EVALUATION OF THE EFFECTS OF EARTHQUAKE MOTIONS ON STRUCTURES BASED ON ELASTO-PLASTIC RESPONSE ENVELOPE SPECTRUM WITH TIME-DOMAIN

by

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SYNOPSIS

For the evaluation of the effects of earthquake motions on buildings and structures, it is necessary to consider the effects of repeated cyclic loading. This is especially essential for some type of reinforced concrete structures which collapse by shear failure.

The engineering characteristics of the earthquake motions are usually represented by the structural response spectra. However, no information of the effects of the earthquake motion on structures along the time duration is furnished by these spectral figures.

In this paper, the authors have tried to evaluate the destructiveness of earthquake motions by presenting the elasto-plastic response envelope spectrum with time-domain.

INTRODUCTION

Response spectrum analysis using strong-motion accelerograms has been widely employed for earthquake resistant design of buildings and structures. This analysis is based on the maximum response values of the single-degree of freedom system with viscous damping during the earthquake. Therefore no detailed information of the effects of earthquake on structures along the time duration of the earthquake motion is furnished in the response spectrum.

Suppose that a vibrating system which has specified natural period and damping factor is subjected to two different earthquake motions, A and B, and that response values of the system resemble each other. In case of A earthquake motion, the system is exposed to repeated deformations many times which are nearly equal to the maximum deformation, while in case of B earthquake motion, the system is subjected to the same distortion only several times. Nevertheless, both A and B earthquake motions are considered to have the same effects on structures when the response spectrum is used.

Therefore, the response spectrum commonly used is not sufficient to express the destructiveness of the earthquake motion on structures, especially on such a kind of reinforced concrete structure which is easy to deform into the plastic range and is damaged by being exposed to the repeated earthquake loading.

In order to understand the characteristics of an earthquake motion and its effects on structures more precisely, it is necessary to develop a new method of evaluating the response characteristics of the structure along the time duration of the earthquake motion.

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For the reason mentioned above, the authors have tried to evaluate the effects of the earthquake motion on structures by using the elasto-plastic response envelope spectrum.

METHOD OF ANALYTICAL EVALUATION

The model considered in this analysis is the well-known one-mass bi-linear hysteretic oscillator.

Structural parameters of the model shown in Fig. 1 are as follows:

(1) Acceleration at structural yielding (αy)
It is assumed to be 300 gals in consideration of the strength of structures designed by the Japanese seismic code.

(2) Stiffness after yielding (Kp)
It is assumed to be 1/100 of elastic stiffness.

(3) Damping factor (h)
5% of critical damping of internal type is taken for elastic stiffness.

Response values of the model subjected to the earthquake motion are evaluated with the ductility factor (μ) which is defined by dividing the absolute value of relative displacement response in time history (D) by yielding displacement (Dy). Corresponding to the respective natural periods of the model (T), its yielding displacement (Dy) is defined by equation (1).

$$Dy = \alpha y \cdot \{\frac{T}{2\pi}\}^2 \quad (cm) \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Six earthquake records shown in Table-1 are used as input motions in the analysis. These earthquakes have different magnitudes, epicentral distances, and were recorded on various soil conditions. The peak acceleration values of these six records are adjusted to 200 gals.

RESULTS AND DISCUSSIONS

As are shown in Fig 2 (a), (b), (c), (d), (e) and (f), respectively, the results of response analysis are represented by the topographical maps of ductility factor (μ) as a function of time duration of the earthquake motion (t) taken as abscissa and the natural period of the model taken as ordinate. Selected contour levels of μ are 12; 0.5 and at each interval of 0.2 in the range of 1.0 to 3.0.

On the left hand side of the envelope spectrum, the elasto-plastic relative displacement spectrum of the earthquake motion is presented. Two parabolas in that figure indicate two different ductility levels, which are given by equation (2).

$$D\mu = \alpha y \cdot \mu \cdot \{\frac{T}{2\pi}\}^2 \quad (\mu = 1, 2) \quad \ldots\ldots\ldots\ldots\ldots (2)$$

The following is the discussion on the results of response of the model to each earthquake motion.

(a) El-Centro N-S Component, Fig 2-(a)
This earthquake motion is a typical one recorded on the firm ground

and is used most frequently in the seismic analysis of structures.

In the figure, inelastic response values ($\mu>1$) are distributed in the wide range from 0.1sec. to 0.7 sec. of T. The maximum value of response level (μ) is 1.8 which occurs around 0.5 sec. of T. Where T is below 0.3 sec., many repeated oscillations whose response levels are below 1.4 can be observed. Where T is over 0.3 sec. up to 0.7 sec., the number of repetition decreases, but the response level increases up to 1.8. Where T is above 0.7 sec., the number of repetition decreases and the level of response falls into the elastic range.

(b) Taft E-W Component, Fig 2-(b)

This record is used as frequently as El-Centro N-S component. However, the results obtained from these two are fairly different from each other.

The maximum response value is 2.6 which occurs around 0.3 sec. of T. Where T is above 0.5 sec., both the number of repetition and the response level are very small. These values increase very rapidly in the range below 0.5 sec. of T. Especially where T is between 0.2 sec. and 0.3 sec., many repetitions at high response level can be seen through the time duration of the earthquake motion.

Like the results obtained from El-Centro N-S component, response values distribute in the wide range of T. In general the vibrating systems whose natural period is between 0.2 sec. and 0.4 sec. are affected strongly by this earthquake motion.

(c) Parkfield N65E Component, Fig 2-(c)

The original record has an impulsive peak acceleration whose value is 491 gals at 4 sec. of t. Therefore the response of high level cocentrates in the range where t is around 4 sec. and T is between 0.3 sec. and 0.8 sec. In the other parts, the response values remain in the elastic range.

It is worth notice that the maximum response value obtained from this record is 1.8 which is equal to that of El-Centro N-S component.

(d) Managua N-S Component, Fig 2-(d)

In this record, the maximum acceleration values of three components are equal to 0.3 g and severe oscillation continues for 10 seconds.

Many repetitions and response at high level can be seen in the wide range where T is between 0.1 sec. and 0.4 sec. However, compared with the results obtained from other earthquake motions, response at high level is predominant in the range where T is below 0.2 sec. These features of the response may be characteristic of the earthquake motion recorded near the focus.

(e) Hachinohe N-S Component, Fig 2-(e)

This earthquake motion was recorded on relatively soft ground near Hachinohe Harbor in the Tokachi-Oki event.

Response values at high level can be seen in the range where T is between 0.3 sec. and 0.6 sec. and also near 0.9 sec. Compared with the other results, the number of repetition is small and response values can be observed in the range of the longer periods of T.

(f) Hiroo E-W Component, Fig 2-(f)

This earthquake motion was recorded on the solid ground at Hiroo City Office in the Tokachi-Oki event. This record is like a sine-wave whose period is about 0.25 sec., and response values concentrate in only the range where T is between 0.2 sec. and 0.3 sec. The maximum value of response is about 3, and the oscillations in the plastic range whose levels are over 2 continue after the first 25 seconds in the time duration.

When the level of response and the number of repetition are taken into consideration, this earthquake motion may be one of the severest wave for low-rise structures.

CONCLUDING REMARKS

(1) The effects of the repeated oscillation on structures caused by the earthquake motion along its time duration can be represented by the elasto-plastic envelope spectrum measures. The information on the above mentioned effects is not furnished in the conventional response spectra commonly used.

(2) Analytical model used in this study is the simple one-mass bilinear oscillator whose yielding acceleration is 300 gals. The model is subjected to six input accelerations whose maximum values are adjusted to 200 gals. The topographical map of the response ductility factor is figured as a function of the time duration of the earthquake motion and the natural period of the model in investigating the characteristics of each earthquake motion.

The results show: 1) the pattern of the response, the time-dependent transition of the destructive power and the number of repetition in the plastic range for each earthquake motion are quite different from the others, 2) Taft E-W, Managua N-S and Hiroo E-W components give the severest effects on the structures whose natural periods are between 0.2 sec. and 0.4 sec. and 3) every earthquake motion has large destructive power in the range where the natural period of the model is between 0.2 sec. and 0.4 sec.

(3) The results obtained from Hiroo E-W component may explain the fact that some low-rise reinforced concrete buildings were severely damaged by the shear failure of the short columns subjected to the repeated loading many times in the plastic range.

(4) Because the response envelope spectrum fluctuates significantly with the earthquake motion and the damping factor, the application of this analytical method for the seismic evaluation of the structure should be carefully made, considering the seismological and geological conditions of the construction site.

(5) The analytical results presented in this paper may be referred to when the static loading tests on the structures or the structural components are performed.

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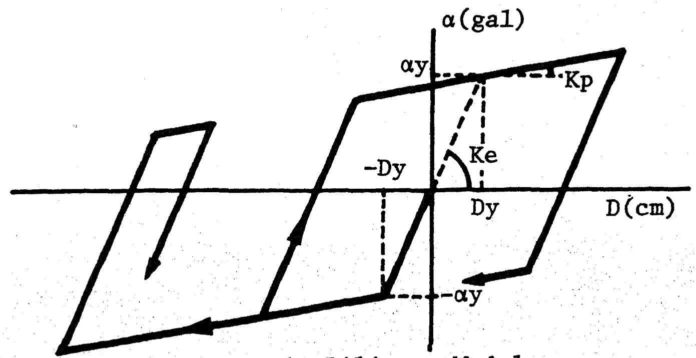

Fig. 1 Bilinear Model

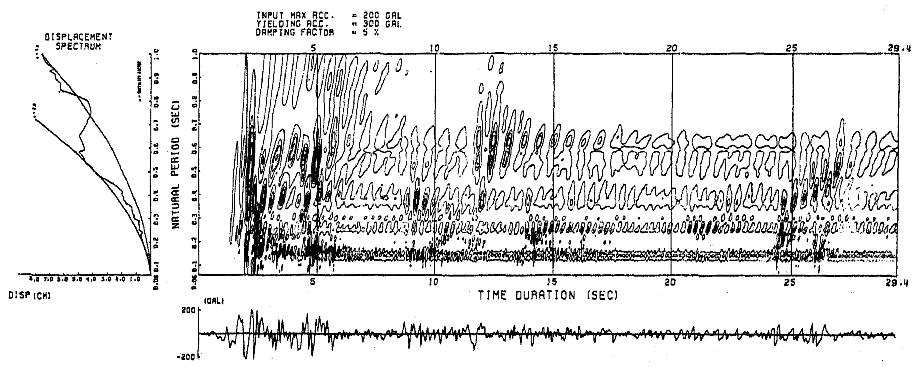

Fig. 2-(a) El-Centro N-S Component 1940.5.18

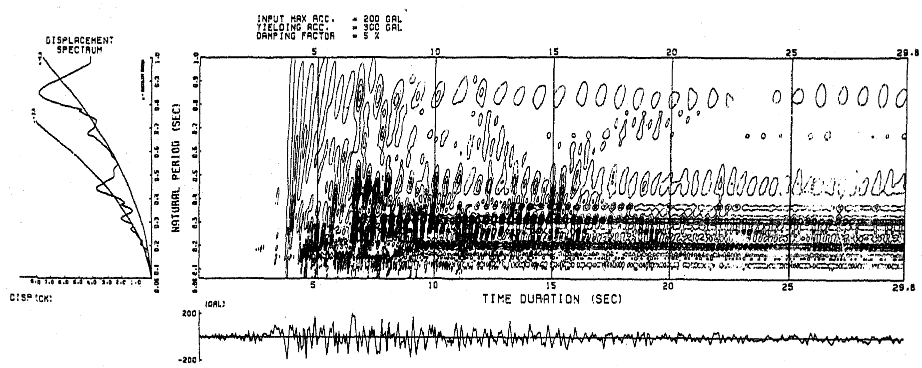

Fig. 2-(b) Taft E-W Component 1952.7.21

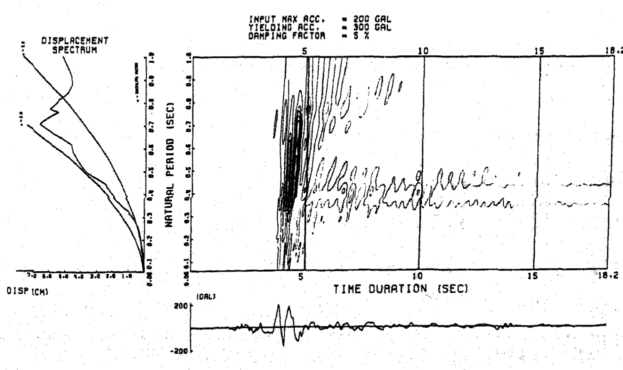

Fig. 2-(c) Parkfield N65E Component 1966.6.27

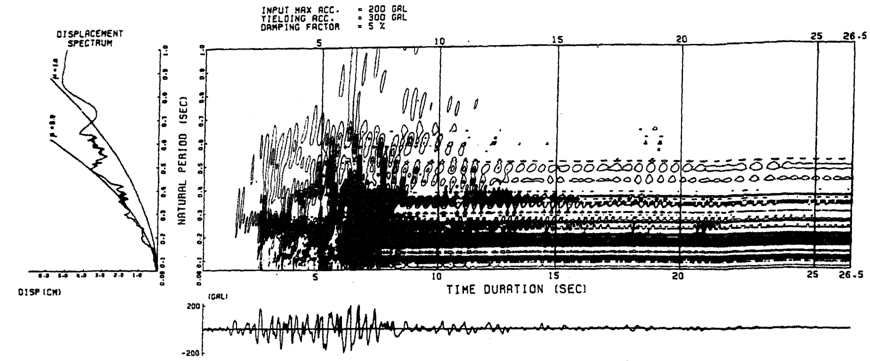

Fig. 2-(d) Managua N-S Component 1972.12.23

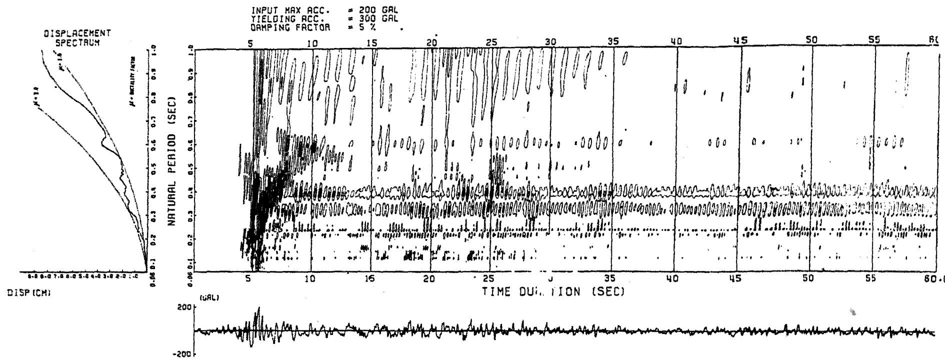

Fig. 2-(e) Hachinohe N-S Component 1968.5.16

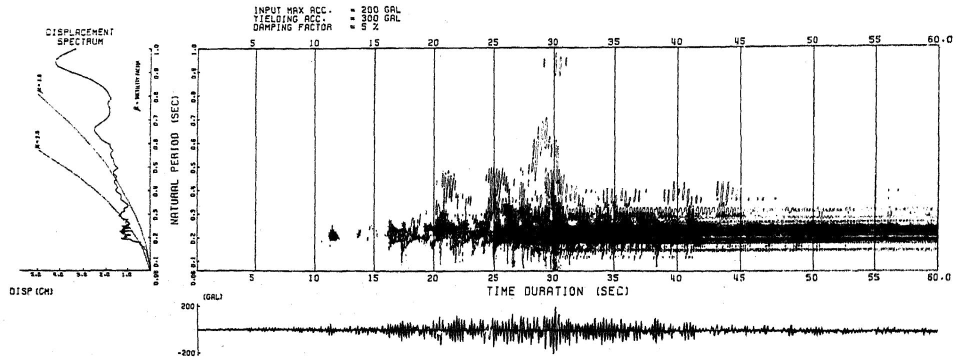

Fig. 2-(f) Hiroo E-W Component 1968.5.16

Earthquake		Date	Mag.	Source Distance (km)	Soil Profile
EL-CENTRO	N-S	18-May '40	7.0	64	Stiff Clay
TAFT	E-W	21-Jul '52	7.7	40	Rock
PARKFIELD	N65E	27-Jun '66	5.6	0.08	Stiff Alluvium
MANAGUA	N-S	23-Dec '72	6.2	4-6	Quaternary Alluvium
HACHINOHE	N-S	16-May '68	7.9	176	Soft Alluvium
HIROO	E-W	16-May '68	7.9	177	Stiff Loam

Table-1 Characteristics of Earthquake Motions