Seismic Analysis of RC Framed Structure with & Without Infill Effect with Different Infill Properties

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Abstract — RC Buildings are very usual type of construction in India. Analytically while modelling the structure, we design only structural members which transmit the load like beams, columns, slabs and footings, where walls are not considered while designing and their impact on the structural response is neglected. Their impact is shown in the global behaviour of RC frames subjected to seismic loads. So it is very significant to study the impact of infill on the RC bare frames. The presence of infill results in increase in the structural stiffness; it also increases natural frequency of vibration which depends on seismic spectrum. In addition to that, it also decreases the storey drift demands and increases the storey lateral forces. This study gives the overview of performance of RC frame buildings with and with-out infill walls. In this study, two different buildings i.e. with and without infill walls are considered, whose analysis have been done for gravity and seismic loads using software (Etabs). The different materials considered in this study for the infill walls are Burnt Clay Bricks, Cement Bricks & Hollow Concrete Blocks. In this study, a G+11 - storied reinforced frames without infill and with infill walls are considered as a strut and with the finite modelling which has been evaluated through linear dynamic analysis. The objective of this paper is to compare various parameters such as Time period, Base shear, Storey drifts, Displacements and to study the performance of the building. Taking the above parameters into consideration, we can compare performance of infill Structures with the structures without infill in severe seismic zone as per IS 1893:2016.

Keywords: Reinforced Concrete Frames, Infill Wall, Time Period, Stiffness, Base Shear, Linear Dynamic Analysis

I. Introduction

The RC (reinforced concrete) frame structures provided with masonry infill walls are the most common type of structures used for multi-storied constructions in many countries. In this type of structures, the outer walls and the internals 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. RC buildings with masonry walls have been usually constructed for residential & commercial use worldwide. Masonry infill characteristically consists of clay brick masonry, fly ash brick masonry, concrete block walls or hollow blocks constructed between columns and beams of a RC frame. Though the masonry infill is considered to be a non-structural element, but it has its own strength and stiffness. Hence if the effect of masonry is considered in analysis and design, it can substantial increase in strength and stiffness of general structure. Present code, IS 1893(Part-I) of practice does not include provision of taking into consideration the effect of infill. It can be observed that if the infill effect is taken into account in the analysis and design of RC framed structure, the behaviour of the structure may be significantly different in seismic regions. Substantial experimental and analytical research is reported in various literatures, which attempts to explain the behaviour of infilled frames. Moreover, infill, if present in all storeys gives a momentous contribution to the energy dissipation capacity, falling considerably the maximum displacements. Therefore, the giving of masonry is of great importance, even though strappingly depending on the sort of the ground motion, especially for frames which has been designed without allowing for the seismic forces. When abrupt change in stiffness takes place along the building height, the storey at which this radical change of stiffness occurs is called a soft story. According to IS 1893, a soft story is the one in which the lateral stiffness is less than 50% of the storey above or below. Another significant issue is related to the numerical simulation of infilled frames. In this study the strength and stiffness of the different material used for masonry infill is considered and is modelled using diagonal strut. The diagonal strut has been modelled using software package Etabs & other FEM software's. The analysis is performed using "Linear Dynamic analysis" for understanding the improvement in stiffness parameters.

A. *Infill Walls*

The infill wall closes the perimeter of a building and 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 divide inner and outer space, substantial up the boxes of the outer frames. The infill wall has the exceptional static function to stand its own weight. The infill wall is an exterior vertical thick type of closure. With reverence to other categories of wall, the infill wall differs from the partition that serves to separate two inner spaces, yet also non-load bearing, and from the load bearing wall.

The seismic design of masonry infilled RC frame buildings is executed in diverse ways across the world. Some of the prevalent design practices are:

- Infills are adequately separated from the RC frame such that they do not interfere with the frame under lateral deformations. The intact lateral force on the building is carried by the bare RC frame alone.
- Infills are built integral with the RC frame, but considered as non-structural elements. The intact lateral force on the building is carried by the bare RC frame only. This is the generally ordinary design practice in the developing countries.
- Reinforced concrete frames with masonry infill walls are a common practice in countries like India, where the region is prone to seismic activity. Generally, the masonry infill walls are treated as non-structural element in structural analysis and only the contribution of its mass

is considered and its structural properties like strength and stiffness is generally not considered. Even though it contributes appreciably to the lateral stiffness of the frame structures. There are no such explicit references to infill walls in the Indian seismic standard (IS 1893:2016) that is currently used in India. So during the analysis infilled frame is considered as bare frame (Fig1.1 a) and neglecting effect of infill wall panels on frame (Fig1.1 b). One of the drawbacks of neglecting the infill as structural member is the irregularities in the building caused by the uncertain position of infill and openings in them.

The traditional modelling of Reinforced concrete frame structures in which infill is not considered assumes the structures more flexible than they really are. The contradiction may occur in the analysis and proportioning of structural member in traditional modelling because it does not take strength and stiffness characteristic into account. Actually there is increase in the overall stiffness of the structure by the effect of infill walls which finally leads to the shorter time periods.

B. Need of the Study

The infilled RC framed building behaves differently as compared to a bare framed building (without any infill) under lateral load. A bare frame is much less stiff than a fully infilled frame; it resists the applied lateral load through frame action when this frame is merged with infilled wall, truss action is introduced. A entirely infilled frame shows a reduced amount of deformation, although it attracts privileged amount of base shear due to increased stiffness. It also yields less force in the frame elements and dissipates high amount of energy in the course of infill walls. The parameters like strength and stiffness of infill walls in such buildings are not considered in the structural modelling in conventional design practice.

The provision of adequate stiffness is a major consideration in the design of building for several important reasons. In terms of serviceability limit state, deflections must first be maintained at sufficiently low to allow proper functioning of non-structural components, to inhibit excessive cracking and subsequent loss of stiffness. An appropriate way to analysed & assessment of RC frame buildings is to model the strength and stiffness of infill walls. Tactlessly, no guidelines are given in IS 1893: 2016 (Part-1) for modelling the infill walls. As an substitute a bare frame analysis is generally used that ignores the strength and stiffness of the infill walls.

The aim of the present analytical research is to study the performance of RC frame building with different material infill wall panels need to be recognized immediately and necessary measure taken to improve performance of building, to lessen the lateral deflection and to assess the economic structure.

C. Objective of the Study

- To study the effect of infill walls and without infill walls on structure.
- To study the effect of different infill materials on structure.
- To study the effect of modelling i.e. use of equivalent diagonal strut approach or FEM approach which gives the better idea to use the certain approach for severe seismic condition.
- The considered objectives are useful to study the overall behaviour of the structure under the seismic load, from which the performance of the structure can be determined.

D. Linear Dynamic Analysis

1) Response Spectrum Method:

In response spectrum method the peak response of structure during an earthquake is obtain directly from the earthquake response spectrum. This procedure gives an approximate peak response, but this is quite accurate for structural design applications. In this approach, the multiple modes of response of building to an earthquake are taken in account. For each mode, a response is read from design spectrum, based on modal frequency and modal mass. In this method the load vectors are calculated corresponding to predefined number of modes. These load vectors are applied at the design centre of mass to calculate the respective modal responses.

The loads acting on the structure are contributed from slabs, beams, columns, walls, ceilings and finishes. They are calculated by conventional methods according to IS 456 – 2000 and are applied as gravity loads along with live loads as per IS 875 (Part II) in the structural model. The lateral loads and their vertical distribution on each floor level are determined as per IS 1893 – 2016 and calculated. These loads are then applied in response spectrum method.

2) Linear Dynamic analysis (Response spectrum)

Here the full design base shear and lateral force all along some principal direction is given in terms of design horizontal seismic coefficient and seismic mass of the building. Design horizontal seismic coefficient depends on the seismic zone importance factor of the structure, seismic zone factor of site, response reduction factor of the lateral load resisting elements and the fundamental period of the structure. The method usually used for the equivalent static analysis is given below:

a) Determination of fundamental natural period (Ta) of the buildings Ta = 0.075h0.075 Moment resisting RC frame building without brick infill wall.

Ta = 0.085h0.075 Moment resisting steel frame building without brick infill walls

Ta = 0.09h /√d All other buildings including moment resisting RC frame building with brick infill walls.

Where, h - Is the height of building in meter

d- Is the base dimension of building at plinth level in m, along the considered direction of lateral force.

b) Determination of base shear (VB) of the building

$$VB = Ah \times W$$

Where,

Ah=(Z/2)*(I/R)*(Sa/g) is the design horizontal seismic coefficient, which depends on the seismic zone factor (Z), importance factor (I), response reduction factor (R) and the average response acceleration coefficients (Sa/g). Sa/g in turn depends on the nature of foundation soil (rock, medium or soft soil sites), natural period and the damping of the structure.

c) Distribution of design base shear The design base shear VB thus obtained shall be distributed along the height of the building as per the following expression:

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_j^2}$$

Where, Qi is the design lateral force, Wi is the seismic weight, hi is the height of the ith floor measured from base and n is the number of stories in the building.

E. Modelling of Masonry Infill Walls

Equivalent Diagonal Strut Approach

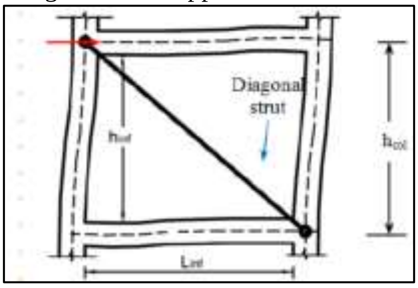


Fig. 1: Equivalent Diagonal Strut Approach

The thickness of strut is usually assumed to be the same of infill panel whereas many expressions are giving for determination of width of the equivalent strut which must be greater at the beginning in order to represent the initial stiffness of the untracked panel and then decrease with crushing of the corners or sliding of the bed joints.

Stafford Smith was the first who introduce a parameter λ expressing the relative stiffness of the frame and infill panel in the equation of width of the equivalent strut giving below:

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 $\boldsymbol{\alpha}$ can be given by –

$$\boldsymbol{\alpha} = \boldsymbol{h}\{(\frac{\boldsymbol{E_m t \sin 2\theta}}{\boldsymbol{4 E_f I_c h}})^{\frac{1}{4}}\}$$

Where E_m – Modulus of Elasticity for Masonry

t – Thickness of Infill Wall

$\boldsymbol{\theta}$ - Angle of Inclination – (Clear Height between Beams / Clear Distance between Columns)

E_f – Modulus of Elasticity for Concrete – 5000 $\sqrt{\boldsymbol{f_{ck}}}$

I_c – Moment of Inertia of Columns

h = Clear Height between Beam of Adjacent Floors

It is important to take into account the progressive degradation of stiffness and strength of infill panel during the cyclic loading but variability of materials and constructive techniques made the task so difficult (mechanical parameters, geometrical configuration and the presence of openings in infill panel). However, for simplicity the effect of openings on stiffness and strength has been ignored.

II. METHODOLOGY

Four models for G+11 storey RC Structure of area 50 m x 50 m. have been prepared, designed and compared in zone V as per IS 1893:2016. The models with different infill properties have been prepared and compared with regular bare frame model whose performance and results were studied and compared.

Details of Models:

Model 1 – Regular RC Bare Frame Building without infill walls of area 50 m x 50 m

Model 2 – RC Frame Building with infill walls using equivalent strut approach (burnt clay brick) of area 50 m x 50 m

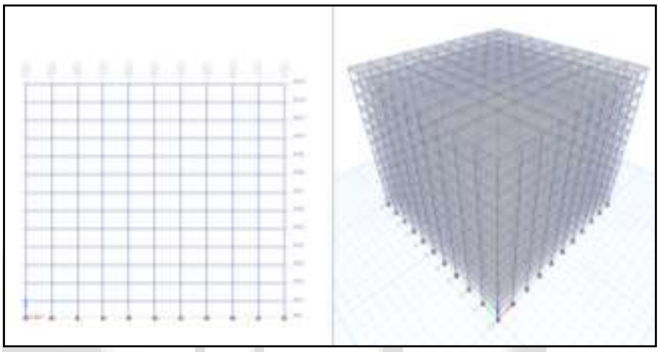
Model 3 – RC Frame Building with infill walls using equivalent strut approach (cement brick) of area 50 m x 50 m

Model 4 – RC Frame Building with infill walls using equivalent strut approach (hollow concrete block) of area 50 m x 50 m

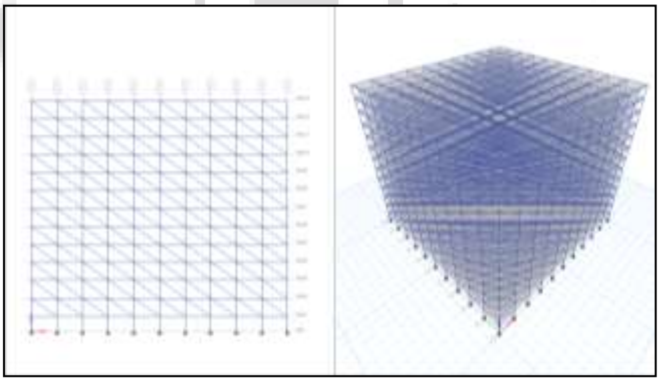
Model 5 – RC Frame Building with infill walls using finite element modelling (burnt clay brick) of area 50 m x 50 m

Model 6 – RC Frame Building with infill walls using finite element modelling (cement brick) of area 50 m x 50 m

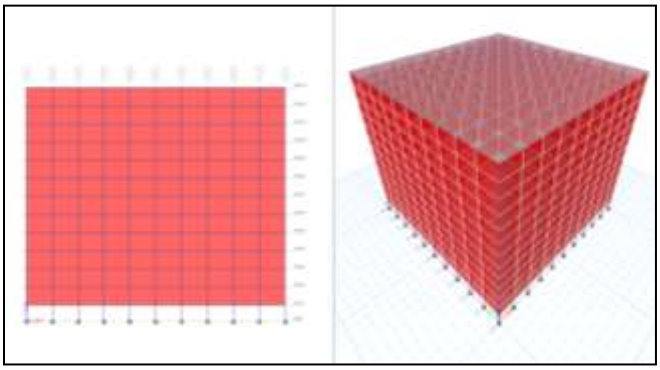
Model 7 – RC Frame Building with infill walls using finite element modelling (hollow concrete block) of area 50 m x 50 m



RC BARE FRAME



RC FRAME WITH INFILL WALL AS EQUIVALENT STRUT



RC FRAME WITH INFILL WALL AS FEM

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+11
Typical Storey Height	3.5 m.
Size of Column	300 x 1000
Size of Beam	300 x 600
Thickness of Slab	150 mm.
Thickness of Wall	230 mm
Material Properties	
Grade of Concrete	M 30
Grade of Steel	Fe500
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)

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 –

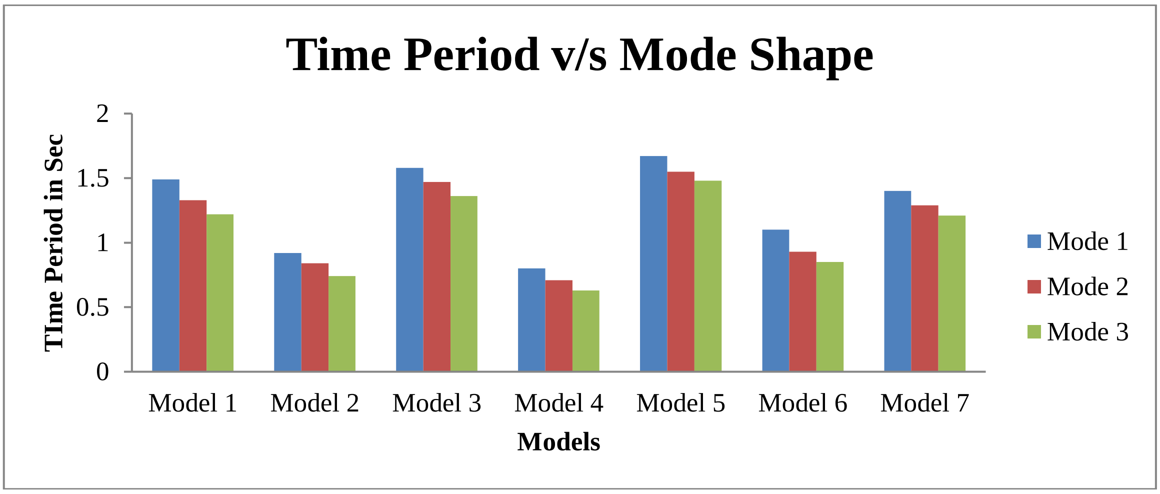
$$\alpha = h\{(\frac{E_m t \sin 2\theta}{4 E_f I_c h})^{\frac{1}{4}}\}$$

Where E_m – Modulus of Elasticity for Masonry
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

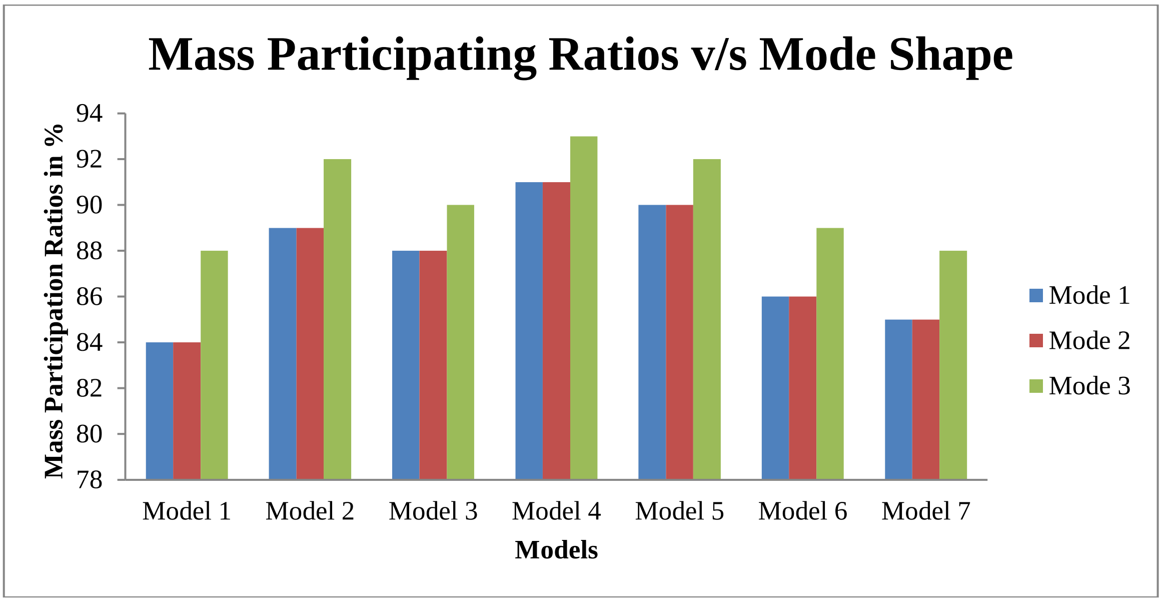
Size of Masonry	Material of Infill Material	Compressive Prism Strength of masonry fm (N/mm2)	Modulus of Elasticity Em (N/mm2)	Value of Stiffness Factor in X direction	Value of Stiffness Factor in y direction	Width of Strut in X Dir.	Width of Strut in Y Dir.
200 x 100 x 200 mm	Burnt Clay Bricks	6.3	3465	1.532	2.841	815	570
200 x 100 x 200 mm	Cement Bricks	8.46	6278	1.481	2.796	830	585
400 x 150 x 200 mm	Hollow Concrete Blocks	6.08	5898	1.75	3.245	775	540

III. RESULTS

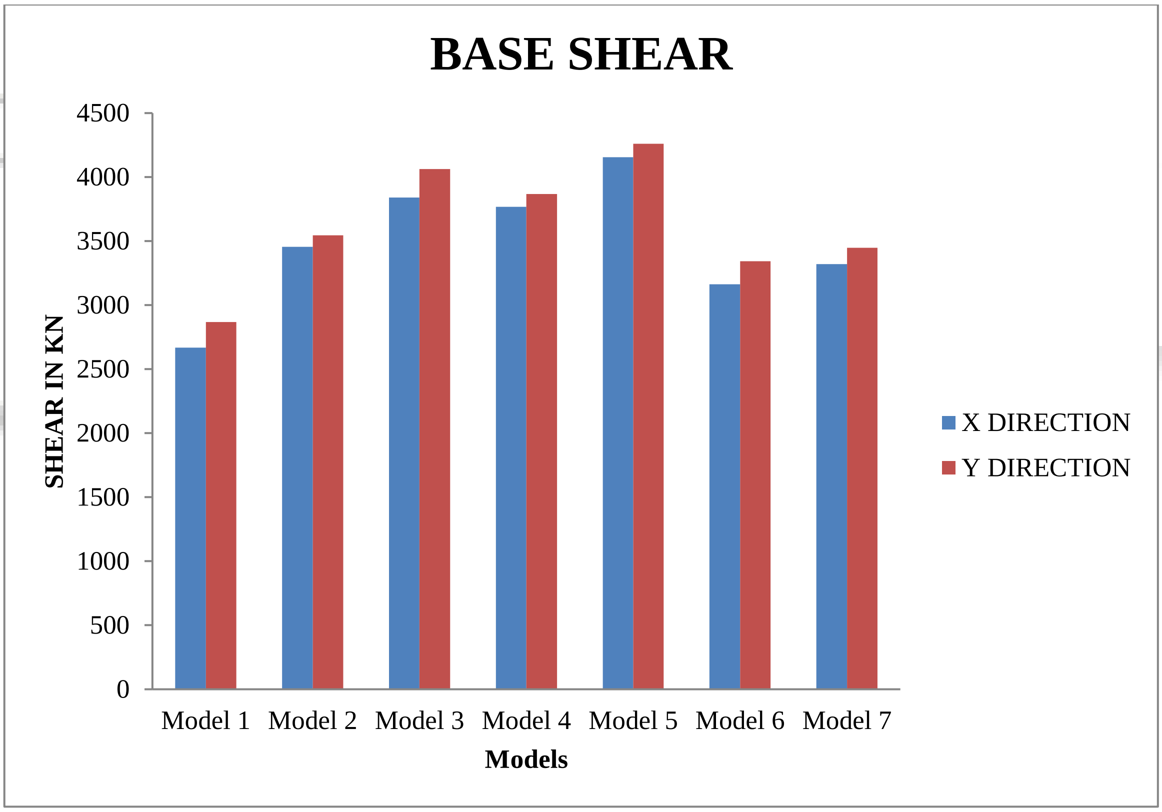
A. Time Period & Mode Shapes –



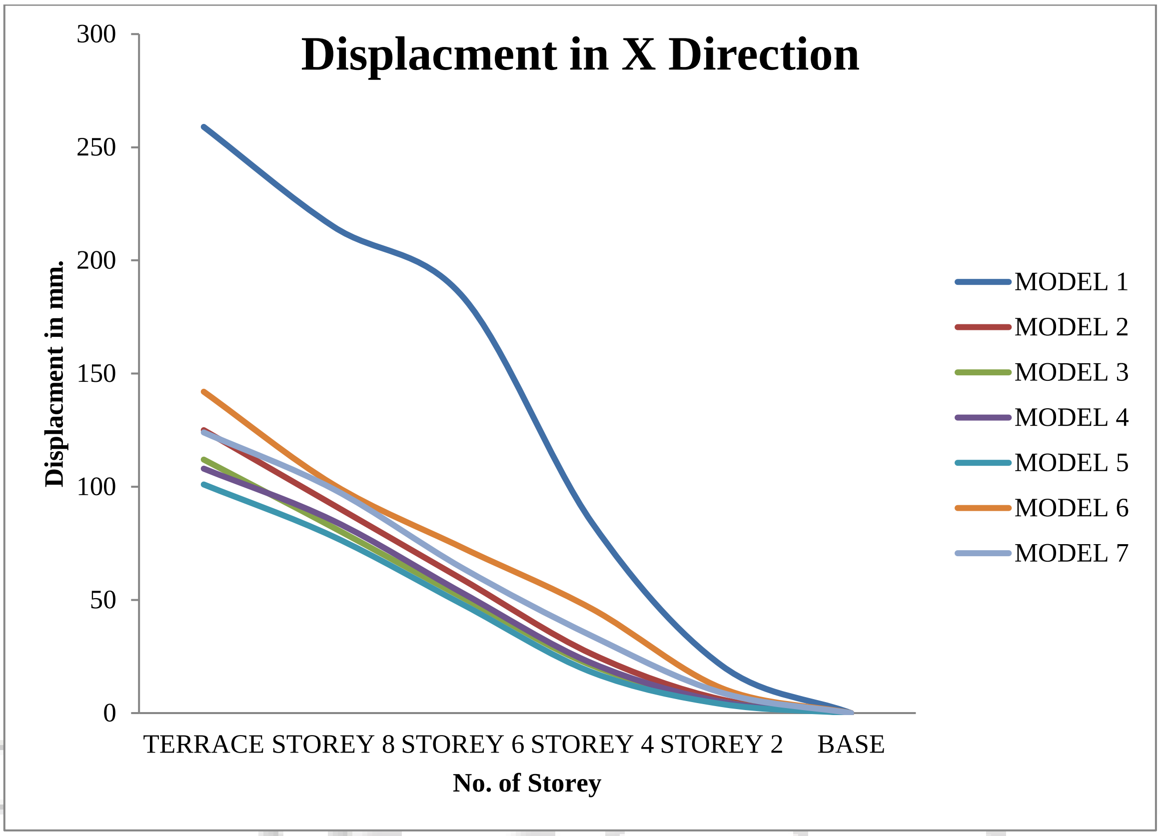
B. Mass Participation Ratios & Mode Shapes –

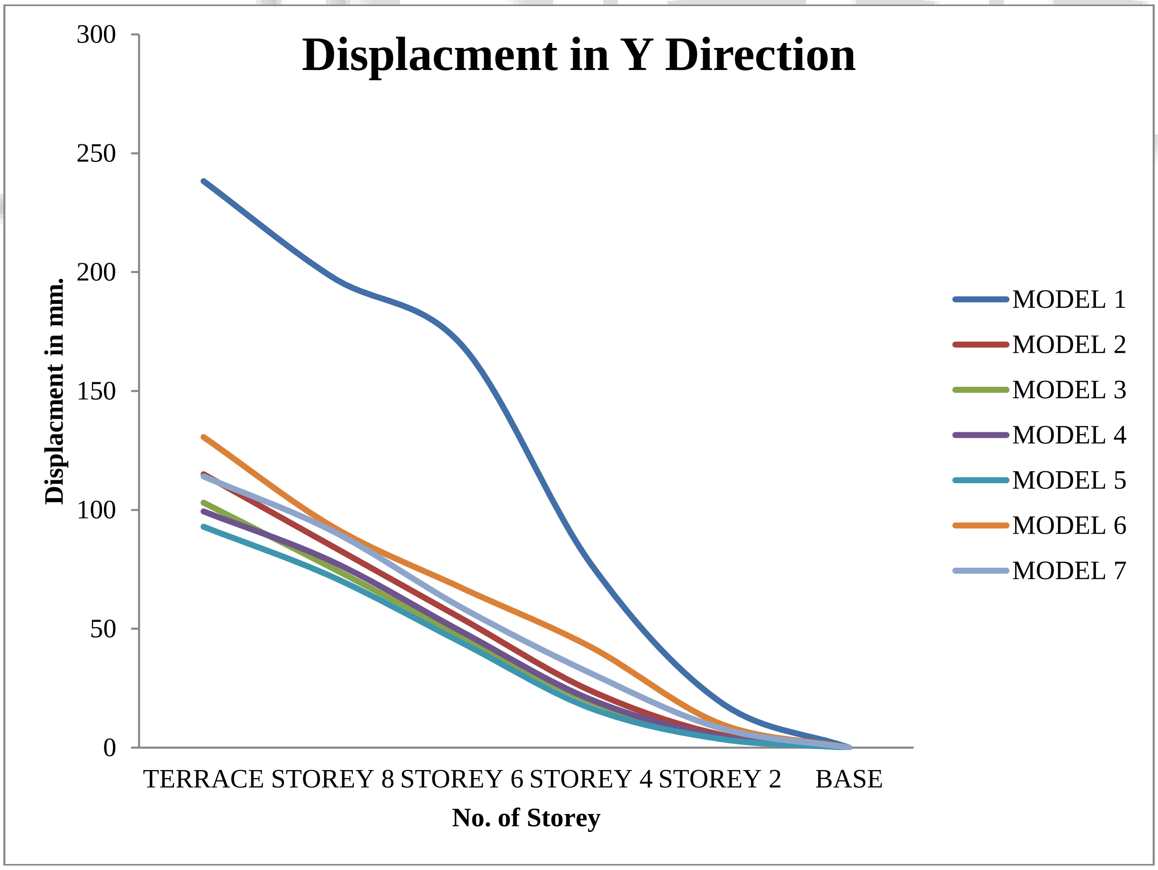


C. BASE SHEAR

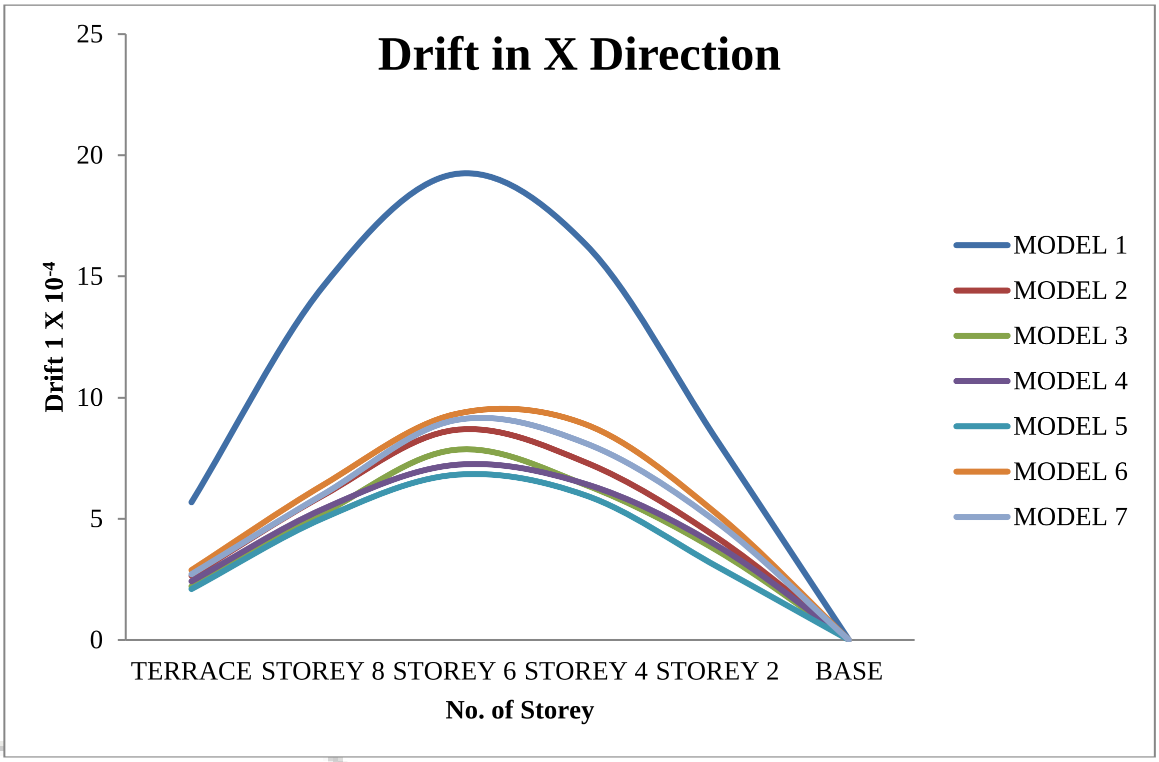


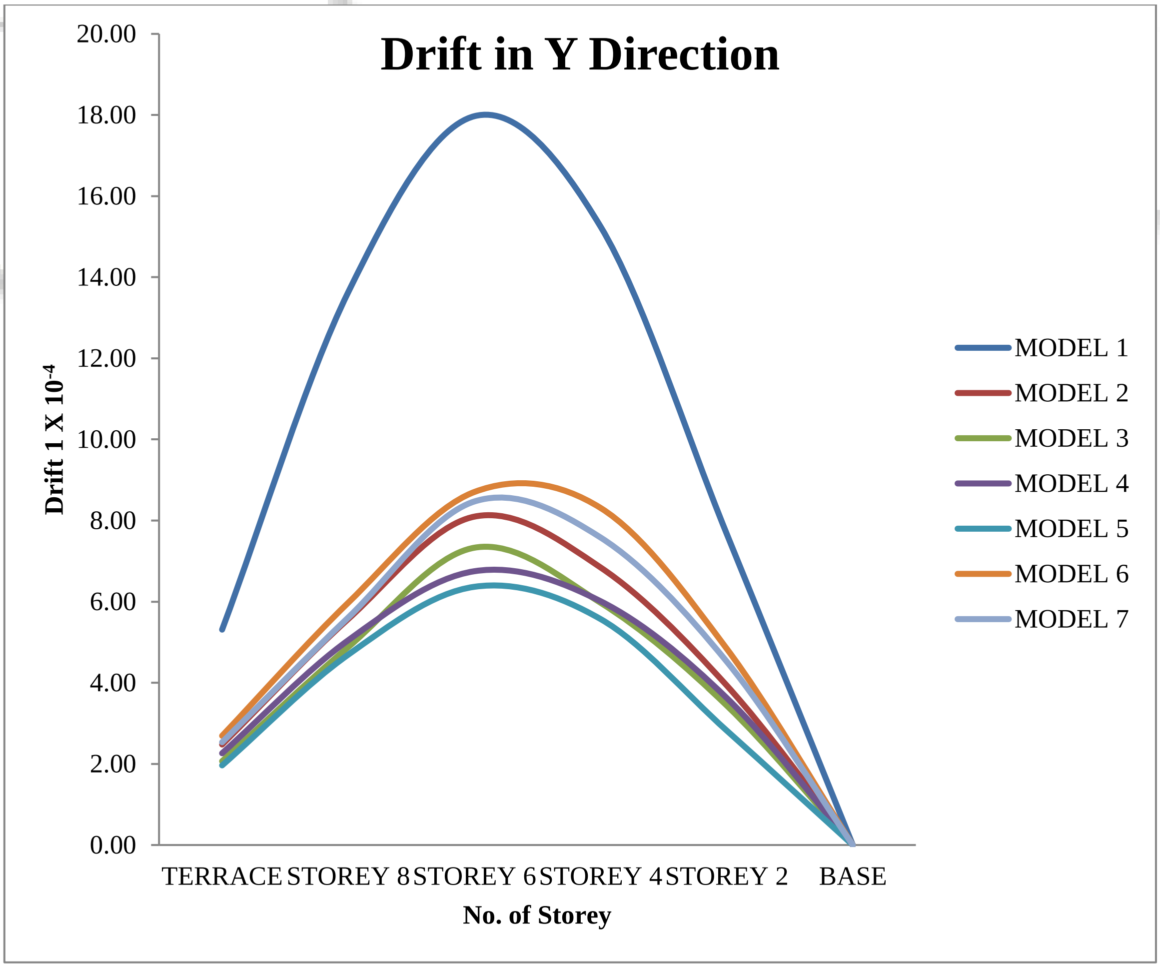
D. Displacement –





E. Drift


Drift in X Direction
25
20
15
10
5
0
Drift 1 X 10-4
TERRACE
STOREY 8
STOREY 6
STOREY 4
STOREY 2
BASE
No. of Storey
MODEL 1
MODEL 2
MODEL 3
MODEL 4
MODEL 5
MODEL 6
MODEL 7


Drift in Y Direction
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Drift 1 X 10-4
TERRACE
STOREY 8
STOREY 6
STOREY 4
STOREY 2
BASE
No. of Storey
MODEL 1
MODEL 2
MODEL 3
MODEL 4
MODEL 5
MODEL 6
MODEL 7

IV. Conclusion

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

1) The Time period of the RC structure with Infill as equivalent strut is less than the RC structure without infill due to the increment of stiffness while the time period using FEM infill walls is more than the conventional RC Structure due to increase in mass & too.
2) The Natural Time Period increases up to 6 % for cement bricks when compared to burnt clay brick as FEM model, while the value decreases for hollow concrete blocks up to 10 % when they compared to red burnt clay bricks for the same.
3) The time period decreases for the structure having infill using equivalent strut approach up to 28% when compared to conventional structure.
4) 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. While comparing on the basis of material properties, cement bricks considered as FEM shows less values as compared to other types of bricks. The value reduces up to 55% when compared to conventional structure, while comparing with Equivalent strut approach FEM infill wall shows 7% reduction in the value of displacement.
5) In X-direction and Y-direction, the storey drift is less for RC structure with Infill considered as FEM than RC structure without infill. While comparing on the basis of material properties, cement bricks shows less values up to 13 % as compared burnt clay brick while the value of drift for concrete block is 18 % higher than the value with conventional bricks.
6) In the presence of infill wall, the stiffness of the structure and base shear increases. For Cement brick material the value of base shear is 44% higher than the conventional structure due to increase in mass while with comparing with other type of material it shows increment up to 10%. Hence, the lateral load resisting mechanism of infill frames differs from bare frames as well as both approaches shows a impressive difference variation too.

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