eq. 5, the ratio of the H/V spectrum ratios of microtremors at the two points can be approximated as the ratio of the Fourier spectra of horizontal motions. Using this approximation, the seismic motions at JH stations can be estimated from the earthquake records at the nearest K-NET stations by the following two methods.

Estimation of Response Spectrum

Employing the approximation (Eq. 6) between the Fourier spectrum and the velocity response spectrum (S_V) with zero damping, and another approximation (Eq. 7) between the S_V and the acceleration response spectrum (S_A), the acceleration response spectra at JH seismic stations can be predicted by Eq. 8.

$$E_S \approx S_V^{h=0.0} \quad (6)$$

$$S_V \approx \frac{1}{\omega} S_A \quad (7)$$

$$S_{A \text{ predicted}}^{JH} \approx S_A^{K-NET} r_{H/V}^{J/K} \quad (8)$$

Estimation of Acceleration Time History

Considering the close distance between a JH seismic station and a corresponding K-NET station, we assume that the phases of the acceleration records at the two points are same. Obviously this is not true, but it may be allowed as a crude assumption. Under this assumption, Equation 9 predicts the Fourier spectrum at the JH station.

$$E_S^{JH \text{ predicted}} \approx E_S^{K-NET} r_{H/V}^{J/K} \quad (9)$$

Employing the inverse Fourier transform to the predicted Fourier spectrum, the acceleration time history at the JH station can be estimated.

Examples

Figure 9 compares the predicted acceleration time history by Eq. 9 with the recorded acceleration at JH Utsunomiya. Figure 10 compares the predicted acceleration response spectra by the two methods and those calculated from the records at two JH seismic stations. Good agreement is observed in these figures, especially for the time history estimation method, in spite of the crude assumption. In these stations, prediction of seismic motion based on

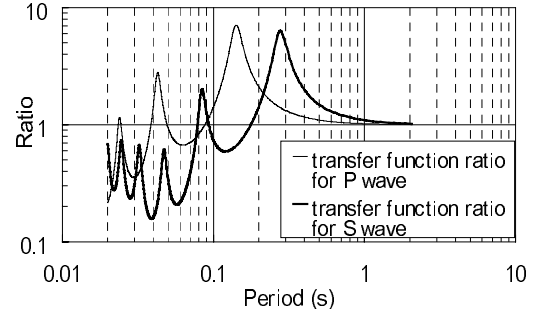


Figure 8. Transfer function ratios between two stations for the S and P-wave propagation

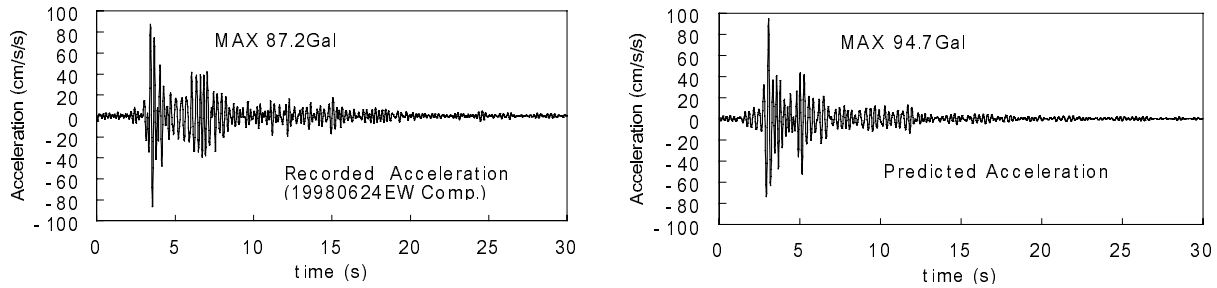


Figure 9. Comparison of predicted acceleration time history with the recorded acceleration at JH Utsunomiya station

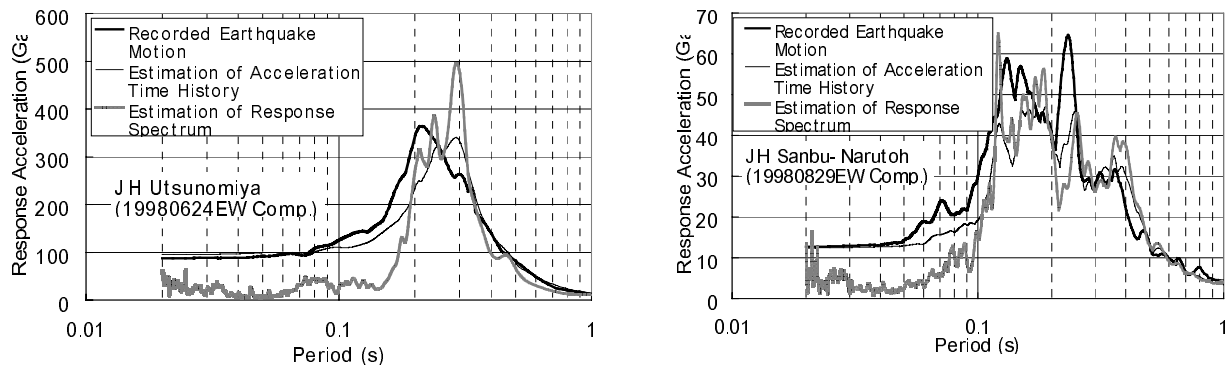


Figure 10. Comparison of predicted acceleration response spectra (5 % damping) with those calculated from the records at JH Utsunomiya and Sanbu-Naruto Stations

one-dimensional wave propagation analysis using the K-NET record as an input also gave good agreement with the observed record. However, the proposed method has advantage such that it does not require soil column data. The predicted S_A by the response spectrum estimation produces small values in the short period range due to the limitation of approximation by Eq. 7.

Conclusion

This paper proposed a method to predict a seismic motion at a location of microtremor observation, using the ratio of H/V spectrum ratios of microtremor and a seismic record at a neighboring station. The method is simple and does not require soil profile data. Using this method, if microtremor measurements are conducted at one seismic station and other neighboring locations systematically, the distribution of the seismic motion can be predicted. This estimation can be helpful for an efficient expressway traffic control just after an earthquake.

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