Modifications of Design Optimisation of Hollow Steel Transmission Tower

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Abstract— *There are Different Methods have been used In Order to assess the behavior of hollow steel transmission tower with respect to Shear, Torsion, Buckling etc. of the steel Structure. Generally the behaviors of these structure components are analyzed experimentally. With the Advanced progress in the numerical tools like Finite Element Model in STAAD Pro. V8i software, it becomes easy to model and analyze the complex and detailed behavior of structural members like Beam, Column and Joints. In this present paper Model of hollow transmission tower subjected to axial and uniformly distributed loading are used. The Finite Element Analysis is used to Design optimisation of hollow steel transmission tower by STAAD Pro.V8i software.*

Keywords— Shear, Torsion, Buckling, Beam Column Joint, Finite Element Analysis,

I. INTRODUCTION

We are using electricity since from last five hundred years. The German physicist Otto von Guericke experimented with generating electricity in 1650. The first transmission of electrical impulses over an extended distance was demonstrated on July 14, 1729 by the physicist Stephen Gray, in order to show that one can transfer electricity by that method. Transmission lines are used to distribute electricity to places often far away from where it has been produced. The main supporting unit of overhead transmission line is transmission tower. The first transmission towers were small wooden poles that were tempting for children to climb but had no environmental impact. To avoid the risk of electric shock these transmission lines are kept at considerable height. This idea of keeping transmission lines to considerable height was emerged from ancient poles. In North-America large wooden structures were common until the Second World War. The increasing voltage and need for crossing large valley and rivers resulted in appearance of steel towers.

To avoid black out of the power, lines are interconnected, which is known as a grid. The basic grid is one power plant, one transmission line and distribution line and then one consumer. -India has been demarcated into five electrical Regions viz. Northern (NR), Eastern (ER), Western (WR), Southern (SR) and North Eastern (NER). However, NR, ER, WR and NER have been synchronously interconnected and operating as single grid – Central Grid (capacity about 110,000MW). In order to meet growing requirement, development of strong transmission system between resource generation complex and bulk consumption centre‟s arrequired.

Abdul Muttalib I [1] Formulation of the optimum design problem by the present method has yielded good results with overall convergence behavior in relatively shot time. The tower of type X-brace with unequal panels has the minimum weight compared with other type of tower and the optimum design is satisfied when the angle of main leg is equal to 87o.

Alaa C. Galeb. [2] Tranmission Tower subjected to multiple combinations of wind, seismic and dead loads are optimally designed for least weight. The member areas and joint coordinates are treated as design variables. Members are designed to satisfy stress limit. Joint coordinates variables are linked to reduce the number of independent design variables.

C.Preeti and K.Jagan [3] carried out a study on the hollow steel Tramission Tower with help of finite element method. They aimed to determine the effect of the diameter of longitudinal reinforcement of the Tower on the parameters like strength, deformation and ductility in the beam-column joint using STAAD. After analysis and result Square Tower 5571 Kg Triangular Tower 5353Kg Guyed Mast 3708 Kg Analysis of Towers as a 3-D space structure with STAAD Pro.2004 is showing maximum axial compressive force in leg member of the lowest panel.Units

Gopi Sudam Punse [4] have also analyzed and tested the hollow transmission tower subjected to loading and then he performed studies by varying the parameters like different bracing system i.e X bracing system, K bracing system & XBX bracing system. After analysis and result, It was observed that the saving area up to 45% is resulted when X bracing system is compared with K and XBX bracing system.

In this Paper the Transmission Tower is modeled and analyzed using Finite Element Model in Software STAAD Pro.V8i is used to evaluate Total Elastic Strain, Elastic Stress and Total Deformation. The Material Models, Analysis Techniques and Elements are used with reference of Past researchers work which are validated by the results with experiments hence it need not to be validated again.

2. FINITE ELEMENT MODELLING

The purpose of transmission line towers is to support conductors and one or two ground wires at suitable distances above the ground level and from each other.

Again based on alignment, towers may be of two types: (*1*) line towers or tangent-towers and

(2) angle towers. Towers on straight line portion of the transmission line are known as linetowers. Angle towers are provided at angles in the lines and are designed to resist the angular component of the cable pulls. These are placed in such a way that the axis of cross-arms bisects the angle between the deviated transmission lines. IS 802 (part F) 1977 „Code of practice for use of structural steel in over head transmission line towers", recommends the following four types of towers,

The selection of the most suitable type of tower for transmission lines depends upon the actual terrain of the line and the number of circuits to be supported. Towers can be broadly classified as follows:

(i) Tangent towers with suspension string (0^0 to 2^0): These are used on straight runs and for line deviation up to 2^0. The conductor is supported by a string of insulators hanging vertically from the tower cross-arms.

(ii) Small angle towers with tension strings (2^0 to 15^0): These are used for lines with deviation between 2^0 and 15^0.

(iii) Medium angle towers with tension strings ($15^0$to 30^0): These are used for line deviation from 15^0 to 30^0.

(iv) Large angle (30^0 to 60^0) and dead end towers with tension strings: These are used for lines with deviation from 30^0 to 60^0 and for dead ends.

The angles of line deviation specified are for normal spans. The span may be increased up to an optimum limit by reducing the angle of line deviation. Tangent towers are designed for supporting the tensioned conductors. Angle towers, which are provided at points of line deviation, are designed to resist the angular pull of the conductors. These towers are positioned such that the axis of the cross arm bisects the angle in the line. The height of the towers is fixed such that there is an adequate ground clearance (6 to 10 m) at the point of greatest sag. The tower heights range from 10 to 45 m depending upon the span, terrain and conductor voltage. Power conductors are supported by one or more strings of insulators, hanging vertically from the tower cross-arms. The conductors or weirs hand between the towers, and are in tension. The spacing of tangent towers (also known as suspension towers) depends upon the terrain. Tangent towers are spaced from 200 to 400 m apart for lines with voltage of 220-300 kV and from 400 to 600 m for lines with high voltage Because of high voltage carried by the conductors, there should be a clear vertical distance of 6 to 10 meters between the ground level and suspended conductors. Due to this reason, the height of tower ranges from 20 to 40 meters, depending upon the spacing of towers. The weight of a single suspension, tower for 220-500 kV may range between 40 to 80 kN. Where, from terrain considerations, it is considered advantageous to have tangent towers with 0^0 line deviation, the towers may be designed accordingly. The angle of line deviation specified above is for the normal span.

3. METHODOLOGY

In modeling 27 tower are modeled in which base width and bracing system are different, for base width 4m,5m,6m and X, XBX and K type of bracing system are incorporated. In modeling firstly base width points are plotted and height of tower up to waist of towers is plotted with square shape of 1.8m on either directions. Tower cage is modeled in which tower peak of tower is plotted then width and lengths of wings are plotted. All nodes are joined by using beam cursor. Now we have towers complete height with base width and tower cage we have to divide tower body into different number of panels. As shown below fig.

After modeling of all tower cages models are further tower body's are modeled as per variation in bracing and base width as shown in fig. 3.1

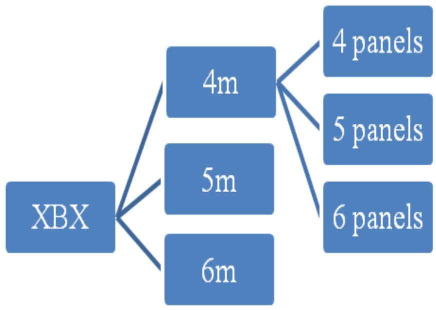

Fig. 3.1Combination for Modeling

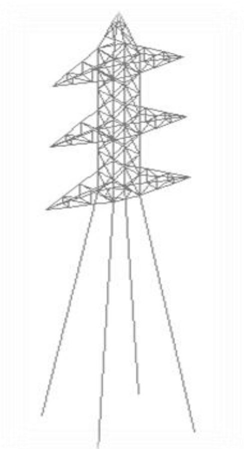

Fig.3.2Model of Transmission tower

In above fig 3.2 combination for XBX bracing shown in above fig panels system are only shown to base width 4m these panels are for 5m and 6m base width also likewise 9 models are made for one bracing system. Similarly another 18 towers are prepared for K and X bracing system. Supports, sections and load are assigned

The step-by-step procedure in Staad Pro.V8i software

4. FINITE ELEMENT ANALYSIS OF TRANSMISSION TOWER

4.1 Analysis of Tower:

A transmission line tower is a three dimensional cantilever truss. Its analysis as a space frame is highly tedious. Majority of forces act only at its top end. The standards under IS 802 series have been prepared with a view to establish uniform practices for design, fabrication, inspection, and testing of overhead transmission line

With reference to IS 802 (Part I/ Section I): 1995

Design Wind Speed, V_d [clause no, - 8.3]

It may be expressed as follows:

$V_d = V_R \times K_1 \times K_2$

a) Risk coefficient, K_1, and

b) Terrain roughness coefficient, K_2

With reference to IS 802 (Part I/ Section I): 1995

I) Risk Coefficient, K_1[clause no, - 8.3.1]
towers. 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..

3.2 load calculations.

Conductor type	S (ZEBRA).
Unit wt of conductor	= 1.625 kg/m.
	= 1.625 × 9.81 N/m.
	= 15.94 N/m.
	= 0.01594 KN/m.
Tensile strength	= 13316 kg.
	= 130619 N.
	= 130.629 KN.
Young"s Modulus	= 0.842×10^5 N/mm^2.
Coefficient of Expansion	= 0.199×10^{-4} /^{0}c.
Shape factor	= 0.67
Diameter	= 28.6 mm.
Maximum Temperature. (t_2)	= 75^{0}c.
Minimum Temperature. (t_1)	= 0^{0}c.

Calculation of wind pressure as per IS 802 (Part I/ Section I) : 1995

With reference to IS 802 (Part I/ Section I): 1995

a) Basic wind speed, V_b[clause no, - 8.1]

V_b= 39 m/s. (For wind zone 2.)

With reference to IS 802 (Part I/ Section I): 1995

b) Metrological Reference Wind Speed, V[clause no, - 8.2]

$V_R = V_b/K_o$

Where,

$K_0$is a factor to convert 3 seconds peak gust speed into average spee

10 minutes period at a level of 10 meters above ground.K_0may be ta

∴ V_R=39 / 1.375.

V_R= 28.36 m/s.

Table 2, of IS gives the values of risk coefficients K_1 for different wind zones for the three reliability levels. With reference to IS 802 (Part I/ Section I): 1995

K_1= 1

With reference to IS 802 (Part I/ Section I): 1995

Terrain Roughness Coefficient, K_2[clause no, - 8.3.2] Table 3 of IS 802 (Part I/ Section I): 1995 gives the values of coefficient K_2 for the three categories of terrain roughness corresponding to 10 minutes averaged wind speed.

K_2= 1.08

1) Category 1 - Exposed open terrain with few or no obstruction and in which the average height of any object surrounding the structure is less than 1.5 m.
2) Category 2 - Open terrain with well scattered obstructions having height generally between 1.5 m to 10 m.

3) Category 3 - Terrain with closely spaced obstructions.

With reference to IS 802 (Part I/ Section I): 1995

f. Design Wind Pressure, P_d [clause no, - 8.4] The design wind pressure on towers, conductors and insulators shall be obtained by the following relationship:

V_d= 30.62 m/s.

P_d= 0.6 V_d^2

Where,P_d = Design wind pressure in N/m^2, and

Vd = Design wind speed in m/s.

∴ Pd = 0.483 KN/m2.

With reference to IS 802 (Part I/ Section I): 1995

g. Design wind pressures Pd for the three reliability levels and pertaining to six wind zones and the three terrain categories have been worked out and given in Table 4 of IS .
[clause no - 8.4.1]

3.3 WIND LOADS

With reference to IS 802 (Part I/ Section I): 1995 a.

Wind Load on Tower[clause no, - 9.1]

In order to determine the wind load on tower, the tower is divided into different panels having a height „h". These panels should normally be taken between the intersections of the legs and bracings. For a lattice tower of square cross-section, the resultant wind load Fwt in Newton, for wind normal to the longitudinal face of tower, on a pannel height „h" applied at the center of gravity of this pannel is;

Fwt = Pd × Cdt × Ae × GT.

Pd = design wind pressure, in N/m2.

Cd t = drag coefficient for pannel under consideration against which the wind is blowing. Value of Cdt for different solidity ratios are given in Table 5, of IS 802 (Part I/ Section I): 1995. Solidity ratio is equal to the effective area (projected area of all the individual elements) of a frame normal to the wind direction divided by the area enclosed by the boundary of the frame normal to the wind direction. [Drag coefficient takes in to account the shielding effect of wind on the leeward face of the tower. However, in case the bracing on the leeward face is not shielded from the windward face, then the projected area of the leeward face of the bracing should also be taken in to consideration.]

Ae = Total net surface area of the legs, bracings, cross arms and secondary members of the panel projected normal to the face in m2. (The projections of the bracing elements of the adjacent faces and of the plan-and-hip bracing bars may be neglected while determining the projected surface of a face)

G_T= Gust response factor, peculiar to the ground roughness and depends on the height above ground. Values of Gt for the three terrain categories are given in Table 6, IS 802 (Part I/ Section I): 1995.

With reference to IS 802 (Part I/ Section I): 1995

b. Wind Load on Conductor and Ground wire[clause no, - 9.2]

The load due to wind on each conductor and groundwire, Fwc in Newtons applied at supporting point normal to the line shall be determined by the following expression:

Fwc = Pd × Cdc x L × d × Gc

Where,

Pd = design wind pressure, in N/m2;

Cdc = drag coefficient, taken as 1·0 for conductor and 1·2 for ground wire;

L = wind span, being sum of half the span on either side of supporting point, in meters;

d = diameter of cable, in meters;

Gc = Gust response factor, takes into account the turbulence of the wind and the dynamic response of the conductor. Values of Gc are given in Table 7, of IS 802 (Part I/ Section I): 1995, for the three terrain categories and the average height of the conductor/ground wire above the ground. [The average height of conductor / groundwire shall be taken up to clamping point of top conductor / groundwire on tower less two-third the sag at minimum temperature and no wine.]

Fwc =Pd × Cdc x L × d × Gc

= 0.483 × 1 × 300 × 0.02862 × 2.16

= 8.96 kN

As per IS the projected area of conductor is found as 0.67 times its diameter and intensity of wind is decreased by 75% in order to account the swinging effect of the conductors

Fwc = 8.96×1 × 0.75

= 6.72 kN.

With reference to IS 802 (Part I/ Section I): 1995

Lateral load due to line deviation of Conductor.

Conductor / groundwire tension at everyday temperature and without external load, should not exceed the following percentage of the ultimate tensile strength of the conductor:

...[Clause no - 15]

Initial unloaded condition =35 percent

Final unloaded condition = 25 percent

Permissible tension (T) for conductor = 25% of ultimate strength

= 32.65 KN.

2T Sinθ = 2.279 kN. [T = 32.65 kN. And θ = 20]

∴ Total lateral load at cross arm points is = 6.72 + 2.279

= 9 kN

Wind Load on Conductor due to Broken Wire Condition.

For Conductor Wire:

Because of broken wire condition, 60 percent span is considered to calculate wind load on conductor.

Fwc = 8.96 × 0.6

= 5.38 KN.

Fwc = 5.38×1 × 0.75

= 4.032 kN.

Load due to line deviation remains unchanged.

2T Sinθ = 2.279 kN. [T = 32.65 kN. And θ = 20]

∴ Total lateral load at cross arm points is = 4.032 + 2.279

= 6.31 kN.

Wind Load on Ground wire;

Fwc =Pd × Cdc x L × d × Gc

= 0.483 × 1.2 × 300 × 0.00945 × 2.16

= 3.55 kN.

As per IS the projected area of conductor is found as 0.67 times its diameter and intensity of wind is decreased by 75% in order to account the swinging effect of the conductors

Fwc = 3.753×1 × 0.75

= 2.66 kN.

Lateral load due to line deviation of Ground wire.

Permissible tension T for groundwire = 25% of ultimate strength

= 14 KN.

2T Sinθ = 0.977 kN. [T = 14 kN. And θ = 20]

∴ Total lateral load at cross arm points is = 3.55 + 0.977

= 4.527 KN.

Wind Load on Ground Wire

due to Broken Wire Condition. For Ground Wire: Because of broken wire condition, 60 percent span is considered to calculate wind load on groundwire.

Fwc = 3.55 × 0.6 = 2.13 KN.

Fwc = 2.13×1 × 0.75 = 1.56 kN.

Load due to line deviation remains unchanged.

2T Sinθ = 0.977 kN. [T = 14 kN. And θ = 20]

∴ Total lateral load at cross arm points is = 1.56 + 0.977

= 2.57 KN

With reference to IS 802 (Part I/ Section I): 1995

1. Vertical Loads:
   a. Self weight of tower structure up to the point/level under consideration.
   b. Loads due to weight of conductors/groundwire based on design weight span, weight of insulator string and accessories. In computing the weight of conductor and earth wire, the weight span which is 1.5 times the normal span or wind span, is used.
      i. Weight of the conductor = (weight span × unit weight of conductor)

      = 450 × 0.01594

      = 7.173 KN.

      ii. Weight of ground wire unit weight of groundwire) = (weight span ×

      = 450 × 0.004218

      = 1.9 KN.

iii. Weight of ground wire attachment = 2 KN. [Assumed].

iv. Vertical load due to String Insulator = 3 kN. [Assumed.]

2. Load of 3.5 KN considered acting at the tip of cross arms up to 220 kV and 5 kN for 400

   kV and higher voltage for the design of cross arms.

3. Erection loads at lifting points, for 400 kV and higher voltages. [cl no,-12.2.3….(iv)]

4. A load of 1.5 KN considered acting at each cross arm, as a provision of weight of lineman

   with tools. (Applied at each panel point also)

5. Results and Discussion

Results obtained in XBX bracing system:

A 220 kV transmission line tower is analyzed and designed for various parameters explained in the initial stage. Optimum weight of the tower is obtained for various

Geometric configuration and graphs are plotted. Here following table and graph represents the optimum weight of the tower for various parameters studied.

Table 5.10: Optimum weight of the tower for various parameters studied.

Type of Bracing	Width to height ratio	No of Panel	Weight of tower (KN)
XBX	0.139	4	**41.01**
XBX	0.139	5	43.39
XBX	0.139	6	46.18
K	0.112	4	**40.49**
K	0.112	5	45.40
K	0.112	6	42.80
X	0.112	4	**40.84**
X	0.112	5	43.65
X	0.112	6	45.73

Graphs plotted earlier (Graph no II, IV, and VI) for the optimum weights of the tower are presented all together in above graph (Graph 5.13). From the above graph it is seen that,

For 'XBX' bracing system, optimum width to height ratio is 0.167 o (i.e. base width 6 m.)

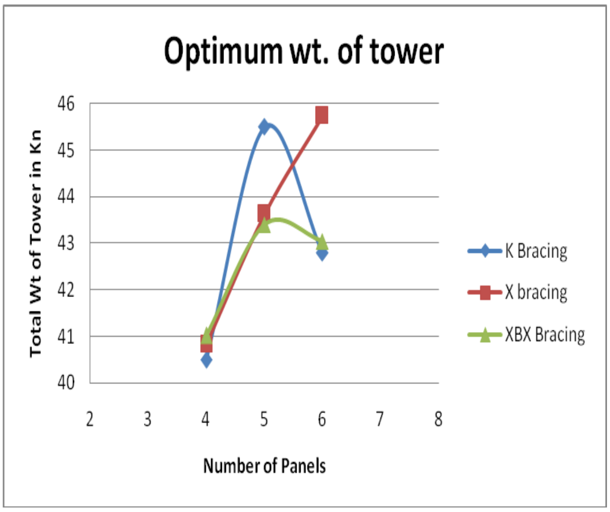

Fig. 5.11 Optimum Weight of the Tower for Various Parameters

For 'X' and K bracing system, optimum width to height ratio is 0.112 (i.e. base width of 4 m.). Where the land is costly and restrictions are laid regarding corridor available, in such situations it is preferable to adopt 'X or K' bracing system. Because for this bracing system optimum base width is 4 m, so land required is less and extra corridor is readily available because of compact tower geometry.

5.2 Axial Forces in Transmission Tower

5.5.1Axial Forces in XBX bracing system Transmission Tower

220 kV transmission line tower is analyzed and designed. In this case effect on axialforce in the body and cage of tower is studied for various parameters. Here 'XBX' bracing system is adopted and effect on axial force, for variation in w/h ratio and number of panels is studied

From Table 5.14 and Graph 5.14, it is seen that, as the width to height ratio of the tower increases from 0.112 to 0.167, axial force in the body of the tower decreases in the range from 20 percent to 25 percent. As the number of panels increases, the axial force in the body of tower is nearly same (except a difference of 2-3%) for all the width to height ratios.

Table 5.11 Axial Forces in XBX braced Transmission tower

Width to Height ratio	No. Panels	Maximum axial force in Tower	
		compressive	Tensile
0.112	4	253	220
0.112	5	274	220
0.112	6	246	223
0.139	4	247	187
0.139	5	251	187

0.139	6	251	188
0.167	4	233	187
0.167	5	231	173
0.167	6	237	173

From the Table 5.14, it is seen that, there is not much effect on the axial force in the cage of tower as the width to height ratio increases; the axial force in the cage of tower is nearly the same for all the width to height ratios.

The variation in the graph for axial force is nearly linear for number of panels 4, 5, and 6

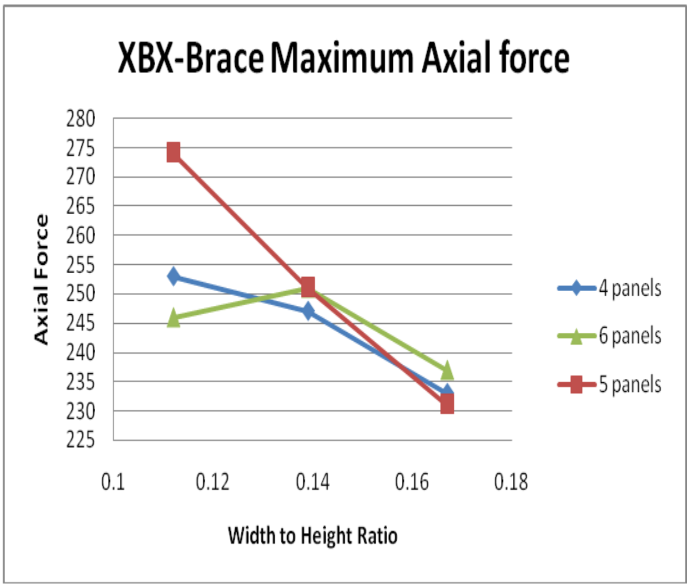

Fig 5.12: Axial Forces in XBX braced Transmission tower

5.5.2Axial Forces in K bracing system Transmission Tower

220 kV transmission line tower is analyzed and designed. In this case effect on axialforce in the body and cage of tower is studied for various parameters. Here 'K' bracing system is adopted and effect on axial force, for variation in w/h ratio and number of panels is studied

From Table 5.15 and Graph 5.15, it is seen that, as the width to height ratio increases from 0.112 to 0.139, axial force in the body of the tower increases from 10 to 13 percent and decreases upto 20 percent to 25 percent for 0.139 to 0.167 in 4 panels. As the number of panels increases, the axial force in the body decreases for 6 panels up to 25 percent . For 5 panels forces decrease for 0.139 upto 12 percent and sudden increase for0.167 upto 15 percent.

Table 5.12 Axial Forces in K braced Transmission tower

Width to Height ratio	No. Panels	Maximum axial force in Tower	
		compressive	Tensile
0.112	4	247	211
0.112	5	256	213
0.112	6	254	218
0.139	4	257	220
0.139	5	246	181
0.139	6	248	182
0.167	4	247	182
0.167	5	252	187
0.167	6	232	166

From the Table 5.15, it is seen that, there is not much effect on the axial force in the cage of tower as the width to height ratio increases; the axial force in the cage of tower is nearly same for all the width to height ratios.

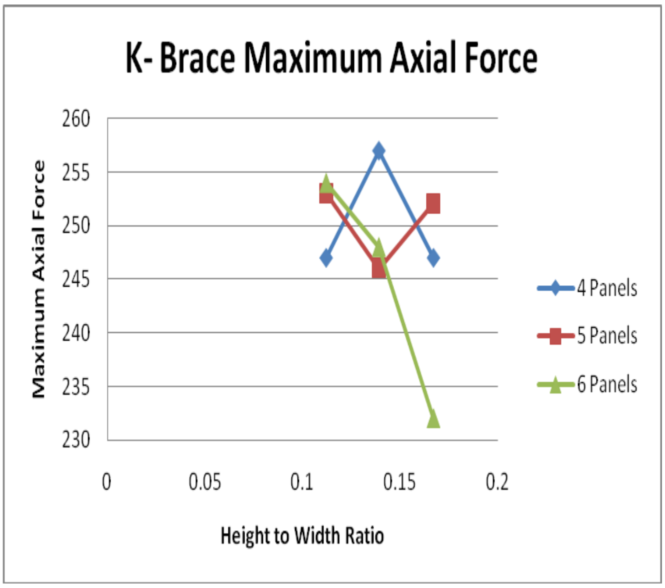

Fig. 5.13 Axial Forces in K braced Transmission tower

5.5.3Axial Forces in X bracing system Transmission Tower

220 kV transmission line tower is analyzed and designed. In this case effect on axialforce in the body and cage of tower is studied for various parameters. Here 'X' bracing system is adopted and effect on axial force, for variation in w/h ratio and number of panels is studied.

Table 5.13 Axial Forces in X braced Transmission tower

Width to Height ratio	No. Panels	Maximum axial force in Tower	
		compressive	Tensile
0.112	4	247	211
0.112	5	256	213
0.112	6	254	218
0.139	4	257	220
0.139	5	246	181
0.139	6	248	182
0.167	4	247	182
0.167	5	252	187
0.167	6	232	166

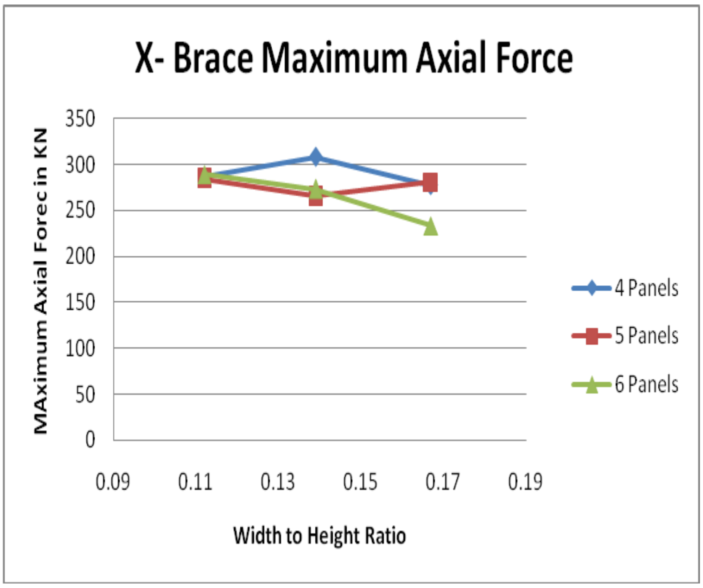

Fig. 5.14: Axial Forces in X braced Transmission tower

From Table 5.16 and Graph 5.16, it is seen that, as the width to height ratio increases from 0.112 to 0.167, axial force in the body of the tower decreases from 15 to 25 percent for 6 and 4 panels. For 5 panels forces decreases upto 0.139w/h ratio and increase for 0.167 As the number of panels increases, the axial force in the body of tower is nearly the same (except a difference of 2-3%) for all the width to height ratios.

From the Table 5.16, it is seen that, there is not much effect on the axial force in the cage of tower as the ratio increases; the axial force in the cage of tower is nearly same for all the ratios.

5.3 Comparison between Hollow section and angular section

220 kV transmission line tower is analyzed and designed for hollow section in earlier discussion. In this attempt has been made to compare hollow optimised tower with angular section in this study K braced tower with width to height ratio 0.112 (base width=4m) found to be more optimised in hollow section. For comparison same K braced tower is analysed and designed by keeping same geometry and design condition. In comparison hollow section transmission tower weight comes to be 40.49 KN. same tower is again analysed and designed by keeping same geometry and loading conditions using angular section weight of transmission tower found to be 56.23 KN after comparing we can say that hollow section give economical results than our regular angle section. In comparison we found that hollow section are almost 35% more optimised than regular section. Hollow tubular sections are more optimised because of its same moment of inertia and same radius of gyration all over sections**[cl no,-12.2.3….(ii)]**

6. CONCLUSIONS

6.1 General:

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, cost effectiveness 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 cost effective tower geometry, different geometric combinations are made in the body of the tower using parameters mentioned above Total Twenty seven towers are analyzed and designed toget economical tower configuration. Initially a study is carried out keeping bracing system constant and considering variations in width to height ratio & number of panels in body of the tower. From this study Optimum width to height ratio for which the weight of the tower is minimum, is worked out. In the similar manner optimum width to height ratio for which the weight of the tower is minimum, is worked out for other two types of bracing systems. Each type of bracing gives an optimum weight of the tower. Optimum weights of the towers obtained for various widths to height ratio and various bracing systems are compared together with respect to number of panels in the body of the tower. After comparing all these various combinations of parameters we come to suggest an optimum geometric configuration for the tower. Maximum axial force developed in the body of the tower and maximum resultant displacement at various points of the tower, is also calculated. Graphs for maximum axial force are plotted by considering optimum weight of the tower.

These towers are analyzed and designed for several loading combinations. During analysis and design, it is observed that the top conductor broken condition is more stringent for the column (leg) members. Design of 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.

6.2 Conclusions are derived from the parametric investigation:

1. For 'K' and 'X' type of bracing systems width to height ratio between 0.112 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 'XBX' type of bracing system width to height ratio 0.139 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 5 numbers of panels to get optimum geometric configuration of the tower. And for 'X' bracing system adopts 4 number of panels to get optimum geometric configuration of the tower.
4. For X type of bracing system, 4 number of panels are sufficient for the ratio 0.112. The increase in panel numbers and width to height ratio with more secondary bracing are not found to be economical for X bracing.
5. 'XBX' 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 XBX 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 restrictions on availability of extra corridor, in such situations, it is preferable to adopt 'K' bracing system. For 'K' bracing system optimum base width is 4 m (Width to height ratio=0.112) which is much less than other bracing systems, so land required is less.
7. For 'K' type of bracing system 20% to 25% area saving can be achieved as compared to 'XBX' and 'X' bracing system.
8. As far as the optimum geometric configuration of the tower is concern 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
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.
10. In comparison between angular and hollow section hollow section found to be more optimised than angular i.e 35% more economy can be achieved

7. ACKNOWLEDGEMENT

This work is supported by all experienced staff and civil Engineering Department OF College of Engineering Pandharpur, Maharashtra, India for providing us valuable guidance.

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