Comparative Analysis of RC Structures with the Influence of Infill Walls Using Equivalent Strut Approach

Gaurav Shrivaiya[1] Sumit Pahwa[2] Murtaza Safdari[3]
[1]MTech Scholar [2]Associate Professor [3]Assistant Professor
[1,2,3]Department of Civil Engineering
[1,2,3]Alpine Institute of Technology, Ujjain, India

Abstract — RC Buildings are very conventional type of construction in India. While analysing & designing the structure, we only consider structural members like slabs, beams, columns, and footings which carries the load and transfer it to another respectively, while walls are not considered under the design criteria and also their impact on the structural response is neglected. In terms of loading only, the effect of walls is considered. But their influence on RC Structural Frames are shown in their global behaviour when subjected to lateral forces. So it is very vital to study its behaviour on RC frames under severe seismic conditions. The presence of infill walls, results in rise in the structural stiffness; also surges natural frequency of vibration which depends on seismic spectrum. In addition to that, it also reduces the storey drift demands & displacements and increases the storey lateral stiffness when it is subjected to lateral loading. In this study a RSA approach is adopted for RC frames with the help of FEM software. The main purpose of this study contains the effect of varying properties of infill wall using different patterns on RC framed structure under lateral load. The FEM model of infill wall was done in Etabs using equivalent strut method. The main objective of this paper is to recognize the performance of the building with varying infill parameters considered like percentage of openings considered, construction material used for infill walls and the performance of such buildings are compared with buildings without infill in zone V as per Indian Standards. In this study, a G+10 RC building is considered with the square plan area of 400 m2. The main parameters are focused in this study have been done on time period, mass participation, storey drifts, storey displacement & base shear and on its basis the performance can be evaluated.

Keywords: Reinforced Concrete Frames, Infill, Time Period, Stiffness, Base Shear, Pushover Analysis

I. INTRODUCTION

The RC (reinforced concrete) frame structures provided with masonry infill walls are the most common type of structures used for multi-storey constructions in many countries. In this type of structures, the exterior masonry walls and the interior partitions are considered as non-structural elements, and usually, the structural interaction between the frame and infill is ignored in the seismic design/assessment especially in the past.

Earthquake can cause greatest damages to humanity among all the natural hazards. Since earthquake forces are unpredictable and random in nature, proper analysis of the structures must be ensured to withstand such loads. The recent developments in the performance-based engineering design have brought the non-linear static (NSP) or pushover analysis to the forefront. It has replaced the conventional analysis procedures due to its simplicity and proved to be a useful and effective tool for assessing the real strength of structures.

Pushover analysis can be either force controlled or displacement controlled. The pushover analysis can provide significant perception and understanding about the weak links in the structure. Etabs V18 can perform static or dynamic, linear or nonlinear analysis of structural systems. To perform pushover analyses in Etabs V18, users can create and apply hinge properties. Etabs V18 is fully equipped with US, Canadian and International Design standards and codes like ACI concrete code, AISC building codes and AASHTO specifications. These integrated design code features can easily generate wind, wave and seismic loads with comprehensive automatic steel and concrete design checks. Pushover analysis is a static non-linear technique in which the magnitude of the structural loading is incremented in the lateral direction of the structure according to a certain pre-defined pattern.

Generally, it is assumed that the behaviour of the structure is controlled by its fundamental mode and the predefined pattern is expressed in terms of either story shear or fundamental mode shape. FEMA-273 and its successor FEMA-356 describe about the non-linear static procedure (NSP) or pushover analysis and its uses in the structural engineering field. It is recommended as a standard tool for estimating seismic demands for buildings. In Etabs V18, a frame element is modelled as a line element having linearly elastic properties and nonlinear force-displacement characteristics of individual frame elements are modelled as hinges represented by a series of straight line segments. There are three types of hinge properties in Etabs V18. They are default hinge properties, user-defined hinge properties and generated hinge properties. Studies show that user defined hinge model gives better results than default hinge model. Moment-curvature relationship is used to model plastic hinge behaviour in non-linear analysis. The seismic performance of a structure can be evaluated in terms of pushover curve, plastic hinge formation etc. The maximum base shear capacity of structure can be obtained from base shear versus roof displacement curve.

A. Infill Walls

The infill wall is the supported wall that closes the perimeter of a building constructed with a three-dimensional framework structure (generally made of steel or reinforced concrete). Therefore, the structural frame ensures the bearing function, whereas the infill wall serves to separate inner and outer space, filling up the boxes of the outer frames. The infill wall has the unique static function to bear its own weight. The infill wall is an external vertical opaque type of closure. With respect to other categories of wall, the infill wall differs from the partition that serves to separate two interior spaces, yet also non-load bearing, and from the load bearing wall. The

latter performs the same functions of the infill wall, hygro-thermically and acoustically, but performs static functions too.

B. Methods of Analysis

1) Equivalent Static Analysis - The equivalent static lateral force method is a simplified technique which substitutes the effect of dynamic loading of an expected earthquake by a static force distributed laterally on a structure. Generally, the total seismic force is evaluated in two horizontal directions which is parallel to main axes of the building. This method assumes that the building responds in its fundamental lateral mode, this assumption is conserved true when the building is low rise and must be symmetric to avoid torsion-al movement under ground motion. The effects caused by seismic forces must be resisted by the structure in either direction, but not in both the directions simultaneously.
2) Response Spectrum Method - In order to perform the seismic analysis and design of a structure to be built at a particular location, the actual time history record is required. However, it is not possible to have such records at each and every location. Further, the seismic analysis of structures cannot be carried out simply based on the peak value of the ground acceleration as the response of the structure depend upon the frequency content of ground motion and its own dynamic properties. To overcome the above difficulties, earthquake response spectrum is the most popular tool in the seismic analysis of structures. There are computational advantages in using the response spectrum method of seismic analysis for prediction of displacements and member forces in structural systems. The method involves the calculation of only the maximum values of the displacements and member forces in each mode of vibration using smooth design spectra that are the average of several earthquake motions.
3) Time History Analysis - In order to examine the exact non-linear behavior of building structures, nonlinear time history analysis has to be carried out. In this method, the structure is subjected to real ground motion records. This makes this Analysis of Masonry Infill in a Multi-Storied Building analysis method quite different from all of the other approximate analysis methods as the inertial forces are directly determined from these ground motions and the responses of the building either in deformations or in forces are calculated as a function of time, considering the dynamic properties of the building structure.
4) Pushover Analysis - Pushover analysis is a static, nonlinear procedure in which the magnitude of the lateral forces is incrementally increased, maintaining the predefined distribution pattern along the height of the building. With the increase in magnitude of the loads, weak links and failure modes are found. Pushover analysis can determine the behavior of a building, including the ultimate load and maximum inelastic deflection. Local nonlinear effects are modeled and the structure is pushed until a collapsed mechanism is developed. At each step, the base shear and roof displacement can be plotted to generate the pushover curve.

II. Objective of the Study

The main objective of the thesis is to investigate the overall performance of the RC frame structure with & without infill and find out the most effective type of structure, according to specific codes. The project also investigated the differing results from the response spectrum analyses completed using Etabs structural analysis programs. Lastly, the results were compared to investigate performances of different infill types with respect to the regular building without infill. The results of the comparison will provide the data for the engineering profession to assess performance-based engineering as it continues to evolve and help engineers choose a building type to use based on the desired performance. The main objective of this study is to investigate the seismic behavior and performance of RC frame multistory structure with different infill walls with & without openings using response spectrum analysis and following are the goals of the study -

- To compare the base shear of RC Structure with and without infill.
- To calculate the displacement of with the effect of infills.
- To compare the storey drift of all building structures.
- To find out the most operative arrangement which proves to be economical and use of material for the severe seismic zone.

III. Structural Modelling

Different models for G+10 storey RC Structure of area 20 m x 20 m. have been prepared, designed and compared in zone V as per IS 1893:2016. The models with different infill properties with & without openings have been prepared and compared with regular bare frame model whose performance and results were studied and compared.

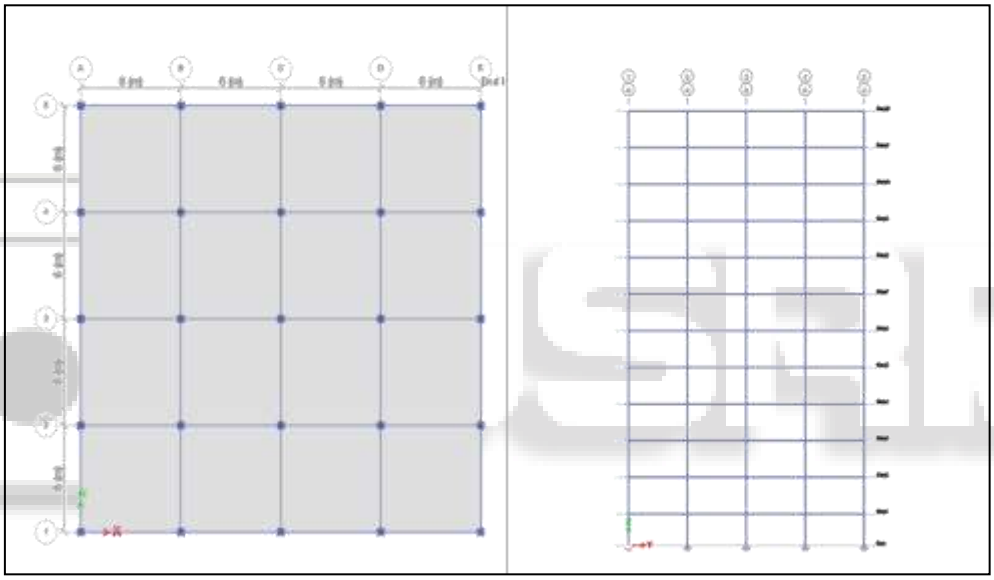
Details of Models:

- Model 1 – Regular Frame Building without infill walls of area 20 m x 20 m.
- Model 2 – Regular Frame Building with infill walls (brick) of thickness 230 mm of area 20 m x 20 m without opening.
- Model 3 – Regular Frame Building with infill walls (brick) of thickness 230 mm of area 20 m x 20 m with 10% opening.
- Model 4 – Regular Frame Building with infill walls (brick) of thickness 230 mm of area 20 m x 20 m. with 20% opening.
- Model 5 – Regular Frame Building with infill walls (fly ash brick) of thickness 230 mm of area 20 m x 20 m. without opening.
- Model 6 – Regular Frame Building with infill walls (fly ash brick) of thickness 230 mm of area 20 m x 20 m. with 10% opening.
- Model 7 – Regular Frame Building with infill walls (fly ash brick) of thickness 230 mm of area 20 m x 20 m. with 20% opening.
- Model 8 – Regular Frame Building with infill walls (hollow concrete blocks) of thickness 150 mm of area 20 m x 20 m. without opening.

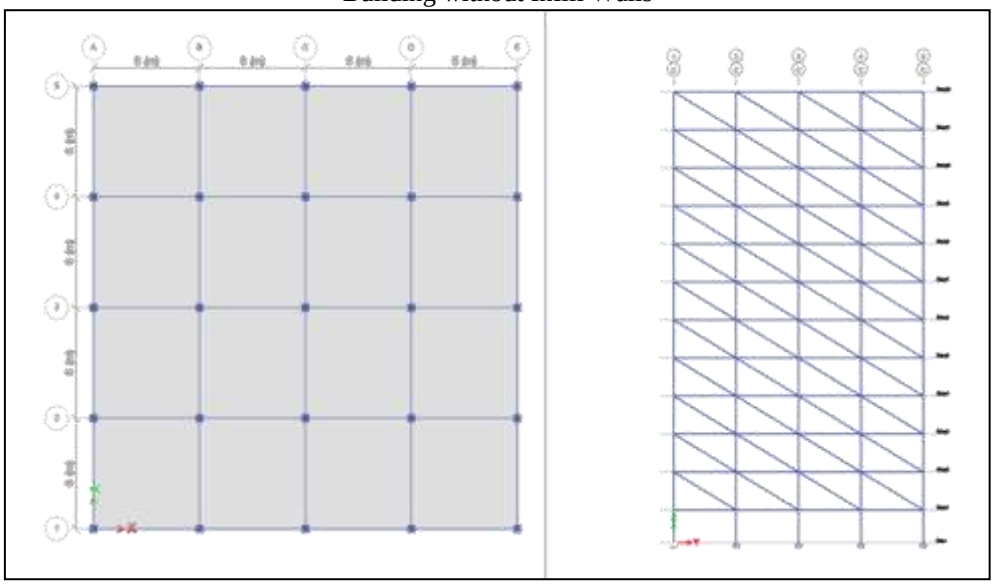
- Model 9 – Regular Frame Building with infill walls (hollow concrete blocks) of thickness 150 mm of area 20 m x 20 m. with 10% opening.
- Model 10 – Regular Frame Building with infill walls (hollow concrete blocks) of thickness 150 mm of area 24 m x 24 m. with 20% opening.

The dimensions of beams and columns have been designed according to the span length. Other data used for the purpose of analysis have been taken from IS 1893:2016

General Properties	
No. of storeys	G+10
Typical Storey Height	3.5 m.
For 4m span length:	
Size of Column	400 x 1000
Size of Beam	400 x 600
Thickness of Slab	150 mm.
Thickness of Wall	230 mm / 150 mm.
Material Properties	
Grade of Concrete	M 30
Grade of Steel	Fe500
For Infilled walls (clay brick)	Unit Weight = 18 KN/m3
For Infilled walls (fly ash brick)	Unit Weight = 20 KN/m3
For Infilled walls (concrete blocks)	Unit Weight = 10 KN/m3
Type of Loading	
Wall Load	14 KN/m
Live Load	2 KN/m^2
Floor Finishing	1.5 KN/m^2
Seismic Details (IS 1893:2016)	
Seismic Zone	V
Zone Factor	0.36
Importance Factor	1.0
Type of Soil	II - Medium
Building Type (R)	5 (OMRF)



Building without Infill Walls



Building with Infill Walls

Equivalent Strut Method
Width of Strut –

$$w = 0.175\ (\alpha)^{-0.4} L$$

Where, w = width of strut
α = Stiffness factor
L = Diagonal Length of Strut
Stiffness factor α can be given by –

$$\alpha = h\{(\frac{E_m t sin2\theta}{4E_f I_c h})^{\frac{1}{4}}\}$$

Where E_m – Modulus of Elasticity for Masonry – 550 f_m
& f_m – Compressive Strength of Masonry
For Clay Brick Masonry – Em = 3160 N/mm2

Size of Infill Wall	Value of Stiffness Factor in X direction	Value of Stiffness Factor in y direction	Percentage of Opening	Width of Strut in X Dir.	Width of Strut in Y Dir.
230 mm	3.22	2.78	0%	525 mm	580 mm
230 mm	4.31	3.12	10%	480 mm	540 mm
230 mm	5.15	4.26	20%	440 mm	490 mm

For Fly Ash Brick Masonry - Em = 3375 N/mm2

Size of Infill Wall	Value of Stiffness Reduction Factor	Value of Stiffness Reduction Factor	Percentage of Opening	Width of Strut in X Dir.	Width of Strut in Y Dir.
230 mm	2.98	2.44	0%	540 mm	620 mm
230 mm	4.15	2.89	10%	510 mm	585 mm
230 mm	4.96	3.92	20%	485 mm	455 mm

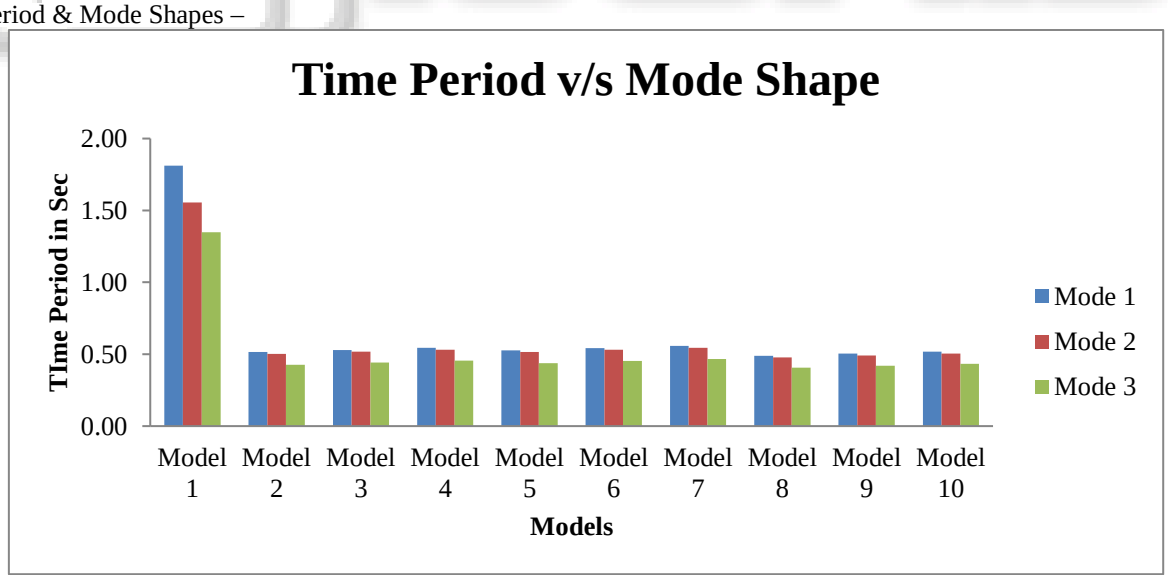
For Hollow Concrete Block Masonry - Em = 2280 N/mm2

Size of Infill Wall	Value of Stiffness Reduction Factor	Value of Stiffness Reduction Factor	Percentage of Opening	Width of Strut in X Dir.	Width of Strut in Y Dir.
150 mm	3.1	2.65	0%	450 mm	520 mm
150 mm	4.12	3.11	10%	400 mm	480 mm
150 mm	5.0	4.02	20%	350 mm	440 mm

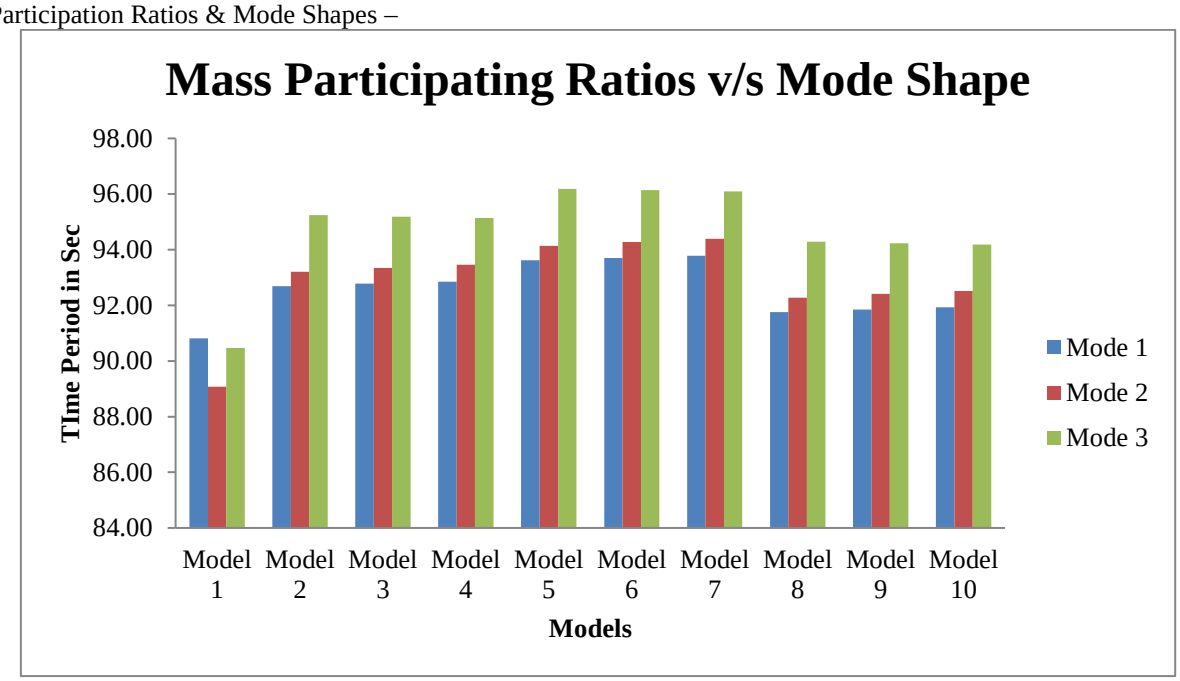
t – Thickness of Infill Wall
θ - Angle of Inclination – (Clear Height between Beams / Clear Distance between Columns)
E_f – Modulus of Elasticity for Concrete – 5000 $\sqrt{f_{ck}}$
I_c – Moment of Inertia of Columns
h = Clear Height between Beam of Adjacent Floors
For This Study, Percentage of Reduction in stiffness factor is governed by percentage of opening.
Percentage of Opening – (Area of Opening / Area of Infill Walls)

IV. RESULTS

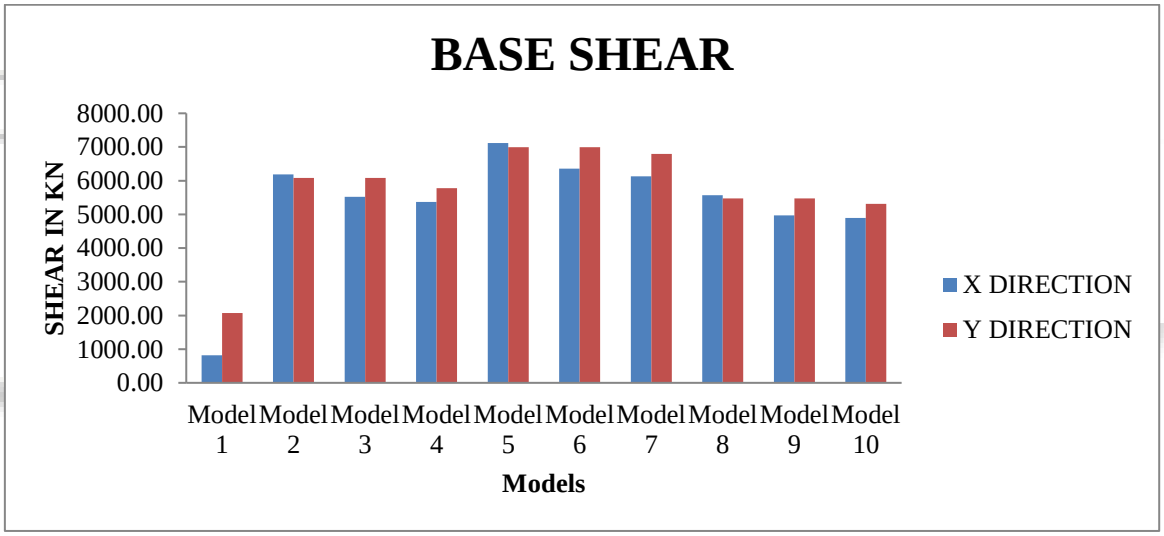
Time Period & Mode Shapes –



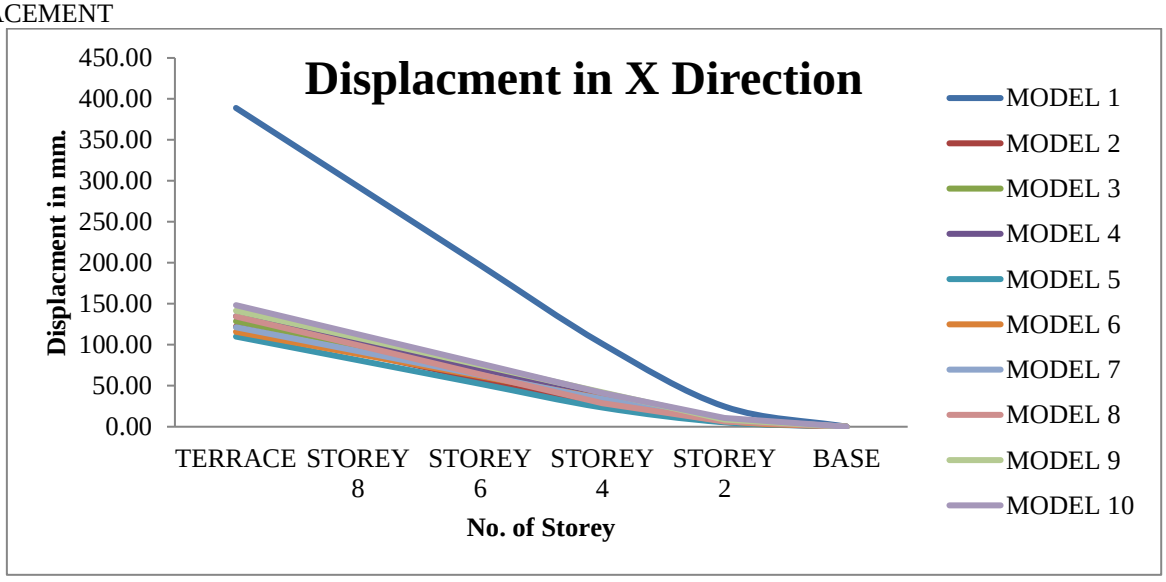
Mass Participation Ratios & Mode Shapes –

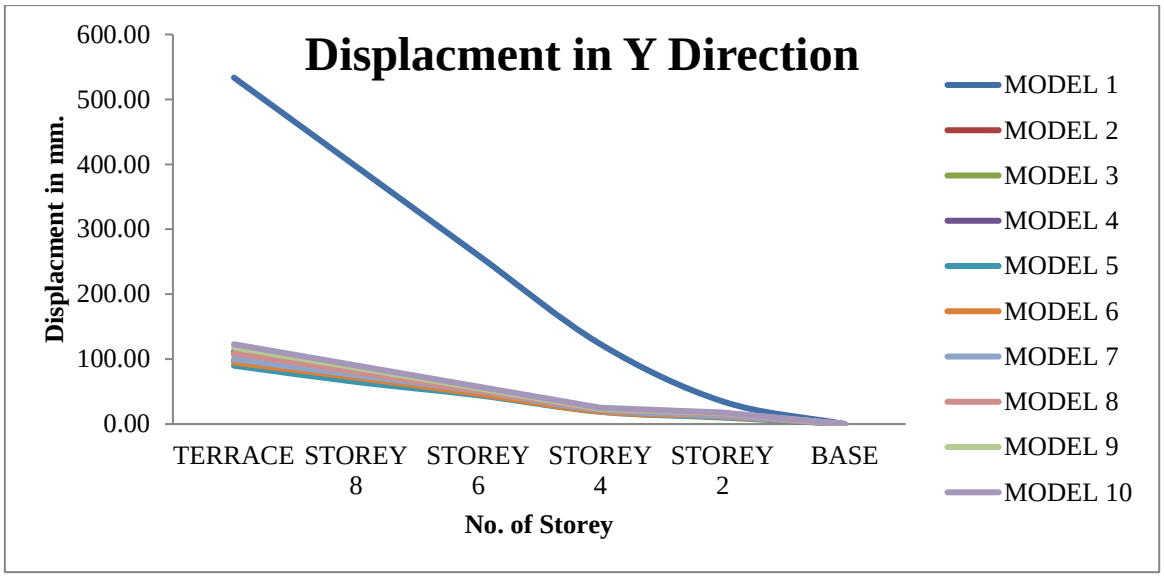


BASE SHEAR

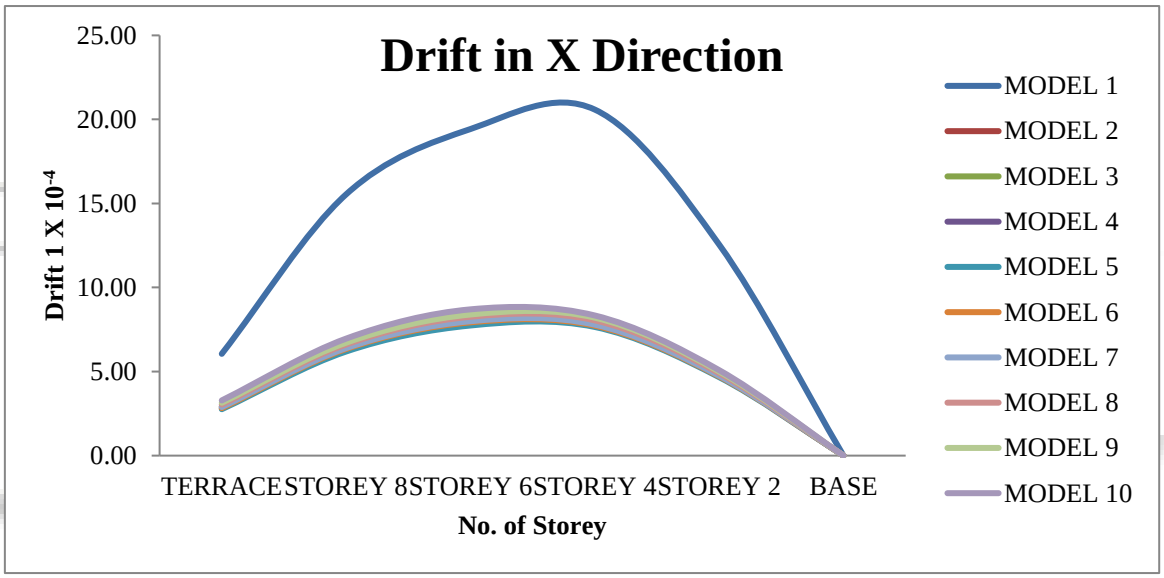


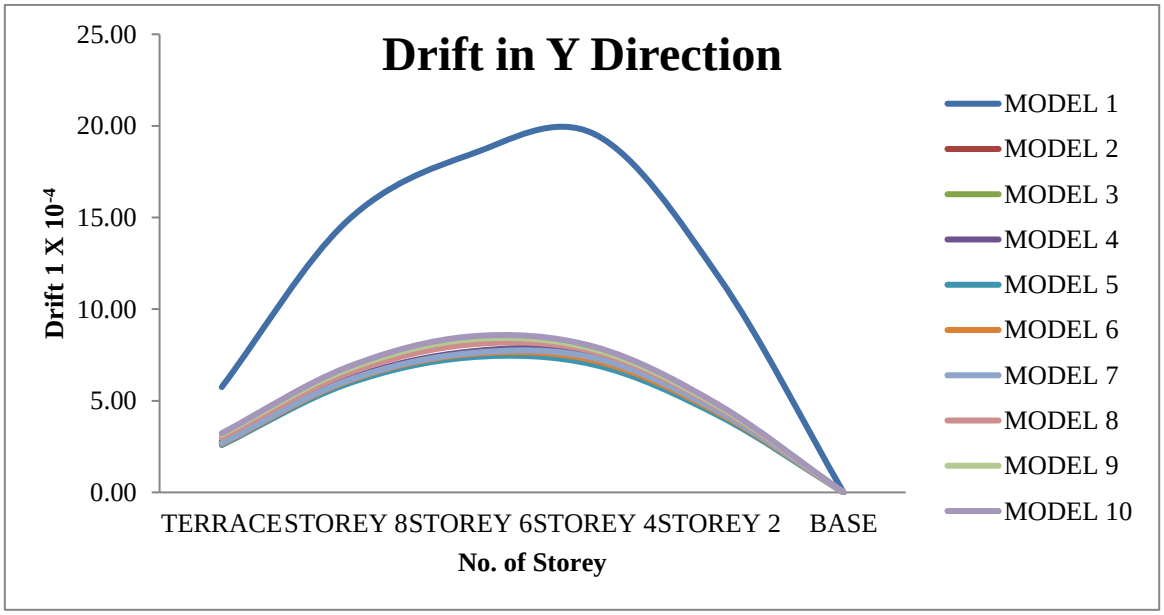
DISPLACEMENT





Drift





V. CONCLUSION

Following are the main conclusions are made from the present study:

- The Time period of the RC structure with Infill is less than the RC structure without infill. The natural time period decrease by 18% for the building with infill when compared to the structure without infill walls.
- The Natural Time Period also decreases up to 3 % for fly ash type brick while the value increases for concrete blocks up to 5 % when they compared to red burnt clay bricks.
- In RC structure without Infill, the storey displacement in X-direction and Y-direction is more when compared to RC structure with infill as shown. The value of displacement is 22% higher in the buildings without infill walls as compare to the structure with infill walls.
- While comparing the values of displacement on the basis of material properties, fly ash bricks shows 3% less values as compared to burnt clay bricks while hollow concrete blocks shows 12% higher values of displacement than burnt clay bricks.
- In X-direction and Y-direction, the storey drift is 26% less for RC structure without Infill structure than RC structure with infill.
- While the values of storey drift comparing on the basis of material properties, fly ash bricks shows less values up to 10 % as compared burnt clay brick while the value of drift for concrete block is 20 % higher than the value with conventional burnt clay bricks.
- In the presence of infill wall, the stiffness of the structure and base shear increases by 27% as compared to building without infill walls.
- While in terms of base shear, building with fly ash brick material the value of base shear is 11% higher than the conventional burnt clay bricks and for concrete blocks, it reduces up to 15%.
- With the actual percentage of opening the value of drift, displacement not varies drastically, hence it can be avoided during the analysis for small openings i.e. up to less than 20%.

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