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# ESTIMATION OF SEISMIC MOTION ALONG AN EXPRESSWAY USING MICROTREMOR OBSERVATIONS

Takashi Kumita[1], Yoshihisa Maruyama[1], Fumio Yamazaki[2] and Tatsuya Hamada[3]

**ABSTRACT:** In order to gather earthquake information at an early stage and to establish an efficient traffic control, Japan Highway Public Corporation (JH) has developed the new seismometer network along their expressways. A national seismic network, Kyoshin Net (K-NET) with 1,000 stations, has also been in operation since 1996. The present authors proposed a technique to estimate seismic motion at the points of microtremor observation using the horizontal-to-vertical (H/V) Fourier spectrum ratio of microtremor as a transfer function. The technique is based on the idea that the H/V Fourier spectrum ratios for microtremor and seismic motion are similar and the H/V ratio of seismic records can be estimated from the transfer function of S-wave propagation. In order to demonstrate the accuracy and efficiency of the technique, microtremors were observed at twenty five points: four JH seismic stations, twenty points along the Tohoku expressway near the seismic stations and one K-NET station. Some of these observations were carried out at both the top and foot of the road embankment. The H/V Fourier spectrum ratios for microtremor and earthquake motions were calculated, and using the H/V ratios, the seismic motion along the expressway was estimated. The proposed method may be useful to estimate strong motion distribution between seismic stations.

**KEYWORDS:** microtremor, expressway, seismic motion, horizontal-to-vertical (H/V) Fourier spectrum ratio, transfer function, K-NET

## 1. INTRODUCTION

Japan Highway Public Corporation (JH) owns expressway networks with a total length of 6,747 km as of December 2000 and plans to extend them up to 11,520 km. For the purpose of gathering information on seismic motion along expressways and establishing an efficient traffic control just after the occurrence of an earthquake, 123 accelerometers had been deployed before the 1995 Kobe Earthquake [1]. The total number of seismometers has been increased to about 400 after the Kobe earthquake. The seismometer is placed at the spacing of about 20 km along the expressways. Using the earthquake information from these instruments, JH closes their expressways if the observed peak ground acceleration (PGA) exceeds 80 cm/s$^2$ or reduces the limited speed if the observed PGA exceeds 50 cm/s$^2$. Since the PGA has been found to be low correlation with structural damages, JH is planning to use Japan Meteorology Agency (JMA) seismic intensity [2] instead of the PGA in the near future. However the variation of earthquake motion is often found comparing with the records from neighboring seismic stations [3].

[1] The University of Tokyo, Japan, Graduate Student.
[2] Institute of Industrial Science, The University of Tokyo, Japan.
[3] Japan Highway Public Corporation, Japan.

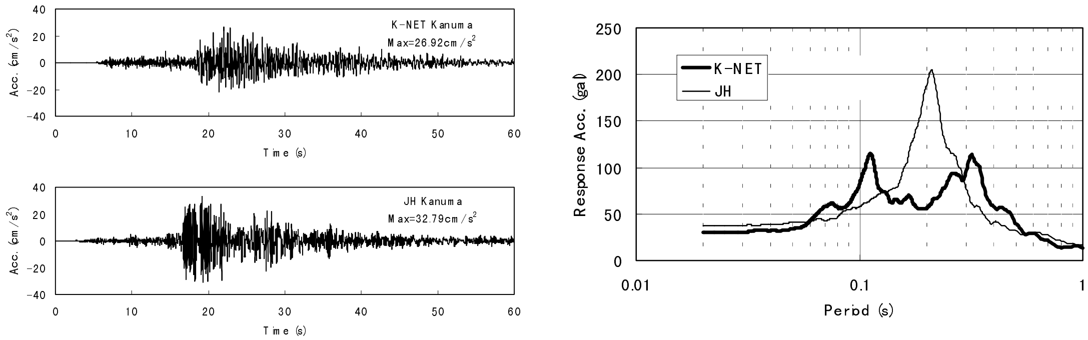



**Figure 1. Acceleration time histories and response spectra at Kanuma City (EW-component, July 21st, 2000 EQ)**

Figure 1 shows the acceleration time histories and the acceleration response spectra of an earthquake on July 21, 2000 recorded at two stations in Kanuma City: JH station, and Kyoshin-Net (K-NET [4]) station. Although these two stations are located within a distance of 5 km, the spectral shape and amplitude of JH Kanuma station are quite different from those of K-NET Kanuma station. Note that 1,000 K-NET stations were deployed all over in Japan by National Research Institute for Earth Science and Disaster Prevention (NIED).

With such variation of earthquake motion, the traffic control just after the occurrence of an earthquake is very difficult. 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. A method to estimate the seismic motion using the horizontal-to-vertical (H/V) ratios for microtremor [5] was proposed by the present authors [3]. In this paper, this method is employed to estimate the seismic motion along the Tohoku Expressway, Japan.

## 2. METHOD TO ESTIMATE THE SEISMIC MOTION USING MICROTREMOR

Figure 2 shows the H/V Fourier spectrum ratios for the earthquake records on July 21, 2000 and microtremor at four JH stations. The similarity of H/V ratios between seismic motion and microtremor was also observed at other seismic stations [6]. Based on this similarity, the seismic motion at a point (without instrument) is estimated by using an earthquake record at the nearest seismic station and the H/V Fourier spectrum ratios for microtremor observed at these two points [3].

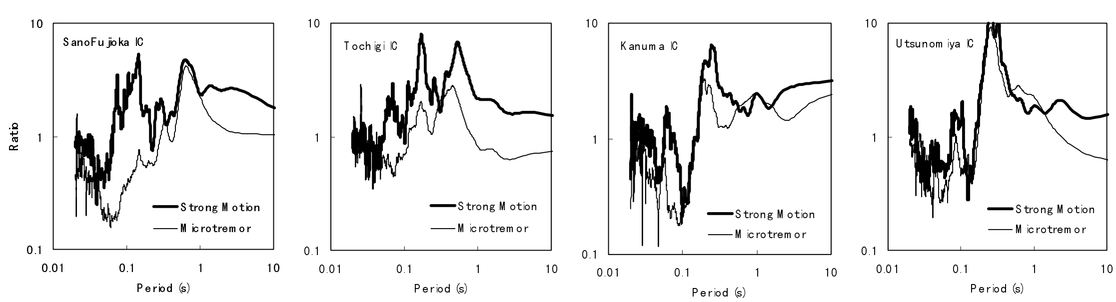



**Figure 2. Comparison of H/V Fourier spectrum ratios for strong motion and microtremor at four JH seismic stations on the Tohoku expressway**

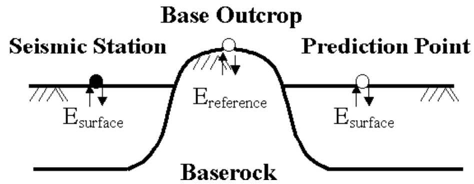


**Figure 3. The soil structure model assumed**

In order to estimate seismic motion using the method, a seismic station (SS) and a point to predict seismic motion (X) must have a common baserock as shown in Fig. 3. The H/V spectrum ratio for the earthquake motion, $R$, at the surface of the seismic station is written as follows [7]:

$$R_{surface}^{SS} = \left(A_H^{SS} / A_V^{SS}\right) \cdot R_{reference} \tag{1}$$

where $A_H$ and $A_V$ are the transfer functions between the surface and the rock outcrop for the horizontal and vertical components, respectively and $R_{reference}$ is the H/V Fourier spectrum ratio for the base outcrop motion. Due to the similarity of the H/V Fourier spectrum ratios for earthquake and microtremor, $R_{surface}$ is approximated as follows:

$$\left|R_{surface}^{SS}\right| \approx r_{H/V}^{SS} \tag{2}$$

where $r_{H/V}$ is the H/V Fourier spectrum ratio for microtremor. The similar relationship among $R_{surface}$, $A_H$, $A_V$ and $r_{H/V}$ can be assumed for the point without instrument.

Then the ratio for the H/V Fourier spectrum ratios for the microtremor observed at the seismic station and the point without instrument is written as follows [3]:

$$r_{H/V}^{X/SS} = \frac{r_{H/V}^{X}}{r_{H/V}^{SS}} \approx \left|\frac{R_{surface}^{X}}{R_{surface}^{SS}}\right| = \left|\frac{A_H^X}{A_H^{SS}}\right| \Big/ \left|\frac{A_V^X}{A_V^{SS}}\right| = \left|\frac{E_S^X}{E_S^{SS}}\right| \Big/ \left|\frac{E_P^X}{E_P^{SS}}\right| \tag{3}$$

where $E_S$ and $E_P$ are the Fourier spectra for the horizontal and vertical components of seismic motion, respectively. In the equation, $R_{reference}$ is canceled with an assumption of soil structure shown in Fig. 3. When the ratios for the transfer functions between two points for the horizontal (S-wave) and vertical (P-wave) components are calculated by using the soil column models from PS-logging data, the transfer function ratio for the vertical component becomes almost equal to 1 at the peak period of the transfer function ratio for the horizontal component [3]. Hence, around the peak period of the transfer function ratio for the horizontal component, Equation 3 can be approximated as

$$r_{H/V}^{X/SS} \approx \left|\frac{E_S^X}{E_S^{SS}}\right| \tag{4}$$

According to Equation 4, the ratio for the H/V Fourier spectrum ratios for microtremors at the two points can be approximated as the ratio for the Fourier spectra of the horizontal seismic motions.

The distance between the seismic station and the point to estimate seismic motion must be close to assume the synchronousness of the phases of the acceleration records at these points. Accordingly, the Fourier spectrum at the point to estimate seismic motion is approximated as follows:

$$E_{S\ estimated}^{X} \approx E_S^{SS} r_{H/V}^{X/SS} \tag{5}$$

Employing the inverse Fourier transform to the estimated Fourier spectrum, the acceleration time history at the point without instrument can be estimated.

## 3. H/V FOURIER SPECTRUM RATIOS FOR MICROTREMORS

Microtremors were observed in August 2000 at one K-NET seismic station, four JH seismic stations, which are located at interchanges (IC), and twenty (20) points along the Tohoku Expressway. Figure 4 shows the 25 observation points and 3 epicenters of earthquakes occurred on March 8, 1998 (magnitude $M$=4.4, depth $d$=52km), June 24, 1998 ($M$=4.6, $d$=73km) and July 21, 2000 ($M$=6.1, $d$=50km). A portable measurement system with velocity sensors of natural period 1 second was used. In each observation, 5 minutes (300 seconds) recording with sampling frequency of 100 Hz was carried out for three components. Ten sets of records with duration 40.96 seconds (30 seconds record and 10.96 seconds trailing zero) were used to calculate Fourier spectra. The average of all these sets is used to calculate the H/V Fourier spectrum ratio.

From the existing boring data at each point and PS-logging data at JH Utsunomiya station, the soil column models at the points around JH Utsunomiya station were made for calculating the transfer functions (the surface motion versus the incidental motion at about -40 m) for S-wave propagation. For the calculation of the transfer functions, the damping ratio of 2 % was used. Figure 5 compares the transfer function for S-wave and H/V Fourier spectrum ratio for microtremor. Figure 6 plots the relationship between the peak periods of the transfer functions for S-wave and the H/V Fourier spectrum ratio for microtremor. In the figure the peak periods look quite similar between them, and hence it is concluded that microtremor can be used for seismic micro zonation.

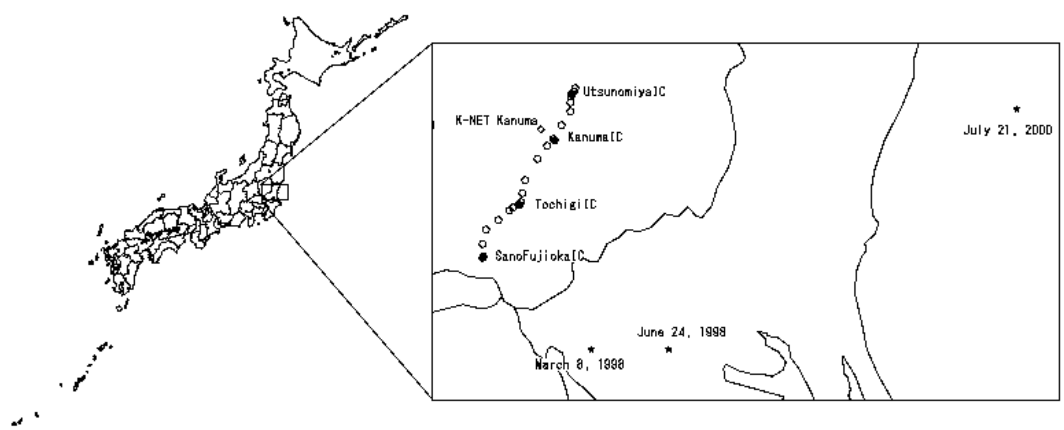
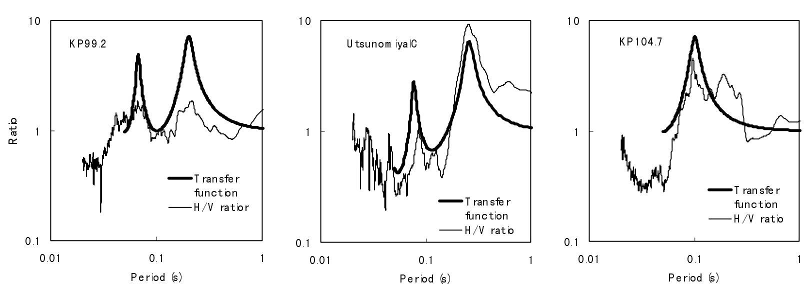



**Figure 4. Microtremor observation points and epicenters of earthquakes used in this study**



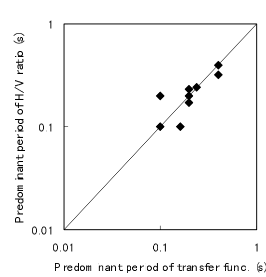




**Figure 5. Comparison of the transfer function for S-wave with respect to rock outcrop and the H/V Fourier spectrum ratio of microtremor at three locations along the Tohoku expressway**

**Figure 6. Peak periods of transfer function and H/V ratio of microtremor**

**Figure 7. Microtremor observation at the top and foot of embankment at KP104.0**

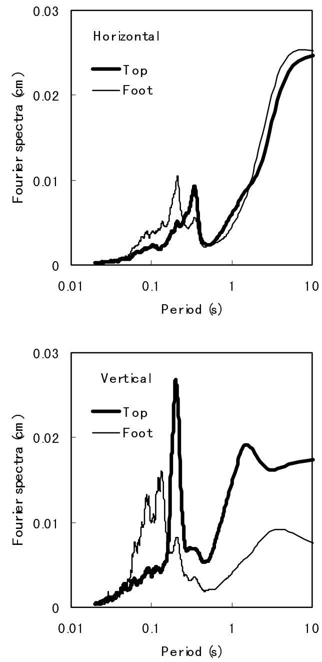



**Figure 8. Fourier spectra of microtremor at KP104.0**

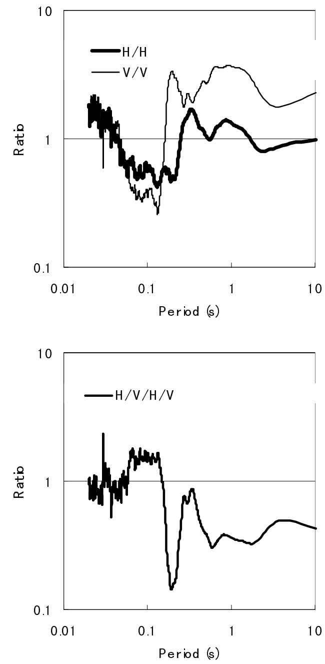



**Figure 9. H/H, V/V, and (H/V)/(H/V) Fourier spectrum ratios**

At some points along the expressway, synchronous observations were carried out at the top and foot of the road embankment as shown in Fig. 7. Figure 8 compares the Fourier spectra at the top and foot of the embankment for the horizontal and vertical components observed at the location KP104.0. The difference of the amplitudes between the top and foot of the embankment for the vertical component is larger than that for the horizontal component. This fact might be explained as the traffic vibration affects stronger to the vertical component than to the horizontal component at the top of the embankment. Between the top and foot of the embankment, the horizontal-to-horizontal ($H_{top}/H_{foot}$) and vertical-to-vertical ($V_{top}/V_{foot}$) ratios were calculated, and are shown in Fig.9. The ratio for the H/V Fourier spectrum ratios between the top and foot of the embankment, $(H_{top}/V_{top})/(H_{foot}/V_{foot})$, was calculated, and is also shown in Fig. 9. Although the peak period of around 0.3 second is found both H/H and (H/V)/(H/V), the amplitude of the (H/V)/(H/V) is smaller than that of H/H. In this method, (H/V)/(H/V) ratio is used to cancel the difference in the source of microtremor between two points [3]. However the influence cannot be canceled properly if the influence to one component is stronger than that to the other. Hence this method has to be used carefully when the microtremor observation is carried out close to heavy traffic, as in the case of this study.

Using the H/V Fourier spectrum ratios for microtremor at these points and acceleration records at four JH seismic stations, the acceleration time histories at these points without instruments were estimated. The JMA seismic intensities at these points were also calculated, and are shown in Fig. 10. In the figure, variation of the JMA seismic intensity almost plus and minus 1 is estimated between the JH seismic stations. Although some discussions still remain on the accuracy of this estimation, it may be very important to consider the variation of seismic motion between instruments if the traffic suspension is carried out using only the recorded strong motion indices.

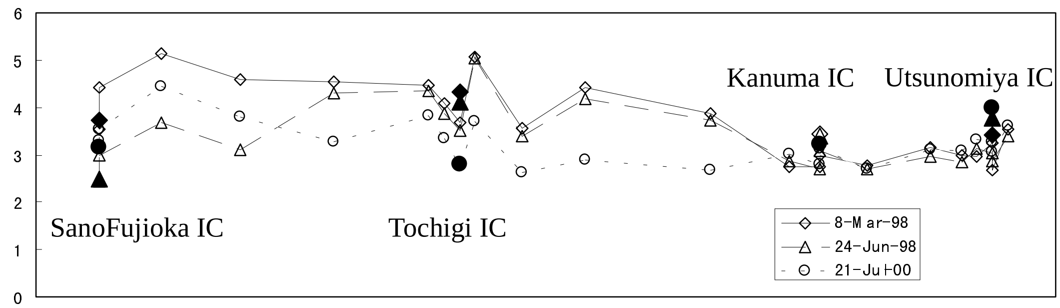



**Figure 10. Estimated JMA seismic intensity along the Tohoku expressway for three earthquakes. Black symbols are recorded values and open symbols are estimated by the proposed method.**

## 4. CONCLUSION

Microtremor observations were carried out at 25 points along the Tohoku Expressway, Japan. The peak period of the H/V Fourier spectrum ratio was similar to that of the transfer function of S-wave. Hence the H/V Fourier spectrum ratios for microtremors are thought to represent the site response characteristics. The Fourier spectra between the top and foot of the road embankment for microtremor were compared. It is found that the effect of vertical motion is different between the top and foot of the embankment, and hence the H/V Fourier spectrum ratios must be used carefully when a microtremor observation is carried out close to the source of microtremor. The seismic motions at the points along the Tohoku expressway were estimated using the H/V Fourier spectrum ratios of microtremor and the observed seismic record at seismic stations. Although some discussions still remain on the accuracy of this estimation, the importance to consider the variation of seismic motion between instruments is highlighted when traffic regulation is conducted based on recorded strong motion indices.

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