# Seismic Analysis of High-Rise Building using Response Spectrum Method

**Pratik Bawankar**[1]
[1]G. H. Raisoni Academy of Engineering & Technology, Nagpur

*Abstract*— A large area of India is susceptible to damage due to the impact of earthquake. Hence, it is essential to consider the seismic load for the design of multi-storied building. For that, program in STAAD Pro. v8i software with different conditions of lateral load resisting system is used. Some models of brace frame and bare frame are prepared and carried out through seismic analysis. A regular reinforced concrete frame structure having 15 floors i.e. (G+14) is designed using different types of bracing like x-cross brace, chevron brace, inverted chevron brace, braced chevron brace etc. Three types of channel sections i.e. (ISMC 150, ISMC 250, ISMC 350) with different cross sectional area are used to compare the results of different patterns of braced structure with unbraced structure. Zone-II is considered for the analysis of unbraced and braced models. Seismic analysis is performed by using response spectrum method for the design of high-rise building. The analysis has produced the effect of actual distribution of forces and higher modes of vibration in a better way. For the purpose of seismic analysis IS: 1893 (part 1): 2002 is used. And test results including time period, bending moment, joint displacement, story drift, base shear and axial force are presented to get an effective lateral load resisting system.

***Key words:*** Multi-Storied Building, Load Resisting System, Response Spectrum Method, Bending Moment, Joint Displacement

## I. Introduction

### A. *High-Rise Building:*

A Structure whose height is minimum 35 meters or it has minimum 12 stories is defined as high-rise structure. The places where there is great population densities and increased land prices (i.e. urban areas) are creating a demand for that buildings which arose vertically rather than spread horizontally, and thus occupying the area of a land which is less precious. Most of the high rise buildings have frames which are made up of steel and concrete or steel. Elevator is the principle means of a vertical transport in this type of buildings. Basically they are designed for only commercial purposes but now many high-rises are planned for various uses. The combination of residential, retail, office, hotel space is common.

### B. *Earthquake:*

Earthquakes are the more dangerous and destructive in all types of natural hazards. Earthquake occurs because of sudden transient motion of earth i.e. ground as a result of release of elastic energy in few seconds. Generally it occurs all on an unpredictable and sudden manner and affects large area, hence its impact is most traumatic. They can cause disrupts of important essential services such as power, transport, communication, sewerage systems, water supply etc. and large scale loss of property and life. They destroy cities, towns, villages, and aftermath leads to destabilize the nations economic and social structure. Earthquake engineering is a branch of engineering which is devoted to mitigating hazards of earthquake. In this broad sense, engineering of earthquake can covers the all investigation and solutions of the problems which are created by damaging earthquake and consequently that work which is involved in practical applications of these solutions i.e. constructing, planning, designing and managing of earthquake resistant structures and facilities.

### C. *Earthquake Hazards:*

The primary hazards that associated with earthquake which are ground shaking and fault displacement. Secondary hazards, include liquefaction, landslides, ground failure, avalanches, seiches and tsunamis.

### D. *Physical Damage:*

Damage occurs to structures, buildings, human, settlements, infrastructure, especially bridges, railways, elevated roads, water treatment facilities, water towers, pipelines, utility lines, transformer stations, and electrical generating facilities. Aftershocks can do much more damage to those structures which are already weakened. Significant secondary effects include landslides, dam failures, and fires, which can block waterways and it can also cause flooding. Damages may occur to that facilities using or manufacturing the dangerous materials which resulting in possible chemical spill. Sometimes breakdown of all communication facilities may happen. Destruction of property in various regions may have a major serious impact on standard of living of local population, economic production, shelter needs. Depending on vulnerability of affected community, large number of families may be homeless in the aftermath of that earthquake.

### E. *Earthquakes Zones:*

In the country at different locations the varying geology implies that the likelihood of various damaging earthquakes which are taking place at different locations is very different. Thus, a map of seismic zone is required so that different buildings and other structures which are located in different type of regions can also be designed to withstand various level of ground shaking. India is divided into four zones i.e. II, III, IV and V.

### F. *Seismic Design Approach:*

Lateral loads due to various earthquake are a matter of concern in tall building. These lateral forces can cause lateral sway of structure, induce undesirable vibrations, induce undesirable stresses in the structure, produce critical stresses in the structure. Drift or sway is the magnitude of lateral displacement at top of the structure relative to its base. Traditionally approaches of seismic design are stated, as the building should be able to ensure small and the frequent shaking intensity without sustaining any type of damage, thus leaving the building serviceable after that event. The building should withstand moderate level of the earthquake ground motion without any structural damage but possibly with some of the structural as well as non structural damage. This limit state may correspond the earthquake intensity which is equal to the strongest either experienced or forecast at the site.

### *G. Bracing System:*

Braced frames are a common form of a construction and it is economic to construct and very simple to analyse. Generally economy comes from inexpensive, nominally pinned connections between columns and beams. Bracing system resists lateral loads and provides stability, may be from a concerete core or from steel member which is diagonal. In construction of braced frames, columns and beams are designed under the impact of only vertical loads, therefore it is assume that bracing system carries total lateral loads. A structural system which is capable of limiting horizontal deformations and resisting horizontal actions can be defined as a bracing. More than one bracing system within one building can be present. In such case some bracing systems are more effective or gives better results than other bracing system in resisting all the horizontal loads. So other bracing systems are neglected.

### *H. Response Spectrum Method:*

The response spectrum is used to represent an envelope of upper bound responses, which is based on several different types of ground motion records. Design spectrum is used to perform seismic analysis. RSM uses an approach of elastic dynamic analysis that depends on one assumption that dynamic response of the building or structure can be determined by considering the independent response of each natural vibration mode and then combining the each response in same way. Hence, this is advantageous because while calculating deflections, shear, moments at various levels of the structure, generally only some of the lowest modes of vibration have significance. Hence this method of analysis is accurate. At each floor the design lateral force of braced and unbraced system is calculated by STAAD Pro. v8i software in accordance with IS: code 1893 (Part I): 2002. This software gives result for axial force, bending moment, storey drift, joint displacement, base shear. And to get efficient and economical lateral stiffness system, these results are used.

## II. MODELING OF BUILDING

### *A. Introduction of STAAD Pro. V8i:*

Its general purpose is the analysis of structure and design program with some applications primarily in structural industry- culverts, turbine foundations, retaining walls, dams, chemical plant structures, industrial structures, highway structures, bridges, commercial buildings. Hence to enable this type of task, the program consists of following facilities.

1) Graphical model generation utilities and text editor based commands are used for creating the mathematical model. Members of column and beam are represented using lines. slabs, walls, panel type entities are represented using quadrilateral and triangular finite elements. Brick elements are used to represent solid blocks. Because of these utilities, user is allowed to assign properties, create the geometry, orient cross sections as desired and assign materials like timber, concrete steel, specific supports, aluminum, apply loads explicitly and have the program generated loads, various design parameters etc.
2) Analysis for performing p-delta and linear elastic analysis, frequency extraction, finite element analysis and dynamic response (steady state, time history, spectrum etc.)
3) Design for code checking and optimization of aluminium, steel and timber members. Reinforcement calculations for concrete beams, columns, slabs and shear walls. Design of shear and moment connections for steel members.
4) Report generation, result viewing, and result verification tools for examining solid stress contours, plate, beam, shear force and bending moment diagrams, displacement diagrams.

### *B. Loads Acting on Buildings:*

In seismic design the lateral loads are used which are highly unpredictable. During earthquakes actual forces which act on the structures are higher than the design forces. It is recognized from past experience that neither the full protection against earthquakes of various types of sizes is economically possible nor design alone based on criteria of strength is justified. The basic approach of the earthquake resistant design should be always based on deformability, lateral strength and ductility capacity of that structure with limited damages but no collapse. Hence, the design philosophy will include provisions to provide limited standards to maintain public safety in the extreme earthquake and protection i.e. safeguard against loss of life and major failures. The design assumes significant amount of inelastic behaviour to occur in the structure during earthquake. The analysis of 15 floors i.e. (G+14) floors is carried out by using STAAD Pro. v8i software for (SMRF) i.e. special moment resisting frame which is situated in zone II. The G+14 structure is analysed with four types of bracing system and in unbraced condition also. Axial forces, story drifts, base shear, joint displacement, bending moments are compared for 5 types of structural systems i.e. four of braced type and one of unbraced type. Loads which are acting on the structure are mainly divided into two types i.e. lateral loads and gravity loads.

### *C. Types of Model:*

Thirteen models of multi-storeyed building having (G+14) floors are prepared to analyse the realistic behavior of that structure during earthquake. The width of the building is 15.27m and length is 16.37m. The columns at the ground level are assumed to be fixed. And equivalent static analysis is performed on the building.

### *D. Structural Configuration:*

(G+14) RC-Framed Structure without any use of bracing system and (G+14) RC-Framed structure with different types of bracing system are studied. Here total 13 types of models are analysed. One is unbraced frame model, four models of ISMC 150 i.e. (Indian Standard Medium Weight Channel 150). Four models of ISMC 250 i.e. (Indian Standard Medium weight channel 250). Four models of ISMC 350 i.e. (Indian Standard Medium weight channel 350). Some pattern of bracings i.e. (x-cross brace, inverted chevron brace, chevron brace, braced chevran brace) are used for all types of channel sections.

### E. Plan:

Plan and centre line plan of RC frame building which is used for the study is shown in figure (1 & 2)

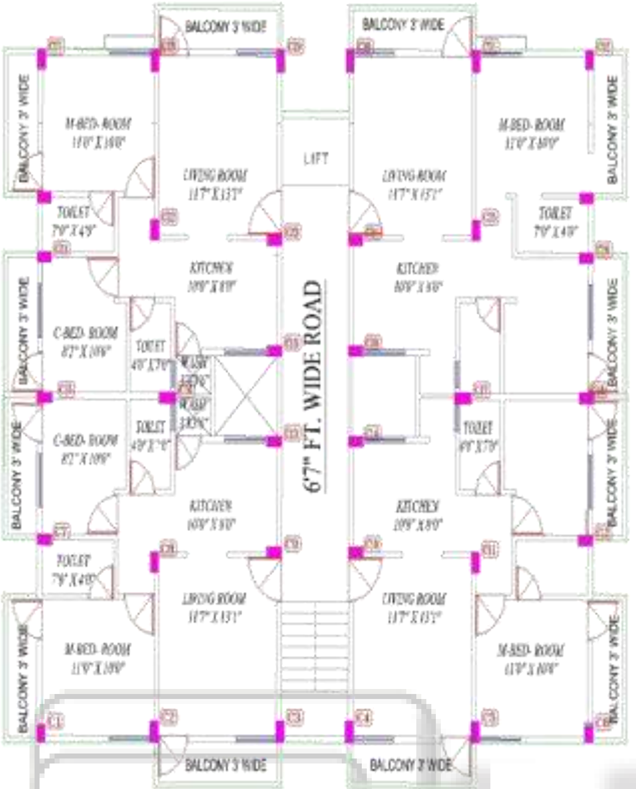



Fig. 1: Plan of RC Building"

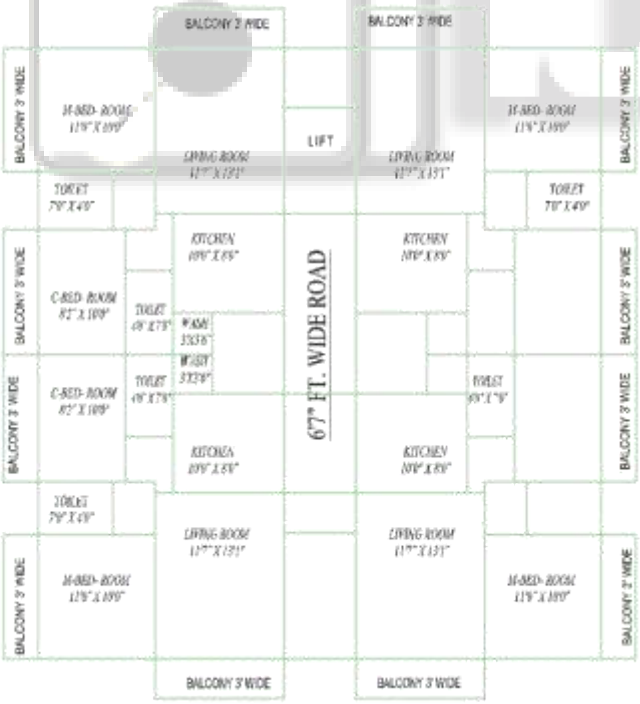
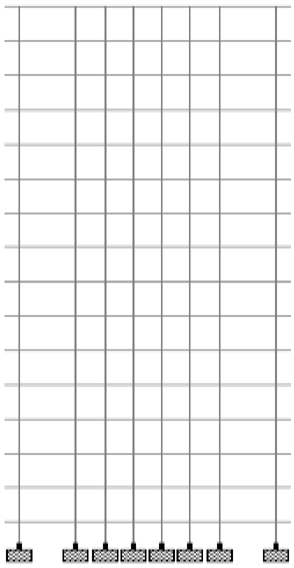
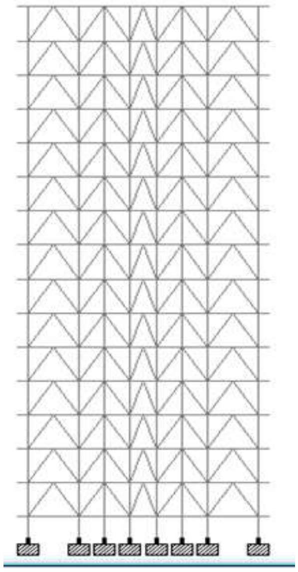



Fig. 2: Centre line Plan of RC Building"

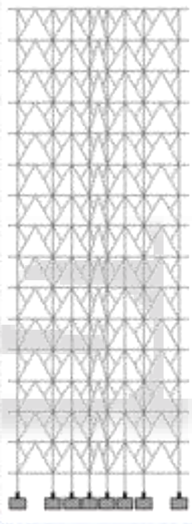
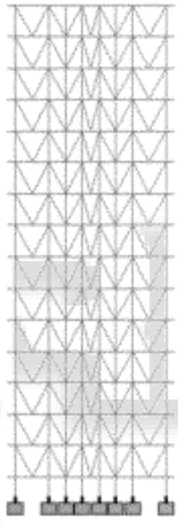
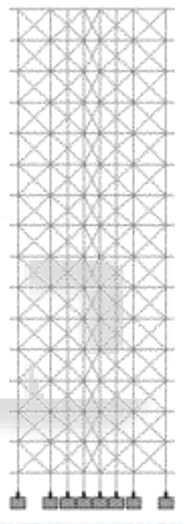
### F. Different Types of Bracing Patterns used in the Study:

Different types of bracing pattern used in the study are shown in figures below:-

Elevation of G+14 Unbraced Chevron Bracing

1) *RCC Framed Structure*

B.C.B. Inverted-Chevron X-Bracing

Fig. 3: Various bracing system"

### G. Load Combinations As per IS 1893 (part 1):2002:

- 1.5(DL+LL)
- 1.2(DL+LL+EQX)
- 1.5(DL+EQX)
- 0.9(DL)+1.5(EQX)
- 1.2(DL+LL-EQX)
- 1.5(DL-EQX)
- 0.9(DL)-1.5(EQX)

### H. Load Calculation:

1) *Dead Load:*
- Dead load of slab = 0.125 x 25= 3.125 kN/m$^2$.
- Floor Finish = 0.05 x 20 = 1 kN/m$^2$.
- Live load = 2.5 kN/m$^2$.

2) *Member Load:*
- External wall load = 0.23 x 2.85 x 20= 13.11 kN/m.
- Internal wall load = 13.11 kN/m.
- Parapet wall load = 0.15 x 1 x 20 = 3 kN/m.

*I. Summary:-*

Analysis of (G+14) storey building has been done. The bracing systems used are chevron Bracing, x-bracing, inverted chevron, braced chvron brace. The different channel sections used for this analysis are ISMC 150, ISMC 250, ISMC 350.

## III. Results & Discussion

*A. Maximum Joint Displacement in X- Direction:*

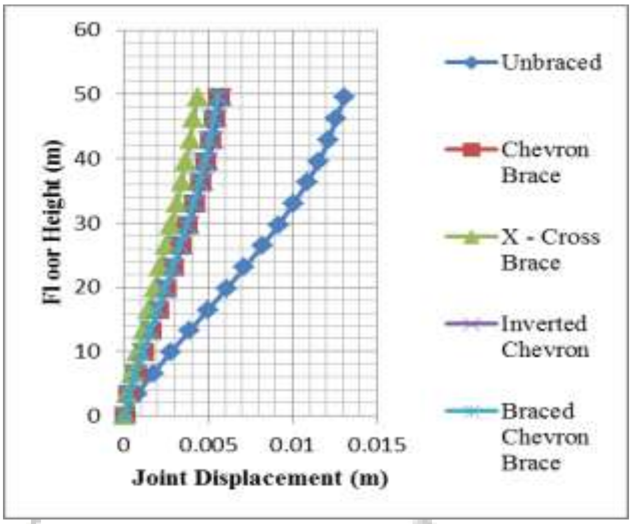



Fig. 4: Maximum Joint Displacement In X -Direction for G+14 Storey Building"

From the Figure. 4, we know that the maximum values of Joint Displacement is reduced in comparison with unbraced building & braced building for using different bracing types with different channel sections such as ISMC 150, ISMC 250, ISMC 350. The percentage difference decreases i.e. reduction for chevron bracing is 56.88% using section ISMC 350, for X-cross bracing is 66.48% using section ISMC 350, for Inverted chevron is 55.40% using section ISMC 350 and for Braced chevron Brace is 57.42% using section ISMC 350.

*B. Maximum Joint Displacement in Z-Direction:-*

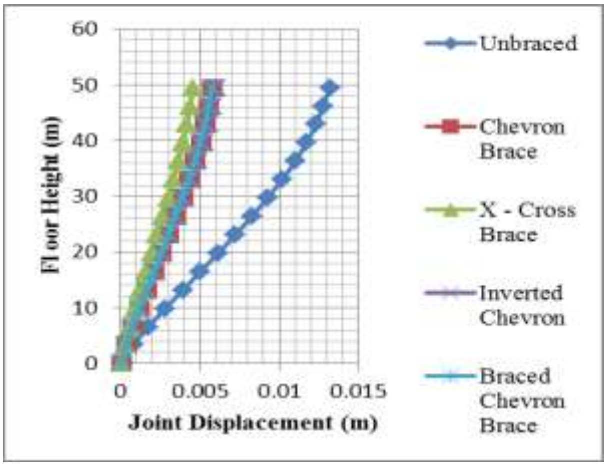



Fig. 5: Maximum Joint Displacement In Z Direction for G+14 Storey Building"

From the Figure. 5, we know that the maximum values of Joint Displacement is reduced in comparison with unbraced building & braced building for using different bracing types with different channel sections such as ISMC 150, ISMC 250, ISMC 350. The percentage difference decreases i.e. reduction for chevron bracing is 56.09% using section ISMC 350, for X-cross bracing is 65.27% using section ISMC 350, for Inverted chevron is 54.68% using section ISMC 350 and for Braced chevron Brace is 56.38% using section ISMC 350.

*C. Maximum Storey Drift in X-Direction:*

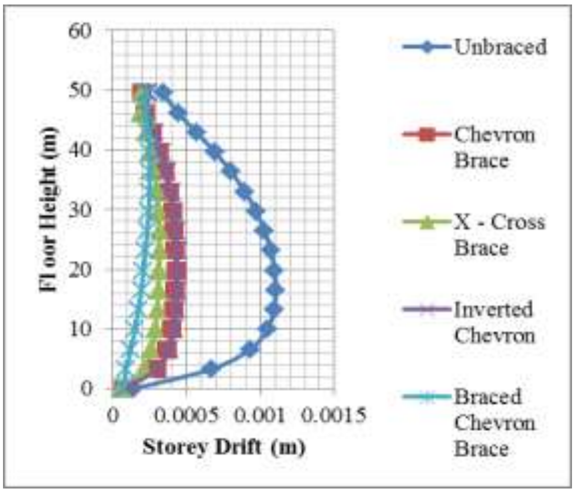



Fig. 6. Storey Drift for Maximum Storey Drift In X Direction for G+14 Storey Building"

From the Figure. 6, we know that the maximum values of Storey Drift is reduced in comparison with unbraced building & braced building for using different bracing types with different sections such as ISMC 150, ISMC 250, ISMC 350. The percentage difference decreases i.e. reduction for chevron bracing is 61.26% using section ISMC 350, for X-cross bracing is 71.04% using section ISMC 350, for Inverted chevron is 62.80% using section ISMC 350 and for Braced chevron Brace is 77.10% using section ISMC 350.

*D. Maximum Storey Drift In Z-Direction:*

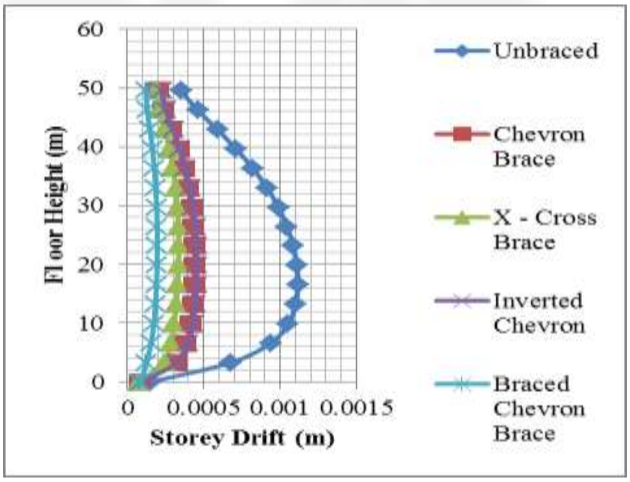



Fig. 7: Maximum Storey Drift In Z Direction for G+14 Storey Building"

From the Figure. 7, We know that the maximum values of Storey Drift is reduced in comparison with unbraced building & braced building for using different bracing types with different sections such as ISMC 150, ISMC 250, ISMC 350. The percentage difference decreases i.e. reduction for chevron bracing is 60.39% using section ISMC 350, for X-cross bracing is 69.80% using section ISMC 350, for Inverted chevron is 59.14% using section ISMC 350 and for Braced chevron Brace is 82.44% using section ISMC 350.

*E. Maximum Base shear:*

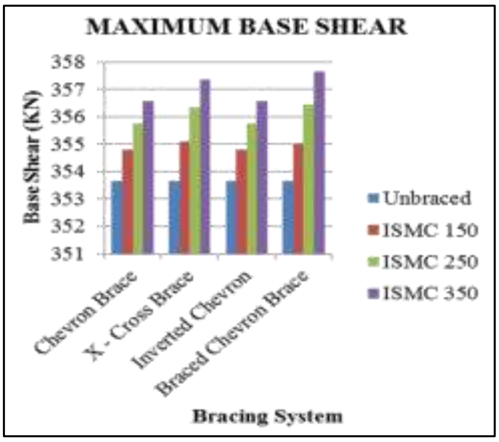



Fig. 8. Maximum Base Shear for G+14 Storey Building For Different Bracing Systems"

From the Figure. 8, it is clear that the maximum values of the base shear in bottom of a column increases for chevron bracing, x-cross bracing, inverted chevron, braced chevron brace when compared to unbraced building, for different sections ISMC-150, ISMC-250, ISMC-350. The maximum percentage difference increases i.e. increment for chevron bracing is 0.31% using section ISMC-150, 0.59% using section ISMC-250 & 0.82% using section ISMC-350, for X-cross bracing it is 0.41% using section ISMC-150, 0.75% using section ISMC-250 & 1.05% using section ISMC-350, for Inverted chevron it is 0.32% using section ISMC-150, 0.59% using section ISMC-250 & 0.82% using section ISMC-350, and for Braced chevron brace it is 0.37% using section ISMC-150, 0.78% using section ISMC-250 & 1.12% using section ISMC-350. On comparison of base shear, it increases in braced building thain in unbraced building. From the above graph it can be clearly seen that the difference in values of Base shear in unbraced & braced building is very less. So the base shear is almost same. From Figure. 9 the maximum base shear for different sections & unbraced RCC frame building is plotted & compared as below.

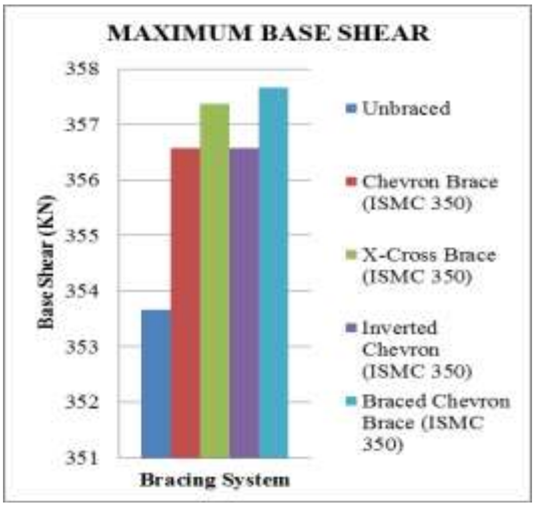



Fig. 9: Maximum Base Shear for G+14 Storey Building For Different Bracing Systems"

Figure. 9, shows that the base shear in Braced Chevron Brace system is more as compared to X-bracing, Inverted Chevron, Braced Chevron Bracing system. The base shear produce in X and Z direction is same because stiffness of the building is same in both direction. As the stiffness of bracing sections increases, the base shear of the building also increases in both directions.

*F. Bending Moment:*

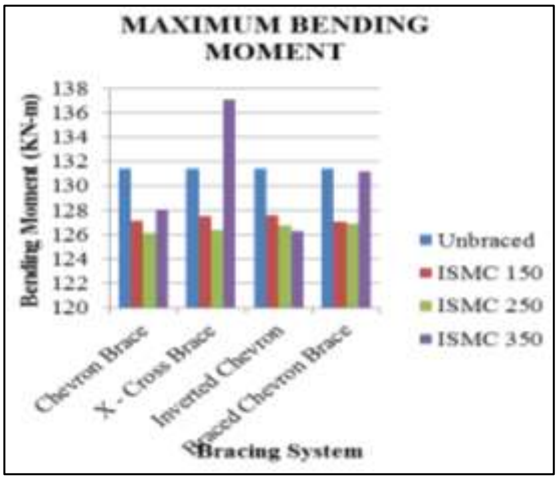



Fig. 10. Maximum Bending Moment for G+14 Storey Building For Different Bracing Systems"

From the Figure. 10, it is observed that the maximum values of bending moment in the members are reduced for chevron bracing, X-cross bracing, Inverted chevron, Braced chevron Brace respectively when compared with unbraced building, for different sections ISMC-150, ISMC-250, ISMC-350. The maximum percentage difference increase i.e. reduction for chevron bracing is 3.29% using section ISMC-150, 4.05% using section ISMC-250 & 2.57% using section ISMC-350, for X-cross bracing it is 2.98% using section ISMC-150, 3.87% using section ISMC-250 & 4.28% using section ISMC-350, for Inverted chevron it is 2.93% using section ISMC-150, 3.57% using section ISMC-250 & 3.94% using section ISMC-350, and for Braced chevron brace it is 3.33% using section ISMC-150, 3.48% using section ISMC-250 & 0.19% using section ISMC-350. On comparison of bending moment the reduction takes place in braced building as compared to unbraced building.

From Figure. 11 the maximum value of bending moment of different sections and unbraced RCC frame building is plotted & compared as below.

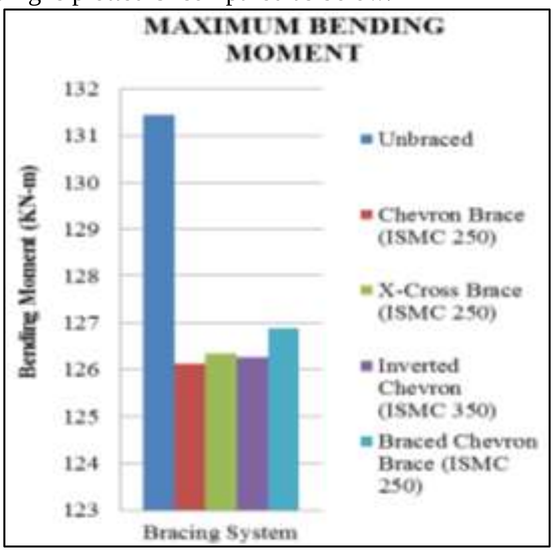



Fig.11: Maximum Bending Moment for G+14 Storey Building For Different Bracing Systems"

From the Figure. 11, it is observed that on comparison of bending moment of unbraced building with braced building. The reduction for chevron bracing is 4.05% using section ISMC-250, for X-cross bracing is 3.88% using section ISMC-250, for inverted Chevron is 3.94% using section ISMC-350, for Braced Chevron Brace is 3.47% using section ISMC-250. On comparison of bending moment the reduction takes place in braced building as compared to unbraced building.

From the above graph it is observed that the bending moment is comparatively reduced, it is due to the load being distributed equally in frame and the braceing system provided. Bending moment in building with Chevron- bracing system is less among of four bracing but other bracings also gives suitable result as compare to unbraced building.

### G. *Axial Force:*

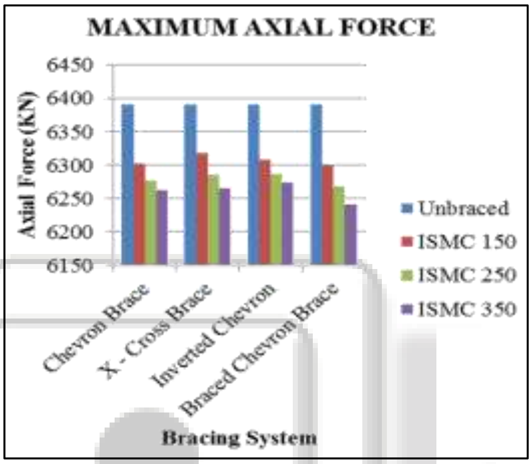



Fig. 12: Maximum Axial Force for G+14 Storey Building For Different Bracing Systems"

From the Figure. 12 it is clear that the maximum values of axial force in the column reduced for chevron bracing, X-cross bracing, Inverted chevron, Braced chevron Brace respectively when compared to unbraced building, for different channel sections ISMC-150, ISMC-250, ISMC-350. The maximum percentage difference increase i.e. reduction for chevron bracing is 1.39% using section ISMC-150, 1.78% using section ISMC-250 & 2% using section ISMC-350, for X-cross bracing it is 1.14% using section ISMC-150, 1.64% using section ISMC-250 & 1.96% using section ISMC-350, for Inverted chevron it is 1.29% using section ISMC-150, 1.63% using section ISMC-250 & 1.83% using section ISMC-350, and for Braced chevron brace it is 1.43% using section ISMC-150, 1.93% using section ISMC-250 & 2.33% using section ISMC-350. On comparison of axial force the reduction takes place in braced building as compared to unbraced building.

From Figure. 13 the maximum axial force of different sections & unbraced RCC frame building is plotted & compared as below.

From the Figure. 13, it is observed that on comparison of axial force of unbraced building with braced building, The reduction for Chevron bracing is 2% using section ISMC-350, for X-Cross bracing is 1.95% using section ISMC-350, for Inverted Chevron bracing is 1.83% using section ISMC-350, for Braced Chevron Bracing is 2.33% using section ISMC-350. On comparison of Axial Force the reduction takes place in braced building as compared to unbraced building. Axial force in building with Braced Chevron Bracing is less among of four bracing and other bracings also gives suitable result as compared to unbraced building.

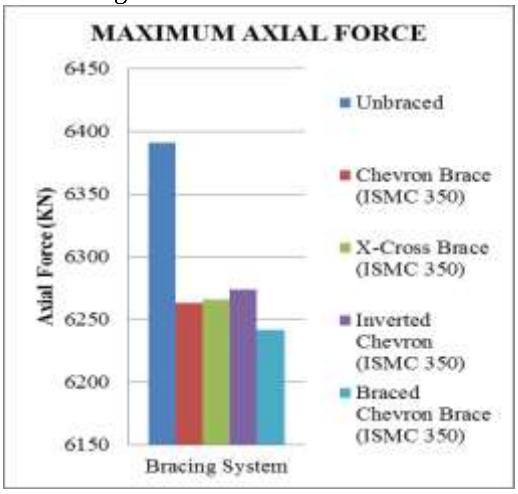



Fig. 13: Maximum Axial force for G+14 Storey Building for Different Bracing Systems"

### H. *Concluding Remark*

In this chapter, results of (G+ 14) storey RCC building are discussed. The comparison of various parameters like joint displacement, bending moment, axial force, base shear & storey drift is done to find out most suitable bracing system and channel section.

## IV. CONCLUSIONS

### A. *General:*

Here the analysis was performed for braced and unbraced type of buildings using STAAD pro. v8i software. The comparision of output i.e. results for braced and unbraced building has been carried out to get the most suitable type of bracing system.

### B. *Conclusions:*

1) The concept of using steel bracing system is one of the advantageous concept which can be used to retrofit the existing building or to strengthen the new building.
2) Steel bracing system can be used as an alternative to the other retrofitting or strengthening techniques available as the net weight of the building will not change significantly.
3) The seismic response of the structure changes with addition of braces in the building.
4) The amount of maximum base shear in braced structure increases as compared to the unbraced structure. Because stiffness of the building is increased by inclusion of braced member.
5) The stiffness of the building increases because of inclusion of bracing and hence vibrations in the building caused due to earthquake are reduced thus reducing the amount of joint displacement of the structure.
6) The horizontal load at the nodes of structure is distributed among brace members along with columns and beams. And bending moment of the

building is comparatively reduced due to addition of bracing system.

7) Time period in the seismic analysis of unbraced and braced framed structure is same.
8) On the basis of increment and reduction in storey drift, axial force, bending moment, base shear, joint displacement. It can be observed that braced chevron bracing and x-cross bracing systems are most suitable. But the values of bending moment, axial force and base shear gives better result in braced chevron brace as compared to x-cross brace and the values of base shear in braced chevron brace and x-cross brace are nearly in same range. The values of joint displacement, axial force, storey drift and bending moment are maximum in case of inverted chevron brace and chevron brace. And the values of base shear are less as compared to x-cross brace and braced chevron Brace. Hence, by comparing all the parameters associated with building, it can be concluded that the brace chevron brace system are more effective than any other bracing systems and as we increase the size of channel section, it shows better performance.
9) From the whole study it is concluded that the use of maximum number of bracing system doesn't lead to satisfactory results.

## V. FUTURE SCOPE OF THE STUDY

The present study on high-rise building has been carried out with a limited constraint of time. However, it is proposed that future study needs to carried out to investigate the following aspects related to the present analysis which can be bring further justification for the conclusion & objectives drawn in the study.

1) The effects of bracing system on high-rise building have been investigated and the effects of bracing in case of steel building can be verified.
2) The effects of tortion in addition to seismic force on unsymmetrical structure can be investigated.
3) The Study on high-rise building by considering non linearity of frame members along with braced members can be carried out.
4) The optimization can be done so that with use of minimum numbers of braces, response of the building can be considerably improved.

## REFERENCES

[1] Bahador Bagheri, Krishna Nivedita, Ehsan Salimi Firoozabad, "Comparative damage assessment of irregular building based on static and dynamic analysis", International journal of civil and structural engineering Volume 3,No 3, 2013.
[2] Takey M. S. & Vidhale S. S., "Seismic response of steel building with linear Bracing system", 2(1), page no. 17-25, 2011.
[3] N. N. Shah, Prof. S. N. Tande, "Study of the Stiffening Systems For Seismic Loads in Multistoreyed Building", International Journal of Engineering Science and Technology (IJEST), ISS: 0975-5462 Vol. 6 No.6 Jun 2014.
[4] H. Ghaffarzadeh and M. R. Maheri, "Cyclic Tests on the Internally Braced RC Frames" JSEE: Fall 2006, Vol. 8, No. 3.
[5] Manju, Department of Civil Engineering, Sahyadri College of Engineering and Management, Mangalore, Karnataka."Dynamic Analysis of Infills on R.C. Framed Structures", International Journal of Innovative Research in Science, Engineering and Technology (An ISO 3297: 2007 Certified Organization) Vol. 3, Issue 9, September 2014.
[6] Suresh P., Panduranga Rao B., Kalyana Rama J. S., "Influence of diagonal braces in RCC multi-storied frames under wind loads", A case study, International Journal Of Civil & Structural Engineering 3(1), page no. 214-226, 2012.
[7] Mohammed yousuf, P.M. shimpale, "Dynamic Analysis of Reinforced Concrete Building with Plan Irregularities", International Journal of Emerging Technology and Advanced Engineering Volume 3, Issue 9, September 2013.
[8] Viswanath K.G., Prakash K. B.; "Seismic analysis of steel braced reinforced concrete frames", International Journal Of Civil And Structural Engineering, 1(1), page no. 114-122,2010.
[9] Pravin Ashok Shirule, Bharti V. Mahajan**,** "Response Spectrum Analysis of Asymmetrical Building", International journal of science, spirituality, Business and technology (IJSSBT), vol. 1, no.2, February 2013.
[10] Eghtesadi S., Nourzadeh D. & Bargi K., "Comparative Study on Different Types of Bracing System in Steel Structures", World Academy Of Science & Technology, page no. 1863-1867, 2011.
[11] T. Fatima, S. Fawzia and A. Nasir, "Lateral Movements In Composite High-Rise Buildings Under Seismic Action", Department of Civil Engineering, Queensland University of Technology.