



## A STUDY ON AMPLIFICATION FACTORS OF EARTHQUAKE MOTIONS OBSERVED AT A GRANITE SITE AND RELATIONSHIPS BETWEEN THEIR VERTICAL AND HORIZONTAL MOTIONS

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### ABSTRACT

In order to clarify the site amplification factors and the relationships between their horizontal and vertical motions on a granite site regarded as a basin, we examine two kinds of spectral ratios using observed motions obtained from a vertical array observation system on its site. One is obtained by ratios between particular two points on and in the granite site, the other is by ratios of the vertical components to the horizontal ones at the points respectively. We compare the two kinds of spectral ratios with the theoretical estimations based on Silva's method in which inelastic layers on an elastic half-space are considered, and conclude that occurrences of vertical motions after the arrival of S-wave are strongly affected by the deep ground structure over the depth of 4 kilometers and the incident angles to the deep half-space.

### KEYWORDS

Granite Site; Vertical Array; Amplification Factor; Vertical Motion; Deep Ground Structure; Incident Angle

### INTRODUCTION

The authors have set up a vertical array observation system on a granite site to research the characteristics of motions in and on a rock site. The site, S-4, on an outcrop of granite layer in Shibata, Miyagi Pref., is one of the sites that constitute the array observation system named "KASSEM" (Shimizu *et al.*, 1988). We added the new observation point, S-4D, in the granite layer and have observed ground motions since 1991. Although the site is geologically considered to be on the outcrop of the granite layer in which the deepest observation point of "KASSEM" exists and is also generally regarded to indicate amplification characteristics of a basin, it is probable that the influence by weathered layers on surface can not be ignored.

In order to clarify the site amplification factors and the relationships between their horizontal and vertical motions on the site regarded as a basin, we examine two kinds of spectral ratios using observed motions of 10 events. One is obtained by ratios between particular two points on and in the granite site, the other is by ratios of the vertical components to the horizontal ones at the points respectively. We compare the two kinds of spectral ratios with the theoretical estimations based on Silva's method in which inelastic layers on an elastic half-space are considered, and examine the amplification factors and the spectral ratios of the vertical components to the horizontal one relating to the ground structure and the incident angle.

## SITE INVESTIGATION AND ARRAY OBSERVATION SYSTEM

### Site Investigation

We investigated the elastic velocity structure by means of PS logging toward the depth of 50 meters in the bore hole as well as the density structure by means of gamma-ray. The results are shown in Fig. 1. The S-wave velocities of the layer in which weathering progresses decrease to around 1.0 km/sec by the depth of 23.5 meters and indicates 2.4 km/sec under its depth. On the basis of the investigation, the elastic velocity structure and the density structure are constructed as shown in Fig. 2. Here, the ground structure under the depth of 50 meters is assumed to be equivalent to the deep ground structure of Tohoku region in the northern part of Japan (Den, 1967).

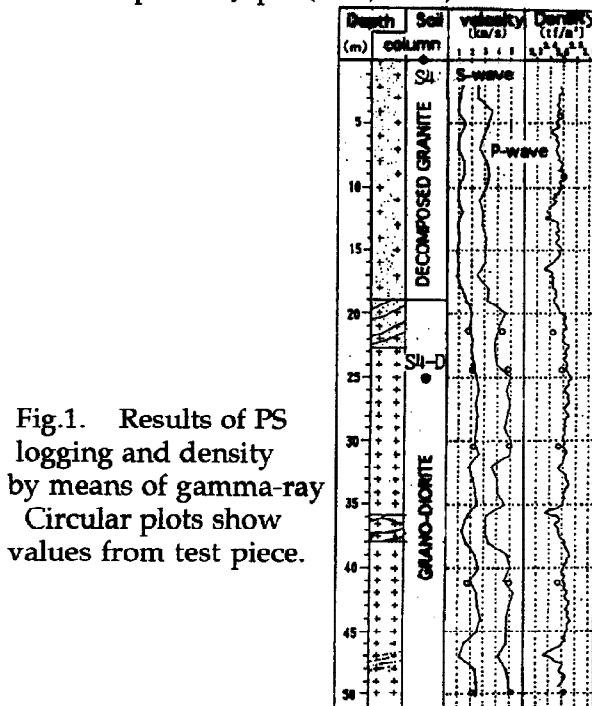


Fig.1. Results of PS logging and density by means of gamma-ray  
Circular plots show values from test piece.

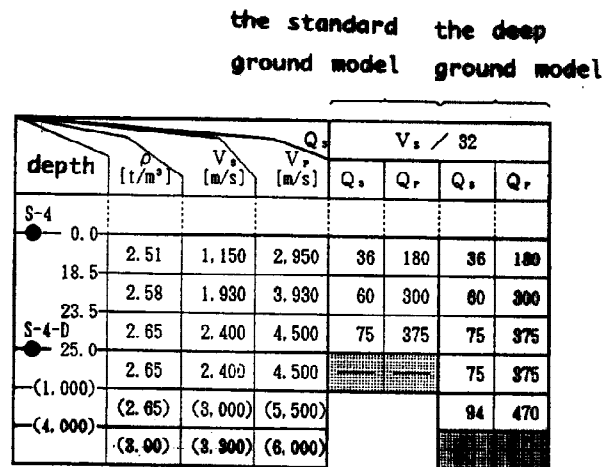


Fig.2. The elastic velocity structure and the density structure

### Array Observation System

An acceleration seismograph of three components (NS, EW, UD) was set at the depth of 25 meters in non-weathered rock constituting a vertical array with seismograph set previously on the outcrop. The depth location of the seismographs is shown in Fig. 2 with the velocity structure. The seismograph SA-375CT manufactured by Tokyo Sokusin Co. Ltd., indicates

the characteristic data as shown in Table 1. The digital data of waves are recorded in the IC card system which have the data capacity of 25 minutes in the case that analog to digital conversion rate is 200 samples per second.

Table 1. Specification of used sensors

Sensor	Type	Full Range	Freq. Range	Amplitude Deviation	Freq. Deviation	sensitivity	Resonance Freq.	Damping Fac.
SA-375 CT	Survo Type	± 1000 gal	0.1 - 30 Hz	± 2.0%	± 5.0%	15μA / gal	5 Hz	100

## COMPARISON OF SPECTRAL RATIOS

### Observed Spectral Ratios

We use the ground motions of 10 events observed from January 1992 to January 1993 as shown in Table 2. Fig.3 shows epicenters for the data set, and Fig. 4 shows the observed motions on the Off Kushiro event as an example. Here, the horizontal component of the waves, both NS and EW direction, is transformed into a wave toward the direction of the epicenter. Using both horizontal and vertical acceleration time histories simultaneously starting at the arrival of S-wave and ending at the duration time defined by eq. (1) (Hisada et al.,1978) from the arrival, we calculate velocity response spectra of which damping coefficient is zero because they are nearly equivalent to Fourier amplitude spectra of acceleration(Hudson,1979).

$$T_d = 10^{0.31M - 0.774} \quad (1)$$

Table 2. Data of events

Event No	Name	N. L (deg.)	Long. E (deg.)	Depth (km)	Mag.	Distance (deg)
1	Center of Yamagata Pref.	38.42	140.53	121	5.7	43
2	Earst off Fukushima Pref.	36.88	141.35	67.6	4.7	142
3	Earst off Fukushima Pref.	37.45	141.03	74	4.5	74
4	Earst off Ibaragi Pref.	36.67	141.26	43.8	5.7	163
5	Far Earst off Sanriku Pref.	39.38	143.67	0	6.9	292
6	Earst off Fukushima Pref.	37.55	141.05	76	4.7	88
7	Earst off Miyagi Pref.	38.15	141.75	52.8	4	87
8	Off Miyagi Pref.	38.93	142.55	33.5	5.9	183
9	Off Miyagi Pref.	38.93	142.57	32	5.7	185
10	Off Kushiro	42.85	144.38	107	7.8	614

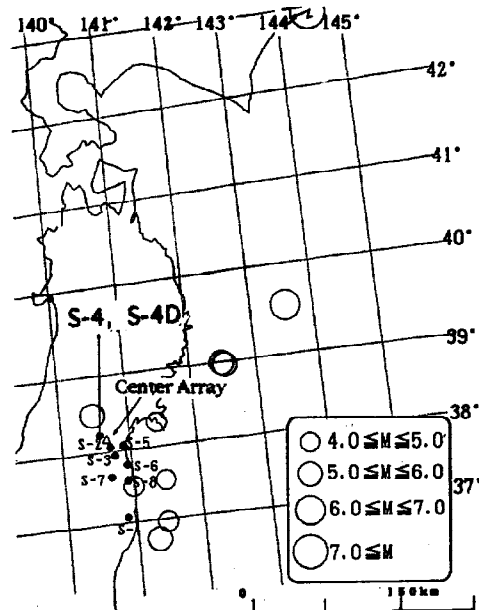


Fig.3. Epicenters and observation sites

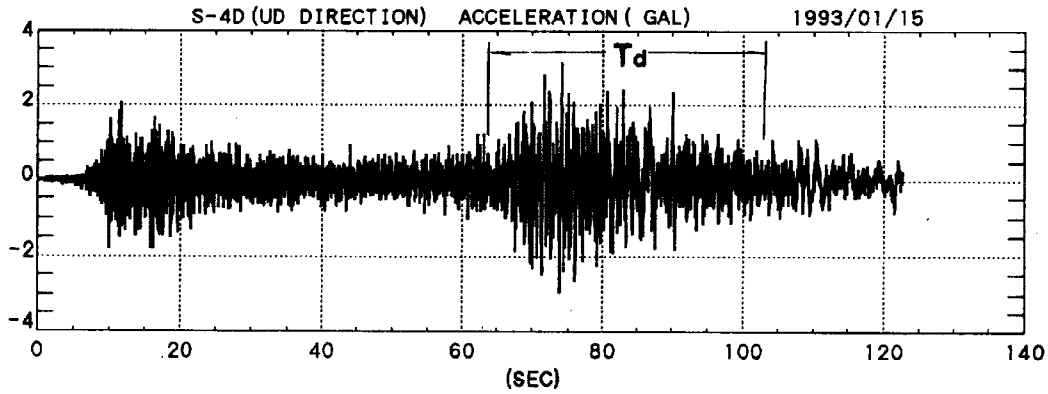


Fig.4. An example of observed motions

Concerning the mean ratios on spectra due to 10 events, Fig. 5(a) shows the spectral ratios of the S-4D point to the S-4 point in both horizontal and vertical directions and Fig. 5(b) shows the spectral ratios of vertical component to horizontal one at the points respectively. As shown in Fig.5(a), the ratios on both horizontal and vertical components tend to amplify substantially in the period range less than 0.2 seconds; horizontal ratios indicate the peak period at 0.07 seconds and vertical ratios have it at 0.035 seconds. In Fig. 5(b), both ratios of vertical component to horizontal one coincide with each other in period range greater than 0.2 seconds. These ratios vary substantially in the period range less than 0.2 seconds as well as the ratios on amplification; the ratios on the S-4 point indicate the off-peak period at 0.08 seconds and these on the S-4D point have the peak period at 0.07 seconds, the off-peak period at 0.035 seconds. On the S-4 point, the ratios of vertical component to horizontal one tend to vary due to the deviations of the amplification ratios between horizontal and vertical components. We calculated the ratios of vertical component to horizontal one on the amplification ratios as shown in Fig.5(a) and illustrated it with the ratios on the S-4 point in Fig. 5(b). Although both ratios are similar in shape, these values are not entirely in agreement with each other, so that the appreciable deviation between both ratios as shown in Fig. 5(b) consequently agrees with the ratios on the S-4D point.

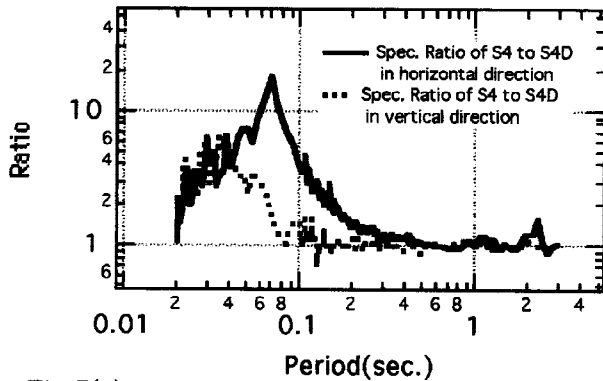


Fig.5(a). Mean spectral ratios of S-4 to S-4D

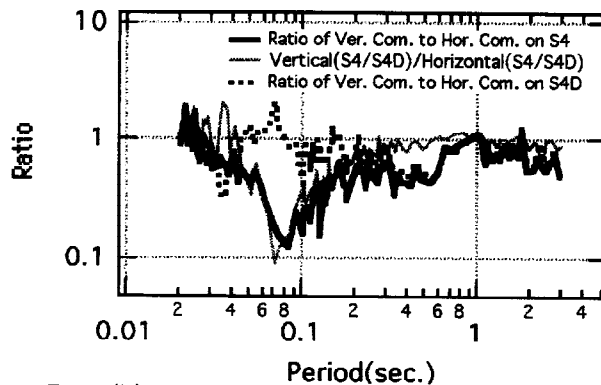


Fig.5(b). Mean spectral ratios of vertical component to horizontal one

### Comparison with Theoretical Spectral Ratios

We compare the observed spectral ratios with the theoretical estimations based on Silva's method in which inelastic layers on an elastic half-space are considered (Abe, 1990). If motions are composed of body waves, the theoretical ratios should be estimated in the case of obliquely incident SV-wave to the layers. Two kinds of ground structure model are



