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OBSERVATION OF EARTHQUAKE STRONG-MOTION WITH DEEP BOREHOLE -COMPARISON OF SEISMIC MOTIONS IN THE BASE ROCK AND THOSE ON THE ROCK OUTCROP-

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SUMMARY

The objective of this paper is the comparison of seismic motions in the base rock and those on the rock outcrop. According to the comparative study of simultaneously observed accelerograms, the seismic motions in the base rock and those on the rock outcrop over the frequency range lower about 6 Hz are in good agreement using the soil system by one-dimensional amplification theory. However, the seismic motions on the rock outcrop are smaller than those in the base rock over the frequency range higher than about 6 Hz.

INTRODUCTION

Array observation network of earthquake ground motion has been established at Iwaki(IWK). Seven accelerometers are arranged vertically from the ground surface down to the base rock where the shear-wave velocity is about 3 km/sec. An accelerometer of sub-station (KDG) is installed on the rock outcrop which corresponds to the base rock at IWK.[1)] The comparison of seismic motions in the base rock and those on the rock outcrop using simulteneously observed accelerograms at 2 stations are discussed in this paper.

OUTLINE OF OBSERVATION STATIONS

Fig. 1 shows the location of observation stations. The distance of IWK and KDG is about 7 km. Fig. 2 shows the detailed velocity structures of shear-wave at IWK and KDG, which were known from the results of PS-log. At IWK station, the Palaeogene sedimentary rock layer is on the base rock.[1),2)] The former has the thickness of about 300 m and has the average shear-wave velocity of 1.4 km/sec. At KDG station, very thin weathering rock is on the rock of which shear-wave velocity is 2.2 km/sec.

COMPARISON OF OBSERVED ACCELEROGRAMS IN THE BASE ROCK AND THOSE ON THE ROCK OUTCROP

Comparison of Observed Accelerograms between IWK-No.1 and KDG Fig. 3 and Fig. 4 show the time-histories of acceleration and the response spectra. These records were obtained during the July 2, 1983, Off Fukushima prefecture earthquake, of which magnitude was Mj 5.8. These time-histories are the transverse components obtained by using Radial-Transverse conversion. Their long-period noise are removed from them. Each waveform in this paper is processed through the same routine.[3] As shown in Fig. 3, the waveform of IWK-No. 1 (GL-330m, in the base rock) is similar to that of KDG (on the rock outcrop), however, the former has the short-period wave component more than the latter.

Fig. 4 shows that the spectral amplitudes of IWK-No. 1 is larger than that of KDG at the period shorter than about 0.1 sec. The former is smaller than the latter at the period of about 1 sec and at the period of about 0.3 sec. These periods correspond to the predominant periods of the surface layer on the base rock (Fig. 5).[4] This means that the superposition of the upward wave and the downward wave make the seismic motion at the base rock small.

The spectral analyses of waveforms were done by using the Fast Fourier transform. The average spectral ratio of IWK-No. 1 to KDG during 6 earthquakes (Table 1, Fig.6) was calculated. Fig.7 shows the superposition of each spectral ratio. The scatter is not large. The logarithmic standard deviation is 0.1 - 0.4.

Provided the upward wave E at the top of the base rock at IWK is equall to that of the rock outcrop at KDG, the abovementioned spectral ratio of IWK-No. 1 to KDG nearly corresponds to the transfer function (E+F)/2E. (F:downward wave at the base rock of IWK) Fig. 8 shows the average spectral ratio IWK-No. 1/KDG and the calculated (E+F)/2E based on two soil systems of IWK. The former is about 2 to 5 times the latter in amplitude over the frequency range higher than about 6 Hz, though the two are in good accord with over the frequency range lower than about 6 Hz. The models are described at the next section.

<u>Comparison of IWK-No.1 between observed seismic motion and calculated one</u> The responses at IWK-No. 1 during 6 earthquakes were calculated by one-dimensional amplification theory using the observed time-histories of acceleration at KDG. In this case it was assumed that the seismic motion at KDG was equall to that of the top of the base rock at IWK. Two soil systems of IWK were used. I-Model was made based on the results of PS-log, formation density log, dynamic shear test and high-pressure dynamic triaxial test. F-Model was made by using optimization method. On this soil system, the shear-wave velocities and damping factors were substituted for new ones respectively, using the fitting method that the transfer functions of one-dimensional amplification theory were made equall to the average amplification spectrum during 40 earthquakes. Fig. 9 shows the soil systems. Fig. 10 shows the average ratio in response spectrum of calculated wave to observed one during each event. F-Model is shown to give better fit in response spectra than I-Model over the period range of 0.02 to 5 sec.[5]

Fig. 11 shows the calculated and observed waveforms of IWK-No. 5 (GL-21 m), IWK-No. 1 (GL-330 m) and the observed waveforms of KDG. KDG is the input wave at the depth of GL-305m in two soil systems. With regard to the predominant period, the calculated waveform corresponds with the observed one at each depth. The former is simpler than the latter. This means that the characteristic of input wave causes this difference to appear.

Fig. 12 shows the response spectrum's ratios of observed wave to calculated one at IWK-No. 1 during abovementioned 6 earthquakes. The response of 2 Models are similar to each other. They make little difference. The response spectra's amplitudes of observed waveforms are larger than calculated ones at the period shorter than about 0.2 sec. Except about the period of 0.5 sec, the two nearly correspond with each other at the period longer than about 0.2 sec. These results are in good accord with the comparison of observed accelerograms between IWK-No. 1 and KDG (Fig. 8). The trough at about 0.5 sec matches the part of about 2 Hz in Fig. 8. This means that the characteristic of KDG of which spectral amplitudes are larger than those of IWK-No.1 appears.

CONCLUSIONS

It was performed the comparison between the observed accelerograms in the base rock and those on the rock outcrop, as well as the response analyses by one-dimensional amplification theory. Following results were obtained:

1 The seismic motions in the base rock and those on the rock outcrop over the frequency range lower than about 6 Hz are in good agreement using the soil system by one-dimensional amplification theory.

2 The seismic motions on the rock outcrop are smaller than those in the base rock over the frequency range higher than about 6 Hz.

The former is a good indication of possibility that the well evaluated soil system can evaluate the seismic motions in the base rock from those on the rock outcrop as well as conversely. Assuming that the rock outcrop and the base rock have the upward wave E in common, the latter indicates the unreasonableness that the amplitude of the downward wave F in the base rock is larger than that of the upward wave E. It is necessary to do active research works in this standpoint.

ACKNOWLEDGEMENTS

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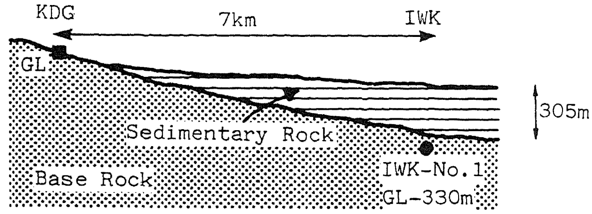


Fig. 1 Location of Observation Stations

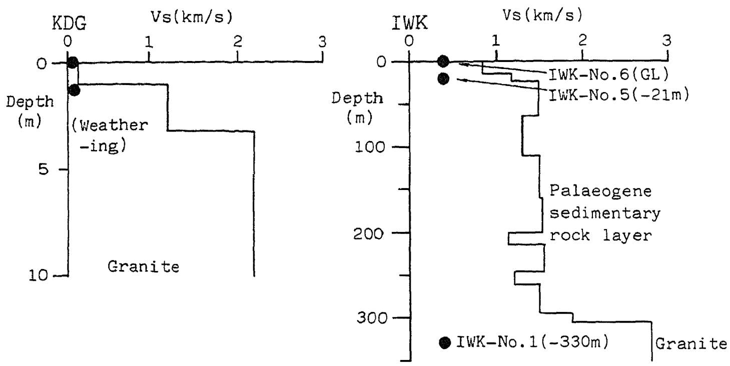


Fig. 2 Velocity Structure of S-wave

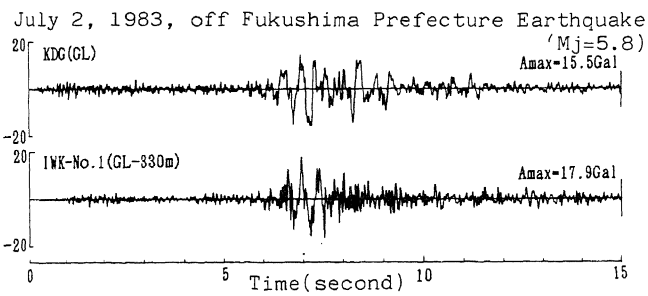


Fig. 3 Observed time-histories of acceleration

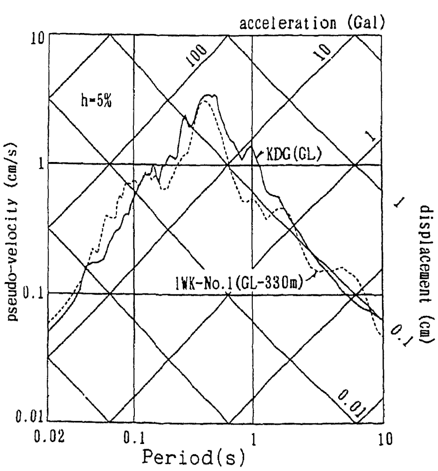


Fig. 4 Response Spectra (h=0.05)

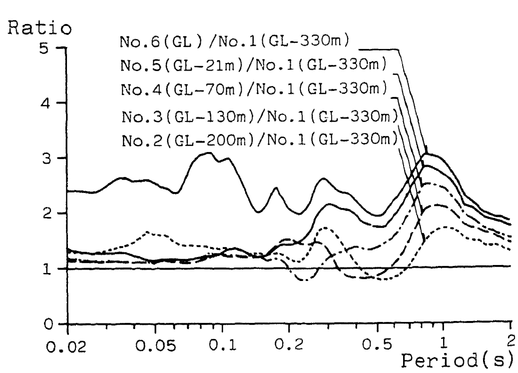


Fig. 5 Amplification Ratio of Average Response Spectrum

Table 1 List of Earthquake Origins and Maximum Acceleration

Earthquake Origin					IWK-No.1 (GL-330m)		KDG (GL or GL-1m)*	
Date			Depth	Mj	X	Amax	X	Amax
Y	M	D	(km)		(km)	(Gal)	(km)	(Gal)
1983	7	2	54	5.8	64	17.9	67	15.5
1983	9	2	49	5.2	68	4.9	72	7.8
1984	1	1	388	7.3	645	6.1	646	8.7
1985	5	11	45	5.3	77	13.1	81	17.2
1985	8	12	52	6.4	124	3.0	125	4.3
1985	10	4	78	6.1	168	2.2	170	3.9

Mj: JMA Magnitude
X: Focal Distance (km)
Amax: Maximum Acceleration (Gal)
*: GL: before May, 1985
Gl-1m: after August, 1985

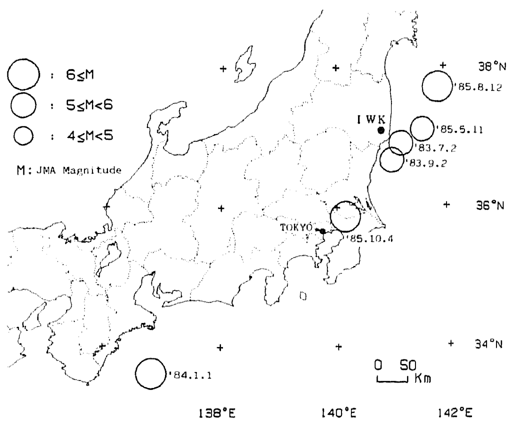


Fig. 6 Distribution of Epicenters

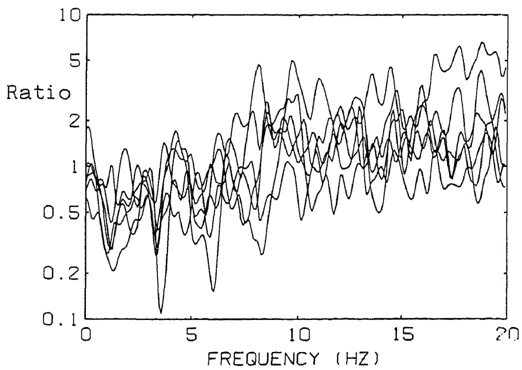


Fig. 7 Scatter of Spectral Ratio of IWK-No. 1 to KDG

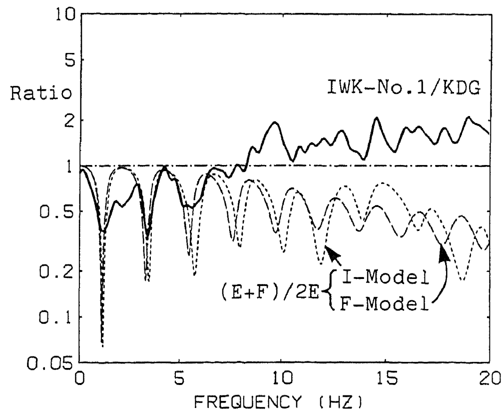


Fig. 8 Average Spectral Ratio of IWK-No. 1 to KDG and Transfer Function (E+F)/2E at IWK (GL-305m)

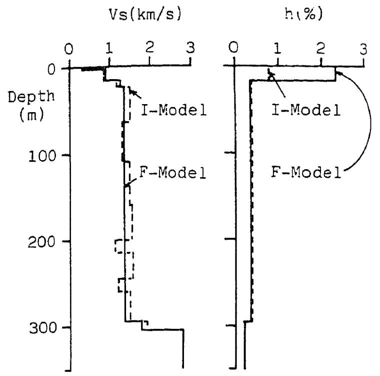


Fig. 9 Velocity Structure of S-wave and Damping Factor

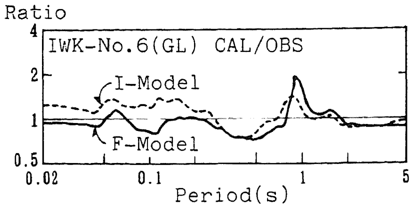


Fig. 10 Average Ratio in Response Spectrum of Calculated wave to Observed One at IWK (GL)

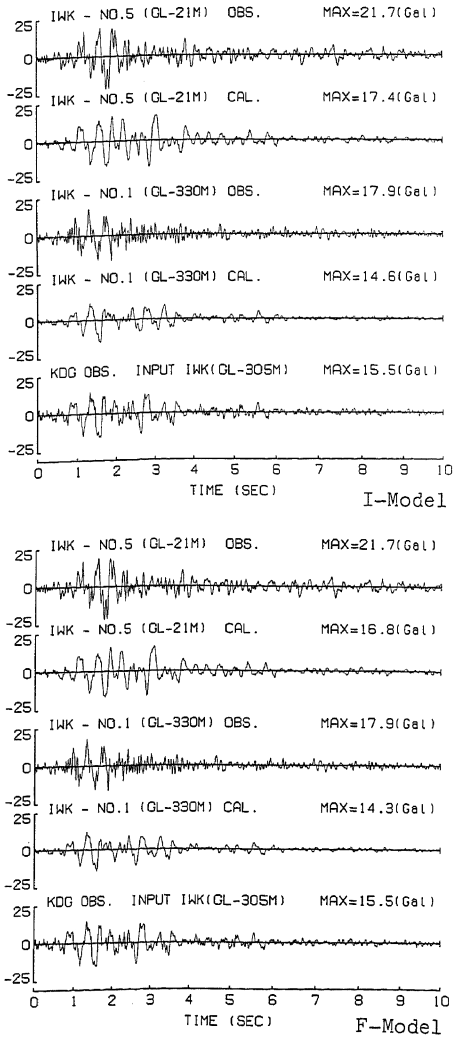
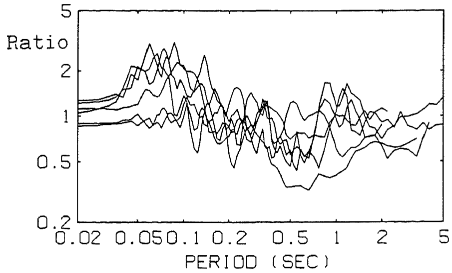
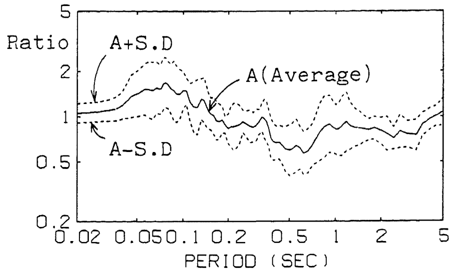


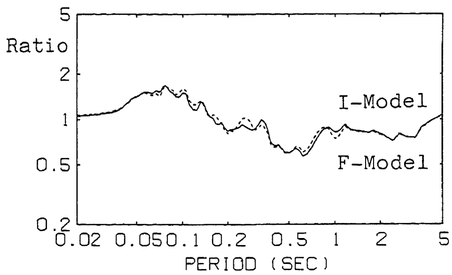
Fig. 11 Calculated and Observed waveforms



(1) Scatter of Spectral Ratios (F-Model)



(2) Average and Standard Deviation (F-Model)



(3) Average (I-Model and F-Model)

Fig. 12 Ratios in Response Spectrum of Observed Wave to Calculated One at IWK-No. 1