International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 8 No. 4 Oct. 2014, pp. 1485-1495

http://www.ijias.issr-journals.org/

# Effect of Variation of Number of Bays on the Seismic Vulnerability of Masonry Infilled Steel and Reinforced Concrete (RC) frame Structures

***Muhammad Khubaib Ilyas Khan, Saim Raza, and Furqan Munir***

Department of Civil Engineering, National University of Sciences and Technology (NUST), 44000, Islamabad, Pakistan



**ABSTRACT:** In general practice, buildings can range from small residential houses to large commercial plazas. Size of the structure may change at base with the type of building and availability of area. Bay analysis has been performed to analyze the effect of variation in number of bays on infilled frames. Four three storey models (Bare and Masonry infilled) with number of bays varying from one to four have been considered in this study. Non-linear static analysis or pushover analysis has been performed in Perform-3D and capacity spectrum method of ATC-40 followed by seismic vulnerability assessment framework proposed by Kyriakides (2007) have been used to derive the vulnerability curves for all models considered in this study. Results of seismic vulnerability assessment have been used to determine the effect of variation of number of bays on the seismic vulnerability of masonry infilled steel and RC frames. Vulnerability curves of bare frames have also been compared with the vulnerability curves of infilled frames for both steel and RC frame structures to determine the percentage decrease in the seismic vulnerability of masonry infilled frames as compared to bare frames.

**KEYWORDS:** Bay analysis, Masonry infill, Perform-3D, Seismic vulnerability assessment, Seismic vulnerability curves, Infilled steel frames, Infilled RC frames, Capacity Spectrum method.

## 1 INTRODUCTION

In many countries most of the frame buildings are infilled with masonry. Infills contribute to the performance of structures which is generally neglected in analysis and design by considering it as non-structural element. However the infill panels have significant in-plane stiffness that contribute to the frame stiffness and as a result presence of the infills significantly increases the strength, stiffness and frequency of the frame structures. Studies have shown that influence of infill on the positive performance of the frame structures decreases with the increases in number of storeys. However no significant research has been done to find the effect of variation of number of bays on the seismic performance of masonry infilled frames.

Seismic Vulnerability assessment has been conducted to evaluate the seismic hazards corresponding to various levels of damage in the three storeys bare and infilled frames by varying the number of bays from one to four for both steel and concrete models. Perform-3D has been used as an analytical tool for this purpose. Cyclic pushover analysis followed by the capacity spectrum method and seismic vulnerability assessment framework proposed by Kyriakides (2007) [1] have been used to derive the vulnerability curves for bare and masonry infilled steel and RC frames.

## 2 PREVIOUS RESEARCH

Analytical and experimental studies on seismic response of infilled frames started from mid-1950. Various research studies have shown that infill improves lateral strength and the stiffness of bare frame significantly and also greatly improves the energy dissipation capability of the structure.

One of the pioneer researchers in this field Polyakov (1958) [2] suggested that infill panel can be considered equivalent to diagonal bracing. This suggestion was practically undertaken by Holmes (1961) [3] who replaced the infill panel by an equivalent pin-jointed diagonal strut having same properties and thickness as infill panel and a width equal to one-third of diagonal length of infill. Polyakov was the first to describe the action of infill as an equivalent diagonal strut.

Mainstone (1971) [4] developed eight equations for equivalent strut, four equations for strut width and four for strength equations. These equations were based on three full scale tests on brick infill and twenty one small scale model brick and micro concrete tests. Mainstone approach estimates the infill contribution both to the stiffness of frame and its ultimate strength.

Kodur et al (1994) [5] indicated that addition of infills significantly changes dynamic characteristics of buildings and influence their behavior during earthquakes. Fardis et al (1999) [6] performed shake table test on single bay two storey RC frames with eccentric masonry infill walls subjected to bidirectional ground accelerations. The main focus of their study was to analyze the effects of eccentricity on the displacement demands of corner columns. Hassan et al. (1997) [7] presented a simplified method of ranking reinforced concrete, low-rise, monolithic buildings according to their vulnerability to seismic damage.

Shunsuke Otani (2000) [8] reviewed development of seismic vulnerability evaluation standards for reinforced concrete buildings in Japan. A general procedure consistent with the present design provisions in Japan was introduced.

Kyriakides (2007) [1] In order to extend vulnerability curves went for the analytical procedures to investigate building behavior when exposed to earthquakes. He concluded that although empirical assessment curves are easy to derive but its drawbacks are that it cannot describe unusual buildings, Expert Judgment method gets limited due to the opinion of the experts, and the inherent uncertainties in the building performance. Analytical procedures are most suitable when past records of building damage are not available, working in detail, and near to exact information is required, but models obtained from analytical methods are to be verified by empirical models.

Haldar et al. (2012) [9] presented an analytical study on the seismic performance and fragility analysis of Indian code-designed RC frame buildings with and without URM infills. HAZUS 1999 [19] methodology along with nonlinear static analysis was used to compare the seismic vulnerability of bare and infilled frames. The comparative study suggested that URM infills significantly increase the seismic vulnerability of RC frames and their effect is needed to be properly incorporated in design codes.

Alok Madan (2013) [10] did an analytical study on the seismic performance and vulnerability of typical planar masonry infilled reinforced concrete (RC) frames considering the effect of distribution of masonry infill panels over the elevation of the RC frame using rational displacement based analysis methods such as non-linear dynamic time-history analysis based on realistic and efficient hysteretic models of the structural elements. The results of the displacement based analyses were used to develop fragility curves for these infilled RC frames.

## 3 METHODOLOGY

Non-linear Static cyclic pushover analysis has been performed in Perform-3D on all proposed structures. Perform-3D has been used as analytical tool due to availability of inbuilt diagonal strut module for infill panel modeling and also its ability to conduct non-linear analysis. Capacity Spectrum Method of ATC-40 [11] is used for the seismic vulnerability assessment of structures. The step by step methodology is described in flow chart below:

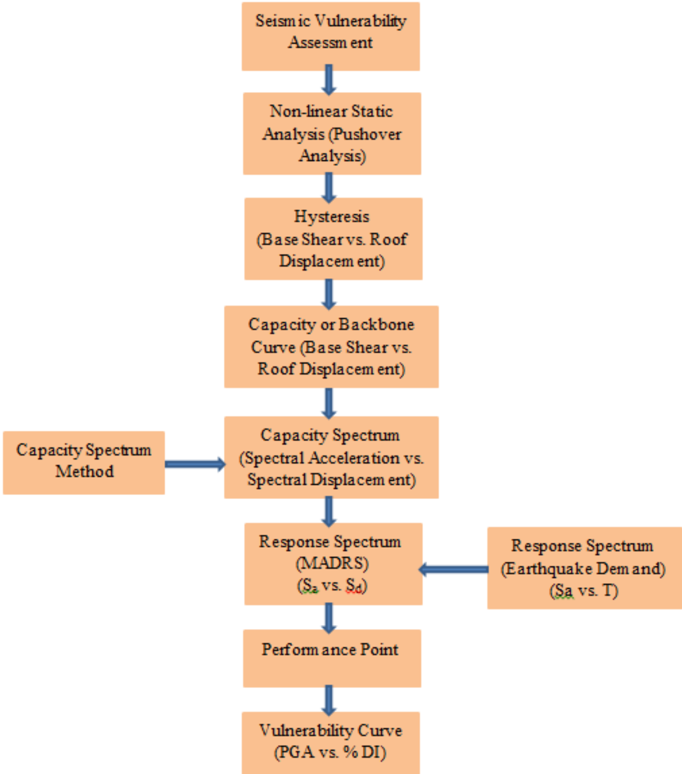



*Figure 1: Seismic Vulnerability Assessment (Flow Chart)*

## 4 EXPERIMENTAL TESTING

For infill panel's construction, burnt clay bricks masonry is most widely used in different areas of Pakistan. Experimental testing has been done to find the compressive strength of locally available brick masonry. Results of compressive strength test for brick masonry are shown below:

*Table-1: Compressive strength of brick masonry prisms*

| Sr. No. | Crushing Load (Kips) | Compressive Strength (Ksi) |
|---|---|---|
| **1** | 23.16 | 0.61 |
| **2** | 28.78 | 0.77 |
| **3** | 25.85 | 0.70 |
| **Average** | 25.93 | 0.69 |

(a)

(b)

*Figure 2: (a) Compression testing assembly for brick masonry (b) Craked Sample after testing*

## 5 Design of Proposed Buildings

Two groups of structures have been considered for this research. First group includes three storeys frame structures with varying number of bays from one to four and the other includes three bays structures with varying number of storeys as three, five, seven and nine. All structures are hypothetical regular and symmetrical moment resisting frame structures. Soil Structure Interaction is ignored and a raft foundation is considered representing fix supports at the base of structure in models.

*Table-2: Geometric parameters of models*

| | |
|---|---|
| Bay Size | 20 ft. |
| First Storey Height | 13 ft. |
| Typical Storey Height | 12 ft. |
| Roof Slab Thickness | 5 inch. |
| Typical floor Slab Thickness | 6 inch. |

*Table 1. Table-3: Materials used for buildings design*

| | |
|---|---|
| Steel (Frames) | ASTM A-36 (Fy=36 Ksi and FU=58 Ksi , AISC LRFD99 Table-2) |
| Concrete | f'c=3000 psi |
| Steel (Reinforcement) | ASTM A615 Grade 60 (Fy =60 Ksi) |

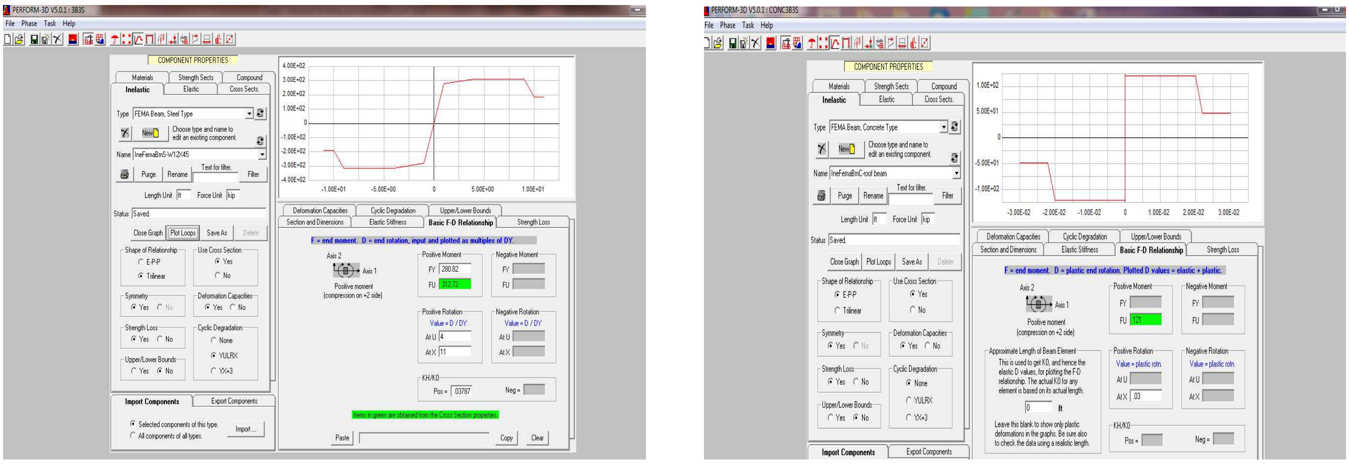
All the buildings are considered as office buildings and are designed in SAP2000 under gravity loading, with live loads being taken from UBC-97 [12]. Concrete frames have been designed according to ACI-318-08 [13] and steel according to AISC LRFD99 [14].

## 6 Modeling in Perform-3D

For non-linear analysis and seismic vulnerability assessment of infilled steel and RC frame structures 2D models of both frames have been exported from SAP2000 to Perform-3D. To make the frames behave as 2D, restraints are applied at all nodes. All nodes except the foundation nodes are free to translate in H1 and V direction and free to rotate in H2 direction. The foundation nodes have fixed supports.

For modeling of beams and columns of steel frames, FEMA beam steel type and FEMA column steel type have been used. F-D relationships, Deformation Capacities and strength loss parameters are inputted using the guidelines of FEMA 356 [15] chapter 5 Steel (Table 5-6). Inelastic strength properties of steel beams and columns have been determined by using plastic section modulus from AISC steel code. Tri-linear behavior has been used for modeling F-D relationships of FEMA beams and columns steel type.

Similarly, for modeling of beams and columns of RC frames, FEMA beam concrete type and FEMA column concrete type have been used. F-D relationships, Deformation Capacities and strength loss parameters of these members have been inputted using the guidelines of FEMA356 [15] chapter 6 Concrete. However in order to determine inelastic strength properties of RC beam and columns an analytical tool XTRACT has been used. Elastic perfectly plastic (EPP) behavior for F-D relationships of FEMA concrete beams and FEMA concrete column is used.



(a) (b)

*Figure 3: Basic F-D relation for FEMA beam (a) Steel type (b) concrete type*

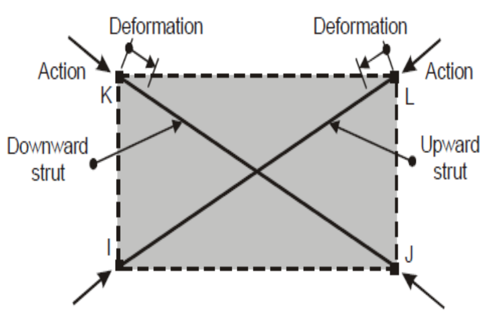
For modeling of masonry infill, infill panel element of Perform-3D has been used. Each infill panel element consists of one infill panel component. The diagonal strut model consists of two struts, each of which resists compression force only. The actions and deformations are the compression forces and compression deformations of the struts, as shown in figure (Perform-3D User guide) [16].

In this study Compression failure mode has been considered for determination of strength of infilled frames. For compression failure of the equivalent diagonal strut, a modified version of the method suggested by Stafford-Smith and Carter (1967) [17] can be adopted (FEMA 306) [18]. The shear force (horizontal component of the diagonal strut capacity) is calculated as:

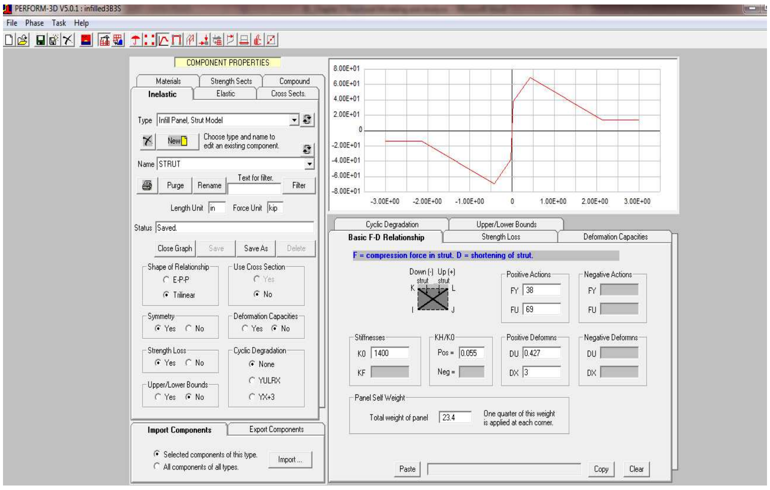
$$\mathbf{V_C = a t_{inf} f'_{m90} \cos\theta}$$

Where:

**a=** Equivalent strut width
$\mathbf{t_{inf}}$ = Infill thickness
$\mathbf{f_{m90}}$ = Expected strength of masonry in the horizontal direction, which may be set at 50% of the expected stacked prism strength $f_m$.




(a)




(b)

***Figure 4: (a) Infill panel diagonal strut model (b) F-D relationship for Infill panel strut model***

## 7 Analysis and Results

For this study a displacement controlled cyclic pushover analysis was performed in Perform3D. In perform-3D, it is easy to visualize the cyclic and hysteric behavior of the structure and investigate the post peak behavior with the effects of strength and stiffness degradation. So after the modeling was completed cyclic pushover analysis was performed on bare and infilled steel and RC frame structures.

For this purpose gravity and fifty pushover load cases were defined in analysis phase in Perform3D. For pushover analysis triangular distribution as given in UBC97 [12] was used. In each step the maximum drift was increased by 0.002 than the preceding step starting from 0.002 in first step in H1 direction (In plane loading). Each next step pushes the structure in opposite direction than the previous step and uses the stiffness at the end of previous pushover load case. In analysis drifts keep on increasing until either the structure fails or maximum allowable push in Perform3D is reached i.e. 10%. After the completion of analysis we can see the hysteresis loop between base shear and roof displacement. Using this hysteresis we can get the capacity or backbone curve which is used to develop the vulnerability curves. Results for infilled steel and infilled RC frames structures are presented separately.

Hysteresis loop for 1 bay 3 storey and 3 bay 3 storeys bare and infilled steel and RC frame structures are shown in figure 5 and 6 respectively. It can be clearly seen from hysteresis plot that with the inclusion of infill panel base shear has increased and roof drift is reduced indicating an increase in strength and lateral stiffness of structure with inclusion of masonry infill. Also base shear for 1 bay structures are less and for 3 bay structures are more.

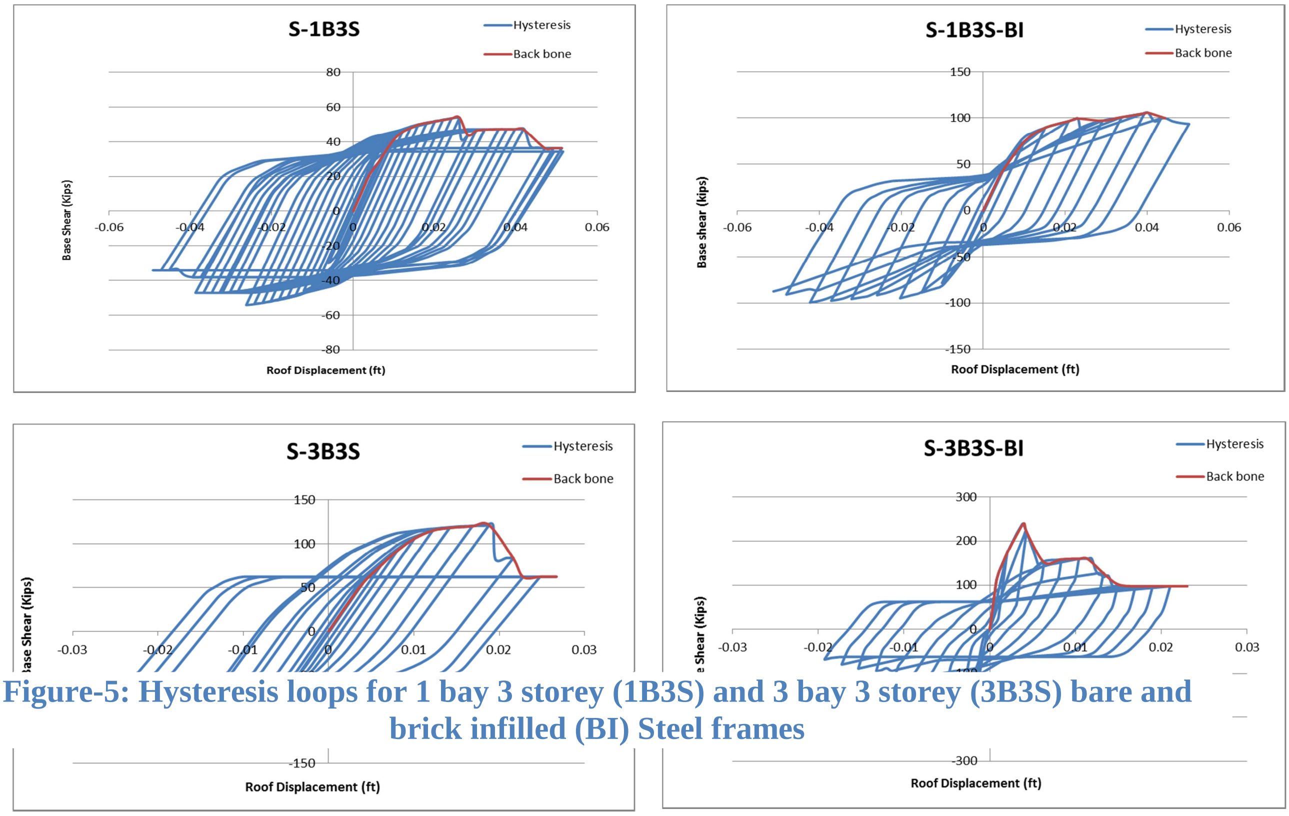



**Figure-5: Hysteresis loops for 1 bay 3 storey (1B3S) and 3 bay 3 storey (3B3S) bare and brick infilled (BI) Steel frames**

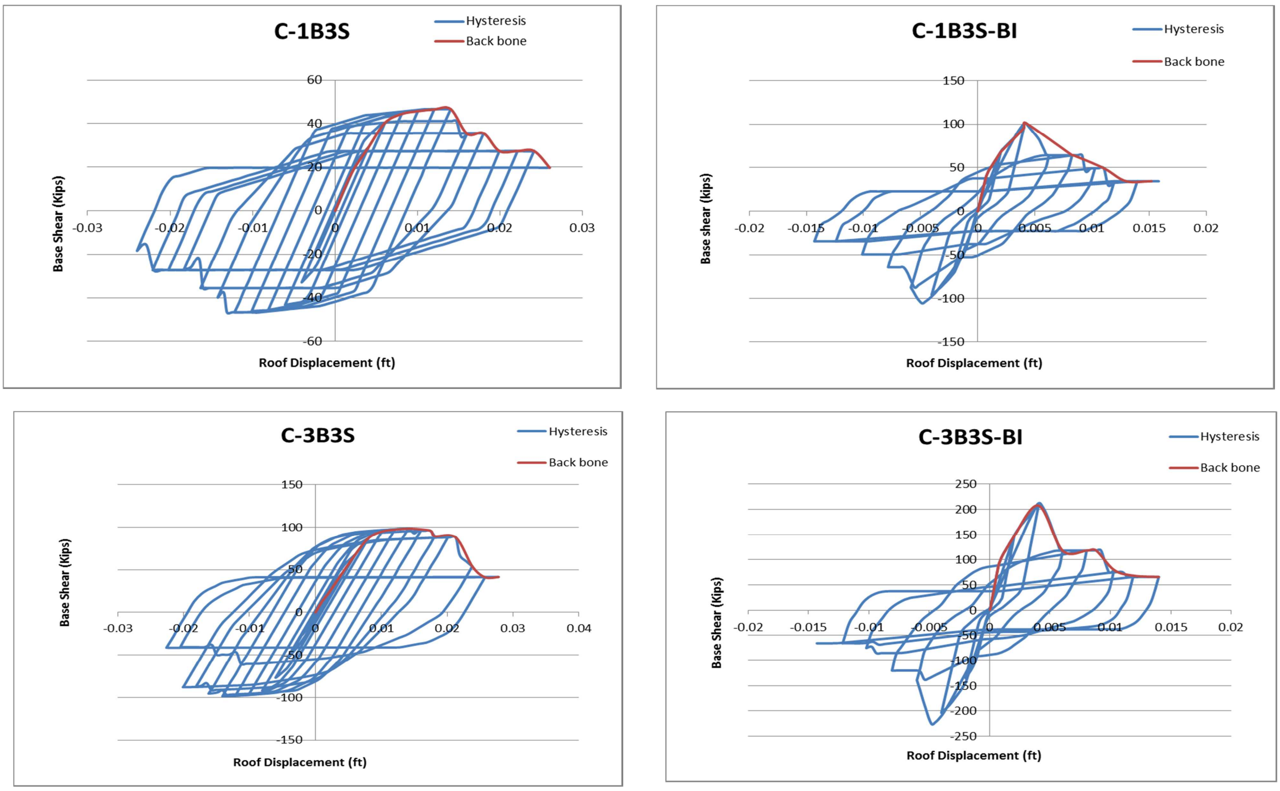



*Figure-6: Hysteresis loops for 1 bay 3 storey (1B3S) and 3 bay 3 storey (3B3S) bare and brick infilled (BI) RC frames*

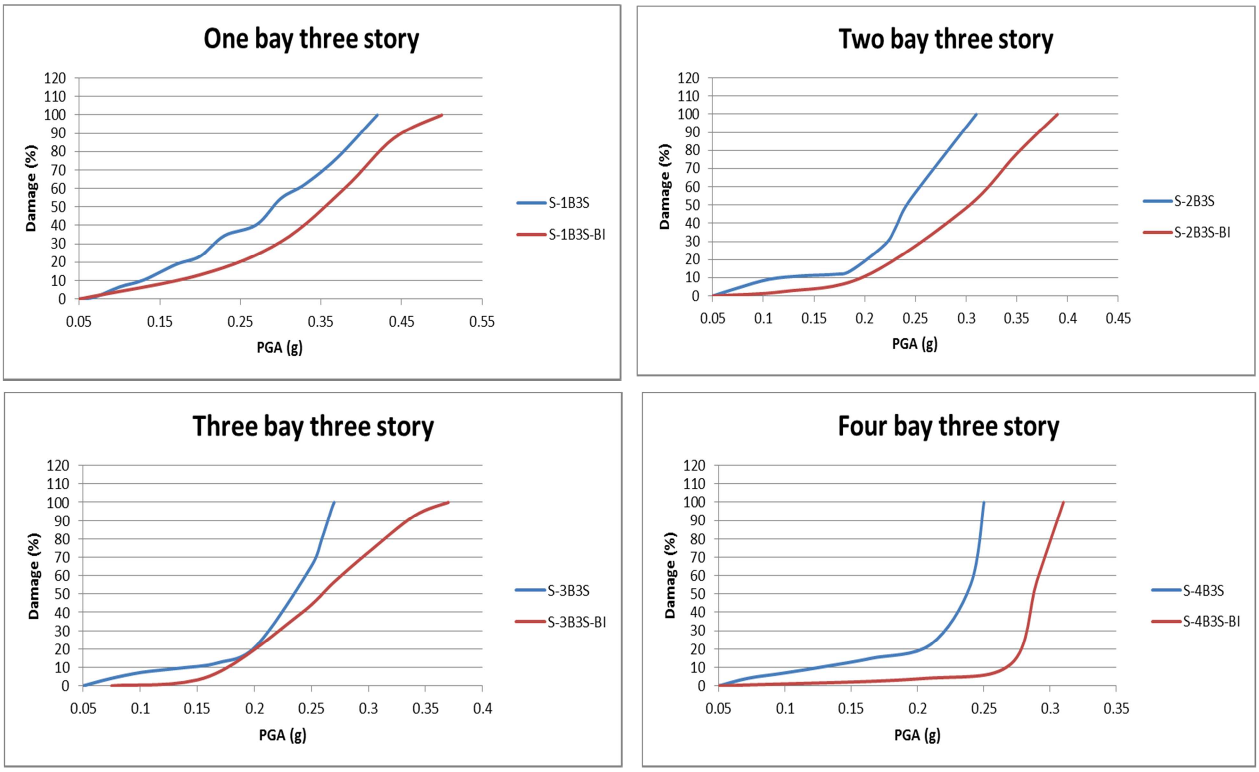



***Figure-7: Vulnerability curves for bare and brick infilled (BI) Steel frames***

## 8 SEISMIC VULNERABILITY CURVES

After the formation of hysteresis loops for all the structures considered in the study, capacity spectrum method mentioned in ATC-40[11] was used to get the performance point of the structures which is actually the intersection point of capacity spectrum and response spectrum. These performance points are then used to determine the hazard level of the structure by determining the PGA at each performance point (Kyriakides, 2007) [1]. Finally a plot between peak ground acceleration (PGA) and damage index (DI) is made which is the vulnerability curve. Vulnerability curves for three storeys bare and infilled steel and RC frame structures by varying number of bays from 1 to 4 are shown in figure 7 and 8 respectively.

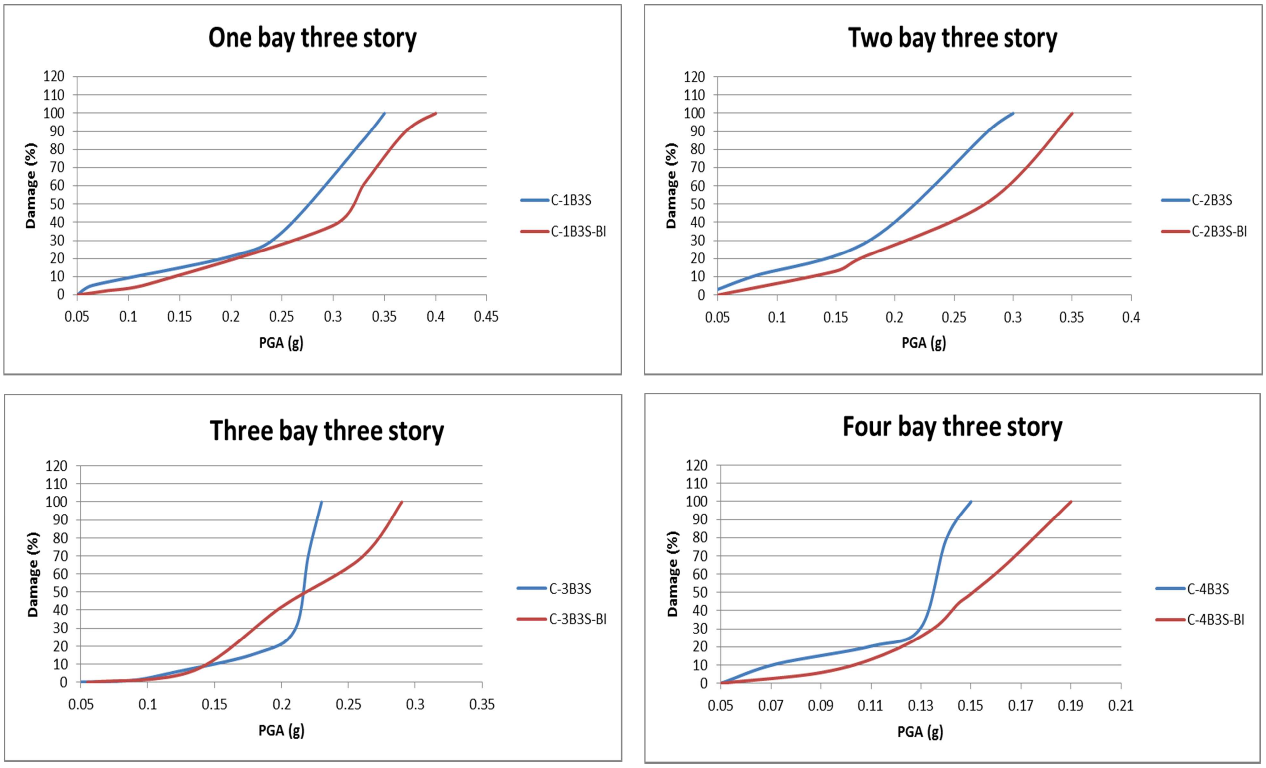



***Figure-8: Vulnerability curves for bare and brick infilled (BI) RC frames***

## 9 DISCUSSION

It can be clearly seen from the results of seismic vulnerability assessment i.e. seismic vulnerability curves that brick infilled frames offer greater resistance to earthquakes than bare frames. A comparison of seismic resistance of bare and infilled frames is presented below in the form of bar charts for both steel and RC frames. Here the PGA at 100% damage of bare frame is compared with the PGA at 100% damage of burnt clay brick infilled frames by varying number of bays from 1 to 4.

A close look at this comparison suggests that as the number of bays are increasing the effect of infill is increases as the PGA increase for one bay three storey brick infilled steel frame is 19% as compared to 1 bay three story bare frame while PGA increase for four bay three storey brick infilled frame is 42% as compared to four bay three story bare frame indicating that influence of infill in positive performance of structure increases as the number of bays increases. Similarly, the PGA increase for one bay three storey brick infilled RC frame is 14.29% as compared to 1 bay three story bare frame while PGA increase for four bay three storey brick infilled frame is 27% as compared to four bay three story bare frame. However the PGA at 100% damage is decreased with increase in number of bays for both infilled steel and RC frame structures. Also brick infilled steel frames are less vulnerable to earthquake damages as compared to infilled RC frames.

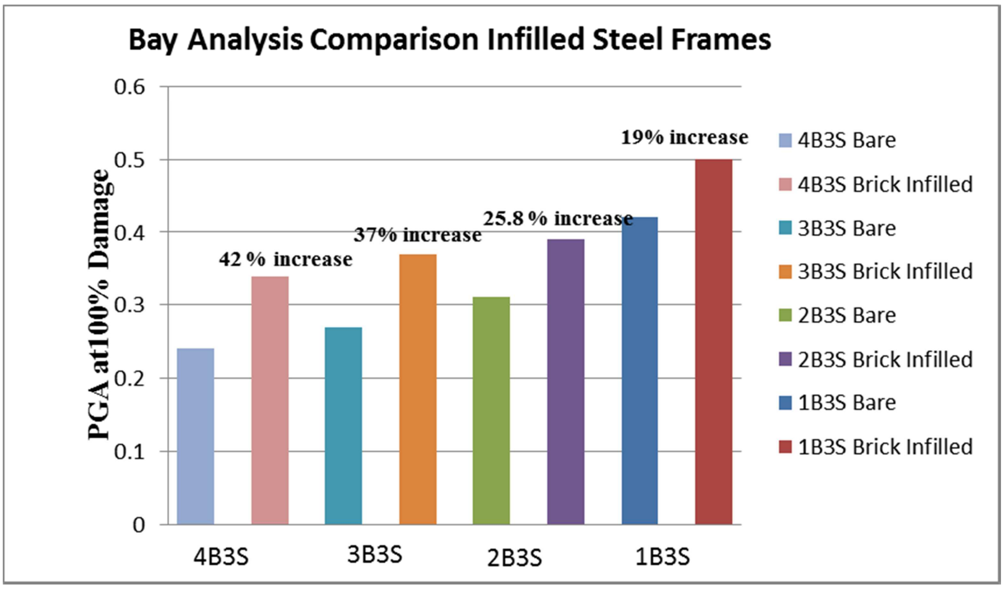



*Figure 9: Comparison of PGA at 100% damage of Brick Infilled Steel frames with variation of number of bays.*

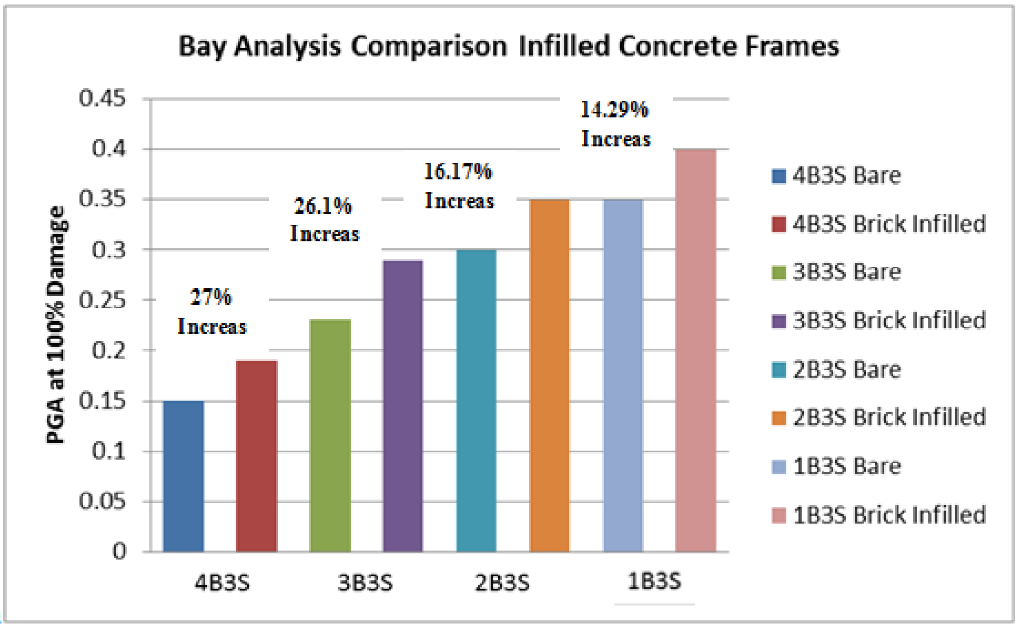



*Figure 10: Comparison of PGA at 100% damage of Brick Infilled RC frames with variation of number of bays.*

## 10 CONCLUSIONS

Following conclusions can be drawn from the results of Seismic Vulnerability Assessment:

- Infilled frames can resist more PGA at 100 % damage thus are less vulnerable to earthquake damages as compared to bare frames.
- With the inclusion of infill panel the collapse of frames become more gradual (Brittle collapse to gradual Collapse).
- As the number of bays increase the effect of infill wall increases. Increase in PGA at 100% damage of infilled frames as compared to bare frames increases with the increase in number of bays.
- Infilled steel frames are less vulnerable to earthquake damages as compared to infilled RC frames.
- The PGA at 100% damage is decreased with increase in number of bays for both infilled steel and RC frame structures due to increased stiffness.

## REFERENCES


[1] Kyriakides N. (2007) Vulnerability of RC buildings and risk assessment for Cyprus, PhD Thesis, Department of Civil and Structural Engineering, University of Sheffield, UK

[2] Polyakov, S. V. (1956). Masonry in Framed Buildings (An investigation into the strength and stiffness of masonry infilling), Moscow

[3] Holmes, M. (1961) “Steel Frames with Brickwork and Concrete Infilling”, Proc., Inst. Civ. Eng., Struct. Build. 19, 473–478

[4] Mainstone, R. J., 1971. On the stiffness and strengths of infilled frames,Proceedings, Institution of Civil Engineers, Supplement IV, 57–90

[5] Kodur, V. K. R., Erik, M. A., and Quenneville, J. H. P., (1998). Seismic analysis of infilled frames,J. Struct. Eng., SERC Chennai 25, 95–102

[6] Fardis M. N., Bousias S. N., Franchioni G. and Panagiotakos T. B. (1999) "Seismic Response and Design of RC Structures with Plan-Eccentric Masonry Infills." Earthquake Engineering and Structural Dynamics, Volume 28, No. 2: 173-191

[7] Ahmed F. Hassan and Mete A. Sozen (1997) “Seismic vulnerability assessment of low-rise buildings in regions with infrequent earthquake”, Structural Journal, Volume 94, Issue 1 (31-39)

[8] Shunsuke Otani (2000) “Seismic vulnerability assessment methods for buildings in japan”, Earthquake engineering and engineering seismology, Volume 2, September 2000, 47–56

[9] Putul Haldar, Yogendra Singh, D. K. Paul (2012) “Effect of URM infills on seismic vulnerability of Indian code designed RC frame buildings”, Earthquake Engineering and Engineering Vibration, June 2012, Volume 11, Issue 2, 233-241

[10] Alok Madan (2013) “Seismic vulnerability of masonry infilled reinforced concrete frame structures”, International Journal of Safety and Security Engineering, Volume 3, Issue 3

[11] ATC-40 (1996), “Seismic evaluation and retrofit of concrete buildings”, volume-1, California, Redwood City

[12] Uniform building code (1997), volume 2, International code council

[13] ACI 318 (2008), “Building code requirements for structural concrete (ACI 318-02) and commentary (ACI 318R-08)”, the American concrete institute.

[14] AISC-LRFD (1999), “Manual of steel construction Allowable stress design”

[15] FEMA 356 (2000), Prestandard and commentary for the seismic rehabilitation of buildings, Federal Emergency Management Agency, Washington, D.C., 2000.

[16] PERFORM 3D (2006), Nonlinear Analysis and Performance Assessment for 3D Structures, user guide, Computers and structures Inc., Berkeley, California, 2006.

[17] Stafford Smith, B. (1967). "Methods for predicting the lateral stiffness and strength of multi storey infilled frames" Building Science 2(3): 247-257

[18] FEMA 306 (1998) Evaluation of Earthquake Damaged Concrete and Masonry wall buildings. Federal Emergency Management Agency, Washington, D.C., 2000

[19] HAZUS-MH MR1, Advanced Engineering Building Module Technical and User’s Manual, Department of Homeland Security Emergency Preparedness and Response Directorate FEMA Mitigation Division Washington, D.C.