RESPONSE SPECTRA ON SEISMIC BEDROCK DURING EARTHQUAKE

by

Hiroyoshi Kobayashi[I] and Sumio Nagahashi[II]

SYNOPSIS

The response spectra of the earthquake motions observed on the ground surface can be illustrated as the product of seismic bedrock motion, which is explained by source mechanism of earthquake and pass of wave propagation, and ground characteristics of amplification of seismic waves. In this paper authors tried to find the ground characteristics and the seismic bedrock motions from the observed data of strong motion accelerograph. As the results of this study, they showed the general nature of the seismic bedrock motions which related to the magnitude of earthquake and hypocentral distance, and proposed empirical formula of attenuation of the intensity on the seismic bedrock.

INTRODUCTION

The data of peak acceleration and particle velocity were influenced by the local conditions of seismic stations, even if these seismic stations stuated on the hard rock. For the evaluation of these effects, amplification factors of ground surface of the seismic stations for the peak acceleration or particle velocity were evaluated by the accumulation of observed data, usually. On the other hand, amplification of seismic waves in the subsurface soil layers was studied by the numerical analyses based on the wave propagation theories using the dynamic soil characteristics. These evaluations were performed at several seismic stations, however, former amplification factors are not sufficient for the evaluation of frequency domain problem and latter methods were nedded the field survey at the seismic stations which reached to the seismic bedrock.

Attenuation curve of the attenuation of peak accelerations and particle velocities of ground motions or seismic bedrock motions were presented already, Kanai's empirical formula *1)* of attenuation of seismic bedrock motions, Shnabel-Seed's attenuation curve of accelerations *2)* and so on were very common for the amplitude range of strong motions, that the maximum acceleration exceeds 100 gals. But these attenuation curves can give the peak accelerations or particle velocities. From the point of view of seismic microzoning method, it is necessary to know the characteristics of frequency domain of seismic bedrock motions due to earthquake, because now the seismic microzoning problem developed to the frequency domain problem, for example, Bostrom-Sherif's method proposed the amplification factors by frequency domain and author also proposed that the amplification of seismic waves should be used in the procedure of seismic microzonig.*3),4)* These new methods of microzoning requested the characteristics of seismic bedrock motions by the frequency domain.

1. DEFINITION OF SEISMIC BEDROCK AND AMPLIFICATION OF SEISMIC WAVES

The response spectra of the earthquake motions observed on the ground surface can be illustrated as following equation:

I Professor of Earthquake Engineering, Tokyo Institute of Technology, Dr. of Engineering

II Professor of Structural Engineering, Nagasaki Institute of Naval Architecture, Dr. of Engineering

$$R(\omega) = F\{O(\omega),P(\omega)\}\times G(\omega) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where $R(\omega)$ means the response spectrum of the ground surface motion due to earthquake, $O(\omega)$ is the source function which is decided by the source mechanism, $P(\omega)$ is the attenuation function of seismic waves in the pass and $G(\omega)$ is the amplification factor of seismic waves at the observed site and surrounding ground. The function of $F\{O(\omega),P(\omega)\}$ was called as seismic bedrock motion and it is denoted by $B(\omega)$ as shown in equation (2):

$$R(\omega) = B(\omega)\times G(\omega) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

On the point of view of the characteristics of ground amplification, it is better way that the response spectra of strong ground motion were indicated by the two-dimensional response spectra, for investigation of these characteristics of seismic waves amplification. An example of the two-dimensional response spectrum was shown in Fig.2. Authors analyzed accelerograms by the two-dimensional response spectra about nine SMAC stations that each station had recorded the several strong motion earthquakes. Fig.1 shows a map of location of SMAC sites where they collected the data used in this paper. The two-dimensional response spectra of these SMAC records were shown in Figs. 3a,3b and 3c. In these figures, the response spectra $R(\omega)$ showed rather similar characteristics at individual site, but they showed quite different response spectra at different places.

If the value of amplification $G(\omega)$ is sufficiently large, the response spectra of individual site have the similar response spectra in spite of the characteristics of earthquake. However, the value of amplification factor $G(\omega)$ is not so large, which corresponds to the case of hard rock ground condition, the response spectra $R(\omega)$ are differ each other at a site and they depend the nature of earthquake.

2. DECISION OF ATTENUATION CURVE OF SEISMIC BEDROCK MOTIONS AND AMPLIFICATION FACTORS OF OBSERVED SITES

Based on the relationship above mentioned, authors obtained the attenuation curve of the seismic bedrock motions and amplification factors of observed SMAC sites. Calculations of these procedures were performed as an approximation using the following steps of the data treatments.

[Step 1] As the attenuation curve of the response spectra of the seismic bedrock motions, they assumed the attenuation function mentioned in equation (3):

$$\log_{10}S_{vo} = a(\omega)M - b(\omega)\log_{10}x - c(\omega) \qquad \ldots\ldots\ldots\ldots(3)$$

where S_{vo} is velocity response spectrum of seismic bedrock motion, M is magnitude of earthquake, x is hypocentral distance and $a(\omega)$, $b(\omega)$ and $c(\omega)$ are the factors which depend to period. As the first approximation of this value of equation (3), authors used the result of Kanai's formula.

$$\log_{10}S_{vo}=0.61M-(1.66+3.60/x)\log_{10}x-(0.631+1.83/x) \ldots(4)$$

[Step 2] Using the result of equation (3) or (4), amplification factor of ground was obtained by equation (5):

$$G_i(\omega) = R_i(\omega) \;/\; S_{vo} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

amplification factor $G(\omega)$ of individual site was obtained by geometrical mean of $G_i(\omega)$:

$$G(\omega) = \sqrt[n]{\prod_{i=1}^{n} G_i(\omega)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

[Step 3] Then they got the seismic bedrock motion $B(\omega)$ by using equation (7):

$$B_i(\omega) = R_i(\omega) \;/\; G(\omega) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

[Step 4] Using the least squar method, they decided the factors of $a(\omega)$ $b(\omega)$ and $c(\omega)$ from the data of $B_i(\omega)$, magnitude of earthquake and hypocentral distance x. Then returned to Step 1.

The authors repeated these steps and finally they got the amplification factors of individual SMAC site $G(\omega)$ and factors of $a(\omega)$, $b(\omega)$ and $c(\omega)$ of equation (3). The final results were shown in Figs. 4 and 7.

3. ATTENUATION OF INTENSITY OF SEISMIC BEDROCK MOTIONS

The seismic bedrock motion of individual site were calculated by the equation (7) and illustrated in Fig.5. From these figures it can be recognized that, in spite of the characteristics of the observed site conditions, general trends of the response spectra of the seismic bedrock motions of the same earthquake were very similar each other and in the period range of rather longer period, the response value of seismic bedrock motion increase in accordance with the period in case of larger magnitude of earthquake and decrease in case of smaller magnitude. Then they rearranged the figures, earthquake by earthquake, as shown in Fig.6. The case of rather small magnitude of earthquake, it is very clear that the above mentioned natures, but in case of large magnitude M=7.9, it is not so evident. In case of large earthquake, source area of the earthquake is very large and hypocentral distances to the observed site are not so clear, so they used the hypocentral distances from the first P-wave origin. The authors supposed that is the main reason of the wide scattering of response spectra of Fig.6-c.

In Fig.8 they showed the proposed response spectra of seismic bedrock motions of hypocentral distance is 100 km. These average chracteristics of seismic bedrock motions illustrated that the response spectra of large magnitude earthquake were increase in accordance with the period and smaller magnitude were decrease.

CONCLUSION

As the conclusion of this paper, authors pointed out following results:
(1) They proposed a new method for getting the amplification factors of seismic waves propagation in layered soil ground without using any soil testing method in situ.
(2) Attenuation curve of the attenuation of intensity of seismic bedrock motions were proposed. In this paper they showed the average response spectra which were decided by the magnitude of earthquake and hypocentral distances.
(3) Average response spectra of the seismic bedrock motions varied the spectral characteristics in accordance with the magnitude of earthquake. In case of larger magnitude of earthquake, the response spectra increase in accordance with the period of ground motion.

These results can be applicable for the out side of the source area, because the data used in this study were limited.

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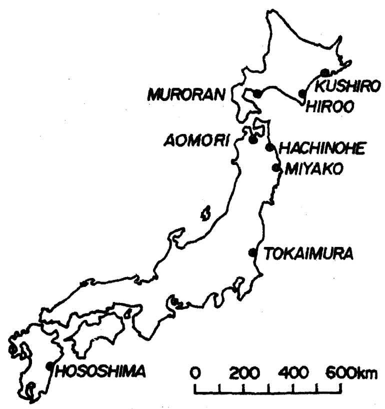


Fig. 1 Location of SMAC stations

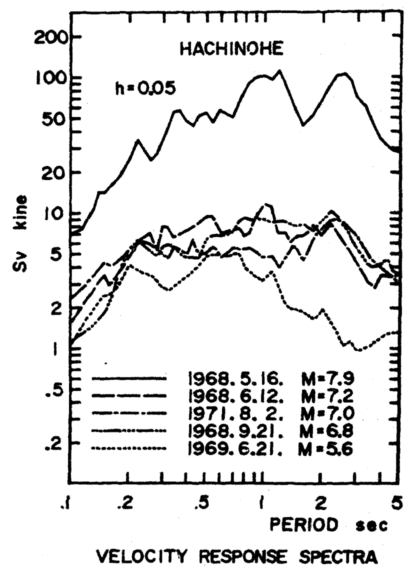


Fig. 3-a

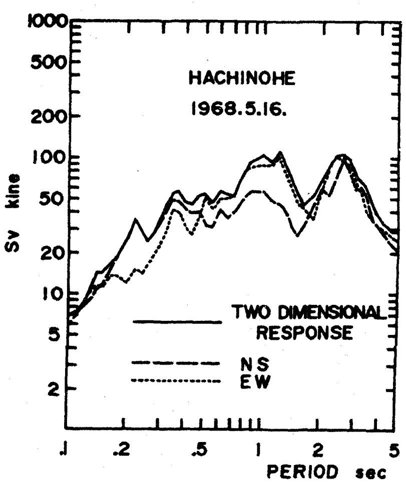
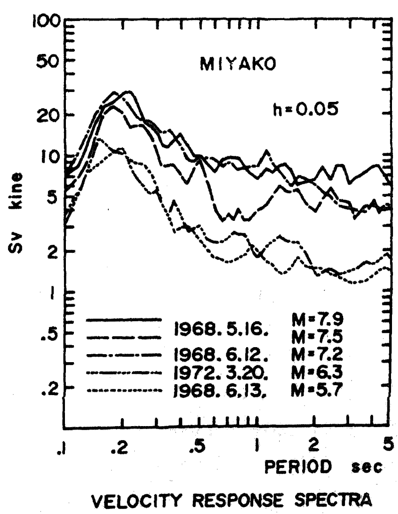
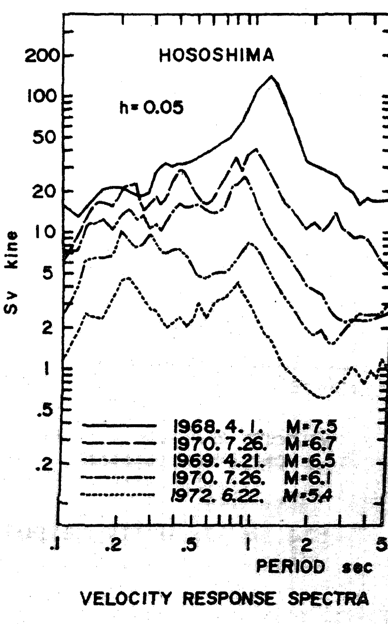


Fig. 2 Two-dimensional response spectrum

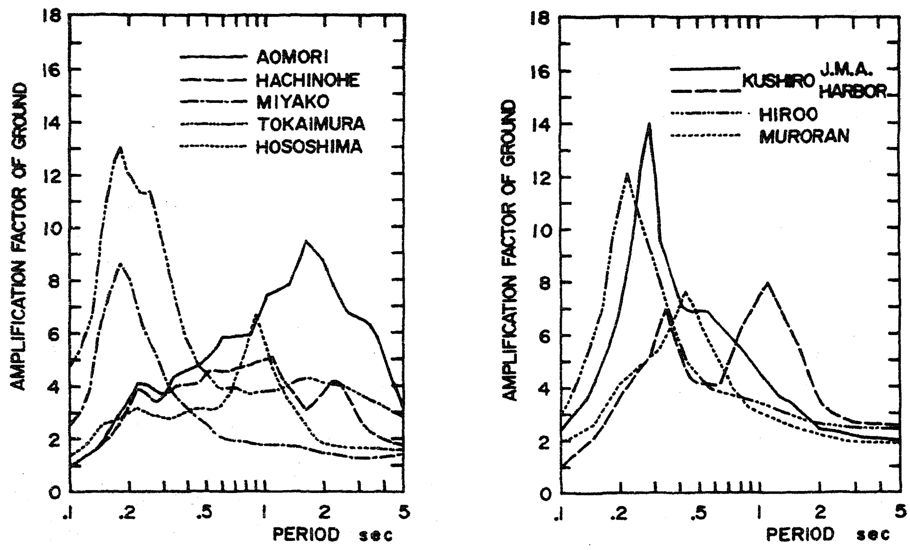


3-b



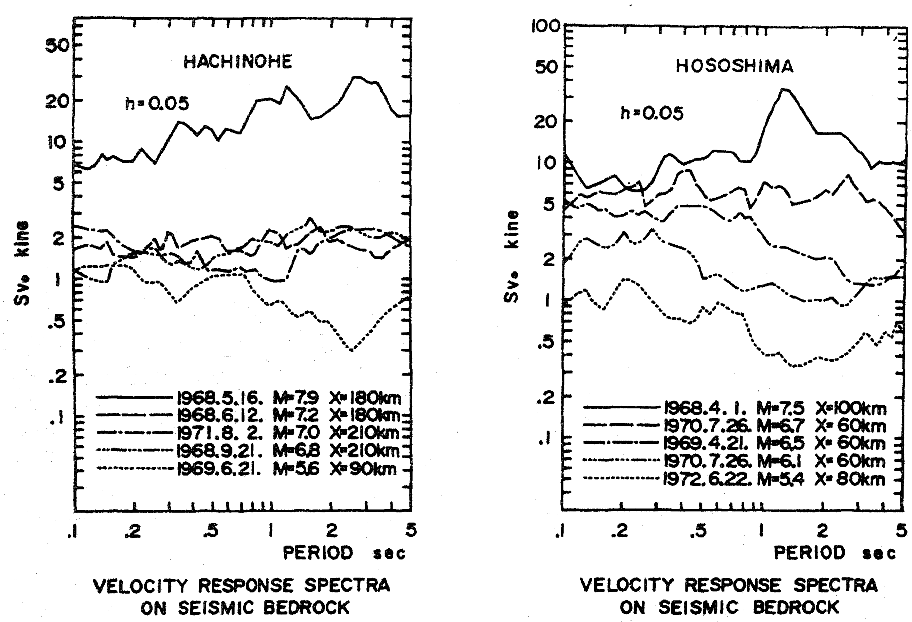
3-c

Fig. 3 Two-dimensional response spectra of individual SMAC site



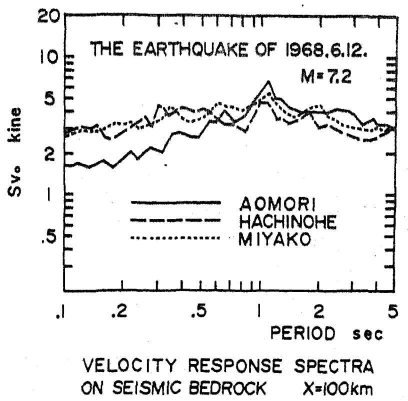
4-a 4-b

Fig. 4 Amplification factor of ground of individual SMAC site

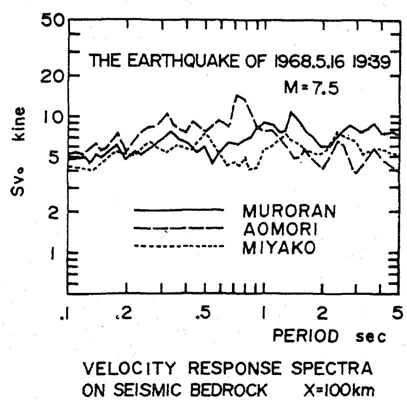


5-a 5-b

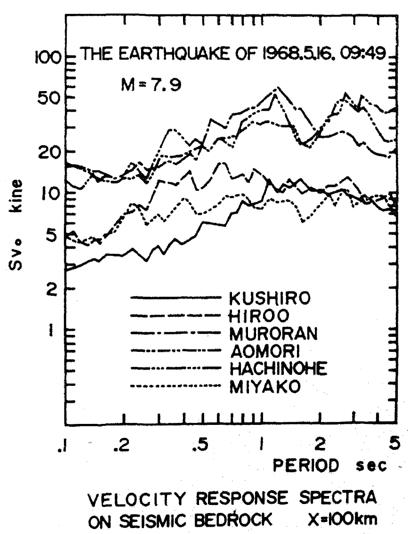
Fig. 5 Velocity response spectra on the seismic bedrock



6-a



6-b



6-c

Fig. 6 Velocity response spectra on seismic bedrock of individual earthquake

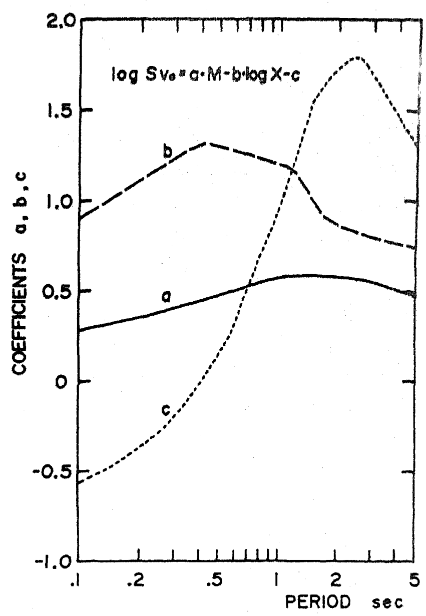


Fig. 7 Value of $a(\omega)$, $b(\omega)$ and $c(\omega)$ of the empirical formula of velocity response spectrum on seismic bedrock

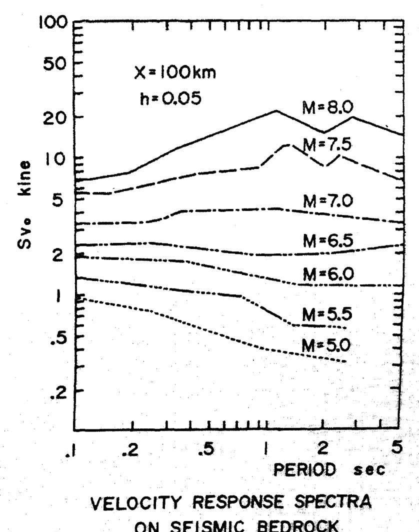


Fig. 8 Response spectra on seismic bedrock by the empirical formula

DISCUSSION

P.N. Agrawal (India)

The focal depths for earthquakes in such a wide magnitude range must be significantly different. Have the authors removed the effect of focal depth on the response spectra when making the comparison for different earthquakes ?

Author's Closure

With regard to the question of Mr. Agrawal, we wish to state that in case of Japan, authors supposed that shallow earthquakes are most dangerous for the earthquake damages of structures. We have no data of the damages of structures by intermediate or deep earthquakes during a century, and historical data of damages of structures can be concluded by the effects of shallow earthquakes. Almost earthquake damages of structures were caused by shallow earthquakes. Then authors collected the strong motion accelerograms caused by shallow earthquakes from the Japanese strong motion seismometer network records. And they got the conclusion from those data.