PREDICTION OF BEHAVIOR OF RC SQUAT WALLS

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ABSTRACT

This paper presents an analytical study of the behavior of RC squat walls. The behavior is proposed to be described as the load-deflection curve of double-curvature RC squat walls/low-rise shear walls. The load-deflection curve illustrated by three linear line segments through cracking, ultimate, and post strength point. The experimental verification indicates that the calculated ultimate points correlate well with the test results. The calculated cracking points have large deviation compared with the experimental results, but the proposed curve after cracking point shows good tendency with the experimental results. The proposed negative slope considerably agrees with tendency of the measured load-deflection curves of double-curvature walls.

Keywords: reinforced concrete, double-curvature, low-rise, squat wall, shear wall, strength, deflection, strut, tie
1. INTRODUCTION
   According to the report of the 1999 Chi-Chi earthquake, shear walls play a significant role as earthquake resistant element in low-rise RC buildings (Tsai 2000). A significant amount of low-rise RC buildings with sufficient amount of shear walls as the earthquake resistant element was survived from the 1999 Chi-Chi earthquake. Base on this evidence, the behavior of low-rise shear walls is important to be investigated.

   In this study, the behavior of shear walls is proposed to be described as the load-deflection curve that consists of cracking, ultimate, and post strength points. The proposed lateral deflection is taken as the summation of flexural, shear, and slip deflection.

2. ANALYTICAL MODEL
   The behavior of shear walls can be classified into a single and double-curvature bending. As the illustration of the single-curvature behavior is the behavior of vertical members that mainly caused the collapse of many traditional houses [Fig. 1(a)] in the affected region of 2006 Yogyakarta earthquake (Bali et al. 2006). Due to lack of strong diaphragm action at the top of vertical members, they act as a cantilever and cause large bending moment at the bottom of the vertical members. In the case of double-curvature behavior, vertical members are usually connected with a strong diaphragm such as a rigid roof or floor at its top [Fig. 1(b)]. In this case, bending moment is distributed at the top and bottom of vertical members.

Figure 1. Single and double-curvature bending of members (Bali 2007)
2.1. Proposed load-deflection curve

The proposed model of shear wall in this study is the double-curvature low-rise reinforced concrete shear walls with the height to length ratio not exceeding two. The proposed load-deflection curve of low-rise shear wall, with three linear line segments through cracking, ultimate, and post strength points, is presented in Fig. 2.

The cracking strength is predicted according to ACI code (2005) based on the smaller of wall panel shear cracking, \[ V_{cr} = \sqrt{\frac{f_{ct} h d}{4 + N d / 4 \ell_w}} \] and wall flexural-shear cracking, \[ V_{cr} = \left( \frac{\sqrt{f_{ct} d}}{2} + \ell_w \left( \sqrt{f_{ct} d} + 2N / \ell_w \ell_w \right) \right) / \left( M / V - \ell_w / 2 \right) \ell_w d / 10 \]
and the cracking deflection could be calculated by the superposition of the shear, flexural and slip deflections. The ultimate strength of reinforced concrete low-rise shear walls is defined as the smaller of flexural and shear strengths. The flexural strength of the wall can be calculated using the flexural moment of the sectional analysis. The shear strength of the wall in this case that failing in diagonal compression can be estimated using simplified procedure of SST model as (Hwang and Lee 2002). For the ultimate deflection, by using the same procedure as the cracking deflection, the total ultimate deflection is contributed by the shear, flexural and slip deflections. The post strength of double-curvature low-rise shear walls is suggested equal to residual strength of 0.4\( V_u \), and the corresponding deflection is equal to shear drift ratio of 0.02 rad (ATC 1996). The proposed procedure for ultimate point of double-curvature wall can be seen in Fig. 3.

2.2. Shear element

The shear element of single-curvature walls and double-curvature wall is slightly different as shown in Fig. 4. In the case of single-curvature walls (Hwang et al. 2001, and Tu 2005), the height of shear element \( \ell_v = H \), and \( \ell_h \) is the horizontal distance between the point of tension force and the point of

![Figure 2. Proposed load-deflection curve of low-rise shear wall (Bali 2007)
Figure 3. The proposed procedure for ultimate point of double-curvature wall (Bali 2007)
compression force of the wall [Fig. 4(a)] and defined as $\ell_h = d - (a_w / 3)$, where $d$ is the distance between the extreme compression fiber and the center of force of all reinforcements in tension.

The height of shear element $\ell_y$ for a double-curvature walls is assumed to be the clear height of the wall panel, $H_n$ (Bali and Hwang 2007). This assumption is based on the condition of top beam of walls that is usually large and set up as a fixed support. Due this condition, the top beam is assumed as a rigid beam. In this case, shear friction between the top beam and the wall panel could be adopted as the ceiling of the shear element of double-curvature walls. Since the assumption of concentrated flow of stresses along the diagonal strut will end at the point of compressive force, the length of shear element $\ell_h$ can be estimated as the horizontal distance between the points of compressive force at the top and bottom walls [Fig. 4(b)] and can be calculated as $\ell_h = \ell_w - 2(a_w / 3)$ (Bali and Hwang 2007).

3. EXPERIMENTAL VERIFICATION

For experimental verification, a total of 25 test specimens of double-curvature shear walls (Lopes 1991, Hidalgo et al. 2002) with a height-to-length ratio not exceeding two were used to verify the prediction of the proposed model. The test setup of double-curvature wall is illustrated in Fig. 5.

Fig. 6 presents the load-deflection curves for the specimens of SW11 to SW18 (Lopes 1991), and Fig. 7 shows the load-deflection curves for the specimens of 1 to 31 (Hidalgo et al. 2002). In general, for all specimens of double-curvature walls, the proposed load-deflection curve up to ultimate point reasonably fit to the measured load-deflection curve as shown in Fig. 6 and Fig. 7. In terms of the post strength curve after ultimate point, the proposed model exhibits good tendency with measured curve in some specimens (Fig. 6 and Fig. 7).

4. CONCLUSION

An analytical model of load-deflec-
The calculated cracking point of the double-curvature walls is considerably large deviation compared with the experimental results but the proposed curve after cracking point shows good tendency with the experimental results.

The ultimate point of the double-curvature walls can be reasonably predicted by using the proposed model.

For the post strength curve, the proposed negative slope after the ultimate point considerably agrees with tendency of the measured load-deflection curves.
REFERENCES
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