FREQUENCY CONTENT, INTENSITY AND YIELD LEVEL IN NONLINEAR DYNAMIC RESPONSE

A paper accepted for presentation at the Central American Conference on Earthquake Engineering to be held in San Salvador, El Salvador in January 1978.

ASRA INFORMATION RESOURCES
NATIONAL SCIENCE FOUNDATION

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO.
NSF/RA-780123

2.

3. Recipient's Accession No.
PB300909

4. Title and Subtitle
Frequency Content, Intensity and Yield Level in Nonlinear Dynamic Response*

5. Report Date
January, 1978

6.

7. Author(s)
A. T. Derecho, M. Iqbal, S. K. Ghosh, M. Fintel

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Portland Cement Association
Advanced Engineering Services
Skokie, Illinois 60076

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G) ENV7414766

12. Sponsoring Organization Name and Address
Engineering and Applied Science (EAS)
National Science Foundation
1800 G Street, N.W.
Washington, D.C. 20550

13. Type of Report & Period Covered

14.

15. Supplementary Notes
*Paper for presentation at the Central American Conference on Earthquake Engineering, El Salvador, 1/78

16. Abstract (Limit: 200 words)

Three major parameters characterizing earthquake motions affect structural response. These include intensity, duration and frequency content. The third, frequency content, appears to be the least explored, particularly with reference to the problem of critical excitation. In this paper, an attempt is made to characterize input motions in terms of frequency content on the basis of their 5%-damped velocity response spectra as "peaking" and "broad band". Results of analyses for isolated structural walls having different fundamental period and yield level are presented. These results indicate the dependence of the critical response on the frequency content of the input motion and the yield level of the structure. The relationship of intensity and frequency content in determining the critical input motion for a structure with a specified yield level is also discussed.

17. Document Analysis a. Descriptors

Earthquakes
Earthquake resistant structures
Dynamic structural analysis
Yield strength
Design
Seismic waves
Elastic properties

b. Identifiers/Open-Ended Terms

Earthquake engineering
Earthquake motions
Input motions

c. COSATI Field/Group

18. Availability Statement
NTIS

19. Security Class (This Report)

20. Security Class (This Page)

21. No. of Pages
12

22. Price
A02-A01

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

FREQUENCY CONTENT, INTENSITY AND YIELD LEVEL IN NONLINEAR DYNAMIC RESPONSE

A.T. Derecho,[1] M. Iqbal,[2] S.K. Ghosh,[3] and M. Fintel[4]

ABSTRACT

In developing a procedure for the earthquake-resistant design of structures, a basic requirement is the determination of realistic estimates of force and deformation demands in critical regions of a structure. An important question involved in the estimation of critical forces and deformations in structures subjected to earthquake motions is the choice of input motions to be used in the analyses. The choice of input motion is particularly crucial where comprehensive data on inelastic response is desired because the analyses involve a significant amount of computing time. Thus, only a very limited number of input motions can be considered.

Three major parameters characterizing earthquake motions affect structural response. These include intensity, duration and frequency content. The third, frequency content, appears to be the least explored, particularly with reference to the problem of critical excitation. In this paper, an attempt is made to characterize input motions in terms of frequency content on the basis of their 5%-damped velocity response spectra as "peaking" and "broad band". Results of analyses for isolated structural walls having different fundamental period and yield level are presented. These results indicate the dependence of the critical response on the frequency content of the input motion and the yield level of the structure. The relationship of intensity and frequency content in determining the critical input motion for a structure with a specified yield level is also discussed.

INTRODUCTION

The economic provision of adequate stiffness, strength and deformation capacity in earthquake-resistant structures depends on a realistic assessment of the maximum forces and deformations that are likely to occur during the expected life of the structure. For a particular site, wide variations in the character of the free field motion can occur as a result of variations in the source location, mechanism, and the transmission path properties. This variation would be greater if the potential earthquake foci were widely separated.

---

[1] Manager and [2] Structural Engineer, Structural Analytical Section, Engineering Development Department; [3] Senior Structural Engineer and [4] Director, Advanced Engineering Services; Portland Cement Association, Skokie, Illinois.

Variation in the character of the ground motion at a site indicates the desirability of considering a number of representative input motions when undertaking an analysis to determine the likely maximum response of a particular structure. However, where inelastic analyses (considered essential in a determination of deformation or ductility requirements) are concerned, only a very limited number of such runs are economically feasible. In recognition of this limitation, it appears desirable to develop a means of classifying accelerograms into broad categories according to selected basic properties. Such classification permits reasonable estimates of the maximum response of structures to potential earthquakes on the basis of a limited number of analyses.

GROUND MOTION PARAMETERS

Insofar as dynamic structural response is concerned, the principal ground motion parameters are intensity, duration, and frequency content. Intensity is used as a characteristic measure of the amplitude of the acceleration pulses in a record. Duration refers to the length of the record during which relatively large amplitude pulses occur, with due allowance for a reasonable build-up time. The frequency characteristics of a given ground motion have to do with the energy content of the component waves making up the motion.

The effects of intensity and duration on dynamic structural response have been studied by other investigators (1). However, very little has been done to determine the effect of the frequency characteristics of the input motion, particularly with respect to the the selection of appropriate input motions.

This report presents the results of dynamic nonlinear analyses of isolated structural walls with hysteresis loops characterized by a stiffness that decreases with increasing amplitudes of inelastic deformation. Particular attention is focused on the interdependence of the frequency content and intensity of the ground motion with the yield level of the structure in producing critical or near-maximum response.

For this investigation, a duration of 10 seconds was used in the analyses. The intensity of the input motion was measured in terms of the "spectrum intensity", i.e., the area under the velocity response spectrum between bounding values of the period representing the limits of the period range of interest. In this case, the range is from 0.10 to 3.0 seconds.

Frequency Characteristics

The importance of knowing the frequency characteristics of a given input motion lies in the phenomenon of resonance or quasi-resonance. This occurs when the frequency of the exciting force or motion approaches the frequency of the structure. Near-maximum response to earthquake excitation can be expected if the dominant frequency components occur in the same frequency range as the dominant effective frequencies of the structure.

A convenient way of studying the frequency characteristics of an accelerogram is provided by the Fourier amplitude spectrum (2). This spectrum provides a frequency decomposition of the accelerogram, indicating the amplitude (in units of velocity - a measure of the energy content) of the component at a particular frequency. Another commonly used measure of the frequency content of an accelerogram is the velocity response spectrum (3). This is a plot showing the variation of the maximum absolute value of the relative velocity of a linear single-degree-of-freedom system with the undamped natural period (or frequency) when subjected to a particular input motion. Figure 1, from Ref. 3, shows the relative velocity response spectra for the N-S component of the 1940 El Centro record, for different values of the damping factor. The dashed curve in Fig. 1 is the corresponding Fourier amplitude spectrum. As in the Fourier spectrum, the peaks in the velocity response spectrum reflect concentrations of the input energy at or near the corresponding frequencies.

Although both Fourier amplitude and undamped velocity response spectra exhibit a jagged character, with peaks and troughs occurring at close intervals, it is usually possible to recognize a general trend in the overall shape of any particular curve. By noting the general shape of the spectrum in the frequency range of interest, a characterization of the input motion in terms of frequency content can be made. While this procedure represents a rather crude method for classifying accelerograms in terms of frequency content, it nevertheless provides a sufficient basis for determining the potential severity of a given input motion in relation to a specific structure.

In this study, where a viscous damping coefficient of 0.05 of critical for the first mode was used as the basic value for the dynamic analysis model, the 5% damped velocity response spectra corresponding to 10 seconds of a number of representative records were examined. On the basis of this examination, the following two general categories were recognized:

(1) a "peaking" accelerogram with a spectrum exhibiting dominant frequencies over a well-defined period range. The N-S component of the 1940 El Centro record is an example of this class.

(2) a "broad-band" accelerogram with a spectrum that remains more or less flat over the period range of interest. The vertical component of the 1940 El Centro record may be classified under this category.

- A sub-class of the broad-band category is a record with a spectrum which increases with increasing period within the period range of interest. This may be referred to as a "broad-band ascending" accelerogram. The E-W component of the 1940 El Centro record is representative of this type of record.

The above two cases are illustrated schematically in Fig. 2.

For a linear structure, or a structure that experiences only limited yielding under ground excitation, a peaking accelerogram is likely to produce a stronger response than a broad-band motion of the same intensity and duration. In this context, a peaking accelerogram is taken to mean one with a velocity spectrum that has its peak approximately centered about the initial fundamental period of the structure considered.

In structures where yielding significantly increases the effective period of vibration, the effect of the dominant frequency components in a peaking accelerogram diminishes as the effective period of the structure moves beyond the peaking range. For such a structure, a broad-band accelerogram of the same intensity is more likely to produce the critical response.

DYNAMIC ANALYSIS OF ISOLATED STRUCTURAL WALLS

To determine the effect of "peaking" and "broad-band" accelerograms, dynamic analyses were carried out on isolated structural wall models using the computer program DRAIN-2D (4). Three sets of analyses were made, as described in Table 1. A total of five accelerograms were used. The corresponding 5%-damped velocity spectra are shown in Fig. 3.

The accelerograms used in Sets (a) and (b), listed in Table 1, were normalized with respect to intensity to 1.5 times the 5%-damped spectrum intensity of the N-S component of the 1940 El Centro record, which is referred to as SI_{ref}. Those used in Set (c) were normalized to 0.75 times SI_{ref}. Intensity normalization factors are listed in Table 1. The entries in the fourth column of Table 1 indicate the classification of the accelerogram as peaking or broad-band relative to the initial fundamental period of the structure considered.

The isolated structural wall considered in the analyses is assumed to form part of a hypothetical 20-story building consisting of a series of parallel walls, as shown in Fig. 4. The moment-rotation relationship for the wall is characterized by a decrease in the reloading stiffness with increasing deformations beyond yield. The structure, as well as other aspects of the results are described in more detail in Reference 5. To save on computer time with little sacrifice in accuracy of results, the 12-mass model shown in Fig. 4b was decided upon after some preliminary analyses.

DISCUSSION OF RESULTS

Set (a). Envelopes of response values for a structure with a period of 1.4 sec. and a yield level, M_y = 500,000 in-kips (56,490 kN·m), are shown in Fig. 5. Figures 5a and b indicate that the E-W component of the 1940 El Centro record, classified as "broad-band ascending" with respect to frequency characteristics, produces relatively greater maximum displacements and ductility requirements than the other three input motions considered. However, the same record produces the least value of the maximum horizontal shear. The artificial accelerogram S1 produces the largest shear. Because all the structures yielded and the slope of the second, post-yield branch of the assumed moment-rotation curve is relatively flat, the moment envelopes for this case do not show any significant differences among the four input motions used.

It is significant to note that as yielding progresses and the effective period increases, it is the "broad-band ascending" type of accelerogram (in this case, the El Centro E-W component) that excites the structure most severely. Response to the other types of accelerogram--and particularly the peaking accelerograms--tend to be less severe. An indication of the change in fundamental period of a structure as the hinging region progresses from the first story upward is given by Fig. 6, for different values of the yield stiffness ratio. This figure is based on the properties of a structure with initial fundamental period, $T_1 = 1.4$ sec.

Set (b). To determine the effects of frequency characteristics for short-period structures with relatively high yield levels, a "peaking" accelerogram (N-S component of the 1940 El Centro) was considered. For this set, a structure with fundamental period, $T_1 = 0.8$ sec. and a yield level, M_y = 1,500,000 in-kips (169,470 kN•m), was assumed.

Figure 7 shows response envelopes for this set. As can be seen, the peaking accelerogram consistently produces a greater response in the structure than a broad-band record. A comparison of Fig. 7c and Fig. 5c indicates that the ductility requirements are significantly less for this structure with a high yield level. In addition, yielding does not progress as high up the wall as in the case of the structure with period $T_1 = 1.4$ sec. and a low yield level.

The greater response of the structure under the N-S component of the 1940 El Centro (peaking) follows from the fact that the dominant frequency components for this motion occur in the vicinity of the period of the structure. In this region the E-W component has relatively low-power components. Also, because of the high yield level of the structure, yielding was not extensive, particularly under the E-W component. Apparently, the effective period of the yielded structure did not shift into the range where the higher powered components of the E-W motion occur.

Set (c). In the third set, the same structure considered in Set (a) was used but with the intensity of ground motion reduced by one-half. The two motions used were the 1971 Pacoima Dam, S16E record (peaking) and the 1940 El Centro, E-W (broad-band).

Calculated envelopes of response are shown in Fig. 8. These support the observation that when yielding in a structure is not extensive enough to cause a significant increase in the effective period, the peaking type accelerogram is likely to produce the more critical response. Figure 8 (c) shows that in this case, yielding in the structure does not extend far above the base when compared to Set (a) where the input motion was twice as intense. It will be noted that in Set (a), the 1940 El Centro, E-W motion (a broad-band accelerogram) with intensity equal to 1.5 (SI_{ref}) represented the critical motion, while the Pacoima Dam record (a peaking motion) produced a relatively smaller response. By reducing the intensity of the motions by one-half in Set (c), yielding in the structure is significantly reduced. Consequently, the Pacoima Dam record becomes the more critical motion, as shown in Fig. 8.

SUMMARY

The extent of yielding in a structure is influenced by the yield level, M_y, as well as the intensity of the input motion. For this reason, both parameters should be taken into account when selecting the appropriate type of motion to use as input with particular reference to frequency characteristics.

In selecting an input motion for use in the analysis of a structure at a particular site, the probable epicentral distance and the intervening geology should be considered. These considerations, which affect the frequency content of the ground motion at a site, may logically reduce the possibility of dominant components occurring in certain frequency ranges. High-frequency components in seismic waves tend to be attenuated more rapidly with distance than the low-frequency components. In view of this, it is reasonable to expect that beyond certain distances (depending on the geology of the area), most of the higher-frequency components from a given source will be damped out. Where this occurs, only the low-frequency (long-period) components need be considered.

Acknowledgment. This material is based upon research supported by the National Science Foundation under Grant No. ENV74-14766. Opinions, findings, and conclusions expressed in this publication are those of the authors and do not necessarily reflect the views of the National Science Foundation.

The review of the paper by Dr. W. G. Corley, Director, Engineering Development Department, Portland Cement Association, is gratefully acknowledged.

REFERENCES

1. Clough, R.W., and Benuska, K.L., "FHA Study of Seismic Design Criteria for High-Rise Buildings", Report HUD TS-3, Federal Housing Administration, Washington, D.C., August 1964.

2. Trifunac, M.D. and Lee, V., "Routine Computer Processing of Stong-Motion Accelerograms", Report EERL 73-03, California Institute of Technology, Earthquake Engineering Research Laboratory, Pasadena, California, October 1973.

3. Analysis of Strong Motion Earthquake Accelerograms, Vol. III-Response Spectra, Part A-Accelerograms HA001 through HA030, Report EERL 72-80, California Institute of Technology, Earthquake Engineering Research Laboratory, August 1972.

4. Kanaan, A.E., and Powell, G.H., "General Purpose Computer Program for Inelastic Dynamic Response of Plane Structures", (DRAIN-2D), Report No. EERC 73-6, Earthquake Engineering Research Center, University of California, Berkeley, April 1973. Modified by Litton, R., and Powell, G.H., to include Takeda decreasing stiffness model and by S.K. Ghosh to include plotting capabilities.

5. Derecho, A.T., Ghosh, S.K. Iqbal, M., Freskakis, G.N., Fugelso, L.E. and Fintel, M., "Structural Walls in Earthquake-Resistant Structures - Analytical Investigation, Dynamic Analysis of Isolated Structural Walls," (Part A: Input Motions and Part B: Parametric Studies), Report to the National Science Foundation, RANN, under Grant No. GI-43880, Portland Cement Association, October 1976.

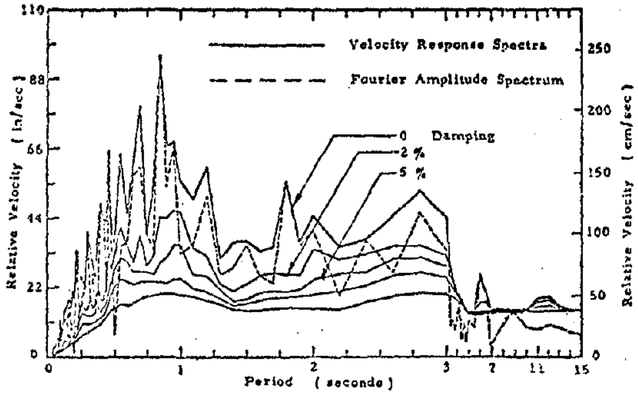
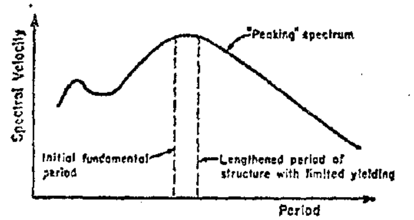
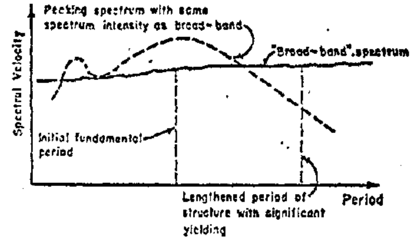


Fig. 1 Velocity Response Spectra - 1940 El Centro, N-S Component (from Ref. 3)



(a) Peaking Spectrum



(b) Broad-band Spectrum

Fig. 2 Typical Basic Shapes of Damped Velocity Response Spectra

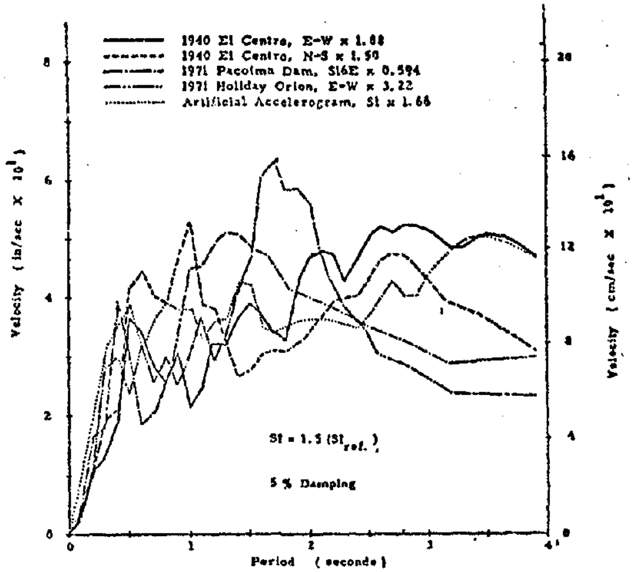


Fig. 3 Relative Velocity Response Spectra for First 10 Seconds of Normalized Input Motions

Table 1 Summary of Input Motions Considered in Study of Frequency Characteristics
1 in-kip = 0.11298 kN·m

Set	Structure Period, T_1 (and M_y)	Input Motion	Frequency Content Characterization#	Intensity Normalization Factor*
a	1.4 sec. (500,000 in-k)	1971 Pacoima Dam, S16E component	Peaking (0)	0.59
		1971 Holiday Inn Orion, E-W component	Peaking (+)	3.22
		Artificial Accelerogram, S1	Broad band	1.65
		1940 El Centro, E-W component	Broad band, ascending	1.80
b	0.8 sec. (1,500,000 in-k)	1940 El Centro, N-S component	Peaking (0)	1.50
		1940 El Centro, E-W component	Broad band, ascending	1.88
c	2.0 sec. (500,000 in-k)	1971 Holiday Inn, Orion, E-W component	Peaking (-)	3.22
		1940 El Centro, E-W component	Broad band, ascending	1.83
		Artificial Accelerogram, S1	Broad band	1.65

(1 in-kip = 0.1129792 kN·m)

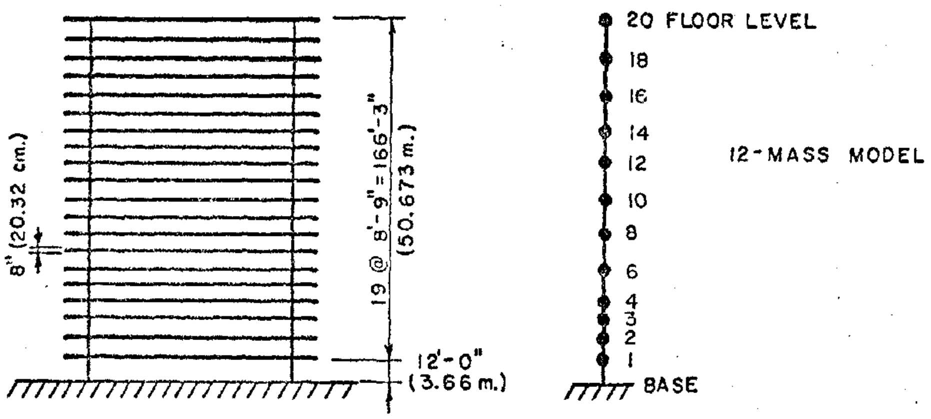


Fig. 4 Twenty-Story Building with 'Isolated' Structeral Walls

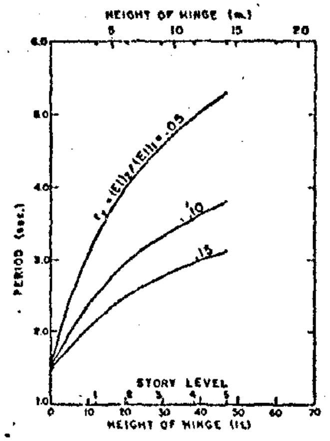
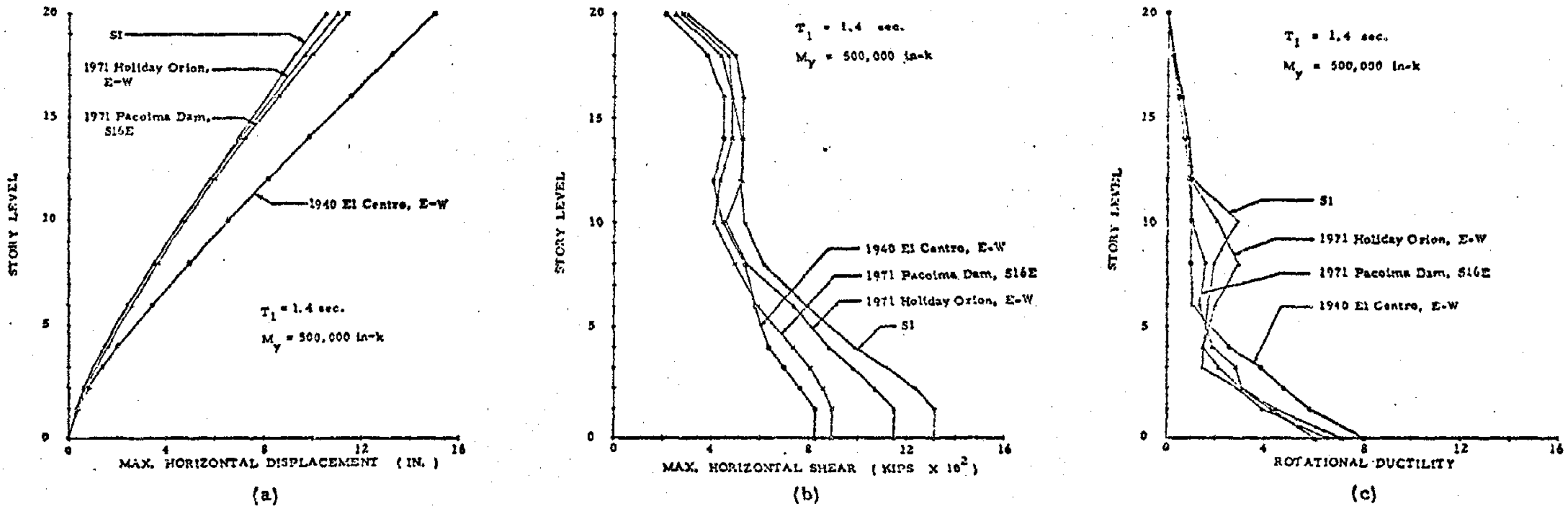
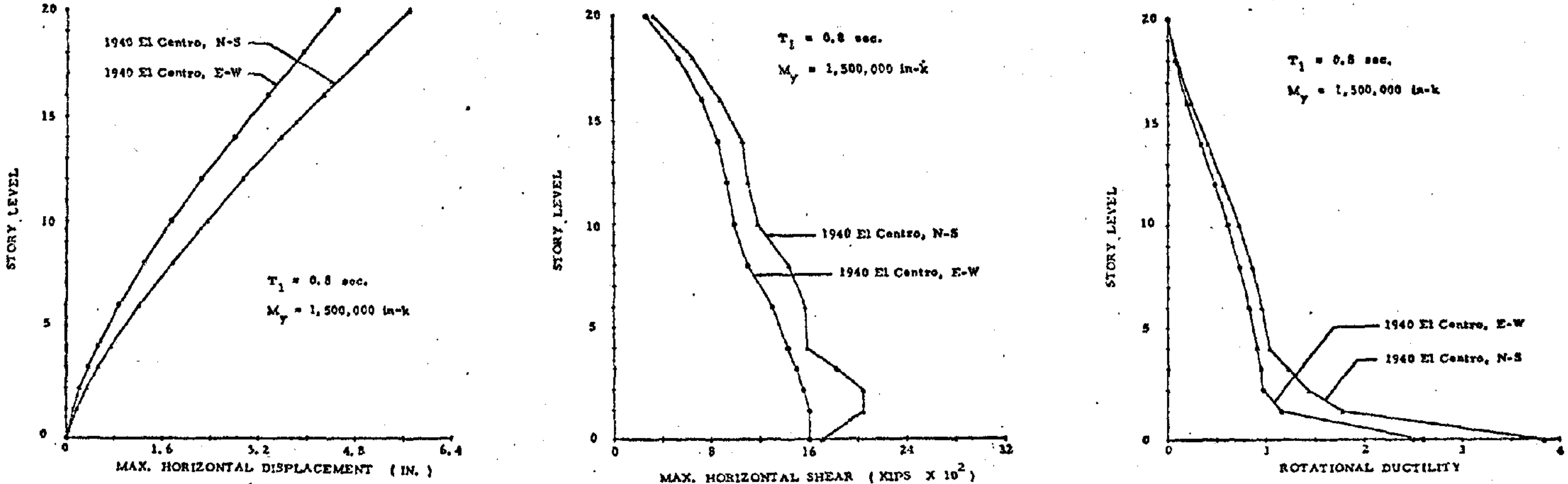


Fig. 6 Fundamental Period vs. Height of Yield Hinge, 20-Mass Cantilever



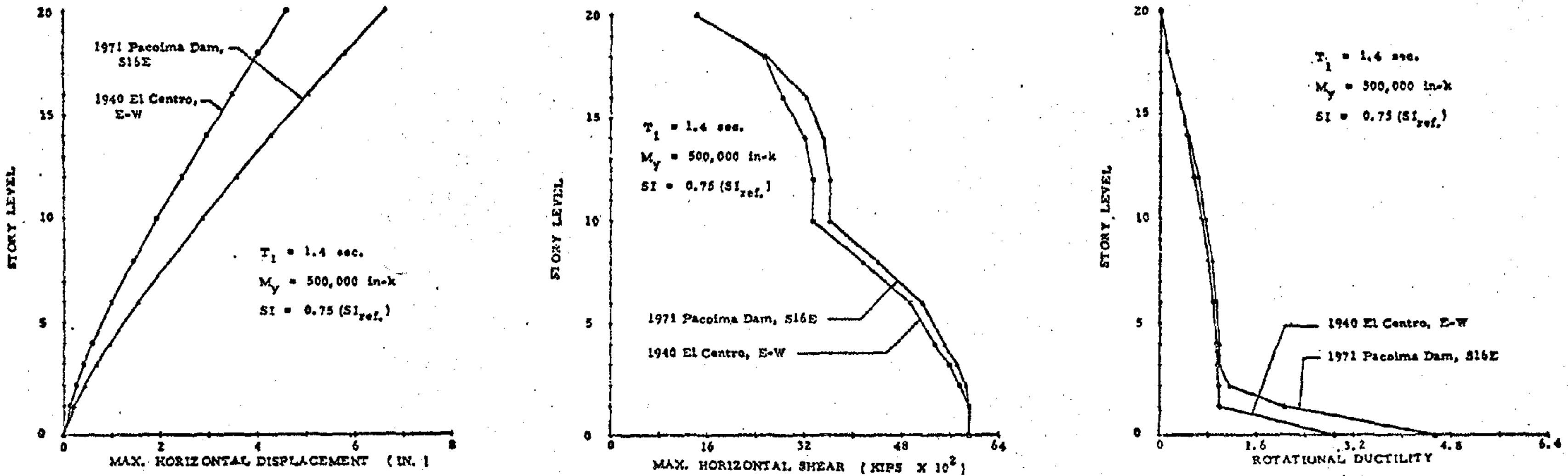
(a) (b) (c)

Fig. 5 Effect of Frequency Characteristics of Ground Motion - Low Yield Level
(1 in. = 2.54 cm. 1 kip = 4.448 kN 1 in-kip = 0.11298 kN·m)



(a) (b) (c)

Fig. 7 Effect of Frequency Characteristics of Ground Motion – High Yield Level
(1 in. = 2.54 cm. 1 kip = 4.448 kN 1 in-kip = 0.11298 kN·m)



(a) (b) (c)

Fig. 8 Interacting Effects of Frequency Characteristics, Intensity and Yield Level
(1 in. = 2.54 cm. 1 kip = 4.448 kN 1 in-kip = 0.11298 kN·m)