

Effect of Openings in Shear Wall on Seismic Response of Frame Shear Wall Structures

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Abstract: *The reinforced concrete shear wall is important structural elements placed in multi-storey buildings which is situated in seismic zones because they have a high resistance to lateral earthquake loads. RC shear walls must have sufficient ductility to avoid brittle failure under the action of strong lateral seismic loads. The adverse effect for tall building is the higher lateral loads due to wind and expected earthquake. Thus shear walls are introduced into modern tall buildings to make the structural system more efficient in resisting the horizontal and gravity loads, ground motions as well thereby causing less damage to the structure during earthquake. Shear walls in apartment buildings will be perforated with rows of openings that are required for windows in external walls or doors ways or corridors in internal walls. It is necessary to know the effects of openings sizes and configurations in shear wall on seismic responses and behavior of structural system so that a suitable configuration of openings in shear walls can be made. Various types of opening may affect the structural ability of the building. Hence it is necessary to evaluate the effect of opening. Moreover there are different types of opening like two band opening, staggered opening and Asymmetric opening. Hence the analysis will help to analyse their structural parameters. Study of effect of the change in aspect ratio of shear wall is also focused here.*

Keywords: shear wall, lateral displacement, storeydrift

1. Introduction

Earthquake is one of the nature's greatest hazards to properties and human lives. It poses a unique engineering design problem. An intense earthquake results in severe loading to which most civil engineering structures may possibly be subjected. The number of earthquakes reported worldwide, are usually followed by enormous death and injury. Not only life but economy is also threatened from this disaster. The approach of engineering design is to design the structures in such a way that it can survive under the most severe earthquakes, during their service lives to minimize the loss of life and the possibility of damage.

The reinforced concrete shear wall is important structural elements placed in multi-storey buildings which are situated in seismic zones because they have a high resistance to lateral earthquake loads. RC shear walls must have sufficient ductility to avoid brittle failure under the action of strong lateral seismic loads. The adverse effect for tall building is the higher lateral loads due to wind and expected earthquake. Thus shear walls are introduced into modern tall buildings to make the structural system more efficient in resisting the horizontal and gravity loads, ground motions as well thereby causing less damage to the structure during earthquake. Shear walls in apartment buildings will be perforated with rows of openings that are required for windows in external walls or doors ways or corridors in internal walls. However the opening sizes in the shear wall building may have an adverse effect on seismic responses of frame-shear wall structures. Relative stiffness of shear walls is important since lateral forces are distributed to the individual shear wall according to their relative stiffness. Simplified methods for stiffness of shear walls with openings are recommended in several design guidelines. It is necessary to know the effects of openings sizes and

configurations in shear wall on stiffness as well as on seismic responses and behavior of structural system so that a suitable configuration of openings in shear walls can be made.

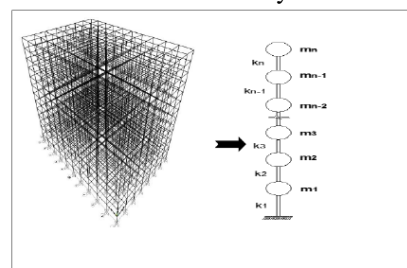
2. Structural Modelling and Analysis

2.1 General

In the present study there are four phases and all the models were modeled and analysed using STAAD Pro V8i, Here for the analysis Equivalent Static analysis Method(EQS) was adopted.

2.2 Equivalent static analysis (esa)

Equivalent Static Analysis (ESA) is linear static analysis in which the response of building is assumed as linearly elastic manner. In this method a three dimensional structure or building is converted into an equivalent lumped mass system with springs connected with them as shown in figure 3.1 and 3.2 The stiffness of the springs is equal to summation of the stiffness of columns of the framed system at that level.



For regular, structure analysis by equivalent linear static methods is sufficient. It includes an estimation of base shear load and its distribution on each story calculated by using formulas given in the code. Equivalent static analysis can therefore work well for low to medium-rise buildings without significant lateral-torsional modes, in which only the first mode in each direction is considered. Tall buildings (over 75 m), where second and higher modes can be important, or buildings with torsional effects, are much less suitable for the method, and require more complex methods to be used in these circumstances. The design base shear shall first be computed as a whole, than be distributed along the height for buildings with regular distribution of mass and stiffness.

2.3 Problem statement and structural modelling

Table 2.1: General Parameters for Analysis

| Sr No. | Particulars | Parameters |
|--------|------------------------------|---|
| 1 | No. of Stories | G+9 |
| 2 | Dimension of Building | 35mx15m |
| 3 | Size of Column | 400mmx600mm |
| 4 | Size of Beam | 300mmx450mm |
| 5 | Shear wall thickness | 275mm |
| 6 | Concrete grade | M20 |
| 7 | Steel grade | Fe415 |
| 8 | Seismic Zone | V(Z=0.36) |
| 9 | Dead load | 5kN/m ² |
| 10 | Live Load | 4kN/m ² 2kN/m ² on top floor |
| 11 | Soil Type | Medium |
| 12 | Response Spectra | As per 1893(Part-1):2002 |
| 13 | Importance Factor(I) | 1 |
| 14 | Response Reduction Factor(R) | 5 |
| 15 | Damping Ratio | 5% |
| 16 | Software used | STAAD Pro V8i |

2.3.1 Material Properties

1. Masonry Density 20 kN/m³
2. RCC
Density 20 kN/m³
Grade of concrete M 20
Poisson's ratio, μ 0.17
Compressive Strength, f_{ck} 20 N/mm²
Young's modulus of Concrete 2.236×10^7 kN/m² ($E_c = 5000 \sqrt{f_{ck}}$)
3. Reinforcement steel
Grade of Steel Fe 415
Young's modulus of Steel 2.1×10^5 N/mm²

2.3.2 Member properties

Initial, member sizes are considered for analysis
 Column 400 x 600 mm (for all columns)
 Beams 300 x 450 mm (for all beams)
 Slab thickness 160 mm
 Wall thickness 200 mm

2.3.3 Support Conditions

All Support conditions for all columns assigned as fixed.

2.3.4 Applying loads

The following loads are considered in structural analysis

2.3.4.1 Dead Loads

Loads of walls, slabs have been calculated and applied in Staad pro as an input for the analysis.

Floor load (Self weight of slab) = $0.16 \times 25 = 4$ kN/m²
 (floor finish) = 1 kN/m²
 Total = 5 kN/m²

Wall load (200 mm thick external walls) = $2.5 \times 0.2 \times 20 = 10$ kN/m

b. Live Loads

Live load (AS per IS 875-1987(part2) = 4.00 kN/m²
 (business and office building, rooms without separate storage)

2.4 Load Cases and Load Combinations

The following load cases and load combinations were considered for the structural analysis and design.

2.4.1 Load Cases

LOAD 1 SEISMIC LOAD ($\pm X$)

Design horizontal Seismic Coefficient (A_h) has been calculated as per IS 1893: 2002 (part 1) and applied in Staadpro along ($\pm X$) - direction.

LOAD 2 SEISMIC LOAD ($\pm Z$)

Design horizontal Seismic Coefficient (A_h) has been calculated as per IS 1893: 2002 (part 1) and applied in Staadpro along (+Z) - direction.

LOAD 3 DEAD LOAD

Dead load of walls, slabs were calculated and applied in the Staadpro software. But the self weight of beams and columns were taken in account through the Staadpro software command " self weight GY-1"

LOAD 4 LIVE LOAD

Live load were applied as per IS 875-1987(part-2)

2.4.2 Load Combination for SLS (Serviceability Limit State)

LOAD COMB 5 1.0 DL + 1.0 LL

LOAD COMB 19 1.0 DL + 1.0 LL + 1.0 EQ(+X)

LOAD COMB 20 1.0 DL + 1.0 LL + 1.0 EQ(-X)

LOAD COMB 21 1.0 DL + 1.0 LL + 1.0 EQ(+Z)

LOAD COMB 22 1.0 DL + 1.0 LL + 1.0 EQ(-Z)

LOAD COMB 23 1.0 DL + 1.0 EQ(+X)

LOAD COMB 24 1.0 DL + 1.0 EQ(-X)

LOAD COMB 25 1.0 DL + 1.0 EQ(+Z)

LOAD COMB 26 1.0 DL + 1.0 EQ(-Z)

2.4.3 Load Combination for ULS (Ultimate Limit State)

LOAD COMB 6 1.5 DL + 1.5 LL

LOAD COMB 7 1.5 DL + 1.5EQ(+X)

LOAD COMB 8 1.5 DL + 1.5EQ(-X)

LOAD COMB 9 1.5DL + 1.5EQ(+Z)

LOAD COMB 10 1.5 DL + 1.5EQ(-Z)

LOAD COMB 11 1.2 DL + 0.6LL + 1.2EQ(+X)

LOAD COMB 12 1.2 DL + 0.6LL + 1.2EQ(-X)

LOAD COMB 13 1.2 DL + 0.6LL + 1.2EQ(+Z)

LOAD COMB 14 1.2 DL + 0.6LL + 1.2EQ(-Z)

LOAD COMB 15 0.9 DL + 1.5 EQ(+X)

LOAD COMB 16 0.9 DL + 1.5 EQ(-X)

LOAD COMB 17 0.9 DL + 1.5 EQ(+Z)

LOAD COMB 18 0.9 DL + 1.5 EQ(-Z)

The general plan structure with and without shear wall is shown in the figure 3.3 and 3.4 respectively.

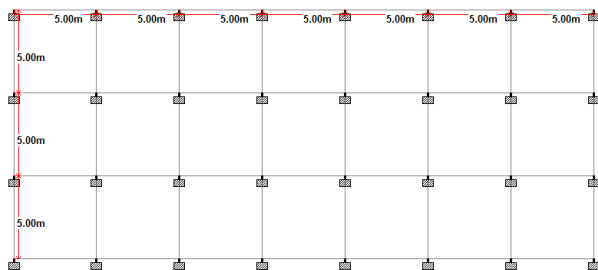


Figure 2.3: General plan of the structure without shear wall

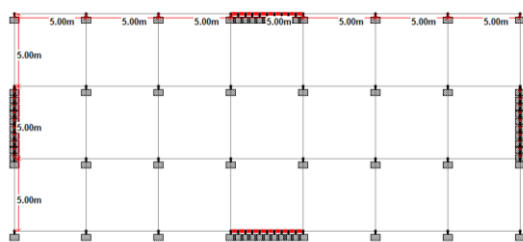


Figure 2.4: 3 General plan of the structure with shear wall

2.5 Phases and Models

The analysis is divided in general into three phases. In that, phase I consists of 4 models, model 1 Bare frame structure, model 2 frame with shear wall, model 3 shear wall frame with 12% opening, model 4 shear frame with 30% opening. In phase II model 5 shear wall frame with aspect ratio 1.4, model 6 shear wall frame with aspect ratio 1.5, model 7 shear wall frame with aspect ratio 1.66 and in phase III model 8 frame with shear wall, model 9 shear wall frame with two band opening

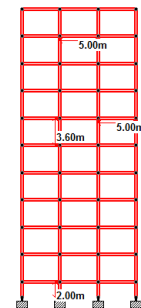
2.5.1 Effect of Increase In opening Area (phase I)

A regular cross-sectional frame of plan area 35*15 sqmetres taken for a G+9 Storey. Here the opening area percentage is

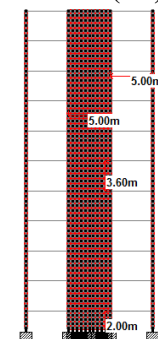
varied by changing the width of opening. Height of opening considered is 2.16m. Height of room is taken as 3.6m. It is shown in table 3.2

Table 2.2: Details about the models considered in phase I

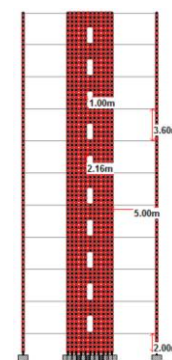
| S. No | Model Number | Width of opening in metre | Opening Area (%) |
|-------|---|---------------------------|------------------|
| 1 | Model 1-Bare Frame(BF) | - | - |
| 2 | Model 2-Frame with shear wall (SW) | 0 | 0 |
| 3 | Model-3 Shear wall frame with 12% opening (12%) | 1 | 12 |
| 4 | Model-3 Shear wall frame with 30% opening (30%) | 2.5 | 30 |



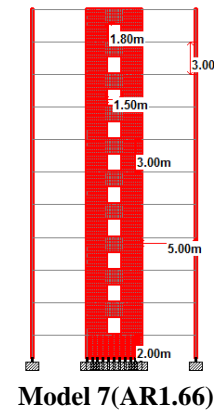
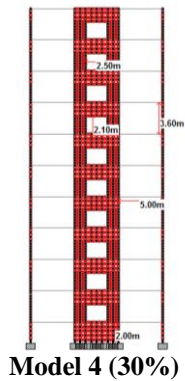
Model 1(BF)



Model 2 (SW)



Model 3(12%)

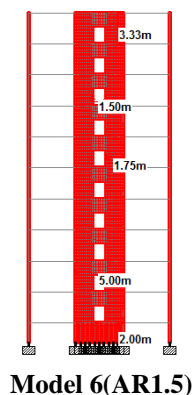
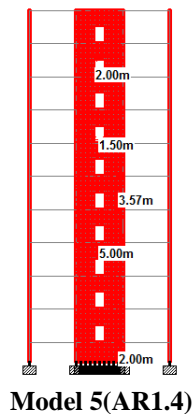


2.5.2 Effect of Aspect Ratio Of Shear Wall (PHASE II)

For a regular cross section of plan area 35*15 sqmetre, aspect ratio of shear wall is changed with a fixed opening percentage of 18%. The width of shear wall is kept fixed at 5m in each case. The various models used in this phase are shown in table 2.3

Table 2.3: Details about the models considered in phase II

| Sr. No. | Model Number |
|---------|---|
| 1 | Model-5 Frame with aspect ratio 1.4 (AR1.4) |
| 2 | Model-6 Frame with aspect ratio 1.5 (AR1.5) |
| 3 | Model-7 Frame with aspect ratio 1.66 (AR1.66) |

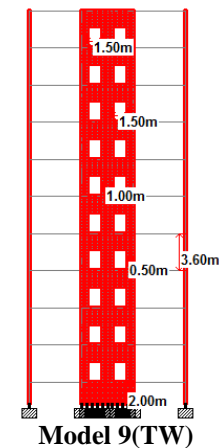
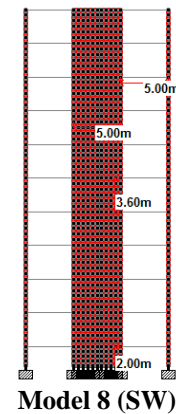


2.5.3 Effect of Type of Opening (PHASE III)

For a regular cross section bay frame of plan area 35*15sqm with a fixed opening percentage of 18%, different types of shear wall with openings are modeled. Height of room is 3.6m. The various models used in this phase are shown in table 2.4.

Table 2.4: Details about the models considered in phase III

| Sr.No. | Model Number |
|--------|---|
| 1 | Model-8 Frame with shear wall (SW) |
| 2 | Model-9 Frame with two band Opening (TB) |
| 3 | Model-10 Frame with asymmetric Opening (AS) |
| 4 | Model-11 Frame with staggered Opening (ST) |



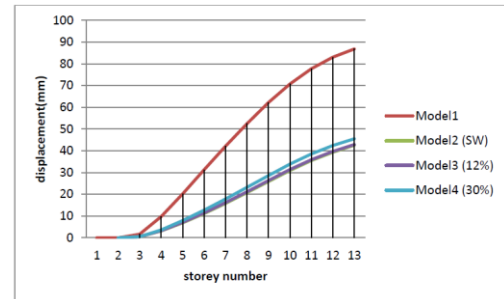
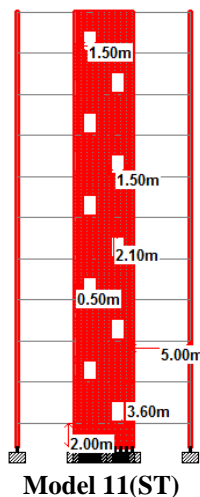
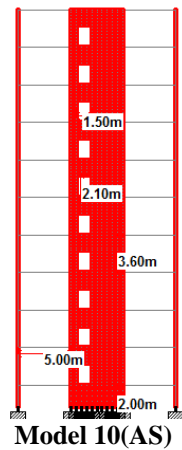


Figure 3.1: Displacement of building in X direction against storey height for different type of models

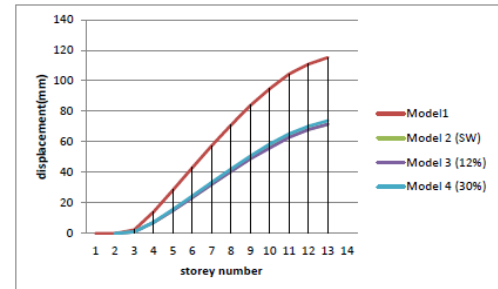


Figure 3.2: Displacement of building in Z direction against storey height for different type of models

Since all the models are fixed at the ground floor, there is no displacement at ground floor. Model 1 shows a maximum deflection in the horizontal direction at the top storey of 86.81 in X direction and 115.29 in Z direction. Similarly Model 2 states 42.55mm and 71.93, Model 3 states 42.85 and 71.5, Model 4 states 45.47 and 73.83 in X and Z direction respectively. As the Shear wall is provided in the model the lateral displacement decreases and it increases when the opening percentage is increased from 12% to 30%.

3. Results and Discussion

3.1 Effect of increase in opening area(phase1)

3.1.1 Lateral displacement

Displacement profile of a structure represents the interaction of flexibility of its different components i.e. column, beam. But the presence of shear walls provides extra rigidity to the frame against lateral forces, thereby reducing the horizontal displacements. The plot of displacement vs story height is shown for various models. As seen from the table displacement is increased as the storey height is increased. This graph is plotted base on linear response of structure. When the shear wall is provided in the structure the displacement is considerably reduced in the structure. When various opening percentage from 12%-30% is incorporated in the given model then again displacement increases gradually.

The maximum lateral displacement for load combination no.(19) (D.L+ LL+EQX) along X-axis and Storey number and Load combination in Fig-3.1 and Fig-3.2 respectively.

3.1.2 Storey Drift

Storey drift is the displacement of one level relative to the other level above or below. As per Clause no. 7.11.1 of IS 1893 (Part 1): 2002, the storey drift in any storey due to specified design lateral force with partial load factor of 1.0, shall not exceed 0.004 times the storey height. Graph is plotted between Storey Drift for Load combination no. (19) (D.L+LL+EQX) along X-axis and Storey number and Load combination no.(21) along Z-axis (D.L+LL+EQZ) and Storey number as shown in Fig-3.3 and Fig-3.4 respectively

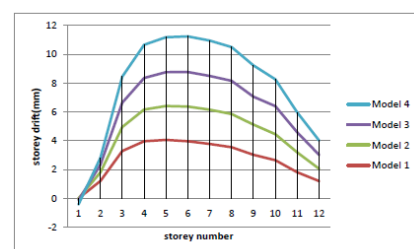


Figure 3.3: Storey drift in mm for load combination 19(D.L+LL+EQX) along X-axis for all models



Figure 3.4: Storey drift in mm for load combination 21(D.L+LL+EQZ) along Z-axis for all models

By comparing the drift values obtained for all models obtained, it could be seen that in models with shear wall the inter storey drift has considerably been reduced when compared to the bare frame model. From figures it is observed that storey drift increases as the height of storey increased and gets reduced at the top floor.

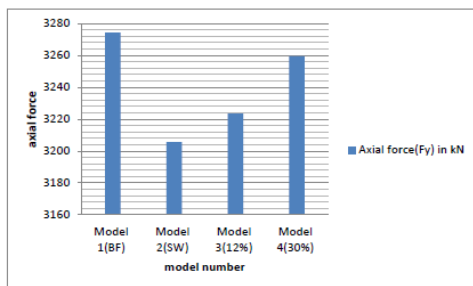


Figure 3.5: Axial Force (F_y) in Column in kN

It can be seen that when the shear wall is provided in the structure the axial force on the column decreases and then gradually increase with the increasing in the opening percentage. There is a decrease of 2% of axial force between model 1 and 2. However for model 3 and 4 the results are comparable.

3.2. Effect of Aspect Ratio Of Shear Wall (Phase II)

3.2.1 Lateral Displacement

The maximum lateral displacement for load combination no.19(D.L+LL+EQX) along X-axis and Storey number and Load combination no.21 along Z-axis (D.L+LL+EQZ) and Storey number are also shown in Fig-3.6 and Fig-3.7 respectively.

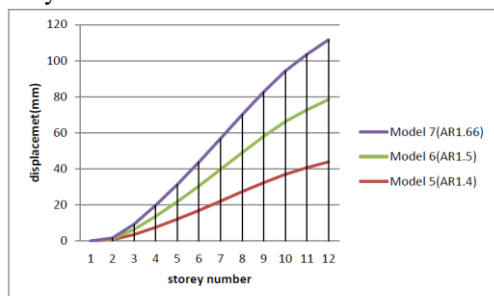


Figure 3.6: Displacement of building in X direction against storey number for different type of models

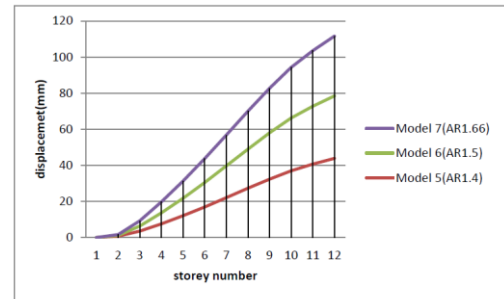


Figure 3.7: Displacement of building in Z direction against storey number for different type of models

Model 5 shows a maximum deflection in the horizontal direction at the top storey of 43.80 in X direction and 72.06 in Z direction. Model 6 shows a maximum deflection of 34.56 and 58.62 in X and Z direction respectively. Model 7 shows a maximum deflection of 33.20 and 58.72 in X and Z direction respectively. There is a 21% and 18.6% decrease in lateral displacement between model 5 and 6 in X and Z direction respectively. From model 6 to 7 there is a decrease of 4% and same lateral displacement in X and Z direction respectively. The lateral displacement variation between model 5 and model 7 is 24% and 18.6% in X and Z direction respectively. It shows that as the aspect ratio increases the lateral displacement decreases in both the direction for the given model.

3.2.1 Storey Drift

Graph is plotted between Storey Drift for Load combination no.19(D.L+LL+EQX) along X-axis and Storey number and Load combination no.21 along Z-axis 21(D.L+LL+EQZ) and Storey number as shown in Fig-3.8 and Fig-3.9 respectively.

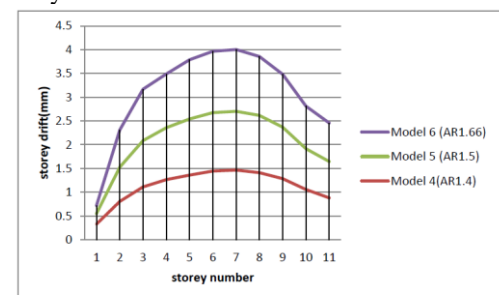


Figure 3.8: Storey drift in mm for load combination 19(D.L+LL+EQX) along X-axis for all models

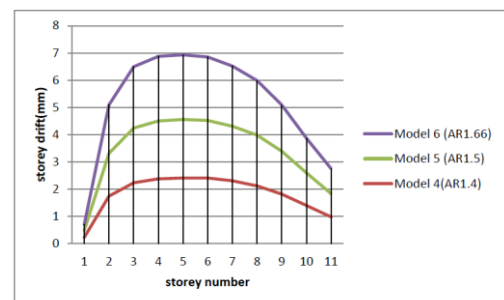


Figure 3.9: Storey drift in mm for load combination 21(D.L+LL+EQZ) along Z-axis for all models

By comparing the drift values obtained for all models obtained, it could be seen that maximum storey drift of model-5, 6, 7 are evaluated about 1.46 mm, 1.24 mm and 1.3 mm along X-axis and 2.4 mm, 2.15 mm and 2.37 mm along Z-axis respectively. There is a decrease of 15% and 10.4% drift in X and Z direction respectively from model 5 to 6. From model 6 to 7 the increase in X and Z direction respectively are 4.6% and 9.2%. Similarly the decrease in drift between model 5 and 7 in X and Z direction respectively are 11% and 1.2%. From Fig-3.8 and Fig-3.9, it has been observed that the best model to resist earthquake is Model-6 with the minimum storey drift for overall building. As the aspect ratio increases the peak drift decreases. Bar chart representing the same is also drawn in the fig:3.10

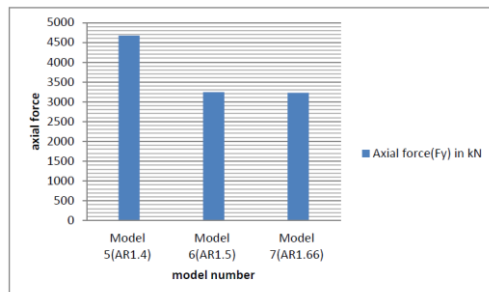


Figure 3.10: Axial Force (Fy) in Column in kN

Figure states that column axial force is the maximum for model 5 and least for model 3. Maximum axial forces in columns is seen to decrease with increase in wall ratio.

3.3 Effect of Type of Opening (phase iii)

3.3.1 Lateral Displacement

The maximum lateral displacement for load combination no.(19)(D.L+LL+EQX) along X-axis and Storey number and Load combination no. (21) along Z-axis (D.L+EQZ) and Storey number are also show in Fig-3.11 and Fig-3.12 respectively

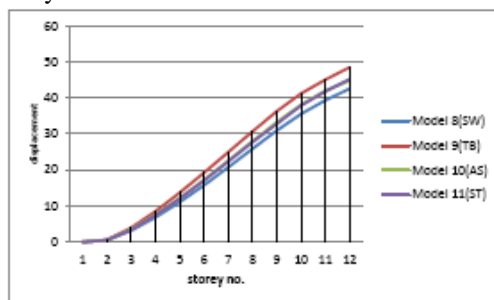


Figure 3.11: Displacement of building in X direction against storey number for different type of models

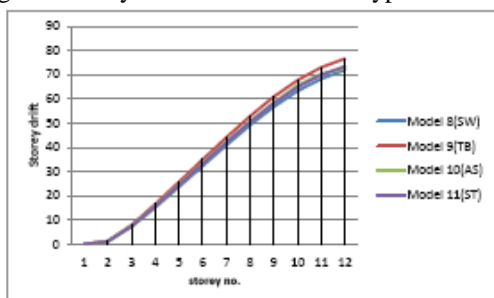


Figure 3.12: Displacement of building in Z direction against storey number for different type of models

Model 8 shows a maximum deflection in the horizontal direction at the top storey of 42.55 in X direction and 71.93 in Z direction. Model 9 shows a maximum deflection of 48.48 and 76.65 in X and Z direction respectively. Model 10 shows a maximum deflection of 44.85 and 72.5 in X and Z direction respectively. Model 11 shows a maximum deflection of 45.18 and 73.42 in X and Z direction respectively. There is a 12.2% and 6.2% increase in lateral displacement between model 8 and 9 in X and Z direction respectively. From model 8 to 10 there is an increase of 5.4% and 1% lateral displacement in X and Z direction respectively. The lateral displacement increase between model 8 and model 11 is 6.2% and 2% in X and Z direction respectively. It can be seen that least deflection among model 9, 10 and 11 is for model 10 in both X and Z direction.

3.3.2. Storey Drift

Graph is plotted between Storey Drift for Load combination no. (19) (D.L+LL+EQX) along X-axis and Storey number and Load combination no. (21) along Z-axis (D.L+LL+EQZ) and Storey number as shown in Fig-3.13 and Fig-3.14 respectively.

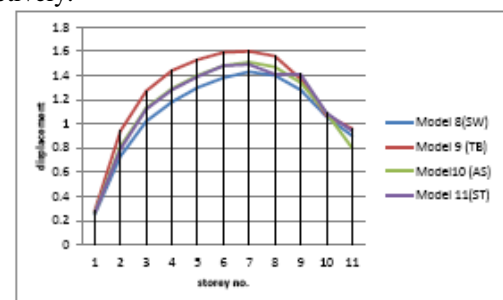


Figure 3.13: Storey drift in mm for load combination 19(DL+LL+EQX) along X-axis for all models

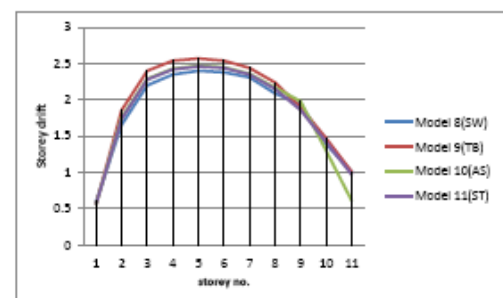


Figure 3.14: Storey drift in mm for load combination 21(DL+LL+EQZ) along Z-axis for all models

By comparing the drift values obtained for all models obtained, it could be seen that maximum storey drift of model-8, 9, 10 and 11 are evaluated about 1.43mm, 1.6 mm, 1.51mm and 1.49mm along X-axis and 2.4 mm, 2.57 mm, 2.47mm and 2.46 mm along Z-axis respectively. There is a 11.8% and 7% increase in storey drift between model 8 and 9 in X and Z direction respectively. From model 8 and 10 there is an increase of 5.5% and 3% storey drift in X and Z direction respectively. The drift increase between model 8 and model 11 is 4.1% and 2.5% in X and Z direction respectively.

3.3.3 Column Axial Force

Bar chart representing the same is also drawn in the fig:4.22

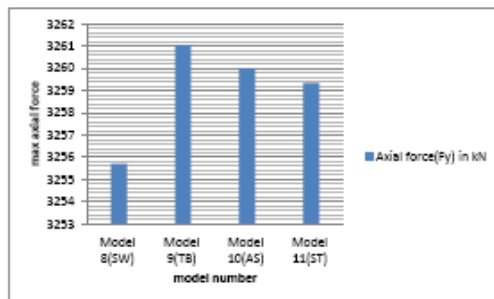


Figure 3.15: Axial Force (Fy) in Column in kN

It can be seen that column Axial force is maximum for Model 3. The increase in column axial force from model 1 to 2, 1 to 3 and 1 to 4 respectively are 0.16%, 0.13% and 0.11%. The results of all the four models are quite comparable to each other.

4. Conclusions

- 1) Among all the load combination, the load combination 19 (DL+LL+EQX) along X-axis and load combination 21 (DL+LL+EQZ) along Z axis is found to be more critical combination for all the models.
- 2) The lateral deflection of the building without shear wall is maximum at 115.29mm. In Phase I, the opening percentage is increased from 12% to 30% lateral displacement increases by around 6.8% and 3.4% in X and Z direction respectively. Peak storey drift increases by around 12% and 2% in X and Z axis respectively.
- 3) When the opening area is increased keeping the height of opening fixed, the results do not vary much. Hence for a height of around 2m, opening area of various percentage can be provided without comprising the structural stability of the structure. Also the functional and aesthetic need of the structure can be satisfied and also the economical aspect of the building can also be kept under the consideration.
- 4) In Phase II, as the Aspect ratio of shear wall increases the lateral displacement decreases along X and Z direction. When the aspect ratio is decreased by around 20%, the lateral displacement decreases by 41.2% along X axis and by 23% along Z axis.
- 5) In phase III, the lateral displacement and peak inter story drift is the least for the asymmetric type of opening and the maximum for the two band type opening. Hence the asymmetric opening is the best among the three models.

References

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