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MODELING OF SHEAR MECHANISM IN RC STRUCTURAL WALLS UNDER SEISMIC LOADING

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SUMMARY

Modeling of the shear mechanism in reinforced concrete (R.C.) structural walls in frame-wall and coupled wall structures under lateral loads and/or seismic motion is presented. The shear idealization is developed for the three behavior states of R.C. defined as; uncracked, cracked, and yielding. The model is based on a proposed variation of shear modulus along the wall cross-section depth. Inelastic shear behavior of the wall is simulated using a set of hysteresis rules. The structural wall elements are idealized using the "Five Variable-Length Subelement Model." Analytical responses are compared with test results of the 1/5 Scale Model 7-Story RC frame-wall structure tested at the University of California.

INTRODUCTION

The nonlinear response of reinforced concrete frame-wall structures under seismic motion has been the subject of extensive experimental and analytical research since the 1960's (Refs. 1,5,8). Recent experimental research on full- and large-scale test structures with structural walls under quasi-static cyclic lateral loading and simulated seismic motion has indicated that the current analytical models are not capable of describing the seismic and cyclic response accurately (Refs. 2,3). Studies have also indicated that improper idealization of shear behavior in wall elements is one of the primary reasons for the poor correlation between the predicted and experimental responses.

The shear model for the R.C. wall element described in this study retains the line element idealization for case in computer implementation, yet, incorporates the two dimensional character of the wall by developing a shear force deformation relationship independent of the flexural model. Modeling of shear behavior is developed for the three behavior states: uncracked, cracked, and yielding. The wall elements are modeled using the "Five Variable-Length Subelement Model." (Ref. 3).

The main goal of this study is to evaluate the shear design requirements of R.C. structural walls. The shear stiffness distribution along the cross section was developed from earlier experiments on wall portions (Ref. 4).

Element Idealization In the "Five Variable-Length Subelement Model," the element clear span consists of a maximum five subelements: an elastic central plus two cracking and yielding subelements at each end, as shown in Fig. 1. Inelastic actions are confined to the cracking and yielding zones.

The subelement lengths are determined at each load increment or time step based on current end moments and the corresponding cracking and yielding moment capacities. The cracking and yielding moment capacities are also determined at each time increment and includes the effect of axial force changes on the cross section. The length of the inelastic region at each end is nondecreasing.

The stiffness properties of each subelement are determined for flexural and shear independently. The inelastic flexural rigidity properties are calculated at the middle section of each subelement from the moment-curvature hysteresis relationship (Ref. 3). The shear rigidity properties of inelastic subelements are calculated from a shear force-shear deformation relationship. Shear force shear deformation model is derived based on an assumed shear modulus distribution along the R.C. wall cross-section. The assumed shear modulus distribution is primarily based on an earlier experimental investigation presented in (Ref. 4). A mathematical model for the variation of shear modulus along the wall cross-section is presented in the next section.

Mathematical Model for Shear During the response of an R.C. structural wall to static cyclic or seismic load, the shear mechanism has a significant effect on the structural response proportional to the aspect ratio of the wall element. An idealization of the shear modulus variation along the wall cross-section depth is formulated based on the following properties, which have been observed and reported in recent experimental research (Refs. 4,5): 1) Shear force is transferred across cracks by bearing and friction mechanisms. 2) Shear rigidity exhibited by the interface shear mechanism is inversely proportional to current cracking width. 3) Shear rigidity is directly proportional to normal stresses on the crack plane. 4) Cyclic shear rigidity in the cracking state decreases with increasing crack width and load amplitude as well as number of load applications. 5) A decrease in shear stiffness is associated with a decrease in normal stresses from a specific level (approximately 0.15 to 0.25 f'_c, where f'_c is the concrete compressive strength).

The shear modulus is calculated for the elastic or uncracked state and the inelastic states independently. In inelastic states (cracked and yielding) the shear modulus "G" is represented as a function of the coordinate "z" along the depth of the cross-section, as shown in Fig. 2. The shear rigidity "K_s" of an R.C. wall section of area "A" is evaluated from:

$$K_s = \int_A G(z)\, dA \qquad (1)$$

For the elastic or uncracked behavior state, equation 1 gives:

$$K_s = \gamma_f \; B_e \; H \; G_0 \qquad (2)$$

For inelastic behavior states, the shear rigidity K_s is:

$$K_s = \gamma_f \; B_e \; [G_1 Z_2/(\gamma+1) + Z_1(\gamma_1+\gamma_2)G_0/2 + \gamma G_0(\bar{Z}-Z_1)] \qquad (3)$$

where γ_f is the reduction factor for confinement, B_e is the effective shear width (equals (5/6)B for a rectangular cross section, B is the width of the web,

G_0 is the elastic or initial shear modulus, $\bar{z}$, z_1 and G_1 are as defined in Fig. 2, z_2 is the distance between the neutral axis to the steel fiber at yield strain (in strain-hardening subelements) and γ, γ_1 and γ_2 are the shear modulus reduction factors, which are different for the cracking and yielding states.

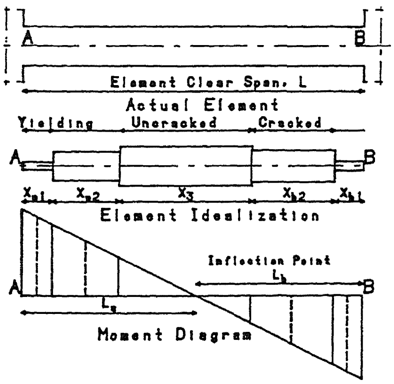

Fig. 1 Five variable length subelement model

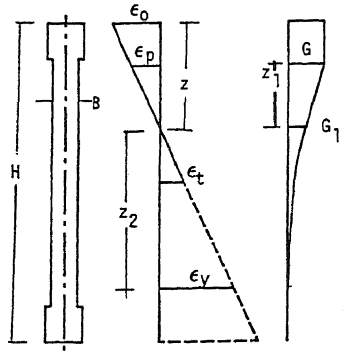

Fig. 2 Model for Shear Modulus variation.

The shear force-shear deformation relationship is obtained at the preanalysis stage for a progressively increasing moment. The change in moment is related to the incremental change in shear forces by a length factor representing the moment to shear ratio of the element. The shear force-shear deformation relationship is simplified to trilinear form to represent the three behavior states and is based on the following assumptions: 1) the behavior states are controlled by the flexural mechanism, and 2) the cross-sectional shear cracking and yielding capacities occur simultaneously with the corresponding flexural capacities.

The assumption given above imply that the cracking and yielding shear capacities will not remain constant for a given cross-section. Instead, the shear strength will be a function of the current moment-to-shear ratio. The current shear cracking and yielding capacities of the element cross-section are determined when the moment at the section exceeds the cracking or yielding moment capacities and are obtained from the current moment-to-shear ratio.

The hysteretic shear behavior is simulated for the inelastic subelements using a proposed set of hysteresis rules (Ref. 3) which are a modification of the Takeda type (Ref. 6).

<u>Numerical Example</u> The 1/5 Scale-Model Seven-Story RC Frame-Wall structure tested at the University of california at Berkeley (Refs. 7,8) is adopted for analytical comparisons under seismic motion. The geometry and properties of the structure and the experiment result were obtained from (Refs. 7,8). An assessment of the effect of the shear mechanism in the wall element at the first floor level on the static and seismic response is presented. In static analysis,load distribution is assumed to be in the first mode shape as the major contributor in the serviceability limit state. The static loads are applied cyclically to assess the hysteretic structural response.

The shear reduction parameters γ_1, γ_2 are taken as 0.4 and 0.2 respectively. Other parameters to represent the shear hysteresis are γ=3, G=1,400 Ksi and f'_c=5.7 Ksi.

The results of the analysis are presented in Figs. 3-7 . Fig. 3 shows the total base shear and wall base shear versus lateral displacement at the seventh floor level. After cracking, a drop in the stiffness associated with gradual degradation is observed. This is due to the propagation of cracking along the wall element. once the yielding initiates at the wall base, a dramatic increase in the lateral displacement is associated with increased load due to the significant loss of stiffness. It is important to note that the contribution of the wall to the total structural stiffness decreases gradually as the loading exceeds the yielding limit. In the unloading stage, the wall gains some of its lost stiffness until the unloading branch terminates. In inner loops, the contribution differs depending on the loading stage (pinching, loading after pinching, unloading and loading) and the number of cycles.

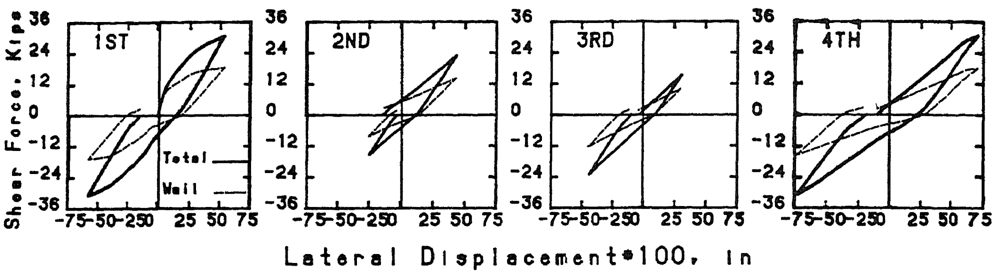

Fig. 3 Wall and Total Base Shear Under Cyclic Loading

The effect of the shear mechanism on wall stiffness is demonstrated by comparing flexural and shear displacement with total wall displacement at the first floor level with wall base shear as shown in Fig.4. From Fig. 4 it is apparent that: 1) before cracking, the shear deformation represents 50% of the total deformation, 2) the contribution of the shear deformation decreases gradually after cracking, and 3) in inner loops, this contribution increases until it reaches almost 50% of the total deformation. The decrease in the shear contribution after cracking is due to the increased contribution of the frame to total lateral stiffness. The increase moment frame to total stiffness after cracking and consequently the moment-to-shear ratio in the wall element increases. However, in inner loops, the wall starts to regain some of the lost stiffness.

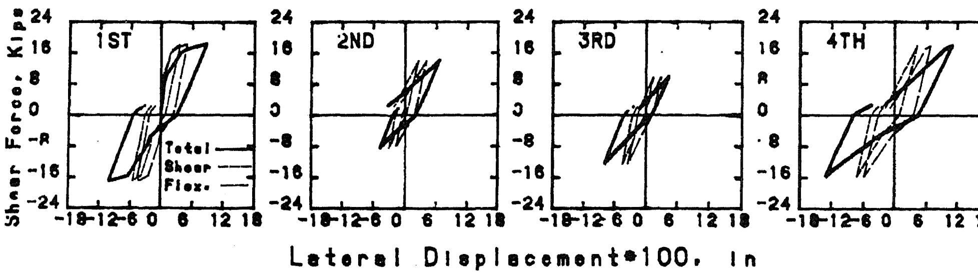

Fig.4. Comparison of Flexural and Shear Contribution to Wall Base Shear

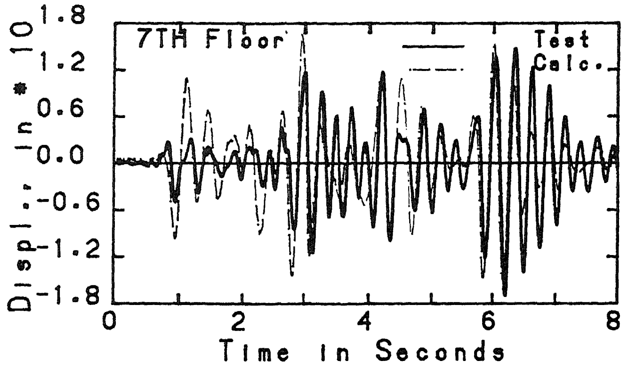

Fig. 5 Analytical and Experimental Building Time History Comparison

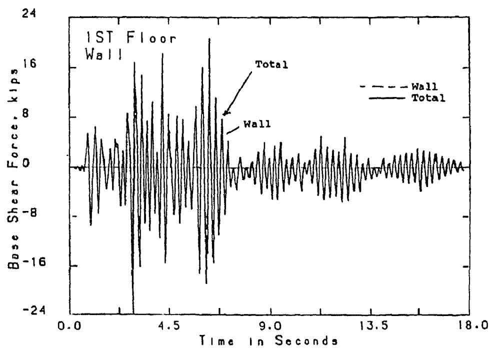

Fig. 6 Base Shear Time History

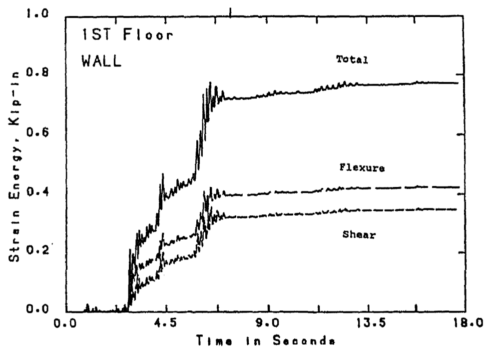

Fig. 7 Components of energy dissipated in wall during seismic action

In dynamic analysis, the serviceability limit state response of the experimental building and the analyzed model are compared, by subjecting the structure to 0.097g of the normalized Miyagi-Oki earthquake record. The displacement time history at the seventh floor level is given in Fig. 5, for comparison purposes. The base shear time history is given in Fig. 6. The experimental and analytical peak values and frequencies of displacement, base shear and moment time histories are in good agreement with the results reported in (Ref. 8). The strain energy consumed by the flexural and shear mechanisms is compared in Fig. 7.

CONCLUSION

A model for the shear force-shear deformation relationship of a reinforced concrete wall cross-section idealized as a line element is presented. The proposed model utilizes shear modulus variation along the wall cross-section depth considering the two-dimensional aspect. The model is represented in terms of a shear force vs. shear deformation relationship independent of flexural hysteresis. The behavior states defined as cracked and yielding are controlled by flexural mechanism, however, the shear hysteresis also contains cracking and yielding capacities

The analytical responses obtained based on the proposed model are in good agreement with the experimental results for large-scale test structure.

Current trend in design of R.C. buildings in seismic zones is to evaluate the structural limit state response from nonlinear time history analysis. This paper provides a realistic shear model that can easily be implemented in current nonlinear time history analysis computer programs by retaining the line element idealization of the wall element. The shear force shear deformation relationship of the wall cross section is developed using a pre-analysis program described in (Ref. 3).

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REFERENCES

1. Abrams, D.B. and Sozen, M.A., "Experimental Study of Frame-Wall Interaction in Reinforced Concrete Structures Subjected to Strong Earthquake Motions," Civil Engineering Studies, Structural Research Series No. 460, University of Illinois, Urbana, Illinois, (May 1979).
2. Hashish, A.A. and Aktan, H.M., "Nonlinear Response of RC Frame-Wall Structures," Proc. 5th Canadian Conference on Earthquake Engineering, Ottawa (1987) pp 231-240.
3. Hashish, A.A., "Nonlinear Modeling Response of RC Frame-Wall Buildings Under Static Lateral Loads and/or Seismic Motion," Ph.D. Dissertation, Wayne State University, Detroit, Michigan, (April, 1988).
4. Aktan, H.M., et al., "Shear Stiffness Degradation of R/C Structural Wall Boundary Elements," Proc. of the 8th European Conference on Earthquake Engineering, Lisbon, Portugal, Vol.4, pp. 7.4-103-7.4-110, (Sept. 1986).
5. Laible, J.P., et al., "Experimental Investigation of Seismic Shear Transfer across Cracks in Concrete Nuclear Containment Vessels," Reinforced Concrete Structures in Seismic Zones, ACI Special Publication SP-53, pp. 203-226, (1977).
6. Takeda,T., et al., "Reinforced Concrete Response to Simulated Earthquakes," Journal of the Structural Division, ASCE, No. ST12, pp.2557-2573 (Dec. 1970).
7. Bertero, V.V., et al., "Mechanical Characteristics of Materials Used in a 1/5th-Scale Model of a 7-Story Reinforced Concrete Test Structure," Earthquake Engineering Research Center, Report No. UCB/EERC-83/21, University of California, Berkely, (Oct. 1983).
8. Bertero, V.V., et. al. "Earthquake Simulation Tests and Associated Studies of a 1/5 Scale Model of a 7-Story R.C. Test Structure". Earthquake Engineering Research Center, Report No. UCB/EERC-84/05, University of California, Berkely, June 1984.