NON SYMMETRIC RESPONSE OF SYMMETRIC R/C STRUCTURES TO BIAXIAL SEISMIC INPUTS

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SUMMARY

The effects provided by the simultaneous action of the two horizontal components of a ground motion (2D motion) on R/C buildings are studied. A simple three-dimensional model in which the inelastic behaviour of the materials and the variation of the axial force produced in the columns by the structures shear type effect are taken into account.

INTRODUCTION

When severe earthquakes occur, the structures must be able to withstand displacements which greatly surpass the elastic limits of the materials. However, reliability against collapse lies in the residual resistances obtained after large seismic displacements. Consequently, it is important to examine to what extent the physical factors which are usually neglected in this field can modify the behaviour of simplified calculation models. Research carried out after San Fernando earthquake in 1971 highlighted the importance of the 2D motion (simultaneousness of the two horizontal components) for R/C structures with non-linear behaviour. Specially, the following consequences have been noted (3): - Plastic deformations requested by earthquakes are greater when a 2D analysis is carried out; - The 2D effect importance is greater for stiffer buildings ($T < 0.5$ sec); - Consequences are more important as the seismic intensity increases; - P-Δ effect increases the 2D effect.

THE PROBLEM STUDIED

All research carried out up to present time (1,3-7) examined single columns or simple three-dimensional model. The columns were taken to be subjected to alternate bending due to seismic actions, while the axial forces were maintained equal to the static effect of gravity (Symmetric-Model SM). In the present study, the 2D behaviour of the model in Fig.1 is examined, taking the variation of the axial forces derived from the shear type behaviour (Non-Symmetric-Model NSM) into account. First of all, this effect was considered only marginally (1,4). In fact, variation of axial forces, whose importance must be examined, produces the following consequences:

1) - The stiffness of the columns varies at every instant. This fact may modify the translational seismic responses.
2) - Variations in rigidity modifies the position of the torsional centre of the system. Torsional oscillations may arise even in buildings which are constructionally symmetric.
3) - A repeated higher intensity reached by the axial forces can cause a more rapid decay of the mechanical response of the columns.

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THE MATEMATIC MODEL

Since numerical development in exceedingly complex, the models must be simplified. The structure shown in Fig.1 is examined from the point of view of shear type behaviour (stiff perimetral beams). The columns have a circular section (Ø = 50 cm) and are reinforced with 8 bars Ø = 22 mm (1.5%). The mass supported is M = 283 t, which corresponds to a compressive stress in the columns of 3.2 N/mm^2. The elastic natural period is nearly T = 0.26 sec. In this way the model approximately simulates the behaviour of a shear type building with a soft first storey. In order to study tha behaviour of structures set mostly under inelastic effect, it is considered that each column can be bent only in extreme zones (plastic hinges) of a particular height (Fig.2). This simplification enables a fairly realistic calculation of the ratio between shifting and bending to be made.

Tha calculation procedure is similar to that already used by other writers(1,3,7). It subdivides the section of each column into elements (Fig.3). The behaviour shown in Fig.4, which arises from a polygonal simplification of the actual behaviour diagrams and which disregards the tensile resistance, is attibuted to the concrete. For the steel reinforcement, hysteretic elasto-plastic hardening behaviour is taken into account (Fig.5). The equations of the motion (two translational and one torsional) are integrated using a step-by-step procedure, based on the two-dimensional accelerations attributed to the basement. By means of successive iteractions, the equilibrium of the sections at each step is calculated in relation to the shifting and to the previously known axial forces. In this way, the shear forces with which the columns react is evaluated. The values depend from the stress condition of the section and from previous displacements history. Two limit states steps was checked: - CF (Concrete Failure) = crushing of all concrete elements; - SF (Steel Failure) = collapse of the reinforcement caused by excessive deformations. The P-Δ effect was disregarded.

EARTHQUAKE RESPONSE OF THE NON-SYMMETRIC-MODEL

The NSM was subjected to the two horizontal components of the accelerograms of El Centro 1940, Taft 1952 and Pacoima Dam 1971. Four levels of seismic intensity (I-IV) were considered and the accelerations were multiplied by the following coefficients: El Centro = .5/1/2/3, Taft = 1/2/4/6, Pacioma Dam = .167/.333/.667/1. The values taken correspond approximately to the Housner's intensity for the three earthquakes (6) and to a later intermediate one. The results were compared with those obtained with similar SM, in which the axial forces in the columns were maintained constant. The main results of the calculations are as follows:

1) - The shear forces in the columns of the NSM differ only slightly from those of the SM. Neverthless, since the sum of the four axial forces must remain constant, the variations are balanced and their total translational rigidities do not differ very much (1). However, the translational shifting is almost the same in both models.
2) - The torsional oscillations of the NSM are present, but the values are not particularly high, except when limit states are approached. The increases in column displacements are less than 12% of the maximum translational values.
3) - On the other hand, the effect produced by the greater mechanical decay of the columns is more important. The most significant result concerns

intensity III (Taft and Pacoima Dam). In the NSM, the structure collapse after approximately 3.5 sec. This phenomenon is not confirmed in the SM. Even in the cases when both NSM and SM collapse, the second collapses after a longer period of time (almost double).

4) - The biaxial motion produces a further effect, which also occurs in the SM, caused by the non-linear behaviour of the materials. In fact, the directions of the shear forces in each column do not correspond to the displacements. This give rise to torsion. Nearly the collapse conditions, the calculated torsional moments produce considerable tangential stresses, in excess of 1 N/mm^2 (refered to the confined section).

Finally, once again (2,8,9) the mechanical decay plays an important role in the evaluation of the collapse conditions under repeated loading. In order to better illustrate point 3), the "Residual Shortening" is worked out at each step of the calculation. This is the hypothetical shortening of the central filament of the section, calculated with equal axial force and supposing that the rectilinear shape will return, i.e. that curvatures will be nil. This shortening was previously suggested (8,9) as the element which characterizes the decay of columns. In Fig.6 and 7 the values of the "Residual Shortening" in columns are shown for two examples of intensity values (III and IV). The axial forces present in the same columns are also shown. Comparison of the NSM and SM values show that this parameter may be taken as an indication of progressive decay. The effect of the variation of the axial forces seem obvious.

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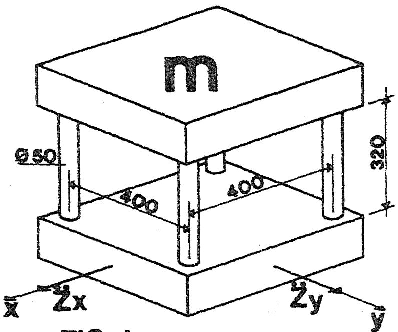


FIG. 1

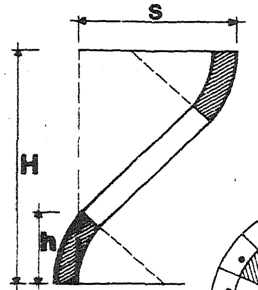
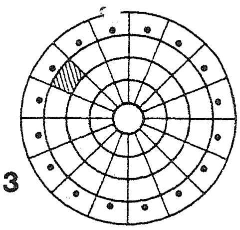


FIG. 2



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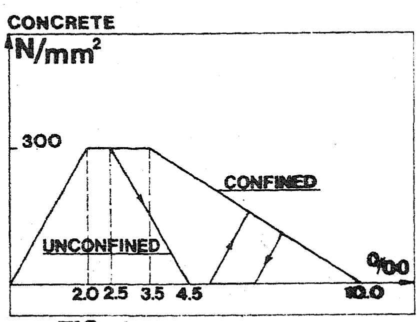

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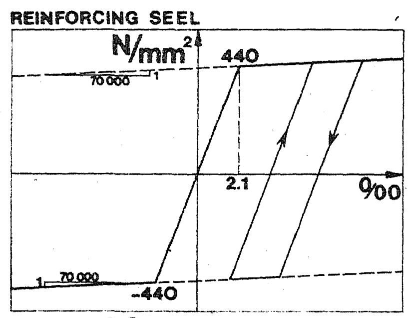

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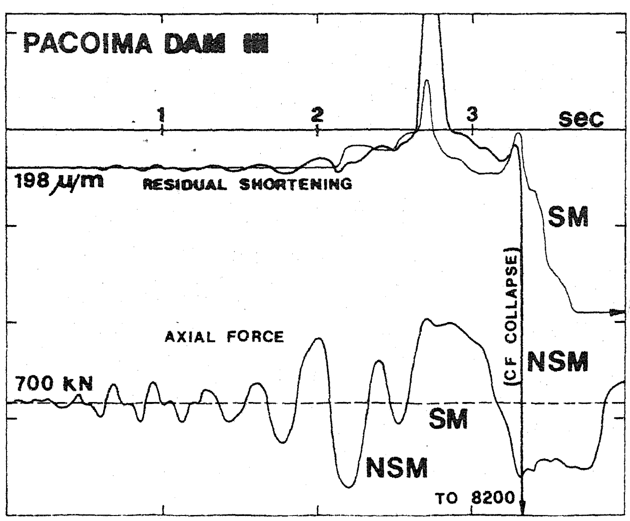

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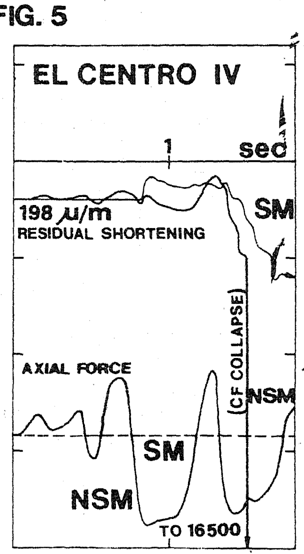

FIG. 7