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Design and Analysis of Transmission Tower for Dynamic Wind Pressure

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Abstract— **It has become incredibly challenging to get land for power transmission lines year after year due to different limitations, like density of population in the urban areas, obtaining forest clearances and nature protection theory. It is necessary to develop technically compact transmission line tower structures to minimize the tower dimensions. Failure of such structures is a major concern. It is very essential to consider appropriate parameters for designing of these towers in order to enhance their sustainability.**

The present work describes the analysis and design of four-legged self-supporting steel transmission line towers models with an angle sections. The performance of various bracing system has been identified and reported. The lateral wind load resistance is a main measure to evaluate the structural performance of towers. Bracing system is the major system providing lateral load resistance in steel lattice towers. Wind loading is calculated as per IS: 802 (2015).

Using STAAD PRO v8i analysis and design of tower has been carried out as a three-dimensional structure. The analysis has been done by taking different combination of loads. The present work describes the analysis and design of transmission line tower of 30 meter height viz. various parameters. The tower is designed in wind zone – V. The various factors including environmental and materials used for the structure is also considered. The load calculations were performed manually but the analysis and design results were obtained through STAAD Pro. Gust factor method is used for wind load analysis.

Transmission Line Towers comprise around 28 to 42 percent of the total cost of the Transmission Lines. The increasing demand for electrical energy can be met more economical by developing different light weight configurations of transmission line towers. In this project, an attempt has been made to make the transmission line more cost effective keeping in view to provide optimum electric supply for the required area by considering unique transmission line tower structure.

Transmission line towers carry heavy electrical transmission conductors at a sufficient and safe height from ground. In addition to their self-weight they have to withstand forces of nature like strong wind.

Keywords- Transmission tower, lateral wind load, STAAD Pro, Gust factor method, angle sections.

I. INTRODUCTION

Electrical transmission networks are essential for economic development and uninterrupted power supply. Transmission towers support conductors at safe elevations while resisting environmental loads.

Transmission towers are highly susceptible to wind forces because of:

- High slenderness ratio
- Large exposed surface area
- Flexible structural configuration
- Dynamic interaction with conductors

Wind-induced failures account for a significant percentage of transmission tower collapses worldwide.

Proper design requires:

- Accurate wind load estimation
- Efficient bracing arrangements
- Economical steel utilization
- Compliance with design codes

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Modern software such as STAAD.Pro enables engineers to perform advanced three-dimensional analysis and optimize tower configurations.

II. OBJECTIVES

The objectives are:

1. To analyze and design a self-supporting steel transmission tower.
2. To study the effect of dynamic wind pressure.
3. To compare K and X bracing systems.
4. To evaluate displacement, axial force, and bending moments.
5. To optimize steel consumption.
6. To identify the most economical bracing system.

III. MATERIALS AND METHODOLOGY

3.1 SOFTWARE USED: STAAD PRO V8I

The structural modelling, analysis, and design of the transmission tower were carried out using STAAD.Pro V8i. STAAD Pro is one of the most widely used structural engineering software packages because it can efficiently perform three-dimensional modelling, load calculations, dynamic analysis, and design verification according to international and Indian standards.

The software allows engineers to simulate real-world loading conditions and evaluate the structural behaviour of transmission towers before actual construction. It can analyze complex lattice structures subjected to multiple loading combinations while ensuring structural safety and economy.

The following tasks were performed using STAAD Pro V8i:

- Three-dimensional modelling of the transmission tower.
- Assignment of steel angle sections.
- Application of dead, live, and wind loads.
- Application of broken wire loading conditions.
- Generation of load combinations.
- Analysis of displacement, axial forces, bending moments, and support reactions.
- Comparison of K-bracing and X-bracing configurations.

3.2 TOWER SPECIFICATIONS

A self-supporting four-legged lattice steel transmission tower was selected for the study. The geometric parameters were chosen according to practical design considerations and Indian standard provisions.

Table 3.1 Tower Specifications

Parameter	Value
Tower height	30 m
Base width	3.65 m
Waist width	1.65 m
Tower span	150 m
Wind zone	V
Terrain category	II
Reliability level	I

1) Description of Parameters:-

Tower Height (30 m)

The total height of the transmission tower is considered as 30 meters. The tower height directly influences the wind force acting on the structure because wind pressure generally increases with elevation.

Base Width (3.65 m)

The base width is selected according to standard tower proportions. A wider base improves overall stability and reduces overturning moments.

Waist Width (1.65 m)

The waist width refers to the narrower portion of the tower between the base and cross arms. This configuration helps reduce material consumption without compromising strength.

Tower Span (150 m)

The span is the distance between adjacent towers. Larger spans increase conductor loads and mechanical tension transferred to the structure.

Wind Zone V

Wind Zone V is the most severe wind zone in India and corresponds to regions experiencing basic wind speeds up to 50 m/s. Designing for this zone ensures adequate structural safety.

Terrain Category II

Terrain Category II represents open terrain with scattered obstructions such as small buildings and trees.

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Reliability Level I

Reliability Level I is adopted for Extra High Voltage transmission lines up to 400 kV, ensuring an acceptable probability of structural safety throughout the service life.

3.3 MATERIAL PROPERTIES

Structural steel angle sections were used throughout the tower.

Table 3.2 Steel Sections Used

Structural Member	Steel Section
Main Legs	ISA 180×180×20 mm
Bracing Members	ISA 80×80×10 mm
Secondary Members	ISA 90×90×8 mm

Main Leg Members

The main legs carry the majority of the compressive and tensile loads transferred from the entire tower. Therefore, larger angle sections were selected.

Bracing Members

Bracing members improve structural rigidity and distribute forces uniformly throughout the tower.

Secondary Members

Secondary members provide additional support and contribute to overall stability.

The steel used satisfies the requirements of IS 2062 and possesses adequate strength, ductility, and durability.

3.4 LOADING CONSIDERED

Several loading conditions were considered to simulate realistic operating scenarios.

3.4.1 Dead Load

Dead load consists of:

- Self-weight of steel members
- Weight of conductors
- Weight of insulators
- Weight of ground wires

Dead loads act continuously throughout the service life of the tower.

3.4.2 Live Load

Live loads represent temporary loads occurring during maintenance operations.

These include:

- Weight of maintenance personnel
- Tools and equipment
- Temporary service loads

3.4.3 Wind Load

Wind load is the most critical loading condition for transmission towers because of their tall and slender geometry.

Wind loading was calculated according to IS 802:2015 using the Gust Response Factor Method.

The design wind pressure was calculated as:

Pd=0.6Vd2P_d=0.6V_d^2Pd=0.6Vd2

Where:

- PdP_dPd = Design wind pressure (N/m²)
- VdV_dVd = Design wind speed (m/s)

The Gust Response Factor method considers:

- Wind turbulence
- Dynamic amplification
- Terrain effects
- Structural flexibility

3.4.4 Broken Wire Condition

Broken wire loading is an accidental loading condition.

When one conductor breaks, unbalanced forces develop and induce:

- Additional bending moments
- Torsional effects
- Longitudinal forces

The structure must safely resist these forces without collapse.

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IV. RESULTS AND DISCUSSION

Two different bracing systems were analyzed.

Table 4.1 Comparison between K-Bracing and X-Bracing

Parameter	K-Bracing	X-Bracing
Lateral displacement	Lower	Higher
Structural stiffness	Higher	Moderate
Steel consumption	Higher	Lower
Material economy	Moderate	Better
Wind resistance	Excellent	Good

4.1 Lateral Displacement

Lateral displacement is one of the most important performance indicators for transmission towers.

The study showed that:

- K-bracing produced lower lateral displacement.
- X-bracing exhibited comparatively larger displacement.

Lower displacement improves:

- Structural stability
- Serviceability
- Conductor clearance safety

4.2 Structural Stiffness

Stiffness determines the ability of a structure to resist deformation.

K-bracing provided:

- Higher stiffness
- Better load transfer
- Greater resistance against wind-induced sway

X-bracing provided moderate stiffness.

4.3 Steel Consumption

Steel consumption directly affects construction cost.

Observations indicate:

- K-bracing required more steel.
- X-bracing reduced overall steel quantity.

Thus, X-bracing is more economical.

4.4 Wind Resistance

Wind resistance refers to the ability to withstand severe wind forces.

K-bracing performed better because:

- Loads were distributed more effectively.
- Structural deformation was reduced.
- Internal force redistribution was improved.

4.5 General Observations

The following observations were obtained from the analysis:

1. Wind loading dominates transmission tower design.
2. Tower height significantly affects displacement.
3. Bracing arrangement influences structural behaviour.
4. K-bracing improves stiffness.
5. X-bracing improves economy.
6. Proper bracing selection enhances safety.

V. CONCLUSIONS

The following conclusions can be drawn from the study:

1. Wind load is the governing design load for transmission towers.
2. Bracing systems significantly influence structural performance.
3. K-bracing effectively reduces lateral displacement.
4. X-bracing reduces material consumption.
5. STAAD Pro is an efficient software tool for transmission tower analysis.

6. Proper optimization can reduce construction cost while maintaining safety.
7. Dynamic wind analysis provides more realistic structural behaviour than static analysis.
8. Selecting an appropriate bracing configuration is essential for achieving both structural efficiency and economy.

VI. RESEARCH GAPS AND FUTURE SCOPE

Despite significant research, several gaps remain.

6.1 Soil-Structure Interaction Effects

Most studies assume fixed supports and neglect foundation flexibility.

Future studies should include:

- Soil stiffness
- Settlement effects
- Foundation behaviour

6.2 Cyclonic Wind Analysis

Extreme cyclonic events are increasing due to climate change.

Future studies should investigate:

- Cyclone-induced wind loads
- Gust amplification
- Progressive collapse mechanisms

6.3 Hybrid Bracing Systems

Very limited studies have investigated combinations such as:

- K-X bracing
- K-V bracing
- Hybrid lattice configurations

These systems may improve performance further.

6.4 AI-Based Structural Optimization

Artificial Intelligence can optimize:

- Member sizes
- Bracing patterns
- Material usage
- Cost efficiency

Machine learning techniques can substantially reduce design time.

6.5 Climate Change Effects

Future climatic conditions may alter design wind speeds.

Research should focus on:

- Long-term climate predictions
- Extreme wind events
- Updated design methodologies

6.6 Fatigue Analysis

Transmission towers are subjected to repeated loading throughout their service life.

Future studies should investigate:

- Fatigue life prediction
- Crack initiation
- Progressive deterioration
- Maintenance scheduling

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