THE SENSITIVITY OF STRONG MOTION ACCELEROGRAMS TO FREQUENCY NONSTATIONARITY AND EFFECTS OF INVOLVED DATA

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SUMMARY

In this research work, first of all the ranges of sensitivity of nonstationary frequency parameters were discussed for the seventy one U.S. and twenty Japanese earthquake acceleration records depending on four types of soil conditions, namely rock, stiff soils, deep cohesionless and soft to medium clay and sands. Secondly, for the most sensitive soft to medium clay and sands, the effect of nonstationary content over response spectrum was illustrated by means of simulated earthquakes ensembles which were obtained including and excluding Niigata strong motion horizontal components.

INTRODUCTION

Since earthquake strong motion accelerograms have nonstationary characteristics both in amplitute and frequency content, it should be expected to give some deviations when they were treated as for obtaining some kind of general response spectrum or in other way the engineers should know how the sensitvity of the frequency parameters representing frequency content and what kind of results could happen even changing a couple of data.

Indeed, the utilization of strong motion data, either in simulation technique or in response analysis of the structures needs the knowledge of nonstationary frequency effects, even though the acceleration records are roughly classified according to Fourier Spectrum.

Herein, it should be understood that the sensitivity of nonstationary frequency parameters were discussed here only taking account differences of the variations of the standart deviations of the parameters.

NONSTATIONARY FREQUENCY ANALYSIS

In order to investigate the nonstationary frequency contents of the accelerograms, stochastic Physical spectrum and Evolutionary spectrum are powerfull tools in the recently developing earthquake engineering. (Ref. 1) Physical spectrum of the earthquake acceleration x(t) is defined by

$$S(\omega,t;W) = E\left[\frac{1}{2\pi}\left|\int_{-\infty}^{\infty} W(t-u).x(u).e^{-i\omega u}du\right|^2\right] \qquad (1)$$

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where ω, t and W are frequency, time and window function respectively. The window function is chosen as bell type as

$$W(t) = (\sqrt{2}/T)^{1/2}\exp(-\pi t^2/T^2) \tag{2}$$

where T is numericaly determined from the previous studies as 2.5 sec. (Ref. 2).

Selection of Earthquake Records

For the analyses of earthquake acceleration records, the selection is based on the work of Seed , Lysmer and Ugas (Ref. 3) and same classification is adopted as in previous study. The number of accelerograms are listed as follows:

(1) 26 records for rock site
(2) 29 records for stiff soil sites
(3) 26 records for deep cohesionless sites
(4) 10 records for soft to medium clay and sands.

Before analysing each record, Arias intensity is applied to each one in order to take into consideration the main power of each accelerogram. So initial times and final times are determined by t_1 and t_2 respectively

$$t_1 \longrightarrow \bar{P}_1 = 0.05 \cdot \int_0^t a^2(t)\,dt \Big/ \int_0^\infty a^2(t)\,dt \tag{3a}$$

$$t_2 \longrightarrow \bar{P}_2 = 0.95 \cdot \int_0^t a^2(t)\,dt \Big/ \int_0^\infty a^2(t)\,dt \tag{3b}$$

here $\bar{P}_1$ and $\bar{P}_2$ represent dimensionless energy ratios. Then using Eq. 1 time dependent frequency content is obtained by means of stochastic physical spectrum, shifting 50 times equally dividing the time axis.

Time Dependent Frequency Parameters

Frequency parameters become very useful and important for both the evaluation of the sensitivity of the contents and the realization of the simulation method.

Frequency parameters will be defined for nonstationary content as follows

$$\alpha_i(t) = \int_0^\infty \omega^i S(\omega,t;W)\,d\omega \tag{4}$$

Vanmarcke had called these parameters as "spectral moments" for the stationary case (Ref. 4), I indise takes the 0, 1, 2,... values. Parameters are derived from the results of the α values.

$$\omega_1(t) = \frac{\alpha_1(t)}{\alpha_0(t)} = \int_0^\infty \omega S(\omega,t;W)\,d\omega \Big/ \int_0^\infty S(\omega,t;W)\,d\omega \tag{5}$$

$$\omega_2(t) = \left(\frac{\alpha_2(t)}{\alpha_0(t)}\right)^{1/2} = \left(\int_0^\infty \omega^2 S(\omega,t;W)\,d\omega \Big/ \int_0^\infty S(\omega,t;W)\,d\omega\right)^{1/2} \tag{6}$$

$$\omega_s(t) = \left(\omega_2^2(t) - \omega_1^2(t)\right)^{1/2} \tag{7}$$

In these equations $\omega_1(t)$, $\omega_s(t)$ and $\alpha_o(t)$ represent the centroid of the frequency region, the radius of gyration of the spectrum and the area of frequency region respectively as shown in the Fig. 1. During the analyses these parameters are determined simultaneously at the each time step. Before that the second normalization was made so that the spectral values of the frequency distribution were adjusted taking the spectral value as unity.

Harmonic Model Based On The Frequency Parameters

Above mentioned frequency parameters are combined so that Gaussian shape function $\bar{S}$ may be proposed redefing the frequency content in Fig. 1.

$$\bar{S}\ (\omega,t) = \frac{a(t)}{\sqrt{2\pi}\ \omega_s(t)}\ \exp\left\{-\frac{1}{2}\left(\frac{\omega-\omega_1(t)}{\omega_s(t)}\right)^2\right\} \tag{8}$$

where a(t) is the ratio coefficient equalled to the ratio of the real physical spectrum area to the positive region of the Gauss curve as follows

$$a(t) = \frac{\sqrt{2\pi}\ \ \omega_s(t)\alpha_0(t)}{\int_0^\infty \exp\{-\frac{1}{2}\left(\omega-\omega_1(t)\right)^2/\omega_s^2(t)\}\ d\omega} \tag{9}$$

Statistical evaluation has been carried out for the frequency parameters after the determination of the frequency contents of all the strong motion accelerograms in each group of soils. The mean and upper bound values of the ninety percentile distribution of the parameters are evaluated at the fixed time moment assuming "t" type (student) distribution function.

The below equations show only the values for central frequency ω_1

$$\omega_{1M}(t) = \frac{1}{N}\sum_{i=1}^{N}\omega_{1i}(t) \tag{10}$$

$$\omega_{1SD}(t) = \left[\frac{1}{N}\sum_{i=1}^{N}\omega_{1i}^2(t) - \omega_{1M}^2(t)\right]^{1/2} \tag{11}$$

$$\bar{S}_I(\omega,t) = \frac{a_M(t)}{\sqrt{2\pi}\ \omega_{sM}(t)}\ \exp-\frac{1}{2}\left\{\frac{\omega-\omega_{1M}(t)}{\omega_{sM}(t)}\right\}^2 \tag{12}$$

$$\omega_{1s}(t) = \omega_{1M}(t) + k\omega_{1SD}(t) \tag{13}$$

$$k = t_c/\sqrt{N-1} \tag{14}$$

where N shows the number of earthquake strong motions at each group and t_c is related coefficient to the student distribution. So in this way new frequency contents $\bar{S}_I$ and $\bar{S}_{II}$ are established once by mean values and ninety percentile values of the parameters. Fig 2, 3, 4 and 5 exhibit the variations of the parameters of each group of soils.

THE SENSITIVITY OF THE FREQUENCY PARAMETERS

Table 1 shows the lower and upper limits of the central frequency and radius of gyration. Since former one characterizes in general sense, the place of predominant frequency and second one represents the dispersion of the peakness of the spectrum, considering the differences of standart deviations $\Delta\sigma\ (\omega_1)$ and $\Delta\sigma\ (\omega_s)$, it is intended to decide the sensitivity of the accelerograms. It has been considered also to take the differences of the frequency parameters at the almost 80% confidence level.

The Results Of The Sensitivity

Results should be summarized at the following tree articles:

a) Maximum difference at the standart deviation at ω_1 frequency as a centroid of the spectrum was seen for the soft to medium stiff clay and sands. Also the difference in the variation of the standart deviation at ω_s frequency became greatest for the same type soil condition. In this sense nonstationary characteristics should be taken into account especially for the accelerograms recorded on this type of ground condition.

b) In view of frequency content, the effect of the nonstationarity was seen as the least for the accelerograms recorded on rock. However, considering the greatness of the variation of the differences of both frequency parameters ω_1 and ω_s it was noticable the sensitivity of these accelerograms on the soft ground.

c) The sensitivity of the accelerograms recorded on stiff soils to nonstationary was seen mostly at the predominant frequency.

The Effect of Involved Data Over Nonstationary Frequency Content

During the Niigata Earthquake in 1964, the accelerograms were recorded at Kawagishicho Apt. No.2 as EW and NS Components (Ref. 5) and they became very interesting in view of frequency content variation which is even clearly observed on the data due to liquefection phenomenon. So, for the soft to medium stiff clay and sands excluding these Niigata earthquake components, nonstationary frequency contents and frequency parameters are obtained and compared with those obtained involving same data. And results are as follows:

a) Frequency parameters approach each other for both $\bar{S}_I$ and $\bar{S}_{II}$ cases between 5 sec and 15 sec resulting almost no effect of involved data

b) Frequency parameters of the group for which Niigata data are excluded, becomes smaller for t<14 sec than the frequency parameters of the involved data,

c) When the $\overline{S}_I$ content is taken into consideration, ω_s is smaller and has small variations for the excluding data.

SIMULATED EARTHQUAKES WITH REDEFINED FREQUENCY CONTENT

Site dependent eartquake simulation had been carried out by the author in Refs. 1 and 6. Here simulation method will be summarized briefly. Simulated strong motion with amplitute nonstationary is defined as follows

$$X_h(t) = \sum_{l=1}^{N} x_h(\omega_l, t) = \sum_{l=1}^{N} z(\omega_l, t).\cos(\omega_l t+\phi_l) \qquad (15)$$

where ω_1 discrete frequencies, ϕ_1 uniform random variables between $0-2\pi$ and $z(\omega_1, t)$ is frequency dependent amplitude. It is approximately related with the physical spectrum of x(t) as follovs

$$z(\omega,t) = \left[4\ \overline{S}(\omega,t;W).\Delta\omega\right]^{1/2} \qquad (16)$$

Since $\overline{S}_I$ and $\overline{S}_{II}$ are redefined frequency contents related to Physical spectrum they are successfully utilized instead of it. So by this procedure simulated earthquake ensembles with included and excluded Niigata data, are generated into 25 sec duration. Only one sample of eight simulated motions is illustrated in Fig. 6. It is noticable that the waves are quite similar in each group of frequency contents.

The Effect of Involved Data On The Response Spectra

In order to compare acceleration response spectra, above mentioned simulated earthquake ensembles are utilized for averaging response spectra for both $\overline{S}_I$ and $\overline{S}_{II}$ frequency contents are illustrated in Fig. 7 and 8 respectively. Conclusions may be done in the following form

a) When $\overline{S}_I$ is taken into consideration in Fig. 7, for the periods smaller than 0.3 sec., involved Niigata data gives higher normalized acceleration values than the excluding ones. But in case of periods, $T \geqslant 0.3$ sec, excluded Niigata data gives higher normalized acceleration values than the included ones

b) When $\overline{S}_{II}$ is taken into consideration, in Fig. 8 for periods $T < 0.3$ sec, normalized acceleration response spectrum with involved data, gives higher values than that with excluded one as well as previous result. It is found that in the period ranges from 0.3 sec to 0.7 sec, the acceleration response spectrum with involved data gives smaller values. And in the periods $T \geqslant 0.7$ sec, there is no difference between the two spectrum. Even for the $\xi = 0.10$ critical damping ratio, this situation may be obtained for the periods $T \geqslant 0.5$ sec.

REFERENCES

1. Hasgür, Z., "Obtaining Site-Dependent Earthquake Simulation" (in Turkısh), Doctoral Thesis, Istanbul, 1982.

2. Hoshiya, M. and Chiba, T., "Physical Spectrum of Earthquake Acceleration", Proc. 4 th Japan Earth. Eng. Symp. No. 264, 1975.

3. Seed, H.B., Ugas, C. and Lysmer J., "Site Dependent Spectra for Earthquake Resistant Design", EERC 74-12, U.C. Berkeley, 1974.

4. Vanmarcke, E.H., "Properties of Spectral Moments With Applications to Random Vibrations", Proc. ASCE, EM2, pp. 425-455, 1972.

5. Digitized Strong Motion Earthquake Accelerograms, Gakujutsu Bunken Fukyukai, ASDI, Tokyo, 1969.

6. Hasgür, Z., "Site-Dependent Earthquake Simulation", Proc. 7WCEE, İstanbul, Turkey, Vol. 2, Part II, Sec. A-7, pp. 327-332, 1981.

Table 1

Frequency Hz.	Rock	Stiff	Deep Cohes	Clay and Sands
ω_1	0.92	1.82	1.57	1.51
ω_s	0.20	0.39	0.60	0.72
$\sigma(\omega_1)$	1.7-2.05	1.53-1.70	1.0-1.15	0.51-1.32
$\sigma(\omega_s)$	0.6-0.9	0.6	0.45	0.48-0.90
$\Delta\sigma(\omega_1)$	0.35	0.17	0.15	0.81
$\Delta\sigma(\omega_s)$	0.30	≈0	≈0	0.30

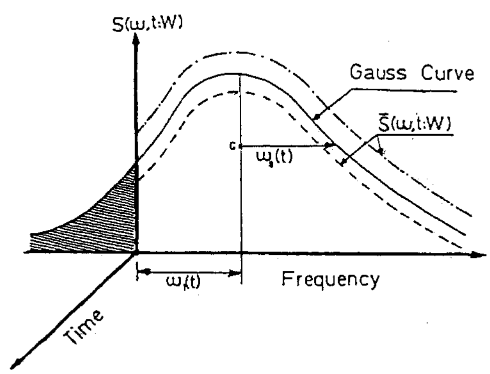

Fig. 1 Shape function and frequency parameters

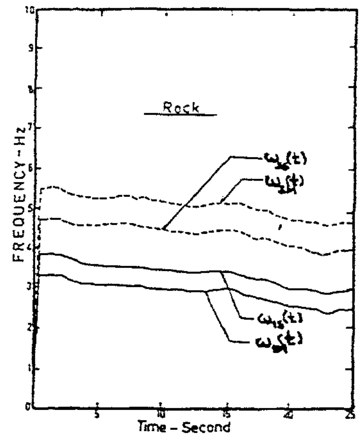

Fig. 2 The variations of frequency parameters with mean values (M) and 90 percentile values (S) as first sub-indices.

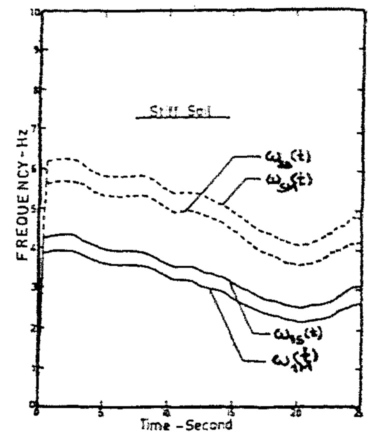

Fig. 3 The variations of frequency parameters with mean values (M) and 90 percentile values (S) as first sub-indices.

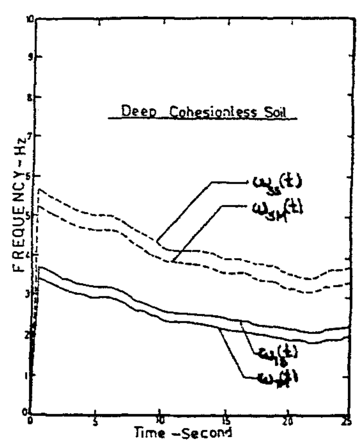

Fig. 4 The variations of frequency parameters with mean values (M) and 90 percentile values (S) as first sub-indices.

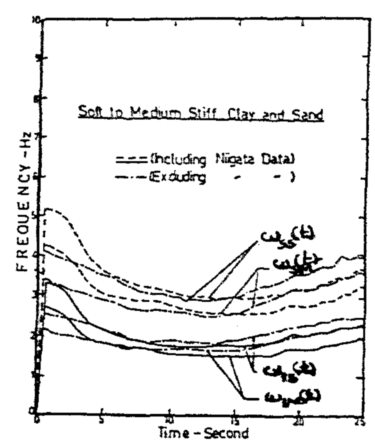

Fig. 5 Comparison of involved data for the variations of frequency parameters

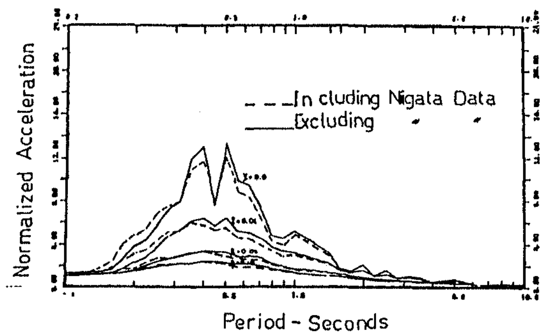

Fig. 7 Acceleration response spectra with described $\overline{S}_I$ (mean valued) frequency content.

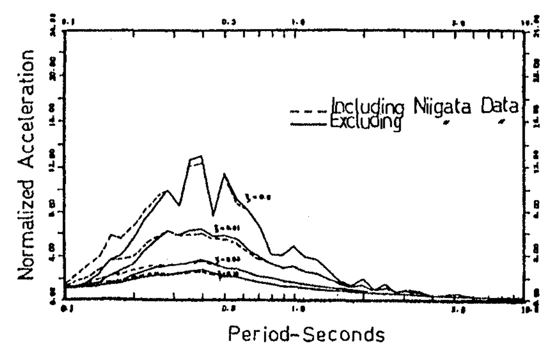

Fig. 8 Acceleration response spectra with described $\overline{S}_{II}$ (90 percentile valued) frequency content.

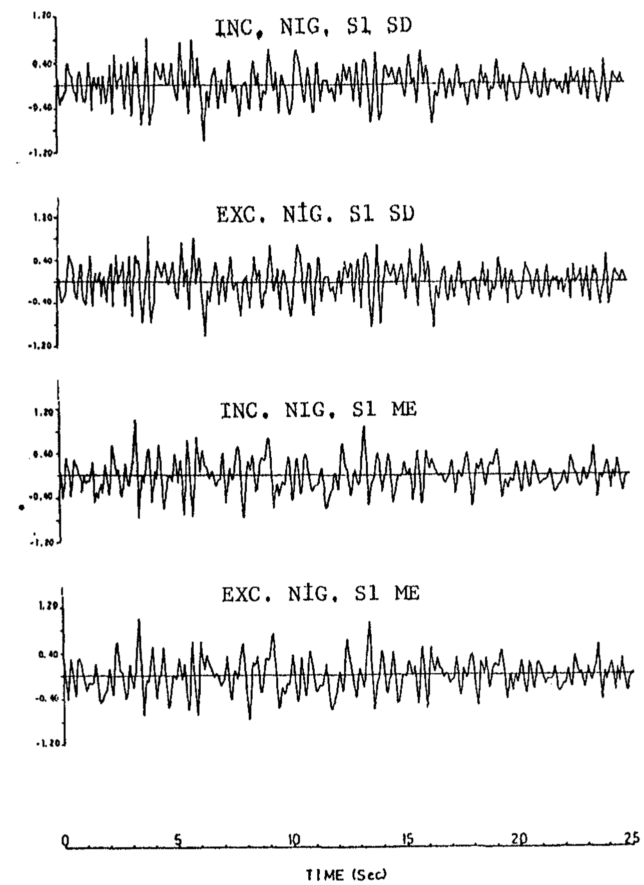

Fig. 6 First samples of simulated earthquake ground motions with including and excluding Niigata components.