THE RESPONSE SPECTRUM ANALYSIS TO AN ARTIFICIAL EARTHQUAKE WITH TWO GROUND PREDOMINANT PERIODS

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ABSTRACT

Analysis of the response spectrum of structure system simulated by one-degree-of-freedom to an artificial earthquake; stationary random vibration with two ground predominant period, is made. This is investigated as the extensive study for the case of single predominant period. Then for the estimation of maximum of the artificial earthquake and response wave form the probability density function of extreme is made use of. According to this analysis both spectra show good coincidence about their shape which could not be seen in the analysis by single ground predominant period. For the case that the structure system has nonlinearity of elasto-plastic characteristic the response spectrum of velocity and displacement in terms of standard deviation is obtained. However general characteristic of the spectrum is same as that for single ground predominant period, the results of the analysis show better agreement with the spectrum to actual earthquake record than those by single ground predominant period did. The expectation and the variance of the spectrum are obtained by assuming probability density function for realization of system parameters as ground predominant period, natural period and damping ratio of structure model. Considering the existence of two ground predominant period close each other suggests that seismic force does not vary irrespective of the fluctuation of the system parameter.

1. INTRODUCTION

The response spectrum of one-degree-of-freedom system simulating structure shows a characteristic of dynamic response of the system to an earthquake record and this also implies characteristics of the earthquake wave form itself. It is given by Housner et al. [1] that the general characteristic of the response spectrum for a number of earthquake is described as that the velocity spectrum keeps constant for the natural period of the system higher enough and the acceleration spectrum has at least one peak and decreases as the period becomes large. Further study by Tajimi [2] has made it obvious that the period where the peak stands corresponds to predominant period contained in earthquake wave form.

There are several merits that artificial or simulated earthquake is made use of for the response analysis in place of actual earthquake record. Statistical approach to predict response spectrum can be made analytically by simulated earthquake as well as it is obtained experimentally. And it also makes it possible to distinguish effect of reciprocal relation of the system parameters as ground predominant period, natural period and damping ratio of structure to the spectrum, shich is easily masked for the spectrum to actual earthquake record because of its complexity.

Response spectrum is originally plotted by taking maximum of time history of the response. As for the acceleration response it also can be represented by taking the ratio of maximum between input earthquake and the response, response spectrum of accleration amplification factor. According to the analysis that the maximum is in proportion to the standard deviation and random vibration corresponding to earthquake has the characteristic of band limitted white noise filtered through one-degree-of-freedom system the natural period of which is equal to predominant period of ground, the response spectrum obtained through the simulation agrees well by covering a number of spectra to earthquake records in sense of an envelope [2]. The author has made an investigation that he applied the probability density function of extreme by Rice [3] in order to find maximum, that is, where the function is small enough was assumed the maximum [4]. The results were similar to the case that the standard deviation was adopted for the maximum.

These analyses were all performed by the simulated earthquake with single predominant period in spite that the spectrum to earthquake has several peaks. Then this paper studies the statistical analysis to simulated earthquake with two ground predominant period which is the simplest case for multi-predominant period. The results are compared with those actual earthquake records. The study is extensively made for the case that structure system has elasto-plastic nonlinearity. For both cases the approach made in this paper gives a better agreement even for the shape of the spectrum in addition to its magitude [5], [6].

If once the response spectrum statistically given is considered reliable by comparing with that of earthquake record, seismic force applied to structure can be approximately predicted by being given the system parameters. However, these parameters realized after construction have naturally stochastic characteristics in estimating them at stage of design beforehand. The mean and the variance based on the analytically estimated response spectrum can be evaluated by assuming probability density function for the parameters. The analysis is made for the spectrum with two ground predominant period, too, and the results are compared with those for single predominant period.

However it has not been studied in this paper, whether ground predominant period is one or more than one is expected to make difference as for results of the analysis taking nonstationarity of earthquake and the response of two-degree-of-freedom system simulating building-machine structure system into consideration.

2. FORMULATION OF BASIC EQUATION FOR LINEAR SYSTEM

The earthquake acceleration is assumed stationary random vibration with gaussian probability density function. It is made evident by Kanai [7] that the ground can be simulated by one-degree-of-freedom system basically for the earthquake with single predominant period. The power spectrum at base of the ground is supposed to be band limitted white. The maximum of the simulated earthquake and the response of structure model simulated by one-degree-of-freedom system to the earthquake is obtained from the probability density function of extreme, that is, where the function reaches small enough is supposed to be maximum.

If two predominant periods are contained in the simulated earthquake, the transfer function of the ground model can be represented as follows,

$$H_g(s)=\frac{2\omega_{g1}h_{g1}s+\omega_{g1}^2}{s^2+2\omega_{g1}h_{g1}s+\omega_{g1}^2}+\lambda\frac{2\omega_{g2}h_{g2}s+\omega_{g2}^2}{s^2+2\omega_{g2}h_{g2}s+\omega_{g2}^2} \qquad (1)$$

If $\lambda=0$ in eq.(1), it is equal to that of single predominant period system on which a number of studies have been carried out. $\omega_{g1}=2\pi/T_{g1}$, $\omega_{g2}=2\pi/T_{g2}$, h_{g1} and h_{g2} are the predominant circular frequency and the equivalent damping ratio of the ground model. T_{g1} and T_{g2} are the ground predominant period.

The probability density function of extreme p(y) for a time functional random process I(t) with Gaussian distribution is given as follows by Rice [3],

$$p(y)=\frac{1}{\sqrt{2\pi}}\frac{\sqrt{I_0 I_4-I_2^2}}{\sqrt{I_0 I_4}}\exp\{-\frac{I_0 I_4}{2(I_0 I_4-I_2^2)}y^2\}+\frac{I_2}{2\sqrt{I_0 I_4}}y\exp(-\frac{y^2}{2})\{1+\mathrm{erf}\frac{I_2}{\sqrt{2(I_0 I_4-I_2^2)}}y\} \qquad (2)$$

where $y=I(t)/\sqrt{I_0}$ (3)

and $I_0=\frac{1}{2\pi}\int_0^\infty|H(s)|^2k\,d\omega,\quad I_2=\frac{1}{2\pi}\frac{1}{4\pi^2}\int_0^\infty|sH(s)|^2k\,d\omega,\quad I_4=\frac{1}{2\pi}\frac{1}{16\pi^4}\int_0^\infty|s^2H(s)|^2k\,d\omega$ (4)

$$H(s)=H_g(s)H_f(s) \qquad (5)$$

$$H(s)=H_b(s)H_g(s)H_f(s) \qquad (6)$$

For the random vibration corresponding to earthquake and for that of response of structure system to it, H(s) is given as eq.(5) and eq.(6). These are substituted into eq.(4) and eq.(2) in order to obtain p(y), where

$$H_b(s)=\frac{2\omega_b h_b s+\omega_b^2}{s^2+2\omega_b h_b s+\omega_b^2} \qquad (7)$$

$$H_f(s)=\frac{1}{(1+\psi_1 s)^2}\frac{s^2}{(1+\psi_2 s)^2} \qquad (8)$$

Integral is performed by making use of residue. It is given as formula by Newton et al. [8]. $H_b(s)$ and $H_f(s)$ are the transfer function of structure model and that of band limitting filter. Where k is a constant related with constant power spectrum at the base of the ground, ψ_1 and ψ_2 are time constant of high pass and low pass filter characteristics, ω_b and h_b are natural circular frequency and damping ratio of structure model. The maximum is represented by a point where p(y) is small enough, in this paper p(y)=0.01 is adopted.

3. EXAMPLES OF RESPONSE SPECTRUM BY THE STATISTICAL APPROACH

Fig.1 (a) shows an example of response spectra for acceleration amplification factor by the statistical approach. $T_{g1}=0.2$s and $T_{g2}=0.5$s are adopted by taking comparison of the spectrum with that of actual earthquake record into consideration. Equivalent damping ratio of the ground model $h_{g1}=0.4$ and $h_{g2}=0.3$ are used. The former is the value recommended as a standard for the case single predominant period and the latter is an example for computation. $\psi_1=0.015$s and $\psi_2=3.0$s are equal to break point frequency $f_1=10.6$Hz and $f_2=0.531$Hz respectively. As damping ratio of structure model $h_b=0.07$ is utilized.

The response spectrum for $\lambda=0$ has simple single peak shape. The magnitude of the factor at $T_{g1}=0.2$s shows maximum and the magnitude of the factor at the peak scarecely varies if the predominant period moves as long as the period is single. The factor at $T_{g1}=0.2$s decreases as λ becomes large. This implies that merging the component of long period makes the acceleration amplification factor decrease in comparison with the case of the original single predominant period. As the result for certain value of λ the spectrum has two peaks at the both predominant periods of the ground.

Even if T_{g2} becomes longer than that of the examples, the tendency does not change. Fig.1 (b) shows another example of the combination of two predominant periods. In this case the longer predominant period exists at five times as much as the short one, however, the sensitivity decreaseing the amplification factor at original short predominant period and increasing that at another long predominant period is much smaller than the case aforementioned.

These results make it obvious that the maximum value of a response spectrum occurs when the natural period of the structure model coincides with the predominant period of the simulated earthquake containing single component, in other words even if the natural period of the structure is equal to either of multi predominant period of the ground, the amplification factor is not larger than that for single predominant period.

Fig.2 (a) and (b) ahow the displacement response spectra by the statistical computation. The parameters used for these correspond to those in Fig.1 (a) and (b) respectively. These figures explain that the appearance of longer predominant period simply increases the displacement response in longer period than longer predominant period. This phenomenon is really observed about the response spectrum for violent earthquake as Niigata (June 16, 1964).

In Fig.3 the analytical results and those by actual earthquake records such as El Centro (NS, May 18, 1940) and Taft (NS, July 21, 1952) are compared. $\lambda=0.9$ are taken for the analysis because of the better agreement with the spectrum by the actual records. Although there is still discrepancy between both computations, the shape of the spectrum shows good agreement. The analytical response spectrum obtained for single predominant period shows same amount of amplification factor as those for the actual record and covers those as an envelope, however it never gives better agreement about the shape as is seen in Fig.3 for the spectrum by El Centro and Taft [4].

Fig.4 is the comparison of the displacement spectrum to earthquake records and that by the analytical computation. This also shows that this simulation provides better agreement than that with the single predominant period of the ground. The magnitude of the displacement spectrum at T_{g2} depends on that of λ.

In Fig.5 the power spectrum of El Centro and that of the analytical ground model are compared. λ is set as 1.0. Frequency where the spectrum reaches the maximum is made equal for both. The actual record has more dominant power than the analytical model around low predominant frequency. For the higher predominant frequency the difference should be said quite large. It is worthwhile noticing that in spite of the discrepancy such correspondence as the magnitude and the shape of the response spectrum in Fig.3 and Fig.4 can be obtained.

4. FORMULATION OF RESPONSE OF ELASTO-PLASTIC NONLINEAR SYSTEM

Response spectrum of elasto-plastic system to the stationary artificial earthquake was studied as for the displacement and the velocity. For the estimation the standard deviation was used as the measure of the maximum. The method of equivalent linearization by Sawaragi [9] was made use of for the analysis of the nonlinearity. The discussion made it clear that general characteristic found in response spectrum could be explained by the analysis, however there remained some differences as for the precise shape of spectrum [4].

Basic equation for the system will be summarized below at first. The model of the vibration system is represented as Fig.6. The system has solid friction characteristic at the top of spring. The displacement and restoring force show a special hysteresis curve as Fig.7. It is the simplest expression of the elasto-plastic deformation system. The equation of motion for the system can be written as

$$\begin{cases} m\ddot{x}=-c\dot{x}-f-m\alpha(t) \\ f=ky, \quad \dot{x}=\dot{y}: \ f<|F| \\ f=F(\dot{x}-\dot{y})/|\dot{x}-\dot{y}|: \ f\geq|F| \end{cases} \tag{9}$$

where m: mass, c: damping constant of the structure model, k: spring constant of the structure model, x: relative displacement of mass to the ground, y: relative displacement of top of spring to the ground, F: yield force and $\alpha(t)$: the ground acceleration. The system can be represented by a block diagram shown in Fig.8. Laplace transform of input to nonlinear element Z(s) can be given as follows,

$$Z(s)=\frac{\omega_b^2}{\kappa s^2+(\omega_b^2+2\omega_b h_b\kappa)s+\omega^2(2\omega_b h_b+\kappa)}(-H(s)) \tag{10}$$

eq.(1) is used as H(s) for the case of two predominant period of ground. ω_b and h_b are natural circular frequency and damping ratio structure model for linear behaviour, and κ is equivalent linear gain for the nonlinear element. U and X in Fig.8 mean relative velocity and displacement respectively. This block diagram shows that displacement of the system is obtained as output of the open loop through an integral. This suggests that response of displacement is originally unstable. Really the displacement response to actual earthquake record is generally has permenent set.

As the equivalent linear gain is used as

$$\kappa=\sqrt{2/\pi}(A/\sqrt{I_z}) \tag{11}$$

where A is saturation value of nonlinear element and corresponds to F in Fig.7. The variance of the input to the nonlinear element I_z is given as

$$I_z=\frac{1}{2\pi}\int_0^\infty |Z(s)|^2 d\omega \tag{12}$$

Z(s) is represented such a function of κ as is seen in eq.(10). Since κ is defined for the input level to the nonlinear element like eq.(11), eq.(11)and eq.(12) are combined and solved. It is necessary to give another condition for the solution, that is,

$$A=\beta\sqrt{I_g} \tag{13}$$

$$I_g=\frac{1}{2\pi}\int_0^\infty |H(s)|^2 d\omega \tag{14}$$

β is an index which provides the ratio of the yield seismicity of structure model to the standard deviation of earthquake acceleration. Since Laplace transform of the velocity and displacement response is given as

$$U(s)=(1+\frac{\kappa s}{\omega^2})Z(s) \tag{15}$$

$$X(s)=\frac{U(s)}{s} \tag{16}$$

The variance of these are obtained by same type of equation as eq.(14).

$$I_u=\frac{1}{2\pi}\int_0^\infty |U(s)|^2 d\omega \tag{17}$$

$$I_x=\frac{1}{2\pi}\int_0^\infty |X(s)|^2 d\omega \tag{18}$$

As soon as κ is obtained by soving eq.(11) and eq.(12), I_u and I_x are acquired by substituting this into eq.(17) and eq.(18). Although these formulation were already given except $H_g(s)$, the summary is described for convenience of discussions.

5. EXAMPLE OF CALCULATED RESPONSE SPECTRUM FOR THE NONLINEAR SYSTEM

Fig.9 is example of displacement response spectrum. $\beta=\infty$ coincides with linear response. The parameters shown are same with those found in case of reponse spectrum of linear acceleration amplification factor. In this figure predominant periods exist in short period, so that details of difference hardly seen. This will be shown later. General characteristics appearing according to nonlinearity do not change in comparison with the spectrum for single predomiant period. These characteristics are that the stronger the nonlinearity is, that is, the smaller β is, the larger the displacement response is in short period, For example $\beta=0.3$ implies yield seismicity of 0.09 for the case of the maximum input acceleration 0.3g. As β increases the response spectrum with nonlinear characteristic approaches the linear response spectrum. $\lambda=0.9$ is the parameter which made good agreement with acceleration response spectrum to actual records in linear system.

Next the velocity response spectrum is payed attention to. Some tendency as in single predominant period, which in short period the spectrum for nonlinear system becomes larger than that for linear system and in longer period this characteristic reverses, is found. Fig.10 shows an example of velocity response spectrum using same parameters as Fig.9. Taking that velocity response does not show permanent excursion as displacement response into consideration, the response spectrum for the nonlinear system depicts such shape that the spectrum for linear system is suppressed. Although slope depends on magnitude of β, the spectrum for nonlinear system increases almost linearly as the period gets large. General characteristics for nonlinear system aforementioned are similar to the case of single predominant period. The existence of the predominant period 0.2s mades the spectrum for linear system increase around the period and region where the spectrum for nonlinear system stands larger than that for linear system. These suggest that the velocity response spectrum is appropriate to describe the response characteristic of nonlinear system.

Fig.11 shows comparison of velocity response spectrum of various cases. As the spectrum for actual record that by El Centro is taken. As for the linear system the spectrum by the artificial earthquake with predominant period 0.2s agrees well in short period with that by El Centro. On the other hand the spectrum for the predominant period of 0.5s may be closer to the real one than that for 0.2s in long period, the tendency in short period is quite different. On the contrary the spectrum with two predominant period is considered to be equal in short period. In longer period there exist some differences quantitatively, but the tendency explains that of the spectrum by real earthquake. The differences can be made small by fitting system parameter β. The spectrum by the artificial and actual earthquake for nonlinear system coincides remarkably both quantitatively and qualitatively taking some differences of β into consideration.

Fig.12 shows an example of velocity power spectra of response of structure model with nonlinear characteristic. System parameters of ground model are same with the various cases aforementioned. As the natural period of structure model $T_b=0.2s$, that is, $f_b=5Hz$ is taken. For the linear system dominant power occupies around 5Hz. As β diminishes, this component looses its power and gradually the component of 2Hz, which corresponds with that of $T_{b2}=0.5s$, gains the power. $\beta=2.0$ which means the system is very close to linear only decreases the power of 5Hz and that of 2Hz does not show particular change. This implies that the existence of small has same effect as increase of damping in structure model. This also affects the response behaviour of machine structure system if it is appended to building structure system.

It is made obvious that although there is some differences as for the response spectrum between the analysis by the artificial and actual earthquake, the characteristic of the spectrum for the latter can be explained applying the analysis of equilinearization for the nonlinear element.

6. EXPECTATION AND VARIANCE OF THE ACCELERATION AMPLIFICATION FACTOR

The analysis by the statistical computation makes it possible to predict seismic force applied to structure system during earthquake by knowing the system parameters as ground predominant period, natural period and damping ratio of structure system [10]. However these parameters are given as design value, the realization of these usually differs from the estimation. According to observation the predominant period appearing in earthquake recorded at an observatory point moves around as is seen in Fig.12 after Kanai [11]. This can be said that appearance of predominant period possesses a probabilistic characteristic. Prediction of natural period and damping ratio also have same sort of probabilistic characteristic as the ground predominant period. Then if probability density function is fitted for realization of the system parameters, the response spectrum given by the statistical analysis as Fig.1 can be represented as that having its expectation and variance.

This is given by the equation for the case that only ground predominant period is assumed probabilistic as follows,

$$E[A]=\int_{T_g'}^{T_g''} A(T_b/T_g)p(T_g)dT_g \tag{19}$$

$$\sigma_A^2=\int_{T_g'}^{T_g''} \{A(T_b/T_g)\}^2p(T_g)dT_g-\{E[A]\}^2 \tag{20}$$

where $E[A]$: the expectation of the acceleration amplification factor, $A(T_b/T_g)$: the response spectrum of acceleration amplification factor obtained by the statistical analysis, $p(T_g)$: assumed probability density function factor and σ_A: standard deviation of amplification factor. The expression of eq.(19) and eq.(20) mean that T_b is fixed through the integral.

As aforementioned generally the other parameters also can be probabilistic variable. If T_b and h_b are treated as the variable, eq.(19 and eq.(20) are written as tripple integral. In addition to these as the earthquake wave form can be considered a sample from a statistical population, the amplification facto itself fluctuates around a mean according to Shibata et al. [12]. If this probabilistic characteristic is estimated by other analysis, the effect also will be able to be combimed with that of these parameters. Fig.14 shows a result of estimated mean and 3σ width for the case that in estimation of ground predominant period and natural period of structure normal probability density function is assumed. Standard deviation of the normal distribution are taken for two abscissas. The damping ratio of structure system remains definite. This makes it evident that the amplification factor is maximum and corresponds with the value of the original response spectrum by neglecting probabilistic characteristic. As the standard deviation increases, mean value of the amplification factor decreases and 3σ width around the mean is made wide. Adding another probabilistic characteristic to either of the first parameter naturally introduces same tendency.

For the case that damping ratio is also taken having probability density distribution Monte Carlo method is applied to performing the integral. According to Fig.14 the mean and the standard deviation are given as

$E[A]=3.40 \quad \sigma_A=0.163$ (21)

for log-normal probability density function with $\sigma_{T_g}=\sigma_{T_b}=0.10$. Taking the damping ratio as a stochastic variable,

$E[A]=3.08 \quad \sigma_A=0.346$ (22)

are provided for $\sigma_{h_b}=0.004$ and same σ_{T_g} and σ_{T_b} of normal distribution. Since the integral is carried out by Simpson method for eq.(21) and by Monte Carlo method for eq.(22), direct comparison is difficult. However the general tendency that E[A] diminishes and σ increases does not vary.

Although eq.(21) and eq.(22) are obtained for $h_b=0.07$ and the spectrum of the single predominant period, Fig.15 shows an effect of two ground predominant period. In Fig.15 only the natural period of structure system is provided the probabilistic characteristic, and the natural period is varied keeping ratio of the standard deviation to the natural period constant. Fig.15 (a) is as for two ground predominant period and Fig.15 (b) is as for single predominant period. The behaviour of mean and 3σ width show that they keep constant for the former and they are almost same tendency as the originally estimated spectrum for the latter. Zigzag curve depends on using Monte Carlo method. However, the result means that once the ground predominant period appears more than one at close period each other, the predicted amplification factor should be constant irrespective of the change of natural period. This is considered important from practical viewpoint in estimating seismic forces.

7. CONCLUSIONS AND ALNOWLEDGEMENT

It is assumed that the earthquake is simulated by stationary random vibration with Gaussian distribution, at the base of ground it has band limitted white spectrum. The maximum of the simulated earthquake is given by the point where the probability density function reaches small enough. These were already studied by the author as for single ground predominant period. In this paper the research that the ground characteristic is represented by combination of one-degree-of-freedom system, that is, two ground predominant period is extensively made. This makes it possible that not only the magnitude of the acceleration amplification factor, but also the shape of the response spectrum coincides with those by the actual earthquake record. The analysis introduces better agreement in displacement response spectrum, too.

Response spectrum for structure model of one-degree-of-freedom system with nonlinear characteristic simulating elasto-plastic deformation is also obtained to the artificial earthquake with two ground predominant period by the statistical analysis. The method of equilinearization is utilized for the treatment of nonlinear characteristic. Velocity and displacement response spectrum explain well the general characteristic found in the spectrum to the actual records qualitatively. As for the velocity spectrum the coincidence is seen also quantitatively by adjusting the comparison of the system parameter.

The mean and the variance are given in predicting the acceleration amplification factor taking the probabilistic characteristic of the system parameters into consideration. The existence of two ground predominant period causes a tendency of the mean and 3σ confidence interval do not vary in spite of the change of estimated period of the system. This suggests that it is generally difficult to economize design seismicity in practice of dynamic aseismic design.

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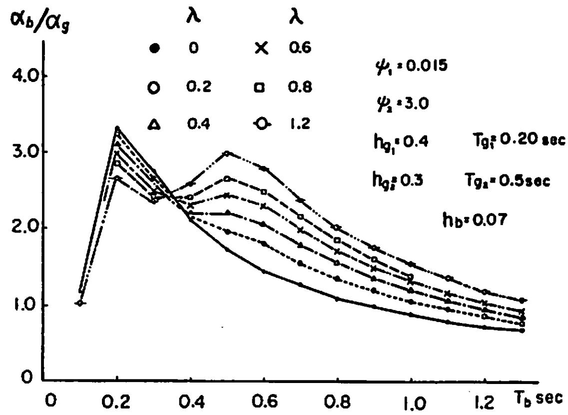


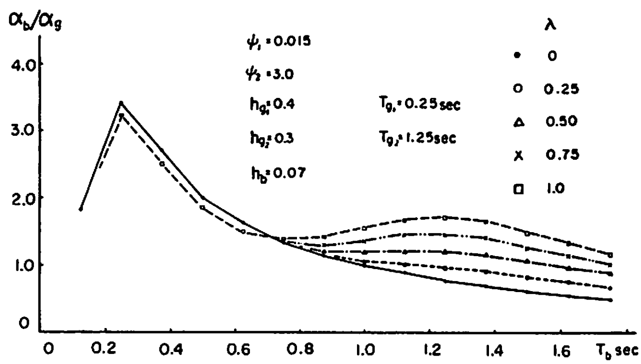
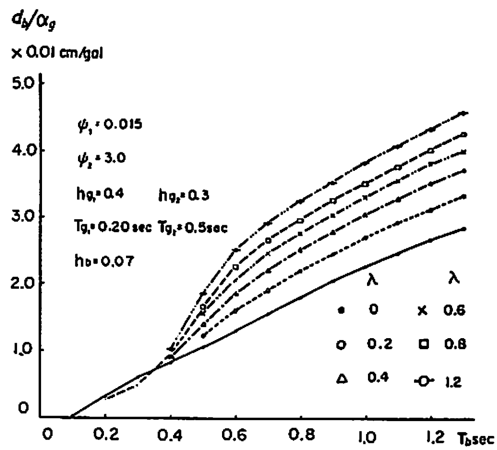


Fig.1 (a)
(b)
Response spectrum of acceleration amplification factor



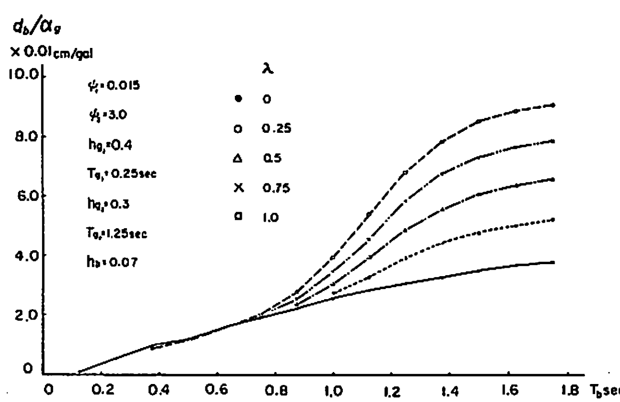


Fig.2 (a)
(b)
Response spectrum of displacement

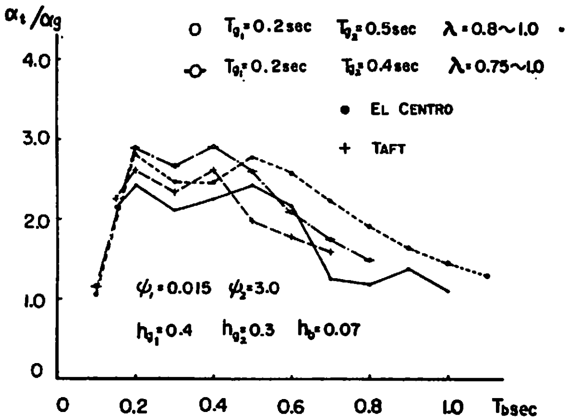


Fig.3

Comparison of the acceleration response spectra by the analysis with those by actual earthquake records

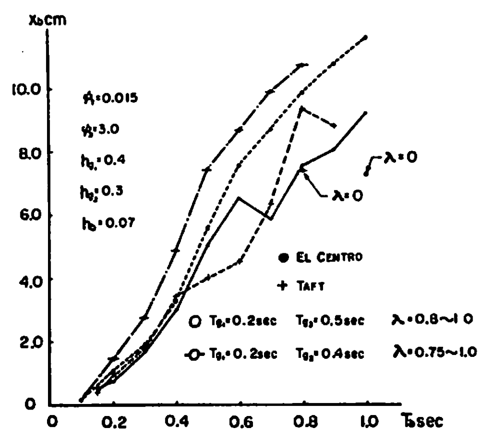


Fig.4

Comparison of the displacement response spectra by the analysis with those by actual earthquake records

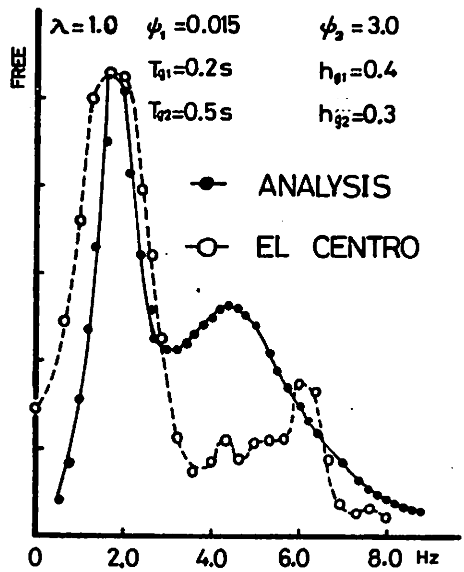


Fig.5 Comparison of power spectrum of the theoretical model with that of El Centro

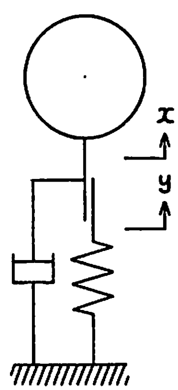


Fig.6 Scheme model of the nonlinear system

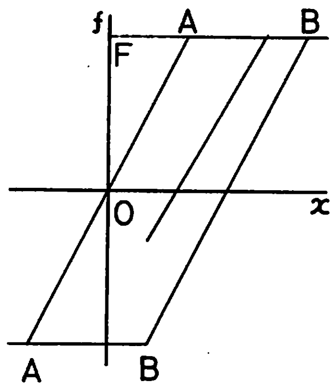


Fig.7 Scheme description of characteristic of the elasto-plastic deformation

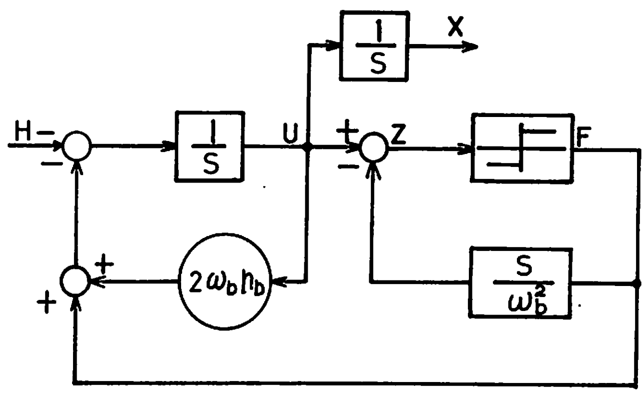


Fig.8 Block diagram of the nonlinear vibration system

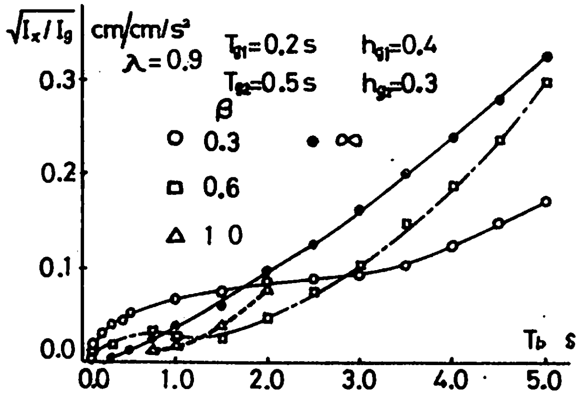


Fig.9 Comparison of the displacement response spectra as for linear and nonlinear system

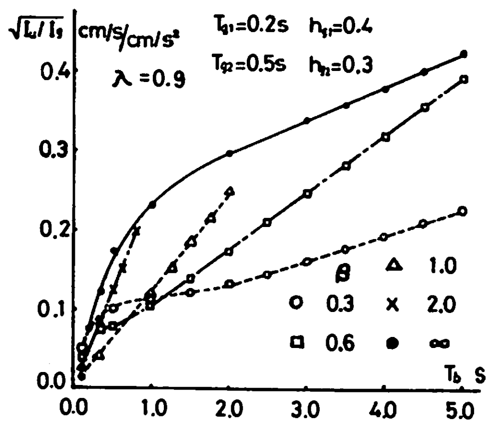


Fig.10 Comparison of the velocity response spectra as for linear and nonlinear system

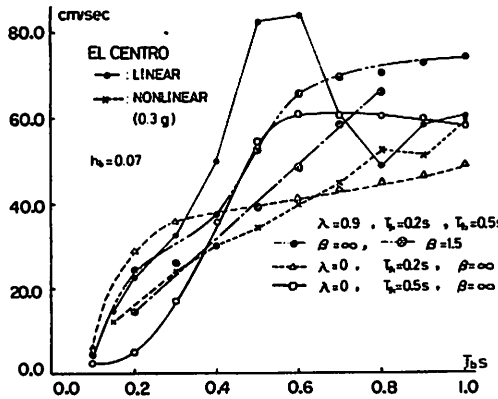


Fig.11 Comparison of the velocity response spectrum of the nonlinear system by the analysis with that by actual earthquake record

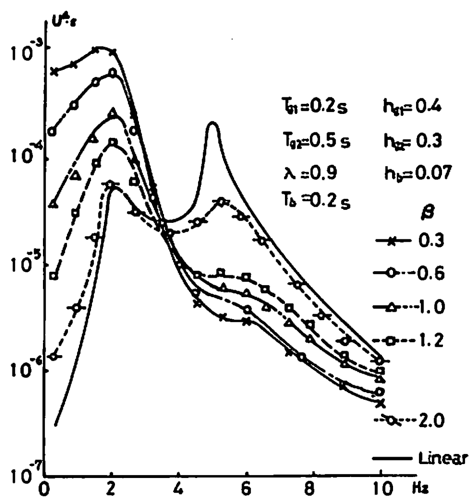


Fig.12 Analytical power spectra of response of the structure model

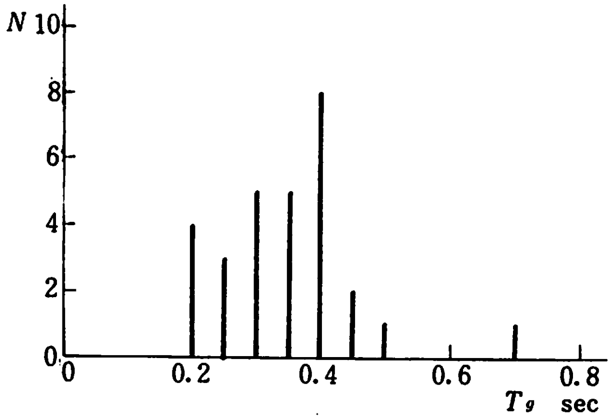


Fig.13 A relation between the ground predominant period in earthquake observed at a place and its occurrence frequency (after Kanai [11])

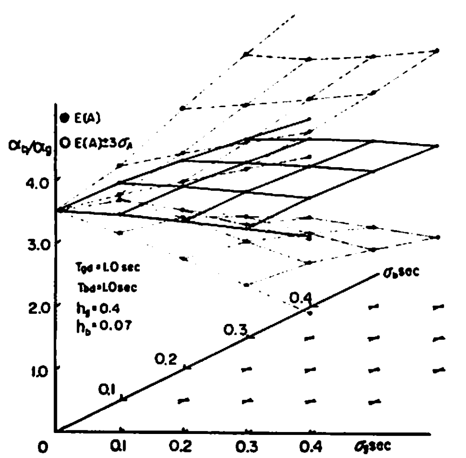
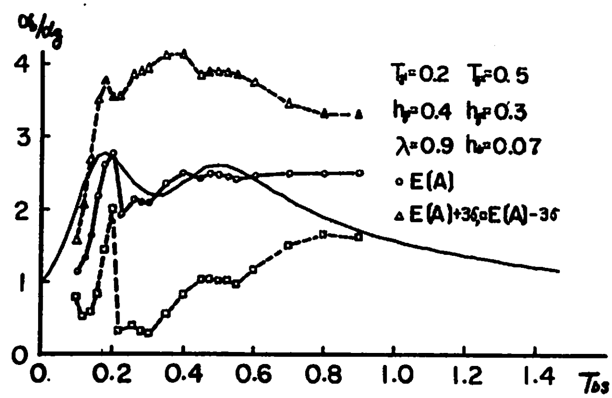


Fig.14 Mean and 3σ width of the acceleration amplification factor (single ground predominant period)



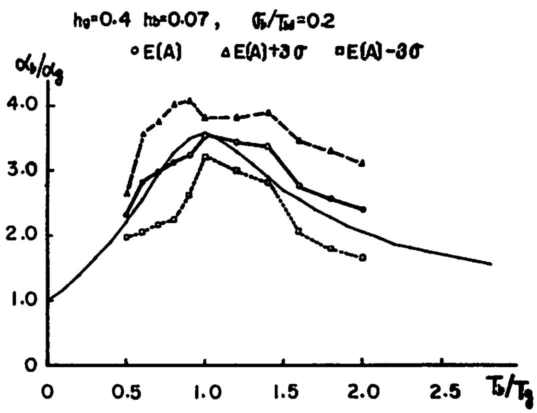


Fig.15 (a)
(b)
Mean and 3σ width along a response spectrum of acceleration amplification factor

DISCUSSION

Q

Ch. CHEN, U. S. A.

In one of the slides the relationship between ground predominant periods and the occurence frequency is shown. Does this relationship apply to all ground conditions, irrespective of competent rock or soft soil ?

A

H. SATO, Japan

No, it is a datum measured at an observatory. I wish I could have this kind of data for various conditions from the engineer's view point.

Q

G. SCHNEIDER, Germany

What is your opinion about Prof. Kanai's method to find out natural or predominant periods of microseismic signals depending on geologic environment and to use these results for predicting predominant periods in earthquake signals ? Since most reactors are or will be installed on more or less thick layers of sediments this would be a good method to determine the amplification of low impedence surface layers.

A

H. SATO, Japan

I am intending to find out the ground predominant period and also the probabilistic characteristic appearing the period. It would be helpful for us to estimate the response of structure by making use of the results of the statistical approach.

Q

H. WÖLFEL, Germany

Is there any possibility to use the response spectrum of a nonlinear one degree of freedom system to calculate nonlinear systems of several degrees of freedom ?

A

H. SATO, Japan

Yes, there is. It may become more complicated and we may have to spend more computer time. It is possible to extend this method for the case of multi-degree-of-freedom systems.

Q

L. ESTEVA, Mexico

The problem of taking into account not only two, but many more ground periods has been studied previously by assuming continuous systems to represent the ground layers. Some of these studies have limited themselves to obtain amplification functions for the Fourier spectra or for the power spectra of the motions, under the assumption of stationarity, but others have introduced corrections in order to account for finite duration and non-stationarity. For the case you studied, what was the advantage of working with a two-mass system ? How did you obtain the properties of the two-mass system from those of the continuous system ? How do you obtain amplification functions for response spectra rather than for Fourier spectra ?

A H. SATO, Japan

I can take the advantage by this rather simple analysis to make the effect of another ground predominant period to the response spectrum obvious. Once we know the effect, we can compose the multi-degree-of-freedom system as far as the number of degrees is considered. I made use of the probability density function of extremes by S. O. RICE. The maximum is represented by the point where the probability density function becomes small enough. This is made for the random process corresponding to the earthquake motion and the response to it. The ratios for both estimations are taken as the amplification factor.