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Elastic and Inelastic Responses of Multi-Storey Buildings Symmetric and Asymmetric in Plan

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Abstract - *The behaviour of high rise building during strong earthquake shaking depends on the distribution of stiffness, strength and mass between the storeys of a building. Regular and irregular buildings are classified based on the distribution of the above parameters either over the height or length or width of a building.*

In this paper, the performance and behaviour of both regular and irregular G+20 reinforced concrete buildings under seismic loading are considered for the study. Two types of irregularities which are in stiffness and mass are considered. Shear walls are provided at different locations. Ductility based design using IS 13920 is carried out. Modeling of building is done using STAAD-Pro V8i and seismic analysis is carried out using response spectrum analysis method. Different parameters like time period, storey displacements, storey drifts and base shear are obtained. By using these parameters a comparative study has been made between regular and irregular buildings.

Key Words: **Ductility, mass irregularity, stiffness irregularity, shear wall, response spectrum method**

1. INTRODUCTION

Earthquake is the wave like motion generated by forces as a result of release of energy in the Earth's crust. This release of energy can be caused by sudden dislocations of segments of crust volcanic eruptions. Earthquake shaking may cause loss of life and destruction of properties.

As per IS 1893, the irregularity in the building structures may be due to irregular distributions in their mass, strength and stiffness along the height or length or width of building. There are two types of irregularities-

1. Irregularities in plan
2. Irregularities over height

2. METHODOLOGY

In this study regular and irregular of reinforced concrete buildings are considered for the analysis namely, structure symmetric in plan with shear walls at different locations and in different directions, structure unsymmetric in plan and structure with mass distribution irregular over height. The structural details of a regular building are shown in tables below.

2.1 Structural details

Table1: Structural details	
Grade of concrete, f_{ck}	M30
Grade of steel, f_{st}	Fe415
Young's modulus of M30 concrete, E	27386.12 N/mm^2
Young's modulus of brick masonry	3.85x10^6 kN/m^2
Concrete density	25 kN/m^3
Density of infill	20 kN/m^3

2.2 Model description

Table 2: Model description	
Number of bays in x-direction	5
Number of bays in z-direction	3
Width of single bay in both the directions	5.0m
Number of storeys	G+20
Height of each storey	3.0m
Depth of foundation	1.5m
Column dimensions	600 mm x 1000 mm
Beam dimensions	300 mm x 600 mm
Infill wall	300 mm thick
Slab	150 mm thick
Shear wall	500mm thick

2.3 Earthquake load details

Table 3: Earthquake load details	
Earthquake Zone	V
Zone factor	0.36
Damping ratio	5%
Importance factor	1
Type of soil	Hard
Type of structure	Special moment resisting frame
Response reduction factor	5

2.4 Loading details

Table 4: Loading details		
Dead load	Floor load	3.75 kN/m^2
	Wall load	18 kN/m^2
Live load	Floor live load	2 kN/m^2
	Roof live load	1 kN/m^2

2.5 Analysis

The modeling and analysis of the building is carried out using STAAD Pro.V8i and the method of seismic analysis used for the present study is response spectrum method.

3. STRUCTURE SYMMETRIC IN PLAN WITH SHEAR WALLS AT DIFFERENT LOCATIONS AND IN DIFFERENT DIRECTIONS

Five types of models are analyzed in this case. Following are the models considered:
Type 1: shear walls placed in the middle parallel to x-direction
Type 2: shear walls placed in the middle parallel to z-direction
Type 3: shear walls placed in the middle in both the directions
Type 4: shear walls placed along the periphery
Type 5: shear walls placed along the periphery in both the directions

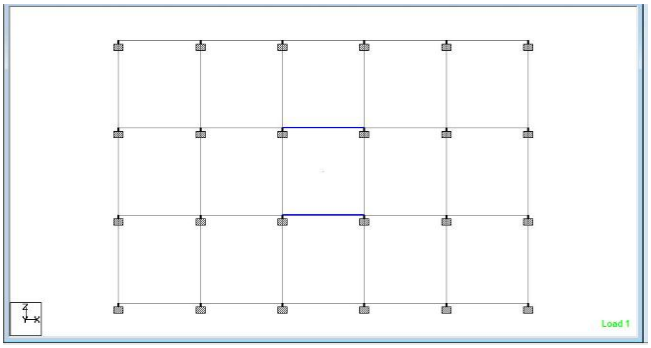

Fig1: Type 1

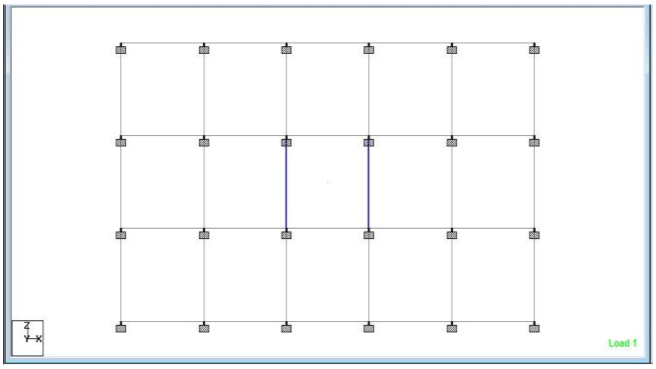

Fig2: Type 2

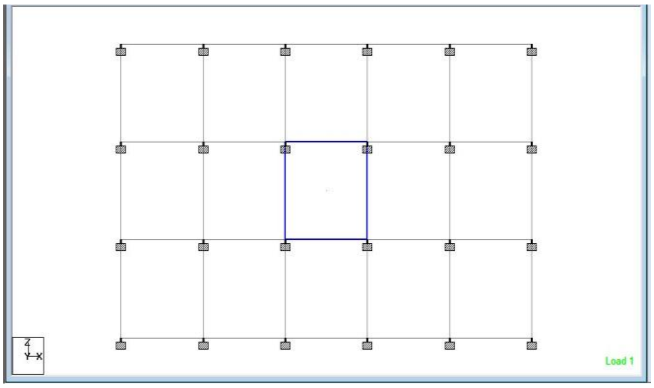

Fig3: Type 3

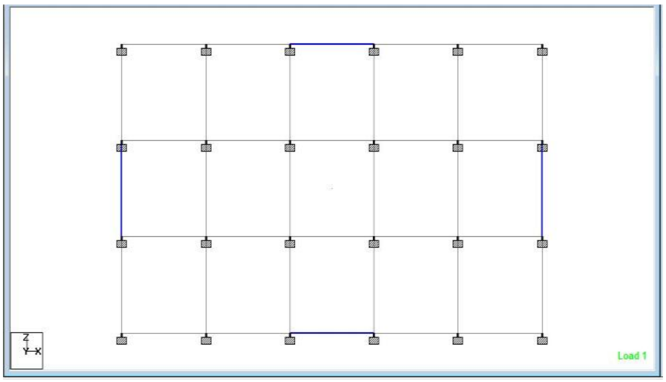

Fig4: Type 4

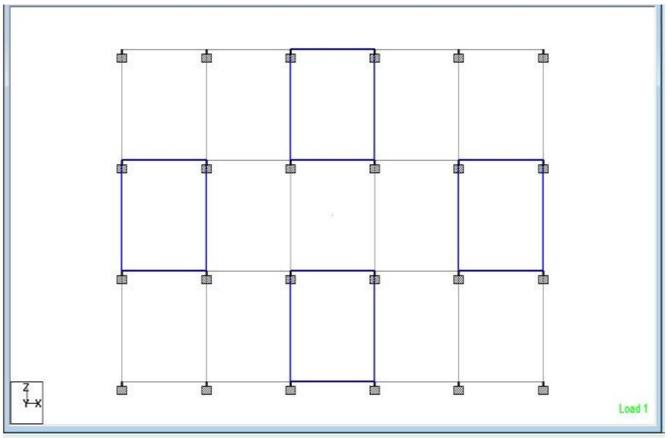

Fig5: Type 5

4. STRUCTURE UNSYMMETRIC IN PLAN

Four types of models are analyzed in this case. Following are the models considered:
Type 6: Regular rectangular shape
Type 7: Cross shape
Type 8: T shape
Type 9: L shape

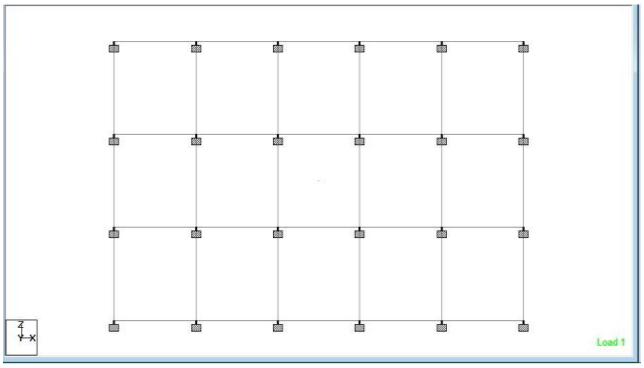

Fig6: Type 6

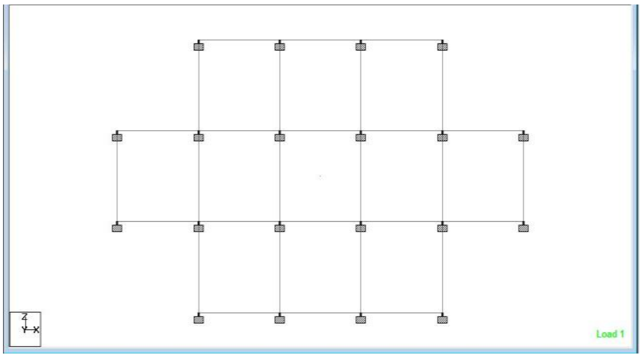

Fig7: Type 7

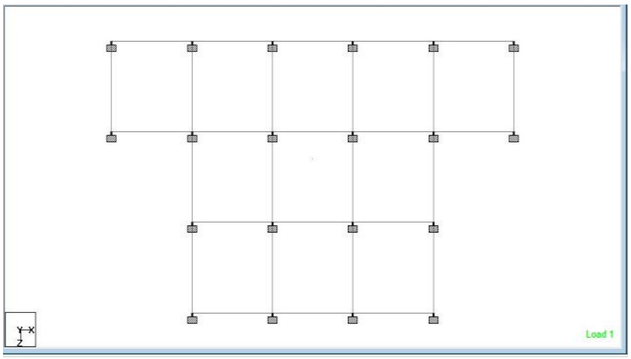

Fig8: Type 8

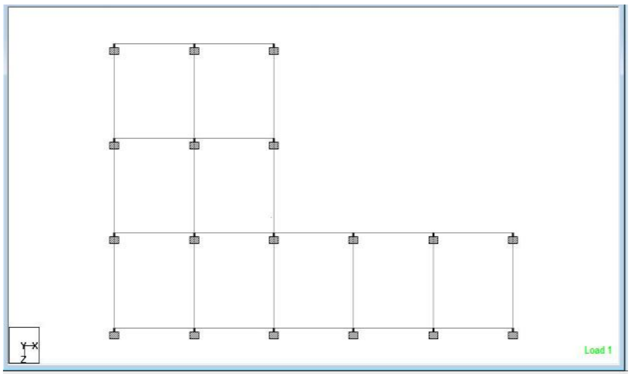

Fig9: Type 9

5. STRUCTURE WITH MASS DISTRIBUTION IRREGULAR OVER HEIGHT

Six types of models are analyzed in this case. Following are the models considered:
Type 10: Bare frame
Type 11: Brick infill wall for the entire frame
Type 12: Open ground storey with brick infill for rest
Type 13: Brick infill wall at bottom storey
Type 14: Brick infill wall at middle storey
Type 15: Brick infill wall at top storey

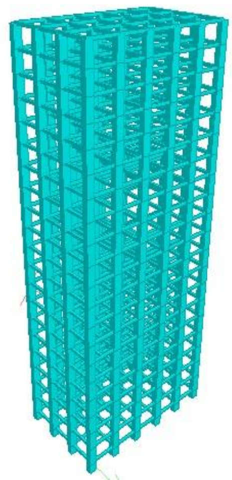

Fig10: Type 10

Fig11: Type 11

Fig12: Type 12

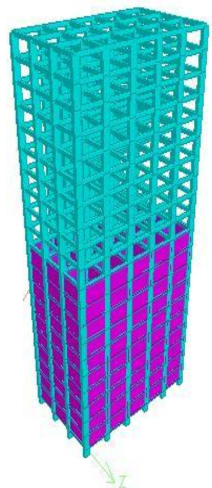

Fig13: Type 13

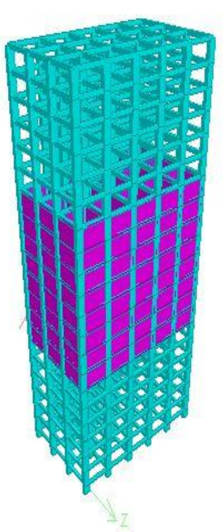

Fig14: Type 14

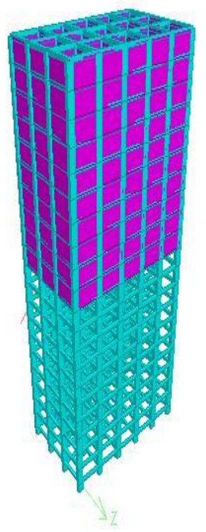

Fig15: Type 15

6. RESULTS AND DISCUSSION

6.1 Case 1: Structure symmetric in plan with shear walls at different locations and in different directions

a) Time Period

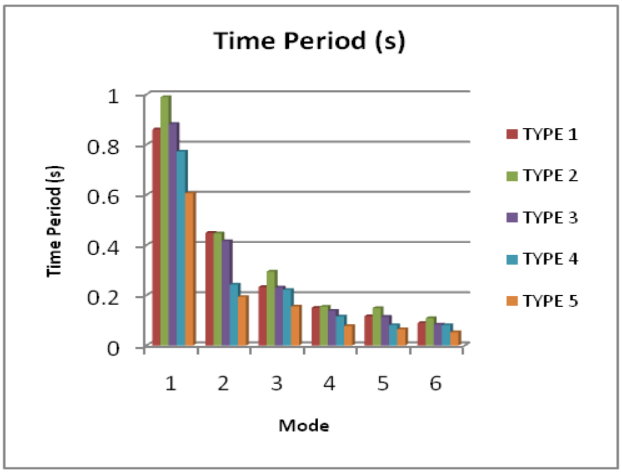

Fig16: Time period

With the comparison of all the models Type 5 model has minimum time period values. Hence shear walls placed along the periphery in both the directions give more stiffness to the structure.

b) Displacement

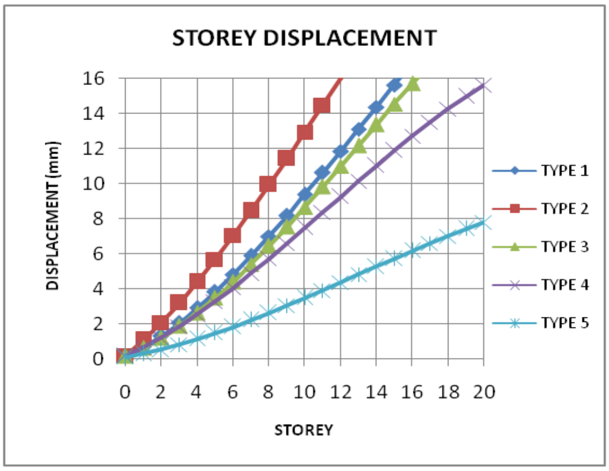

Fig17: Storey Displacement

From the fig17 it is observed that, Type 5 model i.e shear walls placed along periphery in both the directions shows least displacement values when compared with the other models.

c) Drift

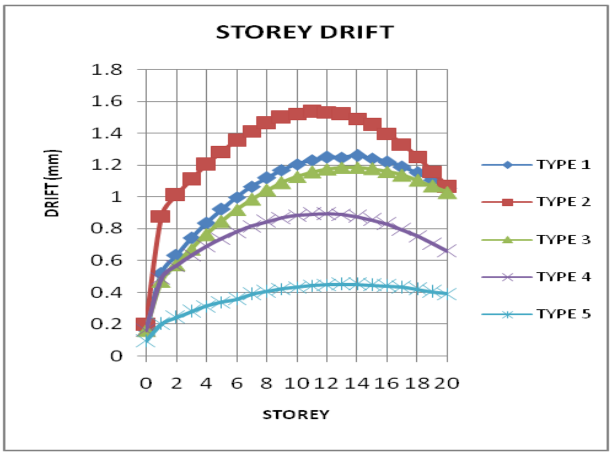

Fig18: Storey Drift

From the fig 18 it is observed that, variation of drift over the height is highly nonlinear for Type 2 (shear walls placed in the middle parallel to z direction), while for Type 5 (shear walls placed along the periphery in both the directions), it is least nonlinear with very little variation.

d) Base Shear

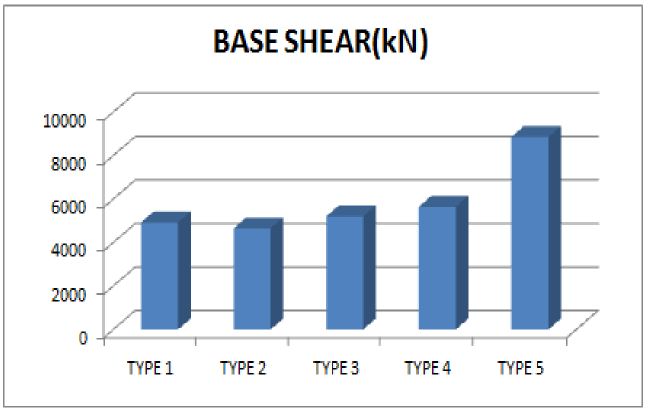

Fig19: Base Shear

From the fig 19 it is observed that base shear is maximum for Type 5 (shear walls placed along periphery in both the directions) model and minimum for Type 2 (shear walls placed at the centre parallel to z direction) model.

6.2 Case 2: Structure unsymmetric in plan with Cross, L and T shapes

a) Time Period

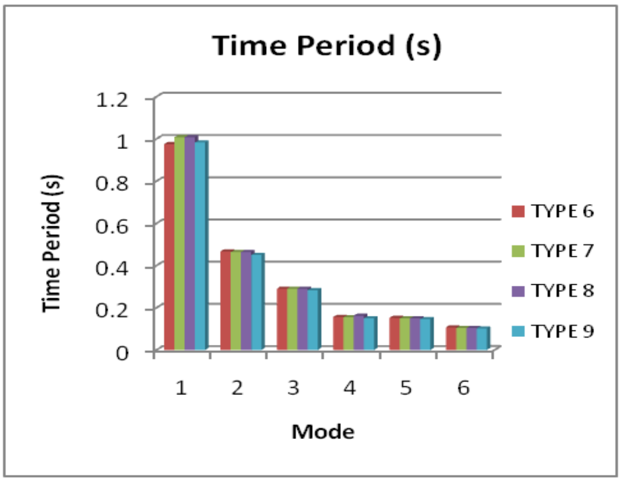

Fig20: Time Period

With the comparison of the other shape models Type 6 (regular shape) model has minimum time period values while, Type 7 (cross shape) and Type 8 (T-shape) models has maximum time period values.

b) Displacement

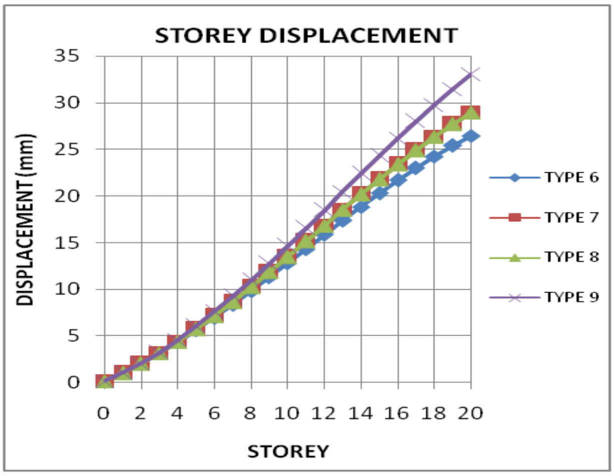

Fig21: Storey Displacement

From the fig 21, it is observed that,

- Type 7 (cross shape) and Type 8 (T shape) models show almost the same displacement values.
- Type 7 (cross shape), Type 8 (T shape) and Type 9 (L shape) models show larger displacement values when compared to Type 6 (regular shape) model.
- Among these models, Type 9 (L shape) model shows maximum displacement values.

c) Drift

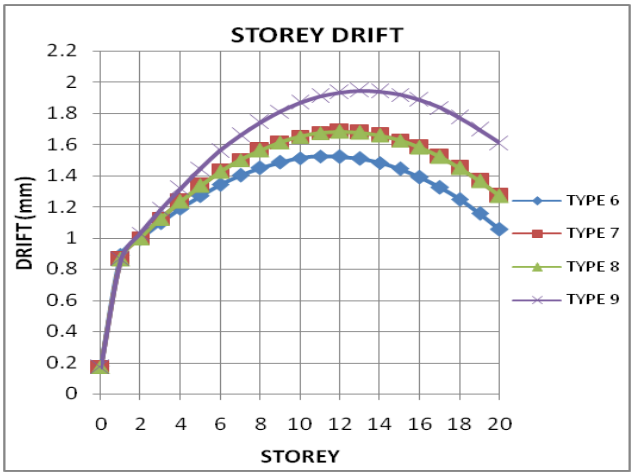

Fig22: Storey Drift

From the fig 22, it is observed that,

- Type 7 (cross shape) and Type 8 (T shape) models show almost the same drift values.
- Variation of drift over the height is highly nonlinear with large variation for Type 9 (L shape) model, while for Type 6 (regular shape) model, it is least nonlinear with very little variation.

d) Base Shear

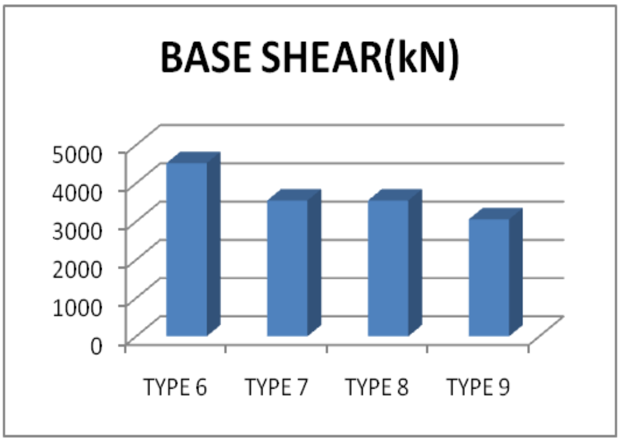

Fig23: Base Shear

From the fig 23, it is observed that,

- Base shear is minimum for Type 9 (L shape) model and maximum for Type 6 (regular shape) model.
- Type 7 (cross shape) and Type 8 (T shape) models show almost the same base shear values.

6.3 Case 3: Structure with mass distribution irregular over height

a) Time Period

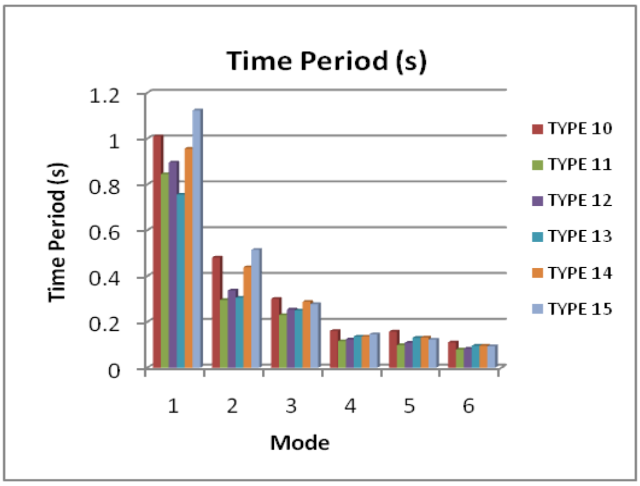

Fig24: Time Period

Brick infill wall for the entire frame (Type 11) model has least time period vibration and hence this structure is stiffer compared to other models.

b) Displacement

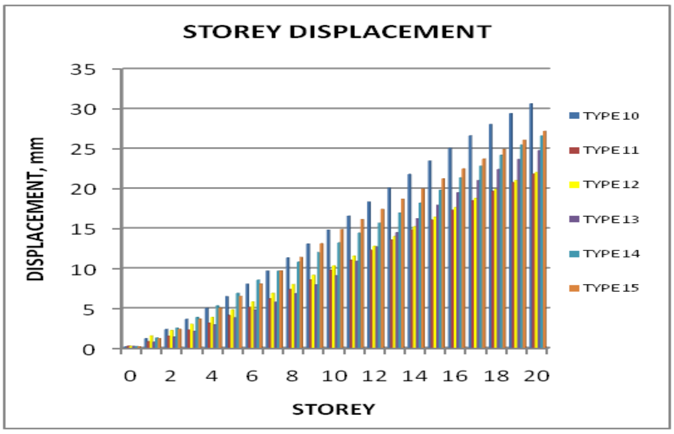

Fig25: Storey Displacement

From the fig 25, it is observed that,

- Bare frame model (Type 10) shows maximum storey displacement values.
- Structure with full brick infill wall (Type 11) shows reduction in storey displacements of about 28.733% compared with those of bare frame model.
- Structure with open ground storey (Type 12) shows slight increase in displacements of about 0.93% compared with those of full brick infill wall frame (Type 11) as there is no infill in ground storey.
- Reduction of displacements is 19.11% in brick infill at bottom storey (Type 13), 13.14% in brick infill at middle storey (Type 14) and 11.23% in brick infill at top storey (Type 15) when compared to bare frame model.
- Therefore brick infills towards the lower storeys will be preferable.

c) Drift

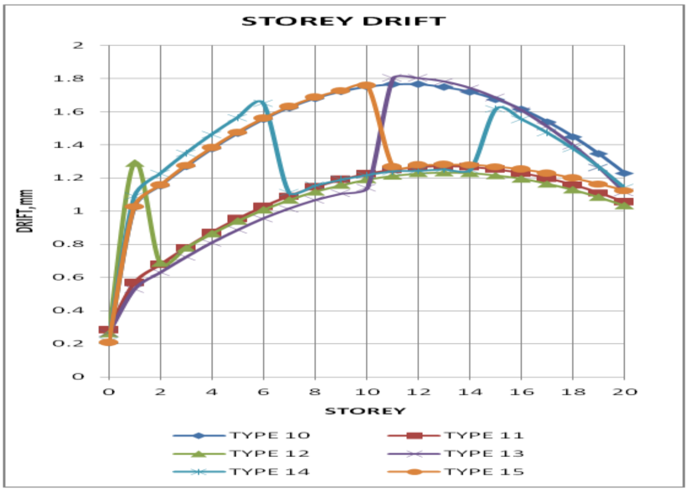

Fig26: Storey Drift

From the fig 26, it is observed that,

- Story drift variation over the height is nonlinear, it increases towards the middle and decreases again towards the top.
- It is observed that storey drift in bare frame (Type 10) is maximum.
- There is reduction of storey drift in structure with full brick infill wall (Type 11) compared to bare frame (Type 10).
- In case of open ground storey (Type 12), the storey drift is very large than the upper storey because of the absence of infill walls in the ground storey.
- In case of brick infill wall at bottom storey (Type 13), storey drift has lesser values up to storey 10 and there is a sudden increase in upper storey because of presence of infill walls at bottom storey.
- In case of brick infill wall at middle storey (Type 14), the storey drift is maximum at bottom and top storeys than the middle storey (storey 7 to storey 14) because of the presence of infill walls at middle storey.
- In case of brick infill wall at top storey (Type 15), storey drift is maximum at bottom storey and there is a sudden decrease in upper storey because of presence of infill walls at upper storey.

d) Base Shear

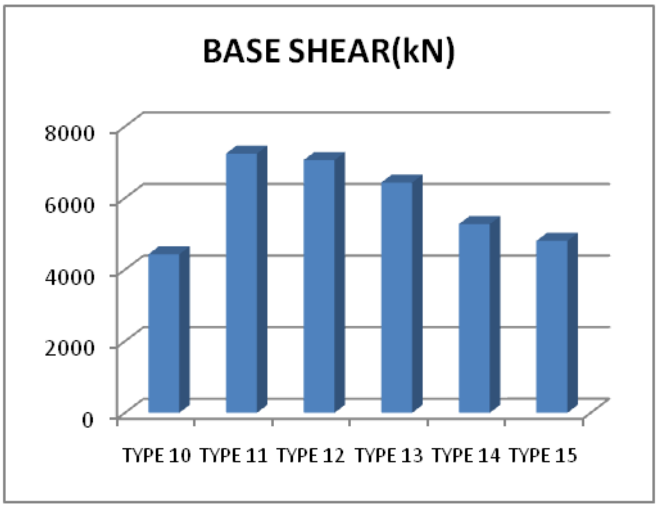

Fig27: Base Shear

From the fig 27, it is observed that,

- Base shear is maximum for full brick infill frame (Type 11) model and minimum for bare frame (Type 10) model.
- Increase of base shear is 38.8% in full brick infill frame (Type 11), 37.27% in open ground storey (Type 12), 31.16% in brick infill at bottom storey (Type 13), 15.95% in brick infill at middle storey (Type 14) and 7.80% in brick infill at top storey (Type 15) compared to the bare frame (Type 10).

6.4 Case 4: Moment Resisting Frames

Column design is done for the structure with SMRF and OMRF as per IS 13920 and as per IS 456. Percentage of steel is compared.

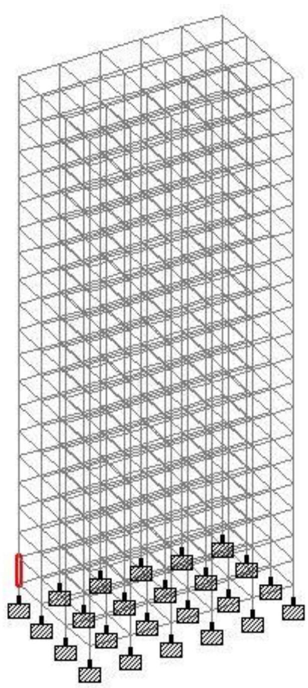

Fig28: Isometric view of a regular structure with columns highlighted

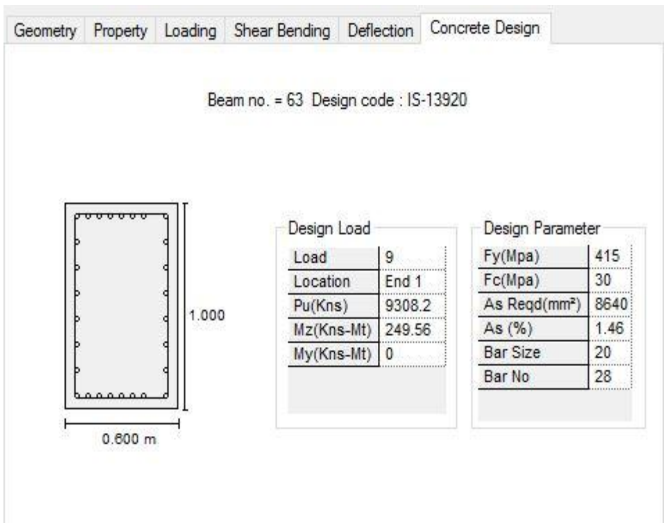

Fig29: Column design for zone V OMRF

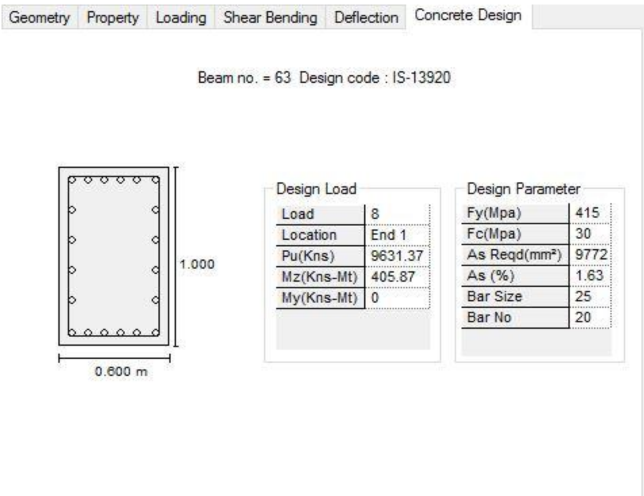

Fig30: Column design for zone V SMRF

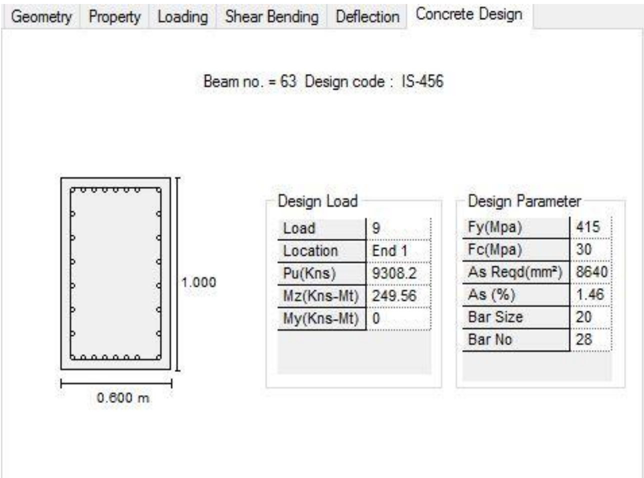

Fig31: Column design for zone V OMRF

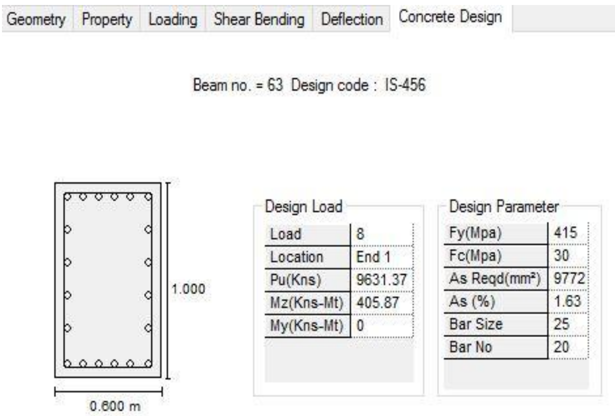

Fig32: Column design for zone V SMRF

Table 5: Percentage of reinforcement

DESCRIPTION	Pt VALUES (%)
As per IS 13920:1993 (R = 5)	1.63
As per IS 456:2000 (R = 5)	1.63
As per IS 13920:1993 (R = 3)	1.46
As per IS 456:2000 (R = 3)	1.46

From the figures 29 to 32 and from the table 5, it is observed that,

- The percentage of steel is same in both the design methods.
- Percentage of steel is more in case of SMRF compared to OMRF.
- The designing of special moment resisting frame structure is suitable because it can resist more earthquake load compared to ordinary moment resisting frame structure.

7. CONCLUSIONS

The following conclusions are drawn from the results:

1. In case of symmetric plan, the type 5 model (Shear walls placed along the periphery in both the directions) shows least displacement and drift values when compared to other models while base shear is found to be highest.

2. In case of unsymmetric plan, L-shape, Cross-shape and T-shape models displacement is more compared to regular model, symmetric in plan.

3. Hence building with irregular plan causes severe damage than regular buildings during earthquake in high seismic zones.

4. In case of mass distribution irregular over height, brick infill wall model shows lesser displacement values, lesser drift values and maximum base shear values compared to other models.

5. Presence of infill walls in the structure makes the structure much stiffer.

6. Special moment resisting frame is more suitable in high seismic zones than ordinary moment resisting frame.

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