ULTIMATE LOAD ANALYSIS OF DEGRADED REINFORCED CONCRETE SHEAR WALLS

CHUNG Yun-Suk[1], LEE Myung-Kue[2]

[1] Nuclear Regulatory Research Division, Korea Institute of Nuclear Safety
19 Guseong, Yuseung, Daejeon, Korea (ROK)
Email : k063cys@kins.re.kr

[2] Department of Civil & Environmental Engineering, Jeonju University
1200 Hyojadong Wansangu, Jeonju, Jeonbuk, Korea (ROK)
Email: concrete@jj.ac.kr

ABSTRACT

Reinforced concrete shear wall is composed of wall, horizontal and vertical flanges. Due to the abrupt change in its geometry, it is difficult to predict the ultimate behavior of shear wall in the action of lateral forces. For the better understanding of ultimate state, the propagation of crack and inelastic compressive zone are reasonably simulated. In this study, for the improvement of analysis result for shear wall with flanges, analyses are fulfilled with the application of some modeling methods including various materials and geometrical models and numerical methods. The results from various modeling methods are compared and the desirable model is proposed.

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 at ultimate state. To propose rational numerical modeling method accounting for the structural discontinuity and material nonlinearity in shear wall, the factors - modeling method for compressive and tensile constitutive relation of concrete, parameters related to the concrete properties, reinforcement model, load increment method - influencing the response of shear wall are compared and reviewed.

SAMPLE SHEAR WALL

Sample Shear Wall Details

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 are discussed in some 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]. A sketch of the shear wall is shown in Fig 1. 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 0.0033. 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 normal to the shear wall under consideration act as flanges and provide moment resistance. The ceiling slab act as a stiff member to distribute 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 in the wall equals to 2.07MPa. The concrete compressive and tensile strength are taken as 27.6MPa and 3.08MPa respectively and the yield strength of reinforcing bar is 414MPa.

Evaluation of Shear Wall Using Analytical Solutions

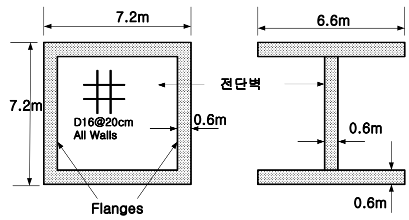
Using ACI 318-05 the shear capacity of the wall can be calculated by the expression [3]:

$$V_n = [0.28\sqrt{f_{ck}}hd + N_u d/(4L_w) + A_v f_y d/s_2] = 9.672\text{MN} \quad (1)$$

Where, h = wall thickness =0.6m
d =0.8*wall width = 0.8*6.0m = 4.8m
A_v = area of horizontal steel within distance s_2 = 2*0.0002m^2 = 0.0004m^2
s_2 = spacing of horizontal reinforcement = 0.2m
N_u = axial load = 2.07MPa*h*L_w = 2.07*0.6m*6m = 7.452 MN

L_w = wall width = 6m

The resulting strength of the wall in shear is calculated to be 9.67MN.



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

Fig. 1 Sample Shear Wall

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

$$V_c = [0.7\sqrt{f_{ck}} - 0.29\sqrt{f_{ck}}(H/L_w - 0.5) + N_u/(4hL_w)]\,hd \quad = \; 9.87 \text{ MN} \qquad (2)$$

Where, H = wall height =6m

d =0.8*wall width = 0.8*6.0m = 4.8m

A_v = area of horizontal steel within distance s_2 = 2*0.0002m^2 = 0.0004m^2

s_2 = spacing of horizontal reinforcement = 0.2m

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 developed from the horizontal and vertical reinforcement ratios(r_h and r_v).

$$V_s = [a\rho_h + b\rho_v]f_y hd \quad = \; 3.97 \text{ MN} \qquad (3)$$

Where, a=1-b

b = 1 ; $H/L_w < 0.5$

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

= 0 ; ; $H/L_w > 1$

$r_h = r_v = 0.0033$

The total shear wall strength is calculated as the sum of equations Eq. 2 and Eq. 3. This results in a shear capacity of 13.84MN, which is about 40% higher than the ACI code predicted strength.

COMPARISION OF MODELING METHODS AND ANALYSIS PROCEDURE FOR FINITE ELEMENT ANALYSIS

Analysis 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 continued until the ultimate state of the shear wall. 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.

Method for Review and Comparing the Modeling Technique and Analysis Procedures

In the review, the ultimate loads under static condition are compared for each analysis case. The reference position to find horizontal displacement for defining the ultimate state of the shear wall is the top center point as shown Fig.2.

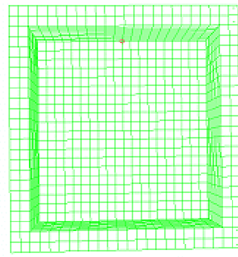


Fig. 2 Reference Position for Displacement Comparison

The load-displacement curve under static load is found as shown Fig. 3 for the commonly used model. Yield displacement is defined as the point that changes largely in slope of load-displacement curve. 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 from experimental equation.

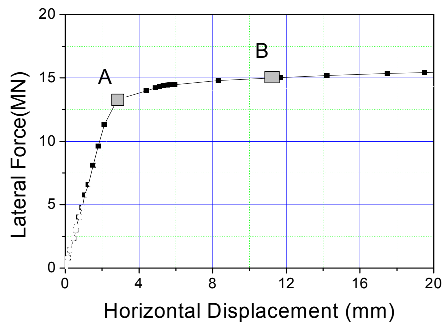


Fig. 3 Horizontal Displacement of Reference Point

Analysis Results according to Analysis Schemes

The results from static analysis method and pseudo dynamic analysis by implicit dynamic procedure are calculated and compared. In static analysis, the solution is got by automatic time (load multiplier) increment scheme. In this static procedure based on the half-step residual method (Hibbitt and Karlsson, 1979), the half-step residual is set as basic shear load. The load-displacement curve of these analysis schemes is shown in Fig.4. The yield load for each case shows the same value 13.3MN at 2.7mm in horizontal displacement. But the ultimate load for static scheme is 14.2 MN smaller than 15.1MN for pseudo dynamic scheme.

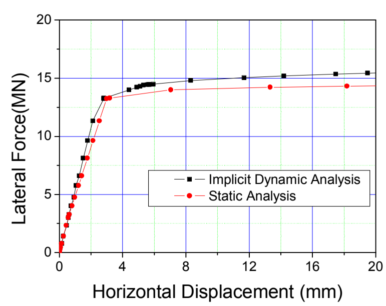


Fig. 4 Load Displacement Relations of Different Analysis Schemes

Material Modeling Methods of Concrete and Reinforcement

The analysis results using smeared cracking model and damage plasticity model are shown in Fig. 5. The yield load of smeared cracking model is lager than that of damage plasticity model, but the ultimate load can not be found because the solution does not converge with more crack propagation.

The influence of reinforcement material models is shown in Fig. 6. The analysis results using elastic-perfect plastic model and elastic linear hardening model show little difference and give same yield and ultimate load.

The influence of concrete ultimate tensile strain with the same tensile strength is shown in Fig. 7. From the results, it is clear that the ultimate strain i.e. tension stiffening has little influence on the structural response of the shear wall.

Fig. 8 shows the influences of $\pm$ 20% change of tensile strength of concrete with the same ultimate tensile strain. The influence on the yield and ultimate load is larger than other cases. The failure of shear wall begins at the connections between horizontal flanges and wall with formation of cracks. This behavior is responsible for the importance of tensile strength of concrete.

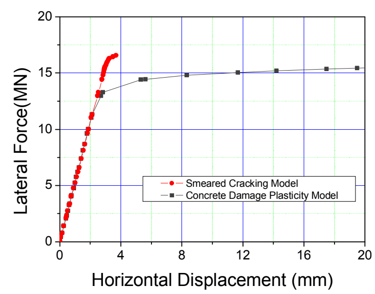


Fig. 5 Load Displacement Relations of Different Concrete Material Models

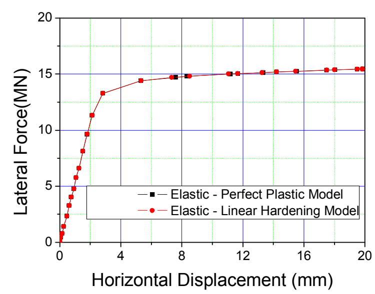


Fig. 6 Load Displacement Relations of Different Reinforcement Material Models

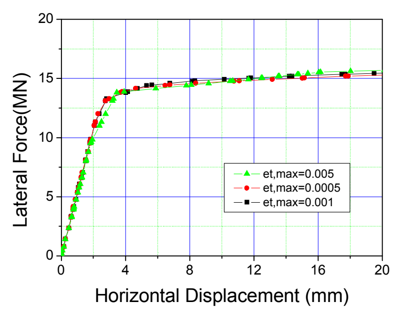


Fig. 7 Load Displacement Relations for Different Ultimate Tensile Strains

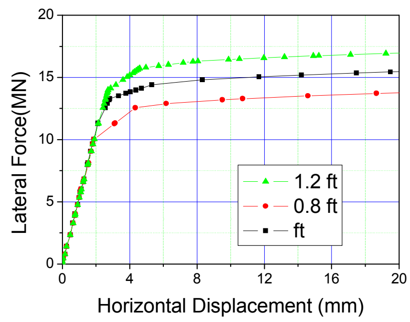


Fig. 8 Load Displacement Relations for Different Tensile Strengths

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 one model is called RC zone used for representing bond behavior near the reinforcement with ultimate tensile strain 0.001 and the other 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 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 load. But, from the point of view of reducing the execution time and getting rational failure mode about crack and compressive damage propagation the fourth model shows best response.

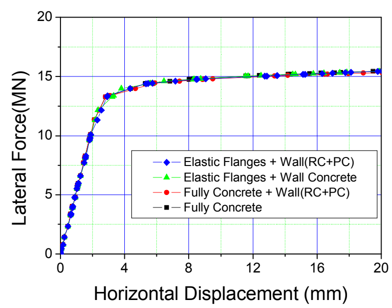


Fig. 9 Load Displacement Relations of Different Section Models

CONCLUSION

To get reasonable response of shear wall structure up to ultimate state which changes abruptly in geometry and stiffness, reviews for modeling method and analysis scheme are fulfilled. 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 can be traced the propagation of crack and compressive damage in the shear wall.

REFERENCE

[1] ASCE, *Stiffness of Low Rise Reinforced Concrete Shear Walls, American Society of Civil Engineers*, New York, 1994

[2] Braverman, J. I., Miller, C.A., Ellingwood, B.R, Naus, D. J., Hofmayer, C.H., Shteyngart, S., and Bezler, P., *Probability-Based Evaluation of Degraded Reinforced Components in Nuclear Power Plants*, NUREG/CR-6715, Brookhaven National Laboratory, April, 2001.

[3] ACI, *Building Code Requirements for Structural Concrete (ACI318-05) and Commentary (ACI318R-05)*, American Concrete Institute, 2005
[4] ABAQUS User's Manual Ver. 6.5, Hibbit, Karrlson & Sorensen, Inc, 2005

[5] ABAQUS Example Manual Ver. 6.5, Hibbit, Karrlson & Sorensen, Inc 2005

[6] Maekawa, K., Pimanmas, A., Okamura, H., Nonlinear *Mechanics of Reinforced Concrete, Spon Press, London*, 2003

[7] NEA/CSNI/R(96)10 Seismic shear wall ISP - NUPEC's seismic ultimate dynamic response test - comparison report

[8] Naus, D.J., Oland, C.B., *Report on Aging of Nuclear Power Plant Reinforced Concrete Structures*, NUREG/CR-6424, Oak Ridge National Laboratory, March 1996.

[9 Braverman, J. I., Hofmayer, C.H., Shteyngart, S., and Bezler, P, *Assessment of Age-Related Degradation of Structures and Passive Components for U.S. Nuclear Power Plants*, NUREG/CR-6679, Brookhaven National Laboratory, August, 2000.