# CHARACTERISTICS OF EARTHQUAKE MOTION AT THE ROCKY GROUND

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## Synopsis

The observation of the earthquake ground motion at the rock ground surface and at the underground, at deepst 67m below the ground surface, has been carried. Results of analysis of the earthquake records obtained aredescribed here.

The relation of the displacements at the ground surface and at the underground, the relation between the max. displacement at the ground surface and that calculated from the usual formula and distribution of the average acceleration along the depth were investigated.

Characteristics of the velocity response spectrum and the relation between number of peaks and peak value in the response velocity were studied.

## § 1. Introduction

Authors have continued the observation of the earthquake ground motion for these several years in the gantry vertical shaft of the underground electric power station on the rock foundation and also lately have started the observation of the tremor in the boring hole with the same depth at the shaft nearby the shaft, for the purpose of getting the available records for the earthquake resistant design of underground power station and of other structures at the rock foundation.

The earthquake ground motion on rock foundations has recieved much attention as one of the basic objects in antiseismic design of the structure, so that authors would like to make these data available for the purpose analysing records in details.

The observation point described here is "Kinugawa Electric Power Station", that is a underground water power station, situated at 150km north of Tokyo. This site is located in the Kanto Mountains around the Kanto Plain, where the geological layer consists of mainly tuff breccia.

The details of Kinugawa power station are shown in Fig.1. The gantry vertical shaft is $5 \times 7$m in its plan and 67.2m in depth,

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and the vertical boring hole is 75mm in diameter, 67m in depth and 17m far from the the shaft. The electro-magnetic seismometers have been settled on the ground and in the gantry vertical shaft. 5 horizontal accelometers have been located at about each 17m level in the gantry vertical shaft. Displacement seismometers also located at the surface of the ground and the bottom of the shaft. As for the boring hole, 8 accelometers were located at the depth shown in Fig.1. The boring hole was grouted with cement milk after setting up seismometers in it.

The observation of earthquakes was started in 1963 and more than 30 records were so far obtained, and it is still continued. The earthquakes and their characteristics analysed are shown in Table.1 and one of earthquake records is shown in Fig.2 as an example.

## S 2. Distribution of Seismic Intensity along Depth of the Ground

In order to survey an earthquake intensity under the ground, the distribution of average amplitude is measured and is shown in Fig.3.

As for the acceleration distribution, in case of the comparatively severe shocks the accelerations at the accelometers No.1, 2 and 3 are twice or more larger than that at the accelemeters No. 4 and 5, while in case of the weak shocks, such inclination could not be found. Of course, in case of the tremors which have mainly long period acceleration, the distribution along the depth is nearly uniform.

As for the displacement distribution, the displacement on the ground had a tendency to be somewhat larger compared with the underground displacement, however, there was no remarkable difference.

The relationships between the largest acceleration on the ground and that at the bottom of the shaft are shown in Fig.4. The former is about 2 times of the latter, but when the acceleration consists of chiefly the comparative long period component, the ratio is nearly equal to 1.

## S 3. Intensity of Earthquakes

For each seismic record the largest displacement was determined. Otherwise, the largest displacement was calculated by the following formula,

$$\log_{10} Am = M - 1.73 \log_{10} \Delta + 0.83$$

where M : magnitude of earthquakes
△ : hypocentral distance in Km
Am : largest displacement in micron

The calculated displacements were compared with the observed in Fig.5 where the calculated values are represented in the abscissa and the observed values in the ordinate. White circles show the values of the ground surface and the black circles that of the bottom of the shaft. In this figure it is seen that the observed value is about half or less of the calculated value, that is, site correction coeffecient is about 0.5 or less at this observation point.

## § 4. Response velocity of the tremors

1) Velocity spectrum of the response

Velocity spectrum of the response to the main part for 2 sec. or more long of the acceleration records, where records are large and apparently stational, were calculated out. Results were shown in Fig.6(a) and Fig.6(b) as examples.

Fig.6(a) is of the earthquake NO.8 numbered in Table.1 that seems to be a representative earthquake at the observation point, and Fig.6(b) is of the Niigata Earthquake that is numbered as NO.5 in Table.1 and the latter seems to be a particular one.

Most of records have similar trends in the velocity spectrum of the response with Fig.6(a). As for the velocity spectrum to the Acc. NO.5 which is a acceleration record at the bottom of the shaft, in lower frequency than 6 - 7 cps velocity spectrum decreases as the frequency decreases and it seems to be nearby the line on which the displacement spectrum are uniform. And within the frequency range from 6 - 7 cps to 15 - 16 cps, velocity spectrum is supposed to be uniform. Furthermore, in the higher frequency than 15 - 16 cps, velocity spectrum decreases as the frequency increases in opposition to the case of the lower frequency than 6 - 7 cps, and the velocity spectrum is supposed to be nearby the line on which the acceleration spectrum are uniform.

Moreover, increasing of magnification factor, that is ratio of the velocity spectrum at each depth to that at the bottom of the shaft, in lower frequency than ca. 12cps, may be due to the characteristics of the surface layer at this site. Since the Niigata Earthquake is one of the large earthquakes and it's epicenter located comparatively far from the site, low frequency component may be more contained in acceleration even at the bottom of the shaft. Then, as shown in Fig.6(b), the response velocity does not decrease but increases in lower frequency than 7.5 cps, differed from the case of Fig.6(a).

However, magnicfication factors for the Niigata Earthquake mentioned above are rather a little smaller than that of the other earthquakes in lower frequency as shown Fig.7.

2) Number of the peaks of the velocity response

When the acceleration input is put to the one mass-spring system, response velocity is obtained. The velocity is a time function and later in this chapter it will be called as the response velocity.

Response velocity is noted to be similar with a pseud sinusoidal wave. In this case, the fact may be practically fitted to the response velocity. Relation between the natural frequency and the number of the peaks in the response velocity of the acceleration records during the earthquake NO.1 and NO.12 are shown in Fig.8(a) and Fig.8(b) as examples. Fig.8(b) is of the earthquake NO.12 which is a local severe earthquake and it's acceleration records at the site contain considerably the comparatively long period component. Meanwhile, the earthquake No.1 has not such comparatively long period as the earthquake NO.12 and has predominancy of the short period vibration. This is the reason for the difference between Fig.8(a) and Fig.8(b). In Fig.8(a), in lower frequency than 7.5 cps the number of peaks in the velocity response for the acceleration record at the bottom of the shaft is larger than the number of peaks obtained by calculation on assumption that velocity response is a sinusoidal wave with the natural frequency considered.

3) Relation between number of peaks and peak value

Generally, response velocity spectrum shows the relationship between the natural period of the one mass-spring system and the maximum absolute value of the velocity response of the system to the input. Considering the failure of structures caused by repeated loading, total number of repeated dynamic loading on the structure during the earthquake is one of the most important factors in designing of antiseismic structures.

Then, supposing the velocity response as sinusoidal wave, relation between the number of the peaks and the peak value was investigated on the representative earthquake records. The peak values are represented by the ratio of the value to the max. peak value. Peak values were arranged in order from max. value to the least value. They are numbered by the ratio of each number to the total in order.

Result is shown in Fig.9 as an example. In the case of the natural frequency 20 cps, 2 peak values will exceed beyond 80% of the max. peak value per second. In Fig.10 the relation for the acceleration records of 4 earthquakes obtained at the bottom of the shaft is shown. In these 4 earthquakes, the Niigata Earthquake, earthquake NO.12 which is local severe earthquake and other 2 earthquakes are contained.

Then authers made the envelope lines boldly along the upper limit of these lines as shown in Fig.11. Using this, expected number of the peak which exceeds over the arbitrary ratio to the max. peak value is easily determined.

4) Response velocity and number of peaks

Assuming that response velocity spectrum to the earthquake motion at the base rock may has such characteristics as mentioned 1), and applying the procedure mentioned in 3) to that response velocity spectrum, result is shown in Fig.12. Ordinate denotes the ratio of the peak value to the max. peak value and parameter denotes the expected number of the peak exceeding over the ratio considered per second. From Fig.12, expected number of peaks of the velocity response during earthquakes which exceeds a assigned value can be obtained. This result may be available to designing of the structures.

Acknowledgement

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Also for this study, many friendly helps by the office of Tokyo Electric Power Co. Ltd. at the observation site were granted.

Fig.1 General View of Power Sation

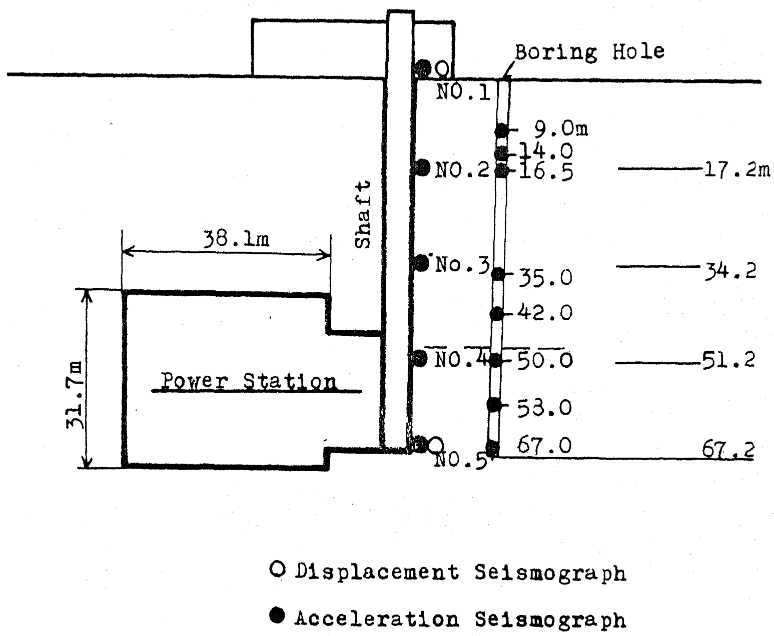



Fig.2 Earthquake Records

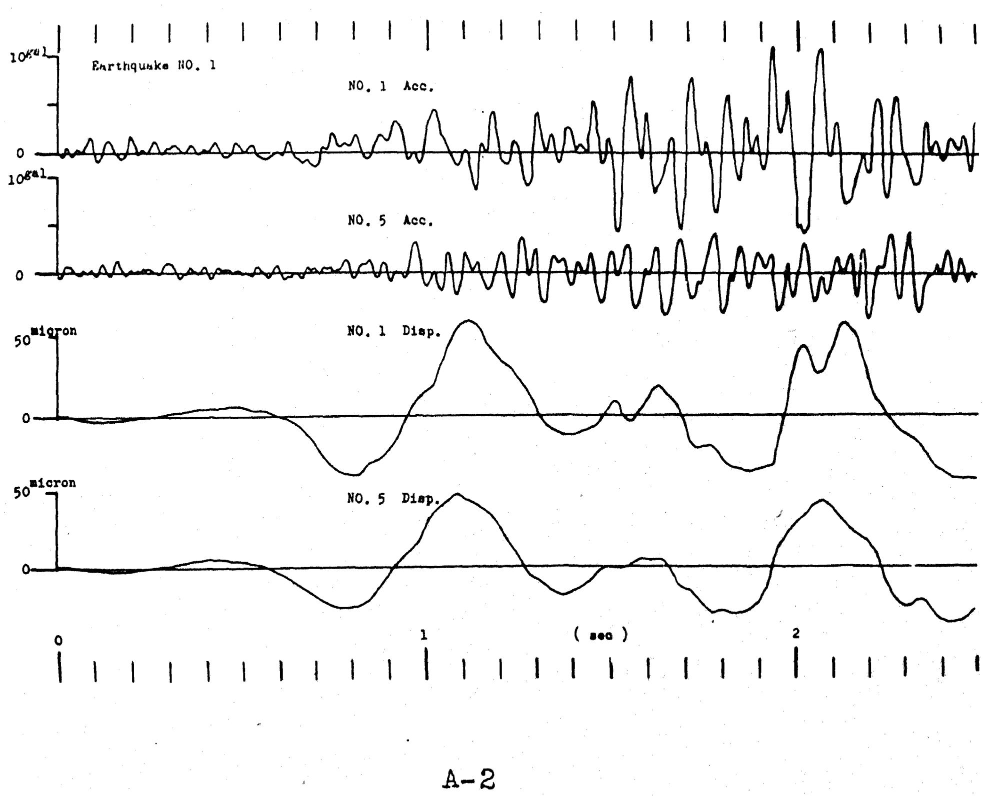


Fig. 3 Average Acceleration vs. Depth

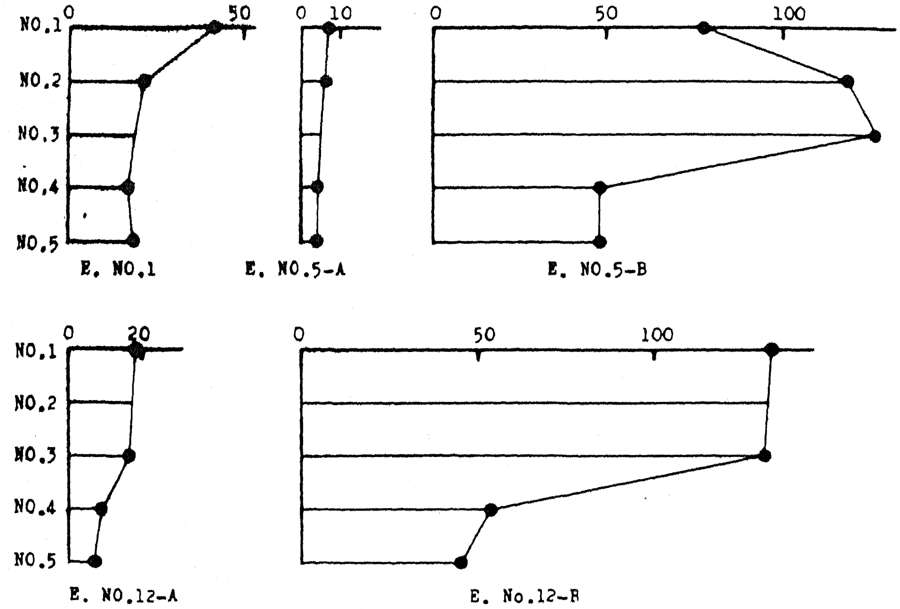



Fig. 4 Largest Acceleration on Surface Rock and at Base Rock

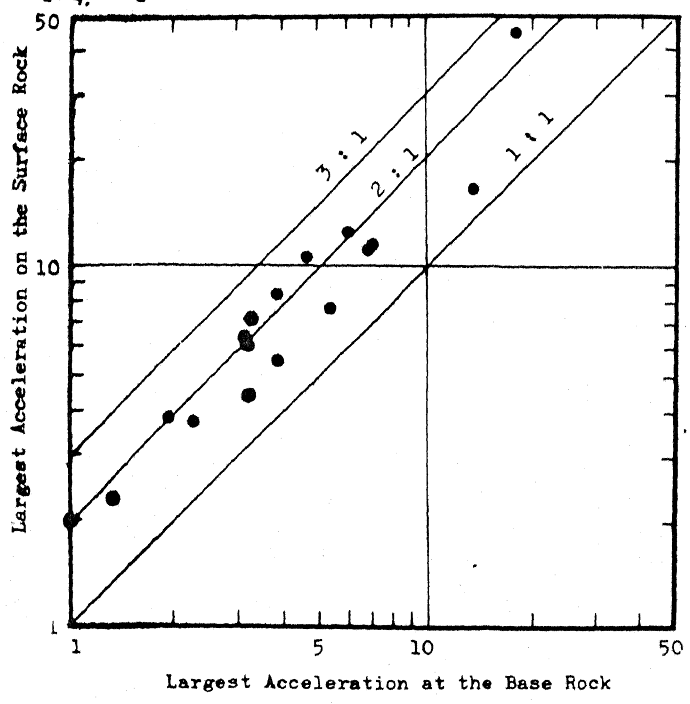


Fig. 5 Correlation between Calculated and Observed Max. Displacement.

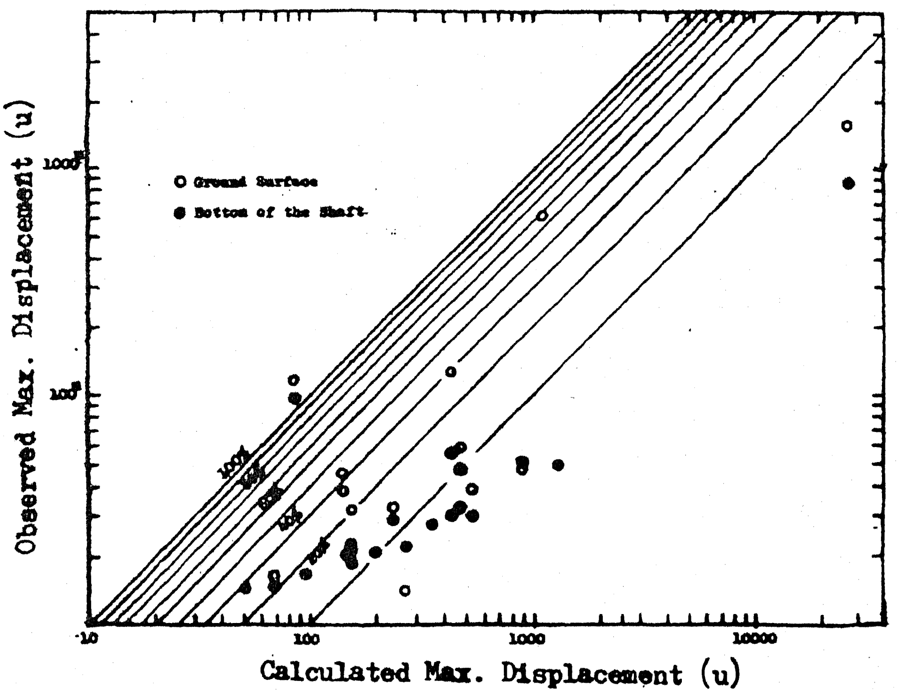



Fig. 6(a) Velocity Spectrum of Response

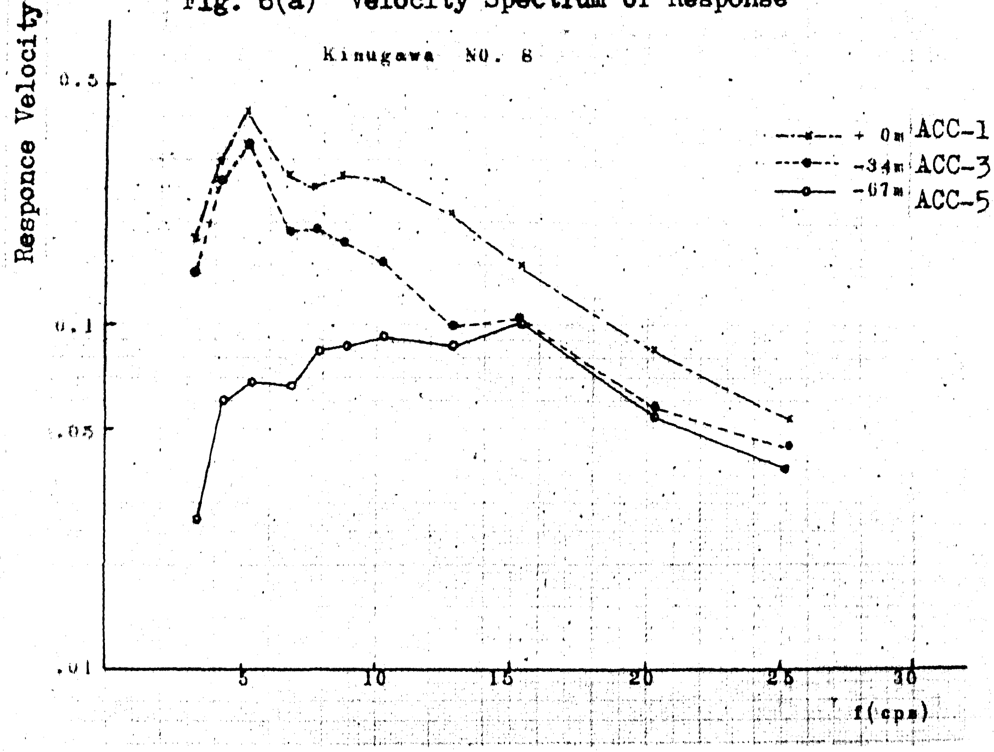


Fig. 6(b) Velocity Spectrum of Response

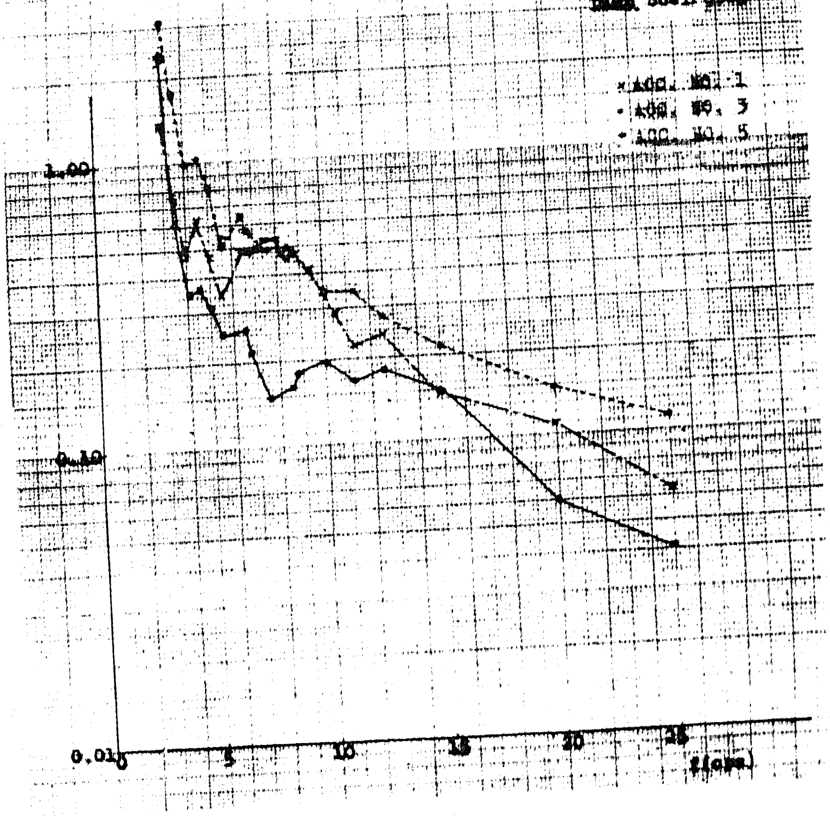



Fig 7 Magnification Factor-Frequency

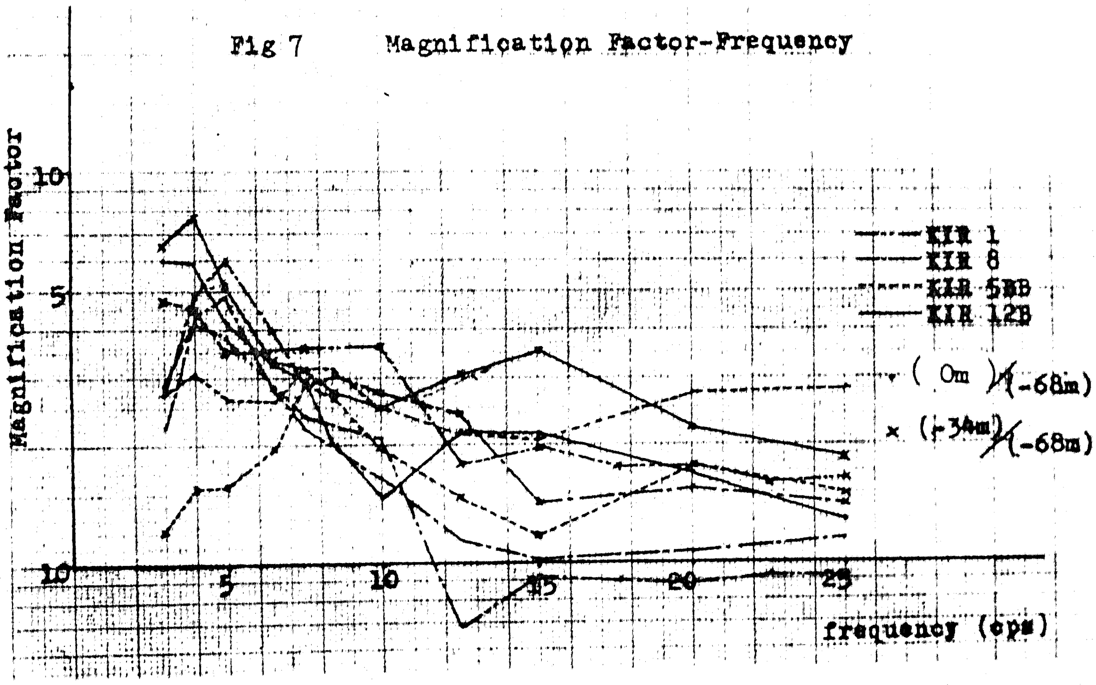


Fig.8-a Relation between Frequency and Number of Peaks

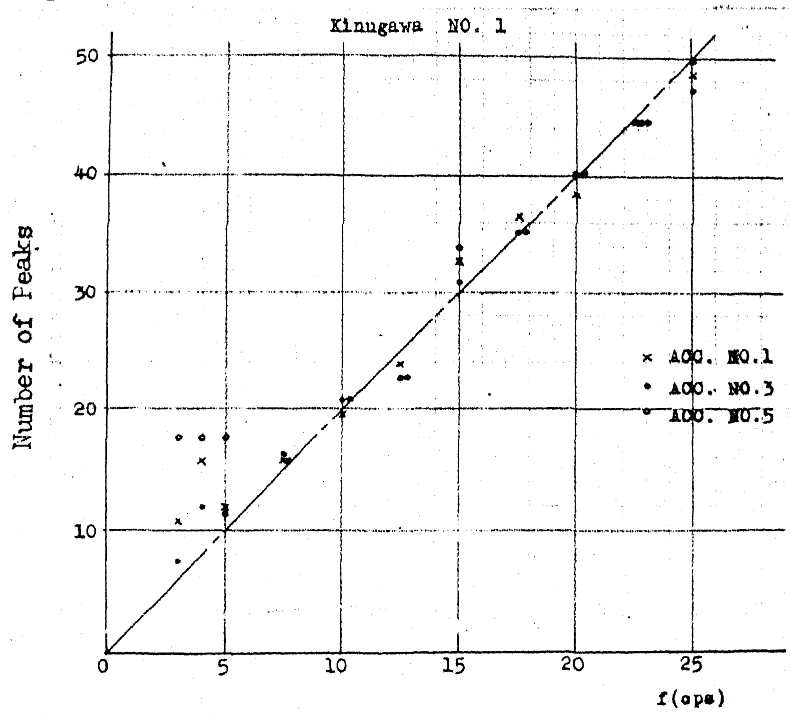
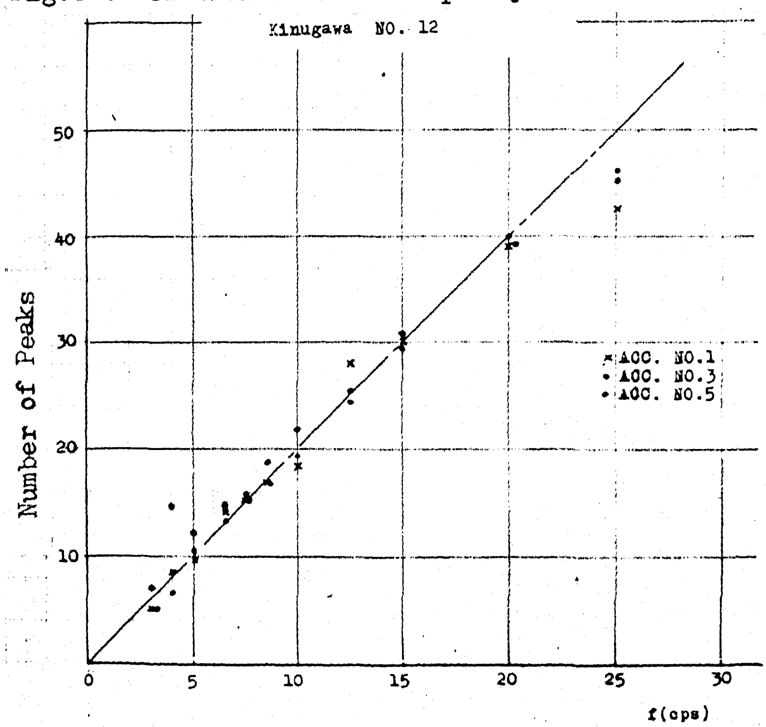



Fig.8-b Relation between Frequency and Number of Peaks



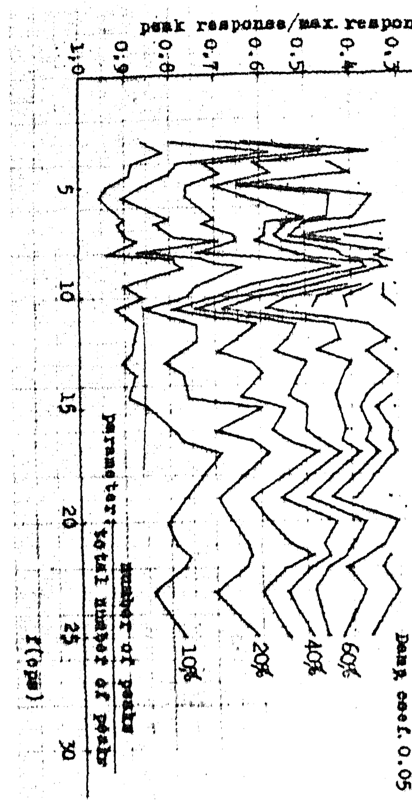


Fig 9 Frequency and Peak Response / Max. Response

Kinugawa NO. 1 ACC. NO.5

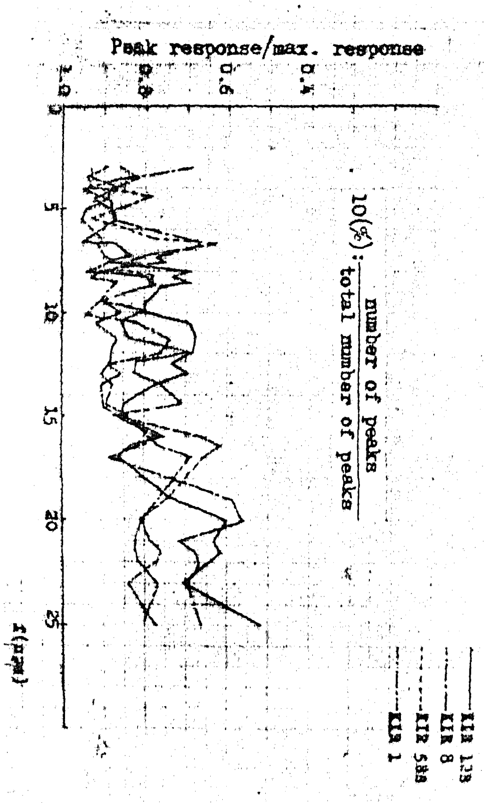


Fig.10 Frequency and Peak Response / Max. Response at the bottom of the shaft.

10(%): number of peaks / total number of peaks

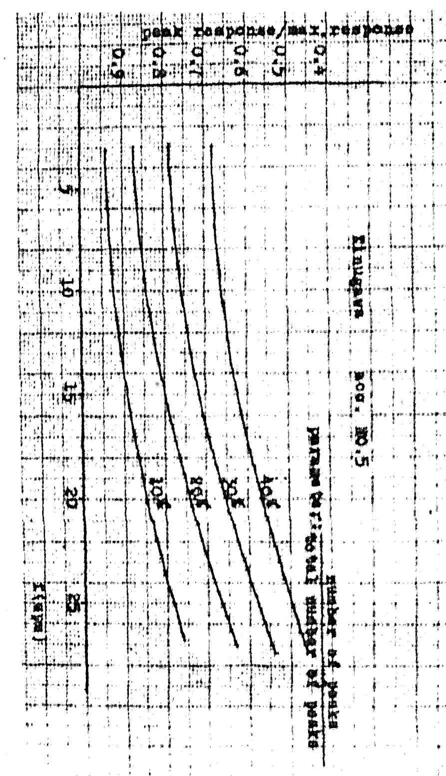


Fig. 11 Relation between Number of Peaks and Peak Response / Max. Response

Kinugawa ACC. NO.5

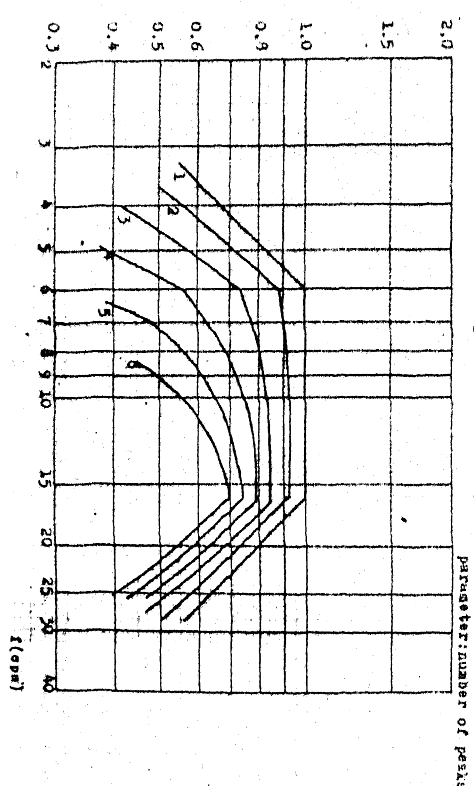


Fig. 12 Response Velocity and Number of Peaks

Kinugawa ACC. NO.5

## Table.1 Characteristics of Earthquake

| Earth-quakes | Date | Epicenter | Depth | Magnitude | Distance | |
|---|---|---|---|---|---|---|
| | | | | | Epi-central | Hypo-central |
| | | | km | | km | km |
| 1 | 1963.12.24 | 36.1N,140.0E | 60 | 5.2 | 87 | 106 |
| 2 | 1964. 5.11 | | | | | |
| 3 | 5.30 | 36.2N,139.6E | 20 | 4.3 | 70 | 73 |
| 4 | 6. 6 | | | | | |
| 5 | 6.16 | 38.4N,139.2E | 40 | 7.5 | 180 | 185 |
| 6 | 11.12 | 36.4N,139.2E | 0 | 4.9 | 55 | 55 |
| 7 | 11.14 | 36.5N,140.6E | 40 | 5.1 | 80 | 90 |
| 8 | 12.20 | 37.3N,141.8E | 40 | 5.3 | 190 | 194 |
| 9 | 1965. 1.24 | 36.6N,141.1E | 60 | 5.2 | 120 | 134 |
| 10 | 1.27 | 36.0N,139.8E | 80 | 4.7 | 90 | 120 |
| 11 | 2.14 | 36.1N,139.9E | 60 | 4.3 | 80 | 100 |
| 12 | 4. 6 | 36.1N,139.9E | 60 | 5.5 | 80 | 100 |
| 13 | 9.11 | 37.3N,141.4E | 60 | 5.5 | 157 | 168 |
| 14 | 1966. 5.25 | 36.0N,139.9E | 40 | 4.3 | 95 | 103 |
| 15 | 6. 3 | 35.7N,140.2E | 80 | | 135 | 157 |
| 16 | 10.28 | 35.8N,140.2E | 60 | 5.5 | 128 | 141 |
| 17 | 11.27 | 36.5N,140.6E | 60 | 3.7 | 90 | 113 |
| 18 | 1967. 1.17 | 38.3N,142.1E | 30 | 6.3 | 262 | 264 |
| 19 | 8. 3 | 36.1N,139.9E | 50 | 4.5 | 86 | 99 |
| 20 | 9.15 | 35.6N,140.9E | 40 | 5.6 | 175 | 180 |
| 21 | 11. 4 | 37.3N,141.9E | 50 | 5.8 | 204 | 210 |
| 22 | 11.19 | 36.5N,141.2E | 50 | 6.0 | 138 | 147 |
| 23 | 1968. 2.26 | 37.6N,141.6E | 50 | 5.4 | 187 | 193 |
| 24 | 3. 6 | 36.1N,139.9E | 50 | 5.2 | 87 | 101 |
| 25 | 3. 7 | 35.5N,140.1E | 50 | 5.1 | 148 | 156 |