ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 3, March 2017

Seismic Behavior of Horizontally Irregular RC Buildings

[1]Kartik Suresh Mahajan, [2] Dr. K. Gopi Krishna
[1] M. Tech. Student, Dept. of Civil Engg., NIT Warangal, TS, India,
[2]Assistant Professor, Dept. of Civil Engg., NIT Warangal, TS, India

***Abstract:*— Seismic events viz., Earthquakes are one of the most devastative events faced by mankind which has a potential to cripple even the economy of a nation. Reinforced concrete multi-storied high rise structures have become a common sight in urban habitat. These structures are made irregular in order to provide certain functionalities viz., parking spaces, lighting, ventilation and other architectural considerations in geometry of the structure etc. These irregularities are broadly classified as vertical and horizontal. They cause sudden change in stiffness, strength, mass characteristics of structures, resulting in drastic change in its behavior during earthquakes [10]. It has been established during earlier events at Latur (Maharashtra), Indonesia, Nepal etc., that these types of irregular structures are vulnerable during earthquakes. Hence lot of research is focused in this direction to mitigate the casualties arising due to irregular RC structures. The present paper focuses to study the seismic behavior of RC buildings which have horizontal irregularity (L-, T-, plus- and I-shaped plan configuration) with/without infill walls in comparison to a regular building for various seismic zones in INDIA having soil types I & III. Dynamic analysis using response spectrum from IS 1893 (Part 1):2002 has been performed for regular and irregular buildings using SAP2000. Further, the influence of infill wall, known for its pronounced vulnerability during past earthquakes on the seismic behavior of RC structures is also presented.**

***Index Terms*— Response spectrum, dynamic analysis of RC buildings, structural irregularities, Earthquake analysis.**

I. INTRODUCTION

The world is always susceptible for any natural disaster. Earthquakes are one of the most unpredictable and devastating of all natural disasters. This event has a potential to cripple even the economy of a nation in the form of loss of human lives and destruction of properties. However the prediction and prevention of occurrence of earthquakes is not possible but we can design the structures to reduce the effect of the same by resisting such earthquake forces. To perform well in earthquake, the structure should possess four main attributes, namely simple and regular configuration, adequate lateral strength, stiffness and ductility [12].

Structures with simple regular geometry and uniformly distributed mass and stiffness in plan as well as in elevation are considered as regular structures which have much lesser vulnerability for failure than irregular structures. Nowadays, with the advancement in rapid growth of urbanization, due to agility of structure, RC multi-storied high rise structures are very much preferred. These structures are made irregular in order to provide certain functionalities viz., parking spaces with taller storey height, lighting, ventilation and other architectural considerations in geometry of the structure etc.
These irregularities are broadly classified as vertical and horizontal. The vertical irregularity is due to soft storey, weak storey, mass irregularity, vertical geometrical irregularity and in-plane discontinuity in vertical elements resisting lateral forces. And the horizontal irregularity is due to re-entrant corners, torsional irregularity, diaphragm discontinuity, out-of-plane projections and non-parallel systems [6].

These irregularities cause sudden change in stiffness, strength, mass characteristics of structures, resulting in drastic change in its behavior during earthquakes. The same has been established during earlier events at Latur (Maharashtra), Indonesia, Nepal etc.

In the present study, an attempt has been made to study the seismic behavior of RC buildings which have horizontal irregularity with/without infill walls in comparison to a regular building for various seismic zones in INDIA having soil types I (Rock or Hard soil) & III (Soft soil) considering the parameters like base shear, fundamental natural time periods, storey displacement, stiffness and capacity of the structures. Re-entrant corners in a building are one of the types of horizontal irregularity. According to IS 1893 (Part I): 2002, plan configurations of a structure and its lateral force resisting system is said to have re-entrant corners, where both projections of the structure beyond the re-entrant corner are greater than 15 percent of its plan dimension in the given direction [6]. The study focuses on horizontal irregularity due to presence of re-entrant corners in building frames with and without infill walls. Dynamic analysis using response spectrum from IS 1893 (Part I): 2002 has been performed for regular and irregular buildings using SAP2000. Further, influence of infill walls is also presented.

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 3, March 2017

II. MODELING

The object of this work is to compare seismic behavior of regular and horizontally irregular buildings of similar properties that to having re-entrant corners with/without infill walls considering the parameters like base shear, fundamental natural periods storey displacement, stiffness and capacity of the structures. All the buildings are analyzed for each zone with soil types I and III. For this purpose five different plan configuration building models are chosen namely regular building with plan symmetric about both the axes, L, T, I and plus (+) shaped plan configuration buildings as shown in Fig. 1 to 5. One set of models is of without infill walls and another is with infill walls. Following details are used for modeling and analyzing the buildings in SAP2000:

Material and Dimensional details:

1. No. of Stories: 8
2. Floor height: 3m
3. 3 bays of 5m each in X-direction and Y-direction
4. Grade of concrete: M25
5. Grade of steel: Fe415
6. Bricks:
    a. Unit weight, γ: 18.85 kN/m^3 [1]
    b. Brick of class designation 5 i.e. bricks having average compressive strength (f_m) not less than 5 MPa is considered[2]. Thus, in this study, f_m: 5 Mpa
    c. Modulus of elasticity [5], E: 550f_m = 2750 MPa
    d. Coefficient of thermal expansion [5], α: 7.2 X 10^{-6} mm/mm/^{o} C
    e. Poisson's ratio, μ: 0.17 to 0.29, thus average value has been adopted i.e. 0.23 [8]
7. Size of beams: 230 X 400 mm
8. Size of columns: 450 X 450 mm
9. Depth of slab: 200 mm
10. Walls:
    a. External wall thickness: 230 mm
    b. Internal wall thickness: 115 mm
    c. Parapet thickness: 230 mm & height: 1.2 m

Loading details:

1. Live load on floors: 3 kN/m^2
2. Live load on roof: 1.5 kN/m^2
3. Floor finish: 1 kN/m^2
4. Roof treatment: 1.5 kN/m^2

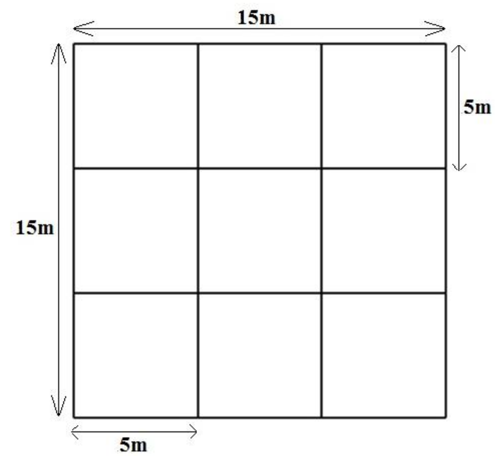

Fig. 1: Plan of regular building

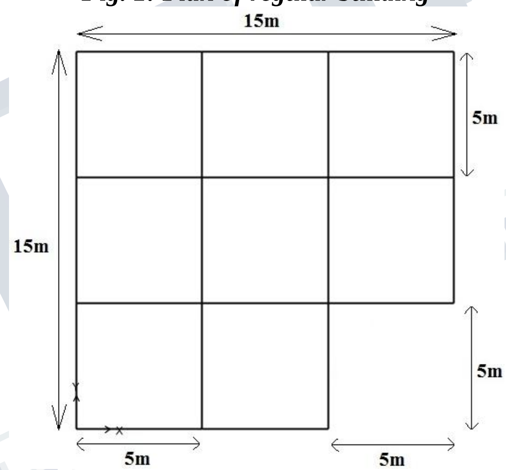

Fig. 2: L - shaped plan configuration

Infill walls are represented by single diagonal strut model whose thickness is equal to the thickness of particular wall (external or internal) and width is equal to the one fourth of the respective diagonal length [5]. In this study construction sequence is not considered in analysis, thus providing infill walls as struts without any gap element [11].

In seismic weight calculations, according to IS 1893 (Part I): 2002, only 25% of live load on floors (since LL $\leq$ 3 kN/m^2) and no live load on roof is considered [6]. For nonlinear static (pushover) analysis, M3 hinges and P-M2-M3 hinges are assigned to beams and columns respectively [5].

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 3, March 2017

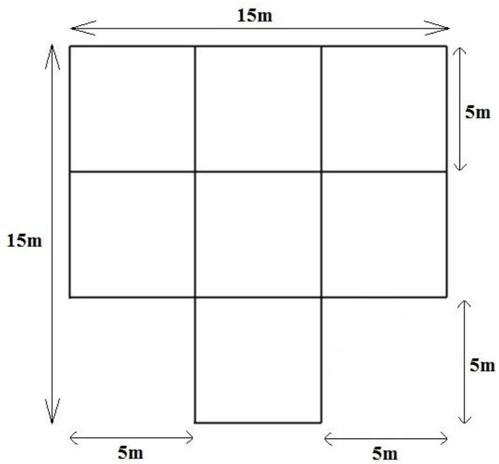

Fig. 3: T - shaped plan configuration

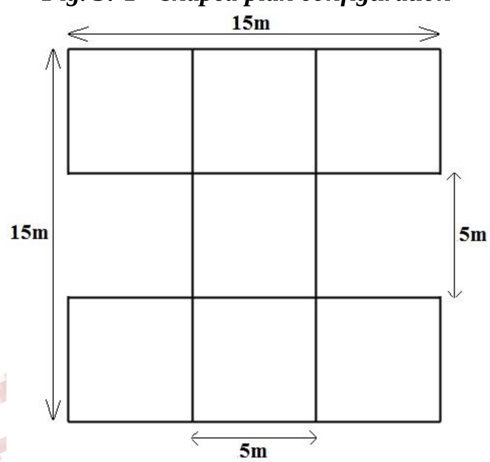

Fig. 4: I - shaped plan configuration

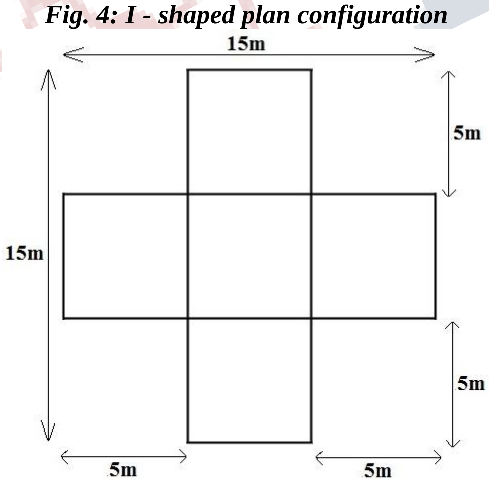

Fig. 5: Plus - shaped plan configuration

III. ANALYSIS

The methods of analysis used in the present study are:

i. Equivalent Static Analysis Method

This method follows linear static procedure, in which the responses (displacements or accelerations) are assumed in a linearly elastic manner. Analysis is carried out as per IS 1893 (Part I): 2002, design base shear along any principal direction is given by multiplication of design horizontal seismic coefficient and seismic weight of the structure. Design horizontal seismic coefficient depends on the zone factor which varies from 0.10 to 0.36 [6], importance of the structure, response reduction factor of the lateral load resisting elements and the fundamental natural time period of the structure. Seismic weight of the structure can be calculated as sum of total dead load and appropriate amount of specified imposed loads.

ii. Response Spectrum Method

In this method linear dynamic analysis of the building models is performed. The maximum response of the buildings which characterizes the design earthquake for the site and considers the performance criteria of the building is estimated directly from elastic or inelastic design spectrum. The software solves the Eigen value problem of the model and calculates the fundamental natural period and frequency values. Hence the mass and stiffness distribution is accounted by generation and distribution of total earthquake loads along the height of the structure. The modeling and analysis is carried out for each zone (II to V) with extremities of soil types i.e. I and III using SAP2000.

iii. Nonlinear Static Analysis Method

The name itself defines that this method follows nonlinear static analysis procedure. Analysis considers material as well as geometrical nonlinearity. The analysis is performed by using SAP2000 in which material nonlinearity is considered by considering nonlinear part of stress-strain curves for each material and geometrical nonlinearity is introduced by assigning the hinges to the frame elements [4],[5],[7]. This nonlinear analysis gives capacity of the structure in graphical format which can be used for visualization of performance as well as stiffness variation of the structure [9].

IV. REULTS AND DISCUSSION

Analysis of the RC building models chosen is performed using SAP2000 and results obtained are displayed and discussed based on different parameters in the below section.

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 3, March 2017

Base Shear

Buildings are analyzed for each zone with soil types I and III. The results are plotted which are as shown in Fig. 6 to 9. According to IS 1893 (Part I): 2002, base shear is the multiplication of seismic weight and horizontal seismic coefficient. For a particular building model in a particular soil type, seismic weight, importance factor, response reduction factor and average response acceleration coefficient (S_a/g) are constant. Therefore base shear is directly depending on zone factor which increases with zone level. So in each case of soil type and building frames with/without infill walls, it is clearly observed that base shear increases with increase in probability of occurrence of earthquake i.e. zone level.

For a particular zone, building built in soil III is subjected to higher base shear than the same building built in soil type I due to higher S_a/g value.

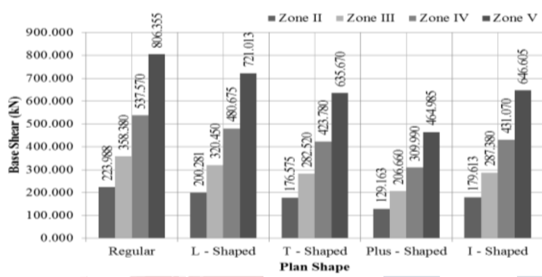

Fig. 6: Base shear for soil type I (buildings without infill)

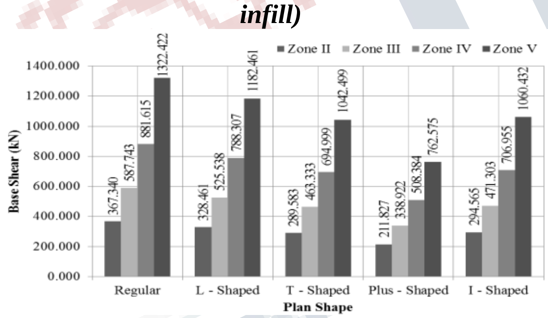

Fig. 7: Base shear for soil type III (buildings without infill)

Seismic weight is consisting of part of imposed load and total dead load of structure. In this study, same amount of imposed loads are applied on each building with/without infill walls. For total dead load of structure, each building has same sizes of beams, columns, slabs and parapet. The only difference between buildings with and without infill walls is presence of the walls (external and internal). Hence, for a particular soil type, building having infill walls is subjected to higher base shear than that of corresponding building without infill walls due to increased dead load.

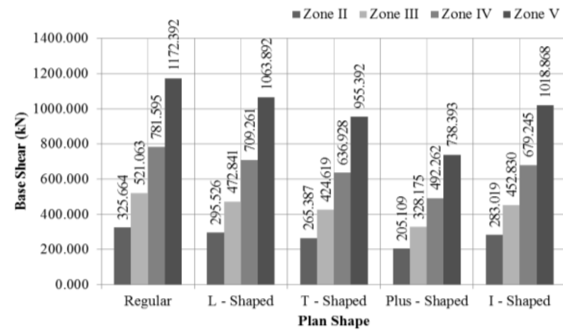

Fig. 8: Base shear for soil type I (buildings with infill)

For example base shear for plus shaped plan building with infill walls in zone V with soil type III is 1210.964 kN which is greater than that without infill walls i.e. 762.575 kN. Since seismic weight of each building is different, Base shear variation for each soil type is as follows: Regular building > L shaped plan building > I shaped plan building > T shaped plan building > Plus shaped plan building.

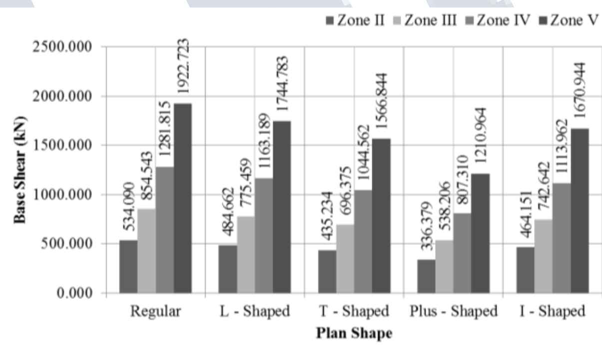

Fig. 9: Base shear for soil type III (buildings with infill)

Fundamental Natural Time Periods

According to IS 1893 (Part I): 2002, the number of modes to be used in the analysis should be such that the sum total of modal masses of all modes considered is at least 90 percent of the total seismic mass [6]. Therefore first three modes are considered. If time periods are closely spaced then absolute summation (ABS) and if not then square root of sum of squares (SRSS) method are used for the calculation of equivalent time period.

Table I: Fundamental Time Periods for Buildings without infill

Mode	Time Period of Building having Plan Shape (sec)				
	Regular	L	T	I	Plus
1	1.0533	1.0318	1.0558	1.0655	1.0707
2	1.0153	1.0318	1.0556	1.0625	1.0707
3	1.0015	1.0079	1.0089	1.0106	1.0117
Teq	3.0701	3.0714	3.1204	3.1387	3.1531

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 3, March 2017

Table II: Fundamental Time Periods for Buildings with infill

Mode	Time Period of Building having Plan Shape (sec)				
	Regular	L	T	I	Plus
1	0.5508	0.6823	0.6883	0.6893	0.6997
2	0.5472	0.6788	0.6817	0.6861	0.6403
3	0.4889	0.5947	0.5929	0.5917	0.6047
Teq	1.2019	1.4854	1.4928	1.4973	1.9447

Lesser the fundamental time period, more will be the stiffness of the structure and vice versa. Table I & II shows time periods of buildings with infill walls are having more stiffness than that in buildings without infill walls due to introduction of infill walls. Variation of stiffness of buildings with/without infill walls is as follows: Regular building > L shaped plan building > T shaped plan building > I shaped plan building > Plus shaped plan building.

Storey Displacement

Buildings having more stiffness undergo less deformation. Since all buildings having infill walls have stiffness more than that of corresponding buildings without infill walls, therefore lesser storey displacements can be observed as shown in Fig. 10-11. It can be clearly observed that stiffness of buildings with infill walls is significantly higher than that of buildings without infill walls since lateral displacements in both X and Y directions are much lesser for buildings with infill walls. Variation of stiffness is similar to that discussed in section IV

(B).

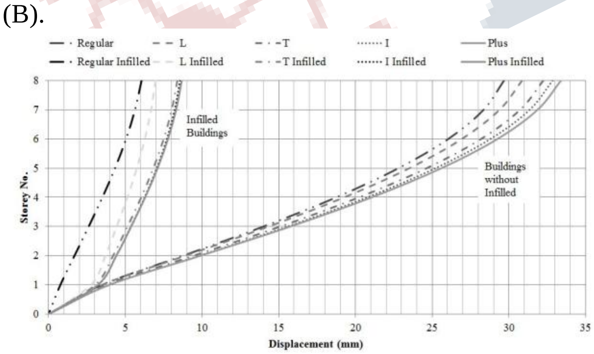

Fig. 10: Lateral displacement in X-direction (buildings without infill)

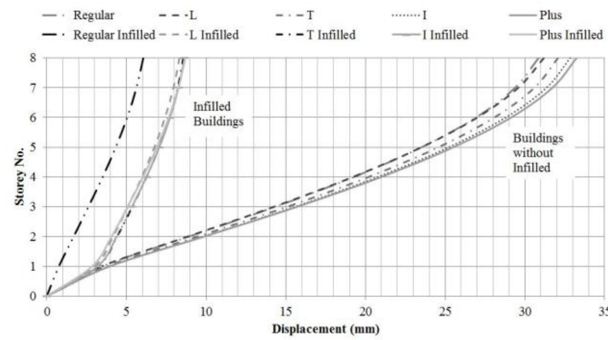

Fig. 11: Lateral displacement in Y-direction (buildings without infill)

Capacity Curves

Nonlinear static (pushover) analysis is performed for evaluating the capacity of the structures. Results of nonlinear static analysis are in the form of capacity curves and demand curves. Capacity curve represents the capacity of the structure which is initially plotted as a graph between base shear and roof displacement. Demand curve represents the demand of the earthquake from the structure which is initially plotted as a graph of spectral acceleration vs. time period. Demand curves given in IS 1893 (Part I): 2002 are used in this study. Both the plots are then converted into ADRS (Acceleration Displacement Response Spectrum) format and overlapped on each other [3]. The intersection point of these two curves i.e. the point where capacity of the structure equals demand of earthquake is known as performance point. In other word, performance point is nothing but the maximum acceleration and displacement that an equivalent SDOF system can attain.

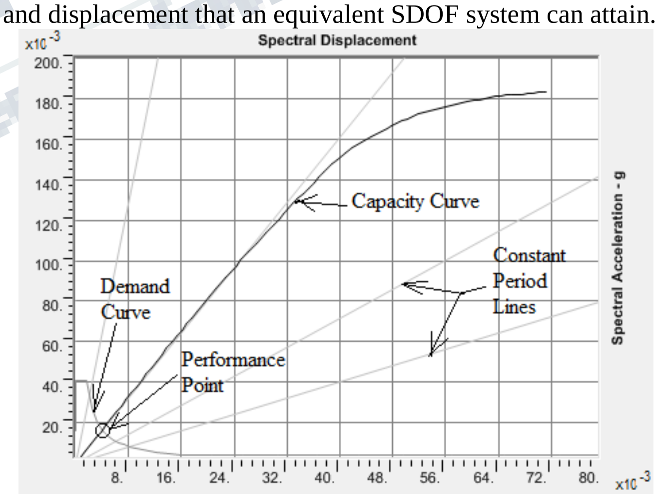

Fig. 12: Regular Building in Z: III & S: I (without infill)

IFERP
connecting engineers... developing research
ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 3, March 2017

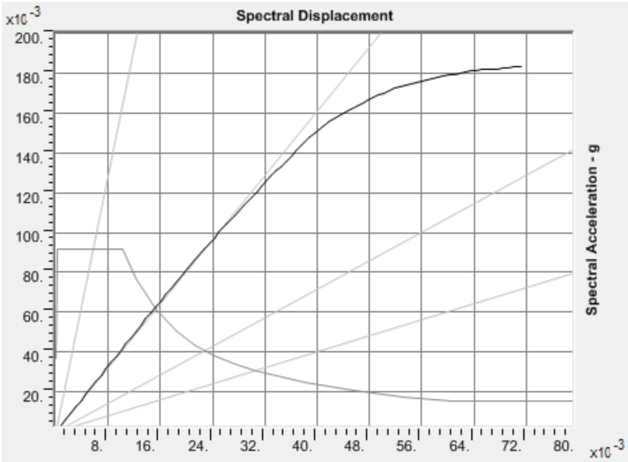

Fig. 13: Regular Building in Z: V & S: III (without infill)

Since, for all zones and soil types, sizes and shape of the building elements along with the material properties are constant. Also, supports defined at bottommost end of all columns are fixed supports i.e. no soil-structure interaction is taken into account. Thus capacity of a building will not change with zones and soil types. E.g., Fig. 12 and 13 shows nonlinear static analysis results for regular building without infill walls for two different zones III & V and soil types I & III respectively. Zone (Z): III & Soil type (S): I demand is less than that of Z: V & S: III, thus performance point is shifted towards origin. This means due to Z: III & S: I demand, structure undergoes less lateral displacement than that due to Z: V & S: III demand. Therefore building needs less capacity to resist lateral forces due to Z: III & S: I demand.

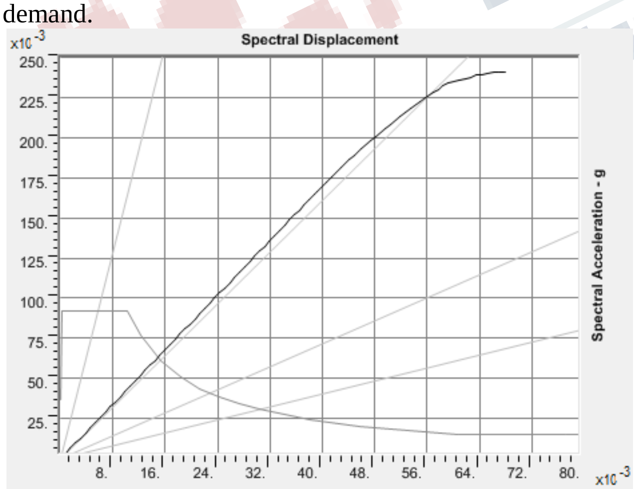

Fig. 14: T – Shaped Plan Building in Z: V & S: III (without infill)

The curves are first plotted based on of effective time (T_{eff}) before converting them into ADRS format. T_{eff}, in other words, is the time required to attain the maximum acceleration and displacement. More the T_{eff}, more time will be taken by the structure to reach the performance point i.e. the structure is more flexible and undergoes large deformations until it reaches performance point. Table III and IV show T_{eff} values for different buildings with/without infill walls.

Table III: T_{eff} for buildings without infill

Plan Config.	Regular	L	T	I	Plus
Time (s)	0.935	0.948	0.973	0.981	0.989

Table IV: T_{eff} for buildings with infill

Plan Config.	Regular	L	T	I	Plus
Time (s)	0.629	0.651	0.663	0.665	0.673

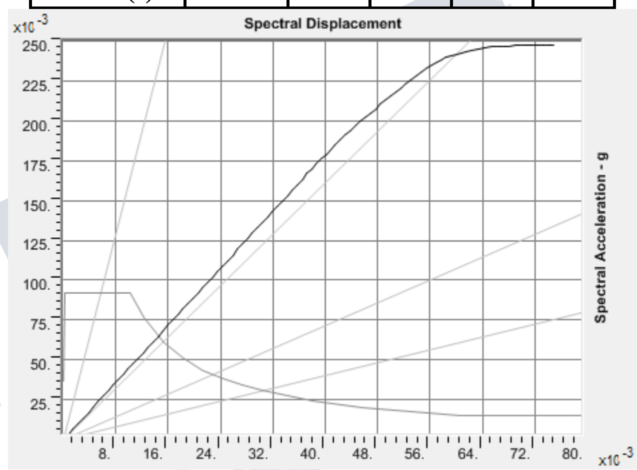

Fig. 15: Plus – Shaped Plan Building in Z: V & S: III (without infill)

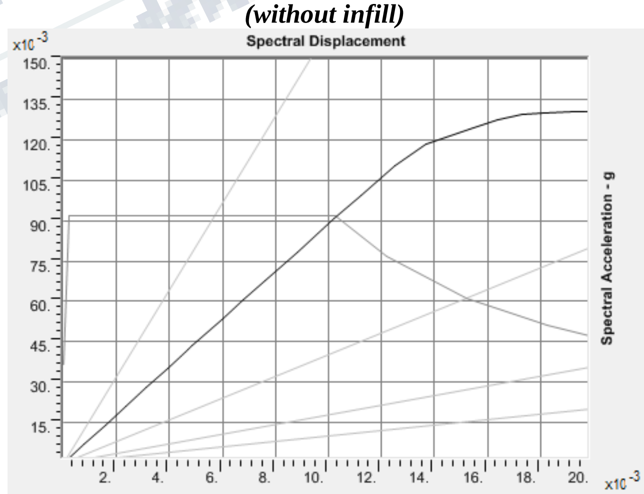

Fig. 16: Regular Building in Z: V & S: III (with infill)

Comparing the Fig. 13 & 16 and/or 14 & 17 and/or 15 & 18, maximum spectral displacements for buildings with infill walls are much lesser than that for buildings without infill walls. The reduction in displacement is due to increased stiffness of the structure which results from the introduction of infill walls. The structure having more stiffness attracts more forces. Again it can be clearly observed that T_{eff} of buildings without infill walls are significantly larger than that for buildings with infill walls. This indicates that buildings with infill walls reach the performance point earlier. Hence, buildings with infill walls are more susceptible for early failures. More the T_{eff} better the performance of the structure. Based on this performance one can select appropriate configuration of structure according to zone and soil type.

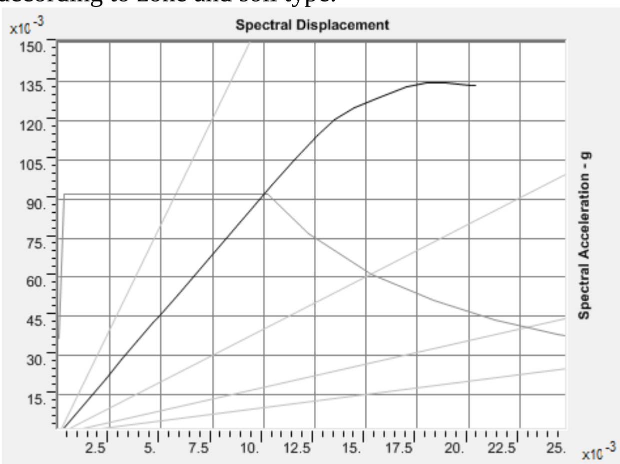

Fig. 17: T – Shaped Plan Building in Z: V & S: III (with infill)

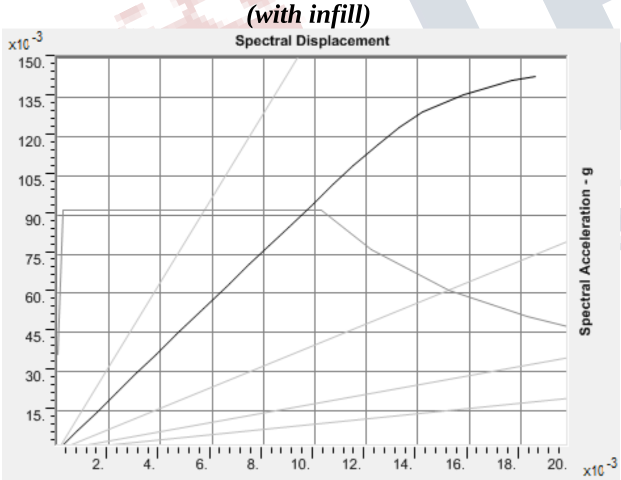

Fig. 18: Plus – Shaped Plan Building in Z: V & S: III (with infill)

V. CONCLUSION

Two sets of building models are used in this study namely buildings without infill walls and without infill walls. Construction sequence is not considered in analysis, thus infill walls are modeled as diagonal struts without gap elements. Introduction of infill walls increases the dead load of the structure resulting into increased base shear for buildings having infill walls. Base shear increases with zone level keeping all other factors constant.

Regular building is the stiffest as well as plus shaped plan building is the most flexible in their set of models. All the buildings with infill walls have more stiffness than that of corresponding buildings without infill walls. Owing to the more stiffness regular buildings undergoes less storey displacements followed by L, T, I and plus shaped plan buildings in their set of models.

Since, for all zones and soil types, sizes and shape of the building elements along with the material properties are constant. Also, no soil-structure interaction is taken into account. Thus capacity of a building will not change with zones and soil types. Performance curves indicate regular buildings are the most suitable for earthquake prone zones in both with/without infill walls conditions.

If construction sequence is considered then infill struts need to be provided with gap elements to simulate practical situations. Since, if earthquake occurs, prior to frame elements walls get damaged even collapsed and alter the performance. This study can be extended to assess this performance alteration and to insure higher efficiency of structure during earthquakes. I would like to express my deep sense of gratitude and sincere thanks to Dr. K. Gopi Krishna for his discerning guidance and valuable suggestions for the completion of this study.

REFERENCES

[1] IS 875 (Part I), “Indian Standard – Code of Practice for Design Loads other than Earthquake for Buildings and Structures – Dead Loads – Unit weights of Building Materials and Stored Materials,” Bureau of Indian Standards, New Delhi, February 1989 (Reaffirmed 2003).

[2] IS 1077, “Indian Standard – Common Burnt Clay Building Bricks Specification,” Bureau of Indian Standards, New Delhi, January 1992 (Reaffirmed 2007).

[3] ATC 40, “Seismic Evaluation and retrofit of Concrete Buildings,” Applied Technology Council, Volume 1, California Seismic Safety Commission, November 1996.

[4] FEMA 273, “NEHRP Guidelines for the seismic rehabilitation of Buildings,” Federal Emergency Management Agency, October 1997.

[5] FEMA 356, “Pre-standard and Commentary for the Seismic Rehabilitation of Buildings,” Federal Emergency Management Agency, November 2000.

[6] IS 1893 (Part I), “Indian Standard - Criteria for Earthquake Resistant Design of Structures - General Provisions and Buildings,” Bureau of Indian Standards, New Delhi, June 2002.

[7] FEMA 440, "Improvement of Nonlinear static seismic Analysis Procedures," Federal Emergency Management Agency, June 2005.
[8] Vlatko Bosiljkov, Yuri Z. Totev, and John M, Nichols, "Shear Modulus and Stiffness of Brickwork Masonry: An Experimental Perspective," International Journal of Structural Engineering and Mechanics, vol. 20, issue 5, pp. 21-43, 2005.
[9] Angelo D'ambrisi, Mario De Stefano, and Marco Tanganelli, "Use of Pushover Analysis for Predicting Seismic Response of Irregular Buildings: A Case Study," Journal of Earthquake Engineering, vol. 13, pp. 1089-1100, November 2009.
[10] C. V. R. Murty, Rupen Goswami, A. R. Vijaynarayanan, and Vipul V. Mehta, "Some Concepts of Earthquake Behavior of Buildings," Gujarat State Disaster management Authority – Government of Gujarat, 2010.
[11] Putul Haldar, and Yogendra Singh, "Modeling of URM Infills and Their Effect on Seismic Behavior of RC Frame Buildings," The Open Construction and Building Technology Journal, vol. 6, pp. 35-41, April 2012.
[12] S. Monish, and S. Karuna, "A Study on Seismic Performance of High Rise Irregular RC Framed Buildings," International Journal of Research in Engineering and Technology, vol. 4, issue 5, pp. 340-346, May 2015.