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Synergistic Analysis of Wind and Thermal Stress on Stability and Serviceability Evaluation of Power Transmission Tower using FEA

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ABSTRACT

Electrical power transmission needs to be dependable and efficient in order to support the country's economic growth and advancement. The size of the effect is influenced by a number of factors, including the tower's height, cross-sectional form, orientation in regard to the wind direction, and wind speed. Indian Wind Code IS 875 (Part 3): 2015 calculates design wind forces. Average temperature of India has increased by about 0.7 °C over the previous century, with bigger increases noted in the country's northern and eastern regions. The interplay of wind forces and temperature change may have a significant impact on the structural integrity and performance of power transmission towers producing large-amplitude vibrations that could put the tower's structural components under stress. It is important to consider the combined effect of wind forces and temperature variation since the thermal strains and the wind-induced vibrations may interact, leading to resonance and amplified stresses that may be greater than the tower's design restrictions. The primary goal of this research paper is to analyze the transmission tower to incorporate the wind load according to IS:875 (Part-3) in association with thermal stresses that are calculated through various thermal stress graphs of ISO. To incorporate combined of wind and thermal stress's effect on structure Finite Element Analysis (FEA) is done through software like ANSYS and design the tower elements to meet required strength and serviceability criteria.

Keywords: ANSYS; Finite Element Analysis (FEA); Power transmission tower; Thermal stress variation; Wind force.

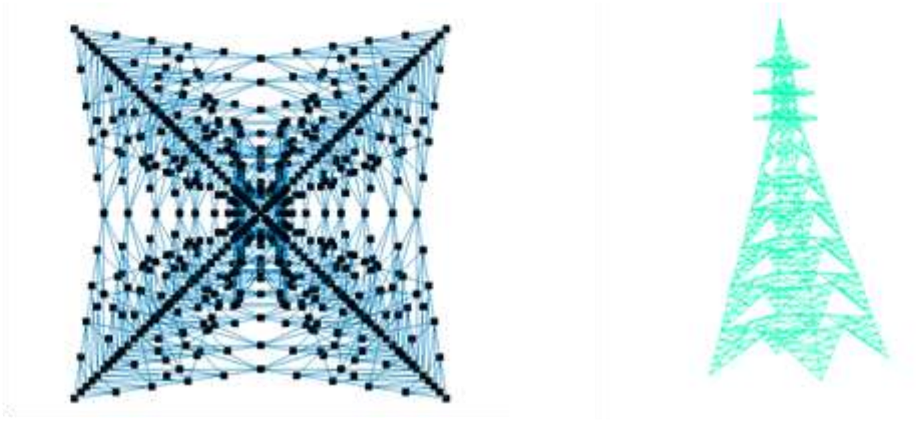
1. Introduction

Power transmission towers are critical infrastructure for the delivery of electricity. They are subjected to a variety of stresses, including wind, thermal, and seismic stresses. These stresses can cause the tower to deform or even collapse, which can result in power outages and other disruptions. The effects of wind load on India's power transmission towers are severe. Due to the diverse climates throughout India, there can be significant regional variations in wind speed. The wind speed in some places might reach 150 km/h (93 mph). As a result, gearbox towers could be put under too much strain and perhaps fall. From a structural standpoint, the following are the principal consequences of wind load on electrical transmission towers. Vibration-prone conductors may vibrate (Also referred to as Galloping; ref. IS 875- Part 3, Pg 46, pt 6 (i)), putting more strain on the conductors and consequently the cables. The fatigue damage caused by this may end up in the wires snapping.Numerous transmission towers have collapsed as a result of cyclones, tornadoes, thunderstorms, downbursts, lightning, ice disasters, and other natural disasters. Wind loading has been ascribed to the majority of these failures. To date, research has focused on the consideration of rain load, lightning effect, snow load, and so on.

The study by Devashri N. Vardhe attempted to understand the behavior of tower structures under intense wind and rainfall excitation while taking lightning damage and snow load into account. STAAD-PRO software was used to create a finite element model of the tower structure. After analysis, the finite element model of the susceptible tower struck by the loads was analyzed for the various load combinations given to estimate its ultimate strength and failure mechanisms. The transmission tower collapse modes for different combinations of loads were evaluated.

Varhade et al. (2023) looked at the behavior of transmission towers under various loads brought on by natual occurrences. To describe the loads caused by tornadoes on lattice constructions, Alipour et al. (2020) devised an analytical method. In order to analyze the wind risk associated with electric power lines owing to hurricane risk, Reinoso et al. For the examination of actual overhead transmission lines' typhoon-induced fragility, Huang et al. (2020) suggested a Bayesian method. The velocity ratio of wind-driven rain and its application on a transmission tower subjected to wind and rain stresses were researched by Tian et al. (2018). A transmission tower damaged by tropical storms was the subject of a failure analysis by Zhang and Xie (2018). A transmission tower that has been struck by lightning was subjected to wind-resistance and failure assessments by Fu et al. (2018).

(2015) Hathout and Callery looked studied how transmission line constructions are affected by intense weather. Yang et al. (2014) studied the physics of overhead transmission line tower demolition and ice disaster preventive systems. Lightning caused a 220 kV double circuit transmission line tower to break, according to Nair et al. (2005).



(a) Top View (b)Lateral View

Figure 1: Structure rendering as per design

1.1. Objectives of study

The objectives of the study of transmission tower stresses due to wind and thermal effects are to:

- Understand the nature of the stresses on transmission towers due to wind and thermal effects.
- Develop methods to calculate the stresses on transmission towers.
- Develop design methods and materials to improve the performance of transmission towers.
- Identify potential weaknesses in the design of transmission towers.

The research questions that can be addressed in the study of transmission tower stresses due to wind and thermal effects include:

- What are the different types of stresses that are exerted on transmission towers due to wind and thermal effects?
- How do the stresses due to wind and thermal effects vary with the design of the tower, the materials used, and the environmental conditions?
- How can the stresses due to wind and thermal effects be calculated accurately?
- What are the design methods and materials that can be used to improve the performance of transmission towers?
- Potential weaknesses in the design of transmission towers?
- It is a difficult and complex undertaking to examine the pressures that transmission towers experience as a result of wind and heat impacts. To increase the security and dependability of electricity transmission, it is a crucial duty.

The following techniques can be used to investigate the pressures on transmission towers caused by wind and heat effects:

- Analytical methods
- Experimental methods
- Numerical methods

The mathematical models of the tower and its surroundings serve as the foundation for analytical techniques. Towers are tested using experimental techniques in a controlled environment. Computer simulations are used in numerical approaches to simulate the behavior of the tower.

The strategy chosen will rely on the study's unique goals. To learn more about the pressures on towers in general, analytical techniques are frequently applied. To check the precision of analytical techniques and investigate the impact of certain environmental factors, experimental approaches are frequently utilized. To analyze the dynamic response of towers and the impacts of corrosion and fatigue, numerical techniques are frequently utilized.

Research is still being done on the problem of transmission tower strains brought on by wind and temperature influences. To examine the strains on these structures, new methodologies are being developed as new technologies are created. This investigation is crucial to ensuring that the towers are built to handle anticipated forces and avoid failures.

2. Methodology

General

Eurocode 8:

Follow the structural analysis requirements in Eurocode 8 for linear static analysis, nonlinear static analysis, and/or nonlinear dynamic analysis, depending on the level of precision required. The seismic activities described in Eurocode 8 for this purpose include, but are not limited to, the design response spectrum, time history analysis, and equivalent static forces. Design the structure's structural elements (such as the beams, columns, and walls) in line with the precise requirements of Eurocode 8.

IS 1893:

Refer to the IS 1893 regulations about structural analysis, which may involve reaction spectrum analysis and linear static analysis. Using the stated response spectrum, calculate the design seismic forces while taking into account any necessary consequences of soil-structure interaction. Design the structural components in accordance with the detailed guidelines and requirements given in IS 1893.

Reinforcement Detailing: Follow the standards and recommendations for reinforcement detailing listed in Eurocode 8 and IS 1893 for the seismic design of structural elements. To ensure the ductile behavior of the

building during seismic events, pay attention to factors including minimum reinforcement ratios, confinement criteria, ductility regulations, and detailed guidelines.

Performance Assessment: Using the standards outlined in Eurocode 8 and IS 1893, assess the building's performance levels under seismic loading. In order to evaluate the structural performance, deformations, and dynamic response of the building, take into account both the serviceability limit state (SLS) and ultimate limit state (ULS).

Construction methods: For earthquake design, consider the geotechnical elements, quality control practices, and construction processes defined in Eurocode 8 and IS 1893. Make sure that the construction methods follow the requirements and regulations of the applicable codes in order to safeguard the building's integrity and seismic performance.

Comparative Analysis: Analysing in comparison, the seismic design strategies used in IS 1893 and Eurocode 8 for the six-story structure. And then, comparing and contrast the design specifications, structural analysis methods, reinforcement details, building procedures, and any areas where the two codes are similar. Examining how these variables affect the building's seismic performance and design.

It is significant to note that based on the precise requirements and rules of Eurocode 8 and IS 1893 applicable to the project, the specific actions and factors may change. For a precise and thorough comparison, it is crucial to consult the most recent editions of the codes and take into account any pertinent revisions or updates.

It is a difficult and complex undertaking to analyze a power transmission tower under thermal and wind loads. To increase the security and dependability of electricity transmission, it is a crucial duty.

When assessing the strains on electricity transmission towers, the following difficulties must be taken into account as the analysis may be more challenging due to the following factors:

- The towers are frequently subjected to dynamic loading

- The materials used in the towers may be weaker due to corrosion and fatigue

- The environmental conditions may vary greatly, making it challenging to predict the stresses on the towers.

Despite these difficulties, analyzing the strains on power transmission towers is a crucial activity that may enhance the security and dependability of power transmission.

Wind Stresses

Towers used for electricity transmission are frequently stressed by the wind. The tower may swing due to the wind, which might result in fatigue damage. The tower may bow as a result of the wind, which might result in structural failure.

The following equation is used to determine how much wind stress a power transmission tower will experience:

$Fw = 1/2 * Cd * A * \rho * V2$

where:

Fw = wind force

Cd = drag coefficient

A = cross-sectional area of the tower

ρ = the density of air

V = wind speed

The tower's form affects the drag coefficient, which is a dimensionless coefficient. The area of the tower that is perpendicular to the wind direction is known as the cross-sectional area of the tower. Air pressure and temperature have an impact on the density of the air, which is a constant. The wind speed is the wind speed at the tower's height. Clause 7.4.3.5 of IS 875 (Part 3) is cited.

Thermal Stresses

The tower's expansion and contraction as it heats up and cools down result in thermal stresses. Using the following equation, the thermal stress on a power transmission tower is determined:

$Ft = \alpha * E * \Delta T$

where:

Ft = force resulting from thermal stresses

α =proportional of thermal expansion

E =Young's modulus

ΔT = variation in temperature

Thermal stresses are produced by the tower's expansion and contraction as it heats up and cools down. The thermal stress on a power transmission tower is calculated using the following equation:

Combined Wind and Thermal Stresses

A power transmission tower's overall stress may be calculated by adding its thermal and wind loads together. The following equation is used to compute the overall amount of stress.:

$Ft = Fw + Ft$

Design of Power Transmission Towers

Wind and thermal strains are taken into account during the design of electricity transmission towers. The structure's design makes sure the tower can sustain the anticipated forces without collapsing.

The design process typically involves the following steps:

- Identify the expected wind and thermal stresses.
- Calculate the total stress on the tower.
- Select the materials for the tower.
- Calculate the dimensions of the tower.

Verify that the tower is able to withstand the expected stresses

Table 1. Structural Specification

	PARTICULARS	STRUCTURAL PROPERTIES
1.	Total height of tower, h	90m
2.	Flare height of the structure, hf	(1/3) × 90 = 30m
3.	Top diameter of structure, D	3.5m
4.	Flare diameter of structure, Df	1.6 × 3.5 = 5.6m
5.	IS code for steel structure	IS:6533-1989
6.	European code for steel structure	EN 1993-3-2

Table 2: Material properties considered in the study

Yield stress of steel	250 KN/m^3
Modulus of Elasticity (E) of steel	2×10^5 N/m^2
Poisson's ratio	0.3
Strain in elastic range	0.2%

2.1 Loads acting on the transmission tower

Various loads are placed on transmission towers, such as:

- Dead load: The weight of the tower itself, including the weight of the cables, insulators, and guy wires, is referred to as the dead load.
- Wind load: The force of the wind on the tower is known as the wind load. Particularly in places with strong winds, such coastal regions, the wind load can be quite significant. Table 33, Section 7.4.3.5
- Ice load: The weight of the ice that builds up on the tower is known as the ice load. Particularly in regions that have regular ice storms, the ice burden can be quite high.
- Earthquake load: The magnitude of an earthquake's impact on a tower is known as the earthquake load. Transmission towers can sustain severe damage from earthquakes, particularly in seismically active locations.
- Lightning load: The lightning load is the force of a lightning strike on the tower. Lightning strikes can cause damage to the tower's components, such as the conductors and insulators.

The loads acting on a transmission tower are complex and vary depending on the specific location of the tower. Transmission towers are designed to withstand these loads, but they can be damaged or even collapse if the loads are too high.

2.1.1 Self-weight

Self-weight of the tower is calculated as per IS 875(Part 1): 1987.

2.2.2 Wind load

Since towers are tall structures, wind action has an important effect on them. High rise structures must be evaluated for their ability to withstand wind loads as the lateral strength of tall buildings is determined by such loads. Wind load should be applied on the external surfaces of a stack. Wind is a primary load for self-supported steel stack or towers.

Wind loads are designed as per IS 875(Part 3): 2015.

As per IS code 875(Part3)2015:

wherein,

V_z= Design wind speed z in m/s.

V_b = Basal wind speed (refer Annex. A, Clause 6.2, IS 875 Part 3; V_b at Lucknow= 50)

k_1 = Risk coefficient

k_2 = Structure size factor

k_3 = Factor of Topographical Variance

k_4= Importance factor for cyclonic region Design wind pressure,

$V_z=V_b\times k_1\times k_2\times k_3\times k_4$

wherein,

p_z= Design wind pressure (N/m2) at height z

V_z= Design wind velocity in (m/s) at height z

[across wind force is not needed to be calculated, IS 875-2015(Part 3), Clause 10.3]

2.2.3 Seismic load

As a natural load, seismic load is an essential factor for towers. Normally, this load is dynamic in nature. For short periods of time, seismic force is predicted to be cyclic. It is important to examine the structural reaction to ground motion when building earthquake resistant constructions. A structure is considered serviceable if it can perform the operational purposes for which it was designed.

IS 1893(Part 4): 2005

The fundamental time period of vibration for structure-like structure is

$$T = C_T\sqrt{\frac{W_t h}{E_s A g}}$$

wherein,

CT = Slenderness coefficient

Wt= Gross weight of the stack,

A = Area of cross-section at the base of the tower

h = Total height of the stack

Es= Modulus of elasticity

g= Acceleration due to gravity

Horizontal seismic force Ah = (Z/2) × (Sa/g) × (I/R)

wherein,

Ah= Horizontal seismic coefficient

Z = Zone factor given in IS 1893:2005 (Part 1), wind l

I= Importance factor ref. IS 875:2015 (Part 3) R=Response reduction factor given in 1893:2005 (Part 4) Sa/ g = Spectral acceleration coefficient.

2.3. Load Combinations

Different load combinations have been considered while analyzing the structure as per IS 6533 (Part 2) 1989

3. Results and Discussions

GENERAL

The structure 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 and displacement at the top of steel stack is recorded. Modelling is done using SAP2000 software. The behavior of self-supporting steel stack in terms of top displacement is observed from the result.

3.1 TOTAL DEFORMATION

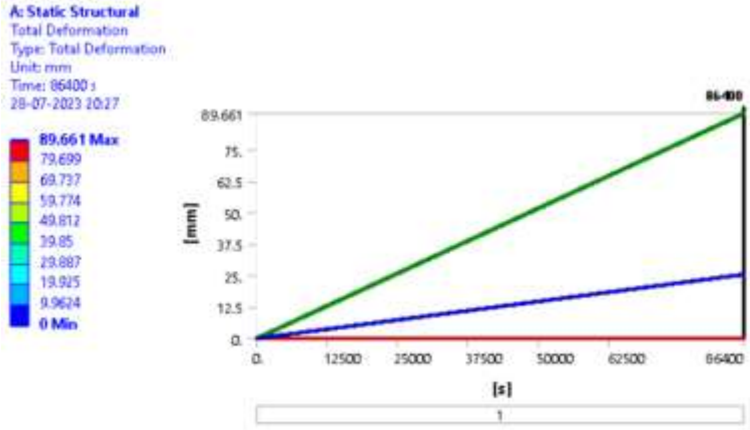


Fig. Total Deformation Diagram for standard loaded tower

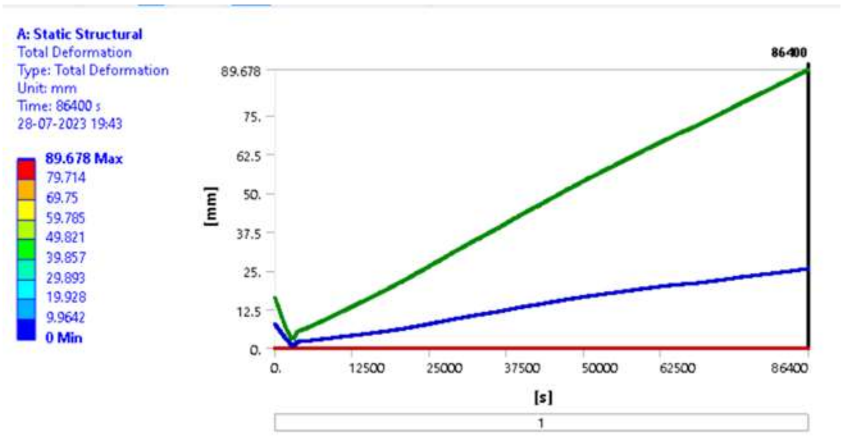


Fig. Total Deformation Diagram for thermally loaded tower

The total deformation of the power transmission lattice tower structure is higher when it is loaded with dead load, live load & wind load along with thermal stresses, compared to when it is loaded with dead load, live load & wind load but without thermal stresses.

This is because thermal stresses add to the overall load on the structure, causing it to deform more. In the first set of data, the maximum deformation is 25.609 mm, while in the second set of data, the maximum deformation is only 1.103 mm. This shows that the total deformation is significantly reduced when thermal stresses are not present.

The average deformation is also higher in the first set of data, at 24.954 mm, compared to 5.1887e-002 mm in the second set of data. This again shows that the total deformation is significantly reduced when thermal stresses are not present.

Therefore, it is important to consider thermal stresses when designing power transmission lattice tower structures, as they can significantly increase the total deformation of the structure.

3.2 TOTAL BENDING MOMENT:

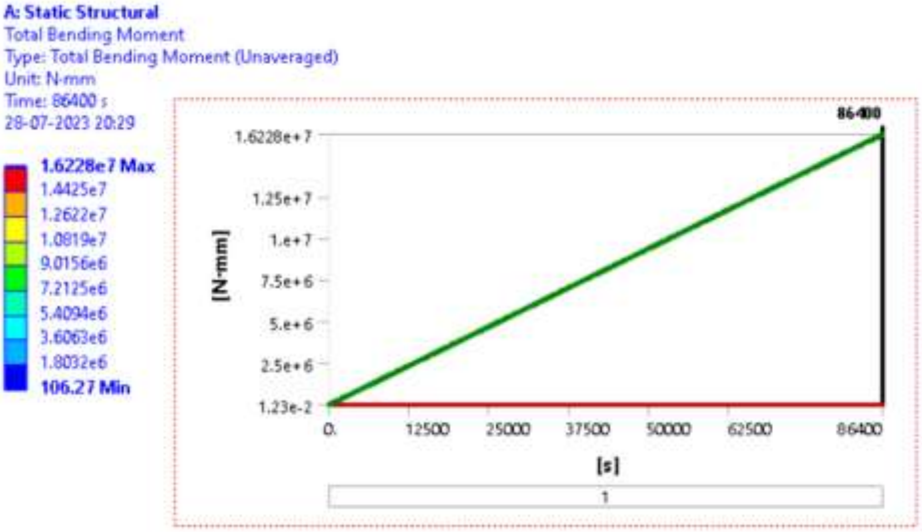


Fig. Total Bending Moment Diagram for standard loaded tower

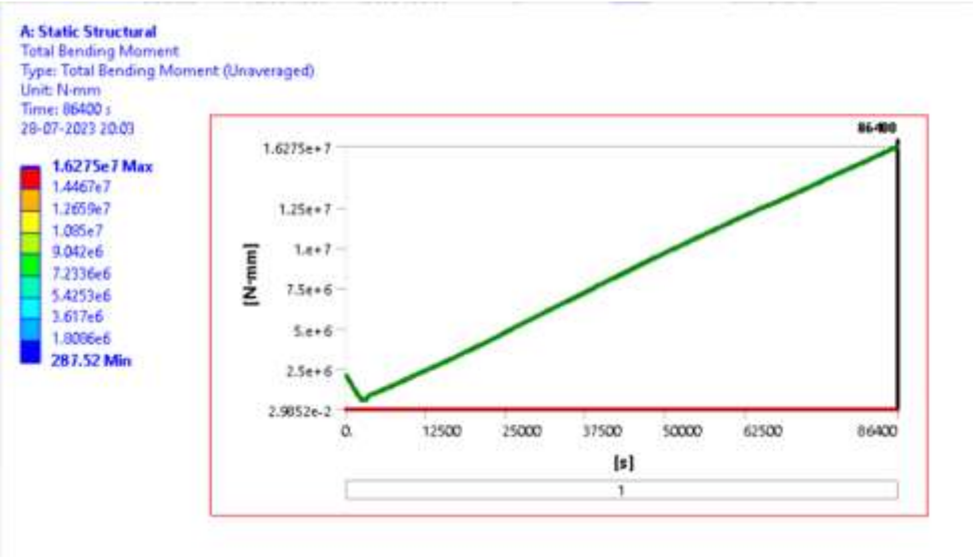


Fig. Total Bending Moment Diagram for thermally loaded tower

The bending moment of a power transmission lattice tower structure is shown in the first dataset together with its dead load and wind load, whereas the bending moment of the same structure with just dead load is shown in the second dataset. Since the wind load adds a considerable amount of force to the structure, the first dataset should have a greater maximum bending moment than the second dataset. While the second dataset has a considerably narrower range of values, from a low of 123 N-mm to a high of 10030 N-mm, the first dataset also has a broader range of values, from a minimum of 1878.2 N-mm to a maximum of 1.6228e+007 N-mm.

The effects of wind load on the bending moment of a power transmission lattice tower structure may be compared using the two datasets. The first dataset demonstrates that, if the structure is not built to bear the additional force, the wind load can dramatically increase the bending moment of the structure, which can result in structural collapse. The second dataset demonstrates that when the wind load is absent, the structure's bending moment is far smaller, indicating that the structure is considerably less prone to break.

The two datasets offer distinct but complimentary knowledge on the bending moment of a power transmission lattice tower structure, in conclusion. The maximum bending moment that the structure is capable of withstanding is shown in the first dataset, while the bending moment that the structure is most likely to endure in the absence of wind is shown in the second dataset. Using this knowledge, a building may be created that is stable and secure in both calm and windy circumstances.

4. Conclusion

An essential step in the design process is the consideration of the pressures on electricity transmission towers. The skyscraper is constructed to withstand the anticipated stresses thanks to this analysis. The two main forms of stresses taken into account in the design of power transmission towers are wind and thermal loads. The overall stress on the tower is determined using the combined wind and thermal loads. The tower is then tested throughout the design phase to make sure it can sustain the anticipated stresses.

The average deformation in the first set of data is likewise greater, coming in at 24.954 mm as opposed to 5.1887e-002 mm in the second set. Similar to how the second dataset has a considerably tighter range of values, from a low of 123 N-mm to a maximum of 10030 N-mm, the first dataset likewise has a broader range of values, from a minimum of 1878.2 N-mm to a maximum of 1.6228e+007 N-mm. The difference between the maximum and minimum bending moments is used to compute the net torsional moment. The net torsional moment in the first set of data is 0.046 N-mm. The net torsional moment in the second set of data is 0.727 N-mm. At the end of the time, the difference in total shear force is taught to be 29N.However, when we examine the net axial shear force, it reveals that the first set of data's greatest axial force is -2484.2 N, occurring at a time of 10 seconds. The second set of data shows that the highest axial force occurs at a time of 10 seconds and is -90.783 N. It is evident from the analysis that the strain energy is the energy stored in the structure as a result of its deformation since the structural energy response is crucial in determining the behavioral pattern of the structure. The energy lost by the dampers in the structure is known as the damping energy. The energy added to the building by artificial forces, including wind forces, is referred to as artificial energy. The data analysis shown above makes it evident that the data set-1 with the thermal stresses results in larger strains compared to a conventional laden tower without taking thermal stresses into account.

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