A MODAL, ENERGY RESERVE METHOD, OF CALCULATION FOR EARTHQUAKE-PROOF STRUCTURES

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Synopsis

The energy reserve method, based on the modal analysis (1) applied to a reinforced concrete structure is presented, in which the ductility of each member resulted defined. The exiting motion is the El Centro earthquake, California, 1940, N-S component, with 10 % critical damping and ductility factor 2.

An example demonstrates that the method does not need to add empiric reduction factors to the instrumentally obtained data, as conventional maximum force method does. The process is entirely analytic.

Glossary of Terms

A normalized maximum semi-amplitude of vibration

E energy

F force

i subindex indicating number of order of the floor

I moment of inertia of columns; I′ moment of inertia of girders

m subindex indicating number of order of the mode; participant mass

P participant weight

T vibration period

W weight

μ ductility factor

β per cent of critical damping

Introduction

The condition for a structure to be collapsed by an earthquake is that the seismic lateral forces move against the resisting forces of the structure as much as necessary for causing that the strains in their members surpass the elastic limit and the plastic zone of their stress-strain diagram. Consequently, the knowledge of the sole seismic forces does not define the destructive effect of the seism if the extent of their movements are not known. It is the product of the forces by their displacements or, what is the same, the work realized by such seismic forces or, the energy transferred to the structure, what entirely defines the destructive effect of a seism.

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The energy reserve method here presented is a step ahead in the conventional modal dynamic method. In fact, as the modal analysis defines the relative maximum seismic forces and displacements of the masses of a structure in each mode, their products define their maximum relative energy and, by means of the energy spectrum of a selected earthquake, the absolute energy transferred to the members of the structure by the seism is also defined.

Seismic Behaviour of a Structure

The example structure of Fig. 1, with 10 % of critical damping and ductility factor 2 is supposed to be subjected to a seism similar to that of the El Centro earthquake, California, 1940, N-S component. The acceleration spectrum and the energy spectrum for this earthquake are shown (2) in Fig. 2. The machanic characteristics of the structure are indicated in Fig. 1. The normalized, extreme mode form, vibration periods and participant masses are indicated in Fig 3.

The maximum shearing forces at the base, according to the acceleration spectrum are indicated in column 8 of Table I. For comparison purpose, in column 9 of Table I, the SEAOC code maxima are indicated. In column 11 the quotient of forces of columns 9 and 8 is shown, being the said quotient approximatively 0,38. This value is the empiric factor adopted in the code to conciliate the calculation with the supposed actual seismic behaviour of the structure in this case.

The shearing forces and bending moments in the columns, for SEAOC code computation, as well as for acceleration spectrum computation, are shown in Fig. 4.

As may be seen forward, the empiric factor disappears in the modal energy analysis here presented, as follows:

The modal energy transferred from the ground to the structure is, obviously, the product of the participant mass of the mode by the ordinate of the energy spectrum corresponding to the period of that mode, as indicated in column 10 of Table I. The distribution of the modal energy among the different masses or floors of the mode is given by the formula:

$$E_{im} = \frac{A_{im}^2 \cdot W_i}{\sum A_{im}^2 \cdot W_i} \cdot E_m$$

being $E_{11} = 2640$; $E_{21} = 10200$; $E_{12} = 364$; $E_{22} = 94$

The combined energy of both modes at each floor may be supposed to be the square root of the sum of the square of the modal energy of the two modes what means that $E_I' = 2660$ kg.cm. in the first floor and $E_{II}' = 10200$ kg.cm. in the second floor, the total energy per floor resulting, approximatively: $E_{II} = 10200$ kg.cm. and $E_I = 12860$ kg.cm., for the second and first floors respectively. The distribution of these energies among the columns, in proportion of their rigidities, is shown in Fig. 5.

The treatment of these energies at each column by the limit design technics (3) and (4), permits one to know their elasto-plastic behaviour, as shown in Fig. 6 for column 0-2, in which the ductility factor is μ = 1,72, as may be seen in the figure. In the same way the ductility factor of all columns appear in Fig 5.

Conclusions

By means of the modal analysis and the reserve energy method, here presented, the energy transferred to each member of a structure, during an earthquake, may be calculated.

In a reinforced concrete structure, as well as in a steel one, the modal analysis energy reserve method and the limit design technics permit one, from the instrumentelly obtained data, directly calculate the ductil behaviour of each member of a structure, no empiric reduction factors being necessary.

Bibliography

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All values in: kg, cm and sec.

Fig. 1

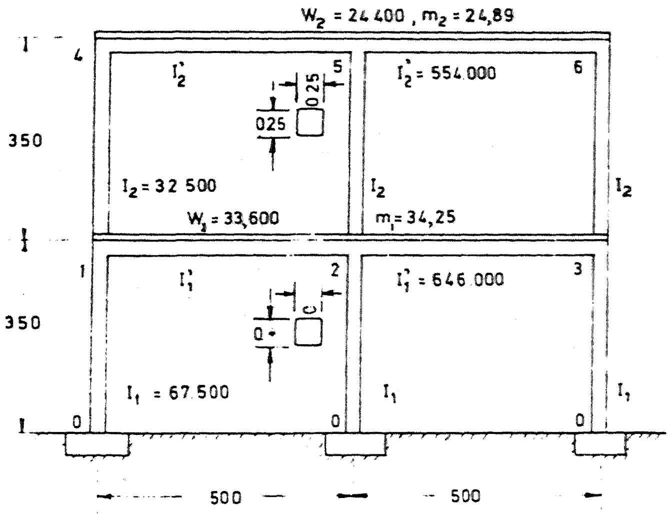
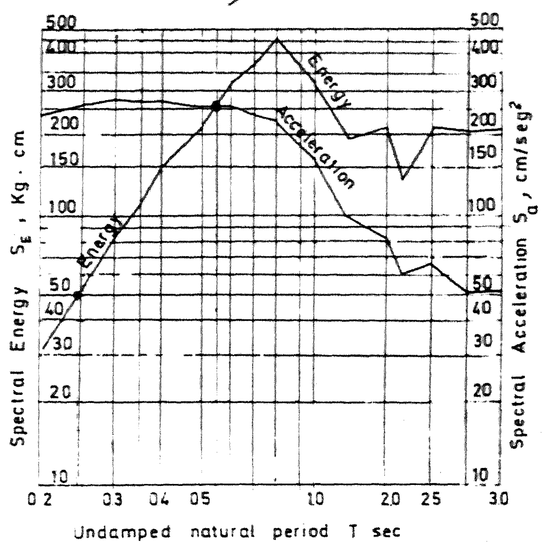


Fig 2

El Centro Earthquake, California, 1940

β = 10 %, μ = 2



1 Mode	1	2
2 Modal Vibration Period	0,537	0,247
3 El Centr spectral acceleration β = 0,10; μ = 2	0,264	0,261
4 Seismic Coefficient SEAOC code	0,1	0,1
5 Spectral Energy for the unity of mass	255	52,5
6 Participant weight	49 400	8550
7 Participant mass	50,3	8,73
8 Base shearing Force (Spectrum)	13 050	2230
9 Base shearing Force SEAOC code	4 940	855
10 Energy	12 820	458
11 Empiric Factor of Reduction	0,377	0,382

Table 1 - Base shearing Force and Energy

Fig 5

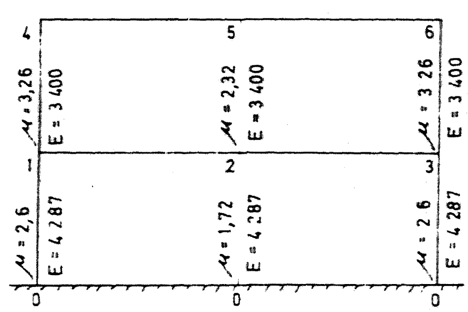


Fig 3

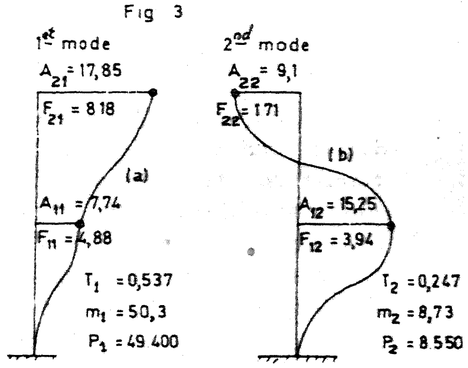
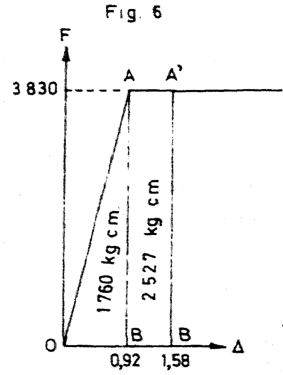


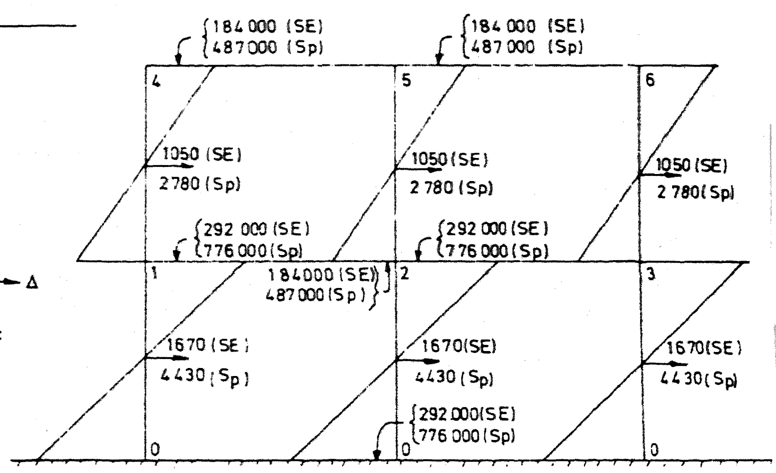
Fig. 6



elasto - plastic behavior of column 0-2

μ = 1,72

Fig 4



Shearing force and bending moment Sp (Spectrum), SE (code)