DESTRUCTIVE POWER OF EARTHQUAKES

by

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SYNOPSIS

A modal analysis of a given space structure, with steel columns and reinforced concrete floors, is presented. The participant mass of the modes of the structure are multiplied by the corresponding ordinates of an El Centro earthquake energy spectra, in order to obtain the energy attained by each mode. An elasto-plastic analysis of the structure receiving those energies is carried out. The area under the energy spectra appears as representing the destructive power of the earthquake. The destructive power of the El Centro and Taft earthquakes, so determined, are compared.

INTRODUCTION

In the study of the response of structures to the ground shaking it has been usual to compute the lateral forces acting on the parts of buildings, forces that are accepted as the destructibility measure of an earthquake. These forces are derived from the maximum acceleration of the ground shaking and from the mass of the said parts. Empiric reduction factors are introduced to take into account the viscous and plastic damping effects and the difference in the behaviour of the various structures and materials. Criticism on this criterion has been exposed by authors, (1), (2), (3), (4), (5). In this paper a method based on the consideration of the said seismic forces and also on their displacements, what is to say, on the energy, is presented.

ENERGY ABSORPTED BY AN EXAMPLE STRUCTURE

According to the method, an energy spectra of an earthquake, supposed to represent the seismic characteristics of the site, must be available, spectra in which the value of the energy $E_1 = 1/2\ S\bar{v}^2$, is plotted versus the period T. The modal analysis (6) of an example structure, Fig. 1, whose proper periods, T_m, characteristic normalized elongations, A_{im}, and forces, F_{im}, and the participant mass, M_m, of each mode have been calculated, is shown in Fig. 2 and Table I. In accordance with the principle of independence of modes, the energy E_m attained by each mode of the structure is ascertained, Table I (b) and Fig. 1, by multiplying the participant mass of the said modes, Table I (a) and Fig. I, by the corresponding ordinates of the energy spectra, Fig. 3 (a). The energy E_{im} absorpted by each mass of each mode, Fig. 2, is obtained on distributing E_m among them in proportion to their energy or to the product of their maximum elongations by their maximum forces, Table I (c). The energy (E'_M) at each mass due to the simultaneous action of the three modes is supposed to be the square root of the sum of the square of the energy

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due to anyone of the modes, Table I (d). So, the energy acting at the top of the columns of the upper floor is $(E_M)_3 = (E'_M)_3$, at the top of the columns of the second floor is $(E_M)_2 = (E'_M)_3 + (E'_M)_2$, at the top of the columns of the first floor is $(E_M)_1 = (E'_M)_3 + (E'_M)_2 + (E'_M)_1$, as shown in Table II (a) and (b).

BEHAVIOUR OF THE COLUMNS

It has been supposed that the yield point of the steel is 2800 kg/cm2, less an allowance of 800 kg/cm2 for load thrust. Supposing bilineal elasto-perfect plastic behaviour of the steel, the energy absorption capacity that must have the columns to resist the lateral seismic action is $(E_M)_i = k\,\Delta_y(\Delta_r - \Delta_y/2)$, in which Δ_y is the horizontal deflection of the columns at the yield point, Table II (d) and Δ_r the elastoplastic deflection due to $(E_M)_i$, Table II (e), deflection that must keep far from rupture. Its ratio to Δ_y appears in Table II (f).

THE ENERGY SPECTRA

The energy spectra of Fig. 3 (a) has been derived from the velocity spectra of the El Centro earthquake, 1940, (7) reduced in 2 per cent critical damping, plus detuning reduction that takes into account the changes of the proper periods of the structure, eluding resonance, in the plastic zone of the steel (8). A sole 10 per cent critical damping, $\mu = 4$, reduction in the same energy spectra, Fig.3 (b), shows rather less ordinates. The magnitude of these reductions, as well as the discrepancies with the elastic behaviour of structures, would be desirable to be investigated in the shaking tables existing in the american or japanese laboratories.

In order to facilitate the availability of energy spectras an inexpensive, self operating, intagrating displacement seismograph, as that of Fig. 5, may be used. This seismograph, already in use at the Faculty of Architecture of the University of Chile, records the maximum amplitude Δ in each of its 8 simple vibrators, of different proper periods, what permits one to draw the spectra values :

$$E_1 = 2\pi^2\, m\, \left(\frac{\Delta}{T}\right)^2 = 1/2\, S_v^2\, m$$

versus the period T, m being the mass of the vibrator.

DESTRUCTIVE POWER OR INTENSITY OF AN EARTHQUAKE

In the preceding study it appears that the possibility of destruction of the example structure here presented depends on the energy spectra ordinates of Fig. 3 (a). Hence, one may conclude that the area under the line of the spectra is the measure of the destructibility of the earthquake for structures in such conditions of damping and detuning. Generalizing, the area under an energy

spectra, with no damping at all, may be seen as the destructive power of that earthquake at the site, which means an instrumental measure of its intensity.

CONCLUSIONS

1. The energy treatment of the seismic response of structures may be based on the modal analysis.

2. The area under the energy spectra of an earthquake may be considered to be its destructive power or intensity at the site of observation.

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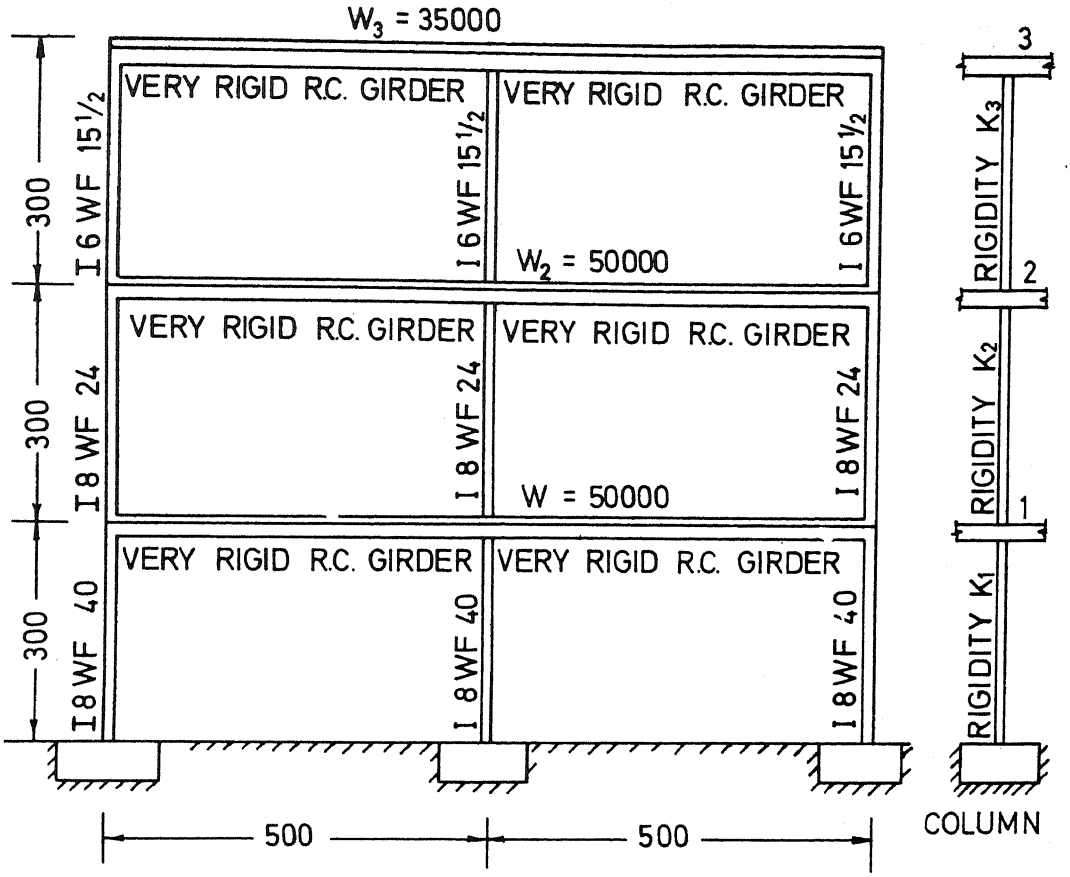


FIG.1.- EXAMPLE SPACE STRUCTURE

FLOORS: REINFORCED CONCRETE GIRDERS AND SLABS

COLUMNS: STRUCTURAL STEEL I WIDE FLANGE

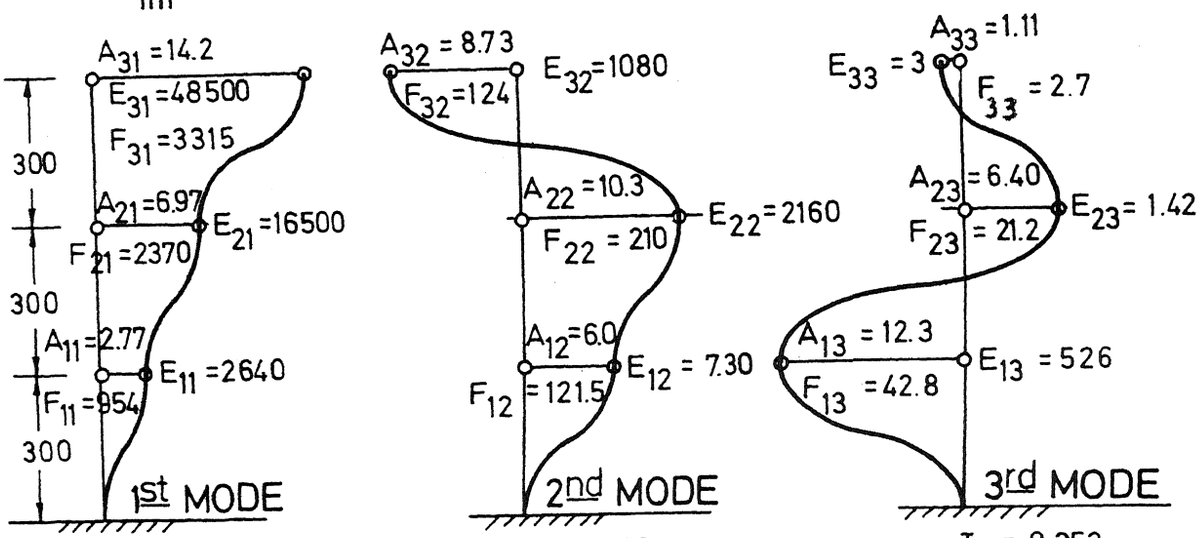
COLUMNS CHARACTERISTICS:				
COLUMN	DIMENTION	AREA	MOMENT OF INERTIA	MOMENT OF RESISTENCE
FLOOR	CMS	CM^2	CM^4	CM^3
FIRST	20.3 x 20.3	75.8	6100	582
SECOND	20.3 x 16.5	45.6	3410	340
THIRD	15.2 x 15.2	29.3	1170	159

ALL UNITIES IN THIS PAPER : CENTIMETERS, KILOGRAMS, SECONDS.

FIG. 2.- MODAL ANALYSIS OF THE STRUCTURE OF FIG. 1.-

A_{im} NORMALIZED RELATIVE AMPLITUDE AT MASS LEVEL

E_{im} ENERGY ABSORPTION BY EACH MASS, IN EACH MODE.



$T_1 = 0.913$ $T_2 = 0.443$ $T_3 = 0.252$

$M_1 = 99.2$ $M_2 = 27.0$ $M_3 = 11.4$

$E_1 = 67500$ $E_2 = 3970$ $E_3 = 672$

TABLE I.- FORMULAS

(A) PARTICIPANT MASS OF EACH MODE : $M_m = \dfrac{(\Sigma A_{im} \times W_i)^2}{\Sigma A_{im}^2 \times W_i}$

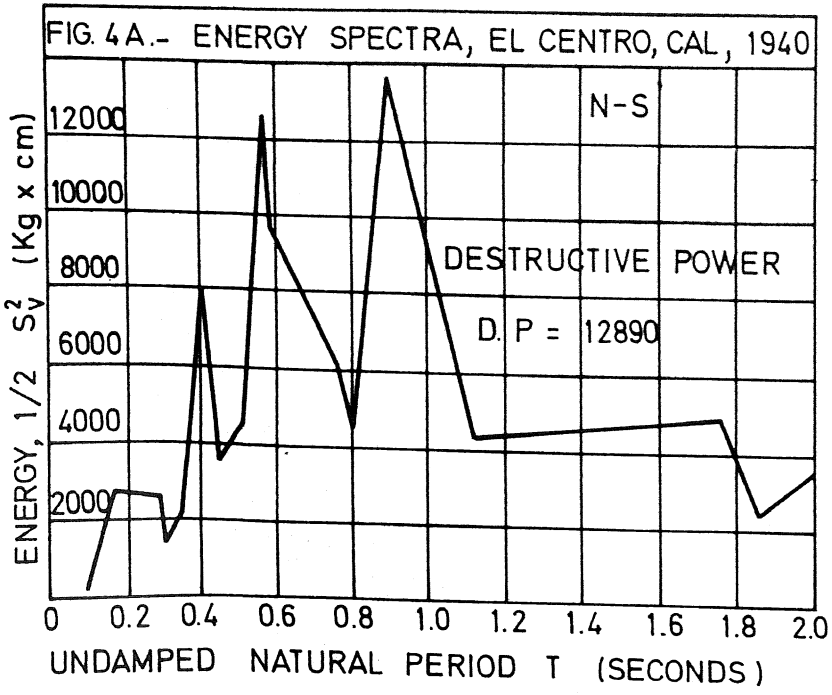
(B) ENERGY ABSORPTION BY EACH MODE : $E_m = {}^1/_2 S_{v,\lambda,d}^2 \times M_m$

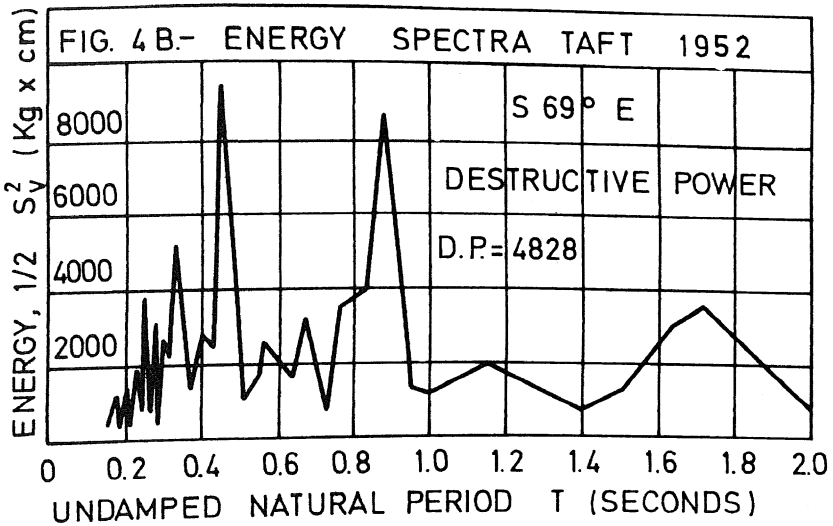
(C) DISTRIBUTION OF E_m AMONG EACH MASS OF THE MODE $E_{im} = \dfrac{A_{im}^2 \times W_i}{\Sigma A_{im} \times W_i} \times \alpha E_m$

(D) ENERGY FROM THE THREE MODES ABSORPTED BY EACH MASS: $E'_{Mi} = \sqrt{\Sigma E_{im}^2}$

$(E'_M)_1 = 2785$; $(E'_M)_2 = 16650$; $(E'_M)_3 = 48550$

TABLE II - ENERGY ABSORPTION	1st FLOOR	2nd FLOOR	3rd FLOOR
(A) ENERGY $(E'_M)_i$ ABSORPTED BY EACH MASS	2785	16650	48550
(B) " $(E_M)_i$ " " COLUMNS	67985	65200	48550
(C) ENERGY ABSORPTION, DUE, CAPACITY OF COLUMNS: $E_{Mi} = K\Delta_y (\Delta_r - \Delta_y/2)$			
(D) YIELD POINT DEFLECTION Δ_y OF COLUMNS	1.355	1.425	1.935
(E) ELASTO-PLASTIC DEFLECTION $\Delta_r = \frac{E_{Mi}}{K\Delta_Y} + \Delta_y/2$	3.610	5.470	8.597
(F) RATIO OF DEFLECTIONS: Δ_r / Δ_y	2.66	3.84	4.43





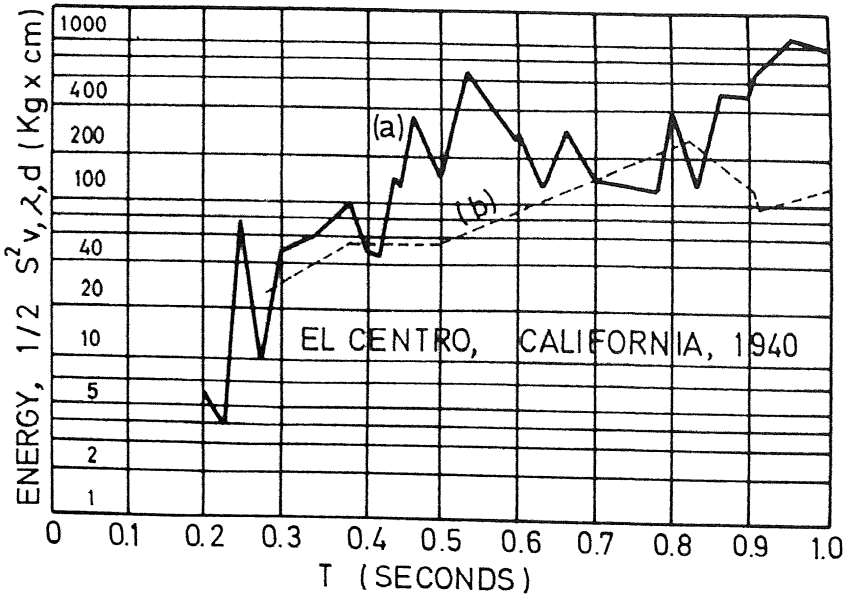


FIG. 3.- ENERGY SPECTRA EL CENTRO 1940
(a) CRITICAL DAMPING: 2% PLUS DETUNING REDUCTION (b) CRITICAL DAMPING: 10 %, $\mu = 4$

NOTE: COEFFICIENT α, IN LINE (C) OF TABLE I, ADJUSTS THE RELATIVE VALUES OF E_{im} TO ITS REAL VALUE, SO THAT $\Sigma E_{im} = E_m$

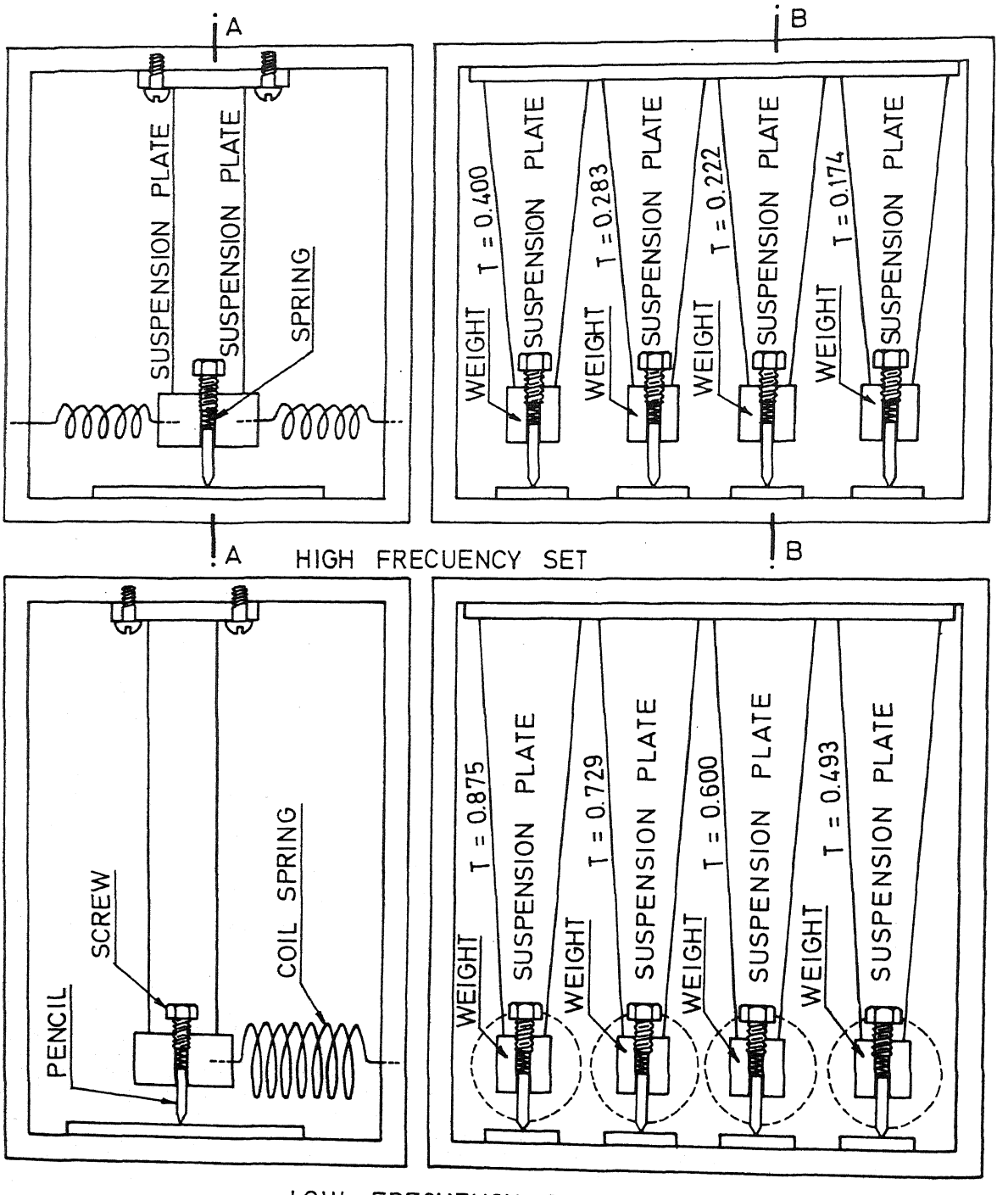



FIG 5 - INTEGRATING DISPLACEMENT SEISMOGRAPH INCLUDING 8 SIMPLE ELASTIC VIBRATORS OF DIFFERENT SELF-VIBRATION PERIODS T, AND MAXIMUM AMPLITUDE, Δ, RECORDING DEVICE. ENERGY : $E = 1/2\ S_V^2 = 2\pi^2 \left(\frac{\Delta}{T}\right)^2$