ON NON-STATIONARY CHARACTERISTICS OF RECORDED ACCELEROGRAMS IN OSAKA PLAIN

by

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SUMMARY

Non-stationary characteristics of the recorded accelerograms in the Osaka plain, in a problem of aseismic design for building structure, are discussed in relation to earthquake magnitude, epicentral distance, and ground properties of the site. The non-stationarity is defined as a amplitude level function and a non-stationary spectral density function, which indicate variation of intensity level of seismic waves in the time domain and time-variant spectral density in the frequency domain, respectively. About 20 accelerograms of the earthquakes recorded on rock site and alluvium site,the seismic intensity scales of which are 1 or more, are available for the numerical calculations and the results are shown graphically.

INTRODUCTION

In the problems of reasonable assesment of input characteristics of a earthquake excitation to building structure at any site, some aspects of the characteristics of input within the frequency range mainly from 0.2 Hz to 3o Hz should be estimated quantatively in reference to various factors concerning a earthquake magnitude,a epicentral distance, and transmission properties of the path. It is a direct approach for this problem to examine statistically the characteristics of actual recorded accelerograms of various classes of earthquake magnitudes and epicentral distances. For this purpose, the earthquake observation in the Osaka plain has been carried out for several years in order to accumulate the acceleration records at ground surface and subsurface and, by making use of these records,some characteristics of wave shape have been investigated with respect to the relation of the factors of earthquake. Especially, from the viewpoint of aseismic engineering, it is hoped that input characteristics in high intensity level are studied on the basis of the acceleration records of strong ground motion. In the Osaka plain, however, a little amount of the accelerograms of strong motion earthquake can be recorded in a few years because of the weak seismicity of the area and, therefore, it is difficult to discuss statistically only on the data of strong motion earthquake.

In this paper, the non-stationary characteristics of an earthquake excitation are examined for 20 acceleration records on several observation points in the Osaka plain for the earthquake, its seismic intensity scale of which is 1 or more, in order to evaluate wholly the input characteristics at the site with regard to some natures of the earthquake. The non-stationary characteristics of the earthquake excitation are represented by two physical quantities in respect to the time and the frequency, which describe a variation of intensity level and a time-variant spectral characteristics, respectively.1) The methods of evaluating these quantities have been discussed by some investigators. This paper examines the non-stationarity of earthquake excitation by means of the concepts of ampli-

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tude level function and time-variant spectral density function and the numerical results are shown.

AMPLITUDE LEVEL FUNCTION

A non-stationarity in the time domain is defined here by an amplitude level function, which corresponds to a time variation of intensity level of an earthquake excitation. 2),3) In general, an amplitude level function is supposed to be slowly varying time function and to change its properties according to epicentral distance, earthquake magnitude et al. For the estimation of a variance of intensity level of the acceleration records , a local variance of wave shape, which is calculated as an averaged value in the finite time interval by means of weighting functions,has been used but it is considered to indicate obscurely a time variation of energy level of wave shape and the analytical results are influenced by the selection of a weighting function.

For the purpose of discussing the intensity level within the specific frequency range and of estimating more or less precisely in the physical meanings, the function $E_a(t)$ and its time differential $\dot{E}_a(t)$ for the acceleration a(t) are defined as a integration of the squared absolute values of finite Fourier transform and its time differential, as to the wave shapes within the finite frequency range as follows:

$$E_a(t) = \int_0^f | F_a(\eta, t)|^2 d\eta \qquad \text{(EQ. 1)}$$

where,

$$F_a(f, t) = \int_0^t a(\tau) \exp(-j2\pi f)\, d\tau \qquad \text{(EQ. 2)}$$

The representation of amplitude level function $E_a(t)$ corresponds to the integration of instanteneous power spectrum defined by C.H.Page. 4) Fig.1 shows the amplitude level function $\dot{E}_a(t)$ evaluated by equation (1), in comparison with the local variances calculated by making use of the rectangular and triangular weighting functions, for SMAC accelerograms of moderate intensity earthquake in the Osaka plain. The good agreement among these results is clear in this figure. The numerical results of the integrated amplitude level function are shown in Fig.2, 3, and 4.

NON-STATIONARY SPECTRAL DENSITY

An earthquake excitation is a comparatively strong non-stationary phenomenon lasting from about 10 seconds to several minutes, and therefore there are various difficult problems in the evaluation of non-stationary spectral characteristics with regard to a resolution and a stability. The non-stationary spectral density function of an earthquake excitation is defined in this paper as the finite time-averaged variance of output process through a narrow band filter, shown in the following equation:5)

$$\phi(f,t) = \frac{1}{t_o} \int_{t-\frac{t_o}{2}}^{t+\frac{t_o}{2}} d\tau \cdot \frac{1}{\Delta f} \iint_{-\infty}^{\infty} g(\xi_1) g(\xi_2)\, K_x(\tau-\xi_1, \tau-\xi_2)\, d\xi_1 d\xi_2 \qquad \text{(EQ. 3)}$$

where g(t) is a narrow band filter characteristics with band width Δf and $K_x(\tau, t)$ is a covariance function of x(t) as to the time t and τ. It is cear that this function $\phi(f,t)$ is a positive real valued function with respect to two variables, frequency f and time t. Physically, this function is supposed as an approximate representation of spectral density in the neighbourhood of an instant of time t under the condition $\Delta f t_o \gg 1$ and, for this definition, the following generalized Wiener-Khintchine theorem can be led, introducing the time-averaged covariance function ${}_oK_x(\tau,t)$:

$$\phi(f,t) = \int_{-\infty}^{\infty} {}_oK_x(\tau,t)\frac{\sin 2\pi\Delta f\tau}{\pi\Delta f\tau}\exp(j2\pi f\tau)\, d\tau \qquad \text{(EQ. 4)}$$

$${}_oK_x(\tau,t) = \frac{1}{t_o}\int_{t-\frac{t_o}{2}}^{t+\frac{t_o}{2}} K_x(\eta,\eta-\tau)\, d\eta \ .$$

As to the filter characteristics g(t) in the equation (3), the ideal rectangular filter with center frequency f_o and narrow band width Δf are used in this section. Furthermore, in the case that the transfer characteristics of one-mass-system with appropriate damping value is adopted as a narrow band filter, mean squared response due to an earthquake excitation can be estimated by means of the same procedure as the method of estimating maximum response from response spectrum by modal analysis.

RECORDED ACCELEROGRAMS IN OSAKA PLAIN

Osaka plain, which faces the Osaka-wan bay, locates almost in the central part of Honshu-island of Japan and its dimension of the area is about 45 by 30 in kilometers. The geological structure of the plain is comparatively complex, the depth of base rock in which is about from 600 meters to 1500 meters. The observation points of earthquake in the Osaka plain are indicated in Fig.5, where the accelerograms are recorded at ground surface and subsurface by bore-hole type accelerometers. Concerning to the ground characteristics of the observation points, one is on rock site near the ground surface , which is considered as a part of stratum of the base rock of the Osaka plain, and the other are on alluvium site.

There is few of acceleration records of strong ground motion in the Osaka plain up to now because of the weak seismicity of the area. Owing to the earthquake observation by the accelerometers, whose the sensibility of the starter is 0.05 kine, the number of occurences of earthquake is on an average about 20 in a year. Among these recorded accelerograms on the site, the records by the earthquake, the intensity scale of which is 1 or more in the Osaka area, are selected in order to analyze in this paper. The total number of the records on the rock and the alluvium sites is 20 and the earthquake magnitude of these records are from 4.8 to 6.8.

ANALYTICAL RESULTS

Some of the numerical calculations of the integrated amplitude level function for the records both on the rock and the alluvium sites are shown graphically in Fig.2, 3, and 4. In order to investigate the characteristics of pattern of wave shape as to a time variation of intensity level, the amplitude level functions within various frequency range, that are 0-5 Hz, 0-10 Hz, 0-25 Hz for rock site and are 0-1 Hz, 0-3 Hz, 0-5 Hz, 0-10 Hz for alluvium site, are evaluated here as the ratios to maximum value within the whole frequency range. It is pointed out in Fig.2 that the numerical results for the records on rock site indicate a linearly variate increasing ratio of the intensity level corresponding to the part of main shock of wave shape , in comparison with the results for alluvium site in Fig.3.Using the estimation results of the interval of these linear part shown by the dotted line in Fig.2, the time duration ${}_sT_d$ of the part of main shock are plotted , in relation to earthquake magnitude Δ,in Fig.5. As shown in the figure, the values of the duration ${}_sT_d$ increase linearly according to the value of earthquake magnitude M. As for the increasing ratios of integrated amplitude level function, the values of the increasing ratio decrease as the values of the epicentral distance Δ increase, shown in Fig.7. The maximum values of the integrated amplitude level function, which represented a total intensity of wave shape within each frequency ranges, are shown in Fig. 8 for the rock site as to earthquake magnitude. The figure shows that these values increase generally as the earthquake magnitude increase, though the scattering of the values in the frequency range 0-25 Hz is rather intense than that in the frequency range 0-10 Hz.

Fig.9-a and Fig.9-b show the ratios of the total intensity within various frequency ranges in respect to the earthquake magnitude, in the case of taking the standard as the value in 0-5 Hz range for the rock site and in 0-1 Hz range for the alluvium site, respectively. Though the results are rather scattered within higher frequency range, it can be pointed out the comparatively distinct tendency in the relation of the ratios of total intensity and the epicentral distance. In Fig.3-b and 4-b, the analytical calculations for the velocity of wave shape for the records on alluvium site are shown. The variation of the increasing ratios in this case is nearly linear corresponding to the epicentral distance. in the total duration time, in contrast with the case of acceleration records.

Fig.10 and Fig.11 show some of the calculation results of non-stationary spectral density function for the acceleration records, at three instants of the time in the duration. The spectral characteristics at the site is cosidered as the results composed of original spectrum in origin and transmission properties in the path, which are difficult to discuss separately on each factors from the observation records. Therefore, the non-stationary characteristics is necessary to be taken into consideration in the analysis of wave shape in order to evaluate the generation and the propagation of spectral characteristics in the paths. With respect to the spectral characteristics on the rock site shown in Fig.10 for example, the predominant frequencies in the range above 1 Hz are unstable, in general, regarding with earthquake magnitude and orientation to epicenter. In the case of the epicentral distance far over 100 km, the predominant frequencies remain only in the frequency range from 1 Hz to 2 Hz, but the relation concerning to the earthquake magnitude is not clear. It is indicated, on the other hand, that the spectral characteristics for the alluvium site become to be simple as the epicentral distance is far and the predominant frequency remove toward in the lower frequency range slightly according to the lapse of the time. From these numerical results in this paper, the relation of the non-stationary characteristics and the natures of earthquake can not be pointed out distinctly because of the insufficiency of the number of the observation records.

CONCLUDING REMARKS

In this paper, some discussion on the method of evaluating the non-stationary characteristics of the earthquake excitation are presented, in which the non-stationarity are defined as the amplitude level function and the non-stationary spectral density function. By using these methods, the non-stationarity of the recorded accelerograms in the Osaka plain are investigated numerically, in relation to the earthquake magnitude and the epicentral distance. Some conclusions are as follows:

1) Amplitude level function is very effective to estimate a time variation of intensity level of wave shape within the specific frequency range.
2) The duration time of the part of the main shock on the rock site increases linearly according to the values of earthquake magnitude.
3)The increasing ratios of the integrated amplitude level function are well corresponded to the epicentral distance.
4) The ratios of the total intensity level within various frequency ranges are related with the earthquake magnitude and the epicentral distance, though the estimation results are scattered, to some extent, with regard to the frequency range.
5) The spectral density distribution in the frequency range higher than 1 Hz is unstable in the whole duration time and the predominant frequencies in the higher frequency range have no distinct reference to the earthquake magnitude and the epicentral distance.

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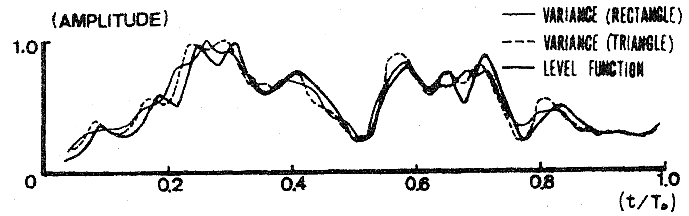
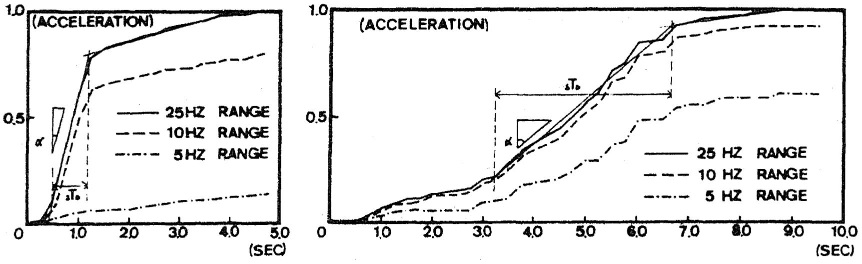


Fig.1 Comparison of Amplitude Level Function and Local Variance.



(Δ =26 km) (Δ =167 km)

Fig.2 Amplitude Level Function of Acceleration on Rock Site.

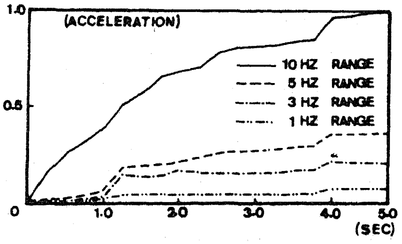


Fig.3-a Amplitude Level Function of Acceleration on Alluvium Site. (Δ =24 km)

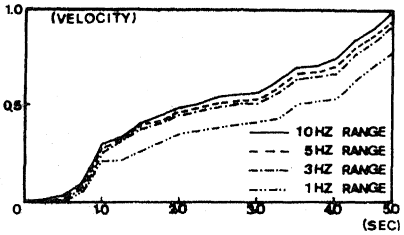


Fig.3-b Amplitude Level Fnction of Velocity on Alluvium Site. (Δ =24 km)

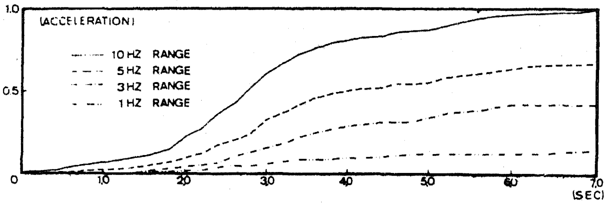


Fig.4-a Amplitude Level Function of Acceleration on Alluvium Site. (Δ =140 km)

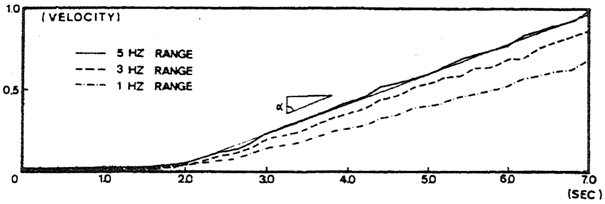


Fig.4-b Amplitude Level Function of Velocity on Alluvium Site.
(Δ =140 km)

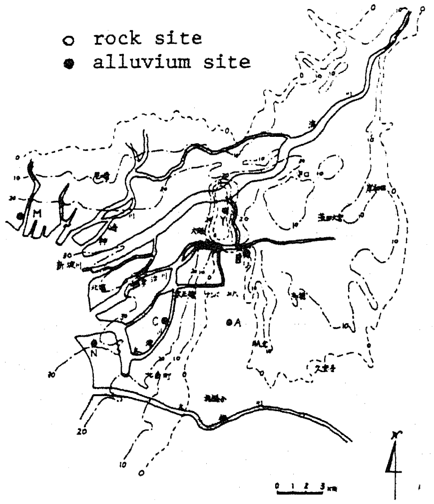


Fig.5 Observation Point in Osaka Plain.

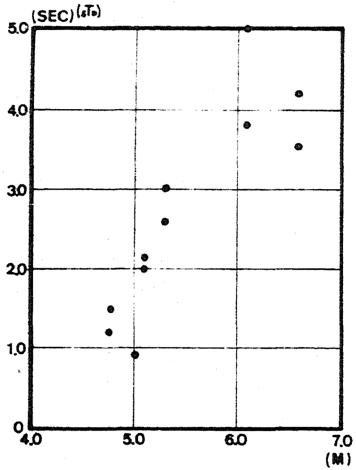


Fig.6 Relation of Duration in High Intensity Level and Earthquake Magnitude on Rock Site.

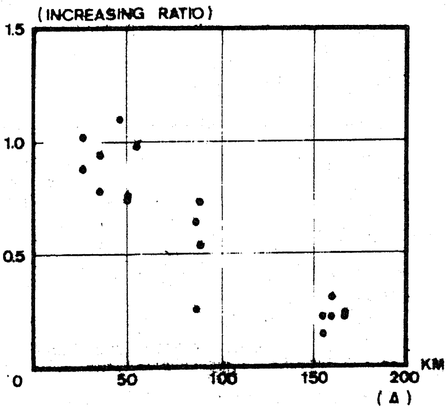


Fig.7 Relation of Increasing Ratio of Intensity Level and Epicentral Distance.

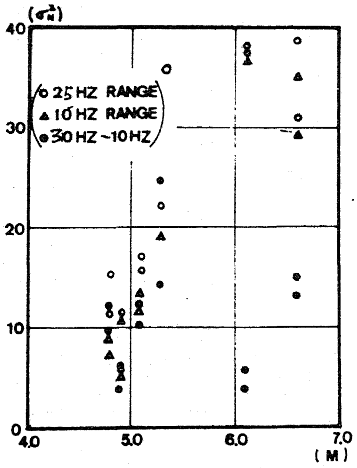


Fig.8 Variation of Total Variance within Various Frequency Ranges as to Earthquake Magnitude.

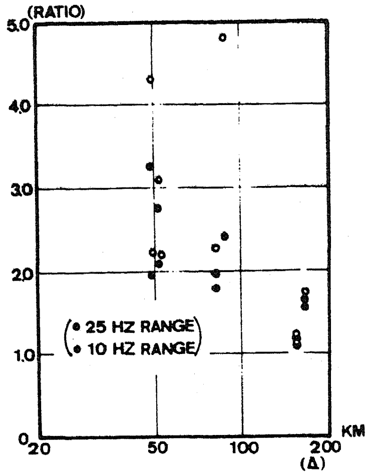


Fig.9-a Ratio of Total Variance within Various Frequency Ranges as to Earthquake Magnitude. (on Rock Site)

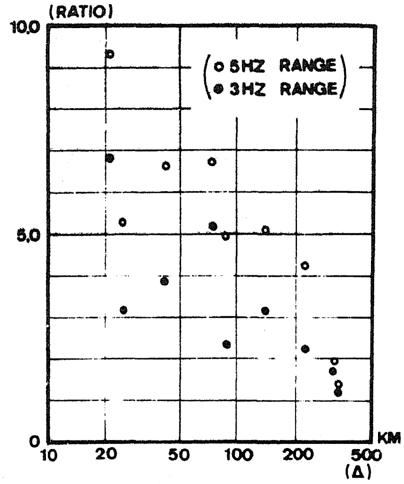


Fig.9-b Ratio of Total Variance within Various Frequency Ranges as to Earthquake Magnitude. (on Alluvium Site)

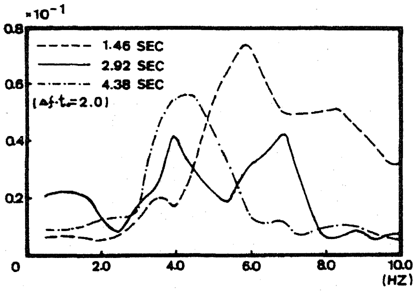


Fig.10-a Non-stationary Spectral Density Function of Acceleration on Rock Site. (Δ =86 km)

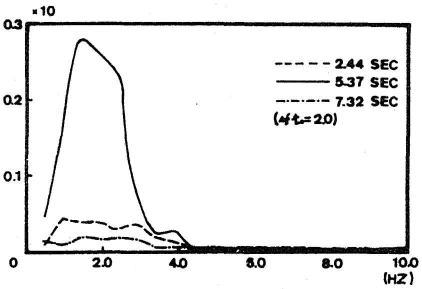


Fig.10-b Non-stationary Spectral Density Function of Acceleration on Rock Site. (Δ =155 km)

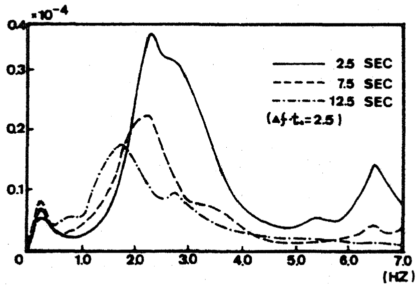


Fig.11-a Non-stationary Spectral Density Function of Acceleration on Alluvium Site. (Δ =21 km)

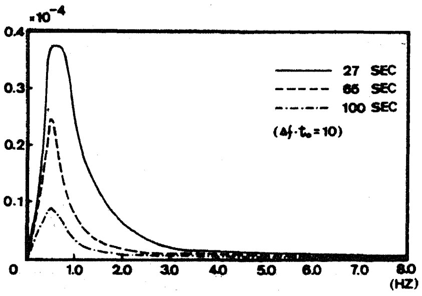


Fig.11-b Non-stationary Spectral Density Function of Acceleration on Alluvium Site. (Δ =340 km)