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EXPERIMENTAL AND THEORETICAL STUDY ON ASEISMIC BEHAVIORS OF LOW-RISE R.C. SHEAR WALLS

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SUMMARY

This paper tries to obtain and predict the cyclic behaviors of low-rise R.C. shear walls without boundary elements subjected to both lateral and axial loads. The dimensions of the tested specimens were either 100cm X 50cm X 10cm or 100cm X 75cm X 10cm, and reinforcements were uniformly distributed in both vertical and horizontal directions. The experimental research investigates not only "total" lateral deflection, but also "resolved" bending deflection and shear deflection. The theoretical research, besides applying constitutive laws of concrete and rebar, proposes inclined crack model and softening curvature approach to solve for bending, shear, total deflections and forces of rebars across the inclined crack. The analytical method well predicts those deflections up to post-crushing stage.

INTRODUCTION

Various researches on seismic behavior of shear walls have been studied, including the experimental tests of shear walls with rectangular cross section (Ref.1,2,3,4), I-section (Ref.5), or wall panels with boundary elements (Ref.6). Some recent studies (Ref.7,8) decomposed the total deformation into flexural and shear deformation for flexural type shear walls with boundary elements. This paper attempts, experimentally and theoretically, to obtain and predict the propagation of inclined crack, forces of rebars across the inclined crack and the cyclic behaviors of low-rise R.C. shear walls.

The experimental instrumentation is shown in Fig.1. Axial and lateral loads are applied to the specimens through five high tension bolts. Potentiometers PT1-PT7 and PT9-PT15 measure "total" lateral deflection; potentiometers PT8 and PT16 measure shear-slip at the base of wall. Clip-on gages G1-G14 calculate "bending" deflection (including semi-rigid joint rotation at the base of wall); clip-on gages G15 and G16 determine "shear" deflection. Two groups of low-rise R.C. shear walls with height/width ratio =0.5 or 0.75 were tested. Totally thirty specimens subjected to constant/varying axial load and monotonic/cyclic lateral force were executed, and main test results as well as materials properties are detailed in Ref.2,3,4.

INCLINED CRACK MODEL

For a cantilever R.C. wall before inclined crack appears, flexural stress is maximum at the base of wall. Therefore, the angle of potential shear crack is approximately equal to $\tan^{-1}(2\tau/fr)/2$ as shown in Fig.2. fr is the rupture modulus of concrete ($fr=2\sqrt{fc'}$); τ is the shear stress where fr occurs at the base of wall (crack tip -- point O in Fig.2). Once inclined crack initiated and cut the shear wall into lower-left and upper-right parts, dramatic change in structural behavior of this cantilever is observed.

For the clarity of explanation, only a vertical rebar is shown in Fig.3. The upper-right wall behaves like a tie-cantilever system as shown in Fig.3(a). Duing to the interactions between tie (vertical rebar) and tapered cantilever, a inflection point in tapered wall is formed as shown in Fig.3(b). In each horizontal section, resultant compression force and flexural stress (curvature) can be determined by equilibrium process as shown in Fig.3(c). The horizontal section passing through the inflection point sustains uniformly distributed compression stress. Owing to this behavior, the shaded region in Fig.3(d) is in compression and upper-right corner in tension. In most tests for deep beams and low-rise R.C. shear walls, this inclined crack model clarifies traditional observations of diagonal compression strut in shaded region and arch-rib crack in upper-right corner.

In order to maintain rotation compatibility at the top of tapered wall, elongation length of vertical rebars and curvature at each horizontal section of tapered cantilever are interactive and can be determined by iteration. Elongation length of vertical rebars is not just the product of steel strain and steel length, but must be modified by a reduction factor α . α is to account for the tension-stiffening effect of embedded rebars due to concrete (Ref.9). If α equals unity represents the vertical tie is a bare bar without concrete surrounded and anchorage bond-slip. α is derived from test results ($0.6< \alpha <1.1$). In this model, the strains of those rebars across the inclined crack are assumed to be proportional to the distance from bottom crack tip (point O in Fig.2). From equilibuium of horizontal force, vertical force, and moment for upper-right wall, each steel force across inclined crack can be deteremined.

Shear resistance (deformation) at each horizontal section of R.C. wall is assumed to be contributed by the concrete in compression zone and dowel action of both tension and compression steels, aggregate-interlock action in tension zone of concrete is neglected. Extended use of the concept of failure envelope for concrete due to combined action of compression and shear stresses (Ref.10), the average shear strain of concrete in each horizontal section is iteratively determined from principal strain of concrete by using equilibrium process. The requirement is that the corresponding principal stress of concrete can balance simultaneously the normal compression force and shear force in each horizontal section of tapered cantilever. The shear deflection is thus obtained by integrating shear strains along the height of wall. Bending deflection is also determined by doubly integrating curvature along the height of wall. Stress-strain curves for concrete and steel under cyclic loading follows the relationships determined by Kent and Park (Ref.11).

PREDICTIONS IN POST-CRUSHING STAGE

Once the bending moment at the base of wall reaches peak moment "Mp", as shown in Fig.4(a), the corresponding location in moment-curvature curve ABC is point C in Fig.4(b). When the wall is in the post-crushing stage, moment (load) capacity of wall decreases even if deflection increases. In other words, if the lower portion near the base of wall exhibits loading (crushing) behavior, the most upper portion of shear wall is unloading. Therefore, the softening moment-curvature curve, curve EFD in Fig.4(b), must be derived to calculate bending deflection in the posting-crushing stage. Assign an arbitrary bending moment (M') at the base of wall, which is smaller than peak moment (Mp), and then solve for new neutral axis and new curvature. Once new curvature $\phi'$is obtained, the position of point D on softening moment-curvature curve, as shown in Fig.4(b), is obtained too. From point D draw a line DF parallel to line CB. Since the bending moment at point B is less than Mp, the unloading path BF follows the initial flexural stiffness. At any point (say A) where bending moment is also less than Mp, the unloading path AE is parallel to BF, and its magnitude is portional to BF. Thus, the softening moment-curvature curve is found as the dash line shown in Fig.4(b). Fig.4(c) shows the changing of curvature along the height of wall. The flexural deflection in post-crushing stage is obtained by integrating the softening moment-curvature curve. Determination of shear deflection is similar to that in pre-crushing stage. If the strain in compression steel exceeds ultimate concrete strain, that portion of steel is assumed to be unsupported. Once the unsupported length of extreme compression steel increase to a certain extent, buckling of compression steel shall occur, the theoretical prediction stops right at this step.

COMPARISON OF THEORETICAL PREDICTION AND TEST RESULTS

The comparisons between theoretical predictions and test results for load-deflection curves are illustrtated in Fig.5. Specimen SWN-1D and SWN-5D have different height/width ratio. Both were subjected to constant axial load and cyclic lateral load. "Total" lateral deflection curves recorded by potentiometer PT1 of specimens SWN-1D and SWN-5D are shown, respectively, in Fig.5(a) and Fig.5(b) with solid line. Dash-line curves represent the prediction curves. This inclined crack model well predicts the cyclic response of low-rise R.C. shear walls up to post-crushing stage.

CONCLUSIONS

From the experimental results and theoretical predictions, the conclusions are summarized as follows:

1). The analytical method presented is capable of predicting the cyclic response of low-rise R.C. shear walls without boundary elements under axial compression force and lateral force.
2). The inclined crack model can predict the direction and propogation of inclined crack, and stresses of horizontal and vertical steels across the inclined crack.
3). The softening curvature approach is very useful in predicting deflections around and beyong peak loading, especially those specimens with high ductility ratio.
4). The fully flexural capacity of most low-rise R.C. shear walls can be developed through not only the presence of horizontal steels but also well arrangement of both horizontal and vertical steels.

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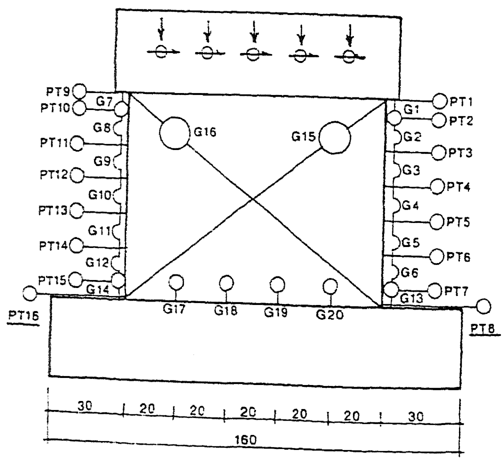


Fig.1 Instrumentation

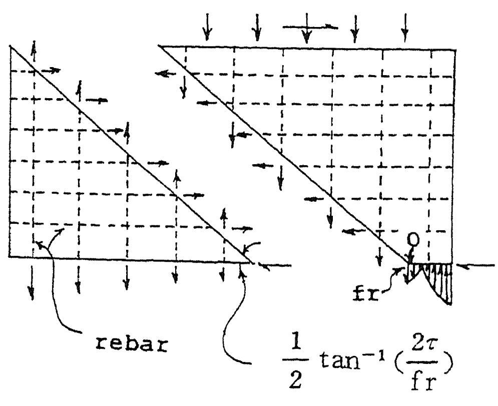


Fig.2 Angle of inclined crack

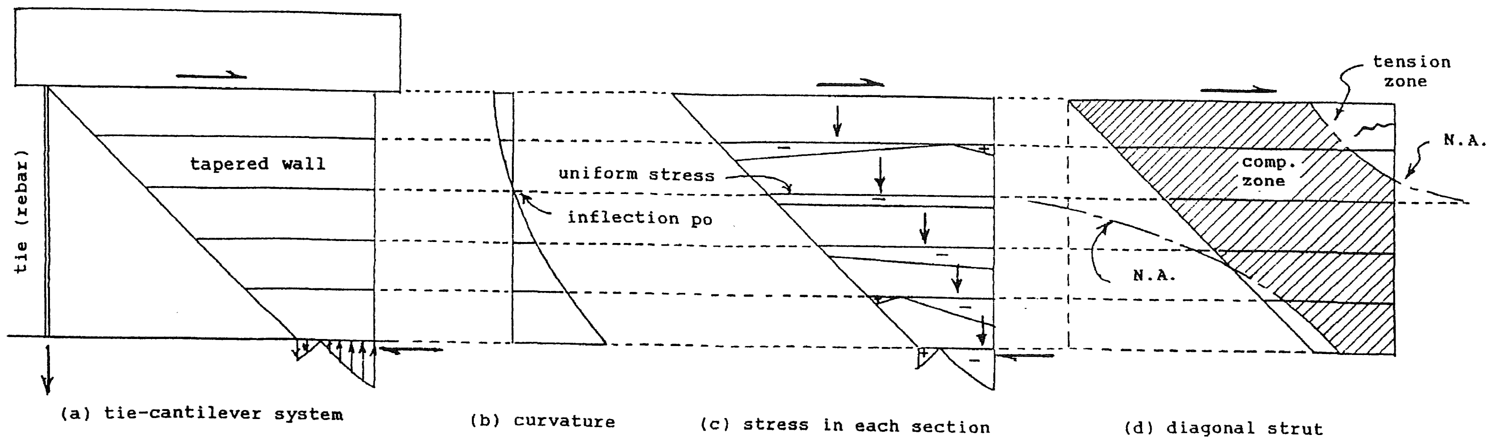


Fig.3 Inclined crack model

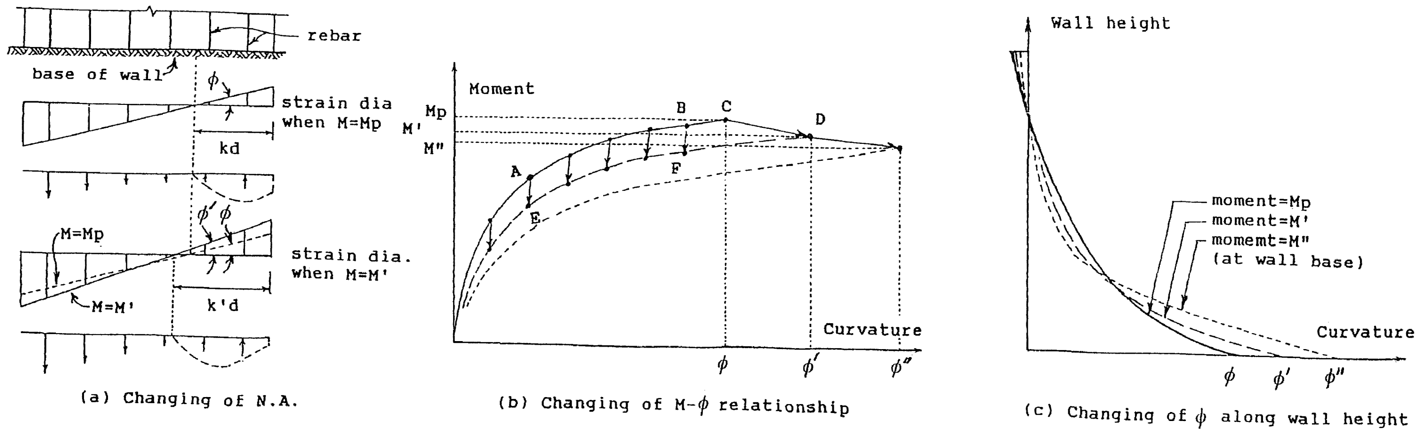
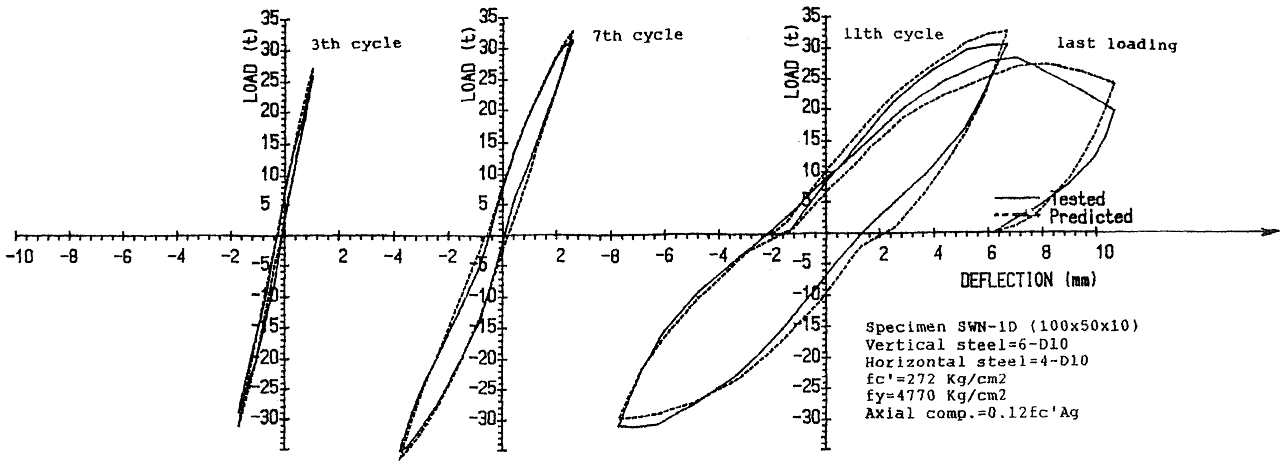
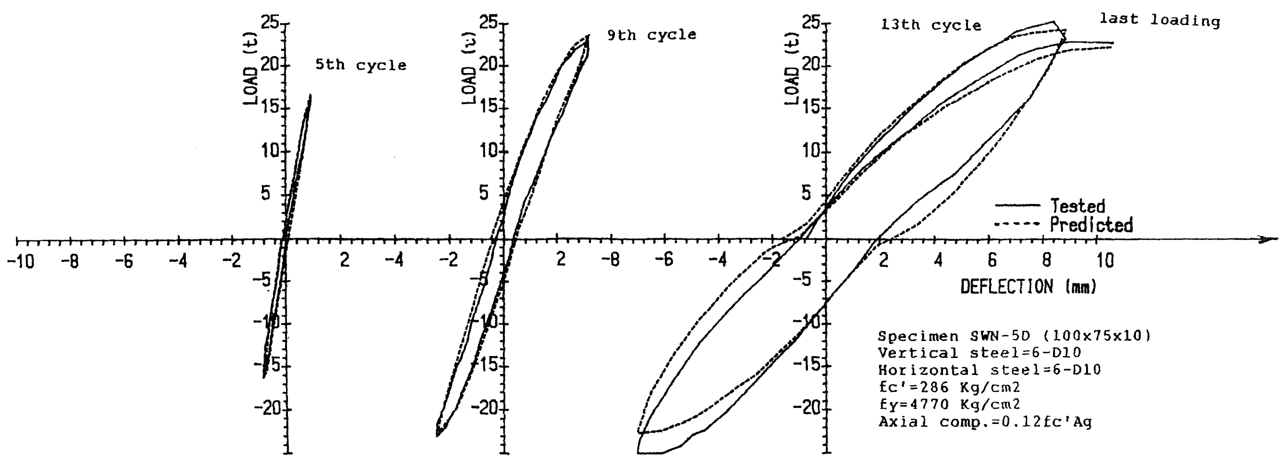


Fig.4 Determination of deflection in post-crushing stage



(a) Specimen SWN-1D (100cm X 50cm X 10cm)



(b) Specimen SWN-5D (100cm X 75cm X 10cm)

Fig.5 Comparisons of theoretical predictions and test results