Investigation of Seismic Performance of Vertically Irregular Reinforced Concrete Buildings

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Abstract: Generally buildings hold irregularities in plan or sometimes in elevation as well. This develops a damaging influence on seismic performance of building. The paper discusses the comparative study of performance evaluation of RC (Reinforced Concrete) Buildings with vertical irregularities (i.e., setbacks). A five story vertically regular building is designed by equivalent static load method of seismic analysis by using UBC (Uniform Building Codes) 1997. Nine vertically irregular models are derived from the regular building by omitting different stories at different heights creating setbacks. For numerical solution ETABs 9.7 nonlinear version software is used. Time History and Response Spectrum Analysis are performed for ground acceleration data of ElCentro (1940) earthquake. The study as a whole is a slight attempt to evaluate the effect of vertical irregularities on RC buildings, in terms of dynamic characteristics such as Story Displacement, Overturning Moment, Base Shear, Story Drift and Participating Mass Ratio.

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Key words: Vertical irregularities, Seismic performance, Dynamic characteristics, Overturning moment.

1. Introduction

It is a known fact that the Globe is facing a threat of natural disasters from time to time. With particular records based on earthquake occurrence, the consequences are loss of human lives and destruction of properties, which ultimately affects the natural economy. The occurrence of an earthquake cannot be predicted and prevented but the preparedness of the structures to resist earthquake forces become more important. However, more recently, many destructive earthquakes, including the 1960 Chile earthquake, 1964 Great Alaska earthquake, 1999 Athens (Greece) earthquake, 1999 Chi Chi (Taiwan) earthquake, 2001 Bhuj (India) earthquake, 2003 Boumerdes (Algeria) earthquake, 2004 Off the West Coast of Northern Sumatra earthquake, 2005 Muzaffarabad (Pakistan) earthquake and the 2011 Near the East Coast of Honshu (Japan) earthquake have given more insights to performance of RC frame constructions. These earthquakes are a wake-up call to enforce building and seismic codes, making building insurance compulsory along with the use of quality material and skilled workmanship.

The part of the land on the globe for which lines of national boundaries are now indicating the country as Pakistan has experienced many destructive earthquakes throughout its history. Most notable events of major earthquakes experienced by this part of land area since 1668 to 2013, in 1668 the epicenter was Shahbandar (Sindh), 1827 Lahore (Punjab), 1889 Jhalawan (Balochistan), 1909 Sibi (Balochistan), 1935 Ali Jaan (Balochistan), 1974 Hunza Hazara (North-West Frontier Province), 2005 Muzaffarabad District, Azad State of Jammu and Kashmir (North-West Frontier Province) and it was at Awaran District, Balochistan in 2013. In many respects, including seismological and geotechnical, the October 08, 2005 earthquake was a case of history repeating itself 31 years later and has made the engineering community in Pakistan aware of the need of seismic evaluation.

Based on the technology advancement and knowledge gained after earthquake occurrences, the seismic code is usually revised. In 1986, the Pakistan Building Code was completed; however, it was not enforced practically, because it was not adopted as Governmental regulations and due to lack of due process of adoption and implementation. The devastating earthquake of October 08, 2005 in the Northern Pakistan and Azad Jammu and Kashmir which claimed over 74000 lives and left over 100,000 severely injured/incapacitated, drew the attention of engineers to review the adequacy of design and construction practices in Pakistan. Pakistan is one of the more seismically active regions of the world and it is important to that Code for improving the seismic safety be developed urgently. Pakistan will improve earthquake-related requirements in its building safety codes. After an October 2005 earthquake devastated a large area in northern Pakistan, Ministry of Housing and Works, Government of Pakistan engaged the National Engineering Services Pakistan (Pvt.) Limited (NESPAK) to develop revised seismic zoning maps and criteria. NESPAK approached the International Code Council to help Pakistan develop earthquake provisions to save lives and reduce property losses. The International Code Council, USA was contacted for assistance along with ACI and ASIC. Information contained in the ICC codes, ACI 318 Code, and ASIC specifications was used for the development of the Pakistan Building Code (Seismic Provisions -2007). Input of all the relevant agencies and bodies, both in public and private sectors was sought and incorporated while formulating the Building Code of Pakistan: Seismic Provisions 2007 [1].

So after a long gap of about 21 years some new clauses were included and some old provisions were updated. Assuming that concerned authorities will take enough steps for code compliance and the structures that are being constructed are earthquake resistant. Keeping the different points in view during the revision process of the seismic zones in Pakistan, the damage patterns in reinforced concrete frames during the earthquakes have been extensively studied.

Now a days need and demand of the latest generation and growing population has made the architects or engineers inevitable towards planning of irregular configurations.

2. Literature Review

Real building structures often have vertical irregularities, which are inherited from various functional, economical, aesthetical and architectural constraints and city regulations or building by laws. These irregularities cause non-uniform distribution of mass, stiffness, strength, geometry and structural form in elevation. Sudden changes in stiffness and strength between adjacent stories are related with changes in structural system along the height, changes in story height, setbacks, changes in materials and unanticipated participation of non-structural components. Such buildings, having irregular configuration, are prone to earthquake due to concentration of stress and deflections or an undesirable load path in building structural system. Such types of irregularities have been renowned as one of the most important causes of brutal damage or poor performance of structures during earthquakes. Structural damage due to strong earthquake reveals that vertical irregular buildings exhibit unsatisfactory behavior, even though they are designed according to code.

Plan asymmetry and development of its design guidelines has been given focused attention over last two decades. A detailed list of such studies is available in various literatures. Different researchers now had started to investigate the behavior of buildings with irregularity that exists in these buildings in term of mass, geometry etc.

J. H. Cassis and E. Cornejo. 1996 [2], studied the nonlinear response of reinforced concrete buildings having irregularities in elevation. Nonlinear Static incremental analysis was used to calculate the strength and displacement capacity of the buildings. And it was concluded that buildings with irregularities in elevation without infill walls at different heights imparts the brittle failure mode of buildings.

M. Mezzi, A. Parducci and P. Verducci. 2004 [3], carried out an investigation to develop a methodology for building's seismic design by considering the factors which influence the seismic response of buildings. The results thus obtained were commented and presented as sample design.

K. Güler, M. G. Güler, B. Taskin and M. Altan. 2008 [4], had worked on existing vertical irregular building which was retrofitted after the earthquake. It was taken for the study of performance evaluation. For the numerical solution, software (SAP2000 and ZEUS-NL) were used.

V. K. Sadashiva, G.A. MacRae and B. L. Deam. 2008 [5], presented a simple method of determining structural irregularity limits for design using different analysis procedures. Irregularity limits in terms of interstorey drift response due to mass irregularity was computed.

C. M. Ravi Kumar and et al. 2012 [6], discussed the performance evaluation of reinforced concrete buildings with vertical irregularities. This Study included different dynamic influencing parameters which can regulate the Base shear, Time period and Story displacement etc. for various seismic zones of India.

In most of the Seismic Design Codes, design guidelines and formulations of regular or symmetric buildings are well framed. But as yet the codes fall short of providing recommendations regarding design of irregular structures. So, the study on this area must be required by the structural designer for the safe and sound design of vertically irregular building against earthquake, especially because the literature on seismic behavior of vertically irregular building is rare and codes also do not contribute enough in this regard.

Contextually, this research work makes a small contribution to study the response of geometrically irregular RC buildings.

3. Methodology

Since 1988 the UBC (Uniform Building Code) started to distinguish vertically irregular structures ones based on certain limits on the ratio of strength, stiffness, mass, setbacks or offsets with respect to an adjacent story. UBC provides quantitative criteria for defining structural irregularities. These criteria, for different types of irregularity, can be summarized as follows: (i). *Mass irregularity*, the effective storey mass is greater than 150% of the mass of an adjacent storey. (ii). *Stiffness irregularity*, a soft storey is defined when its stiffness is less than 70% of the storey above or less than 80% of the mean stiffness of the three storeys above. (iii). *Strength irregularity*, a weak storey is defined when its strength is less than 80% of the storey above.
(iv). *Vertical Geometric Irregularity (Setback)*, is considered to exist where the horizontal dimension of the lateral-force-resisting system in any story is more than 130 % of that in an adjacent story [7].

The concept of this paper is studied analytically, through a comparative parametric study of several irregular multi story building models with regular one.

3.1 Characteristics of Buildings

For this study total ten model buildings are considered. One model with regular frame is taken as reference building and other nine vertically irregular models are derived from the regular building by omitting different stories at different heights creating setbacks. The line diagrams of regular model and other nine irregular models are demonstrated in the Figure 1.0.

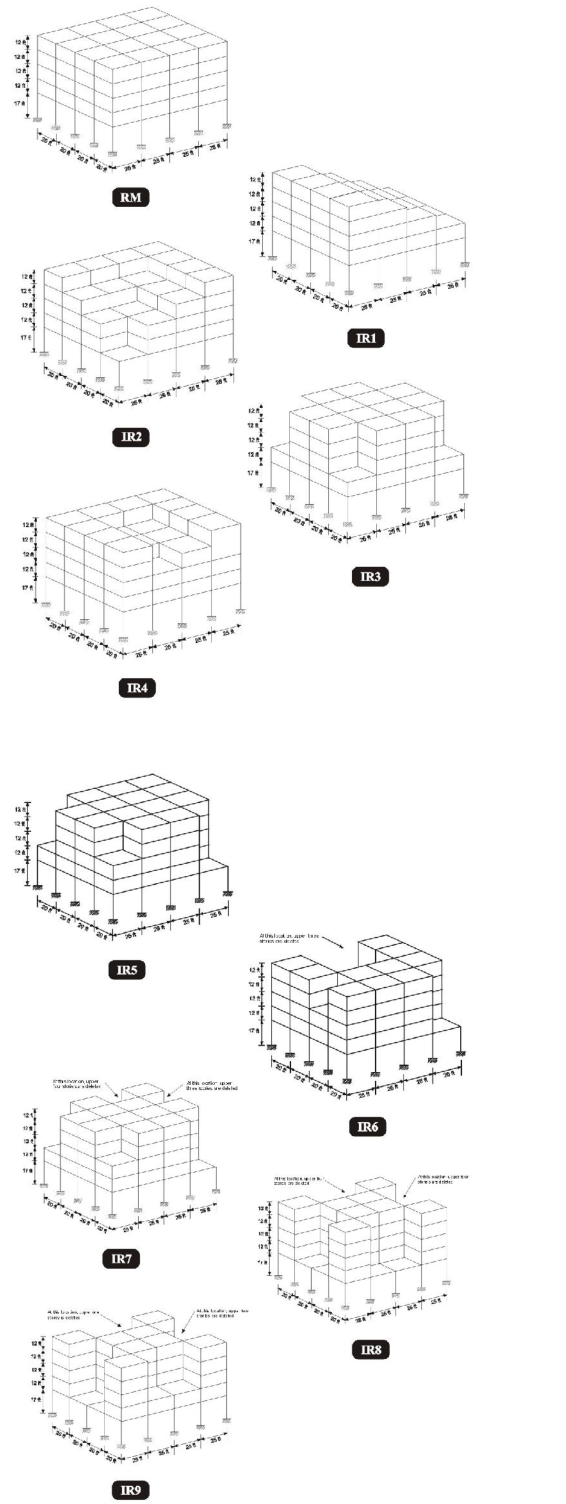


Figure 1.0: Regular structure and nine irregular structures

All models have floor height at each level is 12-ft except ground floor which has 17-ft ceiling height. The buildings have four bays in plan in x-direction, each bay of 20-ft width and in y-direction each bay of 25-ft wide. The structural system of the building is considered as space frames having shell elements representing floors. The columns are assumed to be fixed at base at the foundation level.

For each modeling frame elements are used for columns and beams. Table 1.0 show the beam and column dimensions used for modeling of all frame structures either regular or irregular.

Table 1.0 Dimensions of structural members

Sr. No.	Member	b × h (inch × inch)
1	Beams	12 × 24
2	Columns	18 × 18

3.2 Numerical Analysis

In this study, nine buildings with vertical irregularity are modeled using ETABS software. Time history analysis and Response spectrum analysis are performed for each of x-x and y-y directions and performance level of the buildings are obtained. The response of the superstructure is assumed to be linear elastic.

The earthquake record of ElCentro has been applied in this study for Time history analysis. The details are listed in the Table 2.0.

Table 2.0 Earthquake accelogram

Accelogram	Year	Magnitude	PGA (g)
ElCentro	1940	6.6	0.37

It is noted that the chosen accelogram well suits the elastic spectrum for 0.2 Sec. spectral acceleration S_s = 0.56, 1.0 Sec. spectral acceleration S_1 = 0.39, soil type E and damping equal to 5%.

4.0 Performance of buildings

The dynamic numerical analysis is carried out by using ETABS computer software. For structural system, the material class of concrete and steel modulus of elasticity is 21.53 GPa and 200 GPa respectively.

Seismic performance assessment of the derived vertically irregular buildings has been realized by 3D modeling of the frame structure by introducing elements in ETABS software. The free vibration periods and modal participating mass ratios for 1st mode of all ten models are shown in Table 3.0.

Table 3.0 Free vibration periods and modal participating mass ratio

Code	1st Mode		
	Period *(Sec.)*	Modal Participation Ratio *(x direction)*	Modal Participation Ratio *(y direction)*
RM	1.304	90.913	0.000
IR1	0.877	52.67	24.904
IR2	1.172	66.318	12.132
IR3	1.202	89.033	0.000
IR4	1.233	89.036	0.004
IR5	1.235	89.319	0.086
IR6	1.217	89.066	0.005
IR7	1.187	88.929	0.007
IR8	1.102	85.448	0.000
IR9	1.138	88.196	0.0142

As it is seen, the participating mass ratio is ≈ 82% and it is greater than 70% (i.e., code limit) for the first mode and the height of the building is less than 82-ft, which means the incremental equivalent seismic load procedure, can be used.

5. Analysis and Results discussion

Dynamic Analysis

All the frames were designed in the region of moderately high seismicity with soil type E. the design satisfy the strong column-weak beam requirement of the code and the size and shape of beams and columns are chosen to satisfy code drift limitations. See Figure 1.0 for the respective spectrum (for regular building model) to compare the corresponding pseudo spectral accelerations (g) of rest of the irregular building models.

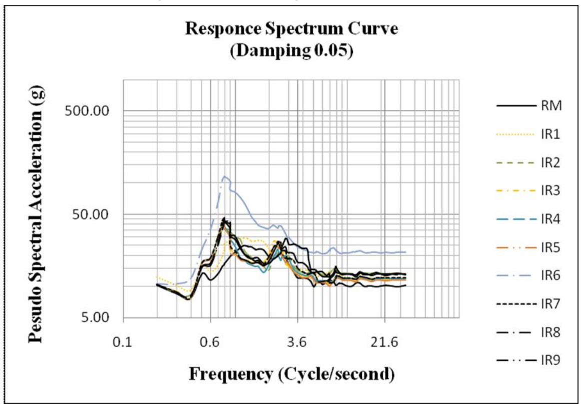


Figure 1.0 Pseudo spectral acceleration (g)

The estimation of the demand from an earthquake and the evaluation of the capacity of the building to deform with 5% damping ratio with respect to the control frame (regular frame) was considered. Figure 2.0 shows the story shear and overturning moment results of the dynamic analysis of regular building.

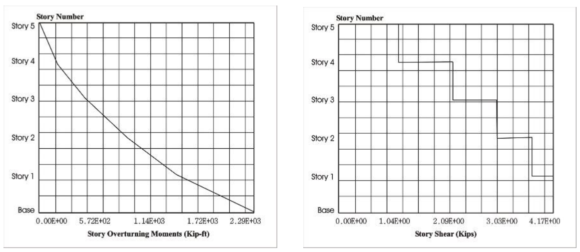


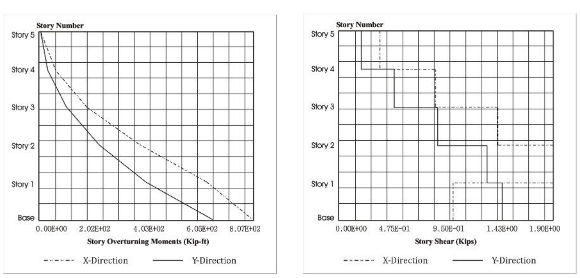
Figure 2.0 Story shear and overturning moment for RM

For the four irregular building models out of all nine models, the comparison of x-direction and y-direction overturning moments and story shear versus different story levels are presented in the Figure 2.1 (a) to (d).

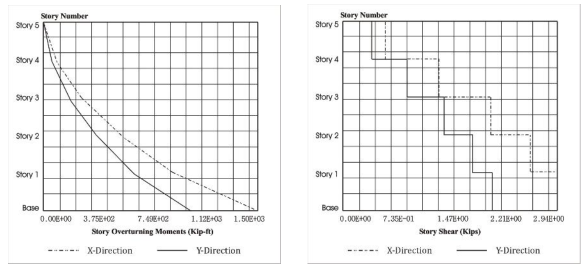
Results of the study indicate that the setbacks of the buildings at the upper levels exacerbate the contribution of torsional moments and the migration of demand from lower stories to upper stories decreased.

Story Drift

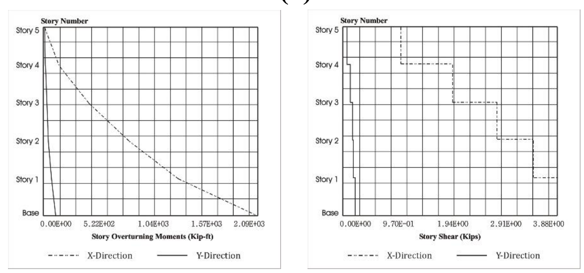
The peak interstory drift ratio within the structure, when it is subjected to a ground motion record of ElCentro, was observed and the comparison of story drift for all ten (1+9) cases are shown in the form of histogram in the Figure 3.0(a) and (b) for x-direction and y-direction respectively.



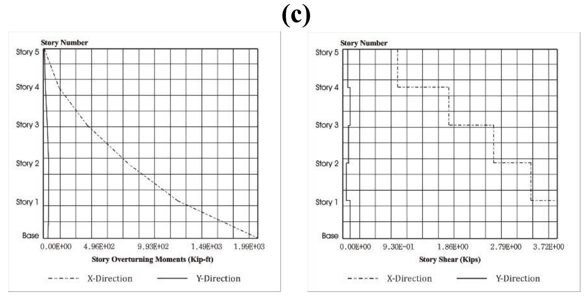
(a)



(b)



(c)



(d)

Figure 2.1 (a) to (d) Comparison of x-direction and y-direction overturning moment and story shear versus different story levels of IR1, IR2, IR5 & IR7 respectively.

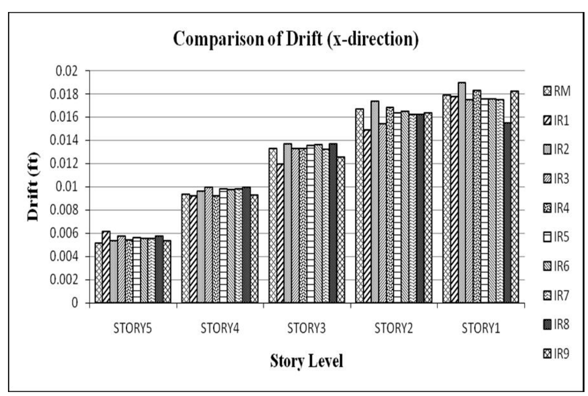


Figure 3.0(a) Comparison of story drifts for all story levels in x-direction

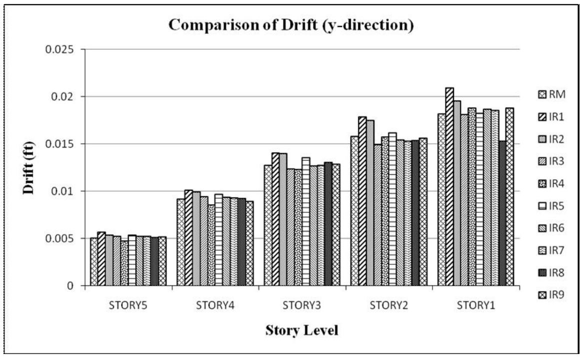
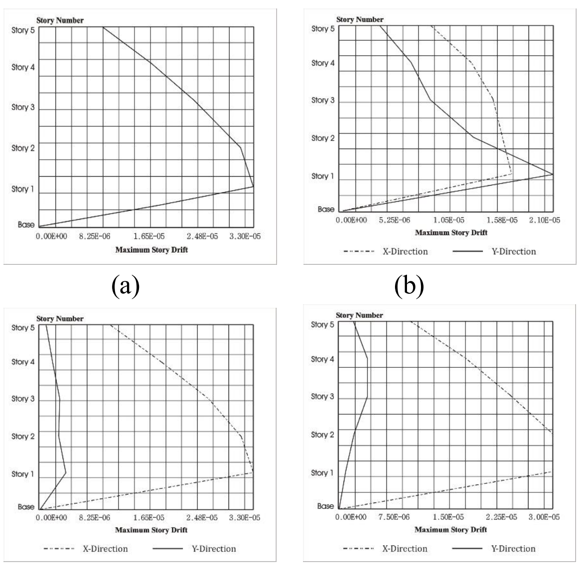


Figure 3.0(b) Comparison of story drifts for all story levels in y-direction

The plots of story drift for the RM, IR1, IR5 & IR7 are shown in the Figure 3.1(a) to (d).



(a) (b) (c) (d)

Figure 3.1(a) to (d) Plot of story drift

From comparison between Figure 3.1, it may be observed that the calculated drift is considerable more in the irregular buildings than the regular building.

Base Shear

The base shear values for the dynamic response of building models both x and y directions are presented in the Figure 3.2 and 3.3 respectively.

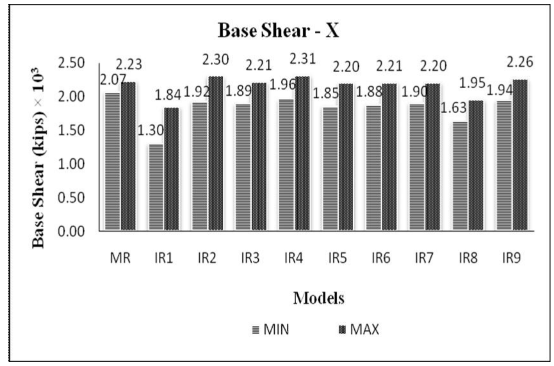


Figure 3.2 Base shear (x-direction)

Minimum value of base shear for all cases, V_b' (Base shear of irregular building) is observed lesser than the V_b (base shear of regular building). The average mean reduction in min. base shear value of irregular buildings is 87.3%, as compared with the regular building.

Maximum value of base shear for most of the cases, VB' is observed lesser than the VB. The average mean reduction and increase in maximum base shear value of irregular buildings is 94.3% and 102.7 % respectively, as compared with the regular building.

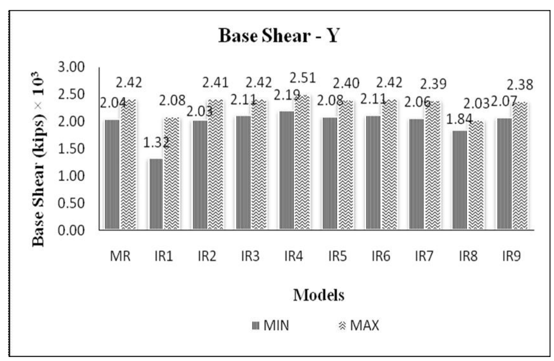


Figure 3.3 Base shear (y-direction)

Minimum value of base shear for most of the case VB' is observed greater than the VB. The average mean reduction and increase in minimum base shear value of irregular buildings is 84.7% and 103.05 % respectively, as compared with the regular building.

Maximum value of base shear for most of the case VB' is observed lesser than the VB. The average mean reduction and increase in maximum base shear value of irregular buildings is 95.6% and

103.5 % respectively, as compared with the regular building..

Thus it has been observed that increase in the base shear value either for minimum base shear value or maximum base shear value the percentage increase is almost equal to ≈103% for both cases. And hence the response quantities like; member forces, story forces and base reactions should be multiplied by factor of 1.3.

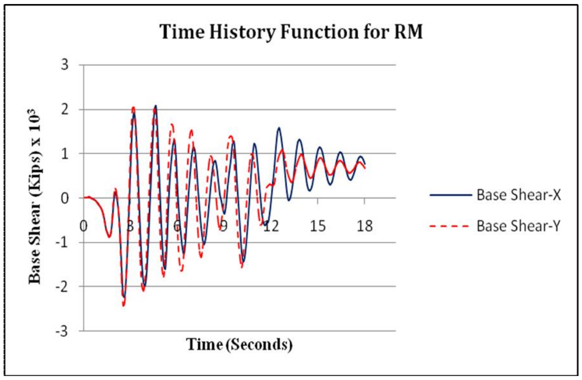


Figure 4.0 Base Shear versus time period for RM

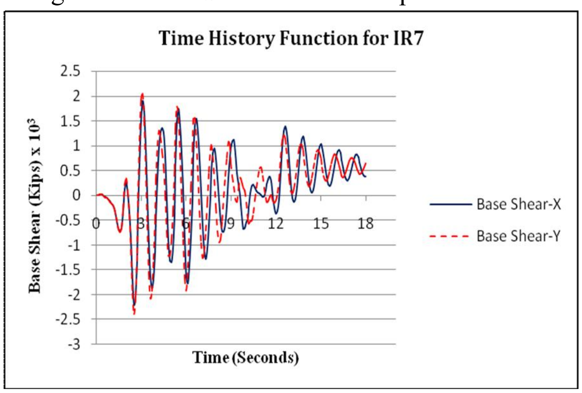


Figure 4.1 Base Shear versus time period for IR7

For all models the time history versus base shear results has been plotted, but only two for RM and IR7 are presented in the Figure 4.0 and 4.1 respectively.

6. Conclusion

In this paper the preliminary results of a large parametric study, whose aim is the performance evaluation of irregularity in elevation for frame buildings, are shown. After the numerical investigation, following conclusions can be made:

Concerning the irregularity established due to setbacks, that even very large variation of irregularity distribution in elevation causes reasonable modifications of the seismic response with respect to the reference regular case.

Maximum story drift and story displacement will increase as the vertical irregularities increase in models.

The scale up factor may 1.3 be adopted as the mean value ≈103% increase in maximum base shear observed for irregular buildings. Thus the response quantities may be modified by an increasing factor of 1.3.

The structural and architectural configurations should be observed keenly to attain the optimum performance of the building in terms of its seismic response.

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