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Analysis and cost-Effective Design of Transmission Line Tower Structure

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Abstract- Transmission towers are very important components of power transmission systems, as they support overhead conductors and maintain safe clearance from the ground. These towers are subjected to various types of loads such as dead load, live load, and wind load, which significantly affect their structural behaviour. In the present study, the analysis and design of 220kV and 132kV transmission towers are carried out using STAAD Pro software. The towers are modelled as three-dimensional steel lattice structures, and the loads are applied as per relevant Indian Standard codes such as IS 802 and IS 875 (Part 3). Different load combinations are considered to identify the most critical loading condition. The analysis results include parameters such as displacement, support reactions, and bending moments. It is observed that the 220kV tower shows higher displacement and reaction values compared to the 132kV tower due to its greater height and exposure to wind load. The design of both towers is performed as per IS 802, and all members are found to be safe under the applied loads. The steel take-off is also calculated, which shows that the 220kV tower requires more steel than the 132kV tower, making it less economical. The study concludes that while 220kV towers are suitable for long-distance transmission, 132kV towers are more stable and cost-effective for medium-range applications.

Keywords: Transmission Tower, STAAD Pro, 220kV Tower, 132kV Tower, Structural Analysis, Wind Load, IS 802, Steel Take-Off, Displacement.

I. INTRODUCTION

Electric power transmission is one of the most essential components of modern infrastructure, as it plays a vital role in delivering electrical energy from generating stations to substations and finally to end users such as residential, commercial, and industrial consumers. The efficiency and reliability of the transmission system directly influence the overall performance of the power sector. Transmission line towers, which are generally made of steel lattice structures, are used to support electrical conductors at a required safe height above the ground level. These towers ensure uninterrupted and safe transmission of electricity over long distances while maintaining proper electrical clearance and mechanical stability. Due to their height and exposed nature, transmission towers are subjected to various types of loads and environmental conditions, such as dead load (self-weight), live load, wind load, temperature variations, and sometimes seismic forces and ice loads in specific regions. Among these, wind load is considered the most critical factor governing the design, as it induces lateral forces and causes significant displacement and stress in the tower structure. Therefore, the design of transmission towers must be carried out carefully by considering all possible loading conditions and following relevant Indian Standards such as IS 802 and IS 875 (Part 3). In recent years, rapid urbanization, industrial growth, and increasing population in India have led to a significant rise in electricity demand. To meet this growing demand, expansion of transmission networks has become necessary, which in turn requires the construction of a large number of transmission towers. However, traditional design practices often result in over-conservative designs, leading to excessive use of steel and increased construction cost.

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Since transmission line projects involve a large number of towers, even a small reduction in material usage per tower can result in considerable cost savings at the project level. Therefore, there is a strong need to develop cost-effective and optimized design approaches for transmission line towers without compromising structural safety and performance. The structural behavior of transmission towers is complex, as they act as three-dimensional space truss systems consisting of interconnected angle sections forming legs, bracings, and cross arms. The lower portion of the tower carries maximum load due to accumulation of forces from upper members, and hence requires stronger sections compared to the upper part. Proper selection of member sizes, efficient bracing systems, and optimized geometry play an important role in improving structural performance and reducing material consumption. With the advancement of computer-based structural analysis software such as STAAD-Pro, it has become possible to model, analyze, and design transmission towers more accurately and efficiently. These tools help engineers to evaluate various load combinations, determine internal forces, and optimize the design for cost-effectiveness. Considering all these aspects, the present study focuses on the analysis and cost-effective design of transmission line tower structures by comparing different configurations such as 220kV and 132kV towers. The study aims to evaluate parameters like nodal displacement, shear force, bending moment, and steel quantity to achieve an economical and safe design. Thus, this research contributes towards developing efficient transmission tower designs that meet the increasing demand for electricity while minimizing construction cost and ensuring long-term structural stability.

II. METHODOLOGY

Selection of Transmission Tower Types:
In this study, two types of towers are selected based on voltage levels.

Table 3.1: Selection of Towers

Sr. No.	Tower Type	Voltage Level	Type
1	Tower 1	220kV	Double Circuit
2	Tower 2	132kV	Double Circuit

Data Collection:
All required data for analysis is collected from standard codes and design references.

Table 3.2: Data Used for Study

Parameter	Source
Load values	IS 802
Wind data	IS 875 Part 3
Tower geometry	Standard design
Material properties	Steel design codes

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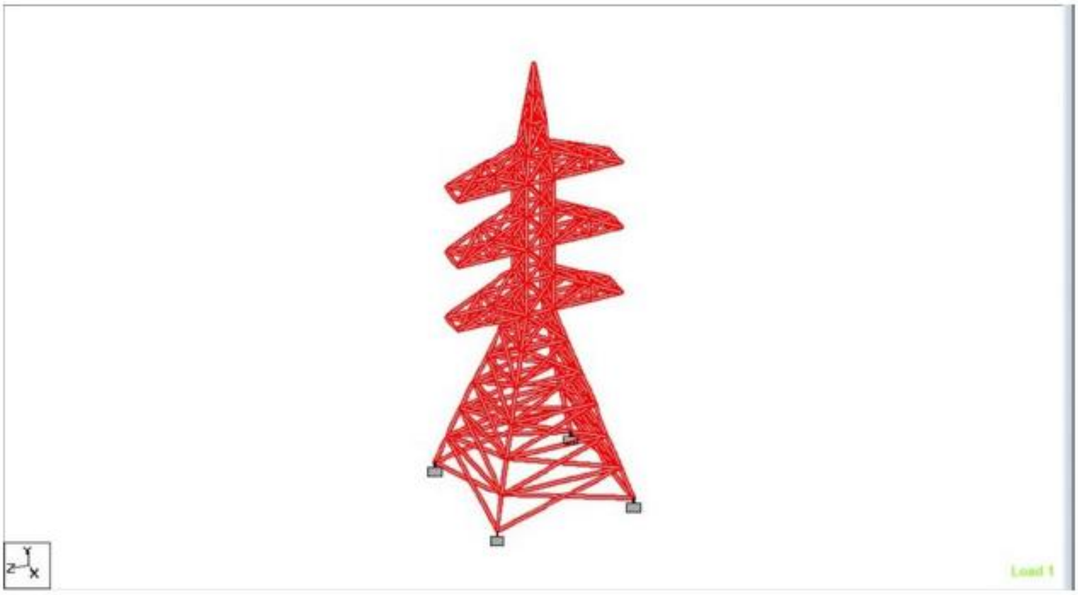

Figure 3.1: Assigning Self Weight for 220kV Transmission Tower

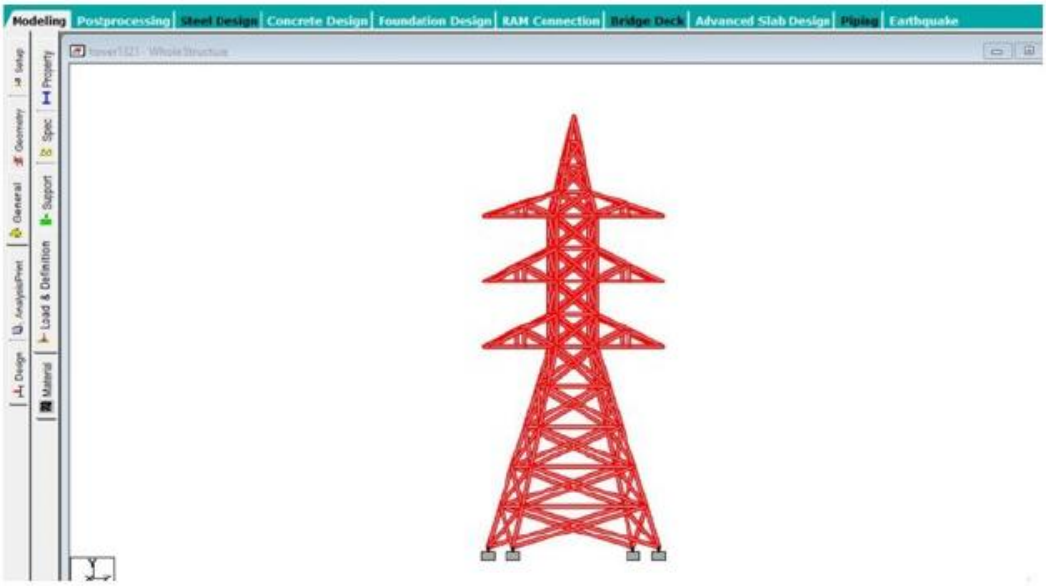

Figure 3.2: Assigning Self Weight for 132kV Transmission Tower

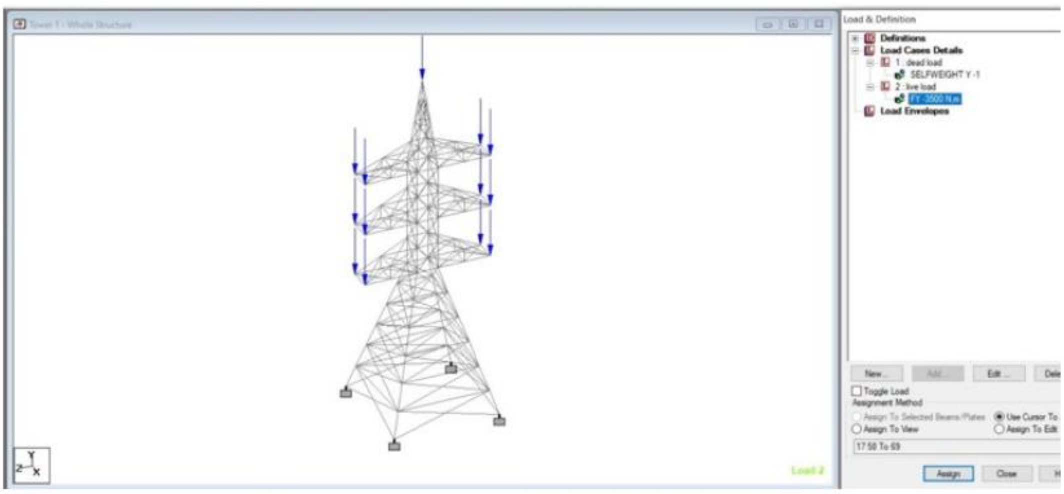

Figure 3.3: Live Load (3500 N) on 220kV Tower

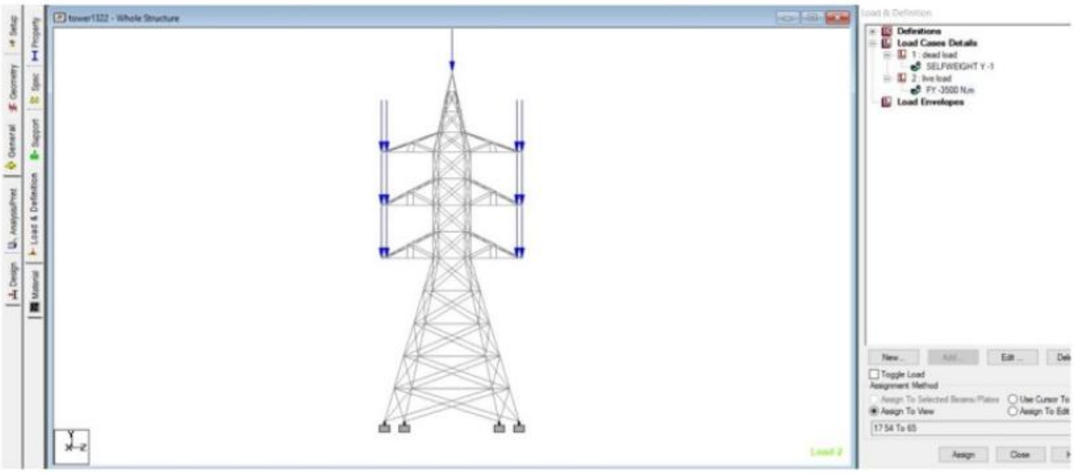

Figure 3.4: Live Load (3500 N) on 132kV Tower

Modelling of Transmission Towers in STAAD Pro:

The modelling of transmission towers in STAAD Pro software is an important step in this research, as it helps to represent the real structure in a virtual environment for accurate analysis and design. In this study, both 220kV and 132kV transmission towers are modelled as three-dimensional steel lattice structures using a coordinate system. The modelling process begins with the creation of nodal points, which define the geometry and height of the tower based on design parameters such as ground clearance, conductor sag, and spacing between conductors. These nodes are then connected using beam elements to form the complete structural framework of the tower. After defining the geometry, appropriate steel angle sections (ISA sections) are assigned to different members of the tower. The main legs of the tower are provided with larger sections such as ISA 200×200×25 because they carry the maximum load, especially at the lower portion of the structure. The diagonal bracings are assigned medium sections like ISA 100×100×8, while the horizontal bracings are provided with sections such as ISA 130×130×10. This variation in section size ensures that the structure is both safe and economical, as stronger members are used where higher forces are expected. The base of the tower is assumed to be fixed support, which represents the actual foundation condition in the field. Material properties of steel, such as modulus of elasticity and density, are defined as per standard values. Once the geometry, sections, supports, and material properties are assigned, the model is ready for load application and analysis. The entire modelling process in STAAD Pro provides a realistic representation of the transmission tower, allowing accurate evaluation of structural behaviour under different loading conditions such as dead load, live load, and wind load.

Modelling of 220kV Tower:

Height Calculation

$$H = h_1 + h_2 + h_3 + h_4$$

= 7.1 + 6.4 + 5 + 5 + 8.5 = 32 m

Table 3.4: Height Parameters (220kV Tower)

Parameter	Value
Ground Clearance (h1)	7.1 m
Sag (h2)	6.4 m
Conductor Spacing (h3)	5 m
Top Distance (h4)	8.5 m
Total Height	32 m

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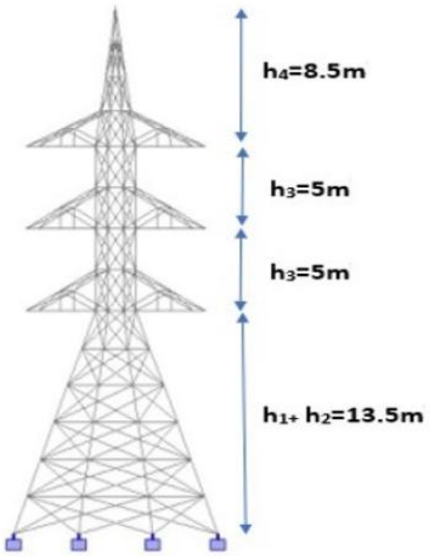

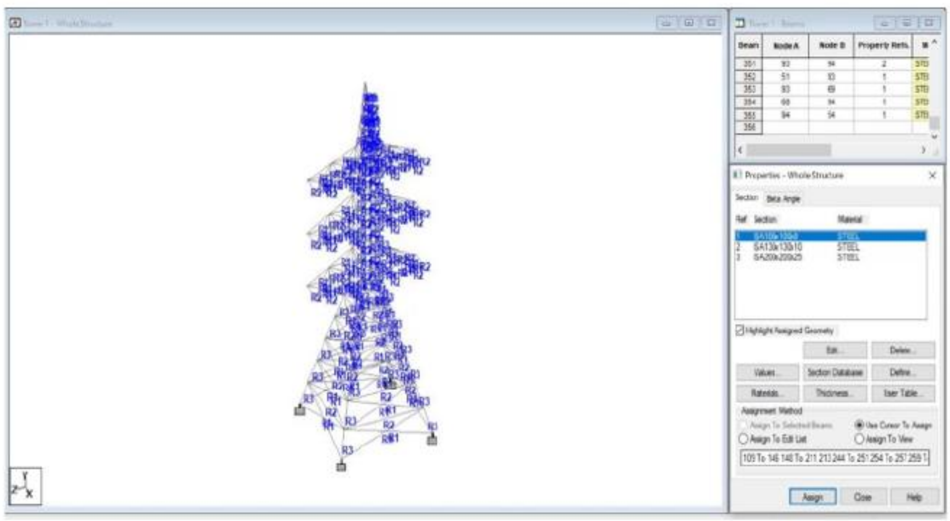

Figure 3.5: Section Assignment in 220kV Tower

Modelling of 132kV Tower:
Height Calculation

$$H = 6.1 + 6.2 + 4 + 4 + 6.1 = 22.4m$$

Table 3.5: Height Parameters (132kV Tower)

Parameter	Value
Ground Clearance	6.1 m
Sag	6.2 m
Spacing	4 m
Top Distance	6.1 m
Total Height	22.4 m

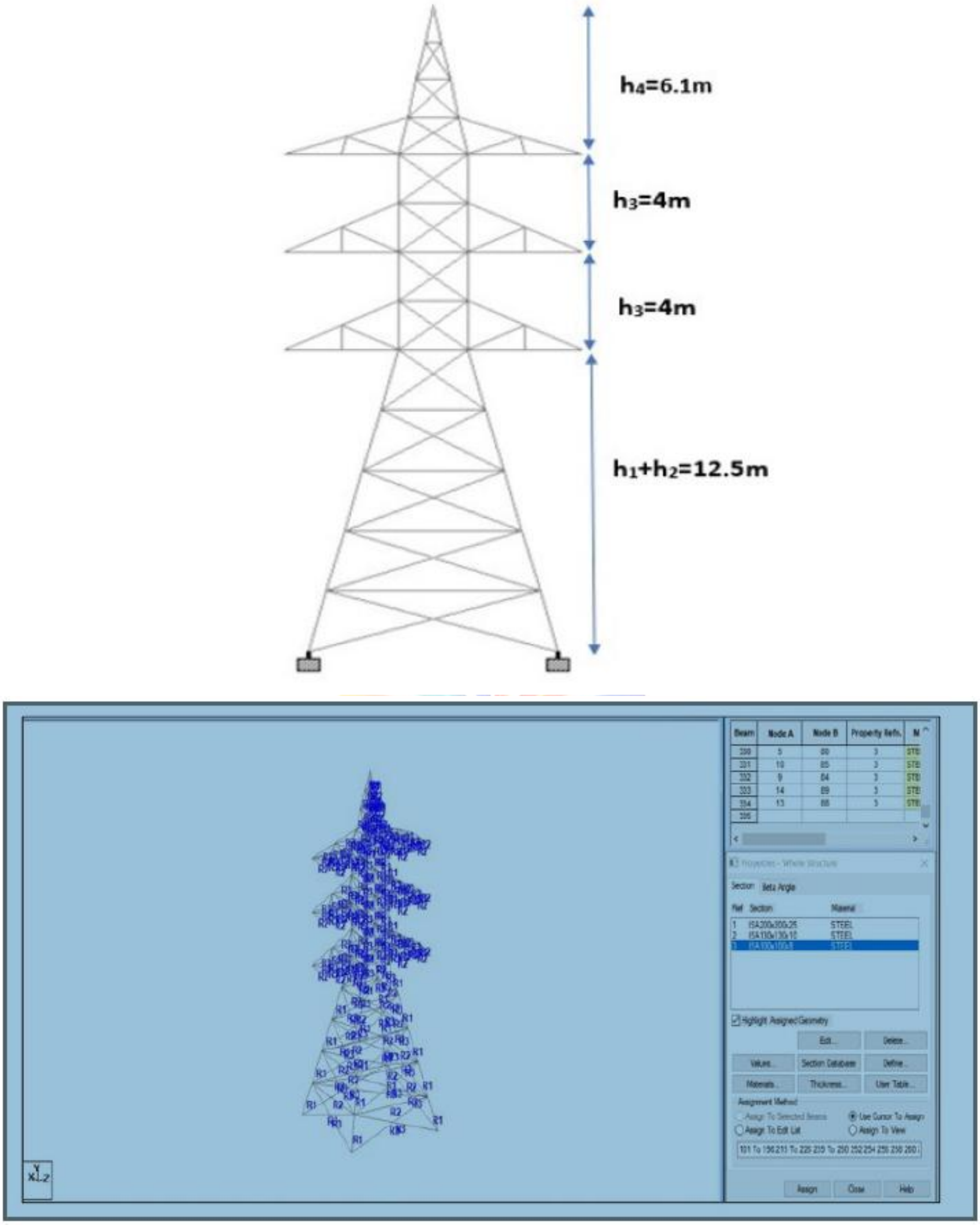

Figure 3.6: 132kV Transmission Tower Model

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III. RESULTS AND DISCUSSION

Comparison of Results:

Table 5.1: Comparison of 220kV and 132kV Transmission Towers

Parameters	220kV Tower	132kV Tower
Displacement (mm)	39.006	8.171
Fx (kN)	96.126	55.370
Fy (kN)	304.909	183.111
Fz (kN)	92.692	49.458
Mx (kN-m)	1.061	1.004
My (kN-m)	1.698	1.000
Mz (kN-m)	1.860	1.744
Steel Take-Off (Tonnes)	24.015	20.625

Discussion on Displacement:
Displacement is one of the most important parameters in structural analysis, as it indicates the deformation of the structure under applied loads.
From Table 5.1, it is observed that:
1. The maximum displacement of the 220kV tower is 39.006 mm
2. The maximum displacement of the 132kV tower is 8.171 mm

This clearly shows that the 220kV tower undergoes significantly higher displacement compared to the 132kV tower.

Reason:
1. Greater height of 220kV tower
2. Higher wind load effect
3. Increased flexibility

Conclusion:
The 220kV tower is more flexible, while the 132kV tower is stiffer and more stable.

Discussion on Support Reactions:
Support reactions represent the forces transferred from the tower to the foundation.

Horizontal Forces (Fx)
1. 220kV = 96.126 kN
2. 132kV = 55.370 kN

The higher value in the 220kV tower indicates greater wind load effect.

Vertical Forces (Fy)
1. 220kV = 304.909 kN
2. 132kV = 183.111 kN

The vertical reaction is mainly due to self-weight. Since the 220kV tower is taller and heavier, it has higher vertical reaction.

Transverse Forces (Fz)
1. 220kV = 92.692 kN
2. 132kV = 49.458 kN

This again confirms that the 220kV tower is subjected to higher lateral forces.

Discussion on Moments:
Moments are generated due to eccentric loading and wind forces.

Mx (Bending Moment)
1. 220kV = 1.061 kN-m
2. 132kV = 1.004 kN-m

My (Bending Moment)
1. 220kV = 1.698 kN-m
2. 132kV = 1.000 kN-m

Mz (Bending Moment)
1. 220kV = 1.860 kN-m
2. 132kV = 1.744 kN-m

Observation:
1. Moment values are slightly higher in 220kV tower
2. This indicates higher bending effects due to wind

Discussion on Steel Take-Off:
Steel take-off represents the total quantity of steel required for construction.
1. 220kV Tower = 24.015 tonnes
2. 132kV Tower = 20.625 tonnes

Observation:
1. 220kV tower requires more steel
2. Increase ≈ 14–15%

Reason:
1. Greater height
2. Higher load
3. Need for stronger members

CONCLUSION

The study clearly shows that the structural behaviour of transmission towers is highly influenced by their height, loading conditions, and configuration. When comparing the displacement values, it is observed that the 220kV transmission tower exhibits approximately 79% higher displacement than the 132kV tower. This is mainly due to the greater height and higher exposure to wind load, which increases the flexibility of the structure. In terms of support reactions, the results indicate that the 220kV tower experience's higher reaction forces compared to the 132kV tower. The increase in reaction values is due to the higher self-weight and wind forces acting on the taller structure. This implies that the foundation design for the 220kV tower must be stronger and more robust to safely transfer these forces to the ground. The comparison of steel take-off shows that the 220kV tower requires approximately 14.11% more steel than the 132kV tower. This increase in steel quantity is necessary to ensure adequate strength and stability of the structure under higher loading conditions. However, it also results in increased construction cost, making the 220kV tower less economical compared to the 132kV tower. Overall, it can be concluded that while the 220kV tower is suitable for long-distance high voltage transmission, it is more flexible and requires more material. On the other hand, the 132kV tower is comparatively stiffer, more stable, and economical, making it suitable for medium-range transmission systems. Both towers are found to be safe and satisfactory as per IS 802 design criteria.

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