International Journal of Engineering Research
Volume No.5 Issue: Special 3, pp: 572-577

ISSN:2319-6890(online),2347-5013(print)
27-28 Feb. 2016

Effect of Opening in Shear Wall

Anand S. Attal, Jyoti P. Bhusari
Department of Civil Engineering, Sinhgad College of Engineering, Pune, India
E-mail-anandsattal@gmail.com, jpbhusari.scoe@sinhgad.edu

Abstract- Shear wall, a continuous vertical member, is an important element in high-rise buildings, which provides the lateral stability and resists the lateral forces from earthquake and wind forces. Finite Element Method is widely used for analysing complicated structural systems. The selected structural model must be simple, produce accurate result and be economical. Important factors affecting the analysis of shear wall structure are the type and number of elements, the distribution of the forces, geometry and section properties.The aim of this study is to investigate the suitability, simplicity, accuracy; effectiveness of different structural models used in the analysis of shear wall and coupled shear wall structures. The study concentrates on the behaviour of the wall with the introduction of opening in it. Different elements used in modelling the shear walls are 6-noded triangular element, 4-noded quadrilateral element & 8-noded quadrilateral element with three refinement of mesh.The structural behaviour in terms of deflections, stresses distribution and dynamic characteristics are presented and discussed.

Keywords Deflections, Opening size, Stress distribution, Natural frequency, Position of openings.

1. Introduction

High rise building is a structure vertically cantilevered from the ground level subjected to axial loading and lateral forces. It consists of frames, beams, shear walls, core walls, and slab structures which interact through their connected edges to distribute lateral and vertical load imposed to the building. Lateral forces generated either due to wind blowing against the building or due to the inertia forces induced by ground shaking which tend to snap the building in shear and push it over in bending. These types of forces can be resisted by the use of shear wall system which is one of the most efficient methods of ensuring the lateral stability of tall buildings. For high rise building, frame action obtained by the interaction of slabs and columns is not adequate to give the required lateral stiffness. It also has become an uneconomical solution for tall buildings. However it can be improved by strategically placing shear walls as it very effective in maintaining the lateral stability of tall buildings under severe wind or earthquake loading. The shear wall can be provided with opening or without opening according to the architectural requirement.

2. Objectives

i. To carry out the analysis of shear wall with & without opening, using FEM tool & study
ii. The results from simple and more complex FEM models of shear wall with and without opening
iii. Key aspects for study include type of element used, level of refinement of mesh.
iv. The deflections of shear wall with respect to the percentage of opening.
v. The effect of change in position of opening in the shear wall with respect to deflection.
vi. The natural frequency of simple and more complex FEM models.
vii. Effect of size of opening & position of opening on stresses.
viii. Effect of opening when provided in staggered opening form with reference to each story level in shear wall.

3. Analytical Work

The tool used for analysis is ANSYS.12 software. There are many types of elements available in Ansys Software. The following elements are used for the analysis of the present work.

(a) Plane2:-

Plane2 has quadratic displacement behavior and is well suited to modeling irregular. The element may be used as a plane element (plane stress, plane strain and generalized plane strain).

(b) Plane 42

Plane42 is used for 2-D modeling of solid structures. The element can be used either as a plane element (plane stress or plane strain) or as an axisymmetric element. The element is defined by four nodes having two degrees of freedom at each node: translations in the nodal x and y directions.

(c) Plane 82

Plane82 is a higher order version of the 2-D, four-node element (Plane42). It provides mixed (quadrilateral-triangular) automatic meshes and can tolerate irregular shapes without as much loss of accuracy. The 8-node element is defined by eight nodes having two degrees of freedom at each node: translations in the nodal x and y directions. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

4. Methodology

The work is carried out in two parts namely static & modal analysis

a) Static Analysis: - The Shear wall is modeled using 3-noded triangular element (Plane 2), 4-noded quadrilateral element (Plane 42) & 8-noded quadrilateral element (Plane 82) with three stages of refinement of mesh for plane stress condition. The results obtained are considering the effect of openings.

b) Modal Analysis: - Natural frequency & mode shapes of all models with or without opening are compared & percentage of difference is calculated.

Table 1. Description of models

Type of opening	Model	Description of opening	Remark
No Openings	A	-	
Single window opening of size (a x 0.9 m)	B1	1.0 m x 0.9 m	Opening is symmetrical about vertical axis of symmetry (ćaô is width of opening)
	B2	1.2 m x 0.9m	
	B3	1.4 m x 0.9 m	
	B4	1.6 m x 0.9 m	
	B5	1.8 m x 0.9m	
	B6	2.0 m x 0.9 m	
	B7	2.2 m x 0.9 m	
	B8	2.4 m x 0.9m	
	B9	2.6 m x 0.9 m	
	B10	2.8 m x 0.9 m	
	B11	3.0 m x 0.9m	
Two Openings (Door 1.2m x 2.1 m & varying window size b x 0.9 m)	C1	1.2 m x 2.1 m & 1.0 m x 0.9 m	Opening centre is at Lĉ/2 (ćbô is width of opening)
	C2	1.2 m x 2.1 m & 1.2 m x 0.9 m	
	C3	1.2 m x 2.1 m & 1.4 m x 0.9 m	
	C4	1.2 m x 2.1 m & 1.6 m x 0.9 m	
	C5	1.2 m x 2.1 m & 1.8 m x 0.9 m	
	C6	1.2 m x 2.1 m & 2.0 m x 0.9 m	
	C7	1.2 m x 2.1 m & 2.2 m x 0.9 m	
	C8	1.2 m x 2.1 m & 2.4 m x 0.9 m	
Varying the position (c) of door (1.2 x2.1m) & window (1.5 x 0.9m) opening	D1	d = -2.0 m	ćdô is the distance between the door opening from vertical axis of wall
	D2	d = -1.5 m	
	D3	d = -1.0 m	
	D4	d = 2.0 m	
	D5	d = 1.5 m	
	D6	d = 1.0 m	
Varying the position of window (1.5 x 0.9m) opening	E1	e = -1.25 m	centre of opening at a distance ćeô from vertical axis of wall
	E2	e = -0.75 m	
	E3	e = -0.25 m	
	E4	e = 0.0 m	
	E5	e = 1.25 m	
	E6	e = 0.75 m	
	E7	e = 0.25 m	
Staggered position of window (1.5 x 0.9m) opening	F1	f = -1.45 m	centre of opening at a distance ćfô from vertical axis of wall
	F2	f = -1.25 m	
	F3	f = -0.75 m	
	F4	f = 0.0 m	
	F5	f = 0.75 m	
	F6	f = 1.25 m	
	F7	f = 1.45 m	

(A) Modeling

A building having overall dimension of 20 m x 13.5 m as shown in Fig. 1 is selected for the study. It has ten floors [G+9], total height of building 35.0 m; two shear wall in X-direction on exterior face have been provided having width of shear wall 5.0 m & floor height 3.5 m. The shear wall for building is modeled as a cantilever wall having fixed support at the base. It is subjected to axial & lateral load calculated by seismic coefficient method. The shear wall is modeled using Plane2, Plane 42 & Plane 82 element. The refinement of mesh in each case is carried out by increasing the numbers of elements in three steps by erefine0. Then erefine1in which number of elements increased four times than erefine0 & erefine2-number of elements increased four times than erefine1 to see the effect of refinement in mesh with respect to deflection.

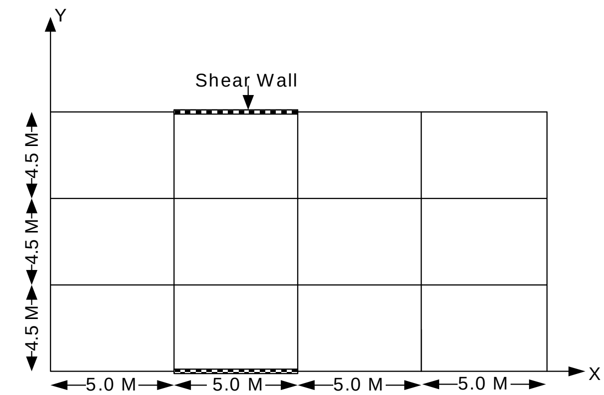


Figure 1. Plan of building

(B) Shear Wall Models

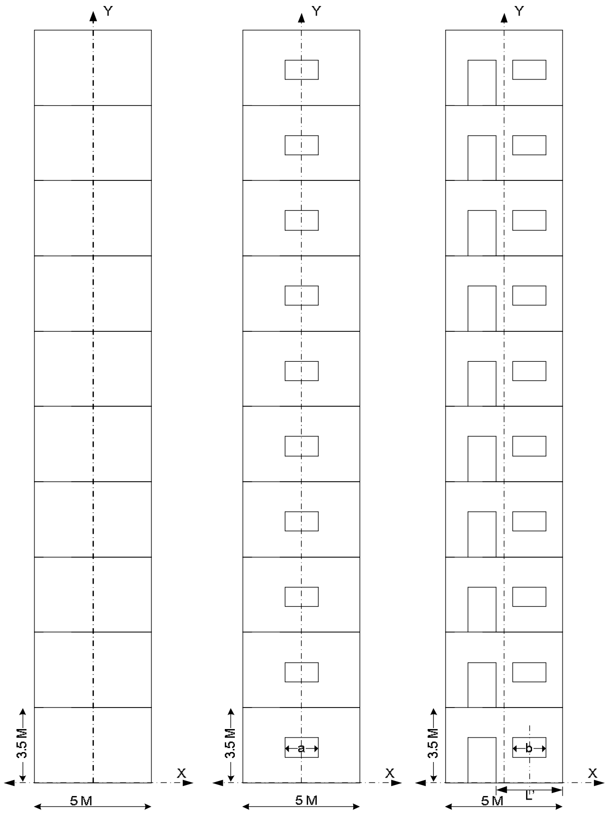
While modeling the material properties of concrete are considered as follows

Density of concrete : 2500N/m 3
Poissonĝs ratio : 0.17
Youngĝs modulus of elasticity : 22 kN/m2

The study covers the behaviour of the shear wall with respect to change in percentage of opening, change in position of openings, effect is also studied when openings are provided in a staggered form with reference to each story level.

The models are classified into six series, depending on the arrangements of its openings as tabulated in table 1

(i) Model A: - No openings
(ii) Model B: -Single band of symmetric opening of size (a x 0.9 m) where ćaô varies from 1.0m to 3.0m with an increment of 0.2 m.



a) Model A **b)** Model B **c)** Model C
Figure 2. Shear Wall Models

(iii) Model C: - Two band of opening, consisting of door opening of size (1.2 m x 2.1 m) at constant position & varying window position (b x 0.9 m) where b varies from 1.0 m to 2.4 m with an increment of 0.2 m.

(iv) Model D: - Varying the position of door & window having size 1.2 m x 2.1 m & 1.5 m x 0.9 m respectively.

(v) Model E: - Varying the position of window opening having size 1.5 m x 0.9 m.

(vi) Model F: - Opening of size 1.5 m x 0.9 m with reference to each story level.

5. Results and Discussions

The analysis of results is focused on the deflections, stresses & mode shapes of shear wall.

(A) Deflections

The analysis is carried out for all the models to study the effect of deflection due to change in percentage of opening & change in position of opening.

(a) Deflections for Model A, B & C

The deflections were measured at all the storey level at left & right side of the wall and the maximum deflections are tabulated for all cases of model A, B, C. These results of deflection include results for model generated using 6-noded triangular element (Plane 2), 4-noded quadrilateral element (Plane 42) & 8-noded quadrilateral element (Plane 82) with refinement in 3 stages erefine0, erefine1 (four times of erefine0) & erefine2 (four times of erefine1). For model B and C shown in Fig. 3 & Fig. 4. , it is seen that as we go for higher order element the deviation of deflection obtained is not much significant with the refinement of mesh in each of the element. The variation of deflection of erefine0 mesh to erefine2 mesh of same element is small about 2 to 3% for ten story building.

Standard deviation of deflection for model A is 0.17 mm. Standard deviation of deflection for model B varies from 0.184-0.280 mm & for model C from 0.307-0.567 mm.

For the model C7 & C8 of category C where % of opening is greater than 25% the deviation is slightly more with the maximum value of deflection being 27.76 mm for plane 82 erefine2 & 24.77 mm for plane 42 erefine0. Hence refinement of the mesh & higher order element may be recommended when the opening in the wall is above 25%

Also the variation of deflection of shear wall with no opening & with single opening is very less when the width of opening is less. As the number of opening increases the deflection in the wall is increased as model C having two openings in the wall.

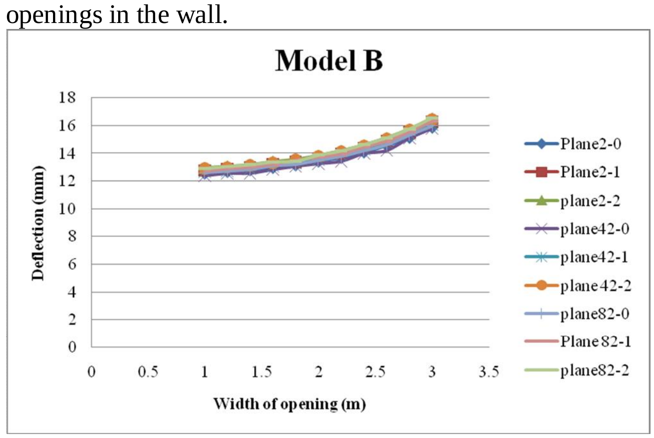


Figure 3. Width of Opening Vs Deflection for Model B

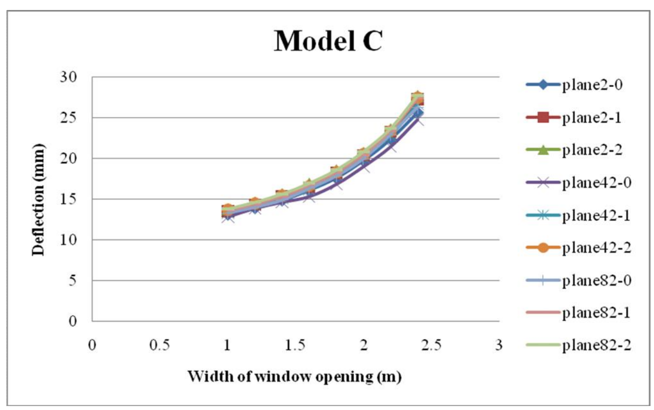


Figure 4. Width of Opening Vs Deflection for Model C

A result of analysis of Plane 2, Plane 42 & Plane 82 element gives nearly same deflection as shown in Fig.3 & Fig. 4

(b) Deflection for Model D, E & F

Further study of effect of change in position of the openings has been carried out by considering all three

ISSN:2319-6890(online),2347-5013(print)
27-28 Feb. 2016

elements with erefine2 mesh. To consider the effect of change in position of a two opening, the opening of size 1.2 m x 2.1 m & 1.5 m x 0.9 m which is a general size of a door & window opening has been considered. The positioning of the opening is varied such that the distance of the door opening from the centroidal vertical axis of the wall varies in x-direction. The results of deflection for this condition are shown in Fig. 5

Considering fact that the lateral load can be either in x-direction or negative x-direction, the deflections have been compared for the cases where the position of the openings in the shear wall having mirror image with respect to vertical centroidal axis of the shear wall. For varying door & window position (Model D). In this case when door

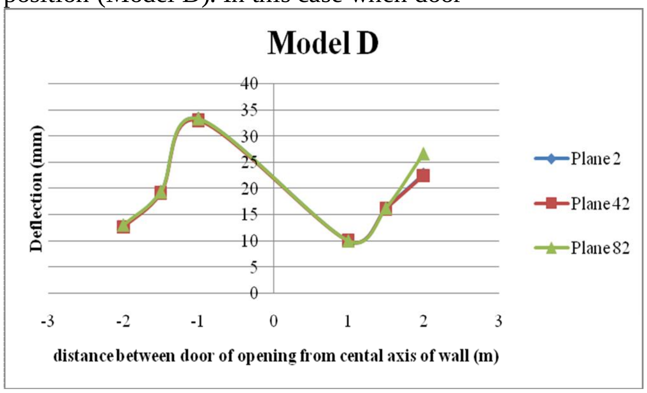


Figure 5. Position of Opening Vs Deflection for Model D

is placed at a distance -2.0 m from vertical axis of the wall (Model D1) deflection is 13.047 mm & mirror image of openings i.e model D6 deflection is 26.681mm.

As the lateral load can be act from any direction. So we find the minimum difference in deflection and that will exist when door is placed at a distance -1.5 m from vertical axis of the wall (Model D2) with the vertical axis of the wall. At this position moment of inertia of right side of wall with opening is equal to the moment of inertia of right side of wall.

Further study to consider the effect of change in position of a single opening, the opening of size 1.5 m x 0.9 m which is a general size of a window opening has been considered. The results are shown in Fig.6. The positioning of the opening is varied such that the distance of the centre of opening from centroidal vertical axis of the wall varies from -1.25m to 1.25 m in the increment of 0.5m.

It is validated in varying the window position (Model E). As in Model E1 & Model E7 distance between axis of moment of inertia & axis of shear wall is more, therefore difference in deflection is also more. It goes on reducing as axis of moment of inertia coincides with the axis of shear wall i.e Model E4.

Further in Model F opening of size 1.5 m x 0.9 m provided in a staggered form with reference to each story level. The positioning of the opening is varied such that the distance of the centre of opening from centroidal vertical axis of the wall varies in x- direction

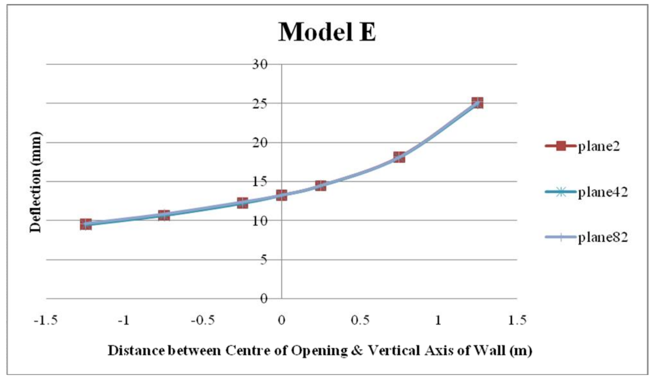


Figure 6. Position of Opening Vs Deflection for Model E

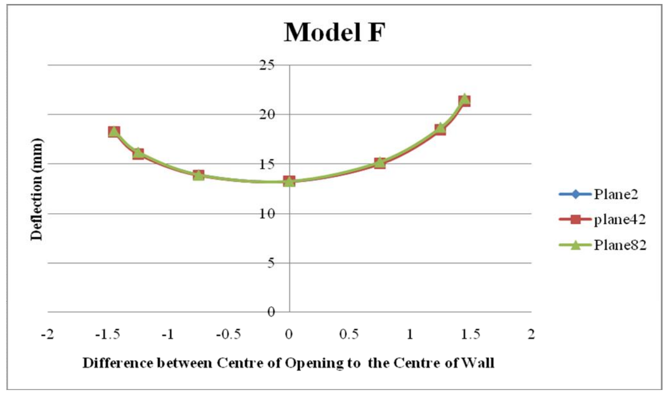


Figure 7. Position of Opening Vs Deflection for Model F

Model F has single opening provided in a staggered form with reference to each story level

It is observed that as the horizontal distance between the openings of floor becomes less, the deflection of shear wall is less as shown in Fig.7. It is slightly greater than the single opening case is placed at the central position of wall in the entire storey (model E4). For architectural requirement opening has to be provided in staggered form then they should be placed at the closest distance between each other.

(B) Stress Analysis:-

The analysis is carried out for all the models to study the effect of stress due to change in percentage of opening & change in position of opening.

(a) Stresses for model B & C

The effect of the change in opening size on the stresses occurring in the shear wall is studied by observing the stress pattern around the openings. The maximum stress for nearly all the cases is observed near the opening at the bottommost level. The maximum stresses around the opening for all the cases are calculated as shown in Fig.8.

It is observed in model B that as percentage of opening increases from the central axis of the wall, the stress increases. This variation is can be approximated as linear variation from 5.295N/mm2 for model B1 to 10.97 N/mm2 for model B11. In model C, the opening of door is kept same for all the cases & window opening is increases. As a

ISSN:2319-6890(online),2347-5013(print)
27-28 Feb. 2016

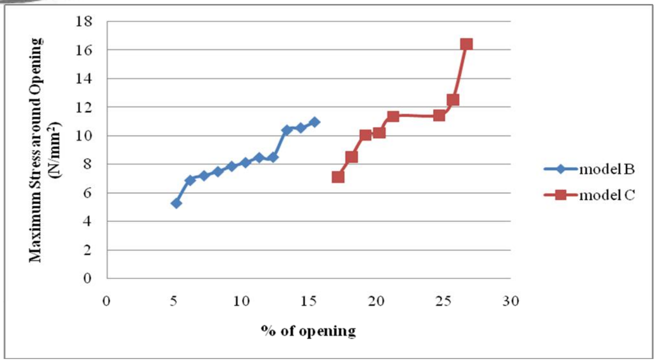


Figure 8. Percentage of Opening Vs Maximum Stress around Opening for Model B & C

result of this the variation of the opening takes place in right side of the shear wall. For model C1 to C4 amount of opening in the left side of wall is much more than amount of opening in the right side of the wall.

As the opening in right side crosses the lines of symmetry of shear wall the amount of the opening on the left hand side also increases. Hence, the maximum stress is found to have a uniform linear variation & later the stress increases non-linearly, abrupt increase in the stress when the percentage of opening exceeds 25%.

(b) Stresses for model D,E & F

The effect of position of the opening on the stresses occurring in the shear wall is studied by observing the stress pattern around the openings. The maximum stress for all the cases is observed near the opening at the bottommost level for model D & E and at ground story & first story for model F are shown in Fig. 9.

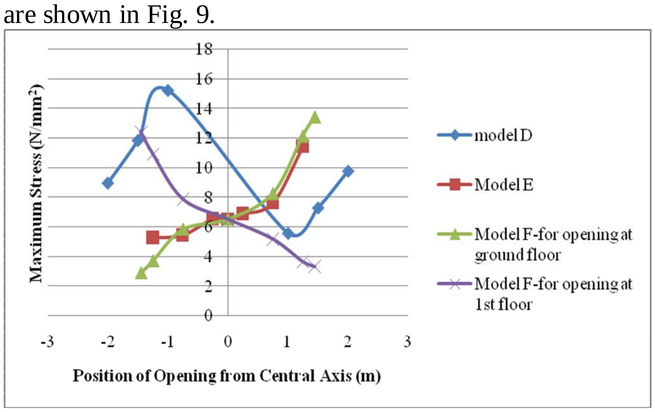


Figure 9. Percentage of Opening Vs Maximum Stress around Opening for Model D,E & F

Considering the fact that the lateral load can be either in x-direction or negative x-direction. The deflections have been compared for the cases where the position of the openings in the shear wall having mirror image with respect to vertical centroidal axis of the shear wall.

For varying door & window position (Model D). In this case when door is placed at a distance -1.0 m from vertical axis of the wall (Model D3) maximum stress around opening is 15.24 N/mm2 & mirror image of opening i.e model D5 stress is 5.58 N/mm2 as lateral load can be act from ant direction. So we find the minimum difference between maximum stresses around the opening and that will exist when door is placed at a distance -2.0 m from vertical axis of the wall.

Similarly, for varying window position (Model E). We find the minimum difference between maximum stresses around the opening and that will exist when centre of opening is coinciding with vertical axis of the wall (Model E4). Further in Model F opening of size 1.5 m x 0.9 m provided in a staggered form with reference to each story level. The positioning of the opening is varied such that the distance of the centre of opening from centroidal vertical axis of the wall. It is observed that the horizontal distance between the opening of floor becomes less, the maximum stresses around opening is less.

(C) Modal Analysis:-

Free Vibration Analysis is done on all the models, the mode shapes and natural frequencies for each mode are determined. The natural frequencies for first 3 modes of each model and also percentage differences of natural frequency for each mode of each model compared to Model A. Model A was chosen as the denominator due to its simplicity. The percentage of differences is calculated using:

$$\% Difference = \left| \frac{f_{\mathrm{mod}\,elA} - f_{\mathrm{mod}\,eli}}{f_{\mathrm{mod}\,elA}} \right|$$

Fig.10 & Fig.11 shows the results obtained for the models created to see the effects of size of openings, effect of refinement. The effect of type of element is also considered and there is no variation in the results. The percentage difference of natural frequency between mode1 (M1) of each model B and model A is very small.

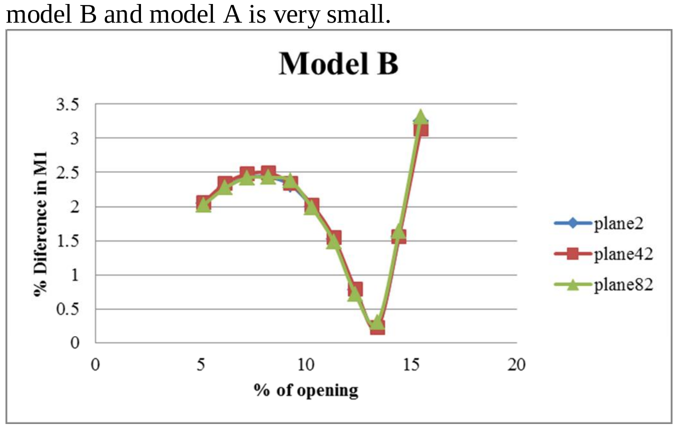


Figure 10. Percentage difference in M1 Vs Percentage of opening for Model B

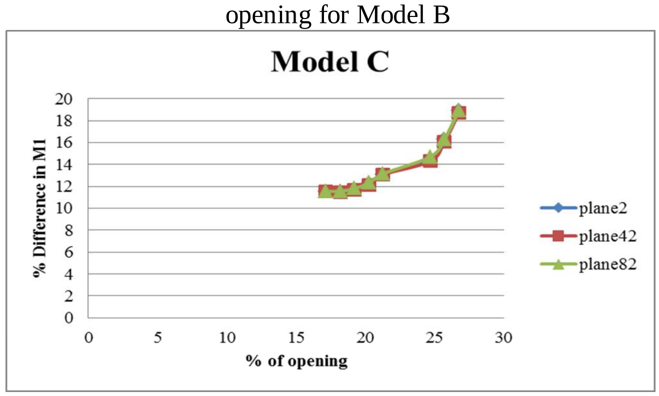


Figure 11. Percentage difference in M1 Vs Percentage of opening for Model C

ISSN:2319-6890(online),2347-5013(print)
27-28 Feb. 2016

As seen Fig. shows when % of opening is increased its percentage of difference in mode1 goes on increasing with percentage of opening upto certain limit (i.e. upto 8.23%). Later, increase in opening percentage causes much decrease in percentage difference in mode1 and reaches the minimum (i.e. 13.37 %). Further increase in percentage of opening results abrupt change in percentage of difference in mode1 and it attains the maximum percentage difference mode1 (i.e 3.3 %).

The percentage difference of natural frequency between mode 1 of each model C and model A is more than between model B. The highest natural frequency for mode 1 is 2.3106 from model C1 in which percentage of opening is 17.14%. The lowest value is 2.1176 from model C8 in which percentage of opening is 26.74%. The maximum difference is thus about 8%.

Thus results from plane2, plane 42 & plane 82 elements shows same behavior of percentage of difference in mode1 with change in percentage of opening. Highest or lowest Percentage of openings does not necessarily yield highest or lowest value of natural frequency. Thus, the free vibration analysis requires less refined mesh and gives same result that of more refined mesh.

6. Conclusions

1. It was observed that as we go for higher order element the deviation of deflection obtained is not much significant with the refinement of mesh. The variation of deflection of erefine0 mesh to erefine2 mesh of same element is small about 2 to 3% for ten story building. Hence, there is no significant difference in terms of Deflection of shear wall by using higher order element or fine refinement.
2. Considering the fact that the lateral load can be either in x-direction or negative x-direction, it was observed that if opening were positioned in such a way that M.I of right side of shear wall is equal to M.I of left side of shear wall deflection & stresses around the opening of wall were less than any other position.
3. It was observed from the results plane2, plane42 & plane82 elements that the highest or lowest percentage of openings does not necessarily yield highest or lowest value of natural frequency. Thus, the free vibration analysis requires less refined mesh and it gives same result as that of more refined mesh.
4. For opening provided in staggered fashion, it was observed that as the horizontal distance between the openings of adjacent floor becomes less, the deflection and stresses around the opening of shear wall become less.

REFERENCES

i. *Arnot, K. Shear Wall Analysis-New modelling, Journal of Structural Engineering- February 2005. Also in CSC (UK) Ltd., February*

ii. *M. Shariq, H. Abbas, H. Irtaza, M. Qamaruddin. Influence of Openings on Seismic Performance of Masonry Building Walls: Building and Environment 43 (2008) 1232-124*

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

iv. *M. Paknahad, J. Noorzaei, M.S. Jaafar, Waleed A. Thanoon. Analysis of Shear Wall Structure using Optimal Membrane Triangle Element: Finite elements in analysis and design 43 (2007) 861-869.*

v. *Hui Wu & Bing Li. Investigating the Load Paths of RC Shear Wall with Openings under Reversed Cyclic Loadings: Pacific conference on Earthquake Engineering (2003) 123-131*

vi. *Hong Guan, Carlia Cooper, Dong-Jun Lee. Ultimate Strength Analysis of Normal and High Strength Concrete Wall Panels with Varying Opening Configurations: Engineering Structures 32(2010) 1341-1355*

vii. *Masato Sakurai, Hiroshi Kuramoto, Tomoya Matsui And Tomofusa Akita. Seismic Performance of RC Shear Walls with Multi-Openings: Proceedings of the 14th World Conference on Earthquake Engineering October 12-17, 2008*

viii. *Fernando Yanez, Maximiliano Astroza, Augusto Holmberg, Oscar Ogaz. Behavior of Confined Masonry Shear Walls with Large Openings: 13th World Conference on Earthquake Engineering (2004) Paper No. 3438*

ix. *M Qamaruddin. In-Plane Stiffness of Shear Walls with Openings: Building Environment 34(1999) 109-127*