Comparative Analysis of Transmission Tower Using XX and XBX Bracing Systems in Different Wind Zones

Anshu Kumar Pal, M. Suneel, P V Rambabu

Abstract**:** ***An electrical power transmission line tower has now become indispensable requirement for the proper and safe transportation of high voltage electricity in our day-to-day life since it constitute 25 to 45 percent of capital cost of the power transmission line project. As the cost of the tower include parameters like labor, transportation, erection, etc. which are constant, major focus should be given in optimizing steel quantity for achieving the economical design without compromising the required strength of tower. In this analyzation, a quintessential 220 KV suspension type, square based self-supporting transmission tower having double circuit is taken for scrutinization. Two bracing systems viz. XX and XBX are being compared in all the six wind zones of India using seven different load conditions as per IS 802 (Part-1 / Sec-I):1995. The structural behavior of tower for both bracing systems are modelled and analyzed in STAAD Pro V8i software. The denouement of XBX – bracing system was concluded to be more economical in comparison with XX – bracing system in all wind zones of India.***

Index Terms**:** ***STAAD Pro., Transmission Tower, Wind load, 'XX' & 'XBX' Bracings***

I. INTRODUCTION

Electrical power has emerged now an in comfort, safety and welfare of humanity in the 21st century. In every developing or developed country, consumption of electricity has prevailed to rise. The rate of increment is superabundant in case of developing nation like INDIA. Which in sequence raise to increase in number of electric-power stations and their capacities and subsequent increment in number of transmission lines from electricity-generating stations to sub-stations and then to subsequent load centers.

The electrical transmission-line tower is a crucial lifeline engineering which undertakes the duty of carrying electricity. In transmission line projects, the cost in construction of transmission tower embodies 25 to 45 percentage of capital cost of the project. Since the other expenses like labor cost, transportation cost etc. is generally immutable, the major task is confined to the optimization in quantity of steel to make the total cost as economical as possible considering the required strength criteria.

Though transmission-line systems are major parts of electrical engineering, designing of those supporting structures like towers, foundation etc. requires the direct liaison of civil engineers – structural and geotechnical. A principal job thus comes on to the structural engineer, not only to make design economical, but also safer and more reliable. Structurally the transmission-tower should be well enough to withstand loads like wind load, snow load and self-weight as well as in all weather conditions.

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II. LITERATURE REVIEW

T. Raghavendra [1] designed a typical 132 KVA double circuit transmission line tower having five different configurations: 4.46m base width having 6 panels, 5.2m base width having 6 panels, 6.0 m base width having 6 panels, 4.46m base width having 4 panels and 4.46m base width having 3 panels./' The towers have been analyzed using STAAD Pro and results with respect to member axial force were validated in ANSYS. The configuration of transmission-tower of base width 4.46m having 3 panels is concluded as optimum configuration and its member gives the least weight of tower.

Dr D. R. Panchal [2] presented research paper on "Various transmission tower analysis and design using professional software". Formex algebra program has been developed to generate single and double circuit transmission line tower. The results of the three large problems and optimal designs after testing were compared with the results of commercial software STAAD Pro. This developed software has liberty in modification of members in order to get most economical tower design.

May Chaw Su Kyi [3] evaluated the design of a 230 KV double circuit, self-supporting, suspension type steel lattice transmission tower with different wind loads of 21 different loading conditions. Effect in wires due to change in temperature were studied. For design AISC-LRFD technical specification and for wind load calculations ASCE Manuals and Reports on Engineering Practice No.74 were used. In this evaluation, it was found that axial forces acting on tower are raised by 47.2 % with 100 mph wind speed than 80 mph. Moreover, the shear capacity and bearing capacity was found to be larger than maximum axial forces acting in each panel.

Lingampally Srikanth [4] performed the dynamic analysis of transmission-line towers using XB bracings. Tower has been analyzed using IS codes IS-875:1987, IS-802:1995, IS-1893:2002 considering ground motion of 2001 Bhuj Earthquake (India). Central Difference Method (developed by using MATLAB) has been used to obtain the ground motion parameters including acceleration, frequency, velocity and tower was analyzed using response spectrum analysis. In this study, it has been found that breaking load will not be the main criteria for design of components and wind is predominant load on such tower structures.

Xing Fu [5] studied the dynamic analysis of transmission line towers under wind and rain loads. Study was carried out using response analysis and the influence of wind attack angle has been also observed. LP810 has been found to have smaller drag coefficient at wind speed 15 m/s, and it gets inversely greater when wind speed is greater than or equal to 25 m/s. It has been found that larger displacement is caused due to heavier rain intensity.

III. METHODOLOGY

In this study a double circuit 220 KV suspension type, square based self-supporting transmission tower is taken for analyzation. The overall height of the transmission tower is deduced to be 35.54 m which is computed according to IS:5613(Part 2/ Sec 1):1995. Two tower-models having XX-bracing and XBX-bracing systems are modelled and analyzed in STAAD Pro.V8i software. All the loads and design calculation were performed accordingly mentioned in IS-802 (Part 1/Sec- 1):1995.

IV. TRANSMISSIOM TOWER GEOMETRY

As stated in the Indian Electricity Rules, clause 77(4) 1956, the overall height of the transmission-tower is determined. The typical model of transmission-line tower is as presented in fig I.

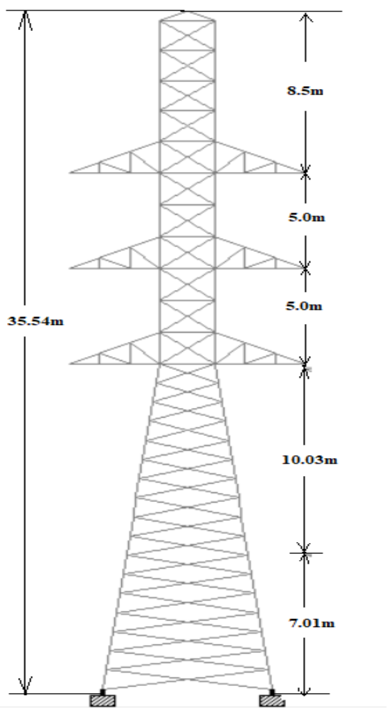


Figure I: Model of transmission tower

The total height of tower is calculated according to the IS code provisions mentioned in IS 5613:1985 (Part 2/ Sec-1).

Table I shows the dimension of tower geometry.

Table I: Dimension of Tower Geometry

Specific Height	Linear distance (m)
Perpendicular distance between conductor and ground-wire (h_4)	8.5 m
Perpendicular distance between conductors (h_3)	5.0 m
Maximal sagging of the lower most conductor (h_2)	10.03 m
Ground Clearing distance (h_1)	7.01 m
Total Height (H)	35.54 m
Width of base (Square)	6.0 m
Span	350 m

V. ANALYSIS OF TOWER

All the load calculation and analysis is performed according to Indian standard code provisions.

A. Load Calculations

According to IS:5613(Part-2/Sec-I)-1985, 3 types of loads act on the transmission tower in 3 different considerations namely, Reliability Considerations, Safety Consideration and Security Consideration. These loads are calculated as per formula mentioned in clauses 9, 12 and 13 of IS:802(Part-1/Sec-I)-1995.

B. Loading Combinations

Loading combination is used as per clause 13 for all the 3 conditions reliability, safety and security conditions. In this work, seven different loading combinations were considered as shown below in Table 2.

Table II: Different Loading Conditions

S. No.	Loading Condition
1.	Reliability Consideration Normal Condition
2.	Security Consideration Normal Condition
3.	Safety Consideration Normal Condition
4.	Security Consideration Top Conductor Broken Wire Condition
5.	Safety Consideration Top Conductor Broken Wire Condition
6.	Security Consideration Ground-wire Broken Wire Condition
7.	Safety Consideration Ground-wire Broken Wire Condition

C. Design Parameters

The design and fulfilling code-check of each member of tower analyzed in STAAD.PRO v8i are formed on the allowable stress design method basis, accordingly IS:802(Part-1/ Sec-1): 1995.

In this work, Indian Steel angle sections are taken for the analysis of tower. The Table III shows the sections used in this analyzation.

Table III: Steel Sections used

in both bracing systems

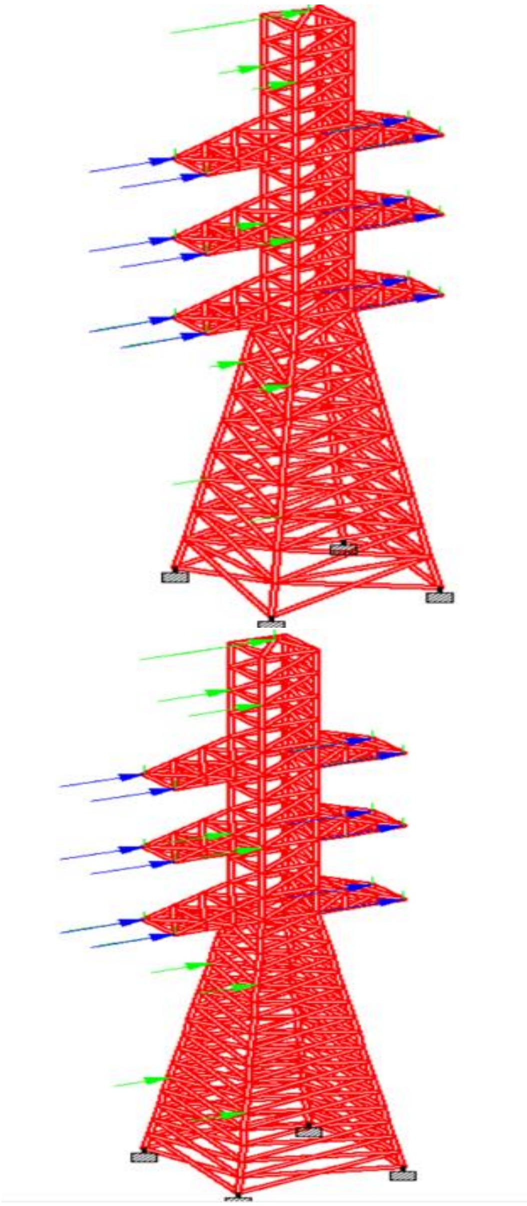
LD ISA 200×150×20	Horizontal & Inclined bracings
ST ISA 150×150×15	Main Vertical Members
SD ISA 65×65×10	Cross arms

The parameters taken in the scrutinization of tower are presented below in the Table IV.

Table IV: Transmission Tower Parameters

Tower type	Suspension tower
Transmission line voltage	220 kV
Angle of line deviation	0^o-2^o
Terrain-type	1
Type of circuits	Double-circuit
Cnductor material "ACSR"	30/7/3.00 mm
Ground wire	7 / 3.66
Coefficient of linear expansion (α) in per degree Celsius "ACSR"	17.73x10^-6
Elastic Modulus (E) in Kg/cm^2 "ACSR"	0.787x10^6
Elastic Modulus (E) in Kg/cm^2 "GSS"	1.933x10^6
Maximal Temperature of conductor	75^o C
Maximal Temperature of Ground wire	53^o C
Everyday temperature	32^o C
Minimum Temperature	-18^o C
Type of Terrain	Plain type
Design Period	50 Years
Type of Peak	Trigonal
Type of Insulator	String type

The figure II shows the wind load acting on both bracing systems viz. XBX (in the left) and XX (in the right) bracing systems.



(A) (B)

Fig: II Wind Load acting on XBX (right) and XX (left) bracing systems

VI. RESULTS AND DISCUSSIONS

In this present work, the nodal displacements due to seven different load cases, were computed for two different types of bracing system as said above at specified points: base of leg, first, second & third cross-arm points and topmost point of the transmission tower using the software STAAD Pro. V8i. Since seven different load combinations give different nodal displacements.

Displacements are calculated at selected specified points. Notations for the specified points are given, base for base, I for first arm cross point, II for second cross arm point, III for third cross arm point and ridge for topmost point of the transmission tower.

Maximum values of the displacements are presented with respect to wind Zones I, II, III, IV, V and VI in tables V, VI, VII, VIII, IX and X respectively.

From the tables V, VI, VII, VIII, IX and X, it is can be

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clearly seen that displacements at the base of leg is zero in all the cases due to the zero bending moment at the base point of the legs.

Table V: Node Displacement in Wind Zone – I

Points	XX-Bracing (Displacement, in mm)			XBX-Bracing (Displacement, in mm)		
	X	Y	Z	X	Y	Z
Base	0	0	0	0	0	0
I	24.85	12.44	13.01	21.70	10.79	11.81
II	45.67	16.42	23.12	39.20	14.26	20.60
III	70.35	17.86	35.63	60.38	15.61	31.74
Ridge	115.3	4.18	58.40	99.31	3.38	45.43

Table VI: Node Displacement in Wind Zone – II

Points	XX-Bracing (Displacement, in mm)			XBX-Bracing (Displacement, in mm)		
	X	Y	Z	X	Y	Z
Base	0	0	0	0	0	0
I	27.95	14.38	13.01	24.20	11.97	11.81
II	51.35	18.90	23.12	43.7	16.20	20.60
III	79.08	29.55	35.63	67.29	17.73	31.74
Ridge	129.5	4.18	58.40	110.56	3.38	45.43

Table VII: Node Displacement in Wind Zone – III

Points	XX-Bracing (Displacement, in mm)			XBX-Bracing (Displacement, in mm)		
	X	Y	Z	X	Y	Z
Base	0	0	0	0	0	0
I	30.937	16.24	13.01	26.61	13.39	11.81
II	56.815	21.28	23.12	48.02	18.07	20.60
III	87.482	23.14	35.63	73.93	19.77	31.74
Ridge	143.271	4.18	58.40	121.37	3.38	45.43

Table VIII: Node Displacement in Wind Zone – IV

Points	XX-Bracing (Displacement, in mm)			XBX-Bracing (Displacement, in mm)		
	X	Y	Z	X	Y	Z
Base	0	0	0	0	0	0
I	32.899	17.47	13.01	28.19	14.32	11.81
II	60.408	22.84	23.12	50.87	19.29	20.60
III	93.006	24.84	35.63	78.29	21.11	31.74
Ridge	152.27	4.18	58.40	128.48	3.382	45.43

Table IX: Node Displacement in Wind Zone – V

Points	XX-Bracing (Displacement, in mm)			XBX-Bracing (Displacement, in mm)		
	X	Y	Z	X	Y	Z
Base	0	0	0	0	0	0
I	34.99	18.77	13.01	29.88	15.32	11.81
II	64.24	24.51	23.12	53.9	20.60	20.60
III	99.89	26.65	35.63	82.94	22.54	31.74
Ridge	161.86	4.18	58.40	136.06	3.382	45.43

Table X: Node Displacement in Wind Zone – VI

Points	XX-Bracing (Displacement, in mm)			XBX-Bracing (Displacement, in mm)		
	X	Y	Z	X	Y	Z
Base	0	0	0	0	0	0
I	38.76	21.13	13.01	32.92	17.91	11.81
II	71.15	27.52	23.12	59.37	22.96	20.60
III	109.51	29.52	35.63	91.33	25.12	31.74
Ridge	179.17	4.18	58.40	149.74	3.382	45.43

Displacement is increasing as the height is increased along three directions of the tower. But displacement along y-direction at the topmost point in all wind zones is found to be less i.e. 3.3 mm for XX-bracing and 2.7 mm for XBX-bracing but along z direction, displacement is same because of same load applied in all wind zones. In both the bracing systems, displacement along x-direction is found to be much higher, nearly twice the displacement along z-direction. As the wind load acting along x-direction is dominant, the displacement is found to be higher than other direction.

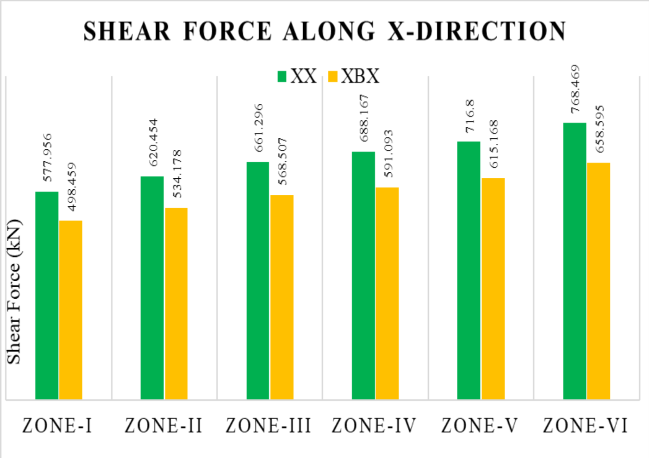

Fig. 3: Shear Force along x-direction

From fig.3 the shear force along x direction in wind zone – I is found to be 577.956 kN in case of XX-bracing system and 498.459 kN in case of XBX-bracing system. Similarly, for all the remaining wind zones, on comparison it is revealed that shear force along x direction affects more XX – bracing system as compared to XBX – bracing system, wind zone – VI having highest effect of axial load i.e. 768.469 kN in XX – bracing whereas 658.595 kN in XBX – bracing system. As the wind load is dominant, axial forces are higher as compared to shear forces acting on the transmission tower.

As shown in the Table 10, the total amount of steel used in XX – bracing system is found to be 905.784 kN and in XBX – bracing system, it is found to be 790.326 kN. It is observed that the amount of steel required in XX – bracing system is found to be much higher i.e. 115.458 kN higher amount than XBX – bracing system.

Table XI: Quantity of Steel required

Steel Angle Section	XX – Bracing System		XBX - Bracing System	
	Length (m)	Weight (kN)	Length (m)	Weight (kN)
LD ISA 200 × 150 × 20	778.27	792.76	664.92	677.30
SD ISA 65 × 65 × 10	360.23	66.41	360.23	66.41
ST ISA 150 × 150 × 15	141.09	46.60	141.09	46.60
Total Weight (kN)	905.783		790.326	

VII. CONCLUSIONS

In this work, an optimized steel bracing system is recommended in the design of transmission line tower using STAAD Pro. V8i software. From the above interpreted results and discussions, following conclusion is made:

1) Shear force along x direction acting on the tower is considerably more in XX – bracing system by 15.95 % in wind zone – I, 16.15 % in wind zone – II, 16.32 % in wind zone – III, 16.42 % in wind zone – IV, 16.52 % in wind zone – V and 16.68 % in wind zone – VI as compared to XBX – bracing system.
2) There is no significant change in shear forces in both the bracing system.
3) The nodal displacement in XX – bracing system is quite higher in x-axis (transverse direction) as compared to XBX – bracing system. i.e. 115.356 mm & 99.319 mm in wind zone – I, 129.591 mm & 110.565 mm in wind zone – II, 143.271 mm & 121.374 mm in wind zone – III, 152.27 mm & 128.484 mm in wind zone – IV, 161.861 mm & 136.06 mm in wind zone – V, 179.165 mm & 149.735 mm in wind zone – VI respectively.
4) The displacement in y-axis (axial direction) and z-axis (longitudinal direction) has very lesser discrepancies in both bracing systems.
5) The nodal displacements in x-direction and z-direction at base of legs, first cross-arm, second cross-arm, third cross-arm and topmost point of tower is found to be continuously increasing but in y-direction, it is found that nodal displacement is increasing up to third cross-arm point and it is decreased to 4.188 mm displacement in all wind zones.
6) The material i.e. quantity of steel required in XBX – bracing system is found to be lesser by 14.61 % as compared to XX – bracing system.
7) XBX – bracing system is found to be optimum and economical in design of electrical transmission line towers in both strength and cost of material required in comparison to XX – bracing system.

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