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Chapter 1

Seismic performance enhancement of telecommunication towers without viscous damper

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Abstract: Telecommunication towers are major infrastructures that are required to be functional during and after the occurrence of an earthquake. Since these towers have slender designs and structures are raised, such towers become very vulnerable to the effects of seismic forces leading to structural damage and loss of service. The study focuses on the application of viscous dampers within telecommunication towers with the objective of improving the seismic resilience of such structures. Viscous dampers are embedded in the tower structure at specific locations to dissipate energy and reduce structural vibrations from seismic loading. The seismic response of the towers with and without dampers is evaluated using FEA simulations for various ground motion scenarios. The key parameters, such as displacement, stress distribution, and damping efficiency, are analysed to quantify the improvement in seismic performance. This is an indication that inclusion of viscous dampers will significantly reduce the values of displacement and stress under such an earthquake condition, and this means that it increases their stability and safety. Also, this provides an excellent avenue to use viscous dampers in the retrofitting of existing structures as well as in the design of new structures in seismic-sensitive areas.

Keywords: Telecommunication towers, Viscous dampers, Displacement, Slender designs, Damping efficiency, Seismic performance, FEA simulations.

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1.1 Introduction

The telecommunications tower today’s one of the most basic infrastructures in the human societies (Khatiwoda et al., 2023). Due to their vital role, the prevention of these structures during natural disaster, like severe earthquake, wind pressure is of outer most priority and hence their wind and seismic analysis should be evaluated properly (Khatiwoda et al., 2023). Many researchers in their studies have been considered the effect of wind and seismic loads induced on the triangular cross-section of steel trussed towers (Meti, et al., 2017). The design of telecommunication towers is necessary, due its lightness and height of such tower's structures (Konno et al., 1973). Most of the research have been focused on the wind loading, in a recent year, much attention is being given to earthquake loading, because of due to adding the antennas over the telecommunication towers and also towers are installed where the high seismic region (Ghodrati Amiri et.al., 2004). In the latest editions of world's most design codes and topic of earthquake loading on such structures have been included (Rajasekharan et al. 2014).

The telecommunications are exposed to special loading like longitudinal loads, construction and maintenance loads, line of galloping and vibration of structures for which it has to design (Amiri et al., 2004). Longitudinal loading might be the results of weather related events or failure of adjacent structures, should be restricted to avoid the cascading failures of structure in the line for this reason, sometimes longitudinal loadings are referred to as "Anticascading", "Containment failure" or security loads (Drisya S et al., 2016). The construction & maintenance load is to avoid the structural member over the stresses during the construction and maintenance operations, this may cause the serious injurious to employee (Rajasekharan et al. 2014). For this effect, such type of load is sometimes referred to as "safety" loads (Meti, et al., 2017). Usually communication towers are tall structures whose construction specially designed to carry the radio antennas, mobile, television signals, GSM, internet traffic and wireless network, so that these towers are necessary to construct for daily need of human society (Drisya S et al., 2016).

1.2 Historical Development of Steel

Steel have been known from 3000 BC, first steel were used during 400-500 BC in china and than in Europe, in India 1st steel was used in Ashokan Pillar, this temple was prepared with steel joints and these are older than 1500years, the modern blast furnece technology which were developed in 1350AD (Guptha in 1998) (Konno et al., 1973). For structural purpose Europe has started the use of iron in large scale in the later part of 18th century. The application of 1st major cast iron was in 30.4m span coal broakadale arch bridge by Darby in England, which was constructed in 1779 BC across the river Severn (Konno et al., 1973). The cast was continuously used up to about 1840 BC. In1740, Abraham Darby was found to convert coal into coke, which revolutionized the iron making process, in

1784 Henry Cortfound found the cast iron, which is stronger, flexible, and had a higher tensile strength than the cast iron (Drisya et al., 2014). During 1829 wrought iron chains were used in Menia Straits suspension bridge was designed by Thomas Telford and Rebort Stephenson's Britannia Bridge was the 1st box girder made with wrought iron, the steel were 1st introduced in 1740 BC (Amiri et al., 2004). But it was not available in large quantity until the England scientist sir Henry Bessemer produced the process of manufacturing of steel in 1885 (Oliveira et al., 2007). Another scientist Siemens and Martins were produced the open-hearth process in 1885 and it was extensively used for production of structural steel (Oliveira et al., 2007). The domain companies were started the standard steel rolled sections during the year 1885. Riveting techniques were used for connection method until around 1950, The steel production Bessemer in Britannia were ended in1974 and open hearth furnace closed in 1980 (Konno et al., 1973). The BOS process using the CD converters were invented in Austria in 1953. Today we have several variety of steel (Amiri et al., 2004). The integration of machine learning and deep learning techniques has proven to be transformative across various domains, including seismic applications, where these models offer innovative ways to analyze complex data patterns (Patil et al., 2024; Rane et al., 2024a; Rane et al., 2024b; Rane & Paramesha, 2024; Rane & Shirke, 2024).

Mainly there are three types of telecommunication towers known to engineers as

i) Monopole.
ii) Self-Supporting tower.
iii) Guyed tower

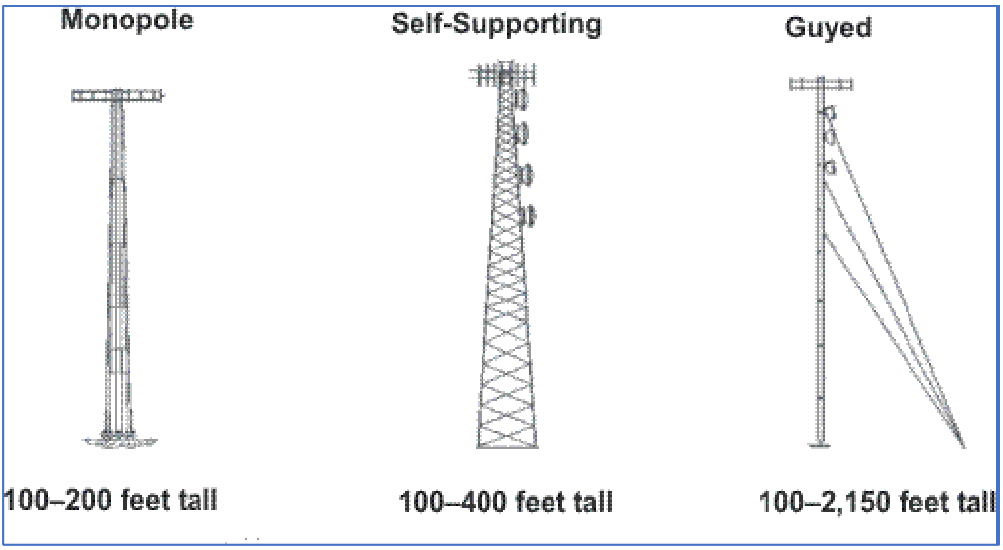


Fig.1.1 Types of Telecommunication Towers

A. Mono pole towers:

The mono pole towers are usually hollow tapered poles made with galvanized iron steel and these towers are constructed with slip jointed welded tubes up to 200feet height (DiSarno et al., 2008). The construction of such towers is very expensive but they are simple to erect, such towers are usually used where limited area is available for base foot print such as in urban areas, the maximum base foot print for such towers is about 200 feet height 6 x 6 feet and 3x2m (DiSarno et al., 2008).

B. Self-supporting towers:

A self-supporting towers are generally constructed without use of guy wire but its have larger foot print than guy wire tower and such towers are usually built with 3 or 4 legged cross section with cross bracing with bolted or welded connections. 3 or 4 vertical legged steel sections used as vertical member for column and it will carry larger load from antennas than the other towers (Patil Vidya et al., 2012). Freestanding towers constructed up to the height 100 to 400 feet tall to carry the antennas loads from tower. The self-supporting towers are classified into two groups (Patil Vidya et al., 2012). a) Three legged towers and b) Four legged towers Most of the researches have been performed on 3-legged self supporting towers and very limited attention has given to dynamic behaviour of 4-legged self supporting towers (Patil Vidya et al., 2012).

C. Guyed tower:

A guyed tower is connected with guy wires and these towers are arranged with set of concrete base on the ground (DiSarno et al., 2008). The guy tower consists of 3 sides of identical section and they are arranged upon each other as the height of the tower goes increase there is no need of tapered section and these towers generally constructed up to the height 100 to 2150 feet tall and which are used to carry the loads of wireless network, cellular and radio antennas (DiSarno et al., 2008).

1.3 Literature review

Telecommunication towers are the essentials infrastructures, especially for emergencies when the need is critical (Karbakhsh et al., 2018). Structural safety becomes a point of research since seismic events can easily undermine the structu re of the communications towers (Jin & Luo, 2020). Their ability in resisting dynamic loads is among the main issues in focusing on the enhancement of strength. Viscous damper is considered as among the most viable options because the simplicity and effectiveness are present (Patil Vidya et al., 2012). This paper reviews existing research on seismic performance of telecommunication towers using viscous dampers, followed by identification of some significant areas for further research (DiSarno et al., 2008).

1.3.1 Seismic Vulnerability of Telecommunication Towers:

Telecommunication towers are highly prone to seismic activities due to their slender structures, high centers of mass, and diverse structural forms. According to research by (Karbakhsh et al., 2018). These towers enhance the ground motion effects because of their flexible cantilever design (DiSarno et al., 2008). The said seismic towers incur relatively large lateral displacements, stresses in joint connections, and base shear forces during ground motions. Such studies emphasize that effective damping solutions are essential in controlling dynamic responses in telecommunication towers (Jin & Luo, 2020).

1.3.2 Role of Viscous Dampers in Seismic Control

Viscous dampers have been known to be efficient devices in dissipating energy. In the works of (Samanta & Saha, 2017) and (Joshi et al, 2019), the integration of viscous dampers was proven to greatly reduce peak displacements and stresses in tall structures. These dampers convert the kinetic energy of seismic forces into heat (Meti, et al., 2017), which is dissipated through the fluid of the damper. Viscous dampers are passive control devices and are therefore relatively easy to install and maintain (Meti, et al., 2017). The effectiveness of viscous dampers in high-rise buildings and other tall structures makes them promising for telecommunication towers (Patil Vidya et al., 2012).

1.3.3 Finite Element Analysis (FEA) and Simulation Studies

Finite element analysis is widely applied to simulate seismic responses and evaluate damper effectiveness. Studies by (Zhang et al., 2019) have been carried out in towers with dampers; such analyses result in a considerable reduction in displacement and base shear. (Modak et al., 2021) used FEA to determine the optimum placement of dampers. FEA simulation will enable the analysis of different seismic scenarios, performance evaluation of the structure, and optimization of the configurations of the damper (Patil et al., 2012). However, differences in assumptions about modeling, parameters, and loading conditions among the various studies make it difficult to standardize designs for dampers of telecommunication towers (Patil et al., 2012).

1.3.4 Optimization of Damper Placement and Specifications

In more recent work, researchers have concentrated mainly on optimizing the placement location and configurations of dampers to maximize performance without deteriorating the fundamental frequencies of a tower (Jin & Luo, 2020). Nanda et al., (2022) studied damper placement in lattice structures: strategic placement at joints yields more efficient damping (Shakib & Patel., 2023). Optimizations, including genetic algorithms and parametric studies, have been applied to tune the damper parameters. (Shakib & Patel., 2023) discussed the potential use of machine learning algorithms for predicting optimal damper settings, but these are still in the experimental stages and mostly require validation in real applications (Modak et al., 2021).

1.3.5 Comparison with Other Damping Techniques

While viscous dampers are among the most widely used passive control devices, comparison studies with semi-active and active systems have been made to establish relative effectiveness (Modak et al., 2021). In the research by (Prasad et al., 2022), while active systems allow for adaptive response, it has been noted that in telecommunication towers, viscous dampers are more favorable as they are simple, economical, and require very minimal maintenance (DiSarno et al., 2008). Comparative studies show that viscous dampers are effective, but there is a scope for enhancement if used with other damping technologies, so hybrid damping systems for telecommunication towers are discussed (DiSarno et al., 2008).

1.3.6 Research Gap

i. Lack of standardized design guidelines for telecommunication towers.

There is a scarcity of standard guidelines, even in damper technology, especially on how to integrate viscous dampers in telecommunication towers (Jin & Luo, 2020). Studies are more generalized nowadays and may not capture the uniqueness of structural characteristics and seismic demands of such towers (Jin & Luo, 2020).

ii. Long-term performance and serviceability under real seismic loads

There is very limited research in the long-term performance of viscous dampers in telecommunication towers, especially due to repeated seismic events or varying environmental conditions. As such, studies by (Arif & Kumar, 2023) reveal the necessity to study damper durability, especially for remote or harsh climates where telecommunication towers are generally located (Arif & Kumar, 2023).

iii. Optimization for Multi-Hazard Scenarios

The most of previous studies only dealt with the seismic loading; however, telecommunication towers are designed to be multi-hazard, with possible wind loading, snowfall, or temperature changes (Jin & Luo, 2020). There are few studies in which multi-hazard analysis is merged with damper optimization, so the developed design shall be more advanced (Jin & Luo, 2020).

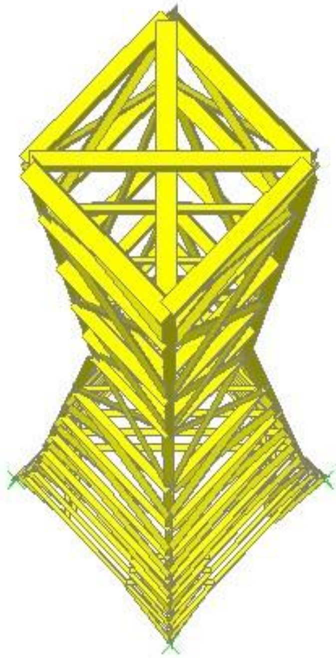
iv. Experimental Validation on Full-Scale Towers

Many of these studies rely on numerical simulations or scaled-down models that are not able to accurately simulate real-world complexity (Zhang et al., 2019). The full-scale experimental validation of damper performance in telecommunication towers has been left wanting, a very critical step in properly ascertaining their effectiveness and reliable design recommendations (Samanta & Saha, 2017). Hybrid Damping Systems for Improved Seismic Response While promising for viscous dampers, hybrid damping systems using multiple control devices could provide superior seismic resilience (DiSarno et al., 2008) . As of now, research is scarce, especially related to telecommunication towers, which leaves room for a number of future studies exploring combined damper technologies (DiSarno et al., 2008).

1.4 Methodology for Seismic Evaluation

The buildings are rested over the ground surface, which begin the vibration when a severe seismic activity occurs since that induces inertia forces on structure I.S: 875-1987 (Part 3). So in order to recover those force and performance of structure throughout the earthquake action, many researchers has been conducted all over the globe. In this study different investigation techniques are involved to find out tangential forces ranges from merely liner towards nonlinear in elastic study, in India identical technique of investigation was referred by means of code of practice IS:1893- 2002 (part-I) i.e. Criteria for Earthquake resistant design of structure.

Design Of Seismic Philosophy: The seismic design philosophy ad0pted in code of practice IS: 1893-2002(part-I) is to certify the structure posses at mainly lowest strength of structures. i. Control the small earthquake (basic design of earthquake -DBE), that can occurs habitually not including any harmful to the structure. ii. Resist reasonable seismic activity (DBE) without any important structural damage throughout non-structural damage. iii. Resist main seismic activity (most measured earthquake -MCE) not including any damage. Design basic seismic activity (DBE) is defined as the most seismic activity that practically can be expected to occurrence at the site once throughout life time of structure, the earthquake corresponding to final safety requirement is frequently called as maximum measured seismic activity (MCE) IS: 1893-2002(part-I). Usually, DBE is half ofthe MCE.



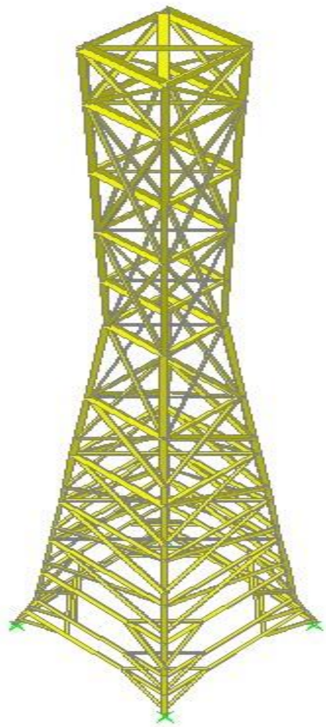


Fig. 1.2 The plans of render view of the tower. **Fig 1.3** Elevation of tower

1.5 Results and discussions

1.5.1 Detailed Procedure for Analysis of Tower for Without Damper.

The detailed procedure of analysis for 4-legged self supporting telecommunication tower without damper is done by using SAP 2000 software. In this procedure first we have prepared the modelling of self supporting tower for without damper with assigning of all material, member properties. In this model analysis end condition is considered as fixed foundation and eccentric bracing has been adopted as bracing system, dead, live load and earthquake load was considered for the analysis and various methods of seismic analysis like static, response spectrum and time history analysis was done for without damper. The comparison is made between static and dynamic analysis.

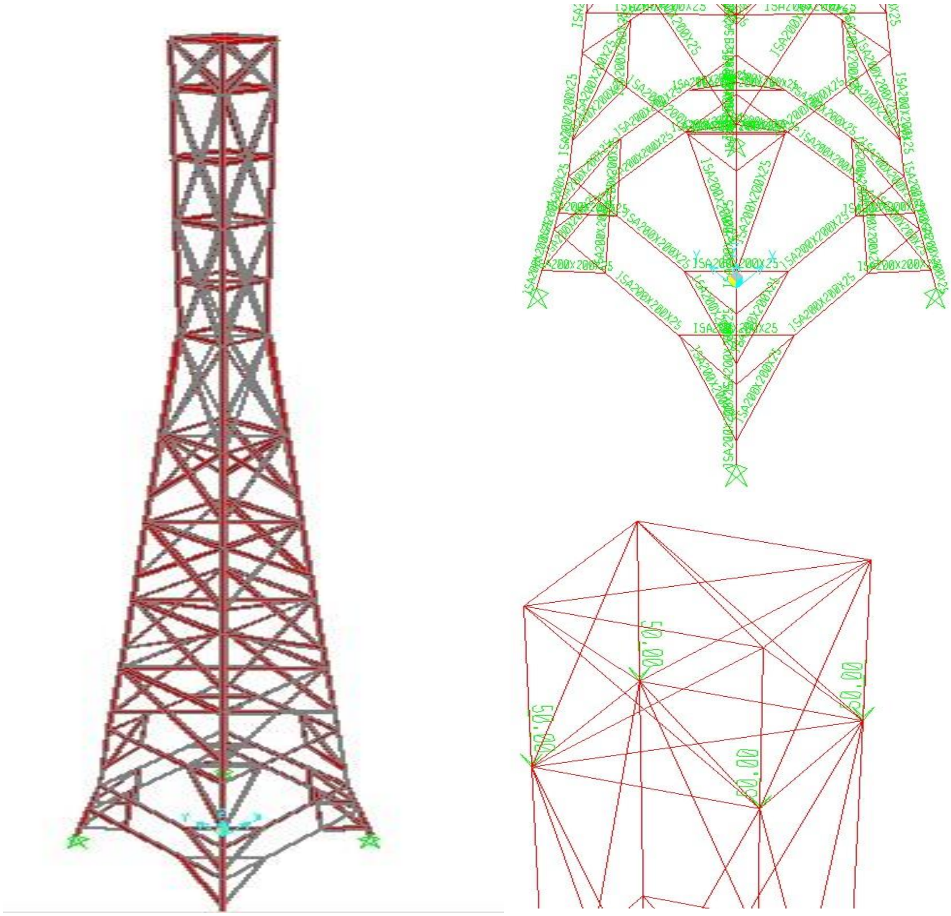


Fig. 1.4 Telecommunication Tower without damper

Table 1.1 Member specification for tower model

Type of section	Members	Specification
Angle section (mm)	Leg member	ISA-200X200X25
Angle section (mm)	Bracing member	ISA-100X100X12

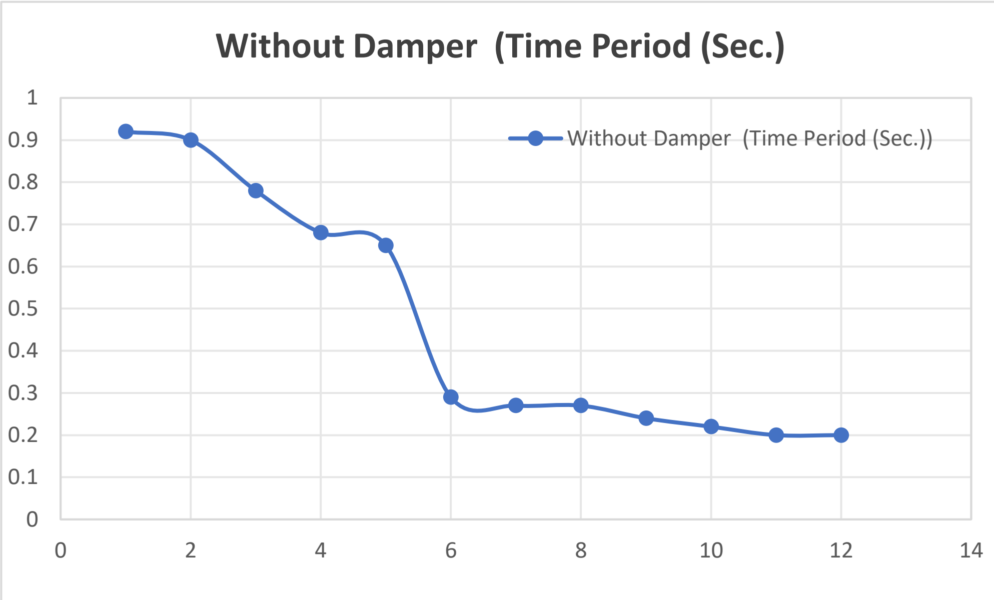
1.5.2 Linear Static Analysis

Linear static analysis is used to calculate response of the structures the most sophisticated analysis such as dynamic method will not give accurate behaviour of structure, so that

LSA is a best method for structures with individual frames with well balanced span & constant scattered stiffness, the response of the structures well captured by major modes of vibration. Hence total applied load will be equal to the product of acceleration R S and tributary weight, the lateral load is applied to vertical centre to the mass of supper structures and it distributed evenly horizontally to mass distribution IS: 1893-2002(part-I). Linear static method is the easy meth0d for analysis of structure, since structural forces are depends on code based fundamental peri0d structures with some empirical formulas IS: 1893-2002(part-I). The design base shear is calculated for whole structure, and then it is distributed along the height of the structure based on simple suitable formula for buildings with regular distribution of mass and stiffness IS: 1893-2002(part-I).

Table 1.2 Comparative values of mode number vs time period

Mode Numbers	**Without Damper (Time Period (Sec.))**
1	0.92
2	0.90
3	0.78
4	0.68
5	0.65
6	0.29
7	0.27
8	0.27
9	0.24
10	0.22
11	0.20
12	0.20



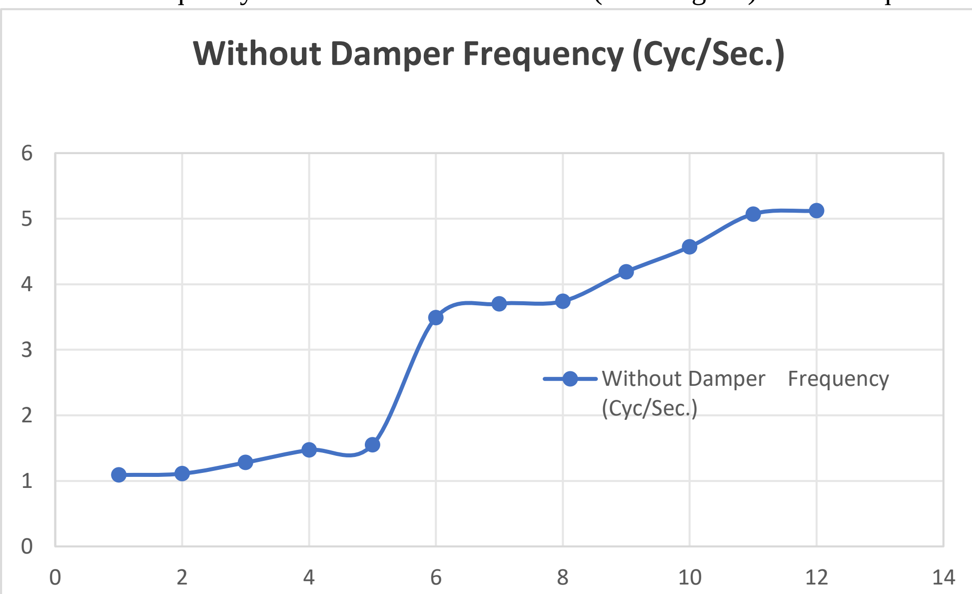
Lower Modes Dominance: The first few modes (especially modes 1 to 5) have relatively higher time periods, which indicates that these are the major modes in which the structure is most flexible and susceptible to larger deflections. In general, lower modes will have more significant effects on the overall structural response, as they represent fundamental frequencies where the structure is most susceptible to resonance under seismic excitations It tends to decrease progressively with a rise in mode numbers just like structures. Higher modes involve local vibrations with quite higher wavelengths and contribute extremely less to the total displacement of the structure. It suggests an increase in the stiffness along with reduced displacement of the structure in the higher modes. Structural Stiffness Indication: The relatively low time periods recorded, especially for the higher modes (from mode 6 onwards), suggest that the tower has some stiff parts, especially at higher frequencies where more local deformation occurs. Modes 6 to 12, with time periods under 0.30 seconds, reflect this stiffness and indicate less significant contributions to overall seismic response compared to the first few modes.

High Modes Are More Susceptible to Resonance: Seismic events, for lower modes with greater time periods - similar to modes 1-3, show more chances of resonance, which reduces the amplitude of vibration; thus, dealing with those modes through the damping mechanisms will improve tower performance with significant reduction in the vibrations' amplitude at those prevalent modes. With modal characteristics as described above, a damping system such as viscous dampers may be introduced in a strategic manner to dampen the effects of the critical lower modes with longer time periods. The impact of resonance would thus be reduced mainly on modes 1 through 5 and enhance seismic resilience without a drastic modification of the higher-mode dynamics.

Table 1.3 Comparative values for mode number vs frequency

Mode Numbers	Without Damper Frequency (Cyc/Sec.)
1	1.09
2	1.11
3	1.28
4	1.47
5	1.55
6	3.49
7	3.70
8	3.74
9	4.19
10	4.57
11	5.07
12	5.12

Dominant Low-Frequency Modes: The lower modes (1 through 5) show frequencies



ranging from 1.09 to 1.55 Hz. This low frequency means that for these modes, the structure is more flexible, thus under excitation, displacements are likely to be larger, especially in the case of lower-frequency ground motions common in seismic input. Because these are the modes in which most of the mass of the structure participates, they are by far the largest contributors to overall dynamic response.

A noticeable rise in frequency takes place as the modes become progressively higher, with over 3.49 Hz reported in mode 6 to mode 12 where 5.12 Hz occurs. Greater frequencies mean stiffer behavior and localized vibration conditions less flexible than overall flexibility. These modes of more periods and higher frequency suggest fewer contributions to general motions with large displacements. Yet, they might appear extremely crucial at localized points, leading to stress build-ups.

Low- and High-Frequency Mode Separation: The large gap between the frequencies of lower modes 1-5 and higher modes 6-12 indicates a distinct separation between global and local responses. The lower frequency modes, 1-5, are likely to dominate the global deflection patterns of the tower subjected to dynamic loads, while modes 6-12 indicate local vibration behavior and could impact specific elements in the tower structure.

Potential Resonance in Low-Frequency Modes: Because the natural frequencies of modes 1 to 5 are quite low, there is the potential for resonance if the excitation frequency (such as seismic frequency content) coincides with these natural frequencies. Resonance can cause amplified vibrations and stresses, which makes the lower modes critical targets for adding damping. Dampers would effectively reduce the amplitude of vibration in those modes and mitigate potential resonance effects, enhancing the resilience of the tower.

Effectiveness of dampers in targeting low-frequency modes: Since seismic excitation have more energy at the lower frequency range, solutions like viscous dampers would be very effective in reducing response in modes 1 through 5. This would allow for substantial attenuation of critical modes that are most contributing to the tower's dynamic response during a seismic event, without having much impact on the higher-frequency modes that are representing local, less critical vibrations.

High-Frequency Modes and Structural Stiffness: The high frequencies in modes 6 to 12 indicate regions of the structure with greater stiffness. These high-frequency modes are less susceptible to large deformations and usually do not significantly contribute to overall deflections during an earthquake. However, they could be relevant for assessing localized stresses or specific structural components that may require attention for durability under dynamic loading.

1.6 Conclusions

Dominant Low-Frequency Modes (Modes 1–5): The initial five modes are the ones with the longest duration of time (0.92 to 0.65 s), and thus they have the lowest frequencies (1.09 to 1.55 Hz). These involve the most fundamental movements of the structure, when the tower becomes more pliable and shows greater shifts. These modes are of paramount importance in seismic analysis because lower frequencies are usually where the energy that seismic waves carry is more. As a result, this is what the tower's response in these modes is based on and hence, its seismic performance as a whole.

Higher-Frequency, Shorter-Time-Period Modes (Modes 6–12): Mode 6 begins the phase of shortened time periods (0.29 s and less) and the frequencies increase, reaching 5.12 Hz in mode 12. The higher frequencies of these periods would indicate the stiffening of the structural components or sections, resulting in local vibrate forms that are generally non-significant to the overall displacement. Moreover, these higher modes are not as probable to be in resonance with the usual seismic frequencies. However, they might be significant in high-frequency localized vibrations, which only impact certain parts and not the entire structure.

According to the data, to dampen vibrations in a structure, we should give importance to modes 1 - 5, as these low-frequency modes are more resonant with the seismic energy. The answer is to add dampers. They can help lower the amplitudes of the displacements, thus, avoiding resonance in the dominant modes. Stiffer and consequently higher frequency modes are less significant for the global response during an earthquake and for the damping strategies, hence they are less severe.

From the time period and frequency, the data shows that the telecommunications tower's construction reply pretty much depends on the lower modes (1-5) that are more flexible and hence need more damping to damp to the seismic reading. However, the higher modes (6-12) are the localized stiff regions that eventually do not contribute as much to seismic displacements. The best damping method can be one that concentrates on decreasing the first few mode vibrations in order to sufficiently increase the overall capacity of the tower and its response to seismic events.

References

Ali, S. E., Hassan, I., & Garcia, R. A. (2013). Seismic study of building with roof top telecommunication towers. *International. Journal of Engineering Research and Application*.

Amiri, G. G., Barkhordari, M. A., & Massah, S. R. (2004, August). Seismic behavior of 4-legged self-supporting telecommunication towers. In *13th World Conference on Earthquake Engineering* (Vol. 215).

DiSarno, L., Elnashai, A. S., & Nethercot, D. A. (2008). Seismic response of stainless steel braced frames. *Journal of Constructional Steel Research*, *64*(7-8), 914-925.

Drisya S and Joshma M "Seismic analysis of low-rise commercial building with roof top telecommunication tower", SSRG International Journal of Civil Engineering (SSRG-IJCE)-Volume 3, Issue 8- August 2016.

Drisya, S., & Joshma, M. Seismic analysis of low-rise commercial building with roof top telecommunication tower. *SSRG International Journal of Civil Engineering (SSRG-IJCE)-Volume*, *3*.

Ghodrati Amiri, G., & Barkhordari, M. (2004). A., Massah, S., R.,"Seismic Behaviour of 4–Legged Self–Supporting Telecommunication Structures". In *13th World Conference on Earthquake Engineering, Vancouver, Canada*.

I.S. 5613: Part 2: Sec: 1: 1989: Code of Practice for Design, Installation and Maintenance for Over Head Power Lines: Lines above 11 KV And Up to And Including 220 KV: Design.

I.S. 5613: Part 2: Sec: 2: 1989: Code of Practice for Design, Installation and Maintenance for Over Head Power Lines: Lines above 11 KV And Up to And Including 220 KV: Installation and Maintenance.

I.S. 802: Part 1: Sec: 1:1995: "Code of Practice for Use of Structural Steel in Over Head Transmission Line Towers-Materials and Loads.

I.S. 802: Part 2: Sec: 1:1995: "Code of Practice for Use of Structural Steel in Over Head Transmission Line Towers-Permissible Stresses.

I.S. 875: Part 3: 1987: Code of Practice for Design Loads (other than Earthquake) for Buildings and Structures: Wind loads.

IS: 1890-2002 (Part-1), "Indian standard Criteria for Earthquake Resistant Design of Structures", Part-1: General Provisions and Buildings, Bureau of Indian Standard. New Delhi.

IS: 875-1987 Part-2,"Code of Practice for Design Loads (Other than Earthquake)"for Buildings and Structures: Part-2, Imposed Loads. Bureau of Indian standards, New Delhi.

Khatiwoda, U., Shrestha, K. C., & Bastola, S. (2023). Seismic Fragility Assessment of Residential RC Buildings with Roof Mounted Telecommunication Tower Structure.

Khedr, M., & McClure, G. (1999). Earthquake amplification factors for self-supporting telecommunication towers. *Canadian Journal of Civil Engineering*, *26*(2), 208-215.

Konno, T., & Kimura, E. (1973, July). Earthquake effects on steel tower structures atop buildings. In *Proceedings of the 5th World Conference on Earthquake Engineering* (Vol. 1, pp. 184-193).

Meti, A., & Vijapur, V. (2017). Seismic Analysis of Telecommunication Tower Using Viscous Damper.

Oliveira, M. I. R. D., Silva, J. G. S. D., Vellasco, P. C. G. D. S., Andrade, S. A. L. D., & de Lima, L. R. (2007). Structural analysis of guyed steel telecommunication towers for radio antennas. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, *29*, 185-195.

Patil Vidya, M., & Lande Abhijeet, C. (2012). Structural Response of Lattice Steel Masts for Seismic Loading. *IOSR Journal of Mechanical and Civil Engineering, ISSN*, 2278-1684.

Patil, D., Rane, N. L., Desai, P., & Rane, J. (2024). Machine learning and deep learning: Methods, techniques, applications, challenges, and future research opportunities. In Trustworthy Artificial Intelligence in Industry and Society (pp. 28-81). Deep Science Publishing. https://doi.org/10.70593/978-81-981367-4-9_2

Rajasekharan, J., & Vijaya, S. (2014). Analysis of telecommunication tower subjected to seismic & wind loading. *International Journal of Advancement in Engineering Technology, Management and applied science*, *1*(02).

Rajasekharan, J., & Vijaya, S. (2014). Analysis of telecommunication tower subjected to seismic & wind loading. *International Journal of Advancement in Engineering Technology, Management and applied science*, *1*(02).

Rane, J., Kaya, O., Mallick, S. K., & Rane, N. L. (2024a). Artificial intelligence in education: A SWOT analysis of ChatGPT and its implications for practice and research. In Generative Artificial Intelligence in Agriculture, Education, and Business (pp. 142-161). Deep Science Publishing. https://doi.org/10.70593/978-81-981271-7-4_4

Rane, J., Kaya, O., Mallick, S. K., & Rane, N. L. (2024b). Smart farming using artificial intelligence, machine learning, deep learning, and ChatGPT: Applications, opportunities, challenges, and future directions. In Generative Artificial Intelligence in Agriculture, Education, and Business (pp. 218-272). Deep Science Publishing. https://doi.org/10.70593/978-81-981271-7-4_6

Rane, N. L., & Paramesha, M. (2024). Explainable Artificial Intelligence (XAI) as a foundation for trustworthy artificial intelligence. In Trustworthy Artificial Intelligence in Industry and Society (pp. 1-27). Deep Science Publishing. https://doi.org/10.70593/978-81-981367-4-9_1

Rane, N. L., & Shirke S. (2024). Digital twin for healthcare, finance, agriculture, retail, manufacturing, energy, and transportation industry 4.0, 5.0, and society 5.0. In Artificial Intelligence and Industry in Society 5.0 (pp. 50-66). Deep Science Publishing. https://doi.org/10.70593/978-81-981271-1-2_3