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MODAL ANALYSIS OF SELF-SUPPORTING STEEL CHIMNEY

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Abstract: Modal analysis of a steel chimney is a critical process in structural engineering, aims to comprehend the dynamic behaviour and inherent frequencies of the structure. The chimney's response to different dynamic loads, such as wind, seismic forces, or even industrial vibrations, can be predicted using modal analysis. An effort is being made to compare the design outputs of self-supported steel chimneys under the European code (EN 1993-3-2) with the Indian code (IS:6533-1989). This research focuses on evaluating the results of Modal analysis conducted on self-supported steel chimneys. The study specifically examines a 90-meter self-supported steel chimney. Using the SAP2000 software, the steel chimney is modelled and analysed under seismic zone III conditions and wind loads equivalent to a fundamental wind speed of 47 meters per second. Mode shapes are calculated to understand the structural response of the steel chimney to these forces.

***Index Terms* - Chimney, seismic analysis, self-supported Steel chimney, wind analysis, Modal analysis.**

I. INTRODUCTION

The primary function of a chimney is to remove harmful exhaust flue gas by directing it upwards to a higher elevation. Despite adverse weather conditions such as earthquakes, strong winds, and turbulence, chimneys are built to last for a significant period of time. Chimneys are designed to be vertical in order to allow for the unobstructed flow of gases

There are two primary types of steel chimneys:

i. **Self-supporting steel chimney:** These chimneys are freestanding and do not rely on external support structures. They are frequently deployed in industrial environments to vent gases or emission produced by various processes. Self-supporting steel chimneys are engineered to endure both wind and seismic forces and are typically tall structures, designed to ensure structural stability.

ii. **Guyed steel chimney:** In contrast to self-supporting chimneys, Guyed steel chimney are upheld by a network of guy wires or cables. These cables anchor the chimney to the ground, providing stability. Guyed chimneys are commonly used when the chimney's height exceeds the practical limit for self-supporting design. They are commonly encountered in applications like telecommunication and certain industrial chimneys.

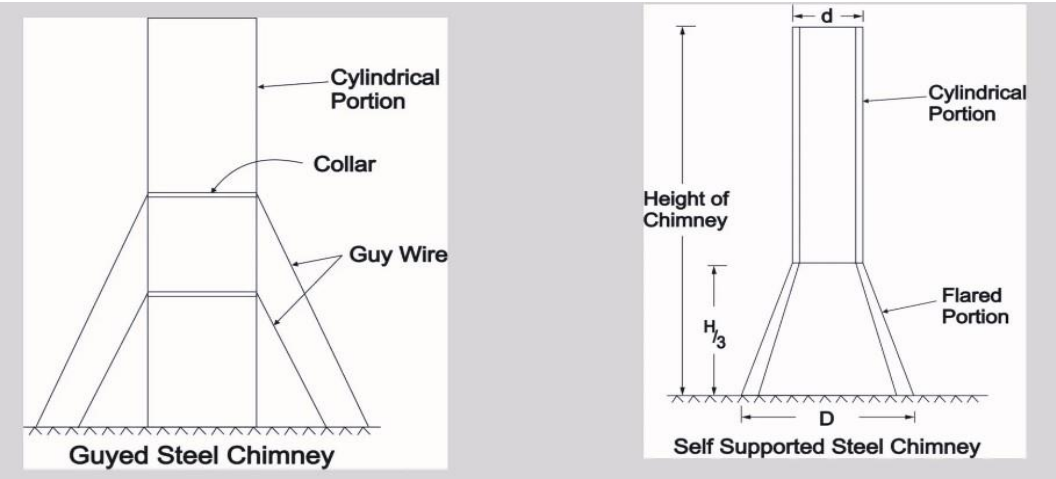

Figure 1: Types of steel chimney

Several researchers have studied the performance of chimneys under lateral loads. In **2022, Lei Wang**[1] compared the vortex-induced vibration displacements of six chimneys using wind load codes from Europe, China, Japan, Canada, and the United States. The displacements calculated by the Chinese code and Japanese recommendation for steel chimneys were only about 30% and 70% of the actual measured value, respectively. Most codes, except for ASME-STS and EN-2, consistently underestimated the displacement. The actual displacement for steel chimneys was approximately one-third of the measured displacement. In **2020, B. Prathyusha Yadav**[2] used STAAD.Pro V8i to evaluate the effects of wind and seismic forces on a 100 m reinforced cement concrete chimney. The study found that wind loads had a greater influence on the design of the chimney compared to earthquake loads. In a study conducted by **Mohd. Mohsin Khan in 2017**[3], the impact of wind loads on an Industrial RCC Chimney was investigated using CFD simulation. The study concluded that extensive wind tunnel testing is necessary to accurately calculate wind loads and their effects. When interference was present in the model, the bending moment at the base of the chimney was found to be 40% smaller compared to when the chimney was isolated. The accuracy of the results was also influenced by factors such as proper scale modelling, appropriate meshing of the model geometry, and realistic definition of physical property values. **J. Králik**[4] described the static and dynamic evaluations of welded steel chimneys in accordance with European Norms EN1991 and EN1993. The article demonstrated the use of a conventional spring and damper model as well as an FEA model created with shell elements in the ANSYS system. The study also discussed the impact of wind cycle loading on the fatigue assessment of the chimney. Overall, the article provided a comprehensive analysis of the deflection of the chimney's top with and without a damper. **M. Pavan Kumar**[5] conducted a computer-based study on the impact of wind and seismic activity on chimneys of different heights in India. The study focused on self-supporting steel stacks with heights of 90m and 110m, analysing their response to wind and seismic loads. The evaluation was carried out using STAAD Pro software, considering seismic Zones II, III, IV, and V, as well as wind loads with varying speeds. The base of the chimney was assumed to be fixed for modelling purposes. The study found that earthquake zone V resulted in the highest displacement of the chimneys, while areas with higher wind speeds showed the maximum displacements. Wind load had a greater impact on the chimneys compared to seismic load.

Rajkumar and Vishwanath B. Patil[6] designed an industrial chimney, taking into account wind load, dead load, and earthquake load. The design was based on the Bureau of Indian Standards (BIS) code. A parametric analysis was conducted on chimneys ranging from 150 to 250 meters in height, considering Zone II and Zone V. Microsoft Visual Basic 6.0 was used for the analysis, and the results were compared. It was concluded that M25 should be the minimum grade of concrete used for chimneys, as lower grades failed at permissible stresses. The study also found that the tension caused by an earthquake in the critical zone was similar to the stress caused by wind at the minimum fundamental rate, suggesting that seismic reaction should not be the sole design criterion, even in critical zones. **Murali (2012)**[7] studied three chimneys with a height of 55 meters, designed according to IS 6533 (Part 2) 1989. The wind load was determined based on IS: 875 (Part 3) 1987.

II. METHODOLOGY

2.1. Description of structure:

Primary objective regarding to this paper is to investigate the wind effect and seismic behaviour of steel chimney. For this study, a hypothetical case of Self-supporting steel stack of height 90m subjected to seismic and Wind loads are considered. The chimney is considered to be fixed at base. Self-supported steel chimney of heights 90m is designed as per Indian Standard codes IS 6533 (Part 1and 2): 1989 and European code (EN 1993-3-2**) [10**] in seismic zones III for wind speed 47m/s. The related calculations are shown below.

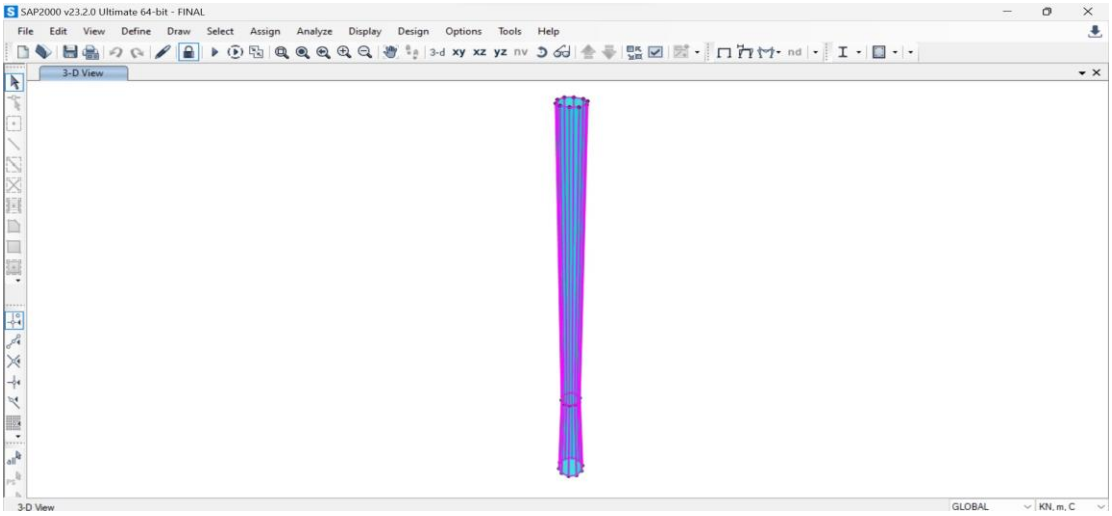

Figure 2: 3-D view of steel chimney

	Particulars	Structural properties
i.	Total height of chimney, h	90m
ii.	Flare height of the chimney, h_f	(1/3) × 90 = 30m
iii.	Top diameter of chimney, D	3.5m
iv.	Flare diameter of chimney, D_f	1.6 × 3.5 = 5.6m
v.	IS code for steel chimney	IS:6533-1989
vi.	European code for steel chimney	EN 1993-3-2

2.2. LOADS ACTING ON STEEL STACK OR CHIMNEY

Self-supporting steel chimneys are exposed to various vertical and lateral displacements, necessitating consideration of multiple loads. In addition to the self-weight and imposed load on service platforms, significant loads that frequently affect steel stacks include wind, earthquake, and temperature loads. This study specifically focuses on wind loads, self-weight of the chimney, and earthquake loads.

1. **Self-weight of chimney:**
   The constant downward force exerted on the chimney, which consists of the weight of the steel structure and permanent elements such as liners and access platforms, is known as the self-weight. It is crucial to properly distribute this self-weight load among the chimney's components to maintain stability and prevent excessive deflection or buckling.
   The determination of the stack's self-weight follows the guidelines specified in EN 1991-1-1 and IS 875 (Part 1): 1987.

2. **Wind load:**
   Wind loads are an essential factor to be taken into account when designing self-supporting steel chimneys, particularly for structures of significant height. The magnitude of wind force exerted on the chimney is subject to considerable variation, influenced by factors such as the chimney's elevation, geographical placement, and prevailing wind patterns in the area. In the context of self-supported steel stacks or chimneys, it is essential to consider the application of wind load on their external surfaces. This is due to the fact that wind constitutes a significant primary load for such structures.
   The wind loads are determined in accordance with the standards EN 1991-1-4 and IS 875(Part 3): 2015.

3. **Seismic load**
   Steel chimneys can experience dynamic lateral forces and ground motions during earthquakes, posing significant challenges due to their transient and unpredictable nature. Seismic design aims to consider the mass, stiffness, and damping properties of the chimney to ensure its ability to withstand lateral forces and mitigate the potential for structural damage or collapse.
   The seismic load of the stack is determined in accordance with the specifications outline in EN 1998.1.2004 and IS 1893 (Part 4): 2005.

III. RESULT AND DISCUSSION

3.1. GENERAL

The chimney is considered free on the top and fixed from the bottom for modelling purpose. Wind load and seismic loads are applied with different load combination. Modelling is done using SAP2000 software. The behaviour of self-supporting steel stack in terms of modal analysis is observed from the result.

3.2. MODAL ANALYSIS

A modal analysis was conducted on the chimney, resulting in the determination of modal periods and frequencies. Mode shapes refer to the distinct patterns of vibration that a structure displays when it is subjected to dynamic loads or excitations at a particular natural frequency. The quantity of mode shapes possessed by a system is dictated by its degrees of freedom. The base shear values indicate that higher modes play a substantial role in the overall behaviour of the structure. A tabulation of the modal periods and frequencies for the 12 modes has been provided.

Table 1: Modal periods and frequencies of the Industrial chimney

Mode No	Period (sec)	Frequency (Hz)	Mass Participation ratio
1	1.927815	0.518722088	0.49379
2	1.927815	0.518722088	0.49685
3	0.210988	4.739617255	0.52502
4	0.210988	4.739617255	0.99216
5	0.100822	9.918461752	0.99216
6	0.065098	15.36137571	0.99216
7	0.045575	21.94197503	0.99216
8	0.031977	31.2720419	0.99216
9	0.031977	31.2720419	0.99216
10	0.030849	32.41595706	0.99216
11	0.020493	48.79703412	0.99216
12	0.020493	48.79703412	0.99216

After conducting a modal analysis, the chimney's fundamental period was determined to be 1.927 seconds, while its natural frequency was found to be 0.518 Hz as per IS code.

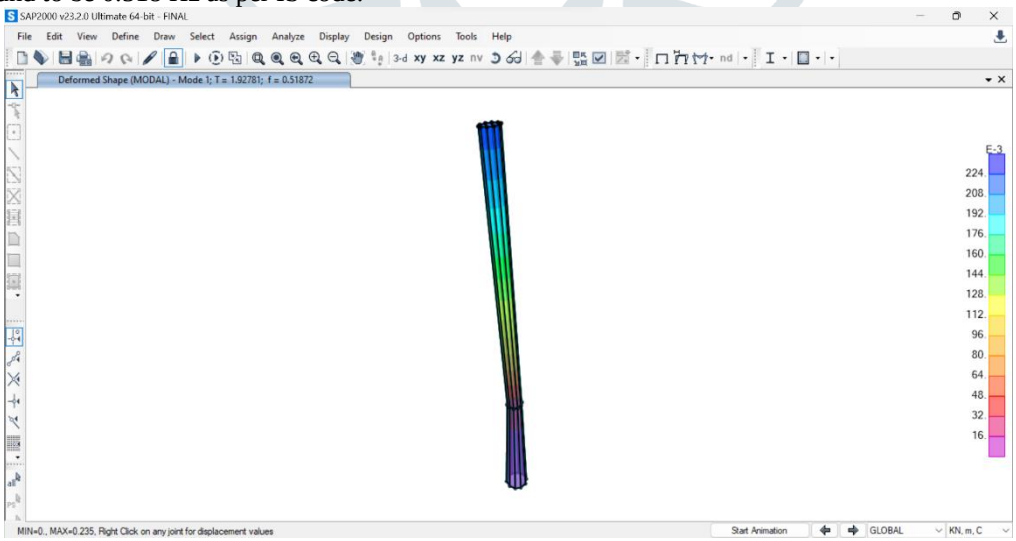

Figure 3: Mode shape 1 as per IS code

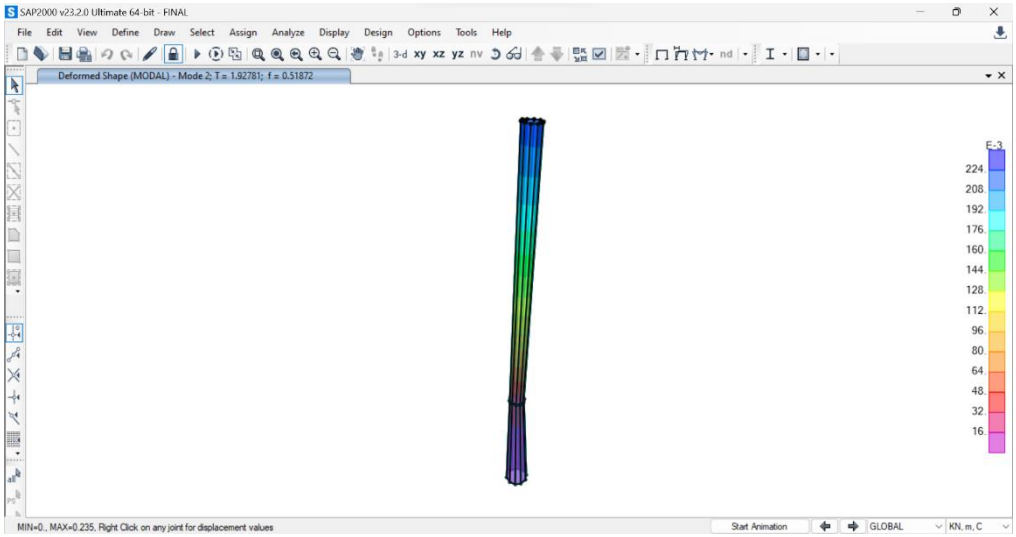

Figure 4: Mode shape 2 as per IS code

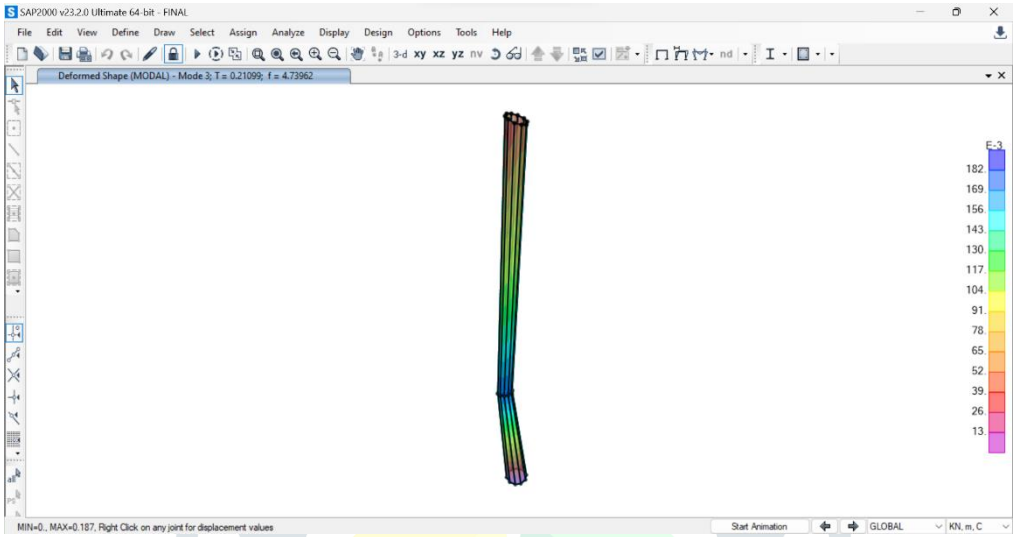

Figure 5: Mode shape 3 as per IS code

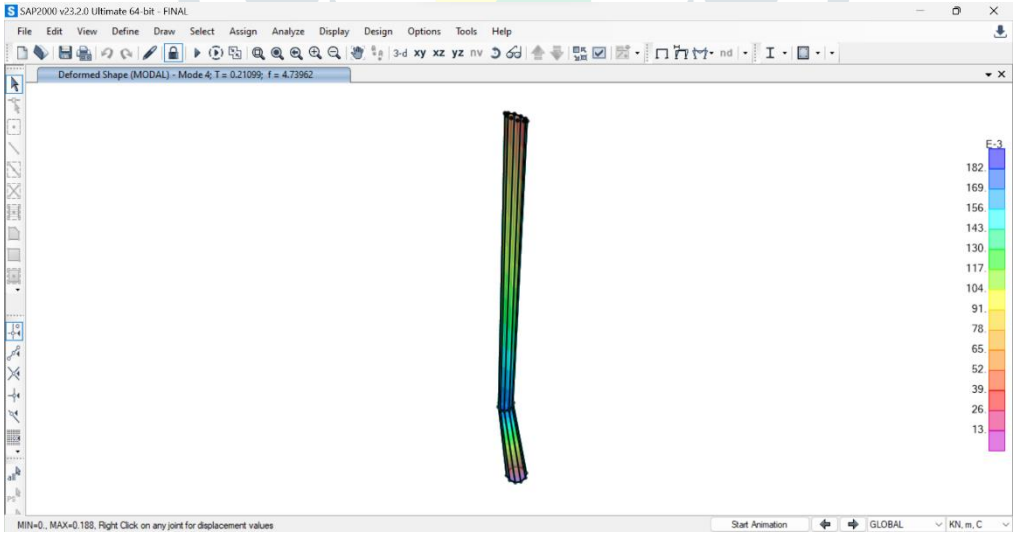

Figure 6: Mode shape 4 as per IS code

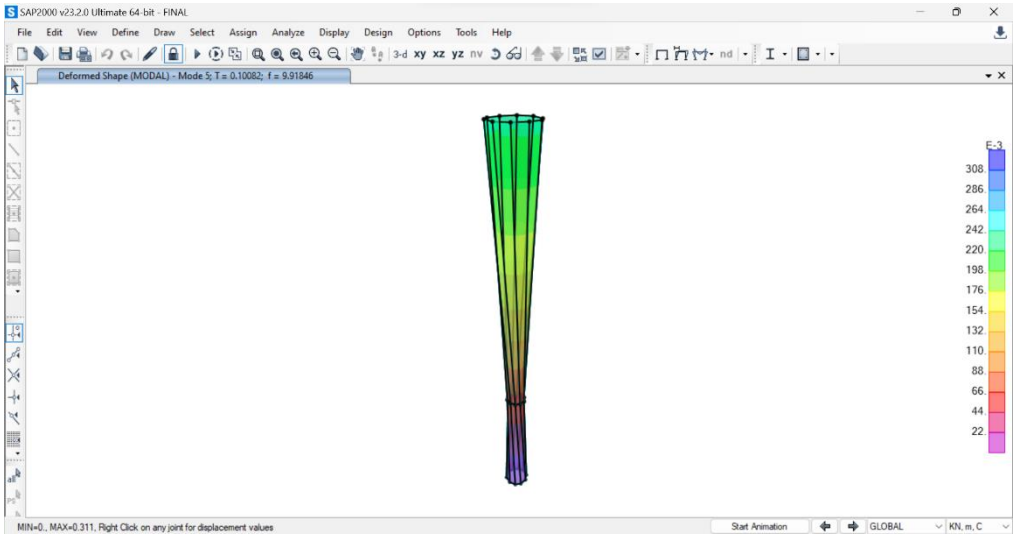

Figure 7: Mode shape 5 as per IS code

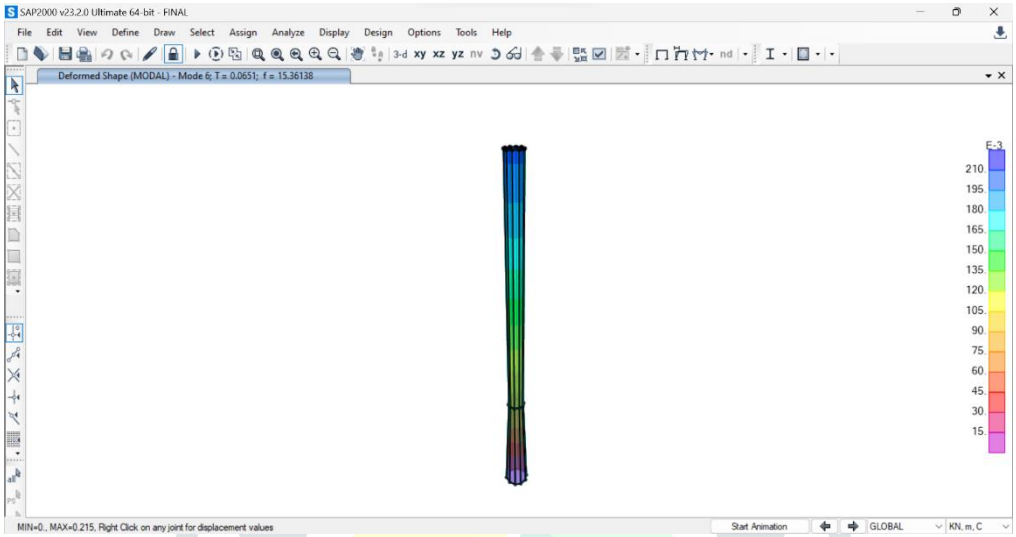

Figure 8: Mode shape 6 as per IS code

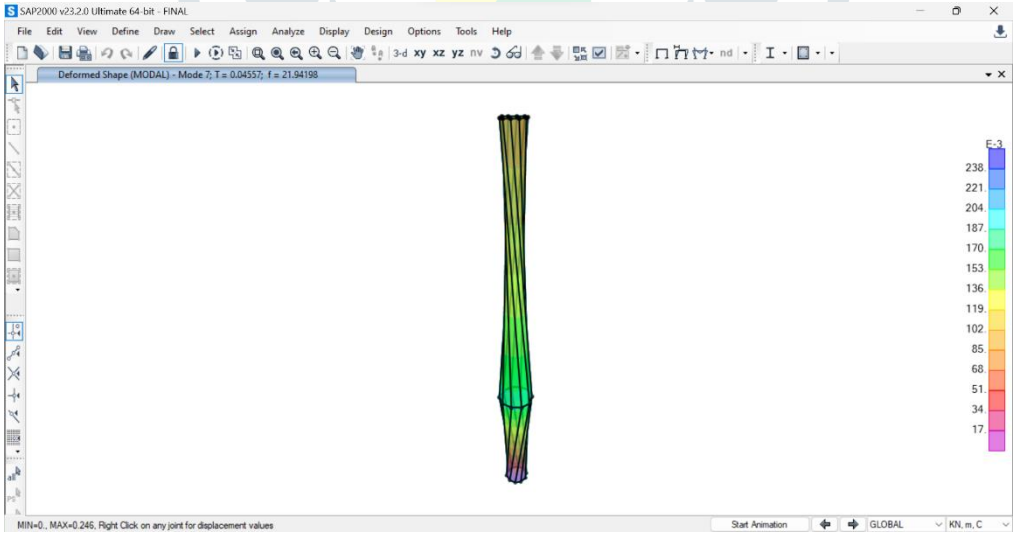

Figure 9: Mode shape 7 as per IS code

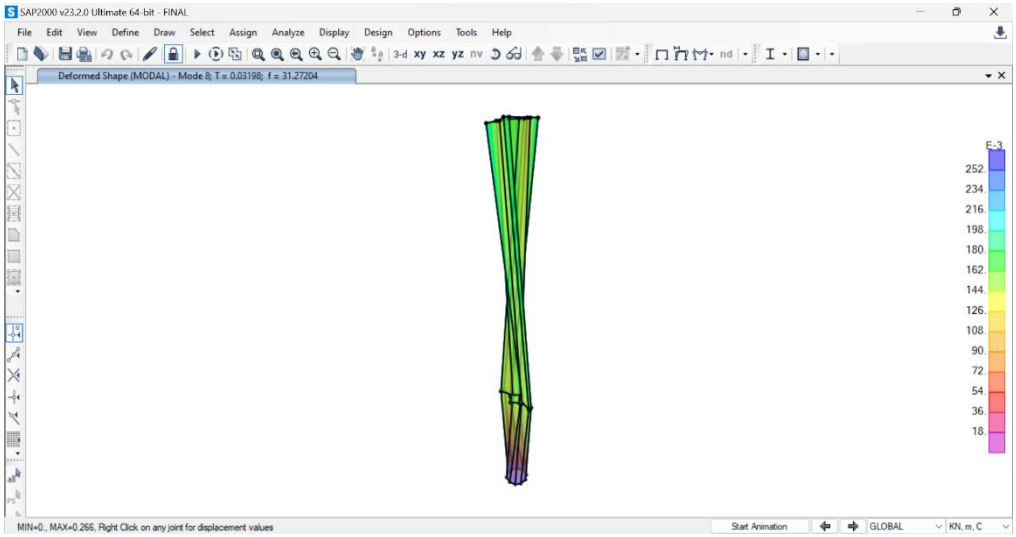

Figure 10: Mode shape 8 as per IS code

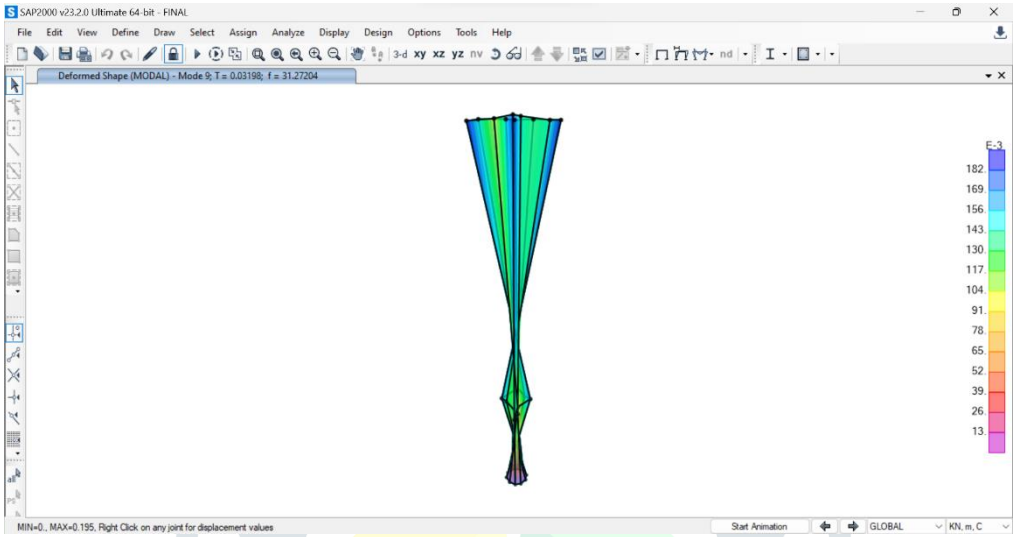

Figure 11: Mode shape 9 as per IS code

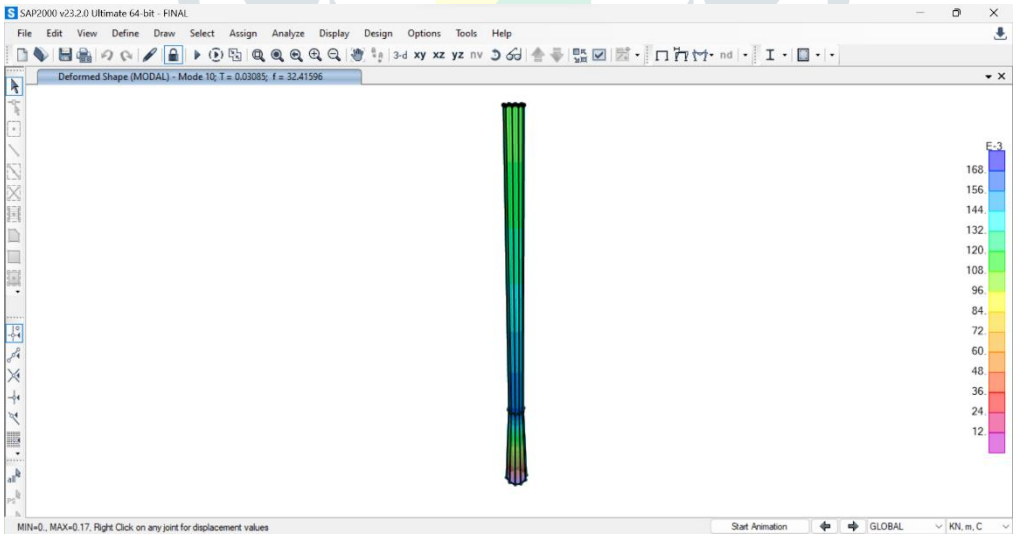

Figure 12: Mode shape 10 as per IS code

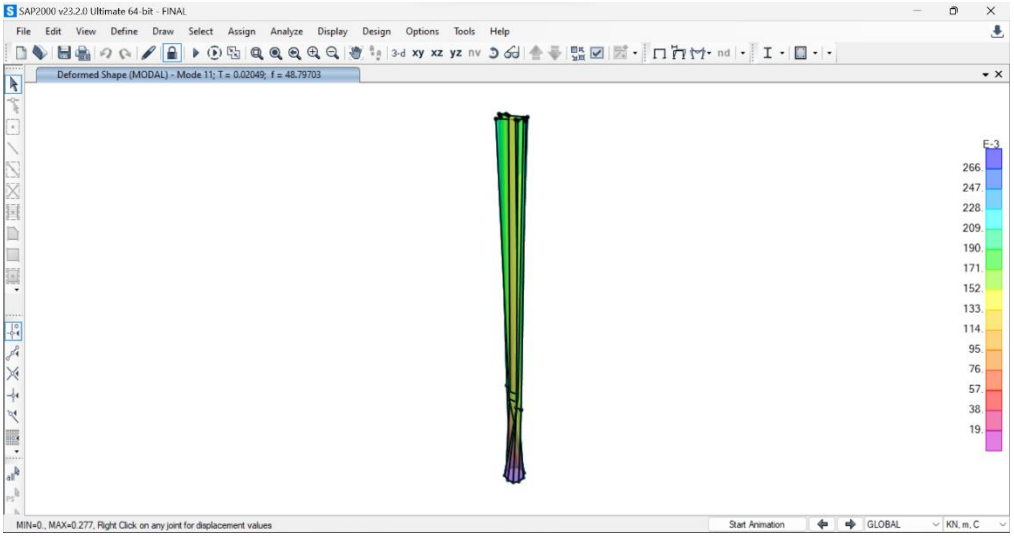

Figure 13: Mode shape 11 as per IS code

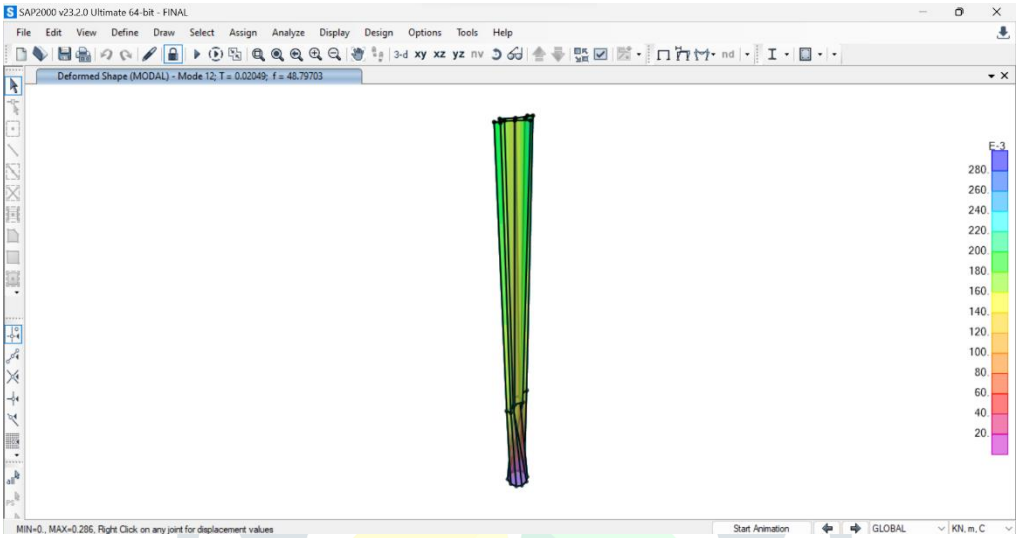

Figure 14: Mode shape 12 as per IS code

Table 2: Modal periods and frequencies as per Eurocode

Mode No	period (sec)	frequency	Mass Participation ratio
1	1.981679	0.504622493	0.45884
2	1.981679	0.504622493	0.49685
3	0.216883	4.610787798	0.51649
4	0.216883	4.610787798	0.99216
5	0.103639	9.648864024	0.99216
6	0.066917	14.94383193	0.99216
7	0.046848	21.34556131	0.99216
8	0.032871	30.42202385	0.99216
9	0.032871	30.42202385	0.99216
10	0.031711	31.53484579	0.99216
11	0.021066	47.47066216	0.99216
12	0.021066	47.47066216	0.99216

After conducting a modal analysis, the chimney's fundamental period was determined to be 1.981 seconds, while its natural frequency was found to be 0.504 Hz.

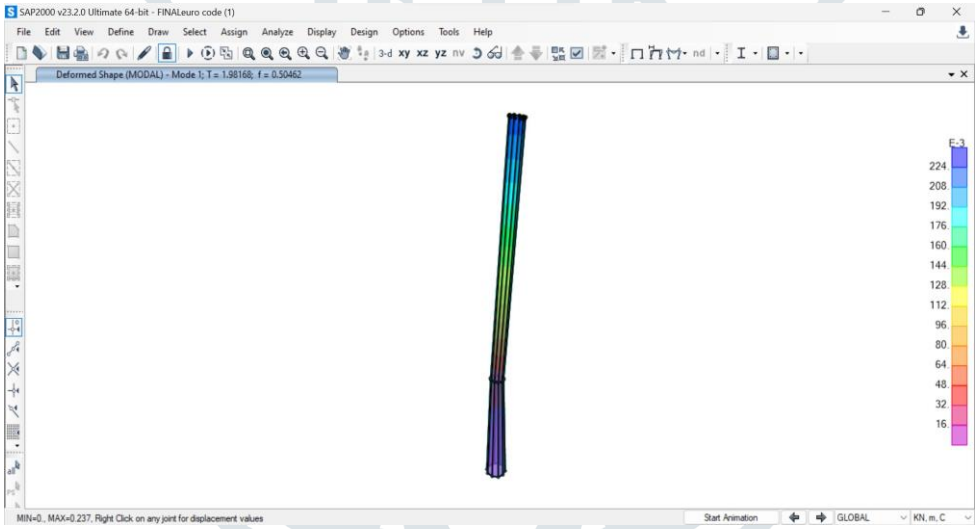

Figure 15: Mode shape 1 as per Eurocode

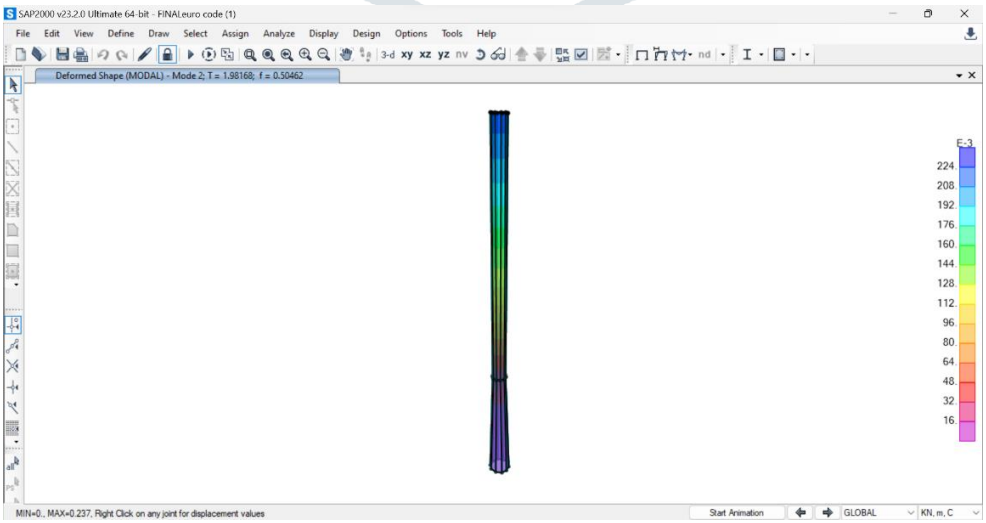

Figure 16: Mode shape 2 as per Eurocode

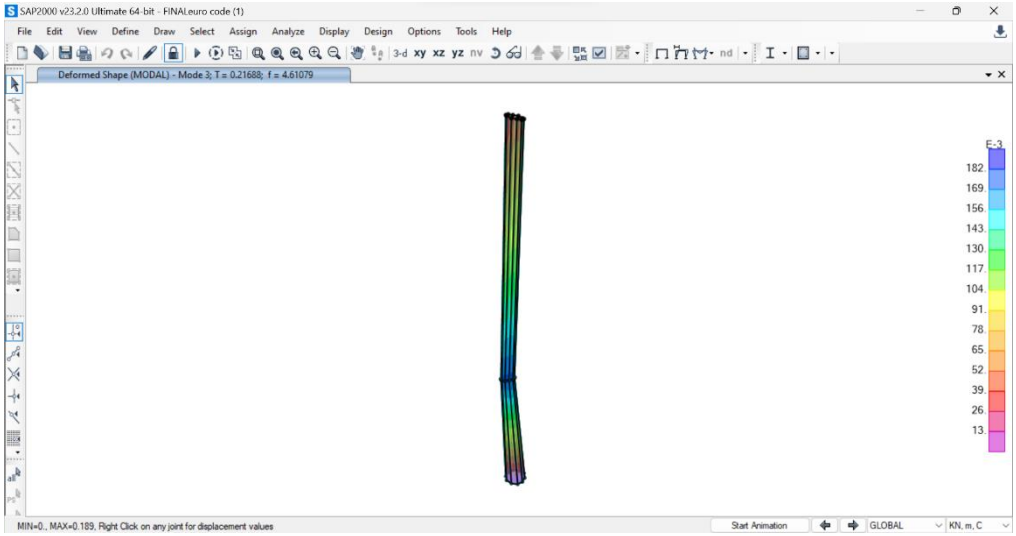

Figure 17: Mode shape 3 as per Eurocode

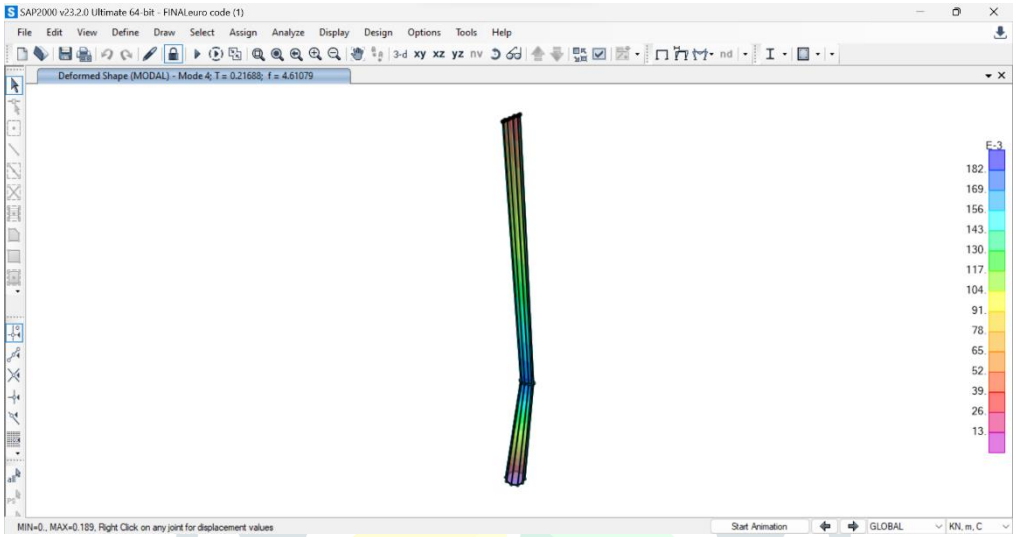

Figure 18: Mode shape 4 as per Eurocode

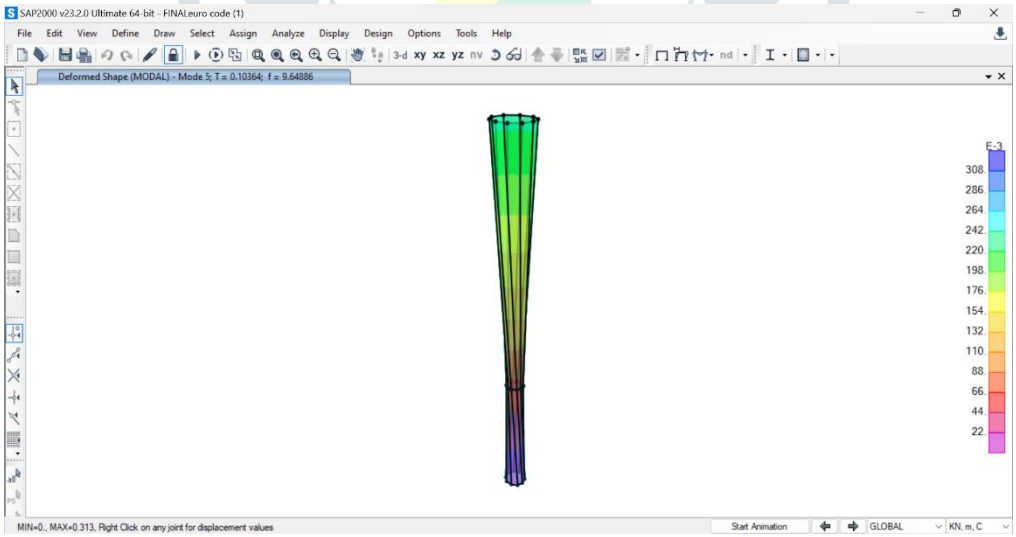

Figure 19: Mode shape 5 as per Eurocode

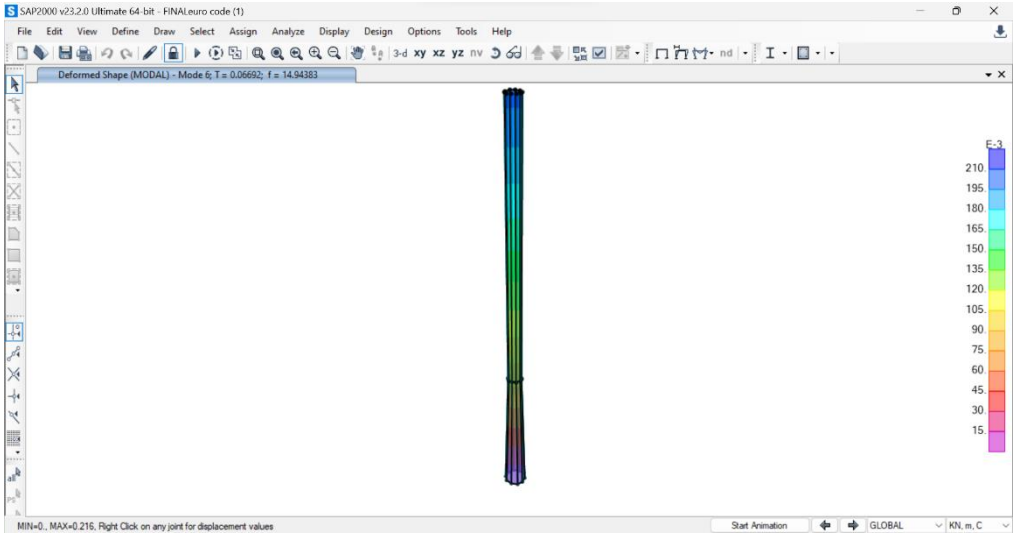

Figure 20: Mode shape 6 as per Eurocode

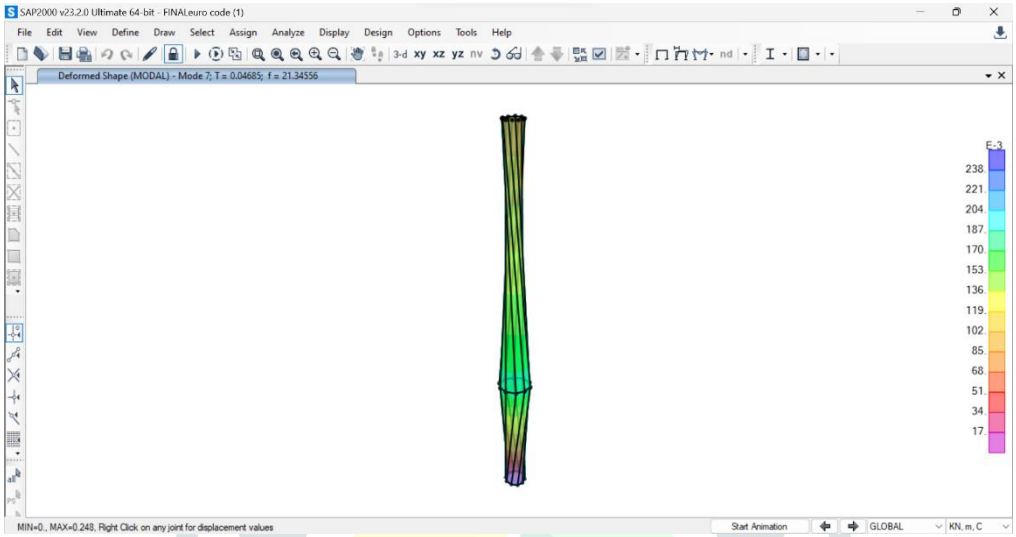

Figure 21: Mode shape 7 as per Eurocode

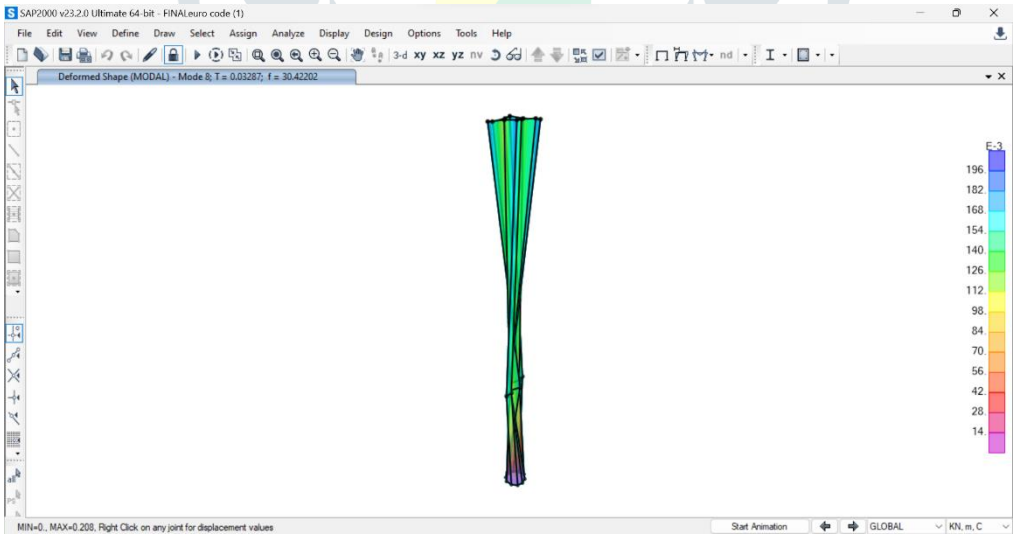

Figure 22: Mode shape 8 as per Eurocode

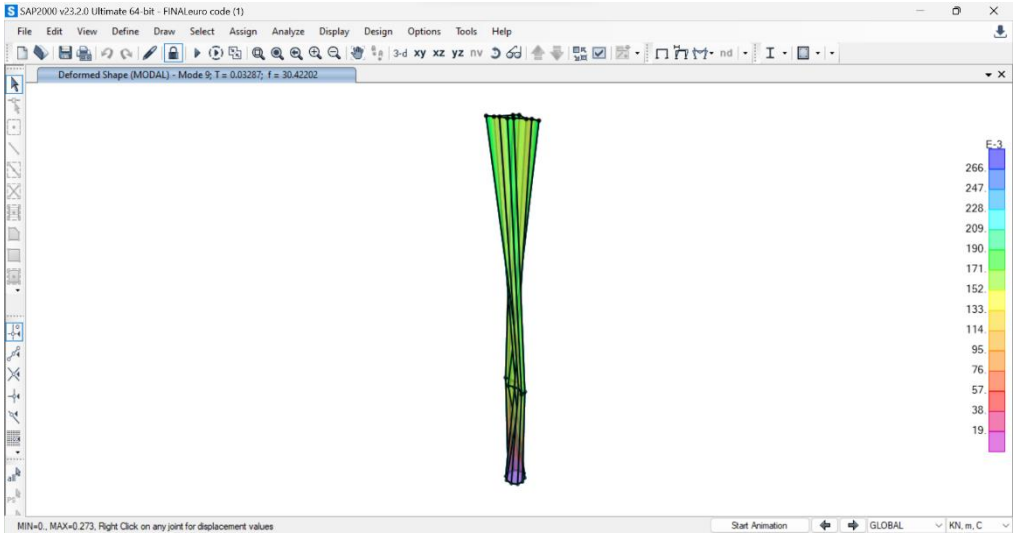

Figure 23: Mode shape 9 as per Eurocode

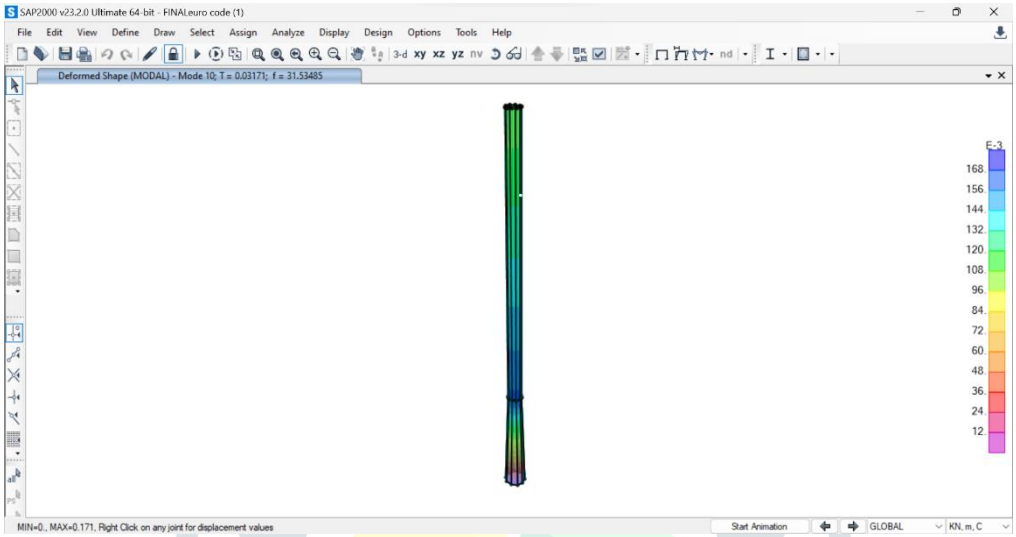

Figure 24: Mode shape 10 as per Eurocode

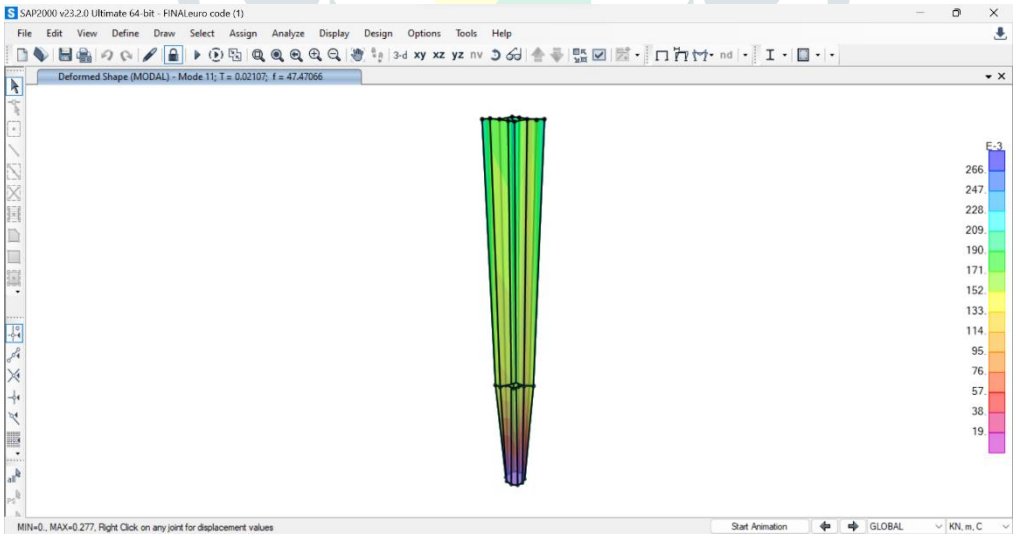

Figure 25: Mode shape 11 as per Eurocode

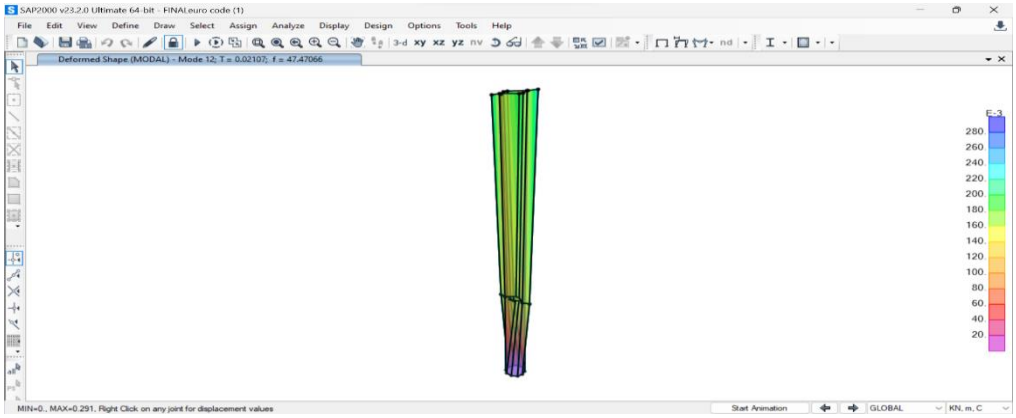

Figure 26: Mode shape 12 as per Eurocode

IV. CONCLUSION

A study was conducted to analyse a self-supporting steel chimney, utilizing both Indian standards (IS code) and European Norms (EN). The steel chimney was modelled using SAP 2000 Software. The analytical investigation presented in this paper yielded several specific and general conclusions. The fundamental period and the natural frequency of the chimney, after performing a modal analysis, was calculated as 1.927 sec and 0.518 Hz, respectively as per IS code. In conclusion, it can be said that the self-supporting steel chimney designed according to both code is safe but Indian code safer and economical as compare to European code.

REFERENCES

[1] L. Wang, Z. Wang, N. Huang, X. Y. Fan, and Z. hua Zhang, "Comparative analysis of cross-wind load code for high structures with circular sections," Structures, vol. 43, pp. 1177–1186, Sep. 2022, doi: 10.1016/j.istruc.2022.07.008.

[2] B. Prathyusha Yadav, S. Anitha Reddy, J. Ganesh Yadav, and C. Venkata Siva Rama Prasad, "Estimation of seismic and wind loads for design of a 100 m self supported industrial RCC chimney," in Materials Today: Proceedings, Elsevier Ltd, 2020, pp. 1562–1567. doi: 10.1016/j.matpr.2020.09.406.

[3] M. M. Khan, A. Kumar, and R. Assistant, "CFD SIMULATION OF WIND EFFECTS ON INDUSTRIAL RCC CHIMNEY," CFD Simulation of Wind Effects on Industrial RCC Chimney. International Journal of Civil Engineering and Technology, vol. 8, no.1, pp.10081020,2017, [Online]. Available: http://www.iaeme.com/IJCIET/index.asp1008http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=8&IType=1 http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=8&IType=1

[4] J. Králik, "DETERMINISTIC AND PROBABILITY ANALYSIS OF THE STEEL CHIMNEY UNDER WIND LOADS," 2011.

[5] M. Pavan Kumar, P. M. Raju, N. V. Babu, and K. Roopesh, "RIC STUDY ON LATERA NCE OF STEEL CHIMNE," International Journal of Civil E, vol. 8, no. 7, 2017, [Online]. Available: http://www.iaeme.com/IJCIEhttp://http://wwhttp://www.iaeme.com/IJCIEwww.iaeme.com/ijciet/issues.asp?JType=IJCIET&VT

[6] Rajkumar and Vishwanath. B. Patil, "Analysis of Self-Supporting Chimney," International Journal of Innovative Technology and Exploring Engineering, 2013.

[7] G. Murali, B. Mohan, P. Sitara, and P. Jayasree, "Response of Mild Steel chimney Under Wind Loads," International Journal of Engineering Research and Applications (IJERA) www.ijera.com, vol. 2, pp. 490–498, [Online]. Available: www.ijera.com

[8] M. Bhavan, B. Shah, and Z. Marg, "Indian Standard CODE OF PRACTICE FOR DESIGN AND CONSTRUCTION OF STEEL CHIMNEY PART 2 STRUCTURAL ASPECT (First Revision) B U R E A U O F I N D I A N S T A N D A R D S," 1998.

[9] M. B. Bureau of Indian Standards, Design Loads (Other than Earthquake) for Buildings and Structures-Code of Practice Part 3 Wind Loads (Third Revision). 2015. [Online]. Available: www.standardsbis.in

[10] N. Europeenne and E. Norm, "EN 1993-3-2: Eurocode 3: Design of steel structures - Part 3-2: Towers, masts and chimneys – Chimneys," 2006.

[11] S. Rahman, A. K. Jain, S. D. Bharti, and T. K. Datta, "Comparison of international wind codes for across wind response of concrete chimneys," Journal of Wind Engineering and Industrial Aerodynamics, vol. 207, Dec. 2020, doi: 10.1016/j.jweia.2020.104401.

[12] R. B. D and A. Professor, "Analysis of Cantilever Steel Chimney As Per Indian Standards," 2015. [Online]. Available: www.ijera.com

[13] M. Bhatt and S. Vasanwala, "Comparison of Ultimate Capacities of RC Chimney Sections under Wind Loading," Trends in Sciences, vol. 19, no. 1, Jan. 2022, doi: 10.48048/tis.2022.1722.

[14] K. R. C. Reddy, O. R. Jaiswal, and P. N. Godbole, "Wind and Earthquake Analysis of Tall RC Chimneys," 2011.

[15] R. Sarkar, D. Shrimal, and S. Goyal, "Seismic analysis of a 275 m tall RCC multi-flue chimney: A comparison of IS code provisions and numerical approaches," in Advances in Structural Engineering: Dynamics, Volume Two, Springer India, 2015, pp. 1015–1025. doi: 10.1007/978-81-322-2193-7_80.

[16] H. F. Fasel, F. Meng, E. Shams, and A. Gross, "CFD analysis for solar chimney power plants," Solar Energy, vol. 98, pp. 12–22, Dec. 2013, doi: 10.1016/j.solener.2013.08.029.