

Analysis Of Frame With And Without Knee Bracing For Lateral Load

Sanket Suryakant Kamale¹, prof. Abhijeet Undre², Dr. Atul Pujari³

¹Dept of MBA

²Research Co-guide

³Research guide

^{1, 2, 3} KJ College of Engineering & Management Research Tal-Haveli,
Dist-Pune.

Abstract- *The present study deals with the analysis of a framed structure with and without knee bracing under lateral loading. Lateral loads due to earthquake and wind action produce storey displacement, inter-storey drift, base shear, overturning effect, and additional forces in structural members. In ordinary moment-resisting frames, lateral stiffness is comparatively low, which may lead to excessive deformation and serviceability problems. To improve the lateral load resistance, knee bracing is introduced as an effective structural system. In a knee-braced frame, the main diagonal brace is connected to a short knee element near the beam-column joint. The diagonal member provides lateral stiffness, while the knee element acts as an energy-dissipating component during seismic excitation. In this study, the behaviour of braced and unbraced frame systems is compared by considering important parameters such as displacement, drift, stiffness, member stress, velocity, acceleration, and overall stability. The structural modelling and analysis are carried out using structural analysis software under lateral load conditions. The results indicate that the provision of bracing improves the lateral performance of the frame by reducing displacement and controlling dynamic response. Therefore, knee bracing can be considered an efficient, economical, and practical system for improving the safety and serviceability of framed structures under lateral loads.*

Keywords: Knee bracing, lateral load, framed structure, seismic analysis, wind load, storey displacement, storey drift, structural stiffness, braced frame.

I. INTRODUCTION

In modern structural engineering, the safety and serviceability of framed structures under lateral loading have become major areas of concern, particularly in regions subjected to earthquake and wind forces. Buildings are generally designed to carry vertical gravity loads such as dead load and live load; however, during seismic excitation or strong wind action, the structure is also subjected to horizontal forces that produce lateral displacement, inter-storey drift, overturning moment, and additional internal forces in beams

and columns. If these lateral effects are not properly controlled, the frame may experience excessive deformation, cracking, instability, connection distress, and even progressive failure. Moment-resisting frames are commonly used because they provide architectural flexibility and open usable space, but their lateral stiffness is comparatively low when compared with braced frames or shear wall systems. As the height of the structure increases, lateral displacement becomes a governing design parameter, and therefore a suitable lateral load resisting system is necessary. Steel bracing is one of the most effective methods for increasing the lateral stiffness and strength of framed structures. Conventional bracing systems such as X-bracing, V-bracing, inverted V-bracing, diagonal bracing, and K-bracing are widely used to improve seismic resistance. These systems transfer lateral forces through axial action in the bracing members and reduce the demand on beams and columns. However, conventional concentric bracing may sometimes create architectural obstruction, high axial force concentration, buckling of compression braces, and unbalanced forces in beams. Eccentric bracing improves energy dissipation but requires careful detailing of link beams. In this context, knee bracing has emerged as an effective alternative because it combines the stiffness advantage of braced frames with the ductility advantage of moment-resisting frames. In a knee-braced frame, the diagonal brace is not connected directly to the beam-column joint. Instead, it is connected to a short secondary member known as the knee element, which is placed near the beam-column joint. This arrangement helps in controlling lateral displacement while allowing the knee element to act as a ductile energy-dissipating member during earthquake loading. The main diagonal brace provides stiffness, whereas the knee member yields in bending or shear and absorbs seismic energy. Thus, knee bracing can reduce damage in the main structural members and shift inelastic action to replaceable or repairable components.



Concentric Bracings



Eccentric Bracings

Fig. 1: Different configuration of bracing system

The present study titled “Analysis of Frame with and without Knee Bracing for Lateral Load” focuses on evaluating the structural response of a framed building by comparing an unbraced frame with a knee-braced frame under lateral loading. The need for such a study arises because unbraced frames may show larger storey displacement and inter-storey drift under seismic or wind forces, especially when the building has multiple storeys and flexible beam-column joints. Excessive drift not only affects structural stability but also causes damage to non-structural components such as masonry walls, cladding, partitions, windows, and service lines. By introducing knee bracing, the lateral stiffness of the frame can be improved without fully blocking the bay, which makes it more practical than some conventional bracing systems from both structural and architectural points of view. The study considers important response parameters such as storey displacement, storey drift, base shear, stiffness, bending moment, shear force, and overall stability. The comparison between frames with and without knee bracing helps to identify how effectively the knee bracing system controls

lateral deformation and redistributes forces within the structure. Software-based analysis such as STAAD Pro, ETABS, or similar structural analysis tools can be used to model and analyse the building frame under equivalent static or dynamic lateral load conditions. In such modelling, the unbraced frame represents the basic moment-resisting system, while the knee-braced frame represents the improved lateral load resisting system. The expected behaviour is that the knee-braced frame will show reduced lateral displacement and reduced inter-storey drift because the bracing members increase the lateral stiffness of the structure. At the same time, the knee member is expected to participate in energy dissipation, thereby reducing the direct seismic demand on beam-column connections. This makes knee bracing useful for both new construction and strengthening of existing framed structures. The outcome of this study is significant because it provides a practical understanding of how a simple modification in frame configuration can improve lateral load performance. It also helps engineers, researchers, and designers to evaluate knee bracing as a cost-effective and efficient structural system for improving earthquake and wind resistance. Therefore, the analysis of frames with and without knee bracing is important for achieving safer, stiffer, more ductile, and more serviceable framed structures under lateral loading.

II. LITERATURE REVIEW

Balendra, Huang, and Li developed the early concept of knee-braced frames and explained that the knee element can act as a sacrificial energy-dissipating member while the main diagonal brace contributes to lateral stiffness. Their work established the basic behaviour of knee bracing by showing that the brace need not be connected directly to the beam-column joint; instead, the connection through a knee element allows controlled yielding and improves seismic performance. Clément and Williams studied a five-storey steel frame with dissipative knee elements and applied nonlinear time-history analysis to evaluate the effectiveness of the system. Their study indicated that properly designed knee elements can yield during earthquakes and reduce damage to main beams and columns. Williams further emphasized that knee elements must be designed with sufficient ductility, resistance to local buckling, and low-cycle fatigue capacity so that repeated earthquake cycles do not cause premature failure. Hsu, Juang, and Chou experimentally studied steel knee-braced frame structures using cyclic loading and found that knee bracing improved strength, stiffness, and energy dissipation compared with ordinary moment-resisting frames. Their results also showed that knee bracing can reduce demand at beam-column connections, which is beneficial for seismic design. Leelataviwat, Suksan, Srechai, and Warnitchai proposed a

performance-based plastic design approach for ductile knee-braced moment frames. Their study demonstrated that knee-braced frames can be designed to achieve a desirable yield mechanism, improved drift control, and better distribution of seismic energy. These five studies provide the theoretical and experimental foundation for using knee bracing as a lateral load resisting system.

Miri, Zare, and Abbaszadeh investigated the seismic behaviour of steel frames with knee bracing using pushover analysis. Their study showed that the introduction of knee braces increases lateral stiffness and improves the capacity curve of the frame, thereby reducing displacement demand under lateral loading. Hsu and Lee extended the concept by combining knee-braced moment-resisting frames with stiffened steel slit wall energy dissipation devices. Their experimental work showed that the addition of energy-dissipating devices in knee-braced frames can further improve cyclic performance and enhance seismic resistance. Kanishkavya, Sivakumar, and Velumani analysed frames with and without knee bracing for lateral loads using steel structures and compared different bracing systems such as X-bracing, V-bracing, inverted V-bracing, knee bracing, and zipper bracing. Their study is directly related to the present topic because it focused on the comparison of lateral displacement, storey drift, and seismic response of braced and unbraced steel frames. Doung and Leelataviwat studied buckling-restrained knee-braced frames with single plate shear connections and used performance-based plastic design to evaluate collapse probability under earthquake excitations. Their findings suggested that using buckling-restrained braces as knee elements can improve deformation capacity and reduce undesirable buckling behaviour. Asghari and Gandomi evaluated ductility reduction factor and collapse mechanism of a new steel knee-braced frame system. Their study showed that knee-braced frames can significantly increase building stiffness and that the performance of the system strongly depends on the geometry and configuration of the knee bracing arrangement. These studies confirm that knee bracing is not only useful for stiffness improvement but also important for controlling ductility, damage mechanism, and collapse behaviour.

Sheidaii, TahamouliRoudsari, and Gordini studied the nonlinear seismic behaviour of knee-braced frames using incremental dynamic analysis. They examined the effect of number of storeys, knee length, and moment of inertia of the knee member on ductility, stiffness, and probability of failure. Their results showed that the knee member plays a critical role in controlling nonlinear response and that suitable knee dimensions are necessary for effective seismic performance. Mohebkah and Bazvand studied knee-braced steel moment

frames and highlighted that knee bracing can improve the seismic behaviour of flexible moment frames by reducing drift and shifting damage away from primary frame members. Zhou and co-researchers examined different knee brace layouts in steel frames using time-history analysis and observed that the position and continuity of knee bracing influence natural period, base shear, storey drift, and lateral stiffness. Their results indicated that uniformly arranged knee braces or midspan arrangements provide better seismic performance than side-span-only arrangements. Junda, Leelataviwat, and Doung carried out cyclic testing and performance evaluation of buckling-restrained knee-braced frames. Their work supported the use of buckling-restrained knee braces for stable hysteretic behaviour and improved energy dissipation. Naiyana, Leelataviwat, and Limkatanyu proposed a seismic design method for buckling-restrained knee-braced frames considering cumulative damage. Their study considered three-, six-, and nine-storey archetype frames and used nonlinear static analysis and multiple-stripe analysis. The results showed that buckling-restrained knee braces can accommodate seismic motions with limited damage when cumulative fatigue demand is considered. Overall, the literature indicates that knee bracing improves lateral stiffness, reduces storey displacement and drift, enhances energy dissipation, and provides a practical method for improving the lateral load performance of **framed structures**.

III. METHODOLOGY

3.1. Equivalent static analysis

This method is based on the assumption that whole of the seismic mass of the structure vibrates with a single time period. The structure is assumed to be in its fundamental mode of vibration. But this method provides satisfactory results only when the structure is low rise and there is no significant twisting on ground movement. As per the IS 1893: 2002, total design seismic base shear is found by the multiplication of seismic weight of the building and the design horizontal acceleration spectrum value. This force is distributed horizontally in the proportion of mass and it should act at the vertical center of mass of the structure.

The weight of all the floors and the roof is calculated and total seismic weight of the building is found out.

$$W = \sum_{i=1}^n W_i$$

The approximate fundamental natural period of vibration (T_a), in seconds, of all buildings, including moment-

resisting frame buildings with brick infill panels, is estimated by the empirical expression

$$T_a = \frac{0.09h}{\sqrt{d}}$$

The design horizontal seismic coefficient $h A$ for a structure is determined by the following expression

$$Ah = \frac{Z}{2} \times \frac{I}{R} \times \frac{S_a}{g}$$

The total design lateral force or design seismic base shear is determined by the following expression.

$$VB = Ah \times W$$

The design base shear computed as above is distributed along the height of building as per the following expression.

$$Q_i = VB \frac{W_i h_i^k}{\sum_{j=1}^n W_j h_j^k}$$

IV. MODELING OF COMPOSITE STRUCTURE

The Steel Communication tower is designed for heights of 30 m, 60 m and 90 m. The towers are provided with 5-different types of bracings: K type, XBX-type, V-type, W-type, XX-type STAAD Pro. V8i has been used for modeling, analysis and design of towers.

Configuration of the tower:-

The two towers lies in wind zones V and VI

The height of the tower is 30m.

The base width of the tower is 5 m.

The top width of the tower is 2 m.

The bracing systems used K, XBX, V, W, XX-Bracing

1. LOADS ON TOWER

A platform load of 0.82 kN/m² is applied at 28.5 m, 58 m, and 88 m for 30 m, 60 m, and 90 m respectively. Weight of the ladder and cage assembly is assumed to be 10% of total weight.

Table 1: Antenna Loading for the Towers

Sr No.	Item	Quantity	Diameter (m)	Weight/antenna (kg)	Location from base (30m)
1.	CDMA	6	0.26 x2.5	20	27
2.	Microwave	1	1.2	77	24
3.	Microwave	1	0.6	45	24
4.	Microwave	2	0.3	25	24

5.1 WIND LOAD

Design calculations:-

- i. The basic wind speed in is 50 m/sec.
- ii. The probability factor k_1 is taken as 1.08.
- iii. The Terrain, height and structure size factor k_2 is varying at different levels of the tower and is taken from IS code as follows: k_2 at 12m height = 1.00 k_2 at 21m height = 1.06 k_2 at 30m height = 1.10
- iv. The Topography factor k_3 is assumed to be 1 for plain terrain.

Calculation of wind load:-

The design wind speed is calculated as:

$$V_z = V_b \times k_1 \times k_2 \times k_3$$

$$V_z \text{ at } 12\text{m} = 50 \times 1.08 \times 1.00 \times 1 = 54.00 \text{ m/sec}$$

$$V_z \text{ at } 21\text{m} = 50 \times 1.08 \times 1.06 \times 1 = 57.24 \text{ m/sec}$$

$$V_z \text{ at } 30\text{m} = 50 \times 1.08 \times 1.10 \times 1 = 59.40 \text{ m/sec}$$

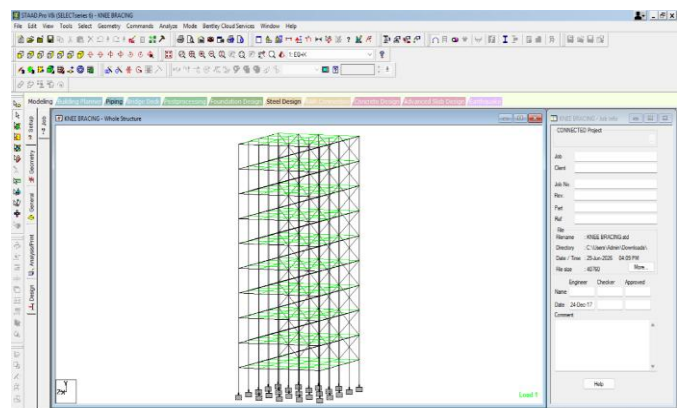
Calculation of Design Wind Pressure:-

$$p_z = 0.6 V_z^2$$

$$p_z \text{ at } 12 \text{ m} = 0.6 \times (54.00)^2 \times 10^{-3} = 1.7496 \text{ kN/m}^2$$

$$p_z \text{ at } 21 \text{ m} = 0.6 \times (57.24)^2 \times 10^{-3} = 1.9658 \text{ kN/m}^2$$

$$p_z \text{ at } 30 \text{ m} = 0.6 \times (59.40)^2 \times 10^{-3} = 2.1170 \text{ kN/m}^2$$



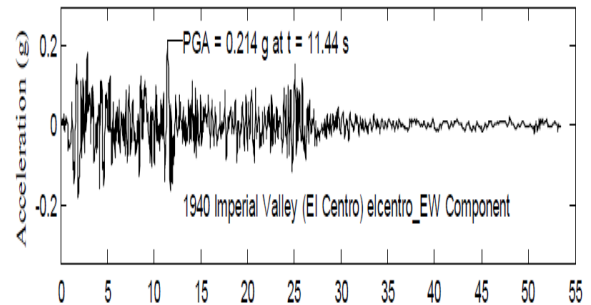
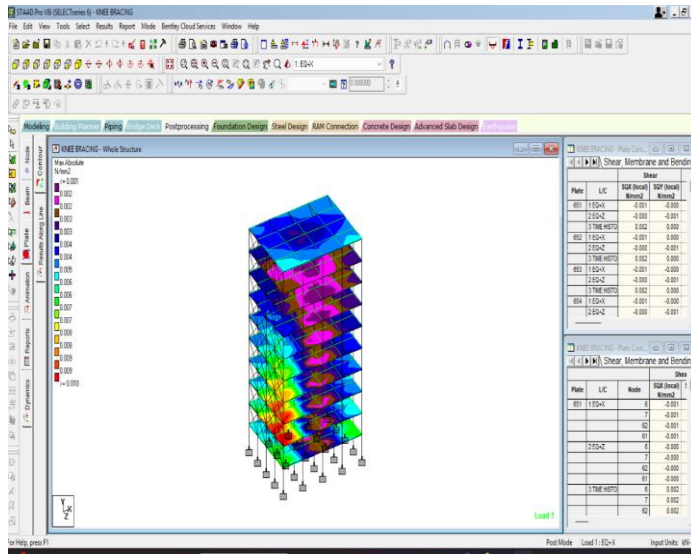
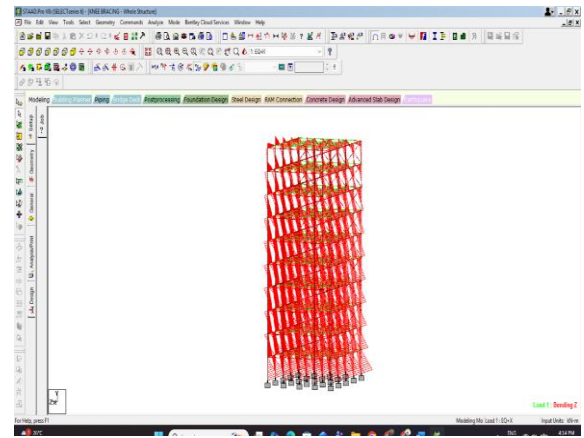
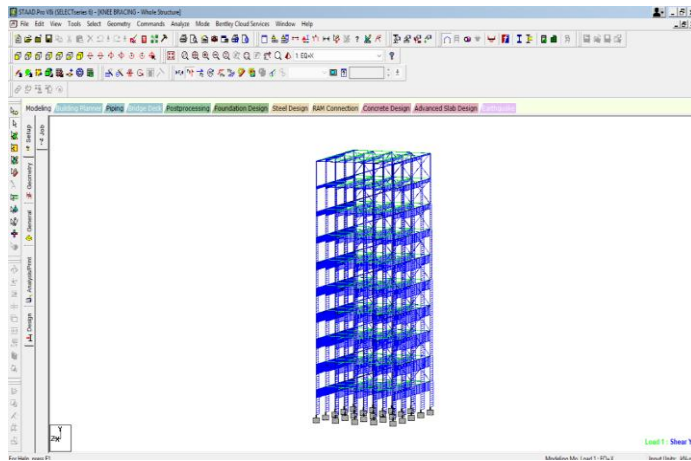


Fig. 2: Ground motion acceleration versus time with PGA value of 1940 Imperial Valley (El Centro) earthquake.

5.2 DYNAMIC LOAD

In addition to wind analysis of the towers the dynamic analysis of the tower considering time history method is also carried out. For time history method, the data of El-Centro earthquake occurred in Imperial valley, Southern California on 18 May 1940 is used and it is applied on the tower. The non-linear time history analysis of the tower has been carried out. The details of El-Centro earthquake are as under. Fig. 4 shows the acceleration time history of El-centro earthquake.

- 1) Name of time history : El Centro
- 2) Magnitude : 7.1
- 4) Peak ground acceleration : 0.214g
- 5) Time for PGA : 11.44 second
- 7) Total no of acceleration records : 1560
- 8) Time step :0.02 second

VI. RESULT AND DISCUSSION

6.1 FOR WIND LOAD

Joint displacement at the top of the tower and the stresses in the bottom leg of tower were obtained for towers of height 30 m, 60 m, and 90 m with different bracing arrangements for wind zones V and VI are tabulated in Table VIII and Table IX, respectively.

Table 2: Joint Displacement(mm) at top of tower

Tower height (m)	Wind zone (m/s)	Displacement (mm)				
		K-bracing	V- bracing	W- bracing	XBX-bracing	XX- bracing
30	Zone-V (50m/s)	32.46	40.27	53.52	36.39	44.81
		157.11	165.57	178.24	163.25	171.68
		172.34	181.03	194.83	178.28	186.94
30	Zone-VI (55m/s)	35.41	43.53	57.85	39.38	48.43
		164.65	172.22	188.24	168.95	179.93
		183.07	194.70	209.63	186.83	205.65

Table 3: Member stresses (N/mm²) in bottom leg with different bracing

Tower height (m)	Wind zone	Stress (N/mm ²)				
		K-bracing	V- bracing	W- bracing	XBX- bracing	XX- bracing
30	Zone-V (50m/s)	67.68	61.70	63.92	55.85	56.84
60		138.59	125.97	128.09	130.62	122.52
90		173.80	167.48	169.80	159.53	157.24
30	Zone-VI (55m/s)	76.25	65.24	90.78	69.42	64.075
60		146.06	135.21	142.03	137.41	132.28
90		189.06	177.88	184.54	174.65	173.79

6.2 FOR DYNAMIC LOAD

For dynamic load El-centro data is applied to the current structural systems and following results were obtained

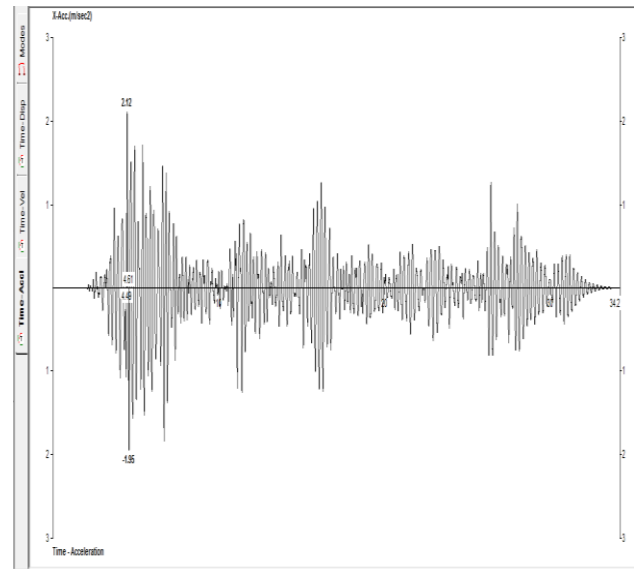


Fig. 3: Top node displacement, velocity, and acceleration of 30m for k-bracing tower due to 1940 Imperial Valley (El Centro) ground motion in x-direction

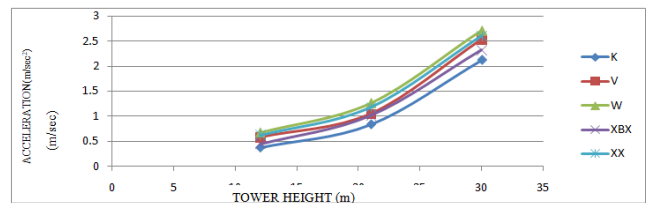
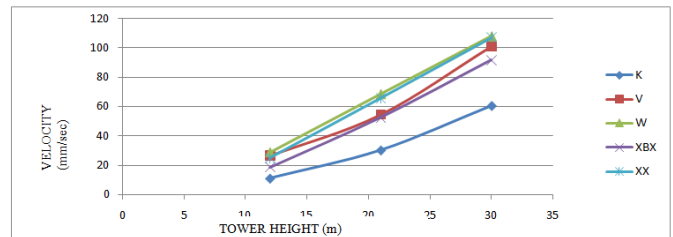
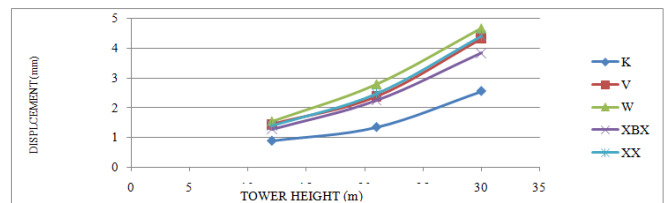
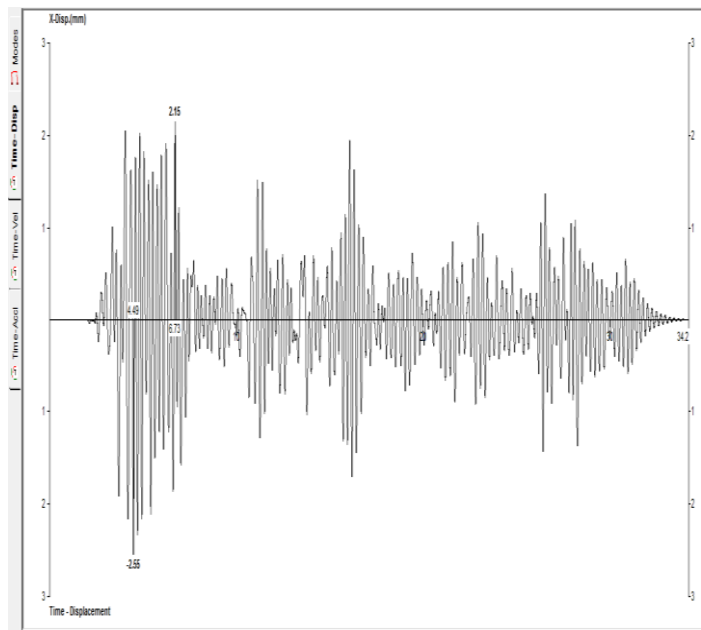


Fig. 4: Nodes displacement, velocity, and acceleration of 30m tower at level of 12, 21 and 30m due to ground motion in x-direction.

VII. CONCLUSIONS

Basic purpose of the study to know the performance of the telecommunication tower under wind and From the present analysis, it can be concluded that lateral load has a significant effect on the performance of framed structures. The frame without knee bracing is more flexible and shows higher lateral displacement and drift when subjected to wind or seismic forces. Such excessive deformation may affect

structural safety as well as non-structural components. The introduction of knee bracing improves the overall stiffness and stability of the frame. The bracing system helps in transferring lateral forces more efficiently and reduces the demand on beams, columns, and beam-column joints. The knee element also provides an additional advantage by acting as a ductile energy-dissipating member, which helps in improving seismic behaviour. The comparison of displacement, drift, member stress, velocity, and acceleration shows that braced frames perform better than unbraced frames under lateral loading. The study also indicates that proper selection and placement of bracing is important for achieving effective structural response. Overall, knee bracing is found to be a suitable and economical lateral load resisting system for framed structures. It can be effectively used in new construction as well as in strengthening existing structures where lateral stiffness and seismic performance need improvement..

REFERENCES

- [1] Aristizabal-Ochoa, J. D. (1986). Disposable knee bracing: Improvement in seismic design of steel frames. *Journal of Structural Engineering, ASCE*, 112(7), 1544–1552.
- [2] Balendra, T., Sam, M. T., Liaw, C. Y., & Lee, S. L. (1991). Preliminary studies into the behaviour of knee braced frames subject to seismic loading. *Engineering Structures*, 13(1), 67–74.
- [3] Sam, M. T., Balendra, T., & Liaw, C. Y. (1995). Earthquake-resistant steel frames with energy dissipating knee elements. *Engineering Structures*, 17(5), 334–343.
- [4] Balendra, T., Lim, E. L., & Liaw, C. Y. (1997). Large-scale seismic testing of knee-brace frame. *Journal of Structural Engineering, ASCE*, 123(1), 11–19.
- [5] Balendra, T., Yu, C. H., & Lee, F. L. (2001). An economical structural system for wind and earthquake loads. *Engineering Structures*, 23(5), 491–501.
- [6] Williams, M. S., Blakeborough, A., Clément, D., & Bourahla, N. (2002). Seismic behaviour of knee braced frames. *Proceedings of the Institution of Civil Engineers: Structures and Buildings*, 152(2), 147–155.
- [7] Kim, J., & Seo, Y. (2003). Seismic design of steel structures with buckling-restrained knee braces. *Journal of Constructional Steel Research*, 59(12), 1477–1497.
- [8] Clément, D. E., & Williams, M. S. (2004). Seismic design and analysis of a knee braced frame building. *Journal of Earthquake Engineering*, 8(4), 523–543.
- [9] Huang, Z., Li, Q. S., & Chen, L. Z. (2005). Elastoplastic analysis of knee bracing frame. *Journal of Zhejiang University Science*, 6A(8), 784–789.
- [10] Mofid, M., & Lotfollahi, M. (2006). On the characteristics of new ductile knee bracing systems. *Journal of Constructional Steel Research*, 62(3), 271–281.
- [11] Mofid, M., & Lotfollahi, M. (2006). On the design of new ductile knee bracing systems. *Journal of Constructional Steel Research*, 62(3), 282–294.
- [12] Conti, M. A., Mastrandrea, L., & Piluso, V. (2009). Plastic design and seismic response of knee braced frames. *Advanced Steel Construction*, 5(3), 343–366.
- [13] Miri, M., Zare, A., & Abbaszadeh, H. (2009). Seismic behaviour of steel frames with knee brace based on pushover analysis. *World Academy of Science, Engineering and Technology*, 3(2), 122–128.
- [14] Hsu, H. L., Juang, J. L., & Chou, C. H. (2011). Experimental evaluation on the seismic performance of steel knee braced frame structures with energy dissipation mechanism. *Steel and Composite Structures*, 11(1), 77–91.
- [15] Leelataviwat, S., Suksan, B., Srechai, J., & Warnitchai, P. (2011). Seismic design and behaviour of ductile knee-braced moment frames. *Journal of Structural Engineering, ASCE*, 137(5), 579–588.
- [16] Shin, J., Lee, K., Jeong, S. H., Lee, H. S., & Kim, J. K. (2012). Experimental and analytical studies on buckling-restrained knee bracing systems with channel sections. *International Journal of Steel Structures*, 12(1), 93–106.
- [17] Hsu, H. L., & Li, Z. C. (2015). Seismic performance of steel frames with controlled buckling mechanisms in knee braces. *Journal of Constructional Steel Research*, 107, 50–60.
- [18] Asghari, A., & Gandomi, A. H. (2016). Ductility reduction factor and collapse mechanism evaluation of a new steel knee braced frame. *Structure and Infrastructure Engineering*, 12(2), 239–255.
- [19] Junda, E., Leelataviwat, S., & Doung, P. (2018). Cyclic testing and performance evaluation of buckling-restrained knee-braced frames. *Journal of Constructional Steel Research*, 148, 154–164.
- [20] Naiyana, N., Leelataviwat, S., & Limkatanyu, S. (2023). Seismic design of buckling-restrained knee-braced frames considering cumulative damage. *Advances in Structural Engineering*, 26(13), 1–18.