The Journal of CPRI,
Vol. 10, No. 3, September 2014 pp. 623-630

Computer aided Analysis and optimization of transmission line tower

Avinash M*, Selvaraj M*, Mohanbabu G** and Prabhushankar G V***

For economic reasons, our next generation overhead power transmission line towers will be built with new design concepts in order to reduce the weight of the support structures. This paper discusses the computer aided design and analysis carried out on a 220 kV Single Circuit transmission line tower built with a combination of Circular Hollow Sections and Angle sections rather than built with only Angle sections. After optimization, the comparative study is presented with respect to stresses, deflection and weight of both Circular Hollow Sections and Angle sections towers. There is a saving in steel weight up to 8% resulted when a Circular Hallow Section tower is compared with an Angle Section type. The analyses results are compared with full scale test carried out at Central Power Research Institute (CPRI) Bangalore, India are presented.

Keywords: *Transmission line tower, finite element analysis, prototype testing, optimization.*

1.0 INTRODUCTION

The design of transmission line (TL) towers is generally based on minimum weight basis. The towers, in general are of lattice type consisting of legs, primary/secondary bracings and cross arm members. Structural design of the tower is mainly governed by wind loads acting on conductor/ tower body, self-weight of conductor/tower and other loads due to icing, line deviation, broken wire condition, cascading, erection, maintenance, etc. Leg, primary & secondary bracings and cross arm members are considered in the analysis. TL towers are generally analyzed by linear static analysis methods and the maximum member forces are arrived at assuming that all members are subjected to axial forces only and the deformation are small. The members are designed based on the prevailing codes of practice. Full scale prototype testing of TL tower is recommended to verify the design and detailing.

The types of tower based on their constructional features, which are in use on the power transmission line are: Self-Supporting Towers, Conventional Guyed Towers, and Chainette Guyed Towers [2].

Self-supporting latticed steel towers are used mainly in India and other countries like FRANCE, CANADA etc... This type of tower has been use in India from the beginning of 21st century for EHV (Extra High Voltage) transmission lines. Self-supporting towers are covered under Indian standard [3]. These are fabricated, using tested quality mild steel structural or combination of tested quality mild steel and high tensile steel structural. There are three types of loads namely, transverse load, vertical load and longitudinal load that act on a transmission line tower. Longitudinal loads probably have more effect on the weight of a transmission line tower than any other loadings. Most of the power transmission

*Junior Research Fellow, Mechanical Engg. Division, CPRI, Bangalore - 560 080, India. E-mail : avinashm013@gmail.com, Mob: +91 9343762266
* Engg. Officer, Mechanical Engg. Division,CPRI, Bangalore - 560 080, India. E-mail : msraj@cpri.in, Mob: +91 9449851236
** M.Tech student, Siddganga Institute of Technology, Tumkur – 572 103, India. Email : mohangkbabu@gmail.com, Mob: +91 9964656247
***Professor and Head, Department of Industrial Engineering and Management, Siddaganga Institute of Technology, Tumkur – 572 103.
Email : prabhu.gvp@gmail.com, Mob: +91 9845430739

utilities all over the world have made prototype testing of TL towers mandatory [1].

The analysis of tower as a space frame is a tedious process. With the advent of electronic computers, exact analysis as space frame has been possible. In the present work a Finite Element Method (FEM) based analysis tool called "ANSYS™ is used for the analysis of the towers.

2.0 PRESENT STUDY

In the present thesis work, the tower has been modeled as a BEAM188 3-D Linear Finite Strain Beam element. This element is a linear (2-node) beam element in 3-D with six degrees of freedom at each node. The degrees of freedom at each node include translations in x, y and z directions, and rotations about the x, y and z directions. The BEAM188 element is suitable for analyzing slender to moderately thick beam structures. Since the weight of the tower plays a major role in the economy of a transmission line system, this thesis deals with the optimization of tower with respect to economy. Only primary bracings and cross arm members are replaced by using Circular Hollow Sections (CHS) configurations as variable parameters. Since CHS members have better mechanical properties e.g. structural efficiency, weight advantage and lower wind resistance compared with the other structural cross-sections available in the industry. The advantage of analytical approach is that, flexibility in applying in loads, analysis of tower by varying the design parameters, varying tower members and performing through analysis.

The methodology that has been followed in this paper is described below.

a. A 220kV S/C suspension tower (Figure 1) is selected for the analysis and all the parameters required for fixing up the tower geometry was worked out.

b. A final load on the tower is calculated from the design conditions.

c. Finite element modelling of the tower was carried in ANSYS™ using BEAM188 3-D Linear Finite Strain Beam element.

d. Static analysis for the tower is carried out usingANSYS™ software.

e. Based on the deflections and stresses on the tower members obtained from numerical method are compared with prototype testing, the conclusions are drawn.

f. Considering primary bracings and cross-arms with circular hollow sections instead of angle sections as per Indian standard IS: 1239 [5] and IS: 808 [4].

g. Optimization of the tower is carried out with respect to weight.

h. Static analysis for the optimized tower is carried out using ANSYS™ software.

i. Total weight of the tower is calculated and weight savings with respect to CHS and angle sections are brought out.

3.0 EXPERIMENTAL TESTING OF THE TL TOWER

In order to ensure the correctness and reliability of all measuring instruments and in turn the validity of the tests the calibration of all instruments before the test is conducted. Calibration of the load cells is done with (Universal Testing Machine) UTM. The prototype tower fabricated as per structural drawings are assembled and erected vertically on a fixed base as shown in Figure 1. Fitment of any member shall be easy, natural and not be a forced one. The bolts should be tightened simultaneously on all four faces. To enable application of the external loads in the most representative manner and to simulate tower design conditions, the tower structure is rigged suitably. Loads are applied as per the approved rigging charts. The load cells are attached to the tower through steel wire rope, positioned as close as possible to the test tower so that friction losses do not cause impact on the load cells.

Full scale testing of transmission tower structures plays an important and integral role in the development of the designs. Guidelines for transmission tower testing are available [6]. The test is generally set up to simulate the most critical design conditions. Loads are normally incremented to 50%, 90%, 95% and 100% of the maximum specified loads. Typically, each load increment is held for one or two minutes. When a premature failure occurs, corrective measures are taken and all failed members are replaced. The load case which caused the failure is replaced until the tower is able to support the ultimate design load.

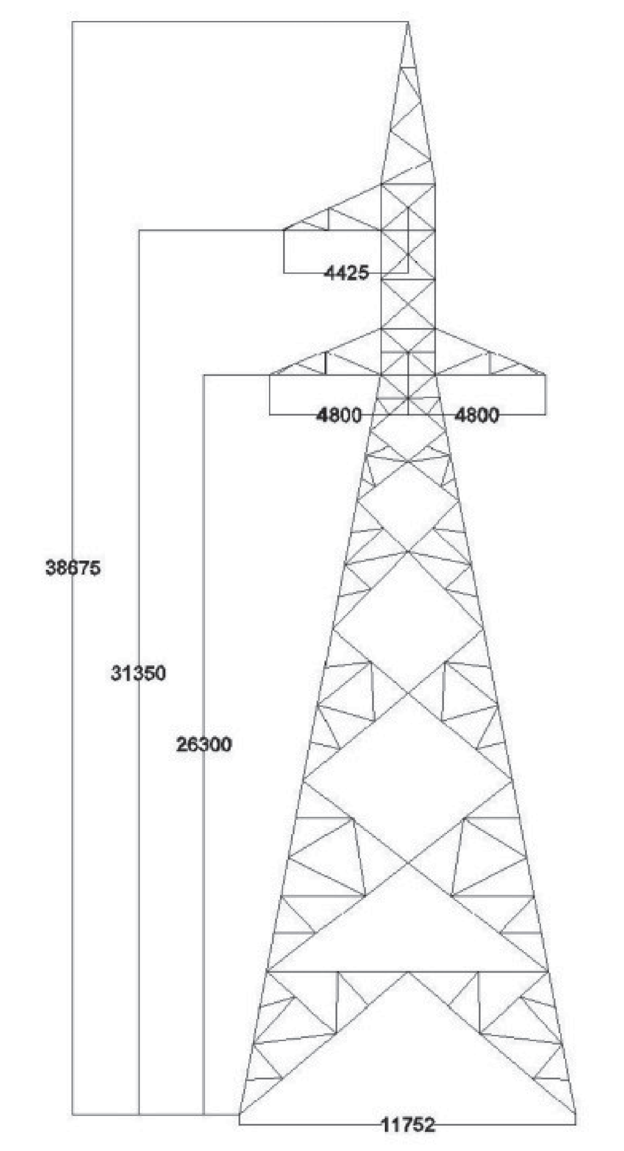

FIG. 1 SINGLE LINE DIAGRAM OF 220 KV S/C TOWER

4.0 LOADINGS

The transverse and vertical loads, shown in Figure 2, are applied as far as possible simultaneously at all points in steps of 50, 75, 90 and 95 %. The waiting period of 120 seconds are maintained in each step and 300 seconds waiting period observed at the final 100% loading. Throughout the process of loading under all tests, the tower is closely observed any visible sign of failure for deformation. The deflection is monitored for each stage of loading whose values are shown in Table 1.

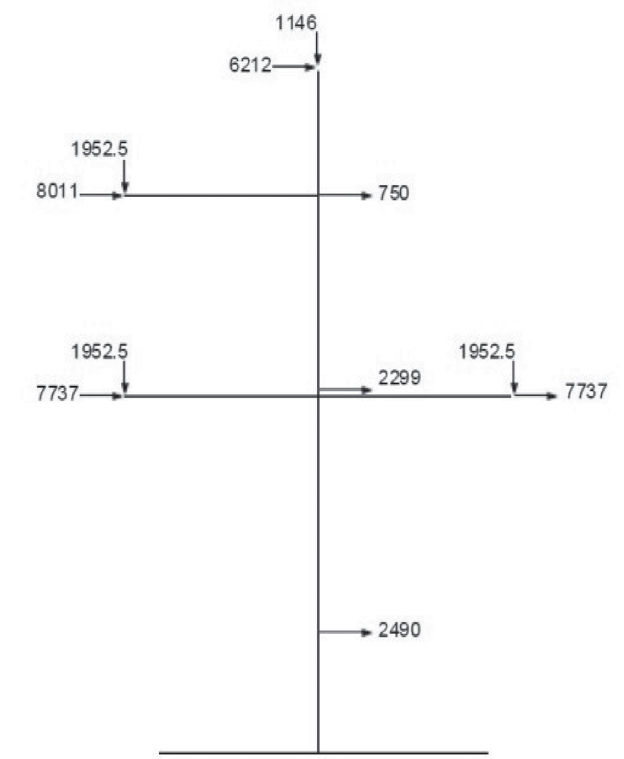

FIG. 2 LOADING TREE FOR RELIABILITY CONDITION

TABLE 1

TOWER DEFLECTION READINGS UNDER RELIABILITY CONDITION

Load (%)	Peak	Top Cross Arm	Bottom Cross Arm
50	210	110	65
75	300	170	100
90	315	205	125
95	325	220	130
100	334	235	140

5.0 OPTMIZATION OF THE TL TOWER

The tower structure 3-D model was created in FEA software "ANSYS™" The angle section as assigned as per the structural drawing of structure. The structure was molded as BEAM188 3-D Linear Finite Strain Beam element. The element is a linear (2-node) beam element in 3-D with six degrees of freedom at each node. The degrees of freedom at each node include translations in x, y and z directions, and rotations about the x, y and z directions. The data available for optimization, loads that has been applied on the tower [6]. Figure 3 shows the 3-D model of 220kV S/C tower modeled in ANSYS™ software.

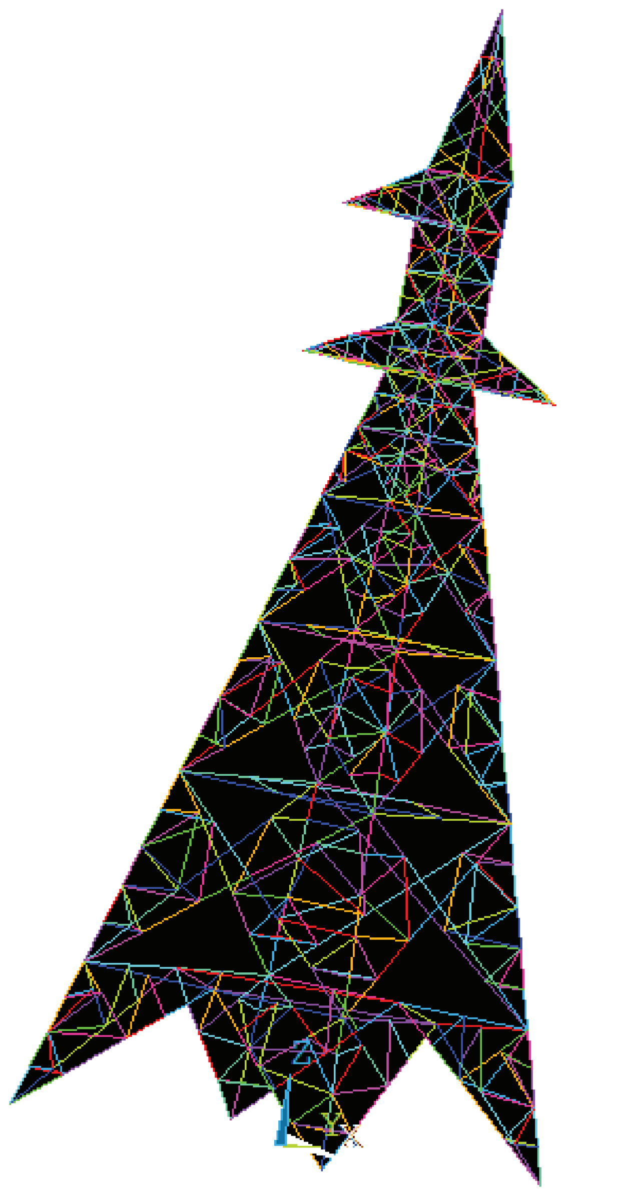

FIG. 3 3-D MODEL OF 220 KV S/C TOWER IN ANSYS™

5.1 Validation of the Results

Results like displacement, axial stress and von-misses stress are obtained from ANSYS™ software and these results are compared with tested tower results. Figure 4 shows the deflection of the tower obtained from ANSYS™ software. Table 2 shows the comparison of the deflection values.

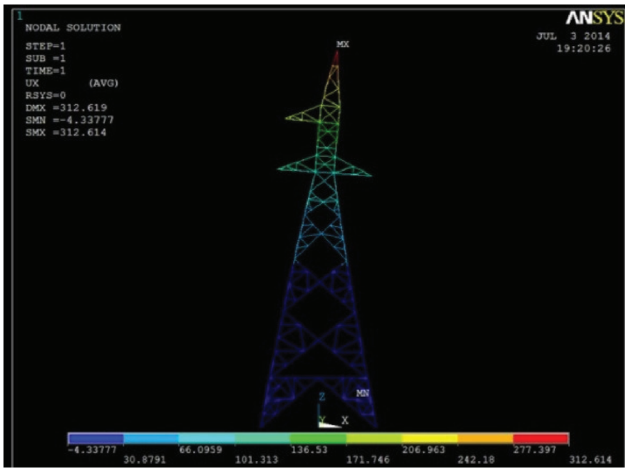

FIG. 4 DEFLECTION OF THE TOWER IN ANSYS™

TABLE 2

COMPARISON OF DEFLECTIONS FOR RELIABILITY CONDITION

	Experimental method	Numerical method
BCA	140	136
TCA	235	206
GW	334	312.614

It is observed that the deflections obtained from analysis were found to be 312.614 mm and the deflection obtained from testing was found to be 334 mm. The deflections are in the limit of acceptance.

Tensile strength and Yield strength of the High Tensile Steel (St 58-HT) is 580 Mpa and 360 Mpa. In the Figure. 5 the maximum stress in the tower is 320 Mpa. So the stress obtained is less than the yield strength of High Tensile Steel (St 58-HT). It concludes that the stresses in the tower member are within acceptable limit.

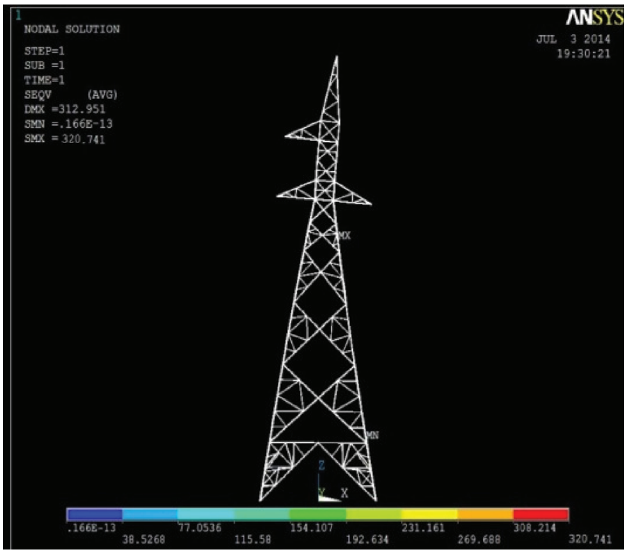

FIG. 5 STRESS PATTERN IN THE TOWER IN ANSYS™

5.2 Optimization

The optimization is carried out using Circular Hallow Section (CHS) members. CHS members have better mechanical properties e.g. structural efficiency, weight advantage and lower wind resistance compared with the other structural cross-sections. Figure 6 shows the ANSYS™ tower model with CHS section. Table 3 shows the details of circular hollow sections selected based on the weight of the angle sections as per IS: 1239, IS: 808.

TABLE 3

SIZES OF ANGLE AND HALLOW SECTION

Angle Sections (mm)	**Circular Hollow Sections(mm)**	
	Nominal bore	**Thickness**
L 90×90×6	Ø 80	3.2
L 75×75×6	Ø 65	3.2
L 80×80×6	Ø 80	3.2
L 75×75×5	Ø 50	2.9
L 65×65×5	Ø 40	2.9
L 70×70×5	Ø 50	2.9
L 50×50×5	Ø 40	2.9
L 70×70×6	Ø 65	3.2
L 60×60×5	Ø 40	2.9

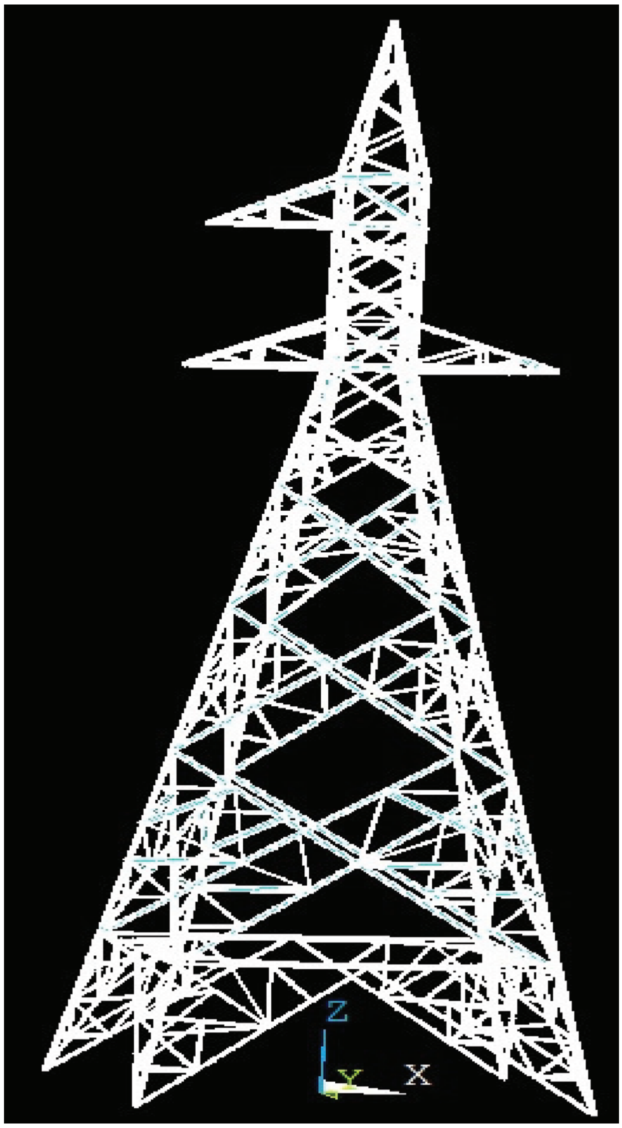

FIG. 6 TOWER MODEL WITH CHS SECTION FOR CROSS ARM AND BRACINGS

6.0 RESULTS & DISCUSSIONS

6.1 Comparison with Respect to Deflection of Structure

The deflection obtained from testing of tower in C.P.R.I tower testingstation for given loading condition was found to be 334 mm from (Table 2) at peak of the tower. Figure 4 shows the deflection of the structure with angle bracings obtained from analysis. It is observed that, deflection obtained from analysis was found to be 312 mm and this deflection when compared with deflections obtained from testing 334 mm was found to be within the limit of acceptance.

Figure 7 show the deflection of structure, with hallow section bracing obtained from analysis. It is observed that the deflection obtained from analysis was found to be 310 mm, which is less than deflection obtained from analysis of structure with angle bracing 312 mm and within the limit of acceptance. Table 4 shows the deflection values with angle bracings and CHS bracing of tower.

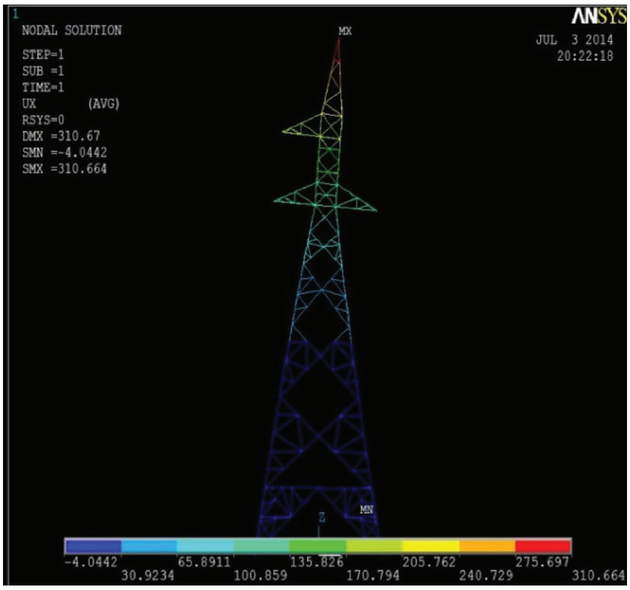

FIG. 7 DEFLECTION OF TOWER WITH CHS BRACINGS

TABLE 4		
DEFLECTION VALUES OF TOWER WITH ANGLE SECTION AND WITH CHS.		
Pull of Points	**Deflection in mm**	
	With angle bracings	**With CHS bracings**
TWLA	30	30.92
BCA	136	100
TCA	242	240
GW	312	310

6.2 Comparison with Respect to Stress in the Tower

The stresses obtained with angle bracing and CHS bracing of tower are shown in Table 5 and Figure 8 shows stressed model of tower with CHS bracing. The stresses at all four positions of the tower are greater than the stress of the tower with angle bracing. From this it can be concluded that as mass of the tower decreases the stresses in the tower increases. Although stresses are high tower with CHS bracing, the stresses are less than the yield strength of the High Tensile Steel (St 58-HT).

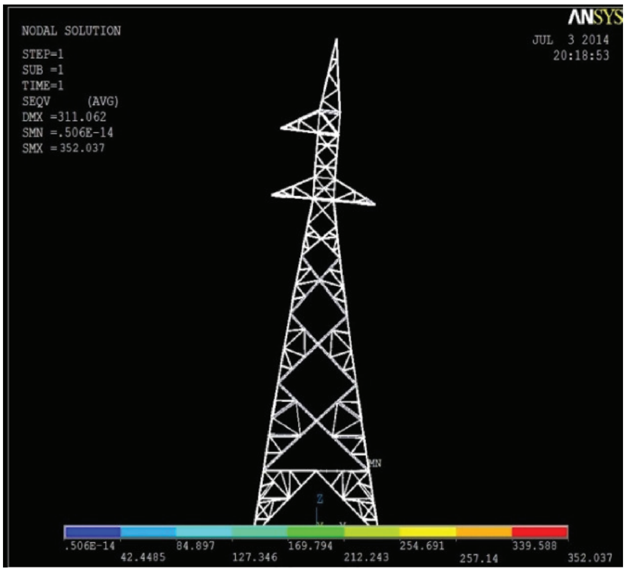

FIG. 8 STRESS IN THE TOWER WITH CHS BRACINGS

TABLE 5		
STRESS VALUES IN THE TOWER WITH ANGLE SECTIONS AND WITH CHS.		
Pull of Points	**Stress in MPa**	
	With angle bracings	**With CHS bracings**
TWLA	115	127
BCA	192	212
TCA	269	287
GW	320	352

6.3 Comparison with Respect to Weight of Tower

The weight of structure is proportional to the cost of the structure; optimizing weight of structure becomes essential while designing any structure. Table 5 shows the weights of structure with angle bracing and with CHS bracing. From equation 1, by considering these two weights, an 8% reduction in weight can be obtained by using structure with CHS bracing in place angle bracing.

TABLE 6	
WEIGHT OF TOWER WITH DIFFERENT BRACING SECTIONS	
Bracing sections	**Weight of tower (Tones)**
angle sections	6.664
Circular Hollow Sections	6.152

Percentage of weight reduction

$$= \frac{weight\ of\ the\ tower\ with\ CHS\ bracings}{weight\ of\ the\ tower\ by\ angle\ bracings}$$

$$= 100 - \frac{6154.79}{6654.45} \times 100 \cong 8\% \quad ....(1)$$

6.4 Comparison with Respect to Cost of the Tower

Also a comparison of cost with respect to the material used is given in Table 7. The cost of High Tensile Steel (St 58-HT) used is INR 52/kg. The rates of High Tensile Steel have been arrived based on present market rates and may change from time to time due market fluctuation. An amount INR 26000/- will be saved per structure which will very economical for any power industry.

TABLE 7	
COST OF TOWER WITH DIFFERENT BRAC-ING SECTIONS	
Bracing sections	**Cost of tower (INR) (weight in kg×cost of High Tensile Steel per kg in INR)**
angle bracings	6654.46× 52=346,000/-
CHS Bracings	6152.45× 52=319,000/-

7.0 CONCLUSIONS

This study reveals that, a saving in steel weight up to 8% resulted when a Circular Hallow Section tower is compared with an Angle Section type. There is scope for developments of optimum tower structure with circular hallow sections and angle sections. Tower structure with least weight is directly associated in reduction of foundation cost. Techno-economical design is used to achieve the reliable performance of the tower structure. Time saving can be achieved by effective usage of Computer Aided Design and FEM software tools.

REFERENCES

[1] S S Murthy and Santhakumar A R, “Transmission line structures”, McGRAW-HILL BOOK Co., New York, p 108-138

[2] C Preeti, K Jagan Mohan, “Analysis Of Transmission Towers With Different Configurations”, Jordan Journal Of Civil Engineering, Volume 7, No 4, Pp 450, 2013.

[3] Transmission Line Manual, Publication No. 268, Central Board of Irrigation and Power, New Delhi.

[4] Bureau of Indian Standard code, IS 808 -1989, “Dimensions for Hot Rolled Steels, Beam, Column, Channel and Angle Sections”, Manak Bhawan, 9 Bahadur Shah Zafar Marg, New Delhi, India.

[5] Bureau of Indian Standard code, IS 1239 (Part1 Steel Tubes)-2004, “Steel Tubes, Tubular and other wrought steel fittings-specifications”, Manak Bhawan, 9 Bahadur Shah Zafar Marg, New Delhi, India.

[6] Bureau of Indian Standard code, IS: 802 (part 3 Testing of towers) - 1978, “Use of structural steel in overhead transmission line towers”, Manak Bhawan, 9 Bahadur Shah Zafar Marg, New Delhi, India.