International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 10, October- 2014

Seismic Performance of RC Framed Buildings With & Without Infill Walls

[1]C. Rajesh
M.Tech-Structural Engineering,
Student at C.M.R College of Engineering&
Technology,Hyderabad, Telangana, India

[2]Dr. Ramancharla Pradeep Kumar
Professor & Director of Earthquake Engineering Research Centre,
IIIT Hyderabad, India

[3]Prof. Suresh Kandru
Dept. of Civil EngineeringC. M. R College of Engineering&
Technology,
Hyderabad, Telangana, India

***Abstract*--In building construction, RC framed structures are frequently used due to ease of construction and rapid progress of work, and generally these frames are filled by masonry infill panels (or) concrete blocks in many of the countries situated in seismic regions. Infill panels significantly enhance both stiffness and strength of frame, it behaves like compression strut between column and beam and compression forces are transferred from one node to another. Performance of building in earthquakes (like Bhuj Earthquake) clearly illustrates that the presence of infill walls has significant structural implications.**

This study gives the overview of performance of RC frame buildings with and with-out infill walls. Here analyses and designs the masonry infill walls using equivalent diagonal strut concept in-order to assess their involvement in seismic resistance of regular reinforced concrete buildings. Modeled the two different buildings with and without infill walls and designed it and analysis done for gravity and seismic loads using software (SAP2000). Comparing the results from the computerized model analyses for with and without infill structures as bare-frame and single strut models respectively. We check the results for total weight of building, time period, base shear, and modal participation mass ratio and comparison of results.

Keywords: Bare-frame, Infill Walls, Equivalent Diagonal Strut

I. INTRODUCTION

Reinforced concrete (RC) frame buildings with masonry infill walls have been widely constructed for commercial, industrial and multi-family residential uses in seismic-prone regions worldwide. Masonry infill typically consists of brick masonry or concrete block walls, constructed between columns and beams of a RC frame. These panels are generally not considered in the design process and treated as non-structural components. In country like India, Brick masonry infill panels have been widely used as interior and exterior partition walls for aesthetic reasons and functional needs. Though the brick masonry infill is considered to be a non-structural element, but it has its own strength and stiffness. Hence if the effect of brick masonry is considered in analysis and design, considerable increase in strength and stiffness of overall structure may be observed. Present code, IS 1893(Part-I): 2000 of practice does not include provision of taking into consideration the effect of infill. It can be understood that if the effect of infill is taken into account in the analysis and design of frame, the resulting structure may be significantly different. Significant experimental and analytical research is reported in various literatures, which attempts to explain the behavior of infilled frames. Moreover, infill, if present in all storeys gives a significant contribution to the energy dissipation capacity, decreasing significantly the maximum displacements. Therefore the contribution of masonry is of great importance, even though strongly depending on the characteristics of the ground motion, especially for frames which has been designed without considering the seismic forces. When sudden change in stiffness takes place along the building height, the story at which this drastic change of stiffness occurs is called a soft story. According to IS 1893(Part-I): 2000, a soft story is the one in which the lateral stiffness is less than 50% of the storey above or below.

Another important issue is related to the numerical simulation of infilled frames. The different techniques for idealizing this structural model can be divided into two local or micro-models and simplified macro models. The first group involves the models, in which the structure is divided into numerous elements to take into account of the local effect in detail, whereas the second group includes simplified models based on a physical understanding of the behavior of the infill panel. In this study the strength and stiffness of the brick masonry infill is considered and the brick masonry infill is modeled using diagonal strut. The diagonal strut has been modeled using software package SAP2000. The analysis is performed using “Linear static analysis” for understanding the improvement in stiffness parameters.

Previous experimental studies also carried out on the behavior of RC frames with in-fills and the modeling, analysis of the RC frame with and without in-fills. *Stafford-Smith B [1]* used an elastic theory to propose the effective width of the equivalent strut and concluded that this width should be a function of the stiffness of the in-fill with respect to that of bounding frame. By analogy to a beam on elastic foundation, he defined the dimensionless relative parameters to determine the degree of frame in-fill interaction and thereby, the effective width of the strut. Also defined the formulation of empirical equations for the calculation of infill wall parameter as strut model like contact length of strut, effective width of the strut. *Holmes [2]* was the first in replacing the infill by an equivalent pin-jointed diagonal strut. He proposed the modeling of infill wall as the diagonal strut and finding the effective width and contact length of the diagonal strut. *Das and C.V.R. Murty [3]* carried out non-linear pushover analysis on five RC frame buildings with brick masonry in-fills. In-fills are found to increase the strength and stiffness of the structure, and reduce the drift capacity and structural damage. In-fills reduce the overall structure ductility, but increase the overall strength. Building designed by the equivalent braced frame method showed better overall performance. *Amato et al. [4]*discussed the mechanical behavior of single storey-single bay in-filled frames performed detailed numerical investigation on in-filled meshes has proved that in the presence of vertical loads it is possible that a strong correlation between the dimension of the equivalent diagonal strut model and a single parameter, which depends on the characteristics of the system. *V.K.R.Kodur et al. [5]*considered a three storey RC frame building models for the analysis. These RC frames were analyzed for three cases i) Bare frame ii) Infilled frame iii) Infilled frame with openings. Based on the analysis results they found that Base shear of infilled frame is more than infilled frame with openings and bare frame. Time period of infilled frame is less as compare to infilled frame with openings and bare frame. The natural frequency of infilled frame is more as compare to infilled frame with openings and bare frame. *Haroon Rasheed Tamboli [6]*considered the bare frame and infill model structures and performs the seismic analysis to see the variation in both the structures. His paper says that in presence of infill wall it affects the seismic behavior of frame structure to large extent and the infill will increase the strength and stiffness of structure. *A.Mohebkhah et al. [7*] performed kinds of numerical modeling strategies to stimulate the in-plane non-linear static behavior of infilled frames with openings with micro and macro modeling. Alsoanalyzed the model of infill frame as three-strut model and performed pushover analysis to check the capability of structures during non-linear analysis in which three-strut model shows more strength and stiffness during the strong ground motion and perform well when stiffness of infill wall is considered. *Neelima Patnala VS and Pradeep Kumar Ramancharla [8]*considered three sets of 2D ordinary moment resisting frames with and without unreinforced masonry infill walls (with and without openings) are considered. Applied Element Method is used to model the frames and nonlinear static pushover analysis is carried out to obtain the capacity curves. It is observed that the strength of the frame with infill is 10 times more than the ordinary bare frame, ductility of the frame increases with the addition of the infill walls. increase in number of storeys, the strength of the bare frame increases, obviously, whereas the strength of the frame with infill decreases it can be said that the difference in behavior of bare frame should not only be verified on a single storey but to be checked with different number of stories.

Methodology of the Work

The methodology worked out to know the performance of the buildings with and without infill walls during the analysis. Considering two buildings of and modeled as bare-frame and with infill walls which infill walls are modeled as equivalent diagonal strut model in the frame. Perform the linear static analysis for all the model buildings using SAP2000 software for both gravity and seismic load analysis and comparative study is taken out from the analysis. Comparison is taken drawn out on all the aspects of the performance of the buildings individually.

II. MODELING & ANALYSIS OF BARE-FRAME BUILDINGS

Considered two buildings of G+5 & G+9 storeys having same floor height and similar properties of the structures. Both the buildings are modeled as bare-frame i.e., buildings without considering infill walls between the vertical and horizontal elements of the building. These are analyzed for gravity loads and seismic loads in the software as per IS 1893(Part-1):2002 condition of analysis.

A. Preliminary Data

To analyze the gravity and seismic load performance of the building we considered two different building of different heights as G+5 and G+9 storeys RC framed buildings of same storey levels. The general parameters required for the modeling of the two buildings has the same parameter are as follows:

- Type of frame :Special RC moment resisting frame fixed at the base
- Seismic zone :V
- Number of storeys :G+5 & G+9
- Floor height :3.5 m
- Plinth height :1.5 m
- Depth of Slab :150 mm
- Spacing between frames :5m along both directions
- Live load on floor level :4 kN/m^2
- Live load on roof level :1.5 kN/m^2
- Floor finish :1.0 kN/m^2
- Terrace water proofing :1.5 kN/m^2
- Materials :M 20 concrete, Fe 415 steel and Brick infill
- Thickness of infill wall :250mm (Exterior walls)
- Thickness of infill wall :150 mm (Interior walls)
- Density of concrete :25 kN/m^3
- Density of infill :20 kN/m^3
- Type of soil :Medium
- Response spectra :As per IS 1893(Part-1):2002
- Damping of structure :5 %

  **Live load on floor level and roof level are taken from IS-875 (Part-) considered RC framed buildings as commercial usage.

B. Member and Material Properties

Dimensions of the beams and columns are determined on the basis of trial and error process in analysis of SAP2000 by considering nominal sizes for beams and columns and safe sizes are as show in the table below.

Table 1: Properties of Bare – Frame, Strut Model Buildings

Type of Analysis	Model	Gravity Load Building		Seismic Load Building	
		BEAM (m)	COL. (m)	BEAM (m)	COL. (m)
G+5 storey Building	Bare-frame	0.40 x 0.40	0.50 x 0.50	0.50X0 .50	0.60 x 0.60
	Single-strut	0.40 x 0.40	0.55 x 0.55	0.45 x 0.45	0.60 x 0.60
G+9 storey Building	Bare-frame	0.50 x 0.50	0.60 x 0.60	0.55 x 0.55	0.70 x 0.70
	Single-strut	0.50 x 0.50	0.60 x 0.60	0.55 x 0.55	0.65 x 0.65

Material properties of the building are like M20 grade of concrete, FE415 steel and 13800 N/mm^2 of modulus of elasticity of brick masonry in the buildings.

C. *Load Calculations*

In this dead and live loads due to slab is transferred to beams using yield line theory as per IS CODE- SP-24-(1983) bending moments in the beams may be determined with sufficient accuracy by assuming that the loading is equivalent to a uniform load per unit length of the beam is as follows:

On the short span UDL $= \frac{W l_x}{3}$

On the long span UDL $= \frac{W l_x}{6}\left[3 - \left(\frac{l_x}{l_y}\right)^2\right]$

Where,

l_x = Shorter span,
l_y= Longer span
W = Load per unit length

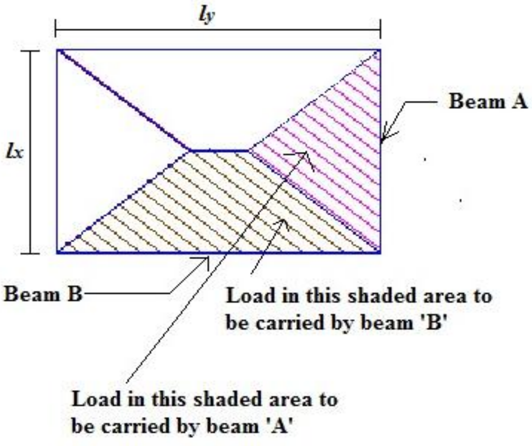

Figure 1: Load Carried By Supported Beams

The distribution of loads are calculated and found as shown in the table.

Table 2: Slab loads on beam using Yield line theory

Type of load	Position	DL of slab	LL of slab	DL of Wall
	Units	(kN)	(kN)	(kN)
Load on roof beams	Exterior beams	10.416	2.5	6.0
	Interior beams	20.832	5.0	0
Loads on Floor beams	Exterior beams	7.916	6.66	15.5
	Interior beams	15.83	13.33	9.3
Loads on Plinth beams	Exterior beams	0	0	15.5
	Interior beams	0	0	9.3

After modeling the buildings the plan, elevation and 3D-views are show in the figures below. Using the load combinations for gravity and seismic loads as per IS 1893(Part-1):2002, clause 6.3.1.2 analyzed the G+5 & G+9 storey bare-frame models using the software and drawn out the results like total weight, time period, base shear and modal participation mass ratio of the two buildings. Also for finding the results of base shear and time period manual process is also done using Equivalent Static Method. The results can be seen in the tables.

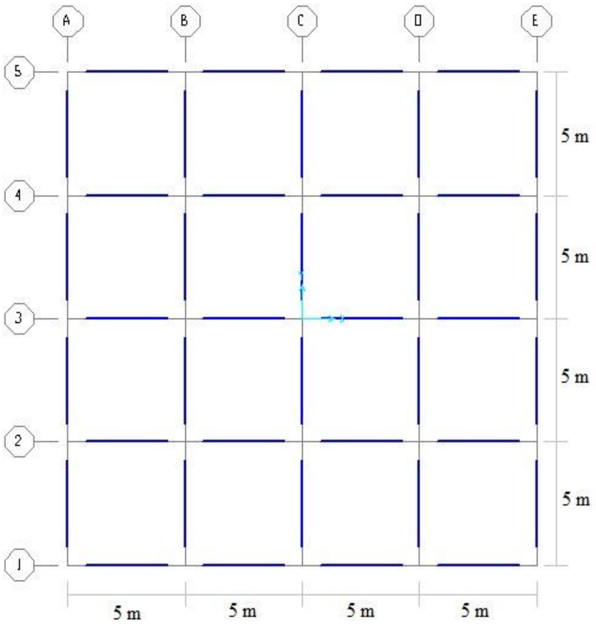

Figure 2: Plan of G+5 & G+9 storey building of all models

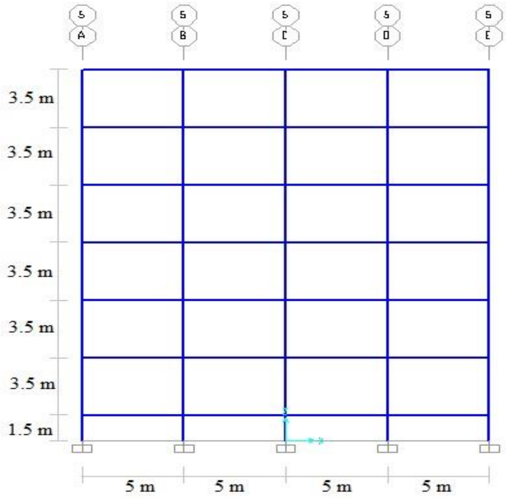

Figure 3: Elevation of G+5 storey Bare-frame model

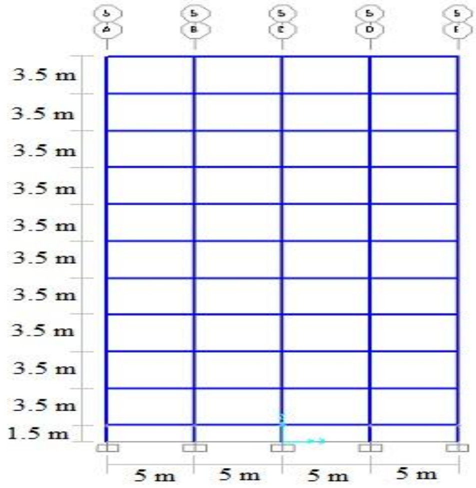

Figure 4: Elevation of G+9 storey Bare-frame model

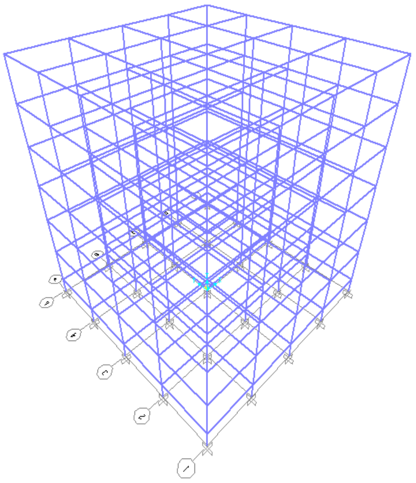

Figure 5: 3D-view of G+5 storey Bare-frame model

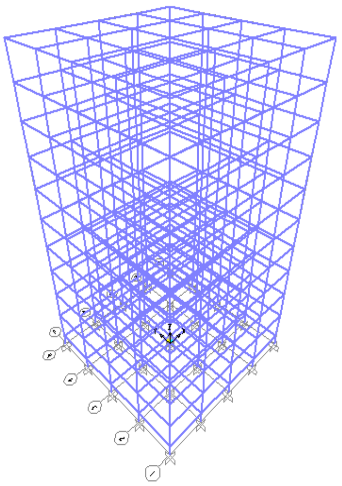

Figure 6: 3D-view of G+9 storey Bare-frame model

III. MODELING & ANALYSIS OF BUILDINGS WITH INFILL WALLS

Modeling of RC framed buildings with infill walls and the behavior of the structure due to gravity and seismic forces in the high seismic intensity zone area. Also deals with the change in the stiffness of the building when considered the infill between the vertical and horizontal resisting elements and the infill is modeled as the Equivalent diagonal strut model which is called as micro-model of analysis of infill frame. The main problem in the approach is to find the effective width for the equivalent diagonal strut. Various researchers have suggested different empirical formulas for finding the width of equivalent diagonal strut. In this study, used the formulas suggested by B.S.Smith [1] to find the width of the equivalent diagonal strut. Finally the infill wall is modeled in the building by transforming into an equivalent diagonal strut between the beam and column and analyzed the buildings.

In this the study is carried by considering the single-strut model of analysis using the equivalent diagonal strut method. In this method of analysis the stiffness and strength of the wall is considered and transformed the wall as a strut by finding the width of the strut which is placed inclined between beam-column joints in the frame as show in the fig.

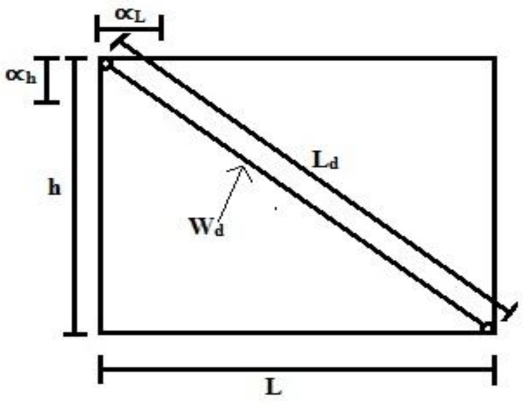

Figure 7: Equivalent Diagonal Strut model

In modeling the equivalent diagonal strut major part is to find the effective width of the strut in which it depend on length of contact between wall and column and between wall and beam. Stafford smith developed the formulations for α_h and α_L on the basis of beam on an elastic foundation. Hendry proposed the equation to find the equivalent diagonal strut width. The following equations are proposed to determine α_h and α_L, which depend on the relative stiffness of the frame and infill walls, and on the geometry of panel.

$$\propto_h = \frac{\pi}{2}\sqrt[4]{\frac{4\,E_f I_c h}{E_m \mathrm{t}\,\sin 2\theta}}$$

$$\propto_L = \frac{\pi}{2}\sqrt[4]{\frac{4\,E_f I_b h}{E_m \mathrm{t}\,\sin 2\theta}}$$

Where,

E_m and E_f = Elastic modulus of the masonry wall and frame material (i.e., concrete), respectively.

L, h, t = Length, height and thickness of the infill wall, respectively.

I_c, I_b = Moment of inertial of column and the beam of structure, respectively.

$\theta = \tan^{-1}\left(\frac{h}{L}\right)$ = angle of inclination of diagonal strut.

The equation to determine the equivalent or effective strut width (w_d), length (L_d) and area of strut (A_d), where the strut is assumed to be subjected to uniform compressive stress.

$$\mathrm{w_d} = \frac{1}{2}\sqrt{\propto_h^2 + \propto_L^2}$$

$$L_d = \sqrt{h^2 + L^2}$$

$$A_d = t\,\mathrm{w_d}$$

By using these formulas the effective width (w_d), length (L_d) and area (A_d) of the diagonal strut is determined.

Consider the same parameters of bare frame modeled buildings of G+5 & G+9 storey building and its loading. Here bare frame model is changed into single-strut model by considering the stiffness of the masonry infill wall which acts as a rigid element. The effective width, length and area of the strut, are calculated for both the buildings separately.

Table 3 Parameters of G+5 storey Diagonal Strut Models

Parameters		**Data**	**Units**
Grade of concrete		20	MPa
Modulus of elasticity of concrete E_f		22360.68	MPa
Modulus of elasticity of brick masonry E_m		13800	MPa
Size of beam (Depth x Width)		0.50 x 0.50	m
Size of column		0.60 x 0.60	m
Moment of inertia of beam I_b		5.2×10^{-3}	m^4
Moment of inertia of column I_c		10.8×10^{-3}	m4
Thickness of External Infill wall t_e		0.25	m
Thickness of internal infill wall t_i		0.15	m
Length of masonry		4.4	m
Height of masonry h	Floor level	3.0	m
	Plinth level	1.0	m
Angle of inclination of strut $\left(\theta = \tan^{-1}\frac{h_m}{L_m}\right)$	Floor level	34.28°	Degrees
	Plinth level	12.80°	Degrees

The width of the single strut building is shown in table below.

Table 4: Calculation of Width of Diagonal of Single – struts

Level	Strut type	$\propto_h$ (m)	$\propto_L$ (m)	W_d (m)	L_d (m)	A_d (m^2)
Floor	Ext. wall	1.53	1.4	1.04	5.33	0.26
	Int. wall	1.74	1.59	1.18	5.33	0.18
Plinth	Ext. wall	1.41	1.7	1.10	4.51	0.28
	Int. wall	1.6	1.93	1.25	4.51	0.19

From the above table W_d the value of width of the strut placed diagonally between the beam and column joints. Using the width of the strut and length of the strut we modeled the single-strut model building with the basic parameters and loading on beams and columns are same as the bare-frame G+5 & G+9 storey building. So after modeling the building with external strut and internal strut we can see the model of buildings as shown in fig. below.

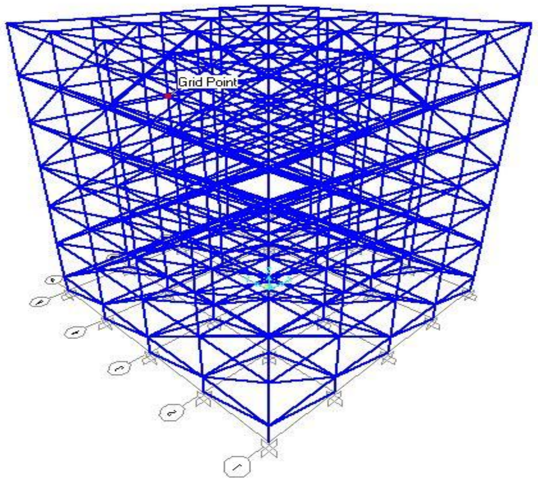

Figure 8: 3D-view of G+5 storeys Single - Strut Model Building

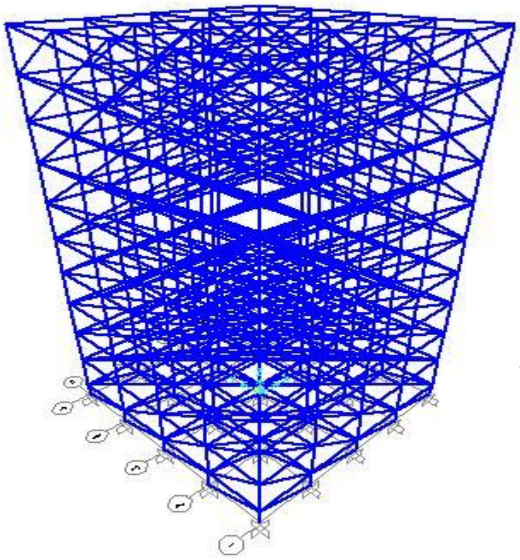

Figure 9: 3D-view of G+9 storeys Single-Strut Model Building

After modeling both the buildings as single-strut models are analyzed for gravity and seismic load analysis using the SAP 2000 software. Observed the results like total weight, time period, base shear and modal participation mass ratio of the buildings.

IV. OBSERVATIONS & RESULTS

In this G+5 & G+9 storey buildings are modeled as bare-frame and strut-model buildings by considering the stiffness and strength of the infill walls in the buildings. The models are analyzed for gravity and seismic loads as per IS 1893(Part-I):2000 are analyzed in SAP2000 software.

Also for bare-frame model the buildings are analyzed manually as per code and found the total weight, base shear and time period of the building. The results are show in the tables

Table 5: G+5 Bare-frame building manual & software results

G+9 storey bare-frame building						
Type of Analysis	**Total Weight (kN)**		**Base shear (kN)**		**Time period (sec.)**	
	Manual	SAP 2000	Manual	SAP 2000	Manual	SAP 2000
Gravity Load Analysis	42114	51195	-	-	-	**1.705**
Seismic Load Analysis	46235	55892	3935	4759	0.774	**1.185**

Table 6: G+9 bare-frame building manual & software results

G+9 storey bare-frame building						
Type of Analysis	**Total Weight (kN)**		**Base shear (kN)**		**Time period (sec.)**	
	Manual	SAP 2000	Manual	SAP 2000	Manual	SAP 2000
Gravity Load Analysis	76309	92123	-	-	-	**2.003**
Seismic Load Analysis	81688	92123	4868	5802	1.113	**1.670**

Table 7: G+5 & G+9 bare frame & Strut Model buildings Results
-

Results of G+5 & G+9 Bare-frame & Strut Model				
Model	**Type of Analysis**	**Total Wt. (kN)**	**Base shear (kN)**	**Time period (sec.)**
		SAP 2000	SAP 2000	SAP 2000
G+5 Bare-frame Model	**Gravity Load Analysis**	51195	-	1.705
	Seismic Load Analysis	55892	4759	1.185
G+5 Single-Strut Model	**Gravity Load Analysis**	51933	-	0.203
	Seismic Load Analysis	54229	6547	0.194
G+9 Bare-frame Model	**Gravity Load Analysis**	92123	-	2.003
	Seismic Load Analysis	97976	5802	1.67
G+9 Single-Strut Model	**Gravity Load Analysis**	92123	-	0.413

VI. COMPARISON OF RESULTS

The comparison of results for bare-frame and strut model buildings are show in the figures, and discussed the comparison of results are based in the analysis of buildings.

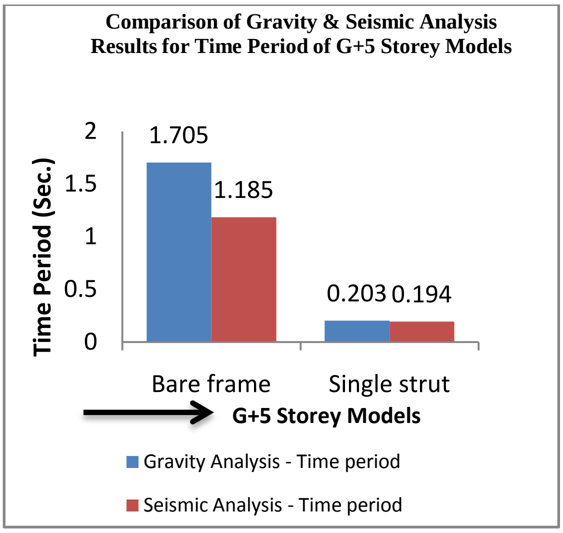

Figure 10: Comparison of Time Period of G+5 storey Buildings

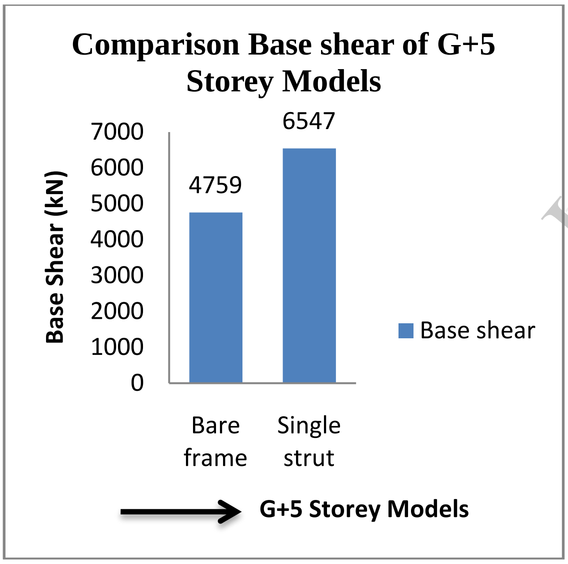

Figure 11: Comparison of Base Shear of G+5 storey Buildings

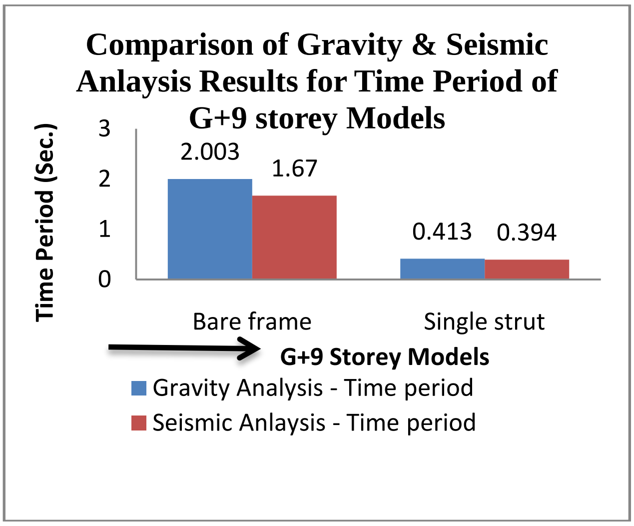

Figure 12: Comparison of Time Period of G+9 storey Buildings

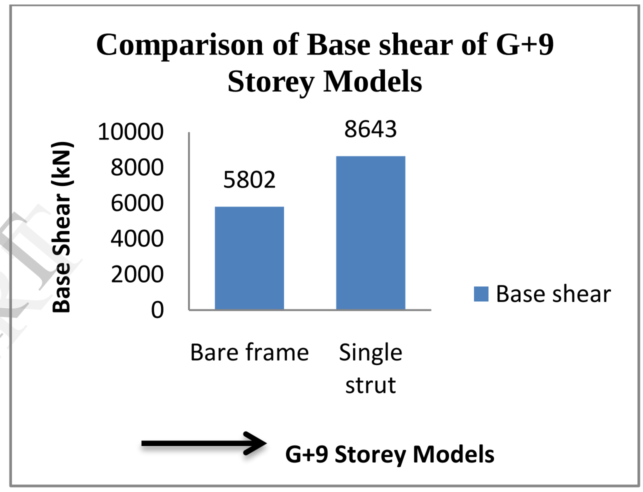

Figure 13: Comparison of Base Shear of G+9 storey Buildings

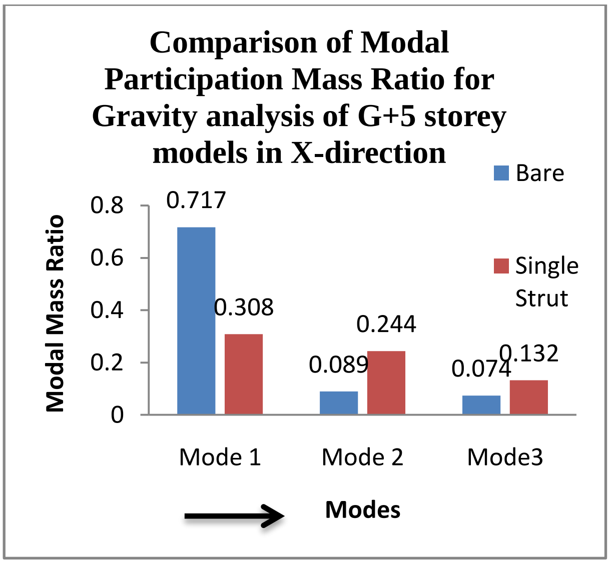

Figure 14: Comparison of Modal Participation of Mass Ratio for Gravity Analysis of G+5 storey Models in X-direction

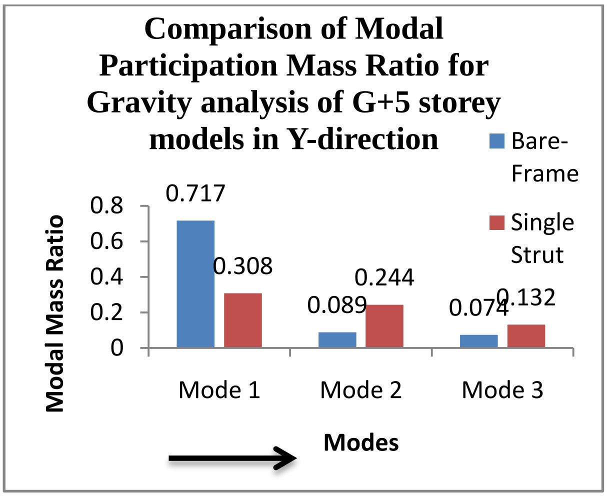

Figure 15: Comparison of Modal Participation of Mass Ratio for Gravity Analysis of G+5 storey Models in Y-direction

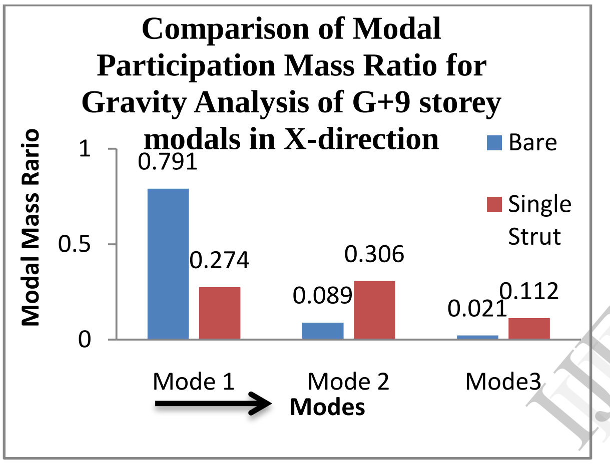

Figure 16: Comparison of Modal Participation of Mass Ratio for Gravity Analysis of G+9 storey Models in X-direction

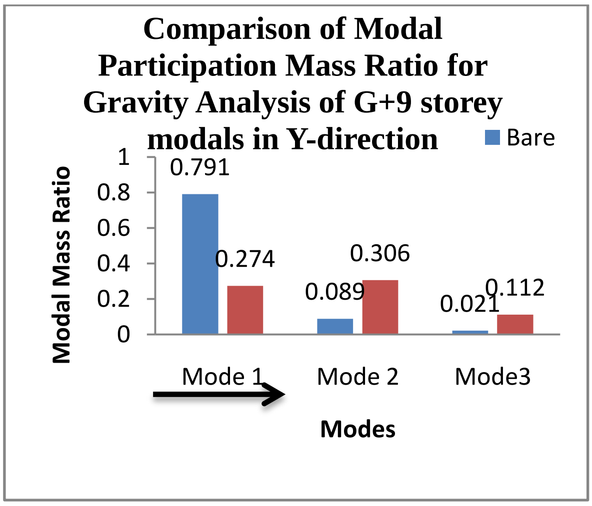

Figure 17: Comparison of Modal Participation of Mass Ratio for Gravity Analysis of G+9 storey Models in Y-direction

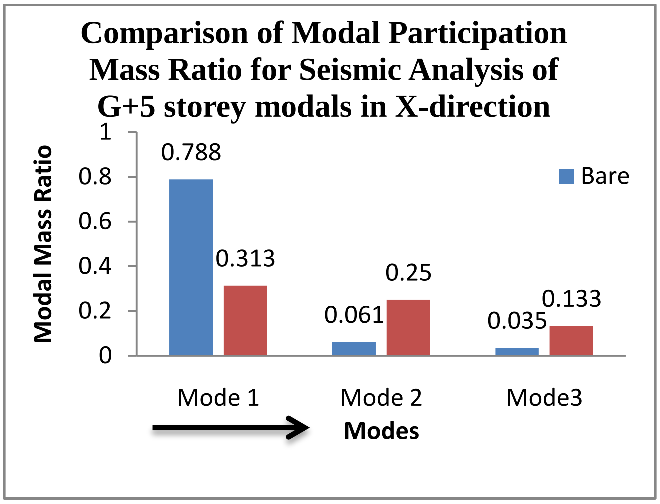

Figure 18: Comparison of Modal Participation of Mass Ratio for Seismic Analysis of G+5 storey Models in X-direction

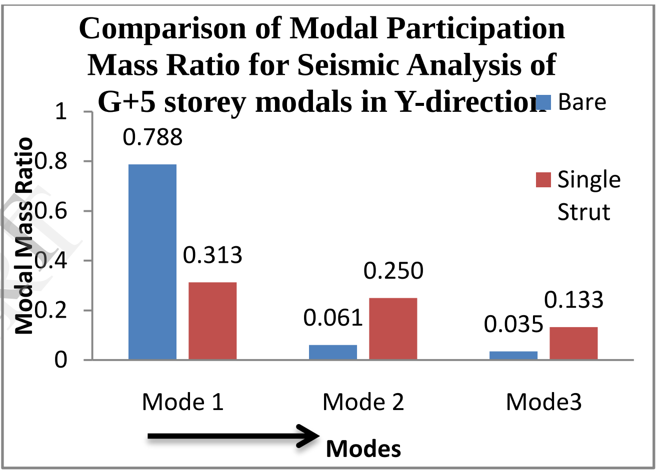

Figure 19: Comparison of Modal Participation of Mass Ratio for Seismic Analysis of G+5 storey Models in Y-direction

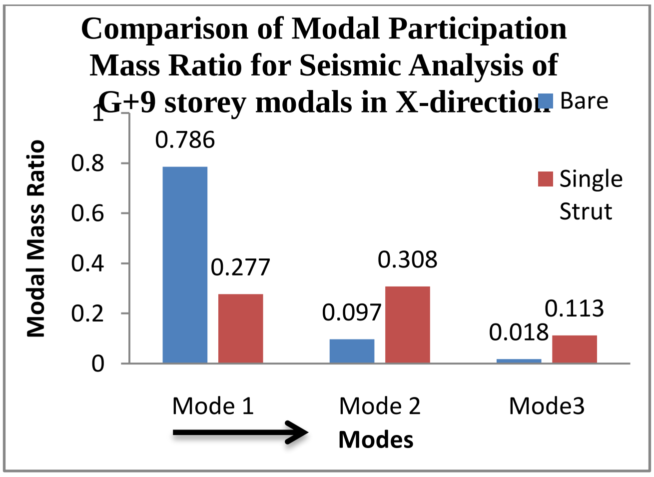

Figure 20: Comparison of Modal Participation of Mass Ratio for Seismic Analysis of G+9 storey Models in X-direction

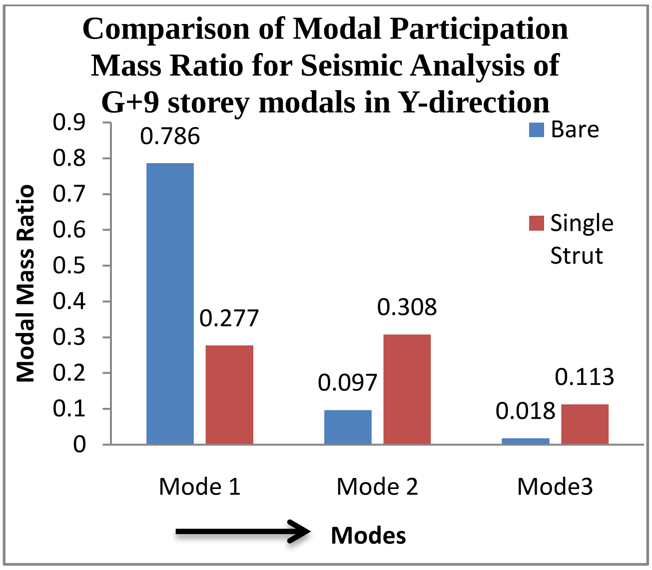

Figure 21: Comparison of Modal Participation of Mass Ratio for Seismic Analysis of G+9 storey Models in Y-direction

VII. CONCLUSION

From the observation of the results it states that decrease in the time period will leads to increase in the base shear of the building and also total weight of the building is less in strut model as compared to bare-frame model buildings. Strut model buildings show the less time period and total weight of the building and higher in the base shear of the building. As if we know time period is inversely proportional to stiffness, here it is seen that strut model buildings has less time period than bare-frame buildings which can say that strut model buildings are more stiffer and safer during the earthquakes than the bare-frame models. From the previous earthquakes like Bhuj in 2001 many of the buildings are collapsed due to the improper analysis and design of buildings which are analyzed without considering the stiffness of the walls which leads to the sudden collapse of the buildings. From this analysis it concludes that strut model buildings gives better and best performance than bare-frame model buildings in the high seismic prone areas.

REFERENCES

1. a. Stafford Smith B, Lateral stiffness of infilled frames, Journal of Structural division, ASCE,88 (ST6), 1962, pp. 183-199.
b. Stafford Smith B. Behaviour of Square Infilled Frames. Proceedings of the American Society of Civil Engineers, Journal of Structural Division, 92, no STI, 381-403, 1966.
c. Stafford Smith B, Carter C. A method of analysis for infill frames. Proc. Inst. Civil Engineering, 1969.
2. Holmes M. Steel frames with brickwork and concrete infilling. Proceedings of the Institution of Civil Engineers 19, 1961.
3. A. DAS D AND MURTY C V R, Brick Masonry Infills in Seismic Design of RC Frame Buildings: Part 2- Behaviour, The Indian Concrete Journal, 2004.
4. A. AMATO G, CAVALERI L, FOSSETTI M, AND PAPIA M, Infilled Frames: Influence of Vertical Load on The Equivalent Diagonal Strut Model, The 14th World Conference on Earthquake Engineering, Beijing, China, 2008.
5. V.K.R.Kodur, M.A.Erki and J.H.P.Quenneville "Seismic analysis of infilled frames" Journal of Structural Engineering Vol.25, No.2, July 1998 PP 95 -102.
6. Haroon Raheed Tamboli and Umesh N.Karadi, Seismic Analysis of RC Frame Structures With and Without Masonary Walls, Indian Journal of Natural Sciences, Vol.3/Issue14, Oct.2012.
7. A.Mohebkhah, A.A.Tanimi, and H.A.Moghadam, A Modified Three-Strut (MTS) Model for Masonry-InfilledSteel Frames with Openings, Journal of Seismology and Earthquake Engineering, Vol.9, No.1,2 , Spring and Summer 2007.
8. Patnala V S Neelima, Ramancharla Pradeep Kumar, Seismic Behaviour of RC Frame with URM Infill: A Case Study, International Journal of Education and Applied Research (IJEAR), Vol.4, Issue Spl-2, Jan-June 2014.
9. Text book: "Earthquake Resistant Design of Structures", by Pankaj Agarwal and Manish Shrikhande, PHI Learning Private Limited, 2013.
10. Text book: "Earthquake Resistant Design of Structures", by S.K.Duggal.
11. IS 456, "Plain and Reinforced Concrete-Code of Practice", Bureau of Indian Standards, New Delhi, 1993.
12. IS 1893, "Criteria for Earthquake Resistant Design of Structures-Part-1": General Provisions and Buildings (Fifth Revision), Bureau of Indian Standards, New Delhi, 2002.
13. SP-16, Design Aids for Reinforced Concrete to IS: 456-1978, Bureau of Indian Standards, New Delhi, 1980.
14. SP 24 (1983): Explanatory Handbook on Indian Standard Code of Practice for Plain and Reinforced Concrete (IS 456:1978, [CED 2: Cement and Concrete].
15. IS 1786 (2008): High strength deformed steel bars and wires for concrete reinforcement- [CED 54: Concrete Reinforcement].
16. IS 875-2 (1987): Code of Practice for Design Loads (Other Than Earthquake) For Buildings And Structures, Part 2: Imposed Loads [CED 37: Structural Safety].