Jordan Journal of Civil Engineering, Volume **7**, No. **2, 2013**

Analysis of Shear Wall with Openings Using Solid65 Element

Mazen A. Musmar

Associate Professor, Al-Ahliyya Amman University, Civil Engineering Department, Amman, Jordan

ABSTRACT

The use of shear wall-buildings is quite common in some earthquake prone regions. During seismic excitation, they contribute in absorbing moments and shear forces and reduce torsional response. Usually, architectural design leads to the existence of doors and windows within shear walls. Previous researches on the behavior of shear walls with openings assumed elastic analysis utilizing shell and brick elements. The present work adopts nonlinear finite element analysis using solid65 element. The analysis comprises both material and geometric nonlinearities. Solid65 element models the nonlinear response of concrete material based on a constitutive model for the triaxial behavior of concrete after Williams and Warnke. Five shear wall models with different opening sizes are analyzed. A sixth model of a solid shear wall is also presented to compare the analysis results. The paper studies the effect of the size of the openings on the behavior of the reinforced concrete shear walls.

The study indicates that openings of small dimensions yield minor effects on the response of shear walls with respect to both normal stresses along the base level of shear walls and maximum drift. Cantilever behavior similar to that of a solid shear wall takes place and analogous to that of coupled shear walls. On the other hand, when openings are large enough, shear walls behave as connected shear walls, exhibiting frame action behavior.

KEYWORDS: Shear wall with openings, Solid65 element.

INTRODUCTION

Shear walls, which are quite common in Earthquake resisting structural systems, may have openings for doors, windows and building services or other functional reasons. Such openings create regions of disturbed stress flow.

Two popular schemes of modeling shear walls are the finite element method which is considered next to exact solution if the material properties are correctly implemented, and the equivalent frame method which involves less modeling effort, but less accurate results. Much research in finite element analysis of shear walls with openings has been undertaken (Husain, 2011; Kim and Lee, 2003; Amaruddin, 1999; Choi and Bang, 1987). However, ideal finite element models were usually adopted, element types were either shell or brick elements that only simulated the elastic deformations of the concrete while reinforcement effect was ignored. Such elements are not capable of simulating the true behavior of reinforced concrete shear wall through the whole load deformation curve that represents the expected response of the shear wall when subjected to severe seismic excitation.

Today, the smeared crack approach of modeling the cracking behavior of concrete is almost exclusively used in the nonlinear analysis of reinforced concrete structures, since its implementation in a finite element analysis program is more straightforward than that of

Accepted for Publication on 28/12/2012.

the discrete crack model. If overall load deflection behavior is of primary interest, without much concern for crack patterns and estimation of local stresses, the smeared crack model is probably the best choice (Kwak and Filippo, 1990).

According to Building Code Requirements for Structural Concrete (ACI 318,11), for walls with openings the influence of the opening or openings on the flexural and shear strengths is to be considered. Capacity design concepts and strut-and-tie models may be useful for this purpose. The code also demands to comply with proper provisions to assure sound force path around openings. It also requires additional precautions to protect the horizontal and vertical segments around the openings.

In this study, solid65 element provided by ANSYS software is used (ANSYS, release 5.5). It simulates the elastic and plastic deformations that would happen in concrete and reinforcement inclusive of cracking until ultimately concrete crushing as the load is stepwise increased.

The objective of this study is to investigate the behavior of shear walls with openings. The study embodies large deformation nonlinear finite element analysis.

Finite Element Analysis of Shear Wall with Openings

ANSYS finite element software is used to model seven reinforced concrete shear walls, one is a solid shear wall that would serve as reference, the remaining six models have openings of 1m width and variable heights starting from 0.5m till 3.0m of 0.5m increments. Solid65 finite element is utilized. It is a dedicated three-dimensional eight noded isoparametric element with three degrees of freedom at each node, translations in the x, y and z directions. Several computer iterations were carried out to determine the proper load step and element size. The fine elements have been distributed in regions of disturbed stress flow such as openings.

Modeling of Shear Wall Using Solid65 Element

The solid65 element models the nonlinear response of reinforced concrete. Solid65 models the concrete material based on a constitutive model for the triaxial behavior of concrete after Williams and Warnke. It is capable of plastic deformation, cracking in three orthogonal directions at each integration point.

The cracking is modeled through an adjustment of the material properties that is carried out by changing the element stiffness matrices. If the concrete at an integration point fails in uniaxial, biaxial or triaxial compression, the concrete is assumed crushed at that point. Crushing is defined as the complete deterioration of the structural integrity of the concrete.

ANSYS allows entering three reinforcement bar materials in the concrete, each material corresponding to the x, y and z directions of the smeared element (ANSYS, release 5.5). A schematic of the element is shown in Figure (1).

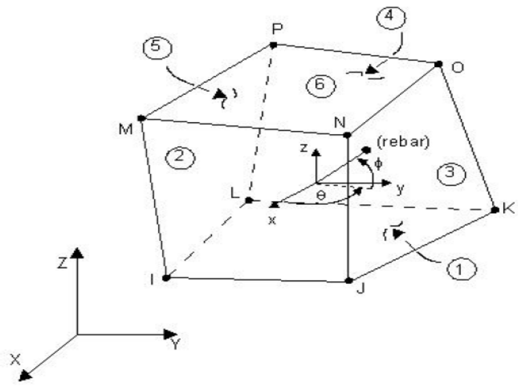


Figure 1: Solid65 element (ANSYS, release 5.5)

Table (1) lists concrete properties within Solid65 element, prior to initial yield surface, beyond that concrete parameters are shown in Table (2).

Solid65 element is capable of cracking in tension and crushing in compression. The multi-linear isotropic concrete model uses the von Mises failure criterion along with Willam and Warnke model to define the failure of concrete.

The compressive uniaxial stress-strain relationship for the concrete model in Figure (2) was obtained using the following equations to compute the multi-linear isotropic stress-strain curve for the concrete (Desayi and Krishnan, 1964).

Table 1. Concrete properties prior to initial yield surface

Material	Material model	Modulus of elasticity MPa	Poisson's ratio
Concrete	Linear elastic	25743	0.3

Table 2. Concrete parameters beyond initial yield surface

Open shear transfer coefficient, β_t	0.2
Closed shear transfer coefficient, β_c	0.9
Uniaxial cracking stress	3.78 Mpa
Uniaxial crushing stress f'_c	30 Mpa

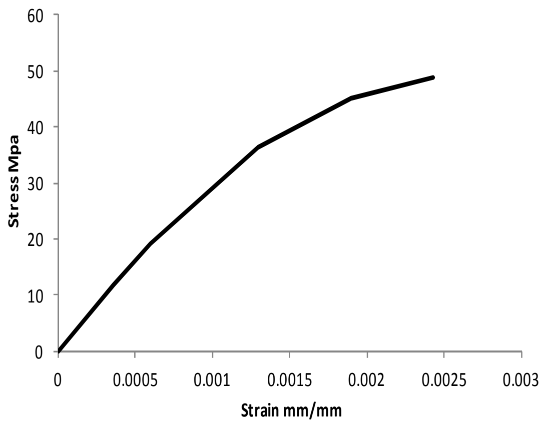


Figure 2: Concrete stress-strain curve for uni-directional monotonic compressive loading

$$f = \frac{E_c \varepsilon}{1 + \left(\frac{\varepsilon}{\varepsilon_o}\right)^2} \qquad (1)$$

$$E_c = \frac{f}{\varepsilon} \qquad (2)$$

$$\varepsilon_o = \frac{2 f'_c}{E_c} \qquad (3)$$

where:

f : stress at any strain.

ε : strain at stress f.

ε_o : strain at ultimate compressive strength.

E_c : Concrete modulus of elasticity.

Cracking and crushing are determined by a failure surface. Once the failure surface is surpassed, concrete cracks if any principal stress is tensile while the crushing occurs if all principal stresses are compressive. The failure surface for compressive stresses is based on Willam-Warnke failure criterion which depends on five material parameters. Tensile stress consists of a maximum tensile stress criterion: a tension cut-off. Unless plastic deformation is taken into account, the material behavior is linear elastic until failure. When the failure surface is reached, stresses in that direction have a sudden drop to zero and there is no strain softening neither in compression nor in tension. As shown in Table (2), two shear transfer coefficients, one for open cracks and the other for closed ones, are used to consider the retention of shear stiffness in cracked concrete.

As shown in Figure (3), material model for smeared steel reinforcement is linear elastic prior to initial yield surface, beyond the initial yield surface it is perfectly plastic, in tension and compression loading.

Steel Reinforcement

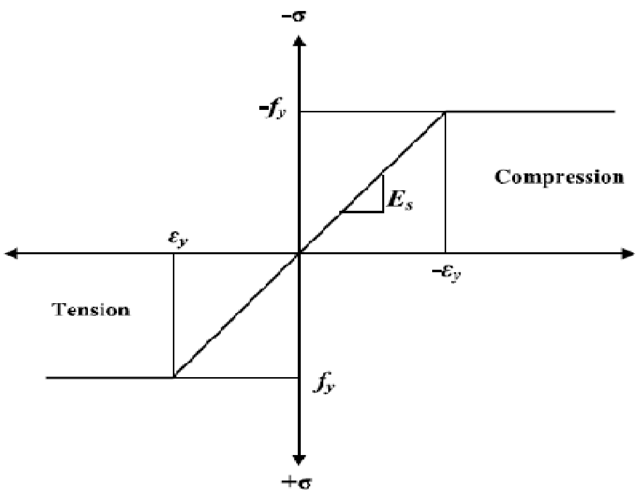


Figure 3: Stress-strain curve for steel reinforcement

Table 3. Properties for smeared steel reinforcement

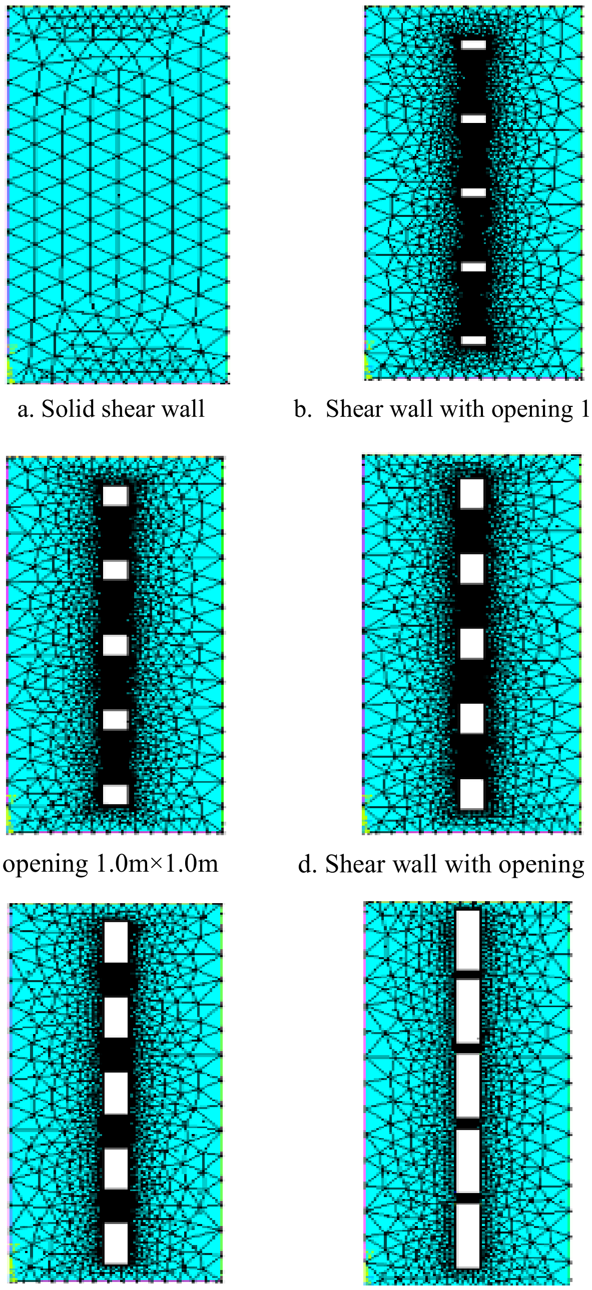
Material model prior to initial yield surface	linear elastic
Elastic modulus, E_s	200 GPa
Poisson's ratio	υ=0.3
Yield stress, f_y	412 MPa
Material model beyond initial yield surface and up to failure	perfect plastic

Numerical Example

The adopted shear wall is 17.5m high, representing 5 stories each of 3.5m height. The wall's horizontal length is 8.0m, and it is 0.3m thick. The openings are located in all stories at the mid length of shear walls. Adopted openings length is 1m, and the opening height is variable ranging from 0.5m to 3.0 m by 0.5m increments.

Loading and Boundary Conditions

The capacity of the structure is represented by a load displacement curve, obtained by non-linear static



a. Solid shear wall

b. Shear wall with opening 1mx0.5m

c. Shear wall with opening 1.0m×1.0m

d. Shear wall with opening 1.0m×3.0m

e. Shear wall with opening 1.0m×2.0m

f. Shear wall with opening 1.0m×3.0m

Figure 4: Finite element idealization for shear walls

analysis, where the load is stepwise increased. This is often called push-over analysis and was used in conducting non-linear analysis for shear walls utilizing ANSYS finite element software and adopting a fixed support condition along the base of the shear wall.

The horizontal loading was applied on the left edge of the shear wall at the top level of each storey, distributed in accordance with the International

Building Code (IBC) provisions (IBC, 2000).

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} \quad (4)$$

where:

w_i, w_x: The portion of the dead load at or assigned to the level i or x.

h_i, h_x: height above the base to level i or x.

k : an exponent related to the building period, assumed '1' for a building period of 0.5 sec or less.

RESULTS AND DISCUSSION

The carried out analysis stimulates the whole load deformation curve, inclusive of elastic deformation, initiation of cracking, as well as tension and shear cracks until ultimate concrete crushing. The load was gradually increased, employing non-linear, large-deflection analysis, until a load level was found whereby the structure became unstable. However, the determination of the ultimate load is difficult, as it is affected by hardening and the associated flow rule, convergence criteria and iteration method used. Thus, several iterations were carried out for each case to attain the closest load to the ultimate.

The load values in Figure (6) represent the seismic forces at the top slab. The remaining lateral loads are distributed to act on the remaining slabs, as illustrated in Figure (5) and calculated in accordance with equation (4). While the load capacities for solid shear walls and up to openings of 1x1m are relatively close as shown in Figure (6), it is observed that for opening sizes of 1mx1.5m and above, the wall load capacity values are about 70% of the load values for solid shear walls. This is attributed to the fact that for small openings, shear walls behave as coupled shear walls. The ductility is relatively increased as may be concluded from Figure (6), without undermining the load capacity of the shear wall.

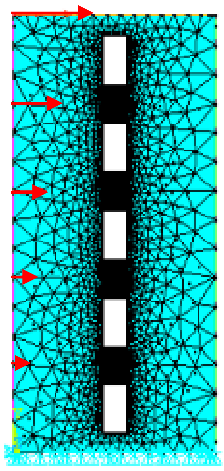


Figure 5: Distribution of load at the level of each storey for load step

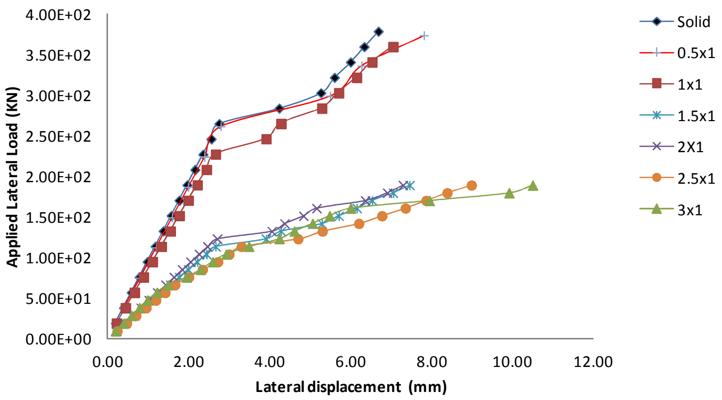
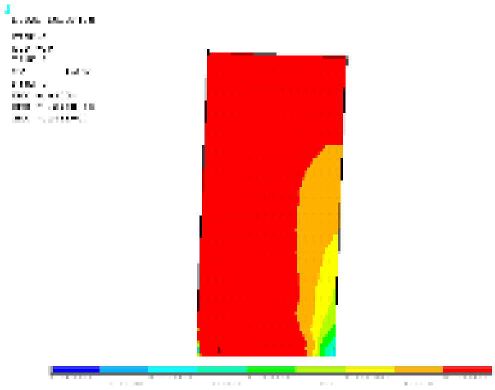
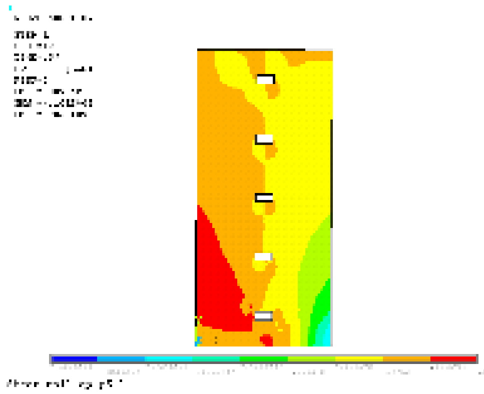


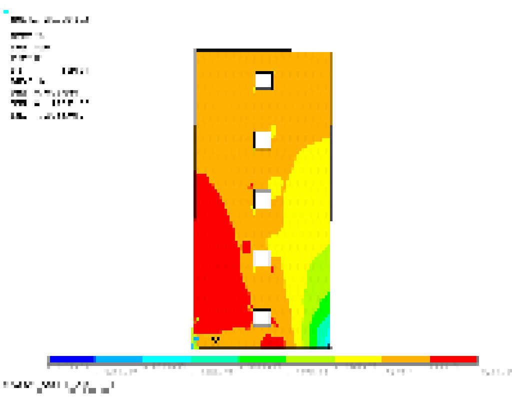
Figure 6: Lateral displacement *versus* applied lateral load



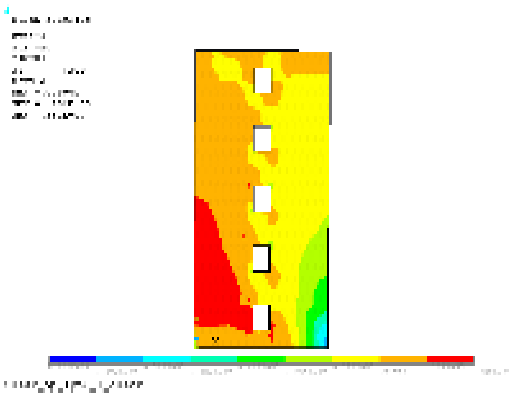
a. Solid shear wall



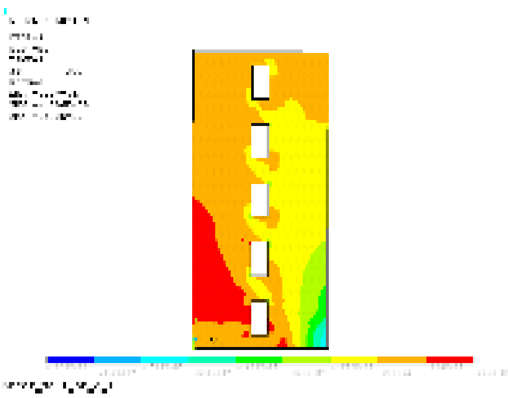
b. Opening 0.5mx1m



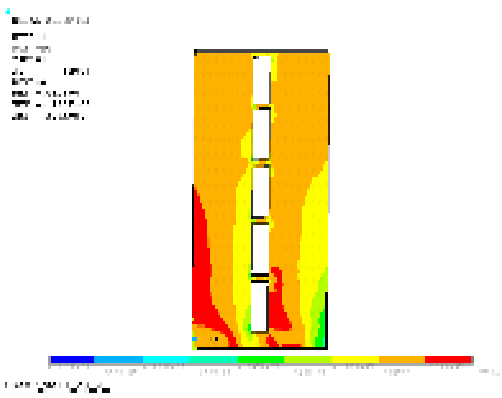
c. Opening 1mx1m



d. Opening 1.5mx1m



e. Opening 2mx1m



f. Opening 3.0 mx1m

Figure 7: Flexural stresses Syy (MPa) at the bottom of the wall

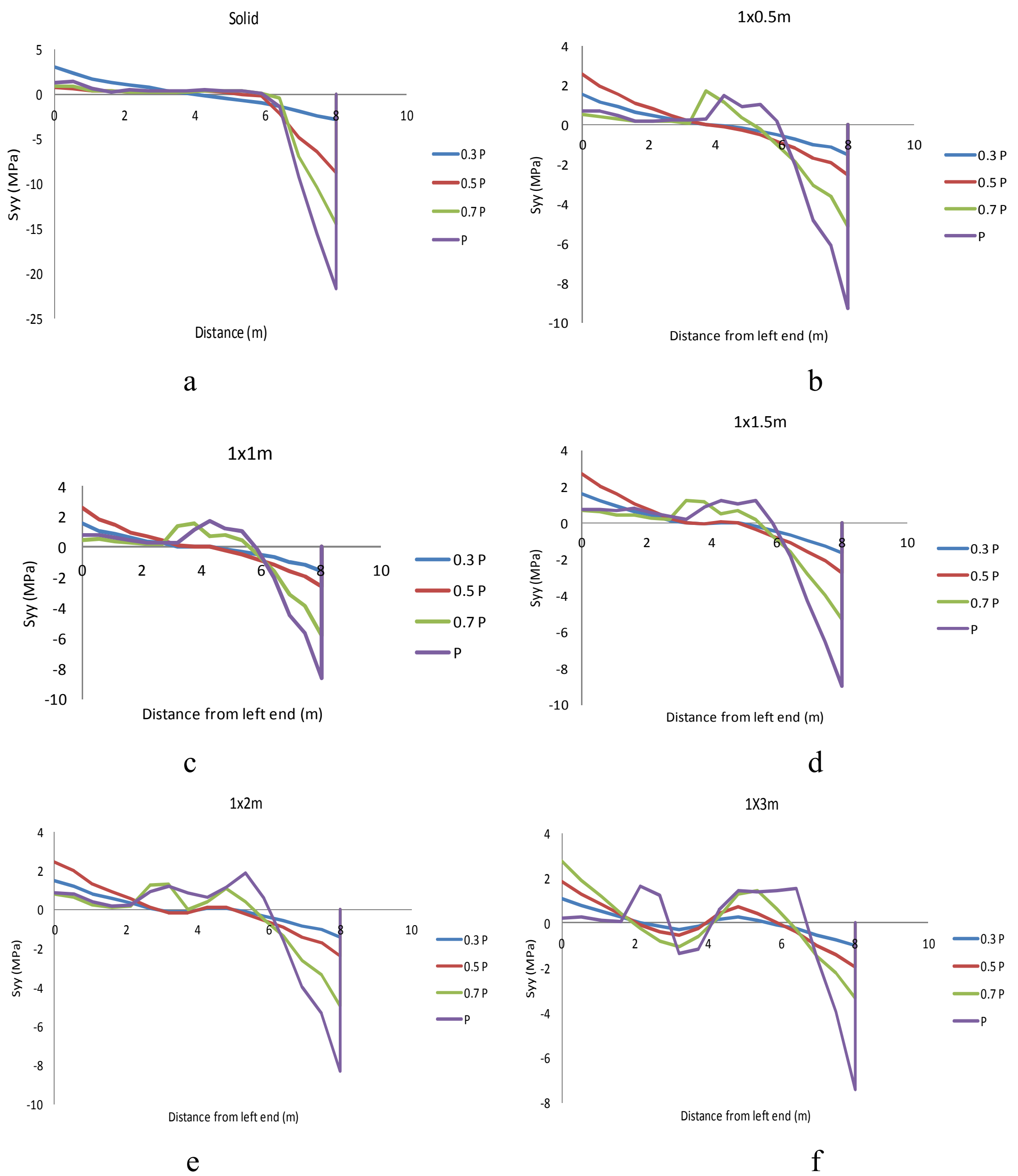
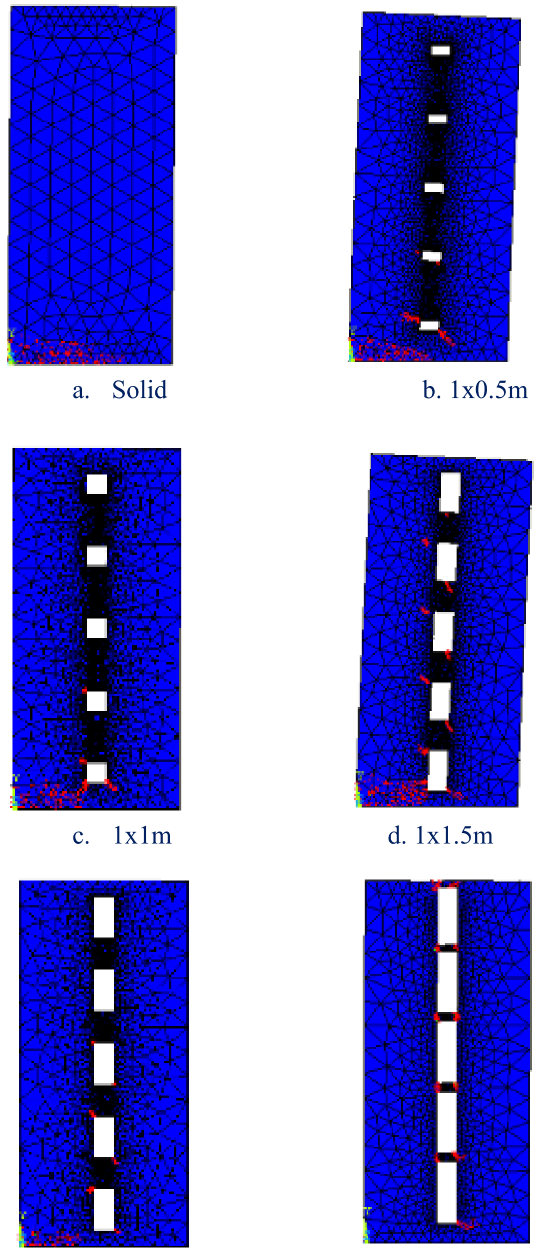


Figure 8: Flexural stresses gradient Syy (MPa) at the base of the wall at different loadsteps

Figure (7) illustrates the distribution of tensile and compressive stresses for the considered shear walls just before failure. It shows the effect of the size of the opening on the stress flow and reveals that the larger the size of the opening is the greater is the amount of stress flow disturbance.

Figure (8) shows the distribution of tensile and compressive flexural stresses along the base of the wall at various load steps. The analysis is initiated by applying relatively low lateral loads that are gradually stepwise increased. At low stresses, the behavior is essentially linear elastic. When the applied load is increased up to about 30% of the loading capacity, cracking is initiated resulting in non-linear behavior. Then, when the applied load is further increased, the stresses in several locations exceed the yield surface resulting in plastic strains and stresses. The load was incrementally applied until the loading capacity was approximately determined.



a. Solid

b. 1x0.5m

c. 1x1m

d. 1x1.5m

e. 1x2.0m

f. 1x3.0m

Figure 9: Initial cracking in different shear walls

Figure (9) shows that in the case of solid shear wall, the initial cracking occurred at discrete locations along and close to the base of the wall. In places where the concrete tensile strength was exceeded, cracking initiated at a lateral deflection of 5.7mm measured at the level of the top slab. For the shear wall with openings of 1.0mx0.5m, the initial cracking started close to the base of the wall. It also appeared at the opposite corners of the opening in the 1st floor at a deflection of 4.6mm as shown in Figure (9b). On the other hand, in the case of the largest opening of 1.0mx3.0m dimensions, the cracks initiated at the beam wall joints and at a deflection of 2.7mm as shown in Figure (9f).

As illustrated in Figures (6-9), when openings are large enough, the load capacity becomes less. The walls behave as connected shear walls (frame action). The joint between the beam above the opening and the walls become, the weakest link, the cracking starts around the openings.

CONCLUSIONS

- For shear walls considered in the study, openings up to 1x1m in size are considered as small openings.
- Small openings yield minor effects on the load capacity of shear walls, flexural stresses along the base level of shear walls, cracking pattern and maximum drifts.
- In case of small openings, the shear walls behave as coupled shear walls. The ductility is relatively increased without undermining the load capacity of shear walls.
- The larger the size of the opening is the greater is the stress flow disturbance within the shear wall.
- When openings are large enough, the load capacity is reduced. In this study, at 1.x3.0m opening size, the load capacity went down to about 70% of that of a solid shear wall. It may be concluded that the walls in such a case behave as connected shear walls maintaining frame action behavior.
- In case of solid shear walls, the initial cracking occurs at discrete locations close to the base of the wall in the regions where the concrete tensile strength is exceeded.
- When the opening size exceeds that of a small opening, the initial cracking starts at locations close to base of the wall and also appears at the opposite corners of the opening.
- When openings are large enough, the initial cracking occurs at the joint between the upper lintel of the opening and the sidewalls.

REFERENCES

Amaruddin, M. 1999. In-plane Stiffness of Shear Walls with Openings. *Building and Environment*, 34: 109-27.

ANSYS (Release 5.5). Structural Analysis Guide.

Building Code Requirements for Structural Concrete ACI (318M-11) and Commentary, American Concrete Institute.

Choi, C.K. and Bang, M.S. 1987. Plate Element with Cutout for Perforated Shear Wall. *Journal of Structural Engineering,* 133 (2): 295-306.

Desayi, P. and Krishnan. 1964. Equation for Stress-Strain Curve of Concrete. *ACI J.,* 61:345-350.

Husain, M. 2011. Analysis of Shear Wall with Openings Using Brick Element, *European Journal of Scientific Research*, 50 (3): 359-371.

International Building Code, IBC. 2000. International Code Council, Inc.

Kim, H.S. and Lee, D.G. 2003. Analysis of Shear Wall with Openings Using Super Elements. *Engineering Structures*, 25: 981-991.

Kwak, H.G. and Filippou, C. F. Finite Element Analysis of Reinforced Concrete Structures under Monotonic Loads, Report no. UCB/SEMM-90/14.