ADVÁNTAGE OF THE ENERGY INSTEAD OF THE FORCE IN THE TREATMENT OF EARTHQUAKE ENGINEERING PROBLEMS

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SUMMARY

An energy approach to the problem of the seismic response of a space frame structure is presented here, by incorporating into the criteria of calculation the acceptance of occasional incursions of the stresses into the plastic zone of the materials, all their safe elasto-plastic capacity for absorbing energy being used, a very important saving of materials being obtainable.

INTRODUCTION

Taking into account: First, that during an earthquake the structures, that do not collapse, deflect till reaching a maximum or extreme position; Second, that in earthquake-proof structure calculation: "For the degree of accuracy required for this problem it is generally feasible to use static force-deflection data as a basis to plot the force-deflection diagram without alteration for dynamic condition" (1), the following statement may be done: The best design of an earthquake resisting space-frame structure is that in which, during the strongest future seism in the site, the resisting members, columns or beams, deflect elastically or elasto-plastically as much as necessary for safely absorbing the energy received from the ground.

In Fig. 1 the sketch of a space frame structure, in reinforced concrete is shown. In Fig. 2 the force-deflection diagram of a resisting member of the structure, of bi-lineal behaviour, is shown. In this diagram the seismic force, during the maximum deflection wave of the member is permited not only to reach the working stress F_s of the material, as the conventional calculation method does, but to surpass the working stress, surpass the elastic limit F_y of the member and go on acting along the line A C till reaching a "safe" deflection point B, being the area under the force-deflection curve the energy received by the member from the ground.

EXAMPLE

In the structure of Fig. 1 the columns are so dimensioned that in extreme deflection, plastic hinges develop at both ends of the columns, the beams keeping up within the elastic range. The mechanical equivalent lineal model of the structure is shown in Fig.3, in which k is the rigidity, P the weight and m the mass. The three normalized vibration modes appear in Fig.4, (a), (b) and (c), where A is the maximum amplitude. In Fig.5 the energy spectra of the El Centro, California earthquake, 1940, N-S component, with 10 % of critical damping and ductility factor $\mu = 4$, (1) is shown. Table I shows: 1) the modes; 2) the vibration periods T_m of the three modes; 3) the ordinates of the velocity spectra of the referred El Centro earthquake for the corresponding modal periods; 4) the ordinates of the acceleration spectra for the same periods; 5) the ordinates of the

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energy spectra for the same periods; 6) the seismic coefficients for the same periods; 7) the participant weight of half structure of Fig 1, for each mode; 8) the base shearing force in half structure of Fig 1; 9) the participant mass of half structure of Fig 1; 10) the maximum instantaneous energy absorbed by the mass of half structure, in each mode. This energy was distributed among the three stories, in proportion to their self vibration energies according to the formulae :

$$E_{im} = \frac{A_{im}^2 \cdot P_i}{A_{im}^2 \cdot P_i}$$

In each story the three modal energies were added probabilistically, so attaining the own vibration energy of each story. The total energy affecting each story being, approximatively, its own energy plus the energy of the upper stories. These total energies, distributed among the columns and beams of the corresponding story, according to their rigidity, is indicated in Fig 6, left side and beams.
Conservatively, the energy absorbed by the beams was not discounted from the energy absorbed by the columns. The effect of the absorption of this energy by the columns was analyzed (2) resulting the ductility factors μ indicated in Fig 6, right side and the longitudinal steel reinforcement of columns indicated in Fig 1, left side.

In the method of force the base shearing force Q_o (column 8 of Table I) produces shearing forces q in the columns as indicated in Fig 6. The effect of these shearing forces was analyzed, resulting the steel reinforcement indicated in Fig 1, right side.

CONCLUSIONS

1.- The energy treatment of some earthquake engineering problems, as space frame structures, for instance, may convey to economical results due to the plain utilization of the ductility of the materials.

2.- The knowledge of the maximum ductility factors developed at the resistant members of the structure, in the energy method, is a factor of confidence on the seismic behaviour of the structures.

3.- The absence of empirical factors in the seismic analysis of the structures, based on energy, may be seen as a technical improvement.

REFERENCES

1.- Blume, Newmark, Corning, "Design of Multistory Reinforced Concrete Buildings for Earthquake Motions", Published by Portland Cement Association, 1967, Pg. 91; Pg. 13, Fig 1-9.

2.- Ibañez, J., "Destructive Power of Earthquakes", Fifth World Conference on Earthquake Engineering, 1973, Session 5 A, Nr. 213.

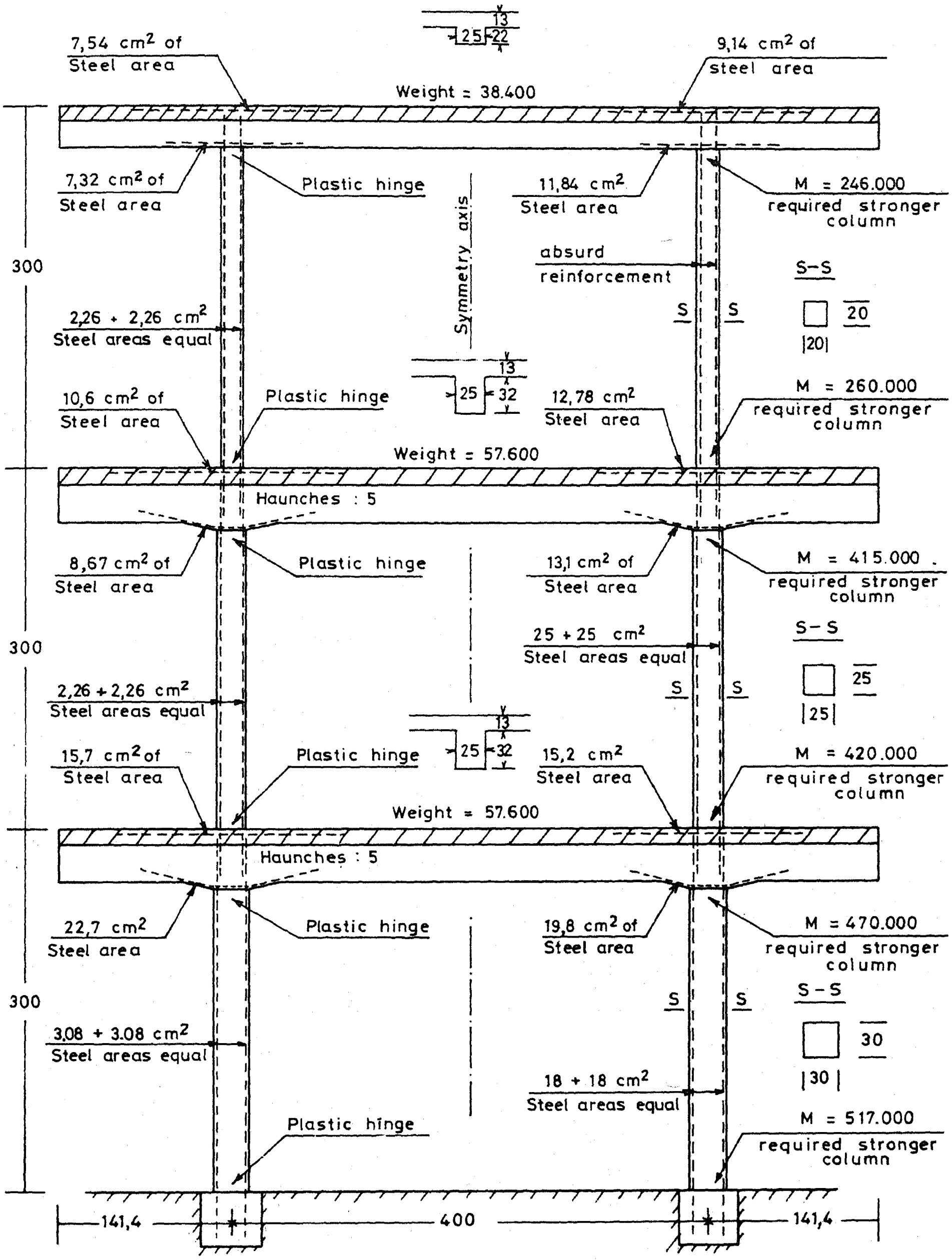


Fig. 1.- Left side was treated by the energy method. Right side was treated by the force method in which steel reinforcement results exaggerated in 1st and 2nd story; in 3rd story is absurd. Adopting the force method a stronger structure had been required, due to the lack of use of the structure ductility.

Base of calculation : $f_c = 84.4$ Kg/cm² ; $f_s = 2110$ Kg/cm² ; n = 12

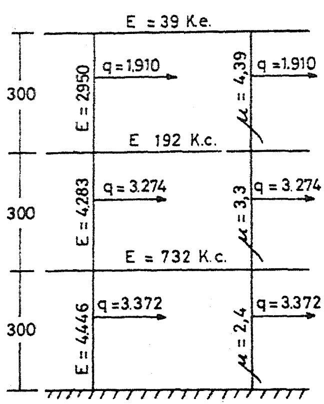


Fig.6.- Energy and Shearing Force

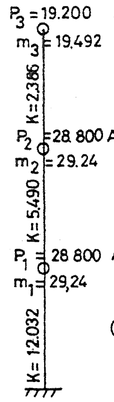


Fig.3.-

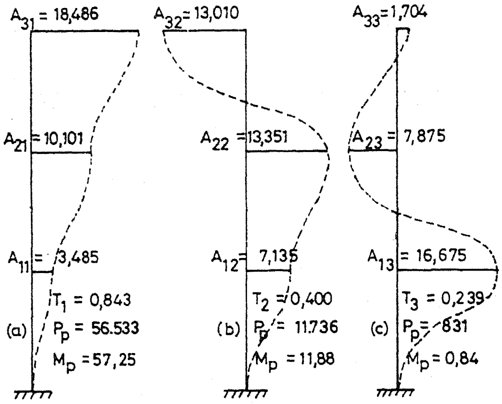
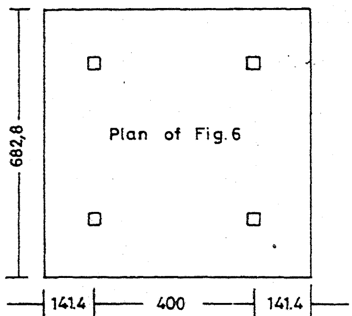


Fig. 4.- Extreme deflection of structure in normalized three modes (a),(b) and (c) A = maximum instantaneous amplitude.



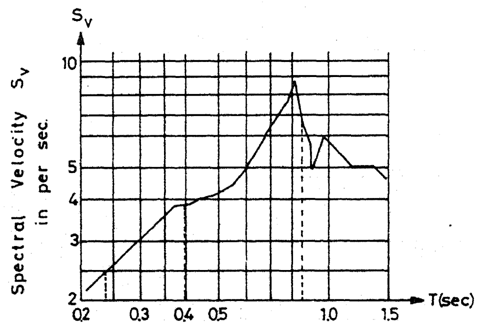


Fig. 5.- Response spectra for elasto-plastic systems with 10 % critical damping, $\mu = 4.(1)$

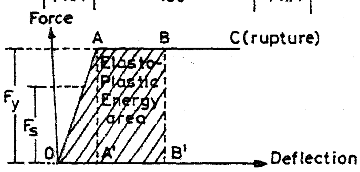


Fig.- 2

All Unities : cm , kg , sec , kg.mass

TABLE 1.-

1	2	3	4	5	6	7	8	9	10
Modes	Vibration period Tm of the modes Seconds	Velocity Spectra ordinates for Tm S_v (See Reference 1)	Acceleration Spectra ordinates for Tm $S_a = \frac{2\pi}{Tm} \cdot S_v$	Energy Spectra ordinates for Tm $E_m = \frac{1}{2} S_v^2$	Seismic Coefficient for Tm $C = \frac{S_a}{g}$	Participant weight for each mode, P_p, for half structure.	Structure shearing force Q_o, in half structure. $Q_o = C \times P_p$	Participant mass of each mode, M_p, for half structure.	Energy absorbed in each mode, by one Kg.mass. $E_m = M_p \times S_E$
1	0,843	17,569	130,6	153,6	0,133	56.533	7.518,9	57,63	8.852
2	0,400	9,779	153,6	47,8	0,157	11.736	1.842,6	11,96	617
3	0,239	6,375	167,6	20,3	0,171	831	142,1	0,84	17