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Comparative Analysis of Bracing Systems and Dampers for Industrial Steel Structures Under Seismic and Wind Effects

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Abstract

The growing susceptibility of the industrial steel structures to the seismic and wind loading forces prompts the use of effective lateral load-resistant systems. The paper is a dynamic analysis of a multi-storey industrial steel structure with multiple combinations of bracing and damping systems included to improve the performance of the structure during the confluent loading of wind and earthquakes. The G +20 steel frame structure is designed and calculated with the help of ETABS software taking into consideration the seismic Zone IV conditions and corresponding load combinations. Bracing systems such as X-bracing, V-bracing and inverted V-bracing are strategically placed at both central and peripheral bays and their effects on structural response parameters are assessed. Response spectrum method is used to obtain dynamic features of the building or response including storey displacement, storey drift, storey shear, and overturning moments. The findings have shown that bracing system inclusion can greatly enhance the lateral stiffness and decrease the displacement and drift relative to unbraced constructions. X-bracing is the best amongst the systems that are taken into consideration as it shows the highest reduction in lateral displacement and inter-storey drift because it has an effective system of transferring axial loads. Also, the damping mechanism integration also increases the capacity of energy dissipation, reducing structural response to dynamic loading. Another effect observed in the study is the location of bracing which is to the effect that outer bay types can be more easily controlled with respect to torsional effect as compared to their central position. All in all, the results uphold that the collective application of optimized bracing frameworks and damp devices is an effective and cost-efficient approach to enhancing the seismic and wind-resistance characteristics of industrial steel structures, which will be provided with higher safety and serviceability at the extreme load conditions.

Keyword: Earthquake-Resistant Structures, Seismic Analysis, Bracing System, X-Bracing, V-Bracing, Inverted V-Bracing, Response Spectrum Method, ETABS, storey drift, lateral displacement, Seismic Zone IV.

Introduction

As a result of the rapid advancement of the industrial infrastructure and high-rise buildings, the necessity to create the buildings that would be able to resist the active loading conditions (including the earthquakes and the wind forces) has become one of the primary demands. The structural integrity of industrial steel structures is particularly susceptible to lateral loads, particularly because these structures are relatively lightweight, flexible and enormous unsupported spans. These characteristics subject them to over displacement, structural imbalance and potential collapse as a result of severe seismic or wind action. This has resulted in the development of stiffness in the lateral direction, strength and energy dissipation capacity as a requisite in the contemporary structural design [1].

The dynamic forces caused by earthquakes are not predictable and these forces are caused through sudden discharging of energy on crust of the earth. The forces lead to ground movements and this generates inertia forces to the structure and lateral movement, inter-storey drifts and the torsional forces. Similarly, tall and slender buildings experience wind load that generates dynamic loads which can be vibrating and damaging because of fatigue with time passage. The interplay between wind and seismic loads has very often been the driving force of the design of steel structures in the industrial sector especially in those regions which fall within the moderate to high seismic regions [2]. In this way, the structural response in such situations of loading needs to be better forecasted and avoided with more sophisticated approaches to analysis and design.
The older structural systems such as moment resistant frames (MRFs) contain lateral ductility and dissipation albeit, lacking proper control of lateral movement in the tall buildings. In order to overcome such inadequacies bracing systems have been employed as one of the popular and cost effective solutions. The bracing systems also

enhance the lateral rigidity of the structures and the introduction of the diagonal members that primarily support the loads with the help of the axial forces but not the bending. This forms a smaller member sizes, increased load distribution, and enhanced structural performance at the dynamic loading [3].

The bracing systems can be classified as concentric and eccentric systems. The concentric braced frame (CBF) shell type is the most commonly used type of bracing with X-bracing, V-bracing and inverted V-bracing being the most common type of bracing, as the frames are stiff and can be constructed easily. They can be applied particularly to the X-bracing to support the lateral loads because it provides the straight direction of loads and minimizes the deformation. The also known chevron bracing systems, are V and inverted V bracing that offer flexibility in architecture but may result into owning forces failing to be even during seismic events of beams [4]. The selection of an appropriate bracing scheme is informed by a variety of variables that includes structural geometry, load conditions and goals of performance wanted.

Even though it has its advantages, the bracing systems may not have the strength to hold structural response in extreme dynamic loading. The past years have witnessed the popularity of the application of the supplemental damping devices as a promising solution in enhancing the energy dissipation in buildings. Dampers work by absorbing and dissipating a portion of the energy received on the structure, and as such, reduce the load on structural members. A number of the dampers have been successfully used in the structural systems and they are; viscous dampers, friction dampers, tuned mass dampers [5].

On the one hand, the integrating systems and mechanisms to ensure dampening is a synergistic solution in terms of structural design, in which the higher the stiffness, the higher the energy dissipation. The hybrid system does not just reduce the lateral movements and inter-storey drifts, but also increases the overall strength and stability of the structure. It has been established that the systems with the bracing and damping systems have significantly lower values of response parameters as compared to the traditional systems particularly in cases where the powerful ground motions occur [6].

Structural response must be modeled in a way that is predictive, as far as the dynamic loading is concerned and this is where advanced analytic means are required. Linear statical methods are however not enough in description of complex behavior of buildings in the activity of dynamic forces. Therefore, time history analysis and response spectrum analysis are the illustrations of dynamic analysis that are ordinarily utilized in modern structural engineering. Response spectrum method particularly provides a good means of estimating the maximum structural responses with the help of dynamic properties of the structure like the natural frequencies and mode shapes [7].

Response spectrum method is based on the principle of the ability of the greatest response of structure to be represented as a product of modal responses. This method particularly applies well to general structures, and is widespread in design codes such as the IS 1893:2002. It enables the engineers to consider the effect of higher modes, and adequately estimate the storey displacement, storey drift, base shear and overturning moments [8].

However, in the irregular structure or the complex structure, more advanced instruments such as nonlinear time history analysis may be required to get the real behavior of the structure when it is subjected to seismic loading. The other significant issue of structural performance is the lateral loads distribution on the height of the structure. The multi-storey buildings usually have the lateral loads concentrated at the storey levels creating a varying response at the various storeys. The maximum displacement is usually at the top of the structure and the maximum shear forces and overturning moments are observed at the bottom. This distribution is of importance to understand how to build effective lateral load-resisting systems and be able to maintain the structural stability in the general sense [9].

Bracing systems also play a big part in terms of structural response with regard to the placement and the structure of the bracing systems. It is typical knowledge that outer bay bracing proves more efficient than central bay bracing in torsional effect control as well as to the general stiffness. This is because the lever arm of outer bracing is higher thus it is more resistant to rotational force. In addition to this, by fitting bracing systems in a symmetric manner, this assists in reducing eccentricity and also in torsional irregularities [10].

The analysis and design of complex structures systems has been rendered extremely simple by the incorporation of modern computerized tools such as ETABS. ETABS is a structure modeling, analysis and design that comprises many methods of analysis and design codes. The software can best simulate it and thus provide the engineer with an opportunity of optimizing the design and improving performance especially when the loading conditions change [11]. ETABS is a powerful dynamic analysis software which can analyze structures due to such capabilities as modal, response spectrum and nonlinear analysis.

The given paper is devoted to the dynamic analysis of the G +20 industrial steel structure under the wind and earthquake loads, and the special attention is paid to the performance of different types of bracing systems and damping. With the assistance of ETABS software, analysis is conducted and various parameters of response such as storey displacement, storey drift, storey shear and overturning moments are taken into consideration. Different forms of bracing as X, V and inverted V bracing are considered and tested at the central and outer bay to see whether they work.



Fig 1:John Hancock Centre

The first goal of the proposed research is to find out the most effective bracing system and arrangement to reduce the structural response during dynamic loading. Also, the research will assess the impact of damping systems on structural performance and also provide a comparative structure in assessing various lateral load-resisting systems. The results should be useful in designing industrial steel construction against earthquakes and wind. Finally, the demand to have resilient infrastructure implies that new structural systems that can withstand dynamic loads should be adopted. The integration of bracing systems and damping devices is a viable solution to the attainment of this goal. These types of systems make structural designs safer, reduce displacements, and increase energy dissipation, thereby making them more efficient. The current work has a contribution to this area since it offers a step-by-step analysis of the behavior of braced steel structures when subjected to dynamic load events and thus contributes to the formulation of effective design strategies to be applied to the contemporary engineering practices.

LITERATURE REVIEW

[1] Behaviour of earthquake braced steel framing.

The recent studies have largely been preoccupied with the process of assessment of seismic performance of the steel structures that are braced with various bracing. An analytical evaluation of the steel tower buildings revealed that braced frame was much superior to moment-resisting frame in the aspects of lateral movement, inter-storey driftage and shedding base. The paper has applied nonlinear analysis of the pushover on the structures between 15 and 35 storeys, but concluded that the X-braced and zipper braced system is better in terms of stiffness, seismic resistance than other systems. The results prove that bracing integration improves the behavior of the global structure by effectively conveying the lateral loads with the help of the axial loads. It was also established in the study that load pattern and height of building is a significant variable that affects the performance of the bracing system and optimization is needed to use it in high rise buildings.

[2] X, V and Eccentric Bracing System Comparative Performance.

The comparison analysis of the various bracing constructions revealed that X-braced frames are stiffer and stronger compared to the eccentrically braced frames (EBFs) that are more ductile and possess great energy dissipating capacity. The test measured the level of structural damage in various earthquake records and discovered that X-bracing reduces the lateral movement, and may not be as ductile as the minimization of damage in high-rise buildings, as EBF systems does. It implies that there is a trade off between the rigidity and ductility of bracing design. The other fact explained as the aspect of consideration in the study was that the choice of the type of the bracing should be based on the structural safety and performance goal especially in the area that is prone to seismic actions.

[3] Effects of Bracing Positioning and Arrangements.

The location and the arrangement of the structural steel works systems are the critical factors of the structural performance. The recent researches on the modeling with the help of ETABS had proved that the bracing systems could lead to the rise of the lateral stiffness and decrease the lateral deformation when they were strategically

located in the structural frame. Observations were discovered to reveal that the outer bay bracing structures are more successful in stabilising the torsional forces compared to the central bay placements due to the fact that it has a greater leverage arm action. In addition, it was discovered that the general seismic resistance with the use of two way bracing installation, minimized motion and increased effectiveness of load distribution. These results point to the relevance of perfect location of braces in the delivery of balance in structural performance.

[4] Bracing Structural Strengthening and Retrofitting.
Another factor that has greatly been adopted is the fact that the steel bracing systems in strengthening the seismic behavior of old structure has been widely adopted as an effective methodology of retrofittage. Research performed on reinforced concrete and steel frame has shown that lateral movement decreases, stiffness goes up and the harm caused on the structure is insignificant in case an earthquake occurs. The bracing systems are thought to be cost effective and simple to install hence can be used in strengthening the weak structures without making major alterations in the building structure in the present case. The paper also confirms that retrofitted buildings perform better in the area of load bearing and collapsive resistance thus portraying a feasible benefits of the bracing structure in rehabilitating the structures.

[5] At the boundary of the vibrating hind legs and the stand, the amplification factor is a factor of 1.58.<|human|>Blending of the Bracing System and Damping Mechanism.
The recent developments in the structural engineering field have taken into consideration the availability to include a braking system with a damping device to increase energy dissipation. Experiments with cable bracing and friction dampers established that cable bracing and friction dampers provided important seismic performance, i.e. increased energy absorption and reduced structural response with cyclic loading. These findings also suggested that the optimized damping systems could be utilized to enhance the hysteretic nature and suppression of residual deformations. In addition, new types of braces have been indicated to be buckling-restrained braces (BRBs) that are very powerful damping elements that are able to bear tension and compression without buckling. The trends bring to focus the changing role of the hybrid systems with the aim of possessing resilient and high performance structures.

Design And Working Methodology
The structural system that will be used in this research is a G+20 industrial steel building, which aims at testing its dynamic behaviour when subjected to seismic and wind load. The sections of structural steel were compliant with IS 800:2007 and Fe415 grade steel was assumed to be used in all of the primary members, including beams, columns, and bracing elements. Modulus of elasticity was determined as 2x105 Mpa and density as 7850 kg/m3. The geometry of the building was 10.5 m plan by 9 m with a constant storey height of 3 m making the total height to be 60 m. A plan assumption of the structural arrangement was that the structure was symmetrical to reduce natural torsional irregularities.

The loading conditions used during the analysis were the dead load, live load, wind load and seismic load as per the IS 875 and IS 1893:2002 requirements. The zone IV that was analysed had medium soil conditions and a damping ratio of 5%. The combinations of loads like 1.2(DL+LL+EQ) were taken to achieve realistic structural response at combined loading condition. Wind loads were also introduced so as to consider the lateral forces that the tall structures bear in order to have a complete dynamic evaluation.

The structure was modeled and analyzed with the help of ETABS software that is designed to give extended capabilities of dynamic analysis. Structural model was constructed with the consideration of frame elements in beams and columns and bracing members were added in different forms including X-bracing, V-bracing and inverted V-bracing. These bracing systems were installed at central and outer bay to assess the effect they have on structural response. The natural frequencies and mode shapes that are important in understanding dynamic behavior were calculated through modal analysis.
The seismic analysis technique used was the response spectrum method which is an effective way of recording peak structural responses to earthquake excitation. This is a technique that takes into account various vibration modes and adds up their effects with the help of SRSS or CQC techniques. Major response parameters were derived out of the analysis results, which included: storey displacement, storey drift, storey shear and overturning moments. These parameters are crucial structural performance measures in a dynamic loading condition.

To achieve accuracy and reliability, the model was tested through verifying the boundary conditions, mass distribution and load application. Other bracing configurations and locations have been compared and analyzed in order to come up with the most effective system. The experiment was designed in a manner that would determine a clear connection between the type of bracing, its position, and response of the structure, hence, allowing optimization of the lateral load-resisting systems.

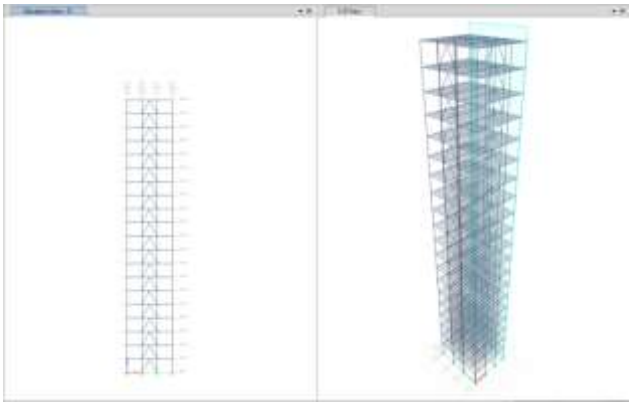

Fig.2. Elevation and 3D view of the building with inverted V bracings at center bay

This picture shows the height and the 3D model of the G+20 building having the reversed V (chevron) support on the core bay of the structure. In this design, both diagonal bracing members run downward of the columns of the upper floor and are joined at the beam level mid-point and it forms the inverted V shape. The bracing is evenly applied around the building heights, and this is advantageous in the sense that it makes the stiffness to be distributed equally. The inverted V bracing type is primarily used to enhance the lateral stiffness and reduce the storey vibration on seismic loading. This system assists in enhancing load resisting mechanism of entire structure through transferring the lateral forces of beams to columns in a useful manner. The middle bay position also gives a compromise on the transfer of force and the removal of eccentricity which reduces the torsional effects. However, the concentration of the axial forces on the beam interface with the brace may result in the increase in the vertical forces in the beams, which should be designed.

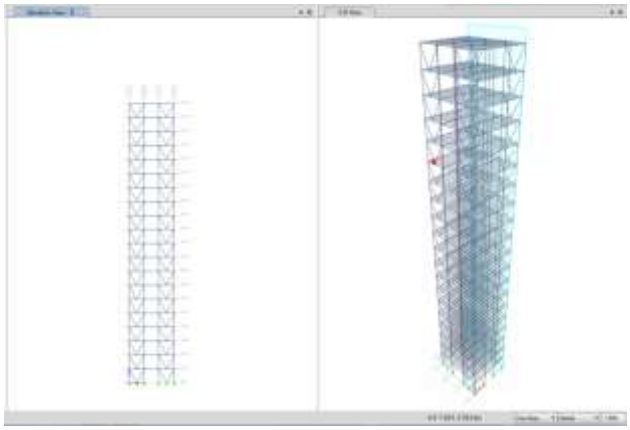

Fig.3. Elevation and 3D view of the building with V bracings at outer bays

Fig. 3 depicts the model of the building that shows the V type bracing which is provided on exterior bays of the frame. In such construction, the beam-column joints on the lower level part the members of the bracing, and the beam members converge at a point on the beam at the top. Outer bay bracing comes in handy in providing increased leverage arm against the lateral forces and this during high rise structures that are susceptible to seismic forces. V-bracing system improves the lateral load path and forces in seismic direction are willingly diverted to the foundation in the axial direction acting in the braces. This arrangement also reduces the storey drift as compared to those with central bay bracing and can also be used in structures that are on a more seismic area.

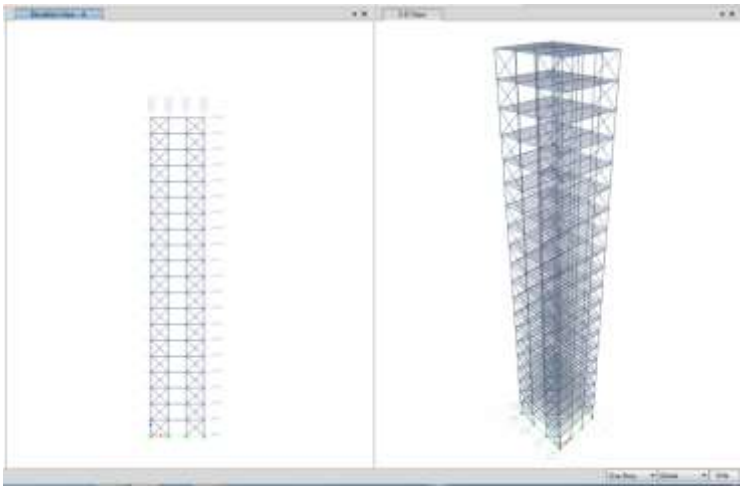

Fig.4. Elevation and 3D view of the building with X bracings at outer bays

X-bracing (cross bracing) will be situated at the outer bays of the building and this is shown in figure 4. Here, there is intersection of the two diagonal members between two consecutive floors forming X- shape. It is one of the best and the most used bracing systems to withstand seismic.

Results And Discussion

The dynamic analysis outcome shows that lateral displacement is greatly minimized because of the incorporation of bracing systems than when structures are unbraced. In this case of inverted V bracing system at the center bay, the maximum top storey movement was recorded at about 109 mm in the X-direction. By moving the same bracing to outer bays the displacement decreased to almost 108 mm, which signifies better stiffness as more leverage arm effect. This proves that the position of bracing is one of the determinants of structural deformation.

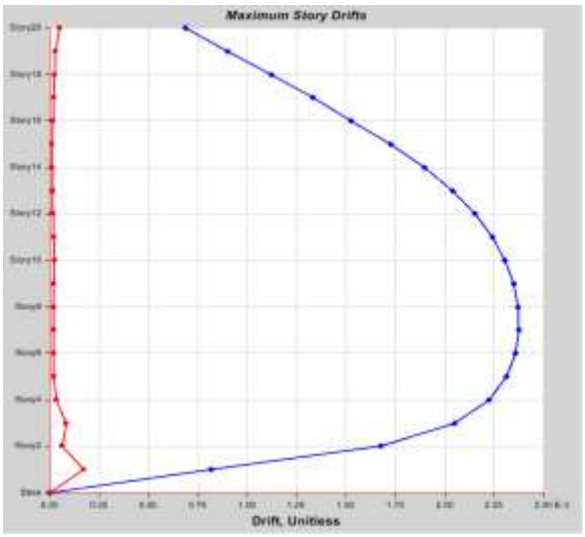

Fig.5. Maximum storey drifts of a building with inverted V bracings at outer bays

The results of the storey drift showed that the maximum drift was posted at intermediate storeys as opposed to the top as is a characteristic of the multi-storey structure. The maximum drift data of inverted V bracing at the center bay was around 0.00247 which is not outside the IS code range. Nonetheless, outer bay bracing exhibited marginally lower drift values and this proves that it is effective in controlling inter-storey deformation and enhances the structure stability.

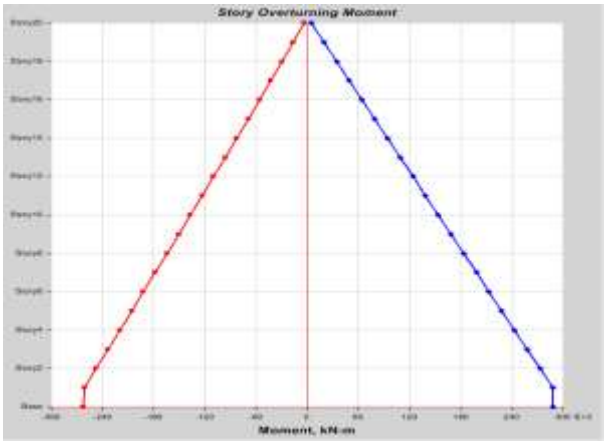

Fig.6. Maximum storey overturning moments of a building with V bracings at center bay

The distribution of the storey shear had assumed a normal distribution with the highest shear at the base and reducing towards the top. The value of base shear was about 358 kN, which means that the forces of a lateral character at lower levels were accumulated. These forces were effectively transferred by the presence of the bracing systems using axial action, and thus, the reduction of the bending stresses in beams and columns.

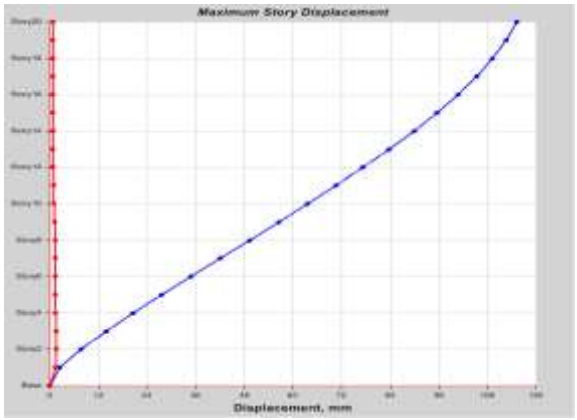

Fig.7. Maximum storey displacements of a building with X bracings at outer bays

It was discovered that the moments of overturning rose steadily to the base with top values being above 289, 000 kN-m. This shows how important lower storeys are in resisting lateral loads. The use of bracing systems also minimized over turns to a great extent by increasing global stiffness and redistributing forces in the most effective way in the structure.

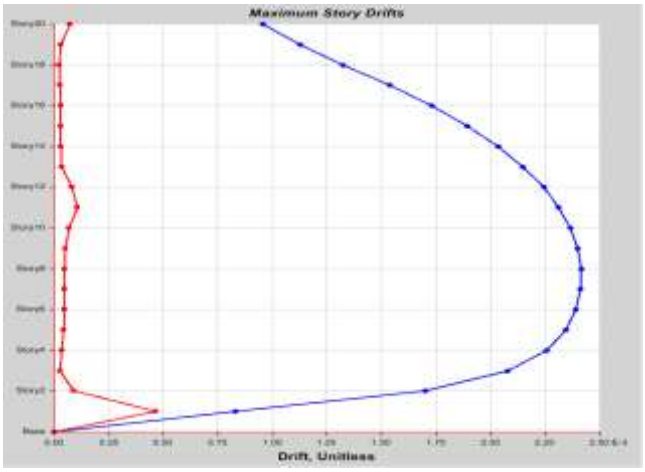

Fig.8. Maximum storey drifts of a building with X bracings at outer bays

A comparative study of different bracing systems showed that X-bracing produced the best findings on the movement and decrease of drift followed by the inverted V-bracing systems and V-bracing system. Secondly, location was never as good in central location as it was in outer bay location since the outer bay is more resistant

to the torsional effects. The results confirm that a significant positive influence of the optimization of bracing set-up on structural performance during dynamic loading is observed.

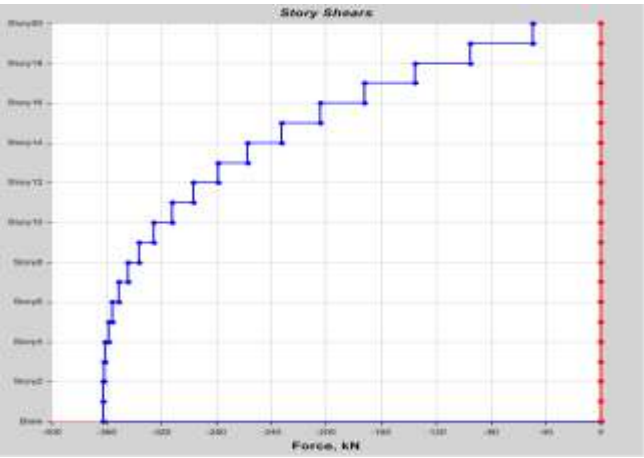

Fig.9. Maximum storey shears of a building with X bracings at outer bays

Conclusion

This research analyzed the dynamic performance of a G +20 industrial steel frame under seismic and wind loads and was aimed at assessing the efficacy of various bracing frameworks. The findings have made it clear that the introduction of the bracing systems can greatly increase the structural performance in terms of enhancing the lateral stiffness as well as the minimization of displacement and drift. Out of all the possible configurations studied, X-bracing was the best performing one with the effective dynamics of load transfer and the increased stiffness capacity. It was also determined in the analysis that the aspect of bracing placement is essential in structural response. The performance of bracing systems placed at outer bays was superior to central bay systems in the sense that they minimized torsional effects and enhanced load distribution. The values of maximum storey displacement and drift proved to be within permissible limits, which proved that the structural design was sufficient during the dynamic loading. The outcomes of storey shear and overturning moment showed that the strongest forces are on the base of the structure and that design of strong foundation and lower storey is important. The merger of bracing systems was done to assimilate the effective element distribution and reduce the primary demand on the members. Moreover, response spectrum analysis gave the right estimation of dynamic behavior, which reflects the effect of higher modes. In general, the research finds that the overall effectiveness of the combination of optimized bracing systems and proper place systems enhances the seismic and wind resistance of the industrial steel structures. The results can be useful in designing safe, economical, and high performance buildings that can handle extreme loading conditions.

REFERENCES

1. B. Patel, “Seismic analysis of braced steel structures,” Int. J. Civil Eng., vol. 5, no. 3, pp. 45–52, 2017.
2. D. E. Nassani, “Comparative study of bracing systems under seismic loading,” Eng. Struct., vol. 140, pp. 457–468, 2017.
3. S. N. Gandhi, “Performance of RC structures with different bracing systems,” Int. J. Struct. Eng., vol. 8, no. 2, pp. 112–120, 2017.
4. G. Hymavathi, “Analysis of steel structures with bracing systems,” Int. J. Eng. Res., vol. 4, no. 6, pp. 78–85, 2015.
5. P. Bhosle, “Seismic behavior of RC buildings with steel bracing,” J. Struct. Eng., vol. 6, no. 4, pp. 210–218, 2015.
6. J. J. S. Jagadish and T. D. Doshi, “Effect of bracing systems in steel buildings,” Int. J. Adv. Struct. Eng., vol. 5, pp. 89–97, 2013.
7. M. D. Kevadkar and P. B. Kodag, “Lateral load analysis of RCC structures,” Int. J. Civ. Eng., vol. 7, pp. 101–110, 2013.
8. N. Mohammed, “Seismic analysis of high-rise structures using bracing,” Int. J. Eng. Sci., vol. 6, pp. 55–63, 2013.
9. Z. Tafheem and S. Khusru, “Behavior of steel structures with bracing systems,” J. Civil Eng., vol. 9, pp. 145–152, 2013.
10. A. Moein et al., “Effect of bracing arrangement on seismic behavior,” Eng. Struct., vol. 34, pp. 67–75, 2012.
11. K. K. Sangle et al., “Dynamic analysis of steel buildings with bracing,” Int. J. Struct. Stability, vol. 12, pp. 223–231, 2012.
12. F. Hejazi et al., “Seismic evaluation of soft storey buildings,” Struct. Eng., vol. 20, pp. 98–106, 2011.
13. O. Alshamrani, “Wind analysis of braced steel buildings,” J. Wind Eng., vol. 35, pp. 200–210, 2009.
14. R. Sabelli, “Seismic demand in braced frames,” Earthquake Eng., vol. 7, pp. 150–160, 2003.

15. IS 1893:2002, “Criteria for earthquake resistant design of structures,” BIS, India.
16. IS 800:2007, “General construction in steel,” BIS, India.
17. IS 875 (Part 3), “Wind load design,” BIS, India.
18. CSI, ETABS User Manual, Computers and Structures Inc., 2018.
19. H. Okamura and M. Ouchi, “Self-compacting concrete,” J. Adv. Concrete Tech., vol. 1, pp. 5–15, 2003.
20. A. K. Chopra, Dynamics of Structures, 4th ed., Pearson, 2012.