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Optimal Bracing System for Steel Towers

A. Jesumi*, M.G. Rajendran**
*(PG student, School of Civil Engineering, Karunya University, Coimbatore –641 114)
** (Professor, School of Civil Engineering, Karunya University, Coimbatore –641 114)

ABSTRACT

The major system providing lateral load resistance in steel lattice towers is bracing system. There are different types of bracing systems for steel lattice towers. The heights of these towers vary from 20 to 500 meters, based on the practical requirements. This study has focused on identifying the economical bracing system for a given range of tower heights. Towers of height 40m and 50m have been analyzed with different types of bracing systems under wind loads. The diagonal wind has been found to be the maximum for towers. The optimal bracing system has been identified and reported.

Keywords **-** bracing system, steel lattice towers, wind analysis

1. INTRODUCTION

Towers are tall steel framework construction used for different purposes such as communication, radio transmission, satellite receptions, air traffic controls, television transmission, power transmission, flood light stands, oil drilling masts, meteorological measurements, etc. The present paper discusses microwave transmission towers. Lattice towers act as vertical trusses and resists wind load by cantilever action. The bracing members are arranged in many forms, which carry solely tension, or alternatively tension and compression. The bracing is made up of crossed diagonals, when it is designed to resist only tension. Based on the direction of wind, one diagonal takes all the tension while the other diagonal is assumed to remain inactive. Tensile bracing is smaller in cross-section and is usually made up of a back-to-back channel or angle sections. The bracings behave as struts, when it is designed to take compression. One of the most common arrangements is the cross bracing. The most significant dimension of a tower is its height. It is normally several times larger than the horizontal dimensions. The area which is occupied at the ground level is considerably limited and so, slender structures are commonly used.

The tapered part of the tower is advantageous with regard to the bracing, as it reduces the design forces. The greater the height of the tower, greater will be the distance it can transmit radio signals. Towers are classified as Self-supporting towers and Guyed towers. Self-supporting towers are generally preferred since they require less base area. Towers are subjected to gravity loads and horizontal loads.

Bracings hold the structure stable by transferring the loads sideways (not gravity, but wind or earthquake loads) down to the ground and are used to resist lateral loads, thereby preventing sway of the structure. Bracing increases the resistance of the structure against side sway or drift. The higher the structure, the more it is exposed to lateral loads such as wind load, since it has higher tendency to sway. If the bracing is weak, the compression member would buckle which leads to failure of the tower. Diagonal braces are efficient elements for developing stiffness and resistance to wind loads. There are different types of bracing systems in common use such as Single diagonal bracing, double diagonal (X-X) bracing, X-B bracing, XBX bracing, arch bracing, subdivided V bracing, diamond lattice system of bracing, K, Y, W, X bracings, etc.

K. Agarwal and K. Garg (1994) have assessed free-standing lattice towers for wind loads. It has been found that large variations have occurred in wind loads on towers and there are several gaps in the present recommendations which are to be answered by more rigorous wind tunnel investigations. The behavior of cross-bracings in latticed towers was studied by Alan R. Kemp and Roberto H. Behncke (1998). The cross bracings have shown complex behavior and the number of bolts in the connection of the bracing to the main legs have been apparent in the results. M.Selvaraj, S.M.Kulkarni and R.Ramesh Babu (2012) have investigated on the behavior of built up transmission line tower from Fiber Reinforced Polymer (FRP) pultruded sections. They have discussed experimental studies carried out on an X-braced panel of transmission line tower made from FRP pultruded sections. The upgradation of transmission towers using a diaphragm bracing system was experimented by F. Albermani, M. Mahendran and S. Kitipornchai (2004). Their results showed that considerable strength improvements were achieved with diaphragm bracings. The upgrading system using the most efficient diaphragm bracing type has been successfully implemented on an existing 105 m-height TV tower. F. Al-Mashary, A. Arafah and G. H. Siddiqi [5] have investigated on the effective bracing of trussed towers against secondary moments. The study showed that improper bracing configuration of the main and/or secondary braces induced high secondary moments. Thus, it is necessary to identify the economical bracing system for a given range of tower height.

The main purpose of the paper is to demarcate the economical bracing system of steel lattice towers. Investigations carried out to analyze towers with different heights and different bracing configurations have been presented. The towers have been analyzed for wind loads with STAAD Pro., to compare the maximum joint displacement of each tower. Optimized design has been carried out to estimate and to compare the weight of each tower. The results have been used to identify the economical bracing system for a given range of height of towers.

2. GENERAL CONSIDERATIONS

In this study, five steel lattice towers with different bracing configurations such as the X-B, single diagonal, X-X, K and Y bracings have been modeled for a given range of height. The heights of the towers are 40m and 50m with a base width of 2m and 5m respectively. The tower of height 40m has 13 panels and the tower of height 50m has 16 panels. 70-72% of the height is provided for the tapered part and 28-30% of the height is provided for the straight part of the tower.

3. TOWER ANALYSIS

The towers have been modeled using geometric coordinates. The member property was assigned to each member of the structure. The leg, diagonal bracings and horizontal bracings are provided with angle sections. Elastic modulus, Poisson's ratio, density, alpha and damping are the material properties used for the analysis. A hemispherical dome was assumed to be mounted at the top panels of the towers. The towers were analyzed considering it to act as a space structure with pin joints, for dynamic wind loading and optimized design was carried out. The displacements and weights of the towers obtained were compared to arrive at an optimal solution.

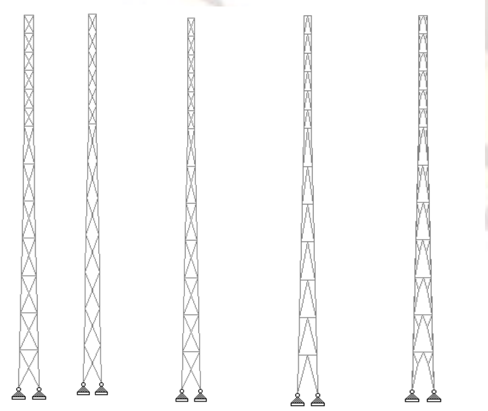

Fig. 1: Models of the towers with different bracing configurations for 40m height

The elevations of the towers of height 40m and 50m with different bracing configurations are shown in fig.1 and 2 respectively.

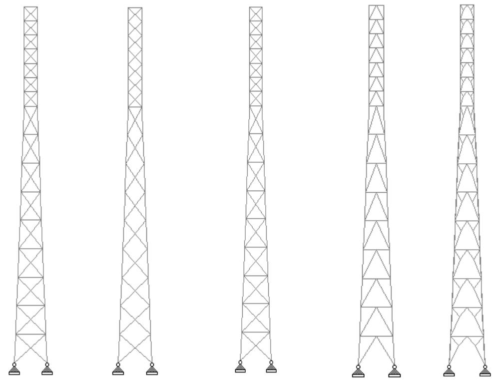

Fig. 2: Models of towers with different bracing configurations for 50m height

4. LOADING

The loads act in three mutually perpendicular directions such as vertical, normal to the face and parallel to the face of the tower. The loads applied to the towers are based on the codal provisions in IS: 875-1987 part 3. Since towers are tall and flexible, it is critical under wind load. The wind load is determined by dividing the tower into different panels of equal heights. The calculated wind load is transferred on each joint of the exposed face of the tower. For square steel lattice towers, the maximum load occurs when wind blows diagonally. Therefore, IS: 875-1987 part 3 recommends the diagonal wind to be 1.2 times the wind blowing normal to the face. The vertical loads act centrally and are distributed equally among the four legs. Bending moments produce an equal compression in the two legs of one side, and equal tension in the two legs of the other side when the wind is considered acting in any one direction. The shear forces are resisted by the horizontal component of the leg forces and the brace forces. Thus, the taper has a major influence on the design of the bracing.

The design wind pressure is calculated at increasing heights of a tower from the mean ground level with the following equation:

$$P_Z = 0.6V_Z^2 \qquad (1)$$

Where,

P_Z is the design wind pressure in N/m^2

V_Z is the design wind speed in m/s

The design wind speed is obtained taking into account, factors such as risk coefficient, terrain roughness, height, size of the structure and local topography. It is expressed as:

$$V_Z = V_b k_1 k_2 k_3 \qquad (2)$$

Where,

V_b is the basic wind speed in m/s

k_1 is the risk coefficient

k_2 is the terrain, height and structure size factor

k_3 is the local topography factor

The basic wind speed for the proposed location was 39m/s. The wind load is the product of the dynamic wind pressure, the overall force coefficient and the effective exposed area of the tower. The force coefficient for the exposed surface depends on the solidity ratio. It is expressed as:

$$F = C_F.A.P_Z \qquad (3)$$

Where,

F is the force acting on the structure

C_F is the force coefficient

A is the exposed surface area of the structure

P_Z is the design wind pressure

5. LOAD COMBINATION

The towers have been analyzed for the following load combinations according to IS: 875-1987 part 3.

1. DL + WL with wind blowing normal to the face of the tower
2. DL + WL with wind blowing diagonal to the face of the tower
3.

6. ANALYSIS

The steel lattice towers have been analyzed, idealizing it as a 3D truss as per IS: 800-2007, with various bracing configurations. The dead loads acting on the tower are self weight of the tower and self weight of antenna. The wind loads are considered acting both normal and diagonal to the face of the tower. Wind loads have been computed by MS Excel and have been incorporated in the analysis done by STAAD Pro.V8i. The joint displacement with respect to normal wind and diagonal wind has been obtained from the analysis for each tower and has been tabulated and shown in table 1. The sizes of leg and bracing members have been checked for the maximum forces computed from the analysis and optimized designed has been done as per IS: 800-2007 and the weight of each tower has been noted and shown in table 2.

7. RESULTS AND DISCUSSION

Table 1: Maximum joint displacement of the tower

Height of the tower m	Maximum joint displacement of the tower mm					
	Type of bracing configuration	X-B	SINGLE DIAGONAL	X-X	K	Y
40	Normal wind	197.538	275.352	277.558	262.36	241.258
	Diagonal wind	117.646	159.418	163.514	154.614	143.99
50	Normal wind	128.965	146.838	144.887	139.476	131.649
	Diagonal wind	75.646	80.618	86.22	83.159	79.197

Table 2: Results showing the weight of the tower

Height of the tower m	Total weight of the tower kN					
	Type of bracing configuration	X-B	SINGLE DIAGONAL	X-X	K	Y
40		65.545	39.252	61.024	61.094	37.203
50		161.633	91.935	132.61	90.186	54.112

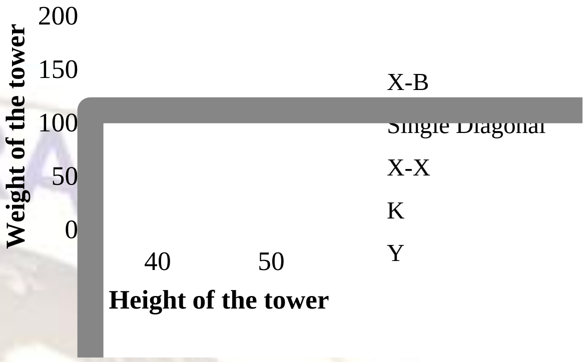

Fig. 3: Weight of each tower

From the above results in table 2 and fig. 3, it has been found that Y bracing is the most appropriate arrangement of bracing system that resists lateral loads for the given range of heights of the towers, as it shows comparatively lesser weight than the other bracing systems. The demarcated economical bracing system is shown in fig. 4.

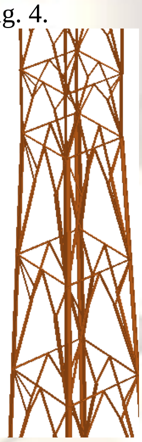

Fig. 4: The economical bracing system of tower

The displacement undergone by the tower is shown in fig. 5.

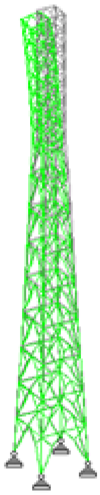

Fig. 5: Displacement of the tower

8. CONCLUSION

In this paper, analytical studies have been presented to find the most appropriate arrangement and cost-effective bracing system of steel lattice towers for the effective resistance against lateral forces. The joint displacement and weights are the significant parameters obtained from the analysis. However, there is no sufficient data regarding the permissible displacement for towers. From the results obtained, Y bracing has been found to be the most economical bracing system up to a height of 50m. Further, the study will be carried out for towers of greater heights.

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