FEM Model of Concrete Structure in Highly Nonlinear Region

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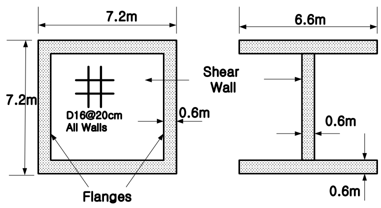
1. Introduction

To get more reasonable structural response of shear wall in the action of horizontal load on the top flange, FEM (finite element method) modeling methods were reviewed and summarized in this study. In shear wall with vertical and horizontal flanges, the abrupt stiffness changes in the connection between wall and flanges cause severe nonlinearity in the ultimate state. In order to propose rational numerical modeling method accounting for the structural discontinuity and material nonlinearity in shear wall, the factors which influence the response of shear wall such as modeling method for compressive and tensile constitutive relation of concrete, parameters related to the concrete properties, reinforcement model, load increment method, are compared and reviewed.

2. Sample shear wall

2.1 Details of Shear Wall

Characteristics of the shear wall are studied and a sample shear wall is selected as representative of those found in nuclear power plants (NPPs). Theses characteristics were discussed in detail in ASCE publication [1]. A specific shear wall, selected as sample structure, has a height/width ratio equals to one, a thickness equals to 0.6m, and a reinforcement ratio equals to 0.003 in each direction similar to the representative structure shown in NUREG/CR-6715 [2]. The wall is 6.0m high and 6.0m wide. The reinforcement consists of 16mm deformed bar spaced 200mm at each face in each direction resulting in a horizontal and vertical reinforcing ratio equal to 0.003. The shear wall is assumed to be part of an enclosure of a square room having similar shear walls on all sides and a ceiling with similar dimensions. The walls perpendicular to the shear wall under consideration act as flanges and provide moment resistance. The ceiling slab acts as a stiff member which distributes the shear load uniformly across the wall. An axial load resulting from gravity loads of the building is included and selected to produce a uniform compressive stress of 2.07MPa in the wall. The concrete compressive and tensile strengths are taken as 27.6MPa and 3.08MPa respectively and the yield strength of reinforcing bar is 414MPa.



fck = 27.6 MPa, fct = 3.08 Mpa, fy = 414MPa

Fig. 1 Sample Shear Wall

2.2 Analytical Wall Capacity

Barda et al. developed the following equation which calculates the concrete contribution to shear strength of the wall based on the low-rise wall test data.

$$V_c = [0.7\sqrt{f_{ck}} - 0.29\sqrt{f_{ck}}(H/L_w - 0.5) + N_u/(4hL_w)]\ hd = 9.87MN \quad (1)$$

Where, H = wall height =6m, d =0.8*wall width = 0.8*6.0m = 4.8m, N_u = axial load = 2.07MPa*h*L_w = 2.07*0.6m*6m = 7.452 MN, L_w = wall width = 6m

To account for the contribution of vertical and horizontal reinforcement to wall strength, Wesley and Hashimoto(1981) developed the following equation for the shear strength based on the horizontal and vertical reinforcement ratios(r_h and r_v).

$$V_s = [a\rho_h + b\rho_v]f_y hd = 3.97MN \quad (2)$$

Where, a=1-b

$b = 1$; $H/L_w < 0.5$

$= 2(1-h/L_w)$; $0.5 < H/L_w < 1$

$= 0$; ; $H/L_w > 1$

$r_h = r_v = 0.0033$

Then, the total shear wall strength can be calculated as the sum of equations Eq. 1 and Eq. 2. This results in a shear capacity of 13.84MN.

3. COMPARISION OF MODELING METHODS AND ANALYSIS PROCEDURES FOR FINITE ELEMENT

3.1Analysis Modeling Methods and Procedures Commonly Used

To get the structural response of shear wall, the ABAQUS computer code is used [4][5]. Newton's method is used for solving nonlinear equilibrium equation, in which the iterative solution finding scheme is used to increase the efficiency of the procedure in case of the discontinuity behavior caused by the formation of crack in concrete member. To increase the convergence speed of solution, line search method that minimizes residual vector correction is also adopted in the solution scheme. To compare with the analytical solutions, the FE analysis is repeated until the ultimate state of the shear wall is reached. The shear load is increased by multiplying the amplitude (load multiplier) to base load with time step amplitude table. The reference solution to be compared is got from the procedure based on the pseudo dynamic analysis.

3.2 Method for Review and Comparing the Modeling Technique and Analysis Procedures

In the review, the ultimate loads under static condition are compared in each analysis case. The reference position in which the horizontal displacement is found for defining the ultimate state of the shear wall is the top center point in Fig.2 shown below. The load-displacement curve under static load is shown in Fig. 3 for the commonly used model. Yield point is defined as the point at which the slope of load-displacement curve changes largely. The displacement of yield point denoted A in Fig. 3 is 2.7mm and corresponding yield load is 13.3MN. The ultimate state of the shear wall is defined as 4 times of yield displacement similar to NUREG/CR 6715. The displacement at the ultimate point denoted B in Fig. 3 is about 10.8mm and corresponding ultimate load is 15.1MN. This ultimate load is larger than that calculated by Eq. (2) based on experiment results.

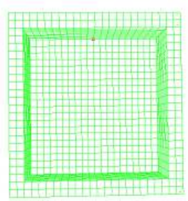


Fig. 2 Reference Position for Displacement Comparison

3.3 Section Modeling Methods

In the analysis, four types of section modeling method are adopted. The first one models all parts of shear wall and flanges as nonlinear concrete model. The second one adopts two types of concrete model in wall section. The former is called RC zone used for representing bond behavior near the reinforcement with ultimate tensile strain 0.001 and the latter is called PC zone for representing the relatively distant from reinforcement with ultimate tensile strain 0.002[6]. The flange is modeled as nonlinear concrete. The third model accounts for the shear wall failure mode that occurs only in wall, not in flanges. Thus the flanges are modeled as elastic material, and only the wall is concrete material. The fourth model has elastic flanges and wall with PC and RC material. The analysis results are shown in Fig. 9. There is no difference in yield and ultimate loads. However, from the viewpoint of reducing the execution time and getting rational failure mode about crack and compressive damage propagation the fourth model shows best response

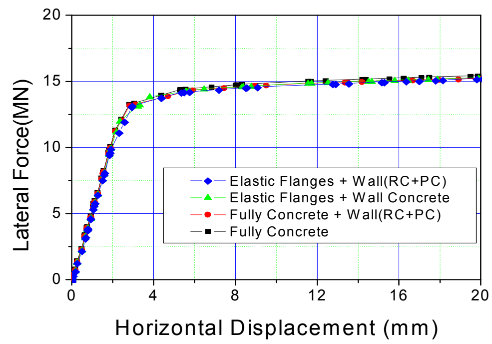


Fig.3 Load Displacement Relations of Different Section Models

4. Conclusions

In order to get reasonable response up to ultimate state of shear wall structure which changes abruptly in geometry and stiffness, reviews for modeling methods and analysis schemes are undertaken. From the review, the best model for shear wall in ultimate analysis is adopted pseudo implicit dynamic analysis scheme in load increment, concrete damage plasticity model of concrete wall with PC zone and RC zone partition and elastic flanges. Using this model, it is possible to trace the propagation of crack and compressive damage in the shear wall..

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