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Analysis and Design of Transmission Tower

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Abstract - Transmission line tower contributes about nearly 28 to 42 percent of cost for the transmission power line projects. The huge increase in the demand for the electricity made for choosing most economical towers by developing different light weight sectional configurations of transmission line towers. The present paper deals with the 400 kV double circuit transmission tower of height 55m and analyzed by using STAAD PRO. In this work towers are differentiated by employing ‘X’, ‘K’ and combination of both bracing system for different height to width ratios and examined using static analysis.

***Key Words*:** transmission tower, bracing, height to width ratio

1. INTRODUCTION

In developing country like India there will be a huge demand for power generating programs. Directly or indirectly, the economy is dependent on electricity as it is one of the basic inputs. Transmission towers are required for the purpose of supply electricity to many regions all over the county. This makes increase in the construction of power stations and increase in power transmission lines from generating stations in many places. Design of transmission tower should be done very carefully so that they do not fail during any natural disaster. The design of transmission tower depends upon various factors like voltage, location, wind zone conditions, deviation angle and type of material to be used. Therefore for transmission tower the analysis and design one of the important factors to be considered is different loading conditions.

Sai Avinash P, Rajasekhar P, et all [1] has designed and analyzed 220 kV double circuit tower of height 49mts for both safe and economical aspects. This paper mainly focused on the optimizing the transmission tower by employing the bracings like 'X' and 'K', and also by varying the sections and examined by using Static analysis method. They have concluded that, the upshots of using 'X' bracing to 'K' bracing have shown more difference and also reduction in the weight of the structure by 6% and having the displacement values have been supplemented.

R. Kumaravel and K. Tamilvanan [2] conducted both analysis and design of a 132kV single circuit both guyed transmission tower and its comparison with a self-supporting transmission tower. Guyed tower design is approximately 15-20% less than that of a self-supporting tower. The member forces, tower weights, support reactions and foundation volumes are compared for both the towers. The overall weight and cost of the guy supported tower is more when compared to self-supporting tower. They have concluded that, the 132 kV guy supported tower provides a right alternative when the available right of way is less than the required right of way of 27 m. The support reactions for the guy supported tower are more when compared to self-supporting tower because they have used heavy angle sections are used as leg members for guy supported tower.

Archana R and Aswathy S Kumar [3] three models of 220 kV double circuit four legged steel transmission tower has been analyzed and designed with an angle, tubular and channel sections. Comparison is carried for different parameters like axial force, deflections, maximum sectional properties, critical loading conditions between these three models of tower. From analysis carried, it is concluded that angular section is more economical and more effective when compared to other sections. Angular section also saves steel weight up to 20.62% when compared to tubular section and it saves 36.10% when compared to channel section.

Y. M. Ghugal and U. S. Salunkhe [4] describes about analysis and design of two models of self-supporting 400 KV steel transmission tower of three legged and four legged for common parameters like height and bracing system. For both the models height is constant and angle section is used for tower members. For both the towers “X” bracing system is provided. When both the models are compared three legged tower showed better performance for axial force, moment, land area, deflection and weight of tower is also reduced than four legged tower.

Umesh S. Salunkhe and Yuwaraj M. Ghugal [5] conducted analysis and design of three legged self-supporting 400 kV double circuit steel transmission line towers models with an angle and tube sections. The axial forces are also increased in all members in three legged tower with angle sections as compared to three legged tower with tube sections during all components. Triangular tower with tube section, deflection is found to increase in normal condition compare with angle sections but within permissible limit. A saving in steel weight of 20.6% resulted when using a three-legged tower tube section compared with an angle sections.

C. Preeti and K. Jagan Mohan [6] conducted analysis and design of 220 kV transmission tower of single circuit for parameters like geometry and behaviour. They have concluded that by using triangular base self-supporting tower shown a saving up to 9.23% in the weight of structural steel, and by using square base guyed mast shown a saving up to 39.96% in the structural steel, which is directly the cost saving in each tower or the structural optimization of the transmission line.

2. METHODOLOGY

A Double Circuit Transmission tower carrying 400kV capacity is analyzed and designed by using STAAD.PRO. The tower height is of 55m which is determined according to IS 5613 (Part 2/ Section 1): 1995. Towers are modeled for ‘X’, ‘K’ and combined bracing systems for different height to width ratios of 3-6. For tower elements Indian angle section with different sectional properties.

2.1 Tower Dimensions

To determine the actual transmission tower height the following need to be considered, the total height of the tower is divided into 4 parts,(a) minimum permissible ground clearance, (b) maximum sag of the conductor, (c) vertical spacing between top and bottom conductor and (d) vertical clearance between ground wire and top conductor. By considering all the above given conditions the total height of the tower is calculated. The height of the tower is kept constant for all the models. The model of transmission tower is shown in figure 1

2.2 Sag Tension Calculation

The sag is calculated for various temperatures and wind pressure conditions. It could be calculated by catenary method or by parabolic method. The parabolic method of sag and tension calculation is followed in IS: 5613 (part 2/Sec 1). The sag and tension are determined for the following temperature and wind pressure combinations.

- Everyday temperature and nil wind
- Everyday temperature and full wind
- Maximum temperature and nil wind
- Minimum temperature and 36 % of full wind
- Minimum temperature and nil wind

The maximum temperature for ACSR conductor is 85^0. The maximum temperature for ground wire is 53^0. The maximum sag of the conductor occurs at maximum temperature and nil wind. The power carrying conductors sags due to its self-weight and the sag is maximum when the temperature is maximum and when there is no wind condition. The maximum sag occurs at the mid-section between the two towers in open country.

Max Sag $S = WL^2/8T$

Where,
W: Weight of the conductor (kg/m)
L: Span Length (m)
T: Tension in conductor (kg)

Table -1: Sag Tension Calculation

Temp	Wind Factor	CONDUCTOR		GROUND WIRE		
		Tension	Sag	Tension	Sag	Sag Ratio
° C		Kg	m	Kg	m	
0	0	4100	9.776	1325	8.798	0.900
0	0.36	5159	7.769	1908	6.111	
32	0	3614	11.269	1201	9.708	0.867
32	1	7972	5.028	3277	3.559	
32	0.75	6631	6.044	2708	4.306	0.712
53	0	3319	12.075	1133	10.289	
85	0	2980	13.258			

Table -2: Tower Dimensions

Description	Length
Minimum permissible ground clearance (h1)	8.84m
Maximum sag of the lower most conductor wire (h2)	13.66 m
Vertical spacing between conductors (h3)	15.8 m
Vertical clearance between ground wire and top conductor(h4)	8.1 m
Total Height of the tower (H)	46.4 m
Bottom Extension of tower	9 m
Span between the towers	400 m

3. THEORETICAL FORMULATION AND MODELING OF TOWER

The tower structure is basically a statically indeterminate structure. Tower is a space frame and also solution becomes complex if all the external loads are simultaneously applied on it. For analytical study purpose various methods are available. Stiffness method has been used for many years; this method can be easily used for the purpose of analysis of pin jointed space truss. For this study, STAAD.PRO has been used for the analysis and design for all the models.

3.1 Analysis of Transmission Tower

As per the code IS 802 (part1/sec1): 2015, the load acting on the tower and its components like conductor etc., can be calculated by following formula.

Wind load acting on the tower

$$F_{wt} = P_d \times C_{dt} \times G_T \times A_e$$

Wind load acting on conductor and ground wire

$$F_{wc} = P_d \times L \times D \times C_{dc} \times G_e$$

Wind load acting on the Insulator strings

$$F_{wi} = Pd \times C_{di} \times G_i \times A_i$$

Where,

P_d = Design wind pressure (N/m^2)
C_{dt} = Drag Coefficient for tower
G_T = Gust response factor
Ae = Total net sectional area of the members (m^2)
L = Wind Span (m)
D = Diameter of cable (m)
C_{dc} = Drag coefficient for Conductor and ground wire
G_c = Gust response factor for conductor
C_{di} = Drag Coefficient for insulator
G_i = Gust response factor for insulator
A_i = 50% of area of the insulator string (m^2)

Table -3: Parameters of Transmission Tower

Transmission Line Voltage	400 kV
Angle of Line Deviation	0 to 15 degree
Terrain type considered	Plain
Terrain Category	2 ((Normal cross country lines with very few obstacles)
Return Period	50 years
Wind Zone	4
Basic wind speed	47 m/sec
Basic wind pressure	71.45 kg/m2
Tower Type	Self-Supporting tower
Tower Geometry	Square based
No. of Circuits	Double circuit
Basic Span	400 m

The loading calculations on transmission tower due to conductor and Groundwire for normal condition (NC) and broken wire conditions (BWC) for both transverse and longitudinal direction wind has been calculated.

3.2 Modeling of Transmission Tower

In order to validate the design, the tower is analyzed and designed using STAAD.PRO. Manual calculations is important for the recommendations of IS codes but the validation of these results and study of effects of these loads on the structure is also an important part to do. Analysis of the performed task is the key to success for the safe and durable serviceability of the structure under various load combinations. Based on validation of results through STAAD.PRO, the important conclusions are made. Star angle sections are used for leg members. Single angle members are used for bracings, belt members subjected to more forces. The section used for leg members are 150x150x15L, 150x150x12L, 130x130x12L, 120x120x10L, 110x110x8L, 90x90x6L, 65x65x5L. The various members used for bracing are 100x100x8L, 90x90x6L, 70x70x5L. The various members used for belt 65x65x5L, 70x70x6L, 75x75x5l. Mild steel of $f_y = 250$ N/mm^2 and high strength steel of $f_y = 350$ N/mm^2 is used for members. Pinned support is provided as support condition. The loads and combination of load cases are also provided for the model.

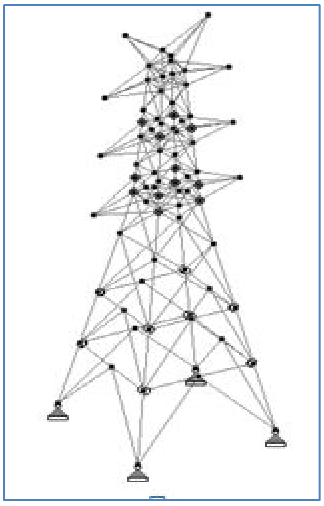


Fig -1: 3D Model of Tower

4. RESULTS

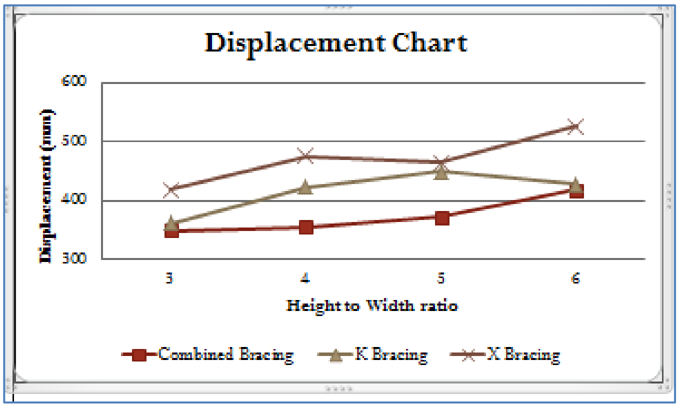
After completing the model and assigning loads to the tower, the analysis is done to calculate the displacement, axial force, total weight for determining the most economical section.

From the below table and graphs, it can be said that, displacement of tower having for combination of both 'X' and 'K' bracing system has less when compared to other two bracing systems for calculated height to width ratios. The displacement has increased 10% for K type bracing system and for X type bracing system it has been increased to 20%. The maximum axial force is carried by X type of bracing system. For each height to width ratio X bracing system has more axial force when compared for K bracing has decreased on an average of 18 percentages and for combined bracing has decreased on an average of nearly 20 percentages. When all the towers are compared K bracing system has more weight for all height to width ratios. X bracing system has reduced to an average 2.76 per cent where for combined bracing on an average 2.21 per cent has been reduced.

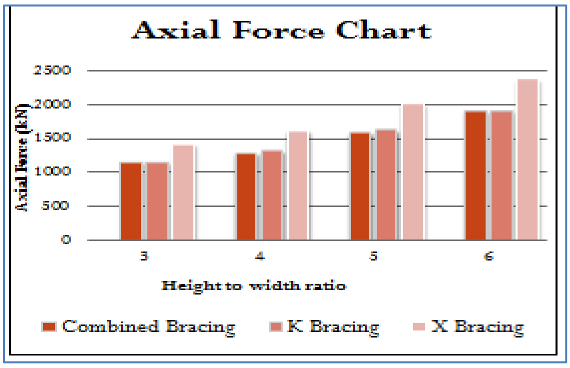
Table -4: Maximum displacement, Axial force and total weight of different transmission towers

Type of Bracing	Height to Width ratio	Total Weight (kN)	Load Carried (kN)	Maximum Displacement (mm)
X	3	132.32	1440	419
X	4	126.07	1637.71	475
X	5	128	2022	464
X	6	124.11	2392.4	526
K	3	135.18	1173	362
K	4	129	1342.4	423
K	5	132	1647	449
K	6	129	1924	427
Combined	3	133.59	1178	349
Combined	4	128.11	1304	356
Combined	5	122.46	1612.2	372
Combined	6	120	1993	418

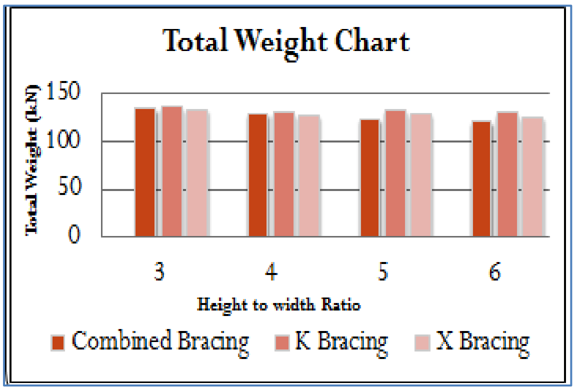
Displacement Chart



Axial Force Chart



Total weight chart



3. CONCLUSIONS

- From the above table and graphs, it can be said that, displacement of tower having for combination of both 'X' and 'K' bracing system has less when compared to other two bracing systems for calculated height to width ratios. The displacement has increased 10% for K type bracing system and for X type bracing system it has been increased to 20%.
- The maximum axial force is carried by X type of bracing system. For each height to width ratio X bracing system has more axial force when compared for K bracing has decreased on an average of 18 percentages and for combined bracing has decreased on an average of nearly 20 percentages.
- When all the towers are compared K bracing system has more weight for all height to width ratios. X bracing system has reduced to an average 2.76 per cent where for combined bracing on an average 2.21 per cent has been reduced.

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