CHAPTER IV

SIMPLIFIED PROCEDURE FOR WALLS CONSIDERING WEB CRUSHING

The shear strength provided by ACI318-05 (2005) for preventing diagonal tension failure has been described in the section 2.3.4 "Lateral load capacity". It is demonstrated that the formula can be adopted for walls using diagonal web reinforcement. The experimental results confirm that all specimens designed against diagonal tension failure following ACI318-05 provisions did not fail in this type of failure.

ACI318-05 code (2005) also specifies an upper limit of shear strength to $0.66\sqrt{f_c'}$ to safeguard against web crushing. It should also be noted that ACI318-05 shear model would predict web crushing mode of failure for all the walls tested, whereas in reality only the wall with conventional web reinforcement failed by web crushing. The web crushing strength provided by ACI318-05 is conservative by about 20% for the conventionally reinforced wall tested and would even be more conservative for walls with diagonal web reinforcement. To obtain a better estimate of web crushing strength, a finite element analysis which can predict the web crushing failure should be performed. However, this approach is too time consuming, and it is generally too complicated in practice. Therefore, a sectional analysis procedure accounting for shear effect is proposed to determine the ultimate lateral load and deformation. With this method, not only flexural failure but also web crushing failure can be determined.

4.1 Section Analysis with Shear Effect

Based on the finite element analyses presented in the previous chapter, the following assumptions are made concerning the strain distributions at the base of the walls:

1. shear strain is constant along the section
2. transverse strain in x direction is zero
3. longitudinal strain in y direction can be assumed to vary linearly

Figure 4.1 contains the flowchart for the sectional analysis procedure proposed. First, the compressive strain at the outermost concrete fiber, ε_c, is defined. Second, the shear strain, γ_{xy}, and compressive length, c, are selected. The value of curvature, ϕ, and longitudinal strain in y direction, ε_y, at all positions of concrete layers and reinforcing bars can be computed using Eq. (4.1).

$$\phi = \frac{-\varepsilon_c}{c} \qquad (4.1)$$
$$\varepsilon_y = \varepsilon_c + \phi x$$

where x is the position of concrete layer or reinforcing steel measured from the outermost concrete layer.

Third, the strains in the principal coordinates can be computed from the strains in the global coordinates using the transformation principle. Then the stresses corresponding to strains can be computed using the constitutive laws that are described in chapter 3. The principal stresses are transformed back to the global coordinate system. Fourth, the equilibrium in the longitudinal direction (axial force) is checked. If it is not satisfied, then, the new compressive length is selected. Finally the shear force equilibrium is invoked. If equilibrium is violated, then a new shear strain is selected and the whole procedure repeated. The analysis will be terminated when either the principal compressive strain in web concrete near the base adjacent to the boundary column reaches 0.0038 or the compressive strain of outermost longitudinal bars reaches ε^* which is an indication of rapid deterioration of the buckled bars in the boundary elements with crushing of the concrete.

4.2 The Results of Sectional Analysis with Shear Effect

The moment-curvature relationships obtained from the procedure described are shown in Fig. 4.2 for all specimens. It is observed that all specimens fail by web crushing. The corresponding compressive strains of longitudinal bars at failure are -0.0192, -0.0326, -0.0305, -0.0317, -0.0311, -0.0183 for specimens WC150, WD150, WD200, WD170, WCD170, WD170A, respectively. It is seen that although the specimens with diagonal web reinforcement are predicted to fail by web crushing, the strains of longitudinal bars of walls with diagonal web reinforcement are close to ε^* (-0.0390) indicating that the bars have experienced significant post-buckling deformation.

The lateral load-displacement curve can be obtained from the moment-curvature relationship. The lateral load is computed by dividing the moment by wall height. The displacement can be estimated from the curvature using the relationships shown in Eq. (4.2) (Park and Paulay 1975).

$$
\begin{aligned}
\delta &= \frac{1}{3}\phi h^2 && ;\phi \le \phi_y \\
\delta &= \frac{1}{3}\phi_y h^2 + \left(\phi - \phi_y\right) l_p \left(h - \frac{l_p}{2}\right) && ;\phi > \phi_y
\end{aligned}
\tag{4.2}
$$

where δ is the lateral displacement, ϕ is curvature, h is wall height, and l_p is plastic hinge length.

In this study, guided by the test results, the plastic hinge length is assumed to be equal to the buckling length of the longitudinal bar where the damage of confined concrete in the boundary elements is concentrated. Figure 4.3 compares the load-displacement curves from the sectional analyses to the experimental results. The peak lateral load capacities predicted agree with the test results within 10%. Furthermore, with this method, not only flexural failure but also web crushing failure can be determined.