A Study on Characteristics of Vertical Earthquake Ground Motions in Array Observations

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ABSTRACT

The purpose of this study is the investigations, (1)～(3), of the characteristics of vertical earthquake ground motions based on the observed records at the vertical array observation points. The observation points are installed in the vertical direction from the seismic bedrock to the ground surface at the sites in Iwaki and Tomioka cities in Fukushima prefecture, Japan.

(1) The relationships between the wave motions of vertical and horizontal (radial) components observed at the seismic bedrock.
(2) The wave propagation aspects of vertical components from the seismic bedrock to the ground surface.
(3) The amplification functions of vertical components through soil deposits.

1 INTRODUCTION

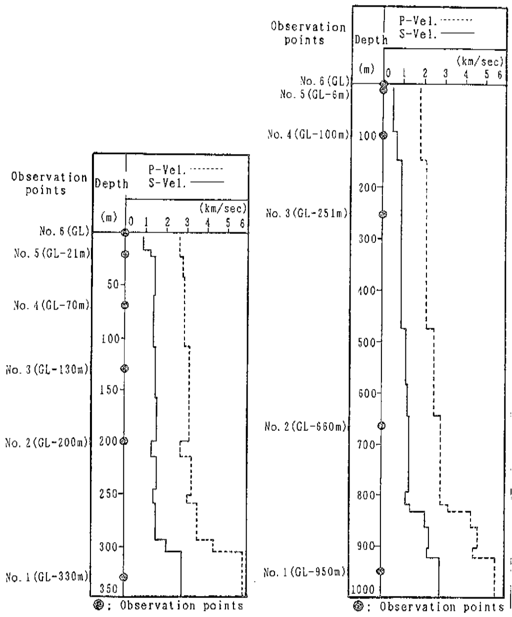
Many array observations have been carried out in Japan, however, few studies on the characteristics of vertical earthquake ground motions have been reported so far (Uetake et al. 1990, Hatori et al. 1990). This paper presents the characteristics of vertical earthquake ground motions (vertical components), such as the incident waves at the seismic bedrock, the wave propagations from the seismic bedrock to the ground surface and the amplification functions, on the observed records at the vertical array observation points in Iwaki and Tomioka sites.

2 OUTLINE OF OBSERVATION SITES AND OBSERVED RECORDS

The velocity structure(Vs,Vp) of S-wave and P-wave obtained by the bore-hole tests and the arrangements of the instruments from the seismic bedrock to the ground surface are as shown in Fig. 1. The velocities of the seismic bedrock are Vs=2.8km/sec, Vp=5.8km/sec at the GL-330m in Iwaki site and Vs=2.8km/sec, Vp=5.5km/sec at the GL-950m in Tomioka site, respectively. In both sites, the variations of Vp in the vertical direction are similar to those of Vs in that direction and so, the values of poisson's ratio(ν) through the soil structure are almost constant.

The numbers of observed records employed in this study are eighteen in Iwaki site and fourteen in Tomioka site. These records are selected on the conditions of magnitude(M_J)$\geqq$5.5, focal depth(D)$\leqq$60km, epicentral distance(Δ) $\leqq$200km and the period limit on the confidence of S/N ratio(Tc)$\geqq$5.0sec, in the acceleration records observed from June in 1979 to December in 1988.

The distributions of epicenters and the relationships between M_J and Δ are as shown in Fig. 2. In this study, the vertical records are divided into two parts which are the durations before and after the first arrival time of S-wave in the observed records of horizontal components. The former is named as D.B.F.S and the latter, D.A.F.S, and the first arrival times of P-wave and S-wave in the observed records are named as F.P and F.S in this paper, respectively.



a) Iwaki site b) Tomioka site

Fig. 1 Observation points and velocity structures

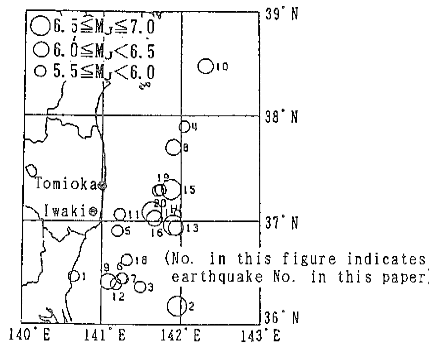


Fig. 2 (a) Distributions of epicenters

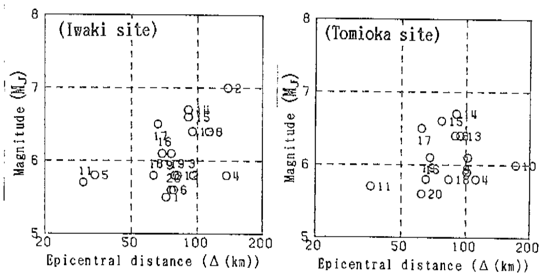


Fig. 2 (b) Relationships between M_J and Δ

3 INCIDENT WAVES AT SEISMIC BEDROCK

The particle orbits diagrams due to the vertical and radial components observed at the seismic bedrock are obtained as shown in Fig. 3 and 4, taking the running time intervals of 2 and 0.5 seconds, respectively. The waveforms of vertical and radial components adopted to calculate the particle orbits are also as shown in these figures. The wave motions in Fig. 3 are the records from starting time to around the attenuating time of S-wave in the observed records of horizontal components. The wave motions in Fig. 4 are of a few seconds around F.S in the wave motions in Fig. 3. In these figures, V indicates vertical component and the upward direction is plus, and R indicates radial component and the propagating direction is plus, respectively.

From the particle motions in these figures, it is found that vertical components around F.P and F.S at the seismic bedrock are derived from the inclined incident P-wave and SV-wave, respectively. This result at F.S is also obtained from the relationships between the phases of vertical and radial components which are inverse each other in the waveforms of Fig. 4.

Therefore, it is found that both vertical and horizontal components at F.S at the seismic bedrock are generated by the same incident wave.

4 WAVE PROPAGATIONS FROM SEISMIC BEDROCK TO GROUND SURFACE

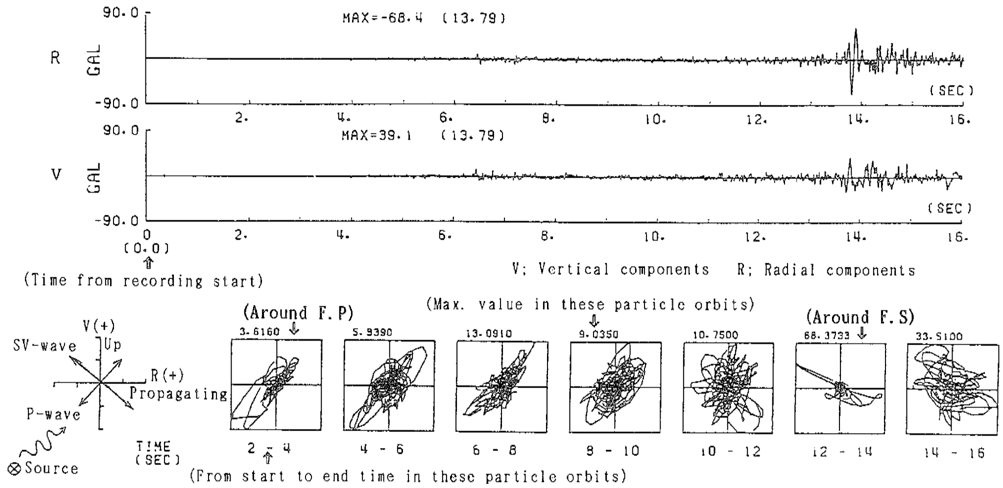


Fig. 3 Example of waveforms and particle orbits at seismic bedrock in earthquake No.15 at Tomioka site (Duration times ; from starting time to around the attenuating time of S-wave in horizontal components)

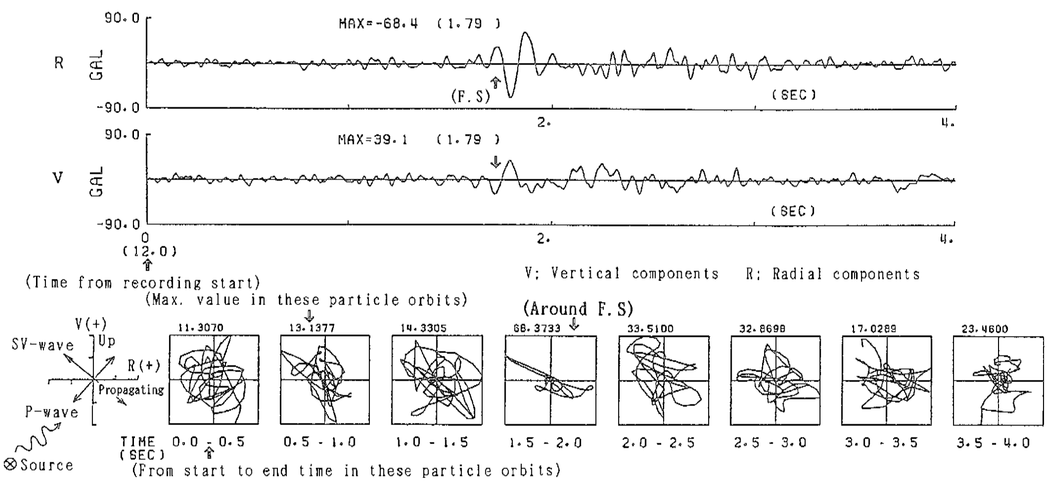
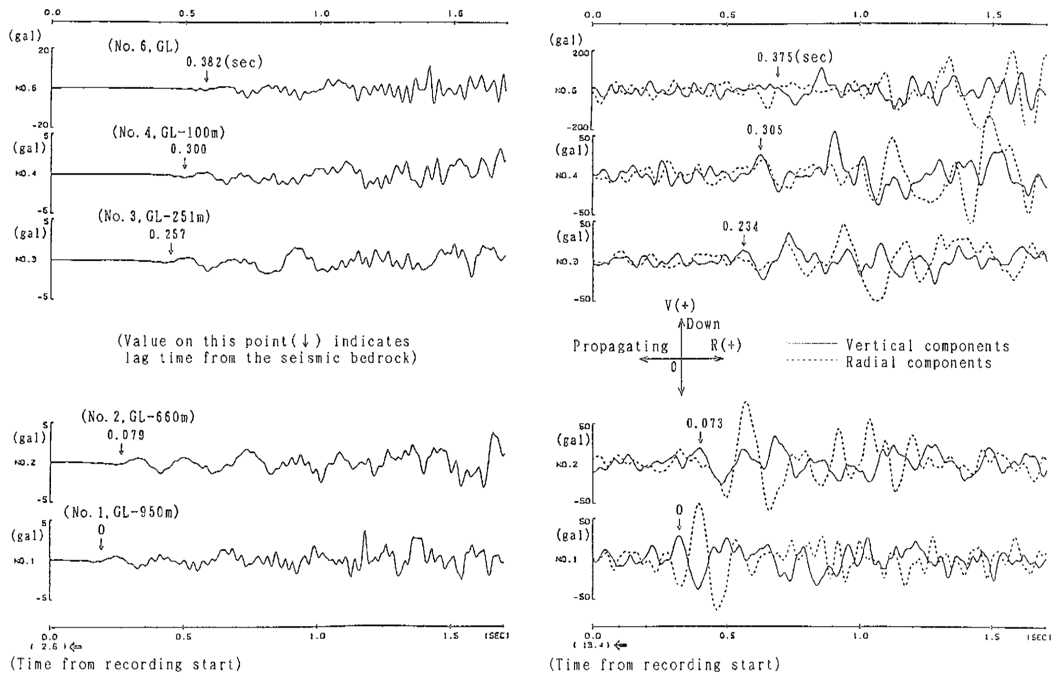


Fig. 4 Example of waveforms and particle orbits at seismic bedrock in earthquake No.15 at Tomioka site (Duration times ; a few seconds around F.S in horizontal components)

The pasted-up diagrams of vertical and radial components recorded at the 5 observation points installed from the seismic bedrock to the ground surface are as shown in Fig. 5 to investigate the wave propagations through the surface soil structure. In vertical components, the time lags from the seismic bedrock to the each observation point by the travel times at F.P or F.S, and by the cross correlation analyses around F.S are obtained as shown in Table 1. In vertical components of Fig. 5 and Table 1, it is found that the time lags from the seismic bedrock to the each observation point at F.S are closely equal to those of F.P and can be explained by the use of P-wave velocities obtained by the bore-hole tests.

Therefore, the P-wave propagation model by the use of P-wave velocities implies the possibility of the explanation for the wave propagations of vertical components of D.A.F.S from the seismic bedrock to the ground surface.



a) Around F.P b) Around F.S

Fig. 5 Example of pasted-up diagrams of vertical and radial components from seismic bedrock to ground surface in earthquake No.15 at Tomioka site

Table 1 Time lags of each observation point from the seismic bedrock

(Unit; sec)

Observation points	Iwaki site				Tomioka site			
	τ_{UPi}	τ_{USi}	τ_{Ui}	τ_{Pi}	τ_{UPi}	τ_{USi}	τ_{Ui}	τ_{Pi}
No. 6	0.110	0.110	0.092	0.105	0.382	0.375	0.399	0.406
No. 4	0.081	0.089	0.088	0.079	0.300	0.305	0.299	0.341
No. 3	0.059	0.066	0.054	0.059	0.257	0.234	0.239	0.265
No. 2	0.037	0.035	0.031	0.037	0.079	0.073	0.069	0.086
No. 1	0	0	0	0	0	0	0	0

τ_{UPi}, τ_{USi}, τ_{Ui}, τ_{Pi} ; Time lags of each observation point from the seismic bedrock obtained by the travel times at F.P and F.S, by the cross correlation analyses around F.S and by calculation using P-wave velocities of bore-hole tests, respectively.

5 AMPLIFICATION FUNCTIONS

The amplification characteristics of vertical components are investigated by using the ratios of acceleration Fourier spectra. The amplification functions are obtained by the following procedures.

(1) The Fourier transform to two parts of acceleration records of vertical components of all observation points are carried out and these Fourier spectra are smoothed by the application of Parzen's spectral window.

(2) The ratios of Fourier spectra between two vertical observation points are estimated.
(3) The geometric means of the ratios of Fourier spectra are calculated.
In this paper, the geometric means of the ratios of Fourier spectra shown in Fig. 6 are considered as the amplification functions of the observed records.

It is well known that the amplification functions of the vertical components of D.B.F.S are characterized by the P-wave propagation.

Comparing the amplification functions of D.B.F.S and D.A.F.S in both sites, though there are small differences of the peak values, the shapes and predominant periods of amplification functions of D.A.F.S closely agree with those of D.B.F.S.

According to this result, it is implied that the P-wave propagation model is available to explain the amplification functions of vertical components of D.A.F.S.

6 COMPARISON OF VERTICAL AND HORIZONTAL AMPLIFICATION FUNCTIONS

The amplification functions of horizontal components (transverse direction) of D.A.F.S from the seismic bedrock to the ground surface are evaluated by the same procedure employed for vertical components and are as shown in Fig. 7.

Based on the assumptions that the poisson's ratios of the geological structure are constant in the vertical direction and the predominant periods of the amplification functions of vertical and horizontal components are explained by vertically incident P-wave and S-wave propagation models, respectively, the relationship between the predominant periods and the elastic wave velocities is given by the following equation.

$$T_{hj}/T_{vj} = Vp/Vs \quad (1)$$

In which, T_{hj} and T_{vj} are the predominant periods of horizontal and vertical components, and j is the ordinary number of predominant periods, respectively.

Estimating the values of T_{hj}/T_{vj} and Vp/Vs from Fig. 7 and Fig. 1 in Iwaki and Tomioka sites, respectively, the mean values in both sites are equal to about 2.0, respectively.

Therefore, it is found that the one dimensional propagation model due to vertically incident P-wave is one of the available models to simulate the amplification functions of vertical components of D.A.F.S.

7 ONE DIMENSIONAL P-WAVE PROPAGATION MODEL

The amplification functions obtained by one dimensional propagation model due to vertically incident P-wave are as shown in Fig. 8 compared with observed records of D.A.F.S. It is found that the predominant periods calculated by one dimensional propagation model due to vertically incident P-wave closely simulate the observed records of D.A.F.S.

8 CONCLUSION

The investigations on the characterisitics of vertical earthquake ground motions are summarized as follows.

a) It is found that both vertical and horizontal components after the first arrival time of S-wave at the seismic bedrock are generated by the same incident wave.
b) The vertical earthquake ground motions are characterized by the P-wave propagation and the amplification functions can be estimated by the one dimensional propagation model due to vertically incident P-wave.

9 ACKNOWLEDGEMENTS

The observed records used in this study were provided us from the project founded jointly by ten electric power companies in Japan. The authors wish to express their sincere thanks to members of the project and persons concerned.

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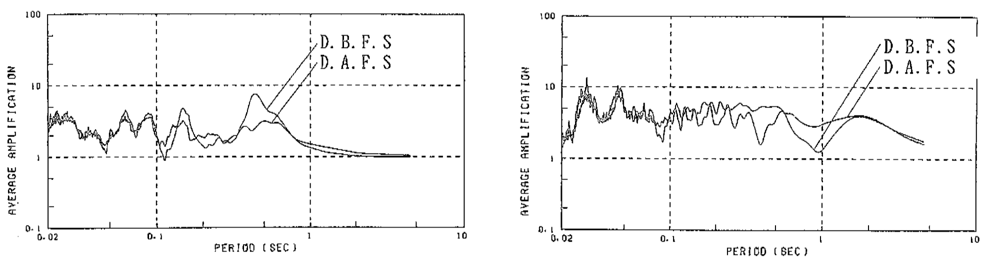
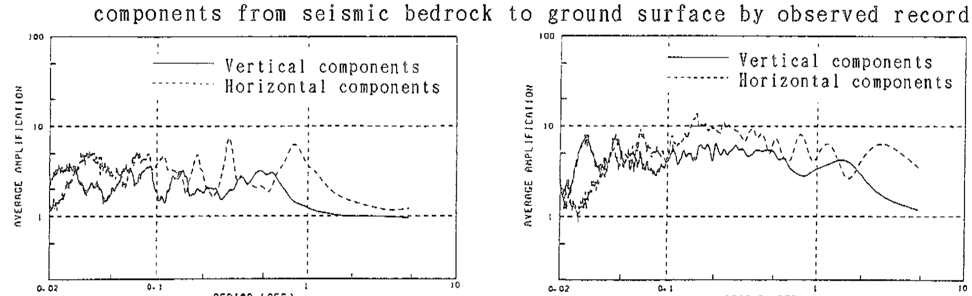


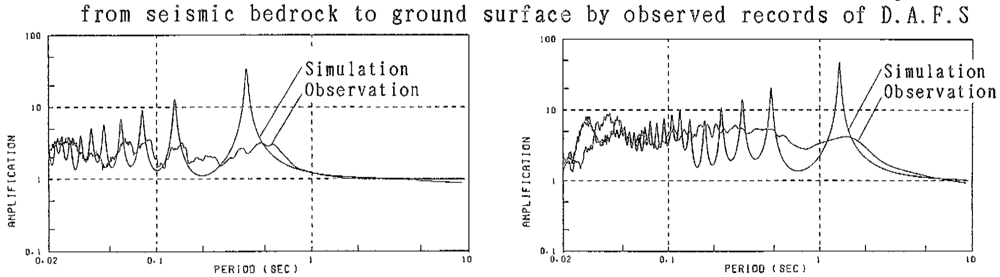
a) Iwaki site (GL/GL-330m) b) Tomioka site (GL/GL-950m)

Fig. 6 Comparison of amplification functions between two parts of vertical components from seismic bedrock to ground surface by observed records



a) Iwaki site (GL/GL-330m) b) Tomioka site (GL/GL-950m)

Fig. 7 Comparison of amplification functions between ver. and hor. components from seismic bedrock to ground surface by observed records of D.A.F.S



a) Iwaki site (GL/GL-330m) b) Tomioka site (GL/GL-950m)

Fig. 8 Comparison of amplification functions between by observed records of D.A.F.S and by one dimensional P-wave propagation model