Analysis and Design of Transmission Line Tower 220 kV: A Parametric Study

Dr. S. A. Halkude[1], Mr. P. P. Ankad[2]
Civil Engg. Dept. Walchand Institute of Technology,
Solapur, Solapur University, India

***Abstract*:- It has become extremely difficult to secure land for power transmission lines year after year due to various restrictions, such as density of population in the urban areas, obtaining forest clearances and nature preservation philosophy. It is necessary to develop technically compact 110/132 kV & 220 kV transmission line tower structures to minimize the tower dimensions. In this study, an attempt is made to get optimum geometric tower configuration by considering various parameters such as width to height ratio, different types of bracing systems and number of panels in a body of tower. The present work describes the analysis and design of self-supporting 220 KV steel transmission line tower viz various parameters. The towers are tangent type and are designed for constant height, common clearances, common span, common conductor and ground wire specifications. In this study constant loading parameters including wind forces as per IS: 802 (1995) are taken in to account. After analysis, the comparative study is presented with respect to slenderness effect, critical sections, forces, deflection and weight of the tower. A saving in area up to 45% is resulted when 'X' bracing system is compared with 'K' and 'XBX' bracing system.**

***Keywords:* Width to height ratio, Bracing system, Transmission line, Broken wire condition, Single circuit.**

1. INTRODUCTION

Transmission line towers contribute nearly 40 percent of the cost to the transmission line project. Electricity is a major source of power for industries, commercial and residential use. Due to rapid growth in industrial area and because of infrastructure development, the need for electricity increases. Because of lesser cost, electricity is now being used for rail transportation in place of fuel-powered engines. Therefore, it is required to transmit the high voltage to the area in need, so we require installing transmission line tower to carry Extra High Voltage (EHV). The construction of E.H.V. lines, design of towers and testing of towers consume 20% of time as a most moderate estimate. The design, testing and fabrication of towers taken together would take about 35% of total project time. The tower which stands on its own without the help of external support is known as a free-standing or self-supporting tower or rigid tower. Self-supporting tower is usually of lattice construction and it is commonly adopted throughout the world. These towers are sufficiently rigid, suitable for multi circuit and compact lines and the only type used for angle and special type towers. They can be tailor-made to any ground condition. The economy of a tower is influenced by a number of other parameters. So, in order to arrive at cost effective tower configuration, one has to consider various parameters which affect the cost of the tower. The parameters selected according to their impact on the cost of the tower are as mentioned below. i) Base width variation. ii) Different types of bracing. iii) Number of panels in body of the tower.

1.1 Objective of the study: The body of the tower forms a major portion of the weight of the tower and bracing contributes significantly to the weight of the body. As discussed, economy of the tower is influenced by parameters like base width, number of panels and types of bracings. In this report analysis is done for constant height of tower.

To arrive at economic tower geometry, different geometric combinations are made in the body of the tower using parameters mentioned above. Program is prepared using excel to calculate wind load on tower. Total eighty towers are analyzed and designed to get optimum tower configuration.

2. TRANSMISSION LINE TOWER

The electric power generated at the thermal hydro and nuclear power plants is distributed far and wide by a network of transmission lines. Transmission lines can therefore be compared to the circulatory system in the human body which distributes the energy required by the various parts of the body. Transmissions lines are, as of today, a set of overhead conductors and a ground wire which transmit the electrical energy as high voltage current. Supporting structures are constructed at intervals to keep these lines at a clear height from the ground level. These structures are known as transmission poles or towers. The Structure Engineer is entrusted with the challenging job of designing and constructing transmission structures to support heavy conductor loads in open weather with high degree of reliability and safety to the general public ensuring satisfactory serviceability

2.1 Tower

Tower may usually contain two main panels with the top one known as the cage and bottom one as the body with legs spreading out to give better stability against overturning moment. These are again divided into sub panels by horizontal planes containing primary joints. Each subpanel will have a particular bracing arrangement on each face. The cage (or basket) portion will have almost upright legs and will be fitted with cross arms to carry the conductor loads at a safe distance from the tower body. Above the basket, there may be a tip formation, which carries the ground (Lightning Shield) wire. The columns and braces in the bottom main panel will be usually very long and carry heavy compressive forces. To improve the compression caring capacity of these members secondary bracing members are provided which reduce the effective length and there by the slenderness ratio. These secondary bracing do not carry significant loads and will be of nominal size.

3. DETAILS OF TOWER CONFIGURATION

For the study purpose the data available for 220 KV transmission line tower with Maharastra state (MAHATRANSCO) is adopted. The body of a typical single circuit tower subjected to the different load combinations is considered for the parametric study of the effect of the parameters on the weight of tower. Different combinations of the parameters are selected and the weight of the structure under the given system of loads is found. Height of the tower is kept constant and variation in other parameters listed earlier is considered. Total eighty towers are analyzed and designed for various geometric configurations.

1. Base width: Different base widths are studied. For 20 m body height widths chosen are from 4 m to 7.5 m with an interval of 0.5 m. Base width variation is considered until we get optimum weight of the tower.
2. Bracing systems: Three different types of bracing systems namely 'XBX', 'K', and 'X' are considered for the study purpose. The secondary bracings are provided such that the leg member (column) has an unsupported length mostly in the range of 1.1 m to 1.3 m. and in exceptional cases up to 1.5 m.
3. Number of Panels: The efficiency of a particular bracing system depends to some extent on the heights of the different panels and a rigorous study requires that the panel heights to be varied for different panels of the tower. This would increase the number of trails to be performed and therefore in this study, the panel heights are kept constant. The number of panel for the 20 m body height of the tower considered, are taken as 4, 5, 6, and 7.

Table 1 lists the details of some parameters typical to a 220 kV double circuit suspension type tower and Table 2 lists the details of some parameters of conductor and ground wire are assumed from IS: 802 (Part 1 / Sec 1): 1995, IS: 5613(Part 2 / Sec 1): 1989.Load and Loading combinations criteria on the groundwire, conductor and all the towers are evaluated using IS: 802.

THEORETICAL FORMULATION AND MODELING APPROACH

Various methods are available for analysis. With the advent of digital computers, emphasis shifted to the methods which fully utilize the capability of these computing machines. Stiffness method has gained immense popularity in the last fifty years. It is an elegant and versatile method of structural analysis. Most commonly occurring example of a space truss is the transmission tower. The stiffness method can be conveniently used for the analysis of pin jointed space truss. The theoretical formulation follows steps almost identical to those for plane truss, with relevant changes in matrix size, degrees of freedom, etc. A transmission line tower is a three dimensional cantilever truss. Its analysis as a space frame is highly tedious. The results obtained by software STADD-PRO are validated by comparing with the solution available in the literatures. The analysis of all framed structures is carried out by STAAD-PRO international analysis and design software package. The general package STADD-Pro2006 has been used for the analyses and design. In this study, 3D analysis of tower considering all the members of the space truss as primary member has been used in STADD-Pro. As transmission line towers are comparatively light weight structures and also that the maximum wind pressure is the main criterion for the design, also concurrence of earthquake and maximum wind pressure is unlikely to take place. The loading calculations on tower due to conductor and ground wire in normal condition as well as broken wire condition considering transverse direction wind showing in fig. 2.

Table 1: Parameters for the transmission line and its components

Transmission line voltage	220 kV.
Tower type	Suspension type.
No. of circuits	Single circuit.
Angle of Line deviation	0^0- 2^0
Terrain type considered	Plain (II).
Basic wind speed	39 m/s.
Basic wind pressure	0.483 KN/m^2.
Maximum temperature	75^0
Average every day temperature	32^0
Min. temperature	0^0
Insulator type	Suspension type.
Weight of insulator disk	3 KN.
Weight of ground wire attachment	2 KN.
Wind span	300 m.
Weight span	450 m.

Table 2: Parameters for the conductor and ground wire

Description.	Conductor.	Ground wire.
Conductor material	0.4 ACRS (ZEBRA).	Earth wire.
Conductor size	54/3.18 mm Aluminum + 7/3.18 mm Steel.	7/3.15
Overall diameter of the conductor (d)	28.62 mm.	9.45 mm.
Area of the conductor	4.824 cm^2.	0.546 cm^2.
Weight of the conductor	1.625 kg/m.	0.430 kg/m.
Breaking strength of the conductor	13316.00 kg.	5710 kg.
Coefficient of linear expansion (α)	0.199 × 10^{-4}/^{0}c.	0.115 × 10^{-4}/^{0}c.
Modulus of elasticity	858307 kg/cm^2.	0.1933 × 10^7 kg/cm^2.

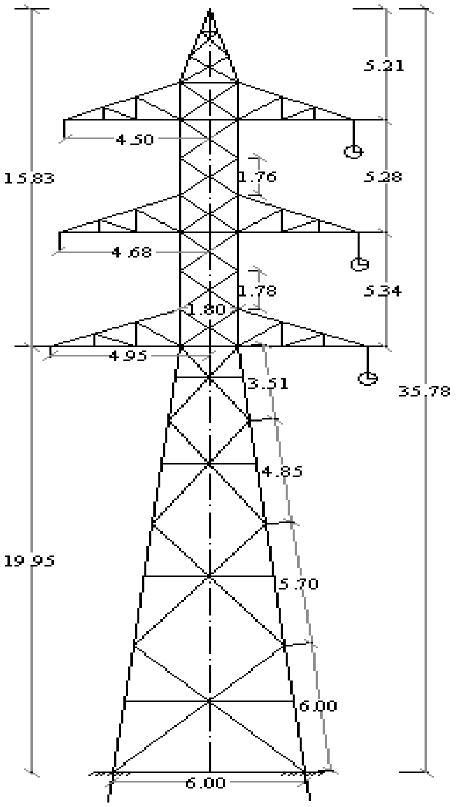


Figure 1: Geometric Configuration of the Tower.

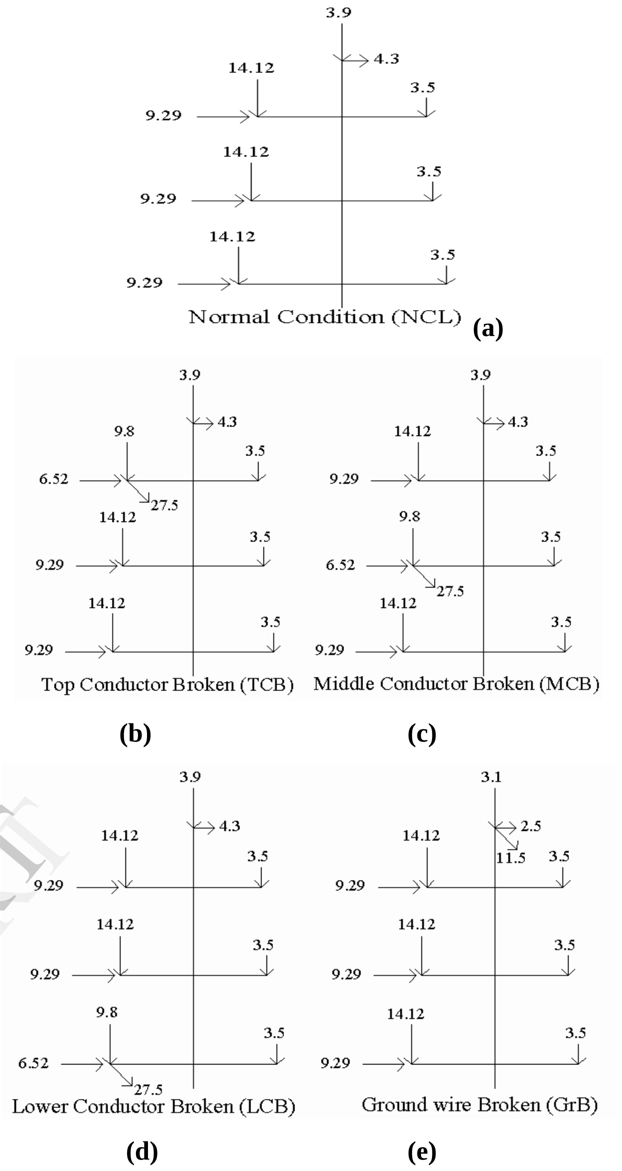


Figure 2: Load on the Tower due to broken conductor and wind load in transverse direction.

4. DISCUSSION AND RESULTS

The body of the tower forms a major portion of the weight of the tower and bracing contributes significantly to the weight of the body. As discussed, economy of the tower is influenced by parameters like width to height ratio, types of bracings systems, and number of panels. To get economic tower geometry, different geometric combinations are made in the body of tower using parameters mentioned above. Total eighty towers are analyzed and designed to get economical tower configuration. These towers are analyzed and designed for all loading combinations. During analysis and design, it is observed that the top conductor broken condition is more stringent for the column (leg) members. The design of main bracing members is governed by middle and lower conductor broken conditions. An effect of above parameters is studied to compare weight of the tower, axial force variation, displacements and weight of secondary bracing.

4.1 Optimum Weight of the Tower

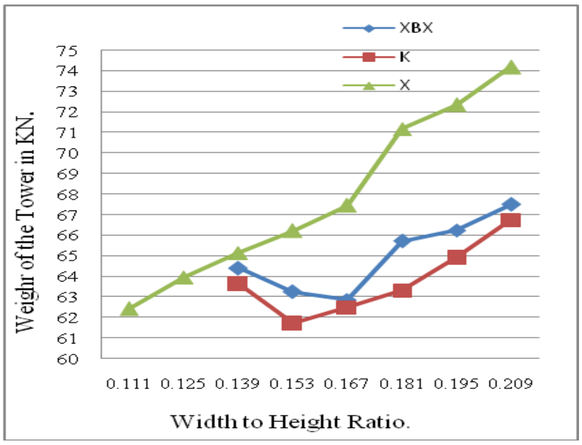
A 220 kV transmission line tower is analyzed and designed. And the effect of base width variation on weight of the tower is studied. Total eighty towers are analyzed and designed considering various combination of parameters, and the graph are plotted to get optimum weight of the tower with respect to width to height ratio. One sample case is considered and following resulted are plotted for different types of bracing systems and number of panels five in body of the tower (Ref. Graph. 1.). It is observed that, In case of ‘XBX’ and ‘K’ bracing, as the width to height ratio increases, weight of the tower decreases up to certain limit, thereafter weight of the tower increases. In case of X bracing as the width to height ratio increases from 0.111 to 0.209 weight of the tower is also increases. So, from the graph 2, it is observed that optimum weight of the tower is obtained for the 0.167, 0.153 & 0.111 and for the bracing system ‘XBX’,’K’ & ‘X’ respectively.

4.2 Land Required for Installation of Tower

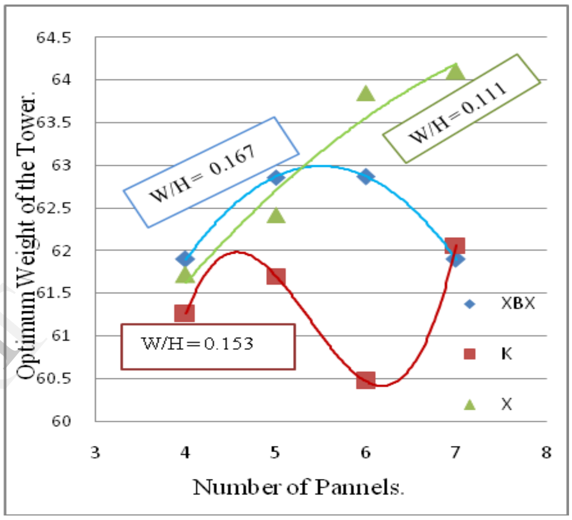
Likewise various combinations of geometric configuration are studied and optimum weight of the tower is obtained as discussed above. Fig.6. Represent the optimum weight of the tower for various parameters. For ‘X’ bracing system width to height ratio is minimum (0.111), so land required is less in case of ‘X’ bracing system as compared to ‘XBX’ and ‘K’ bracing system.

Table 3: Optimum weight of the tower for various parameters studied.

Type of Bracing.	Width to height ratio.	No. of panels	Total weight of tower in kN.
‘XBX’	0.167	4	61.9
‘XBX’	0.167	5	62.86
‘XBX’	0.153	6	62.87
‘XBX’	0.167	7	**61.81**
‘K’	0.167	4	61.26
‘K’	0.153	5	61.7
‘K’	0.153	6	**60.47**
‘K’	0.153	7	62.06
‘X’	0.111	4	**61.72**
‘X’	0.111	5	62.42
‘X’	0.111	6	63.85
‘X’	0.111	7	64.1



Graph 1: Weight of the Tower for various parameters and with number of panels five.



Graph 2: Optimum Weight of the Tower for various parameters.

4.3 Maximum Force Result

From the graph 3, it is seen that, as optimum tower configuration is considered, for ‘XBX’ and ‘K’ type of bracing system axial force in the body of tower is nearly same for even number of panels. For odd number of panels’ axial force in ‘K’ type of bracing system increases from 6 to 10 percent compared to ‘XBX’ bracing.

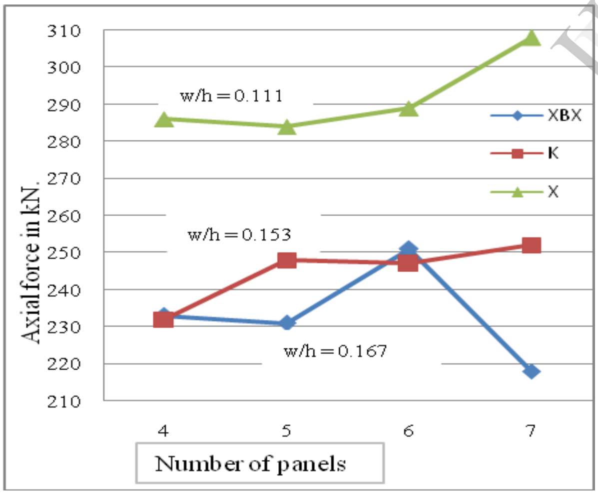
In case of ‘X’ bracing system axial force in the body of tower increases from 20 to 30 percent compared to ‘XBX’ and ‘K’ bracing system.

4.4 Maximum Displacement Results

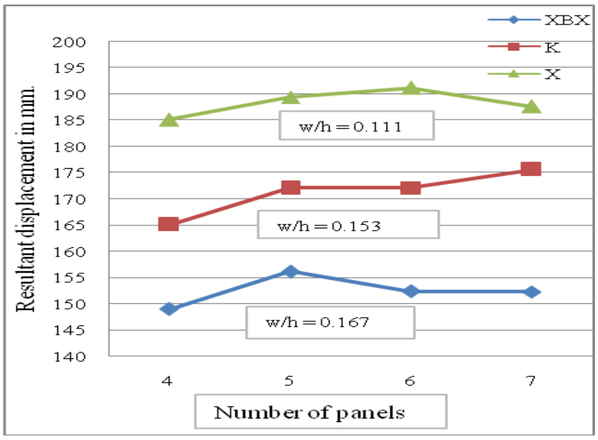
From the graph 4, it is seen that, as optimum tower configuration is considered, in case of ‘X’ type of bracing system, displacement at top cross-arm tip increases from 6 to 10 percent against ‘K’ bracing system and increases up to 20 percent against ‘XBX’ bracing.

Table 4: Maximum Axial Force and Displacement for various parameters studied.

Type of Bracing.	Width to height ratio.	No. of panels	Maximum Axial Force in kN.	Maximum Resultant Displacement at Top Cross-Arm Tip
‘XBX’	0.167	4	233	149
‘XBX’	0.167	5	231	156.18
‘XBX’	0.167	6	251	152.4
‘XBX’	0.167	7	218	152.3
‘K’	0.153	4	232	165.1
‘K’	0.153	5	248	172.1
‘K’	0.153	6	247	172.15
‘K’	0.153	7	252	175.6
‘X’	0.111	4	286	185.15
‘X’	0.111	5	284	189.4
‘X’	0.111	6	289	191.17
‘X’	0.111	7	308	187.6



Graph 3: Maximum Axial Force in the body the Tower for optimum geometric configuration.



Graph 4: Maximum Displacement at top cross arm tip for optimum geometric configuration.

5. CONCLUSION

1. For ‘K’ and ‘XBX’ type of bracing systems, width to height ratio between 0.153 and 0.167 is found to be economical. However, it is necessary to adopt a leg slope from 1/7 to 1/8 for economical tower configuration. If the slope decreases, weight of the tower increases from 3% to 7%.
2. For ‘X’ type of bracing system width to height ratio 0.111 is found to be economical. However, it is necessary to adopt a leg slope of 1/12 for economical tower configuration.
3. For ‘XBX’ bracing system, adopt 4 and 7 numbers of panels to get optimum geometric configuration of the tower. And for ‘K’ bracing system, adopt even number of panels to get optimum geometric configuration of the tower.
4. For X type of bracing system, 4 numbers of panels are sufficient for the ratio 0.111. The increase in panel numbers and width to height ratio with more secondary bracing are not found to be economical for X bracing.
5. ‘X’ bracing system is found to be uneconomical compared to ‘K’ and ‘XBX’ bracing beyond the width to height ratio 0.139. Weight of the tower with X bracing system increases from 3% to 13% as the number of panels and width to height ratio increases.
6. Where the land is costly and restriction are on availability of the corridor, in such situations, it is preferable to adopt ‘X’ bracing system. For X type of bracing system optimum base width is 4 m which is much less as compared to other bracing systems, reducing land required.
7. With use of ‘X’ type of bracing system 45% to 55 % land area can be saved as compared to ‘XBX’ and ‘K’ bracing system.
8. As far as the optimum geometric configuration of the tower is concerned the following observations are made:
    - In case of ‘X’ bracing system, axial force in the body of the tower increases from 20% to 30 % as compared to ‘XBX’ and ‘K’ bracing system.

- In case of 'X' type of bracing system, displacement at top cross-arm tip increases from 6% to 10 % in comparison with 'K' bracing system and whereas displacement increases up to 20 percent against 'XBX' bracing.

9. Further, study regarding the effect of the variation in panel heights may lead to economical panel dimensions of the tower. The observations of the present study give a direction for future research.

ACKNOWLEDGEMENTS

I am thankful to all staff of civil engineering department, Walchand Institute of Technology, Solapur, regarding this paper.

6. REFERENCES

1. M.D. Raghunathan, P.R. Natarajan, "The design of 800 kV transmission line tower: A comparative study". (Journals of Structural Engineering, Vol. 32, No.5, Dec 2005.)
2. N. SUBRAMANIAN, "Investigation on a 220kV cold-formed latticed transmission line tower".
3. M.Selvaraj, S.M.Kulkarni, R.Ramesh Babu, "Behavioral Analysis of built up transmission line tower from fiber reinforced polymer (FRP) pultruded sections". ISSN 0976 – 4399. Volume 2, No 3, 2012.
4. Y.M. Ghugal, U.S. Salunkhe, "Analysis and Design of Three and Four Legged 400kV Steel Transmission Line Towers: Comparative Study". ISSN 0974-5904, Volume 04, No 06 SPL, October 2011.
5. Manual of Specifications and Standards. MAHATRANSCO, (Maharastra State Electricity Transmission Co. Ltd. INDIA).
6. IS: 802 (Part 1/ Sec 1): 1995 – 'Code of practice for use of structural steel in overhead transmission line towers', (Materials, Loads and Permissible Stresses).
7. IS: 5613 (Part 2/ Sec 1): 1985 – 'Code of practice for design installation and maintenance of overhead power lines', Part 2 - up to 220 kV lines, Section 1 – Design.
8. IS: 802 (Part 1/ Sec 2): 1992 – 'Code of practice for use of structural steel in overhead transmission line towers', (Materials, Loads and Permissible Stresses).
9. IS: 802 (Part 2): 1978 – 'Code of practice for use of structural steel in overhead transmission line towers', (Fabrication, Galvanizing, Inspection and Packing).
10. IS: 802 (Part 3):1978 - 'Code of practice for use of structural steel in overhead transmission line towers', Part 3 – Testing.
11. IS: 800 -1984 – 'Code of practice for general construction in steel'

AUTHORS BIOGRAPHY

First Author

Dr. S. A. Halkude,

M.Tech. (IIT, Bombay in Civil Engineering), Ph.D. (IIT Bombay). Dean, faculty of Engineering & Technology, Solapur University, Solapur (Maharashtra, India). Recipient of IGS-Dr. B.B. Rai- S. N. Gupta Bi-ennial Prize for the best paper on "Earth and Earth Retaining Structures". Also recipient of Eminent Educationist Award by National & International Compendium, New Delhi (India). Fellow member of The Institution of Engineers (India), Life Member of Indian Society for Technical Education, New Delhi and Life Member of Indian Society for Rock Mechanics and Tunnelling Technology, New Delhi. halkude60@gmail.com

Second Author

Mr. P.P. Ankad,

B.E. (Civil Engineering), M.E. (Civil - Structures), paragankad@gmail.com