Comparative Study of Effect of Structural Irregularities & Different Types of Bracings in Multistoried Steel Building

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Abstract— In recent years there has been significant rise in usages of irregular structures in plan. Irregular buildings constitute large portion of modern urban infrastructures. Such irregular structures needs to be taken care by structural engineers particularly in high seismic zones. It causes extra shear, torsion etc. Asymmetry in the plan increases stresses of certain structural elements. The control of the dynamic response of the multi-storey building can be achieved by increasing stiffness through the use of bracing system. In present study comparison of Response Spectrum Analysis results of 20 storey irregular steel building under same loading conditions were done using Professional Software ETABS. The building is having different plans for different floors and this building is modeled for four different types of bracing systems. This paper aims to study the effects of seismic forces on plan irregularity and to know which bracing system becomes more efficient by using four different types of bracings.

Key words: Structural Irregularity, Response Spectrum Analysis, Steel Structure, Vertical Irregularity, Asymmetrical Plan, Bracing System

I. INTRODUCTION

The monumental architectural and structural triumphs of ancient days - the pyramids of Egypt, the temples of Greece, the viaducts of Rome - were executed in stone or some form of masonry construction. Today's architects and engineers have building materials that are far superior. Structural steel is one such material which has been in use for a long time. Its use as a versatile and economical building material is on the increase. Within the past two decades, the steel producers have provided architects and structural designers with a broad spectrum of steels. A wider range of structural shapes many of them in high-strength grades, is being produced. Structural irregularities are commonly found in constructions and structures. The existence of an asymmetry in the plan is usually leading to an increase in stresses of certain elements that consequently results in a significant destruction.

Bahador Bagheri [1] investigated dynamic responses of building under actual earthquakes, EL-CENTRO 1949 and CHICHI Taiwan 1999 and concluded that static analysis is not sufficient for high-rise buildings and it's necessary to provide dynamic analysis.

H. Gokdemir [2] has considered torsional irregularity on structures and generated building models with various plans such as L shape, rectangular and square using as moment resisting frame systems and solved under lateral loads using professional software SAP2000. He concluded that eccentricity between center of mass and center of rigidity cause torsion in structures and magnitude of torsional moment is the function of eccentricity ratio.

Raúl González Herrera and Consuelo Gómez Soberón [3] have worked to describes the geometric forms that are repeated more in the urban areas in México (squared, rectangular, section U, section L and section T), as well as its variations from plans observed with extracted aerial photography of Google Earth. They observed that constructions are more vulnerable when more irregular are and the linear analysis provide important information for torsion behavior of weak structures like the studied.

Mahmud Ashraf [4] investigated sway behavior of building frames with stepped configurations using numerical technique & observed that sway values in irregular frames is much larger than regular frames.

S. Varadharajan [5] conducted an extensive parametric study on a family of RC setback frames with 88 different setback geometry to evaluate the inelastic seismic response of the plane RC Moment Resisting Frame. He observed that the variation in inelastic deformation demands along height of the setback frame mainly depends upon the geometrical configuration of setback and in general maximum deformations are observed in vicinity of setbacks.

D.C. Rai and S.C. Goel [6] presented an analytical study of evaluation of seismic behavior of chevron braced frames structure for surviving future earthquakes. A building in North Hollywood area which suffered major damage in 1994 Northridge earthquake was the subject of this study. Response spectrum, nonlinear static (pushover), and nonlinear dynamic (time history) analysis for a ground motion recorded at a nearby site compared well with the observed damage. Here, 2-D analysis using SNAP & 3-D analysis using ETABS is done. They concluded that Chevron Braced Frames have problems associated with their strong brace & weak beam design. Seismic performance can be improved by using Eccentrically Braced Frames.

II. STEEL STRUCTURES

The concept of tall buildings were evolved to solve the various problems like rapid growth of urban population, limited and costly land space, etc. With the evolution of this concept, various structural problems related with tall buildings mainly stability of tall buildings against horizontal forces have also raised. For improving structural performance of tall buildings against horizontal forces, various types of structural systems were required.

In big cities of India, most of the buildings are high-rise. So the use of steel is increasing day by day. Mostly the buildings are designed for earthquake resistant, not the earthquake proof. As the concrete is brittle material and steel is ductile material, so the use of steel is more in high rise buildings. Thus the buildings are designed as per the considerations of mainly lateral forces viz. earthquake force.

III. STRUCTURAL IRREGULARITIES

In multistoried framed buildings, damage from earthquake ground motion generally initiates at locations of structural weaknesses present in the lateral load resisting frames. In some cases, these weaknesses may be created by discontinuities in stiffness, strength or mass between adjacent storeys. Such discontinuities between storeys are often associated with sudden variations in the frame geometry along the height. There are many examples of failure of buildings in past earthquakes due to such discontinuities. Irregular buildings constitute a large portion of the modern urban infrastructure. This may lead to building structures with irregular distributions in their mass, stiffness and strength along the height of building. When such buildings are located in a high seismic zone, the structural engineer's role becomes more challenging. Therefore, the structural engineer needs to have a thorough understanding of the seismic response of irregular structures.

Earthquake is a sudden, arbitrary and destructive lateral load. Buildings are complex structures made up of many structural elements which have different behavior from each other. As a result of this complexity, elastic and inelastic deformation capacity of buildings, which are subjected to earthquake loads, is a function of many variables including structural irregularities. Improper applications which form irregularities on structures lead to a more complex structural system behavior. Unexpected effects can be observed on irregular structures under various load patterns. Earthquake loads cause extra shear, torsion etc. on irregular structures. Therefore, structural irregularities decrease the seismic performance of buildings significantly. Irregular structures should be constructed in parts with separation distances or they will be heavily damaged as a result of torsion effects on structural elements.

A desire to create an aesthetic and functionally efficient structure drives architects to conceive wonderful and imaginative structures. Sometimes the shape of building catches the eye of visitor, sometimes the structural system appeals, and in other occasions both shape and structural system work together to make the structure a Marvel. However, each of these choices of shapes and structure has significant bearing on the performance of building during strong earthquake. So the symmetry and regularity are usually recommended for a sound design of earthquake resistant structure. Earthquake resistant engineering emphasis the inconvenience of using irregular plans, recommending instead the use of simple shapes. Hence at the planning stage itself, architects and structural engineers must work together to ensure that the unfavorable features are avoided and good building configuration is chosen.

IV. PROVISION OF IS CODE FOR IRREGULAR BUILDING

To perform well in an earthquake, a building should possess four main attributes, namely simple and regular configuration, and adequate lateral strength, stiffness and ductility. Buildings having simple regular geometry and uniformly distributed mass and stiffness in plan as well as in elevation, suffer much less damage than buildings with irregular configurations. A building shall be considered as irregular for the purposes of this standard, if at least one of the conditions given below is applicable.

A. Torsional Irregularity:

To be considered when floor diaphragms are rigid in their own plane in relation to the vertical structural elements that resist the lateral forces. Torsional irregularity to be considered to exist when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the storey drifts at the two ends of the structure.

B. Re-Entrant Corners:

Plan configurations of a structure and its lateral force resisting system contain 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.

C. Mass Irregularity:

Mass irregularity shall be considered to exist where the seismic weight of any storey is more than 200 percent of that of its adjacent storeys. The irregularity need not be considered in case of roofs.

D. Vertical Geometric Irregularity:

Vertical geometric irregularity shall be considered to exist where the horizontal dimension of the lateral force resisting system in any storey is more than 150 percent of that in its adjacent storey.

E. Stiffness Irregularity:

A soft storey is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storeys above.

F. Discontinuity In Capacity – Weak Storey:

A weak storey is one in which the storey lateral strength is less than 80 percent of that in the storey above, the storey lateral strength is the total strength of all seismic force resisting elements sharing the storey shear in the considered direction.

V. DETAILS OF THE MODELS

Modelling of the building for five different systems viz. Unbraced frame, Chevron Braced Frame, Eccentrically Braced Frame, Single Diagonal Braced Frame and X Braced Frame under same loading conditions is done using ETABS. The building is having different plan for different floors. Plan of the building for Ground Floor to 10th floor (2500 m2) is as shown in Fig.1, for 11th floor to 16th floor (1600 m2) is as shown in Fig.2 and for 17th floor to 20th floor (1600 m2) is as shown in Fig.3.Grid dimensions are kept 5m in both directions.

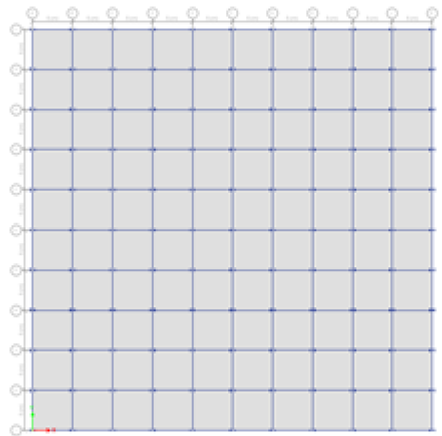

Fig. 1: Plan for Ground Floor to 10th floor

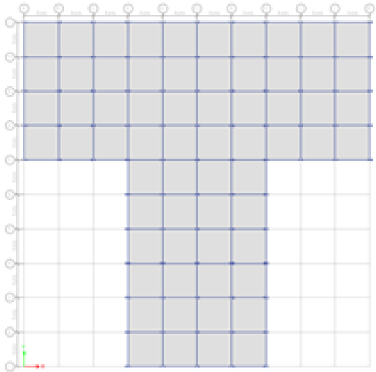

Fig. 2: Plan for 11th floor to 16th floor

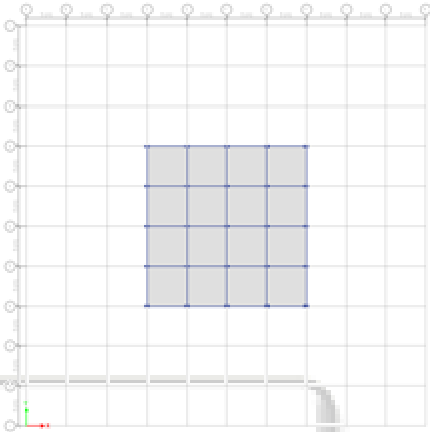

Fig. 3: Plan for 17th floor to 20th floor

All load combinations applied as per IS 800:2007 including Wind Load as per IS 875 (Part-III) and Earthquake Load as per IS 1893 (2002).The earthquake loads applied on the buildings were static as well as dynamic that is Response Spectrum Analysis. Response Spectrum Analysis results obtained using ETABS for different models are compared. Parameters taken for comparison are Base reactions, Axial force in bracings, Storey Acceleration, Storey Displacement, Storey Drift.

The elevations of the building for each bracing systems is shown in Fig.5 to Fig.8 as follows.

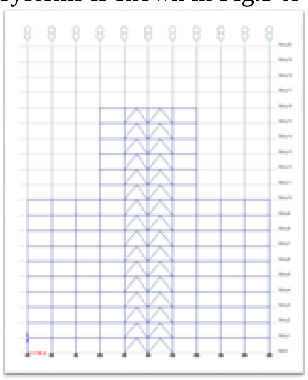

Fig. 4: Chevron Bracing

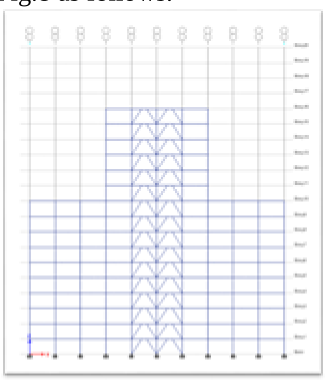

Fig. 5: Eccentric Bracing

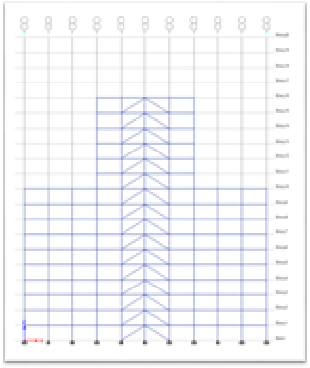

Fig. 6: Single Diagonal Bracing

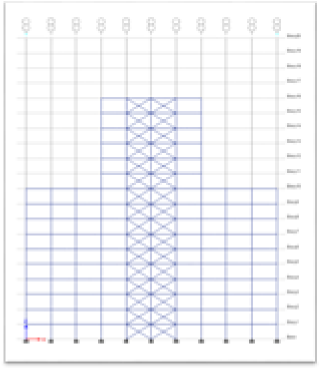

Fig. 7: X Bracing

Location of Bracings in Plan is as shown in the Following Fig.9.

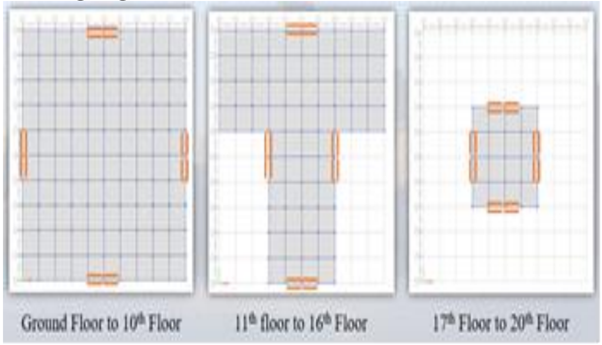

Fig. 8: Plan for 11th floor to 16th floor

The other data are as under:

A. Dead Loads:

Column dimensions are taken as built up sections having ISHB 600 with cover plate of 300mm width and thickness of 20mm for ground floor to 10th floor & ISMB 500 with cover plate of 250mm width and thickness of 15mm for 11th floor to 20th floor. All the beam sections are kept ISMB 500. All the bracings are kept ISHB 450. Thickness of slab was 120mm. Super imposed dead load was 1.5 kN/m2. Concrete grade taken is M25 & Steel grade taken is Fe250.

B. Live Load: 2.5 Kn/M2:

C. Earthquake Load:

Buildings situated in earthquake zone – IV & type of soil taken is medium. Importance factor, I is kept 1 & Response reduction factor, R is kept 5.

D. Wind load:

Wind speed has been taken 39 km/h. Terrain category has been taken 2 and Structure class has been taken C. Risk coefficient & Topography coefficient is kept 1.

E. Response Spectrum Analysis:

Zone factor has been taken as 0.336, Soil type has been taken II and Damping ratio has been taken 2%. Scale factor in X & Y directions are kept same i.e. 0.23. Standard response spectrum based on IS 1893 is shown in Fig.7. (X axis: Period in sec; Y axis: Response acceleration in m/sec2)

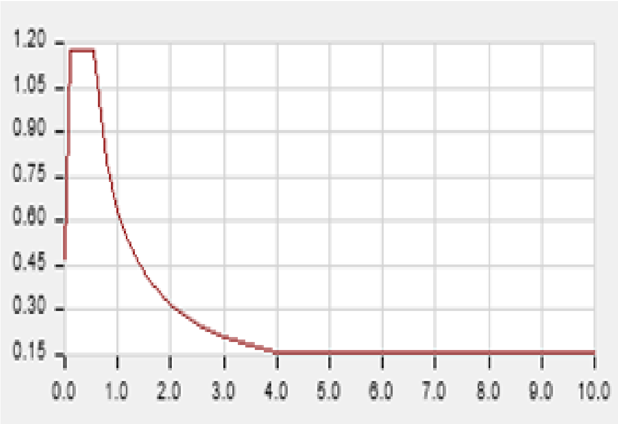

Fig. 9: Response spectrum standard of the model

VI. RESULTS AND DISCUSSIONS

Parameters taken for comparison are Base reactions, Axial force in bracings Storey Acceleration, Storey Displacement, Storey Drift. The maximum base shear of the models from the each load combination as per IS code have been compared and shown in Table. I. Unbraced frame model exhibits lower base reactions compared to other four models. It is observed that X braced frame model exhibits increase in base reactions compared to other three models. From all four braced frame models, Single diagonal braced frame model exhibits lower base reactions compared to other three models.

Model	Fx (kN)	Fy (kN)	Mx (kN m)	My (kN m)	Mz (kN m)
Unbraced	7800.75	5200.5	415236	10280904	257843
Chevron	7842.11	5228.07	416937	10423427	239561
Eccentric	7838.93	5225.96	416861	10420165	249120
Diagonal	7831.62	5221.08	416506	10412651	243494
X Braced	7862.50	5241.67	417776	10444398	239977

Table 1: Maximum Base Reactions.

Fig. 10: Maximum axial force in bracings

The maximum value of axial force in bracings of models for storey 1, storey 10, storey 11, storey 16, storey 17 and storey 20 have been compared and shown in Fig. 10. It is observed that Single diagonal braced frame system exhibits much more axial force compared to other braced frame systems for every storey. Overall Eccentrically braced frame system exhibits lower Axial Force compared to other systems for each storey. Sudden increase is observed in Axial Force for all the systems where plan dimensions changes (i.e.11th storey & 17th storey).

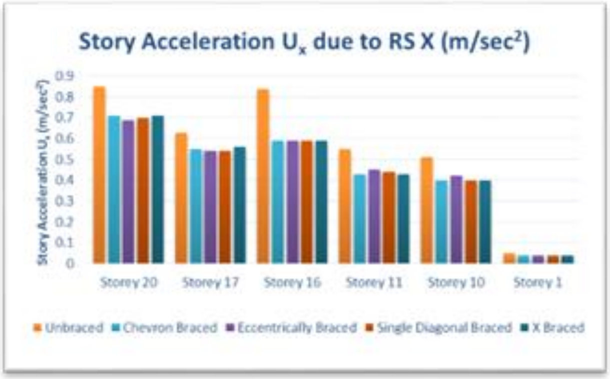

Fig. 11: Storey acceleration (Ux) in X direction due to RS X

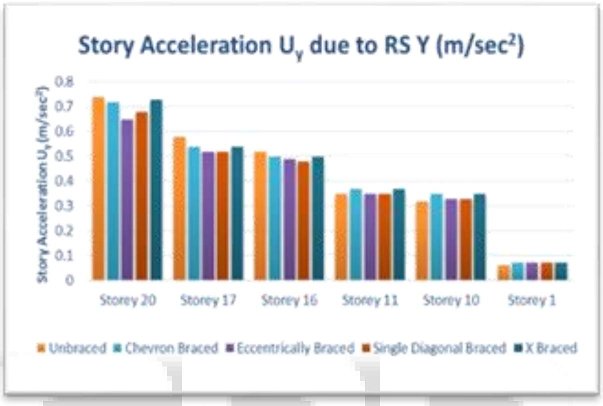

Fig. 12: Storey Acceleration (Uy) In Y Direction Due To RS Y

Storey accelerations in X direction & Y direction for all models due to load case RS X & RS Y have been compared and shown in Fig. 11 and Fig. 12. For load case RS X, Unbraced frame model exhibits much more increase in story acceleration in X direction compared to other models for every stories. For both the load case RS X & RS Y, Eccentrically braced frame model exhibits less story acceleration for upper stories. From all the braced frame models, X braced frame model exhibits larger story acceleration for both the load case RS X & RS Y.

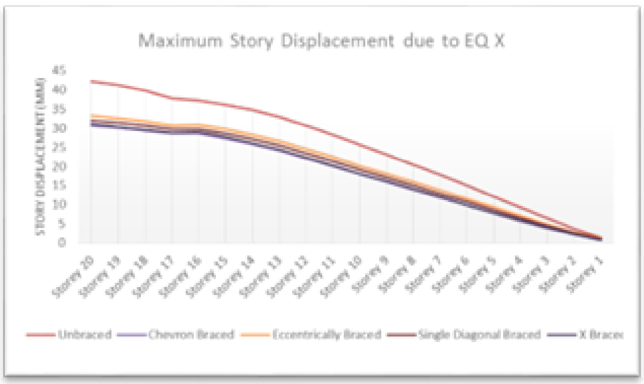

Fig. 13: Storey displacement in X direction due to EQ X

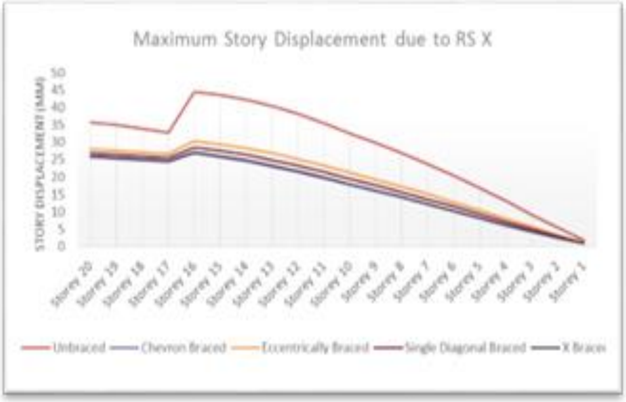

Fig. 14: Storey displacement in X direction due to RS X

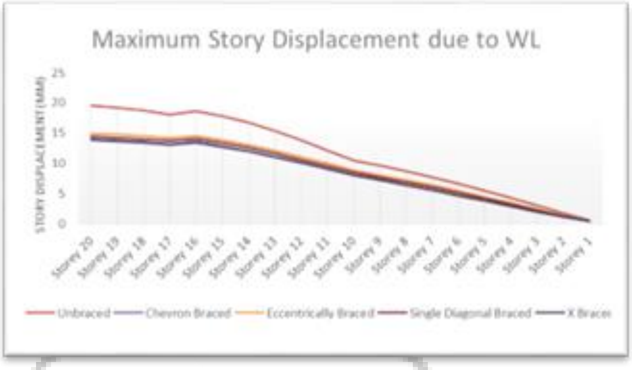

Fig. 15: Storey displacement due to WL

The maximum storey displacements & storey drifts for all models due to load cases EQ X, RS X & WL have been compared and shown in Fig. 13 to Fig. 18. It is observed that Chevron braced frame system & X braced frame system exhibits low story displacements compared to other models for every stories. It is observed that X braced frame model exhibits low storey drifts compared to other models for upper stories; while for lower stories, Chevron braced frame model exhibits low storey drifts compared to other models for lower stories. From all the braced frame system, eccentrically braced frame system exhibits large story displacement and story drift compared to other braced frame systems for every stories. Sudden decrease in storey displacements and story drifts were noted for all the system where plan dimension changes.

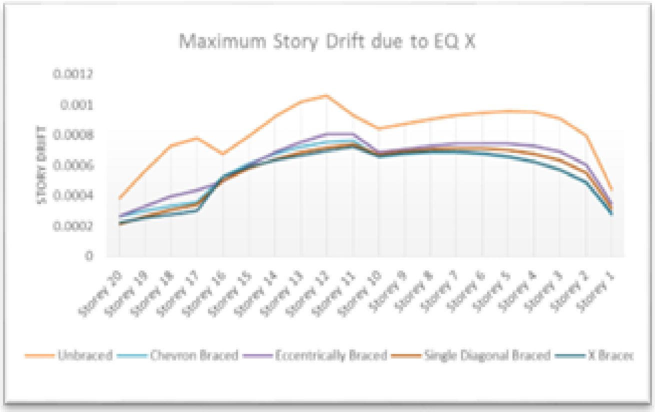

Fig. 16: Storey displacement due to EQ X

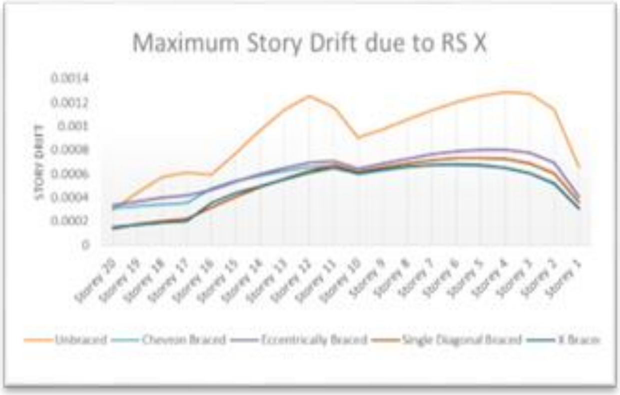

Fig. 17: Storey drift due to RS X

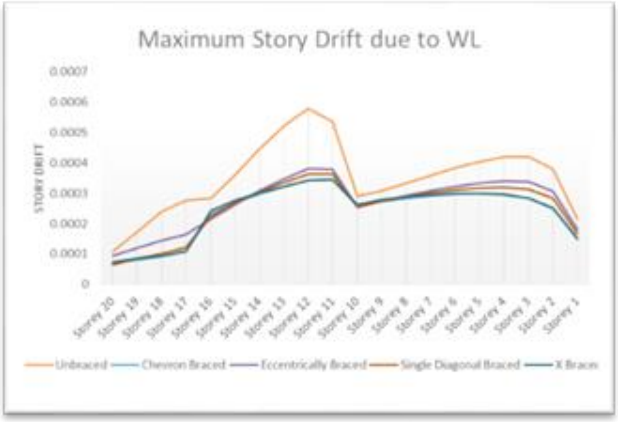

Fig. 18: Storey drift due to WL

VII. CONCLUSION

As a result of comparison between five models, it is observed that Unbraced frame model exhibits lower base reactions compared to other four models. It is observed that X braced frame model exhibits increase in base reactions compared to other three models. From all four braced frame models, Single diagonal braced frame model exhibits lower base reactions compared to other three models. From the analysis of the models, increase in maximum value of axial forces in bracings at every storey is observed in Single diagonal braced frame; while Eccentrically braced frame exhibits lower axial forces compared to other models. The results of storey acceleration indicated much more increase in storey acceleration in X direction for each storey in Unbraced frame model. The graphs of maximum storey displacements & storey drift shows that Eccentrically braced frame exhibits large storey displacement & storey drift compared to other braced frame models and its increment was higher where plan dimensions changes (i.e.11th storey & 17th storey); while Chevron braced frame and Eccentrically braced frame models exhibits lower storey displacement and storey drift values. By considering other parameters like Base reactions, Story Acceleration, Economy (Volume of steel needed); Chevron braced frame system performs better than X braced frame system. Sudden increase in storey drifts were noted for all the models where plan dimension changes.

From extensive comparative study of all five models, we conclude that whenever it is necessary to introduce bracing system for increasing lateral stiffness and improve seismic performance of the building, use of Chevron braced frame system is more efficient than any other braced frame system for the building taken in the present study.

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