NORMALIZATION PARAMETERS OF MAXIMUM VALUES OF EARTHQUAKE MOTION FOR NON-LINEAR RESPONSE ANALYSES OF STRUCTURE

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SUMMARY

To evaluate the severity of vibration, four parameters which will determine the maximum amplitude of acceleration were selected. Two types of earthquakes whose characteristics of frequency contents were quite different were generated. Non-linear response analyses for those two types of earthquakes were conducted, adjusting the maximum acceleration amplitude according to the specific value of those four parameters. Maximum displacements were analysed and it was suggested that spectrum intensity or maximum velocity of ground motion might be the most preferable parameter to evaluate the severity of motion for non-linear response analyses of structures.

INTRODUCTION

It is well known that the seismic safety of structure to strong earthquake is mainly dependent upon the characteristics between the energy absorbing capacity of structure, which is concerned with the period, yield strength, failure mode of structure, and the severity of vibration which may be caused on the amplitude of ground acceleration or the content of frequencies, etc.

However there have been little research on the evaluation method of the severity of vibration, especially of the parameters which will control the above mentioned severity of vibration for non-linear response analyses.

Maximum acceleration, maximum velocity, maximum displacement, spectrum intensity, etc. have been used as the index which imply the severity of vibration.

When the seismic safety of structure for the strong motions will be checked through non-linear response analyses, using several different earthquakes which have different characteristics in their spectrum, unless their severity of vibration should be adjusted to be same, it will be impossible to evaluate the real seismic capacity of the structure because the response results will be very scatter.

In this report, two types of artificial earthquakes were generated which have different spectrum characteristics. One of them are the artificial

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earthquakes whose spectrum characteristics are similar to El-Centro NS 1940 recorded on the rock and the other artificial earthquakes have similar characteristics to Hachinohe EW 1968 recorded on the surface soil. Maximum acceleration, maximum velocity, spectrum intensity and root mean square of the strong phase of the ground acceleration were selected as the parameters mentioned above.

The relationships between parameters, which will cause the destructive power of earthquake motions to the structure, and the periods, yield strengths, hysteresis models of structures were discussed qualitatively and also quantitatively through non-linear response analyses for single degree of freedom systems.

GENERATION OF EARTHQUAKE

Two sets of different types of artificial earthquakes were generated for this analysis. Each set consisted of 20 earthquakes. One set of them was intended to have the similar characteristics in response spectrum to the characteristics of the ground motions recorded on the firm soil or on the rock which present the large peak in the shorter period range. The other set has the similar characteristics in response spectrum to the spectrum characteristics of the strong motions recorded on the surface soil or on the soft soil which present the large peak in fairy long period range and that present the plural peaks.

Former set of earthquakes is called as type S group of earthquakes and latter set of earthquakes is called as type G group of earthquakes respectively.

The examples of time history of each type were shown in Fig-1 and mean response acceleration spectrum and velocity spectrum were also shown in Fig-2. From these response spectrum, it is known that type S earthquake has a single peak at about 0.3 sec. and type G earthquake has plural peaks at the longer period compared to the peak period of type S earthquake. Duration time of each artificial earthquake is 15 seconds.

NORMALIZATION PARAMETERS

It is necessary to determine the maximum amplitude of input acceleration when response analyses, especially non-linear response analyses, will be conducted.

Four normalization parameters (scaling factor of amplitude) are introduced into this research. They are the maximum acceleration (AM), maximum velocity (VM), spectrum intensity (SI) and the root mean square of the strong phase of the ground acceleration (RMS) respectively.

$$SI = \int_{0.1}^{2.5} S_V (h, T)\, dt$$

S_V : velocity spectrum

h : 0.2

$$RMS = \left[\frac{1}{T_D}\int_o^{T_D}(\ddot{y})^2 dt\right]^{1/2}$$

T_D : duration time of earthquake

$\ddot{y}$: ground acceleration

In this analysis, the maximum accelerations of type S earthquakes were fixed to be 1000 gals, and then the mean VM, SI, RMS were calculated to be 80 cm/sec, 154 cm, 210 cm/sec^2 respectively as tabulated in the first row of Table-1. These values were used as the standard value for scaling factor of the type G earthquakes. For instance, the forth row of Table-1 shows the relationships between each value when the spectrum intensity of type G earthquake was adjusted to the value of spectrum intensity of type S earthquake. This case shows the maximum acceleration of type G earthquakes reduced to be almost a half of the acceleration of type S earthquake.

STRUCTURAL MODEL

Single degree of freedom system with four types of different hysteretic characteristics were introduced into this analysis as the structural models. As shown the each hysteresis rules in Fig-3, they are the models commonly called as bi-linear model, degrading stiffness tri-linear model, origin oriented model and slip model.

The natural periods of structure are varied from 0.1 sec. to 4.5 sec. The yield shear coefficient Cy (Qy/W, Qy:yield shear force, W:weight of structure) of each model are varied like 0.5, 0.75, 1.0, 1.5, 2.0, 3.0. The reason why the yield coefficient are settled like so large values, is that standard maximum acceleration (type S) was normalized to be 1000 gals. The damping of the structure was assumed to be 5% of critical at the elastic stiffness and was changed so as to be proportional to the instantaneous stiffness at the inelastic stiffness.

RESPONSE RESULTS

Non-linear response analyses for the above mentioned single degree of freedom models were conducted. Maximum response displacements were analysed. The maximum amplitudes of type S earthquakes were not changed but the maximum amplitudes of type G earthquakes were changed according to the specific values of Table-1 every time when the normalization parameters (AM, VM, SI, RMS) were changed.

Two examples of response displacement spectrum for the origin oriented model were shown in Fig-4. In this figures, both spectrum were drawn when the maximum accelerations of both types of earthquakes were equal to be 1000 gals.

The maximum displacements were very much different from each other by the difference of the characteristics of ground motions. It can be seen that the displacement for type G becomes fairly large compared to the displacement for type S. To investigate the differencies of the maximum displacement by the difference of the characteristics in their frequency contents qualitatively, the displacements for type G motions were divided by those for type S motions as shown in Fig-5.

From these figures, it is able to know which normalization parameters of maximum amplitude of earthquake are most sensitive to the characteristics of the contents of frequencies. When the acceleration amplitudes are adjusted so as SI or VM to become equal, the maximum displacements for both groups of earthquakes are almost equal, besides the very short period zone, in spite of the differencies of spectrum characteristics of the ground motions. However, if the maximum acceleration AM or RMS are used as the normalization parameter, the maximum displacement for type G earthquake which have plural peaks in its response spectrum become larger than those for type S. The strength of structure becomes larger those tendencies above mentioned becomes decrease.

The differencies of response tendency by the difference of non-linearity were not so large, in spite that each value of maximum displacement itself is very much different.

CONCLUDING REMARKS

To evaluate the severity of earthquake motion for non-linear response analyses, it is prefarable to use the maximum velocity of ground motion or the spectrum intensity as the normalization parameter, because the response results are evaluated almost equal for the different types of earthquakes whose frequency contents are quite different, especially when the elastic periods are longer than about 0.3 sec. On the contrary, for the response analysis of the structure whose period is shorter than about 0.2 sec., it is roughly suggested to use the maximum acceleration or the root mean square of the strong phase of the ground acceleration.

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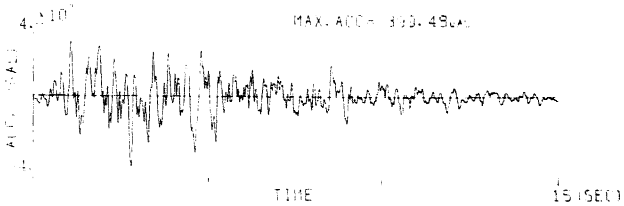
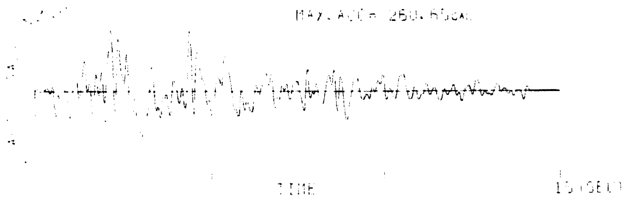
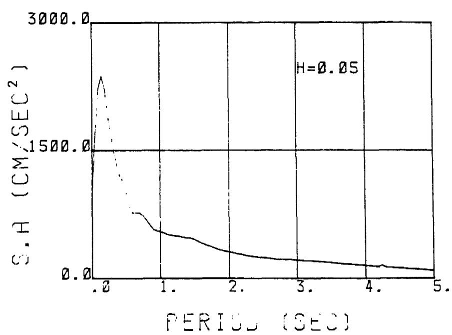


(a) Type S

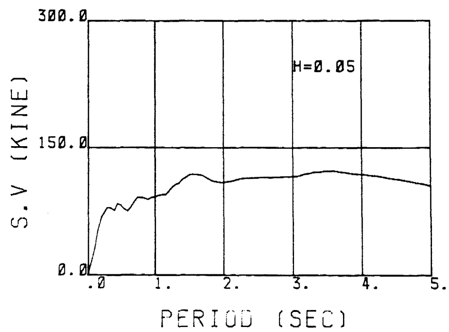


(b) Type G

Fig-1 Example of time history of artificial earthquake

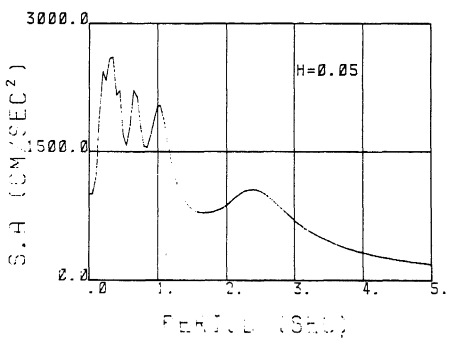


Acceleration Spectrum

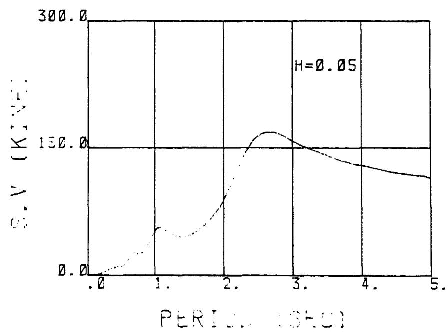


Velocity Spectrum

(a) Type S



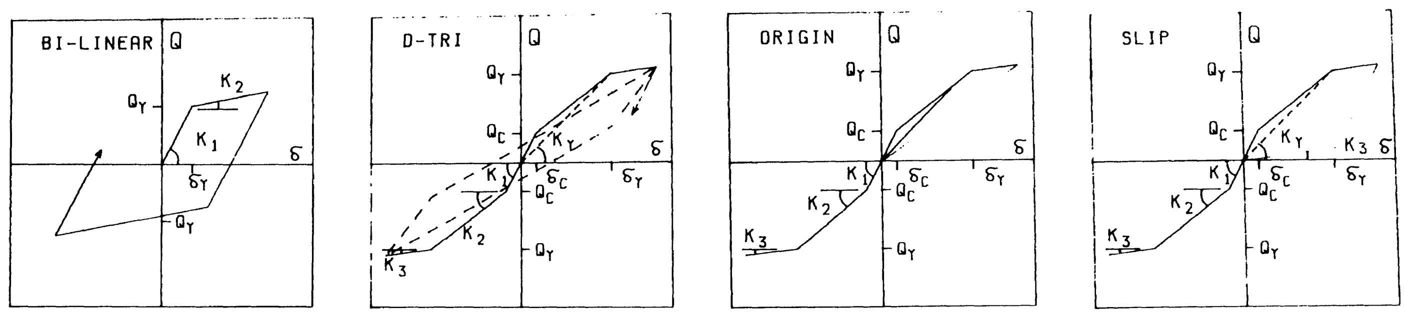
Acceleration Spectrum



Velocity Spectrum

(b) Type G

Fig-2 Mean Response Spectrum



(a) Bi-linear Model (b) Degrading Stiffness Tri-linear Model (c) Origin Oriented Model (d) Slip Model

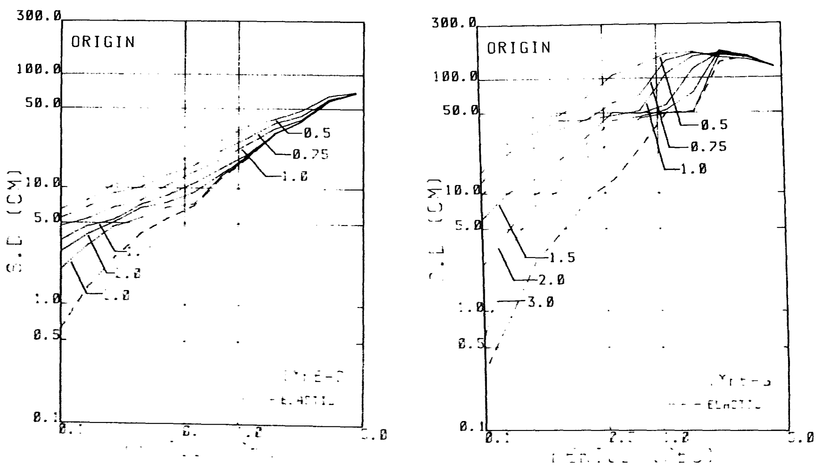
Fig-3 Hysteresis Rules

Table-1

Relation of Each Normalization Parameter

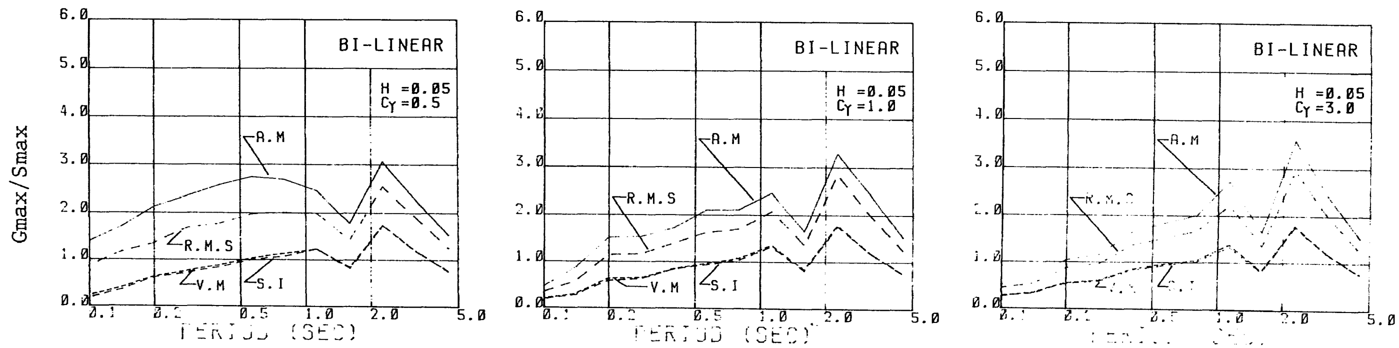
TYPE		AVE. ACC.MAX (GAL)	AVE. VEL.MAX (KINE)	AVE. S.I(20%) (CM)	AVE. R.M.S (GAL)
S		1000.0	80.0	154.0	210.0
	S.D	0.0	25.2	34.6	22.7
	COV	0.0	0.32	0.22	0.11
G		×1000.0	159.9	296.0	253.1
	S.D	0.0	37.1	58.9	32.6
	COV	0.0	0.23	0.17	0.13
		530.8	×80.0	152.3	132.3
		514.1	79.8	×154.0	128.1
		841.3	132.3	244.9	×210.0

S.D : STANDARD DEVIATION
COV : COEFFICIENT OF VARIATION
KINE : CM/SEC



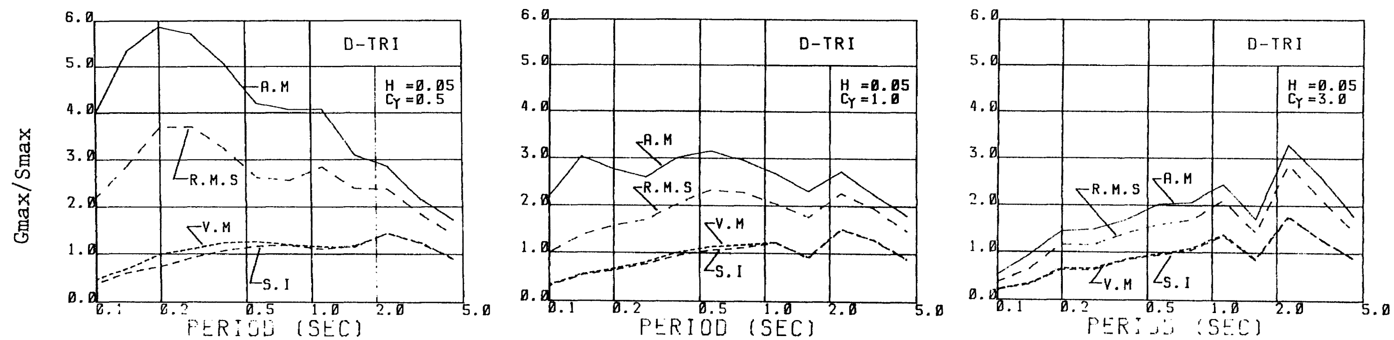
(a) Type S (AM=1000 gals) (b) Type G (AM=1000 gals)

Fig-4 Displacement Response Spectrum for Origin Oriented Model



Cy=0.5 Cy=1.0 Cy=3.0

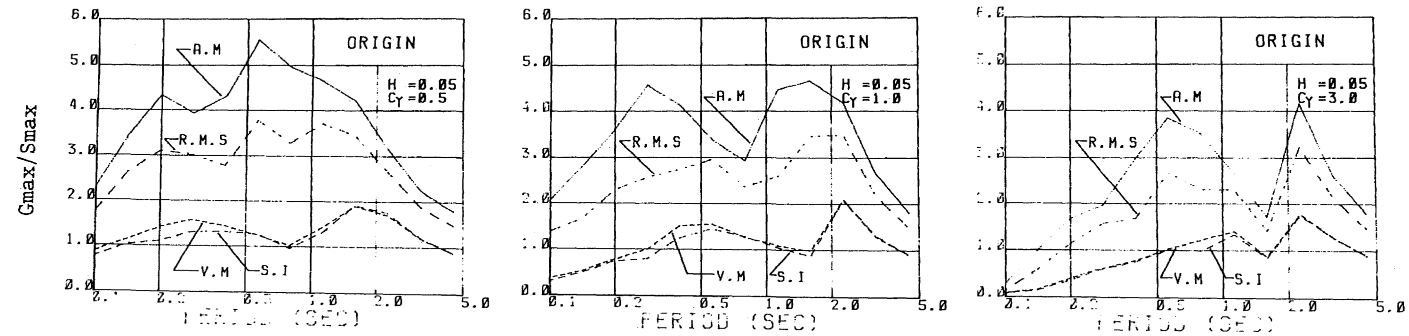
(a) Bi-linear Model



Cy=0.5 Cy=1.0 Cy=3.0

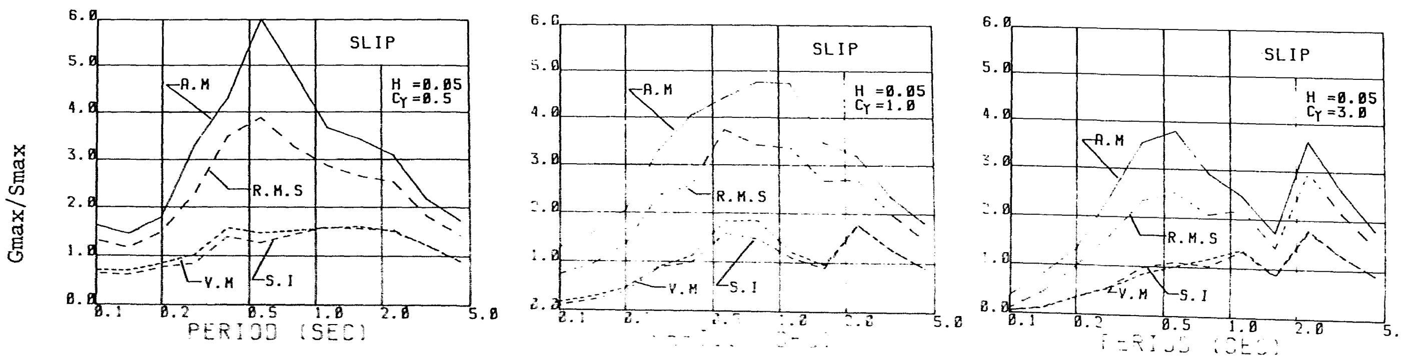
(b) Degrading Stiffness Tri-linear Model

Fig-5 Comparison of Maximum Displacement (Type G/Type S)



Cy=0.5 Cy=1.0 Cy=3.0

(c) Origin Oriented Model



Cy=0.5 Cy=1.0 Cy=3.0

(d) Slip Model

Fig-5 Comparison of Maximum Displacement (Type G/Type S)