

Parametric Study on Structural Behaviour of Mast Tower

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Abstract

The parametric study of the tower testing high mast is carried out in different ways. High mast mainly governs under high conductor tensions due to testing and wind action on an exposed area. These high mast towers are generally used at tower testing stations to test the working towers, transmission line towers and poles. Two masts are present to test a tower, one of them is Longitudinal Mast, and the other is Transverse Mast. These masts have 'n' numbers of columns and beams according to the size of tower beds, the height of towers/poles, conductor tension force and angle of pull. In the study, the tower model is fixed in line with geometry and wind force applied to the exposed area of the mast and conductor tension force with different loading points and locations on the horizontal beams of the high mast. The analysis is done using "STAAD.pro V8i SS5" software. The tower height is taken as 112m in the study with two main beams at 60m and 110m level (bottom of steel) in elevation. The different type of bracing pattern is used to equalise the structural behaviour. The basic parameters which are studied using nonlinear static analysis are the Beam Axial Forces (Compression and Tension), Deflection & Support Reactions of the Mast tower, and it is ensured that the structural members are utilising their full strength to resist and resist the torsion, buckling effects and uniformly distributes force behaviour.

The wind force is computed with IS875: part-III, in which different categories factors are used according to mast height, locations and other ones. The analysis and design of the tower are done with IS: 802 part-2. The applications of the mast towers are at each testing station for testing 132kV to 1200kV gantry, transmission line towers, steel poles and for reviewing the same.

Keywords: - Mast tower, Stresses, Deflection, Structural Behavior

INTRODUCTION

A tower test station is a unique installation to test different tower designs for transmission lines and similar use. A tower test station consists of two

steel supports and one or more foundations on which a tower sample can be built. The number of test conditions is usually limited to six and eight individual cases, with reduced load conditions

such as wind and ice. The towers to be tested are built on rigid foundations, and wire cables are fixed at the required loading point. 'dead' weights can exert the load with the help of pans, winches or hydraulic cylinders. In the latter case, a load cell or dynamometer is placed in the installation next to the loading point in the structure. Charging methods cause voltage by moving the cables away from the tower at the specified loads. The tensile load is indicated by a tension meter that is placed on the tensile point. The charge points in a tower naturally include longitudinal, transverse and vertical components, either as an individual or combined, resulting loads.

The degree of refinement of the control equipment for the application and the registration of the load varies considerably at the individual test stations. From applying unique charging points of individual charging components with associated measuring instruments to electronic equipment capable of using all loads with constant data logging facilities.

The test configuration is performed to comply with the design specifications and verify the suitability of the main components of the structure and their connections to support the static design loads specified for that specific structure as an individual entity under controlled conditions. It provides information about the actual distribution of the voltages of unique configurations, verification of adjustments, structural performance in a different position and other benefits.

THEORY AND MEASURES OF HIGH MAST TOWER

At tower testing stations, two steel columns are used to test the towers, one of them is the high longitudinal mast, and another is the transverse

high mast tower. The longitudinal high mast tower has several vertical columns and several main beams, where wire ropes are attached to test the towers. These pulling points on main beams act as high-tension loading points, under which the mast tower governs in the design of the superstructure.

Therefore, the design of this type of high mast tower is always the most challenging job. To do so, we have used nonlinear elastic analysis of the superstructure using the software.



Figure- 1 Longitudinal High Mast Tower

A. Study of lattice towers:

Lattice towers, also known as Truss towers, are generally freestanding framework towers. These types of towers are used in transmission lines, radio, and observation towers [1].

A limit load assessment & preliminary experimental testing of a lattice-type steel tower were used to support a newly designed prototype small wind turbine having nine blades and a rotor diameter of 3.4m. Small wind turbine and structural engineering standards were followed to implement a system that meets European Union countries' legislation [2].

The supporting lattice tower structure was subjected to a full-scale load test. This test verified that the structure could withstand the design loads. The finite element software ANSYS Mechanical was used to model and analyse the actual structure & to determine the possible failure modes and

their associated load levels. The most probable way of failure for such a structure was elastic buckling of the main corner posts. Several finite element lattice tower models utilising different modelling strategies and solution methods are presented and analysed. The paper highlights the importance of using nonlinear analyses instead of linear analyses and gives recommendations on the most reliable modelling technique. Computational analyses' results are compared with measurements from a full-scale test on the tower structure.

Natural frequencies of guyed masts were determined by modelling the mast as truss elements in one model and beam-column elements in another. Guys were modelled as cable elements in both cases. The natural frequencies from the two models agreed closely with each other. To verify the finite element modelling, two triangular steel latticed scale-modelled guyed masts were fabricated and tested on a shake table especially designed to test guyed masts. The experimental results were in good agreement with the results from the finite element analysis [3].

We also reviewed a paper that describes a nonlinear analytical technique to simulate and assess the ultimate structural response of latticed transmission towers. The technique may verify new tower design and reduce or eliminate the need for full-scale tower testing. The method can also be used to assess existing towers' strength or upgrade old and ageing towers. The technique has been calibrated with results from full-scale tower tests with reasonable accuracy in both the failure load and the failure mode. The method has been employed by electricity utilities in Australia and other countries to (a) verify new tower design, (b)

strengthen existing towers, and (c) upgrade old and ageing towers [4].

B. Analytical response of lattice tower:

During the analytical review, it is observed that the towers are governing in loads. At the same time, they have the worst conditions, and premature failure occurs, which cause the towers to imply all the structural members' loss too [5].

The towers are dynamic components of the transmission lines, and hence, accurate prediction of their failure is significant for the reliability and safety of the transmission system. When any failure occurs, direct & indirect losses are very high, leaving away other costs related to power disruption and process. Different types of premature failures observed during full-scale transmission line towers at Tower Testing and Research Station, Structural Engineering Research Centre, Chennai are presented. Failures that have been observed during testing are studied, and the reasons are discussed in detail. The effect of non-triangulated hip bracing pattern and isolated hip bracings connected to elevation redundant in 'K' and 'X' braced panels on tower behaviour are studied. The tower members are modelled as beam-column and plate elements. Different types of failures are modelled using finite element software, and the analytical and the test results are compared with various code provisions. The general-purpose finite element analysis program NE-NASTRAN is used to model the elastoplastic behaviour of towers. The importance of redundant member design and connection details in the overall performance of the tower is discussed [6].

The cost function to be minimised includes material and manufacturing costs. The optimum shell thickness, number of stiffeners and

dimensions of the stiffeners are calculated using Rosenbrock's direct search method for function minimisation complemented by an additional discretisation to account for available profiles. The results indicate that the minimum cost solution corresponds to the minimum number of ring-stiffeners. The procedure proposed can be treated as a baseline for determining the least cost designs of slightly conical towers that meet the structural requirements of slender structures predominantly loaded by bending due to dynamic loads [7].

According to Hani M. Negm and Karam Y. Maalawi main tower body is built from uniform segments where the influential design variables are chosen to be the cross-sectional area, the radius of gyration and height of each segment. The rotor combination is regarded as a rigid non-rotating mass attached at the top of the tower. Five optimisation strategies are developed and tested. The last one concerning the reduction of vibration level by direct maximisation of the system natural frequencies works very well and has shown excellent results for both towers alone and the combined tower/rotor model. Extensive computer experimentation has shown that global optimality is attainable from the proposed discretised model, and a new mathematical concept is given for the exact placement of the system frequencies. The standard mode method is applied to obtain a forced response for different types of excitations. The optimisation problem is formulated as a nonlinear mathematical programming problem solved by the interior penalty function technique. Finally, the model is applied to design a 100-kW horizontal axis wind turbine (ERDA-NASA MOD-0). It has succeeded in arriving at the optimum solutions showing significant improvements in the overall

system performance compared with a reference or baseline design [8].

Application of structural optimisation to transmission tower design is facilitated since major costs such as material, transportation, erection, and maintenance are directly proportional to structural mass. In this paper, structural topology and shape annealing (STSA), a structural topology optimisation method that combines structural grammars with simulated annealing, is applied to reduce the structural mass of an existing tower. STSA has previously been validated only on smaller-scale benchmark tasks. The challenges of extending STSA for application to full-scale design tasks are presented. Key results include a 16.7% mass reduction of the existing primary members through combined optimisation of the tower envelope, joint locations, and discrete section sizes. Also, the tower configuration was optimised to have 16 fewer joints and 80 fewer primary members. Promising results for a practical, full-scale application validate the STSA method for combined structural optimisation of topology, shape and discrete section size [9].

Even though extensive research has been carried out on transmission lines subjected to normal wind loads, their behaviour under high-intensity wind loads (HIW), such as downburst, is poorly defined. This paper describes a detailed numerical model that can predict the structural performance of transmission towers as part of a transmission line system under downburst loading. The time history of the downburst wind data is based on a previously developed and validated computational fluid dynamic model. The procedure used to scale the velocity wind data and to transform them to forces is described. Three-dimensional linear

adjustable frame elements are used to model the members of the towers.

In contrast, two-dimensional curved beam elements with geometric nonlinearity are used to model the conductors and the ground wires. A transmission line that previously suffered significant damage due to a downburst event is then considered a case study. Comparison between the results of the downburst analysis and those due to a normal wind that is typically used in the design reveals the importance of considering HIW loads when attempting the structural design of transmission towers [10].

Over the past few decades, the wind has emerged as one of the major sources of green and renewable energy for being a cost-effective solution and offering a substantial reduction in greenhouse gas emissions. Currently, onshore wind energy is undergoing rapid development and expansion at an annual rate of approximately 27%. As such, more and more wind farms are being established in earthquake-prone areas resulting from the availability of wind energy in these regions. This paper investigates the optimal selection of lattice wind turbine towers in the seismic areas based on the Cost of Energy (COE). Although various tower types and materials (e.g., steel and concrete-steel composite monopole) are available, this study focuses on steel lattice towers to provide a cost-effective solution and pose a challenging structural optimisation problem. To the knowledge of the authors, design optimisation of lattice wind turbine towers subjected to combined earthquake, wind and gravity loading has not been performed before. Ten tower height-wind turbine size combinations are generated by placing turbines with 100 to 400 kW power

generation capacity on towers with 24 to 42.6 m height. A cost-optimal solution is obtained for each combination. The taboo search algorithm is used to minimise the total cost. The wind and earthquake load on the towers are obtained for a specific case study location. The COE for each combination is calculated using three different wind probability distributions. Instead of using simplified structural models, all the details of rigorous structural analysis, e.g., geometric nonlinearity, are included in the finite element models. Realistic loading conditions, including wind and earthquake, are considered [11].

The design of latticed steel transmission towers is a challenging task involving lengthy modelling and detailing of a significant number of steel members and connections. After that, full-scale testing of buildings validates the modelling and detailing and ensures that the towers are designed to withstand design loads without premature failures. In the present work, a 132-kilovolt double-circuit suspension tower has been considered for the study. The tower was designed using Staad. Pro software and the member forces were calculated at design loads. After the design, the full-scale testing of the tower was carried out. During testing, the strains in some of the critical members were measured using strain gauges. Using these strain values, the actual load in selected members are calculated. The paper compares actual load in members during full-scale testing and computed loads from software. The paper also discusses the possible reasons behind the difference between actual and computed loads. Loads on the tower at different points for different conditions are presented. The paper also provides a discussion about the possible reasons for

premature failure of the tower during full-scale testing or at the site, and the remedial measures are presented to avoid the failure [12].

Since a well-established framework of codes exists nowadays, the previously mentioned wind-sensitive structures can be designed appropriately concerning serviceability, strength, and safety criteria. The respective design procedures with comments on the codes applied along with certain practical aspects on the application of the wind loading on these structures are herein presented. In contrast, specific numerical simulations illustrate the respective recommendations [13].

APPLICATION OF LOADS ON HIGH MAST TOWER

For the parametric study, we have considered loads and geometry of high mast as per the below criteria, and all the observations are taken from standards only.

Following loads shall be considered in addition to analysing mast tower:

- a) Dead load due to self-weight of structure
- b) Wind load on mast calculated as per IS875 Part-3
- c) Conductor Tension load

Following geometrical constraints are considered for modelling of Mast tower:

Basic parameters are:

- Number of columns - 6
- Base width – 12m c/c of columns
- Total width – 70m o/o of structure
- Main Columns – 1.0/1.5m B/B
- Total Height of tower – 110m
- Configuration of tower- Mast tower
- Support Conditions at Base - Pinned

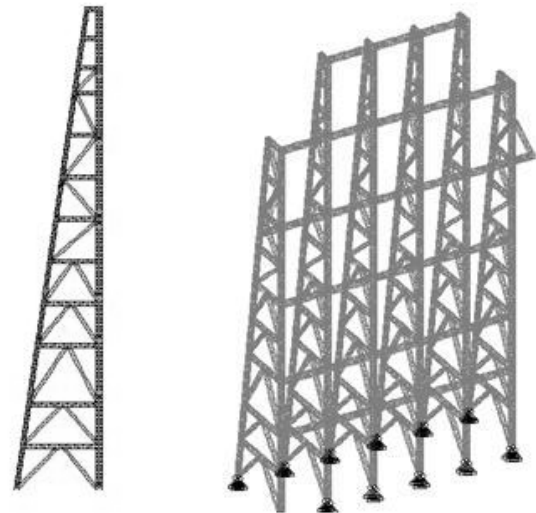


Figure- 2 Isometric and Side View of High Mast Tower from STAAD.pro

We have applied all the loads mentioned above in the model to study the parameters and which are described below:

A. Wind Load:

Wind load is calculated as per IS875:Part3, 2015 and applied to the model to analyse the structure against wind action.

Actually, for a lightweight structure, it is essential to apply the wind load because they govern under the high loads, which almost acting at the member's total gross area, and this may cause bending in the structure. Due to bending, the structure behaves like a cantilever and freestanding framework either made of trusses. Still, the effect of this highly contacted wind load may develop the premature failure of the structure without any other forces or loads.

Henceforth, it is required to analyse the structure under wind action as per standardised codes.

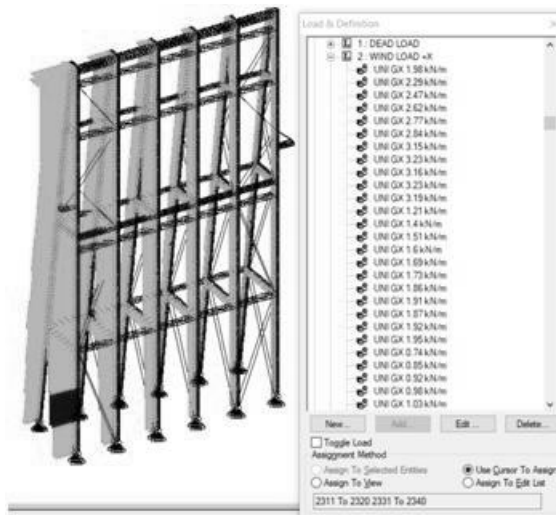


Figure- 3 Wind Load from STAAD.pro

B. Conductor Tension Load:

Conductor tension loads generally load from conductor wires, which implies tension in the structure due to wires connected to the structure directly, as in transmission line towers and gantry towers at substations.

These loads are applied to the structure as point or nodal loads in the model as per Indian Standard. Conductor Tension loads vary from 100Ton to 355Ton Vertical and 30Ton to 112Ton Lateral.

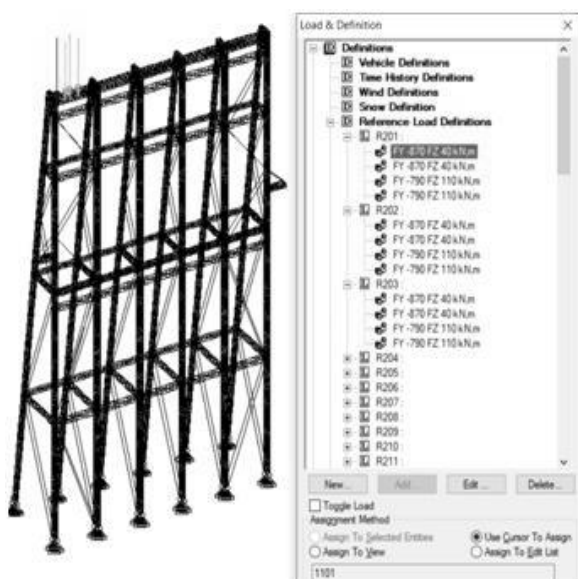


Figure- 4 Conductor Tension Load from STAAD.pro

PARAMETRIC STUDY OF HIGH MAST TOWER:

We made some basic load cases and combinations for the parametric study, which are used to analyse the mast tower and further actions or results found. The essential parameters are described with their snaps from Staad.pro.

A. Beam Axial Force:

The axial compression capacity of the structural members depends on the gross area of the member, while axial tension capacity depends on the net area of the member. Hence, both capacities of all the members of the Staad. Pro model found and checked against the limiting values as per IS802: part-1/sec-2.

	Beam	L/C	Node	Fx kN	Fy kN	Fz kN
Max Fx	27235	299 (1.50 DL)	20436	3558.369	1.001	0.000
Min Fx	27207	299 (1.50 DL)	20427	-3065.500	1.001	0.000
Max Fy	26703	101 (1.50 DL)	46	312.083	9.300	0.000
Min Fy	26703	101 (1.50 DL)	14873	261.864	-9.300	-0.000
Max Fz	2682	103 (1.50 DL)	3683	-22.930	-0.000	4.260
Min Fz	2682	103 (1.50 DL)	3649	-20.905	0.000	-4.260
Max Mx	1	101 (1.50 DL)	2033	284.041	0.000	0.000
Min Mx	1	101 (1.50 DL)	2033	284.041	0.000	0.000
Max My	1	101 (1.50 DL)	2033	284.041	0.000	0.000
Min My	1	101 (1.50 DL)	2033	284.041	0.000	0.000
Max Mz	1	101 (1.50 DL)	2033	284.041	0.000	0.000
Min Mz	1	101 (1.50 DL)	2033	284.041	0.000	0.000

Figure- 5 Beam Axial Force Result from STAAD.pro

B. Support Reactions:

A support reaction is described as the reaction force/forces that are credited to support the structure or system, and it also can be expressed as the response to the action acting on the structure in the form of different forces.

A simple framed structure can be calculated by static equilibrium equations or by the internal forces from the free body diagram of the individual structural members.

After a study of the model, we found that supporting reactions on the leading leg of mast towers vary with the loading points, affecting the lateral thrust on the foundation.

Mode	L.C.	Horizontal	Vertical	Horizontal	Moment
		Fx kN	Fy kN	Fz kN	Mx kN-m My kN-m Mz kN-m
Max Fx	48 1002 (DL +)	330.738	2973.121	-15.802	0.000 0.000 0.000
Min Fx	27 1002 (DL +)	-427.637	1673.262	24.737	0.000 0.000 0.000
Max Fy	36 1002 (DL +)	-15.105	2407.128	-63.295	0.000 0.000 0.000
Min Fy	25 1002 (DL +)	-32.336	-1959.393	42.452	0.000 0.000 0.000
Max Fz	4 1002 (DL +)	-19.204	847.585	124.660	0.000 0.000 0.000
Min Fz	33 1003 (DL +)	-2.145	1042.829	-296.556	0.000 0.000 0.000
Max Mx	1 1001 (DL)	-0.016	40.271	4.616	0.000 0.000 0.000
Min Mx	1 1001 (DL)	-0.016	40.271	4.616	0.000 0.000 0.000
Max My	1 1001 (DL)	-0.016	40.271	4.616	0.000 0.000 0.000
Min My	1 1001 (DL)	-0.016	40.271	4.616	0.000 0.000 0.000
Max Mz	1 1001 (DL)	-0.016	40.271	4.616	0.000 0.000 0.000
Min Mz	1 1001 (DL)	-0.016	40.271	4.616	0.000 0.000 0.000

Figure- 6Support Reaction Result from STAAD.pro

C. Deflection:

Deflection is the degree to which a structural element is moved/displaced from its original position under a load due to its deformation. This may relate to a distance or an angle. For our research model, we found the maximum deflection of 694mm along conductor tension wire loads, and it is under the limitation given by Indian Standard.

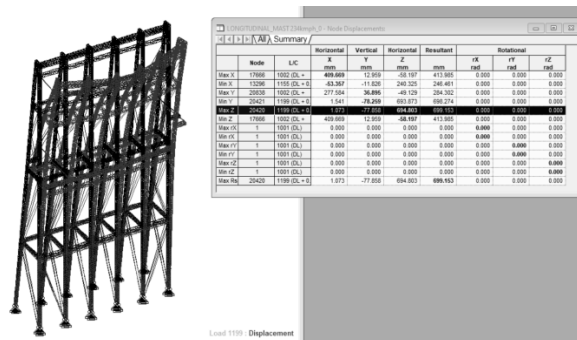


Figure- 7 Deflection Result from STAAD.pro

CONCLUSION

Here, all the required parameters are studied concerning the review papers by the author.

Based on the parametric study of the model, we conclude that due to change in loading points from one horizontal beam to another horizontal beam of width 12m, the behaviour of the structural changes in the form of deflection, axial forces, internal stresses because of the generation of torsion at top-level, i.e. 110m level. As the height is too much and the wind & conduction tension loads are very high at that level, a minor change in the loading

point location will cause high potentials and stresses in the structure.

REFERENCES

- Balagopal, R., Prasad Rao, N. &Rokade, R.P. J. Inst. Eng. India Ser. A (2018) 99: 595 “Simplified Model to Predict Deflection and Natural Frequency of Steel Pole Structures” September 2018, Volume 99, Issue 3, pp 595–607
- Axisa, R., Muscat, M., Sant, T. et al. Int J Energy Environ Eng (2017) 8: 343 “Structural assessment of a lattice tower for a small, multi-bladed wind turbine” December 2017, Volume 8, Issue 4, pp 343–358
- Murty K. S. Madugula Yohanna M. F. Wahba Gerard R. Monforton “Dynamic response of guyed masts” Volume 20, Issue 12, December 1998
- F. G. A. Albermania S. Kitipornchaib “Numerical simulation of the structural behaviour of transmission towers” Volume 41, Issues 2–3, February 2003
- V. N. Jamariya, D. D. Panchal and S. R. Tare, "Structural Optimisation of Truss Using Finite Element Analysis," 2018 International Conference on Smart City and Emerging Technology (ICSCET), Mumbai, 2018, pp. 1-5.
- N. Prasad Raob1G.M.Samuel Knighta S. J. Mohanb N. Lakshmanan "Studies on the failure of transmission line towers in testing" Volume 35, February 2012
- P. E. Uysa J. Farkasb K. Jármaib F. van Tondera “Optimisation of a steel tower for a wind turbine structure” Volume 29, Issue 7, July 2007, 1337-1342
- Hani M. Negma Karam Y. Maalawib "Structural design optimisation of wind turbine towers" Volume 74, Issue 6, 1 February 2000, 649-666

9. Kristina Shea and Ian F. C. Smith, F. ASCE "Improving Full-Scale Transmission Tower Design through Topology and Shape Optimisation" Journal of Structural Engineering Vol. 132, Issue 5 (May 2006)
10. A. Y. Shehataa A. A. El Damatty E. Savory b "Finite element modelling of transmission line under downburst wind loading" Volume 42, Issue 1, October 2005, 71-89
11. Bora Gencturk, Arezou Attar, Cenk Tort "Selection of an optimal lattice wind turbine tower for a seismic region based on the Cost of Energy" November 2015, Volume 19, Issue 7, pp 2179–2190
12. Charalampos C. Baniotopoulos "Design of Wind-Sensitive Structures" Wind Effects on Buildings and Design of Wind-Sensitive Structures pp 201-227
13. Veerendra Kumar Shukla, M. Selvaraj "Assessment of the structural behaviour of transmission line tower using strain gauging method" December 2017, Volume 17, Issue 4, pp 1529–1536
14. IS802 part-1/section-2 "Code of Practice for the use of Structural Steel in Overhead Transmission Line Towers" – Bureau of Indian Standard
15. IS802 part-2 "Code of Practice for the use of Structural Steel in Overhead Transmission Line Towers" – Bureau of Indian Standard
16. IS875 part-3 "Design Loads (Other than Earthquake) for Buildings and Structures - Code of Practice."