Prepared Discussion : Session 1 A on papers Nos. 4 and 6

EARTHQUAKE DAMAGE OF REINFORCED CONCRETE BUILDINGS

by

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Several papers are presented on the damage of reinforced concrete buildings through the 1971 San Fernando earthquake in order to make clear the causes of damage and to establish a new design principle. Chopra, Bertero and Mahin [1)] discussed on the "Response of the Olive View Medical Center Main Building during the San Fernando Earthquake". This paper implies the exixtence of the limitation of the conventional analytical approach to establish an aseismic design principle of reinforced concrete buildings. Bertero, Bresler, Selna, Chopra and Koretsky [2)] discussed on the "Design Implications of Damage Observed in the Olive View Medical Center Buildings". This paper indicates many important problems but little practical means to establish an aseismic design principle of reinforced concrete buildings.

In this prepared discussion it is discussed here the causes of these earthquake damages on our researchs based upon the deformation characteristics of reinforced concrete resisting elements. The most rational and effective means are to consider a reinforced concrete building to be composed of several basic aseismic elements, i.e., shear walls, short columns and long columns. Shear walls and short columns show typical explosive cleavage shear failure without ductility and on the contrary long columns show typical flexural yielding with few or sufficient ductility.

If a building is composed of predominant shear failure type elements, it should resist against earthquakes through their shear resisting capacity. On the other hand if a building is composed of predominant flexural yielding type elements, it should resist through their hysteretic damping capacity.

Fig. 1 [3)] shows the various aseismic characteristics of a reinforced concrete building, which is composed of α-pieces of long column units, β-pieces of short column units and γ-pieces of shear wall units. When the composition of a building belongs to the shear failure mode, and the base shear coefficient is assumed to be 1,0, the critical number of stories or the necessary wall ratios are able to be given from this figure according to the composition of α, β and γ ,

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Fig. 2 [6] shows that the maximum response acceleration decrease with the increase of damping coefficient, and the hyperbolic line ($\beta = \frac{1}{2h}$) is able to be given at the steady-state resonance. From these figures, it can be suggested that, as for a composition of a building with predominant flexural yielding type elements, the base shear coefficient can be decreased hyperbolically with the increase of the equivalent viscos damping coefficient of their elements.

Fig. 3 [4),5)] shows the experimental relationships between the deflection amplitudes and the number of cycles until fracture of reinforced concrete flexural members under the action of constant axial loads. We should be carefull not only of hysteresis loops but also of critical deflection amplitudes of reinforced concrete flexural members.

On the bases of the shear resisting capacity of shear failure type members and of the hysteresis loops and low cycle fatigue limits of flexural yielding type members, the most rational new aseismic design method is able to be now established, especially for public and important buildings.

BIBLIOGRAPHIES

1) Chopra, A. K., Bertero, V. V. and Mahin, S. A. : Response of the Olive View Medical Center Main Building during the San Fernando Earthquake, Proc., 5 WCEE, Rome, June 1973, Vol.I, Seesion 1A, No.4.
2) Bertero, V. V., Bresler, B., Selna, L. G., Chopra, A. K., and Koretsky, A. V. : Design Implications of Damage Observed in the Olive View Medical Center Buildings, Proc., 5 WCEE, Rome, June 1973, Vol. I, Session 1A, No.6.
3) Yamada, M. and Kawamura, H. : Fundamental New Aseismic Design of Reinforced Concrete Buildings, based upon the Combined Deformation Characteristics of Various Aseismic Elements in Structures, Proc., 5 WCEE, Rome, June 1973, Vol. II, Session 3A, No.102.
4) Yamada, M.,Kawamura, H. and Furui, S. : Low Cycle Fatigue of Reinforced Concrete Columns, Int. Report, International Symposium on the Effects of Repeated Loadings of Materials and Structural Elements,Vol.VI RILEM, Mexico, Sep. 1966, pp. 1-13.
5) Yamada, M., and Yagi, S. : Shear Explosion of Reinforced Concrete Short Columns, Proc., 5 WCEE, Rome, June 1973, Vol. I, Session 2D, No.90
6) Takata, T., Okubo, T., and Kuribayashi, : Studies on Earthquake Resistant Design of Buildings, Part I, -- Earthquake Response Spectra, 1964 -- Report of the Public Works Research Institute, Ministry of Construction, Japan, Vol. 128. Apr. 1966, pp.1-51.

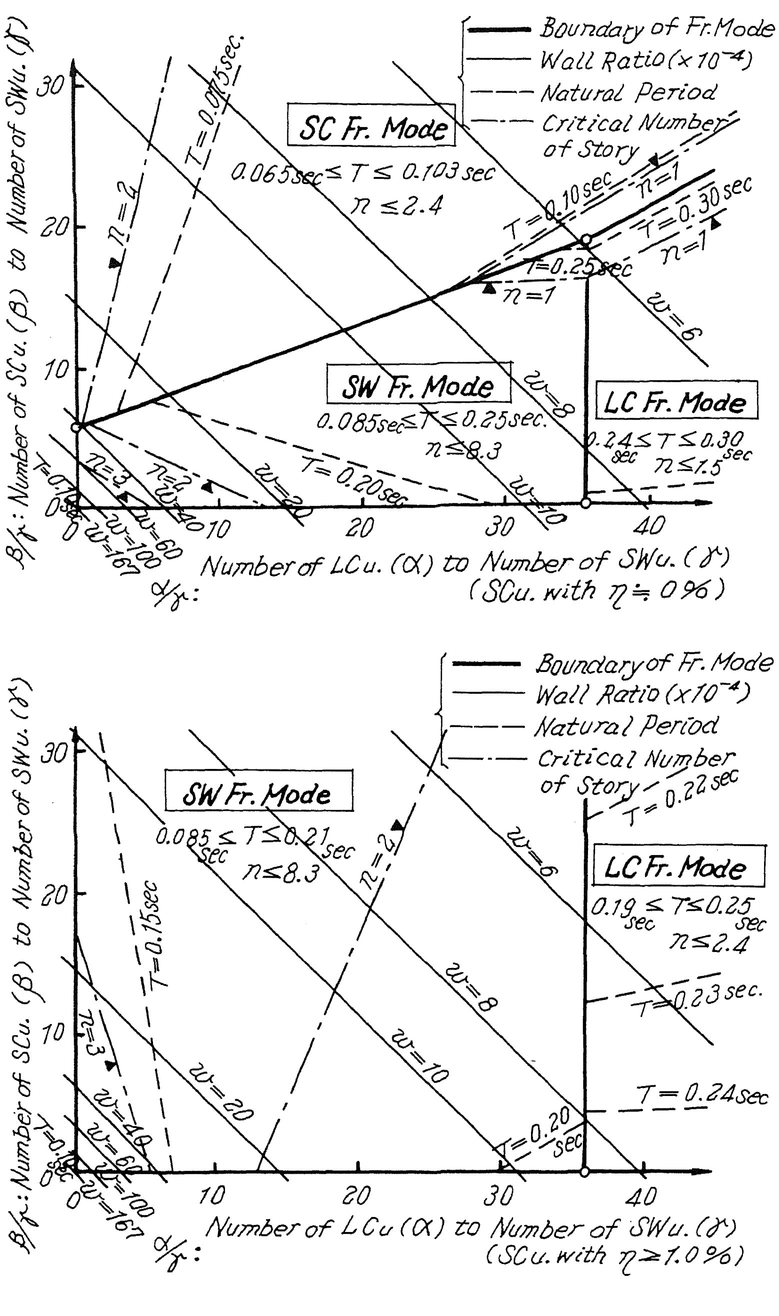

Fig. 1 Fracture Modes, Wall Ratio, Natural Period, and Critical Number of Story in the Combination of α, β and γ Pieces of LCu., SCu. and SWu.

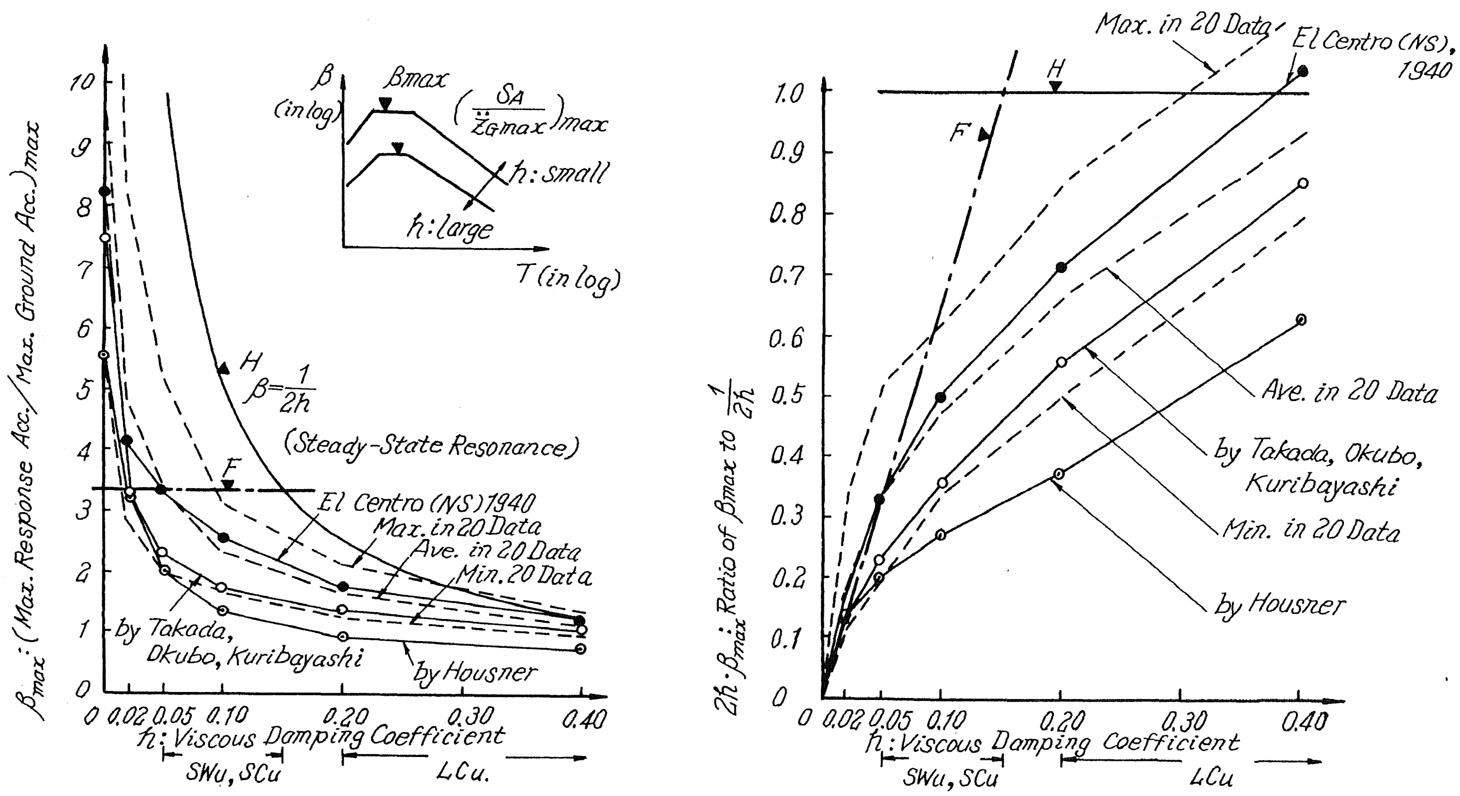

Fig. 2 Tendency of Max. Response Acc. in the Abscissa of

Viscous Damping Coefficient

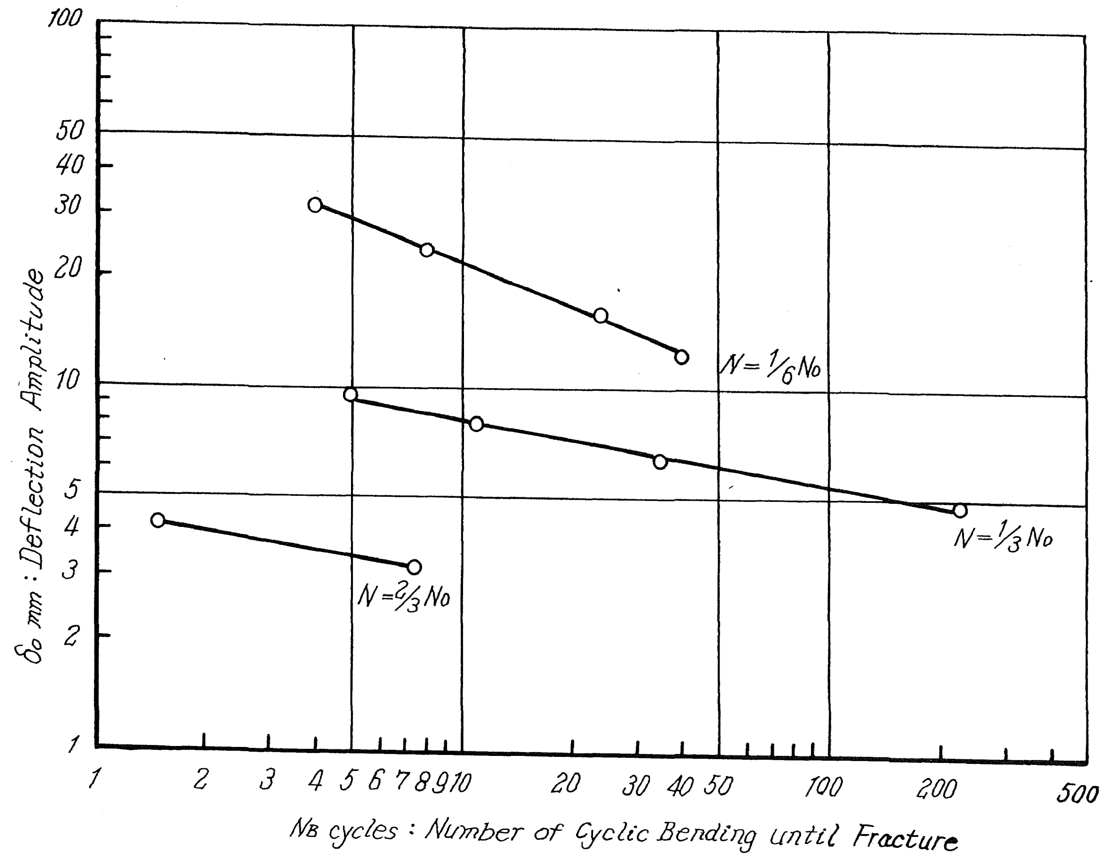

Fig. 3 Relationships between Deflection Amplitude and Number of Cyclic Bending until Fracture

DISCUSSION ON PAPER NO. 4*

H. Aoyama: The Wing D, adopted in the analysis, vibrates in the transverse direction of the structure, when it is subjected to ground excitation in north-south direction. Although the elastic behavior of a wing in the transverse direction and in the longitudinal direction may not be quite different, the inelastic behavior may be significantly different due to the presence of beams in the longitudinal direction. What is the opinion of authors in this regard?

Authors: The inelastic analyses presented in the paper were for response of Wing D in the lateral (north-south) direction. The inelastic behavior of Wing D in the longitudinal direction could possibly be significantly different. Definite statements will have to await analysis of inelastic response in this direction.

H. Aoyama: Although many cracks were seen in the flat slabs indicating yielding of slab reinforcement, I think there were little symptom of premature shear failure of flat slabs. Could they fail in shear?

Authors: As it is illustrated in Fig. 11 of paper No. 6,"Design Implications of Damage Observed in the Olive View Medical Center Buildings", very large upheaval of the floor slabs around columns, specially in the first floor, has been clearly observed. This upheaval was produced by the shear failure that occurred in the drop-panels due to inadequate capacity to resist the shear resulting from the moment transfer between the slab and the column.

M. Yamada and H. Kawamura: Refer to prepared discussion "Earthquake Damage of Reinforced Concrete Buildings".

Authors: The discussion refers to the general problem of earthquake resistant design of reinforced concrete buildings. The only part specifically pertinent to Paper No. 4 is the statement: "This paper implies the existence of the limitation of the conventional analytical approach to establish an aseismic design principle of reinforced concrete buildings".

The main building of the Olive View Medical Center was severely damaged, although it was much stronger than intended by the Uniform Building Code (U.S.A.), primarily because the ground motion was rather severe and the "soft" lower two stories were called upon to absorb almost all the energy thus undergoing very large inelastic deformations. These extremely large ductility requirements in the elements of the first two stories had apparently not been anticipated. This deficiency in the design could have been foreseen with the aid of dynamic analysis of the kind presented in the paper. Any other approach which can achieve the same end result could be used instead of dynamic analysis. There is no implication to the contrary in the paper.

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*"Response of the Olive View Medical Center Main Building During the San Fernando Earthquake", by A. K. Chopra, V. V. Bertero and S. A. Mahin