

## International Journal of Innovative Research in Science, Engineering and Technology

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# Analysis and Design of Angle/Tension Type Double Circuit Tower for 110kv Transmission Line with Extension for Railway Line Crossing to Achieve Vertical Clearance Using STAAD Pro V8i.

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**ABSTRACT:** Transmission line is an integrated system consisting of conductor subsystem, ground wire subsystem and one subsystem for each category of support structure. Mechanical supports of transmission line represent a significant portion of the capital cost of the line and they play an important role in the reliable power transmission. The cost of towers constitutes about quarter to half of the cost of transmission line and hence optimum tower design will bring in substantial savings. They are designed and constructed in a wide variety of shapes, types, sizes, configurations and materials.

The types of supporting structure generally fall into one of the three categories: lattice, pole and guyed. The supports of EHV transmission lines are normally steel lattice towers. The selection of an optimum outline together with right type of bracing system contributes to a large extent in developing an economical design of transmission line tower. The height of tower is fixed by the user and the structural designer has the task of designing the general configuration, members and joint details.

The goal of every designer is to design the best (optimum) systems. But, because of the practical restrictions this has been achieved through intuition, experience and repeated trials, a process that has worked well.

In this paper, analysis and design of a specific angle /tension type double circuit tower with economical sections for 110KV transmission line with 9m extension to have adequate vertical clearance between center line of railway track and bottom most conductor of the transmission line is made.

**KEYWORDS :** Angle/Tension type tower, ACSR Panther conductor, Insulators & Hardware fittings, ISA sections, Vertical clearance, Tower body Extension

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## I. INTRODUCTION

Transmission towers are tall structures having height much more compared to their lateral dimensions. The main purpose of transmission line tower is to support conductors and earth wires. They are space frames or trusses made up of structural steel sections and having foundation under each leg. Transmission line towers constitute about 28 to 42 percent of the cost of the transmission line. The increasing demand for electrical energy can be met more economically by developing different light weight configurations of transmission line towers optimized to satisfy several parameters. The selection of an outline together with right type of bracing system, height, cross arm type, configuration and other environmental factors govern the design and the goal of every designer is to arrive at a systems that satisfy all the requirements at the same time. As transmission towers are tall structures, they are more susceptible to wind load compared to earthquake load. Generally four legged lattice towers are most commonly used as transmission line towers and three legged towers are used only as telecommunication, microwaves, radio and guyed towers.

The EHV network in Tamil Nadu has around 95,000 steel transmission line towers as on date consisting of 400KV, 230KV, 110KV and 66 KV with a total circuit length of 24,497km controlled and maintained through 842 sub-stations.

## II. TYPES OF TOWERS

Classification according to number of circuits:

1. Single Circuit towers
2. Double Circuit towers
3. Multi – Circuit towers Classification according to use:
  1. Tangent/Suspension type tower
  2. Angle or Tension or Dead end tower
  3. Transposition tower

### **1. Tangent/Suspension type tower:**

This type of towers are used along the transmission line where the line is having

angle of deviation  $0 - 2^\circ$  only. They do not carry any loads and are provided just to hold the conductor and earth wire run through.

### **2. Angle or Tension or Dead end tower:**

This type of towers are used in the transmission line at locations where the line is having angle of deviation more than

$2^\circ$ . These towers will take tension loads and hence are also named as Tension type towers. Tension towers are mostly used for turning points and for section isolating locations. The piece of the line from one angle tower to other angle is known as section and length of the section may vary depending on the geographical location. All the towers within the section are suspension towers with prescribed span length.

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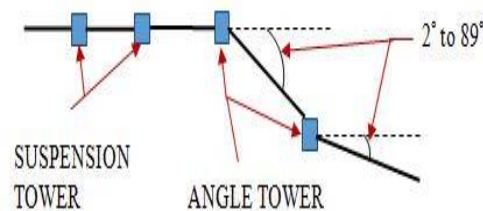
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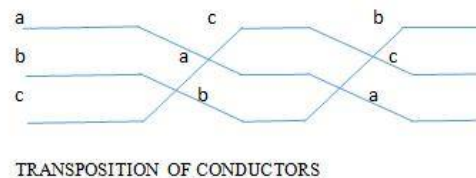
Tension towers can further be divided into two categories:

- i) Towers due to angle of deviation from  $2^\circ$  to  $30^\circ$
- ii) Towers due to angle of deviation from  $30^\circ$  to  $89^\circ$



### 3. Transposition tower:

Transposition towers are used to transpose the conductors of three-phase line. Transposition arrangement is also called as span transposition. These type of towers are widely used in long transmission lines.



The basic purpose for transposition of transmission line is to rotate the conductors which result in the conductor or a phase being moved to next physical location in a regular sequence.

### **SAFETY CLEARANCES IN TRANSMISSION LINE**

Typical high-voltage overhead transmission lines are composed of bare conductors connected to supporting structures by means of porcelain, glass, or plastic insulators. The air surrounding the energized conductor acts as the insulating medium. Maintaining sufficient clearances, or air space, around the conductors to protect the public and utility workers is paramount to the safe operation of the line. The safety clearance required around the conductors is determined by normal operating voltages, conductor temperatures, short-term abnormal voltages, wind-blown swinging conductors, contamination of the insulators, clearances for workers, and clearances for public safety.

Typically, clearances are specified for the following:

- Distance between the energized conductors themselves, communication wires on the same supporting structure, or between other power or communication wires above or below the conductors,
- Distance from the energized conductors to the ground and features such as roadways, railroads, driveways, parking lots, navigable waterways, airports, etc.,
- Distance from the energized conductors to buildings and signs, and
- Distance from the energized conductors to other parallel power lines.

The safety clearances in all ways such as Right of Way Clearance (Horizontal below the conductors), Between

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conductors, Ground clearance in General & at particular locations, Vertical clearances at Power line/Telephone line/Railway track crossings, Clearance over buildings, At middle of span in accordance with the span length, Safety working/Approach clearance & UG cables clearance have been framed by Indian Electricity (IE) Rules & Central Electricity Authority (CEA) for strict adherence as the rules are rigorously related to human life hazards.

## MAINTAINING OF SAFETY CLEARANCES IN TRANSMISSION LINE:

The above clearances should be maintained without fail. Horizontal clearances could be maintained by placing the supports at appropriate location in consideration with the distance from the existing structures. But, vertical clearances for ground or any other crossing such as power line crossing, water body (river) crossing, road crossing, railway track crossing etc. may vary with the nature of terrain also.

## VERTICAL CLEARANCES AT VARIOUS LOCATIONS AND ITS

- Distance between the energized conductors and the supporting structure,
- Distance between the energized conductors and other power or

## NECESSITY:

The transmission line traverses through various geographical areas and the ground level may not be uniform. Further, the supporting structures of the line (i.e) transmission towers are also not having uniform height. According to number of circuits, capacity of the line, angle of line deviation, purpose of use etc. towers are of various heights.

To obtain the minimum vertical clearance as prescribed by IE rules and CEA, extensions can be used over the normal tower of respective type so as to increase the height of the tower. Also, while crossing the existing power line, river, railway crossing, road crossing etc., height of the tower should be increased by providing suitable extensions to the normal tower. As such, the height can be increased either by (i) Leg Extensions or by (ii) Body Extensions.

### (i) Leg Extensions:

Leg extensions are widely used in any leg or any pair of transmission line tower legs, where the locations for which footings of the tower legs are at different levels. These kind of circumstances happen highly in hilly terrain where the ground is not uniform. Unequal leg extension need special care to set the individual stubs using suitable type of stub setting templates. Universal leg extension and individual leg extensions are the major two types of leg extensions which are widely used. Normally, spotting of transmission towers in hilly areas need revetment and benching to provide stability. Provision of leg extension will reduce the extent of benching and revetment.

### (ii) Body Extensions:

Body extensions are generally used to increase the height of the tower where minimum vertical clearance is to be maintained. Body extensions are mainly used for power line crossing, road crossing, railway line crossing, river crossing etc. where ground obstacles exist. As the transmission towers are not uniform in height, the vertical clearances could be achieved by using body extensions according to the need. Normally, body extensions are applied in +3m, +6m, +9m and +12m and so on in multiples of 3m upto +25m in height. There are very few towers which require extensions more than 25m where the site condition and purpose warrant. At the locations where the extensions exceed 25m, the suitability is checked by reducing the span length and angle of deviation.

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VERTICAL CLEARANCE BETWEEN ELECTRICAL LINE AND RAILWAY TRACKS TO BE MAINTAINED:

VOLTAGE	MINIMUM CLEARANCE	
	NON – ELECTRIFIED TRACKS	ELECTRIFIED TRACKS
66KV	14M	14.60M
132KV	14.60M	15.60M
220KV	15.40M	17.30M
400KV	17.90M	18.50M

## TOWER ANALYSIS AND DESIGN

Once the external loads acting on the tower are determined, one proceeds with an analysis of the forces in various members with a view to fixing up their sizes. Axial force is the primary force for a truss element and therefore, the member is designed for either compression or tension. When there are multiple load conditions, certain members may be subjected to both compressive and tensile forces under different loading conditions. Hence, these members are designed for both compression or tension acting separately.

## GEOMETRY OF A 110KV DC TOWER

- Transmission line voltage ... 110KV
- Tower type ... Angle/Tension /Dead end tower
- No. of circuits ... 2
- Angle of line deviation ... >30°
- Tower configuration ... Vertical conductor configuration
- Bracing Pattern ... Diamond bracing
- Cross arm ... Pointed
- Max. Temperature ... 36°
- Every day temperature ... 32°
- Min. Temperature ... 30°
- Insulator type ... I- string
- Height of tower ... 22682mm + 9000mm for extension
- Base width of tower ... 10186 mm
- Terrain category ... 2
- Reliability level ... 1
- Number of insulator discs ... 8 Nos. 120KN for Tension string
- Size of insulator discs ... 285 X 165 mm
- Length of insulator string ... 1580 mm
- Span length of line ... 200m

## LOAD CALCULATION FOR DESIGN OF 110KV DC TOWER

The self- supporting/suspension towers are rigid in both the directions and it is subjected to two types of live loads i.e. wind loads acting transversely and longitudinal horizontal loads.

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Wind/Transverse loads :

Force due to wind on various elements of transmission lines is obtained by multiplying pressure with the projected area of that element.

Wind on wire.  $F_{wc} \dots Pd. L. d. Gc. Cdc$

Wind on Insulator:  $F_{wi} \dots Pd. Ai. Gi. Cdt$

Due to deviation  $F_{wd} \dots 2. T. \sin(\phi / 2)$

*Longitudinal horizontal loads :*

Longitudinal load is due to the weight of conductor and earth wire.

Unit Weight of ACSR Panther conductor =976Kg/Km

For 6 wires of span 200m... $6 \times 0.20 \times 976 = 1171 \text{Kg}$

Weight of Earth wire... $1 \times 0.20 \times 451 = 90$

Total weight =1261Kg

Assuming 30% of load only to be transferred (i.e) 378Kg. 500Kg was taken as live load including the weight of hardware fittings

**MODELING OF TOWER:**The general software STAAD Pro has been used for modeling. It is more user friendly and versatile program that offers a wide scope of features like static and dynamic analysis, non linear dynamic analysis and non linear static pushover analysis, etc.

**SOFTWARE USED:** STAAD Pro V8i is a comprehensive and integrated finite element analysis and design offering, including a state of the art user interface, visualization tools and design codes. It is capable of analyzing any structure exposed to static loading, a dynamic response, wind, earthquake, and moving loads. STAAD Pro V8i provides FEM analysis and design for any type of project including towers, culverts, plants, bridges, stadiums and marine structures.

**STAAD. Pro** is a structural analysis and design computer program originally developed by Research Engineers International at Yorba Linda, CA in year 1997. In late 2005, Research Engineers International was bought by Bentley Systems. STAAD. Pro is one of the most widely used structural analysis and design software. It supports several steel, concrete and timber design codes. It can make use of various forms of analysis

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from the traditional 1st order static analysis, 2nd order p-delta analysis, geometric non linear analysis or a buckling analysis. It can also make use of various forms of dynamic analysis from modal extraction to time history and response spectrum analysis.

### PLAN AND DIMENSION DETAILS

The following are the specification of 22.68m with 9m (Extension) height Angle/Tension tower for 110KV DC Transmission line crossing the railway track. Here four legged transmission tower is used in the model. The complete detail of the structure including modeling concepts is given below:

Details and Dimension of the Tower

Type of tower	110 kV double circuit 4 legged tower
Height of tower	22.68m +9m Extension
Base width of tower	10.186 m square base
Length of cross arm	3 m
Type of bracing	Diamond bracing
Width of top hamper	2 m
Conductor Material & Type	Aluminium Conductor Steel Reinforced-Panther
Span of tower between two towers	200 m
Vertical spacing between conductors	3 m

A square base transmission tower with 10.186 m base width and 31.680m height was considered in this study. Figure 4.1 shows the plan of the tower representing the X and Y direction used for analysis. Figure 4.2 shows an elevation of the transmission tower. Figure 4.3 shows a three dimensional line sketch of the transmission tower in the X, Y and Z direction.

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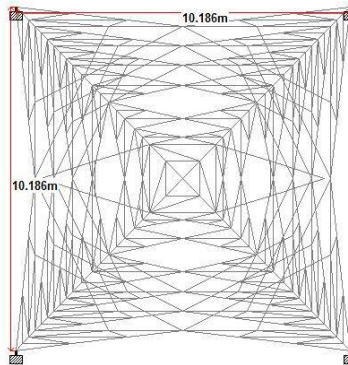


Figure 4.1: Plan of Tower

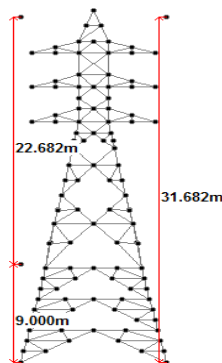


Figure 4.2: Elevation of the Transmission Tower

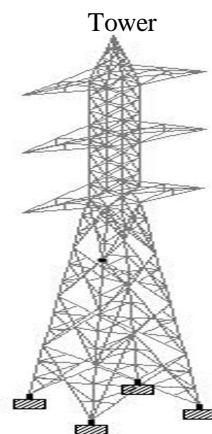


Figure 4.3: Three Dimensional View of Transmission Tower



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## ASSIGNING SUPPORT

The support provided for the transmission tower is fixed support. They are provided at the four legs of the tower. They are rigidly fixed to the foundation. (Figure 4.4 shows assigning support) of insulators, wires & hardware fittings as 8.60 Kn

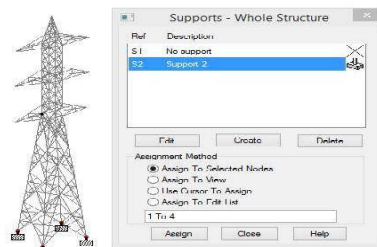


Figure 4.4 Assigning support

## ASSIGNING MEMBER PROPERTY

The member property provided for the transmission tower is Indian type angle section. They are provided for all the members of the tower. (Figure 4.5 shows assigning member property)

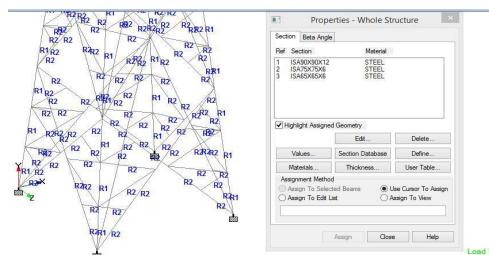


Figure 4.5 Assigning member property

## LOAD ASSIGNING

The load acting on the towers are:

1. Dead load. Self-weight of the tower. Figure 4.6 shows the assigning of dead load.

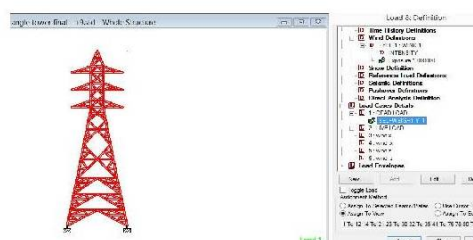


Figure 4.6 Assigning of dead load

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2. Wind load calculated as per IS 875 (Part-3) for zone - 5

The basic wind speed is also determined by the return period, which is related to the reliability level of the transmission lines.

The comparison of return period is presented in Table 1 of IS 875 (Part-3) for zone - 5. For example, the 50- year return period wind speed has a probability of 0.02 of being exceeded in any one year.

2. Live load. Imposed weight of the conductors and wires. Figure 4.7 shows the assigning of dead load. Total weight

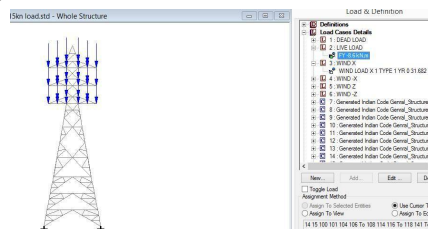


Figure 4.7: Assigning of live load

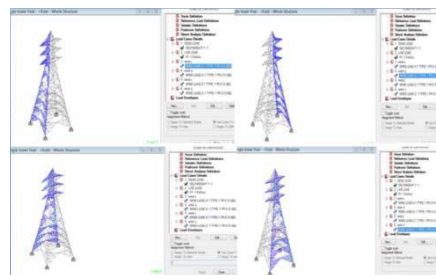


Figure 4.8: Assigning of wind load

## ANALYSIS OF TOWER:

After assigning the loads to the structure, analysis is done to evaluate the axial force displacement and steel take off for determining the economic section. After analysis, design can be executed in the software STAAD Pro V8i as it includes various international codes and the structure can be designed using these codes. After following above mentioned steps, the results obtained from the study are summarized below for maximum Axial force & maximum displacement for angular section, Tubular section and Channel section.

Axial Force diagram, Displacement diagram and bending moment diagram of angular section is shown in figure 5.1, 5.2 and 5.3. Axial force & deflection are calculated and Tabulated in Table 5.1 & 5.2 respectively.

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**Table 5.1.A** Maximum Axial Force for angle section(110 KV)

S. No	Different Node Point	Beam No.	Member property	Axial Force(kN)
1	Bottom leg	484	ISA 150X150X16	31.184
2	Top column	4	ISA 150X150X16	6.534
3	Bottom horizontal member	442	ISA 100X100X8	-0.042
4	Top horizontal member	245	ISA 90X90X8	0.908
5	Bottom bracing	549	ISA 90X90X8	1.546
6	Top & cross arm bracing	334	ISA 65X65X5	0.639
7	Inclined member in cross arm	367	ISA 65X65X5	0.648

**Table 5.1.B** Maximum Axial Force for Tubular section(110KV)

S. No	Different Node Point	Beam No.	Member section	Axial Force (kN)
1	Bottom leg	484	TUB 1501506	32.385
2	Top column	4	TUB 1501506	7.378
3	Bottom horizontal member	442	TUB 1001006	-0.173
4	Top horizontal member	245	TUB 90904.5	1.581
5	Bottom bracing	549	TUB 90904.5	1.926
6	Top & cross arm bracing	334	TUB 70704	0.999
7	Inclined member in cross arm	367	TUB 70704	0.751

**Table 5.1.C** Maximum Axial Force for channel section

S. No	Different Node Point	Beam No.	Member section	Axial Force (kN)
1	Bottom leg	484	ISMC 250H	33.481
2	Top column	4	ISMC 250H	8.333
3	Bottom horizontal member	442	ISMC125	0.156
4	Top horizontal member	245	ISMC100	1.947
5	Bottom bracing	549	ISMC100	2.345
6	Top & cross arm bracing	334	ISMC75	1.857
7	Inclined member in cross arm	367	ISMC75	1.039

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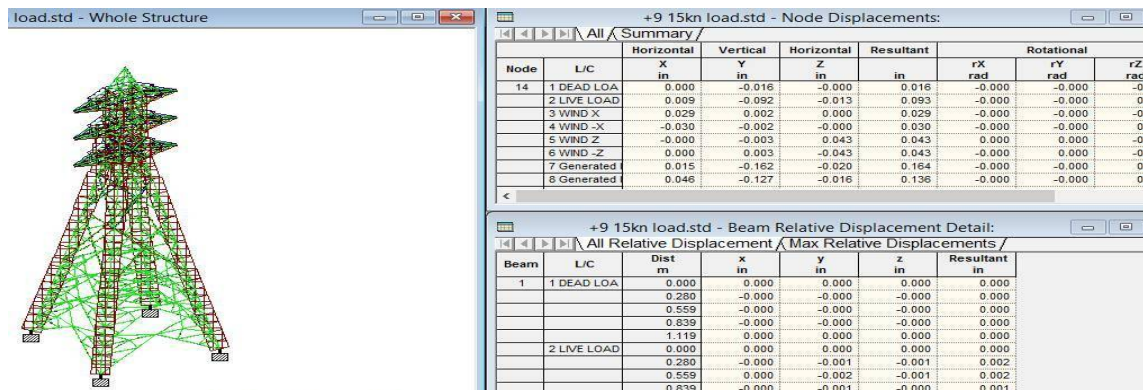


Figure 5.1: Axial force diagram of angular section

Table 5.2.A Maximum Displacement for angle section

S. No	Different Node Point	Beam No.	Displacement(mm)
1	Bottom leg	484	0.043
2	Top column	4	0.412
3	Bottom horizontal member	442	0.1222
4	Top horizontal member	245	0.676
5	Bottom bracing	549	0.291
6	Top & cross arm bracing	334	0.513
7	Inclined member in cross arm	367	0.808

Table 5.2.B Maximum Displacement for Tubular section

S. No	Different Node Point	Beam No.	Displacement(mm)
1	Bottom leg	484	0.067
2	Top column	4	0.728
3	Bottom horizontal member	442	0.385
4	Top horizontal member	245	0.937

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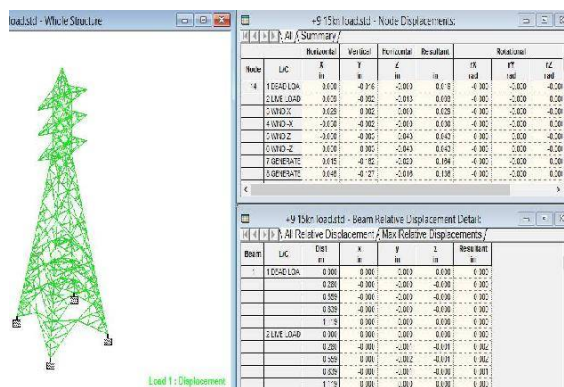
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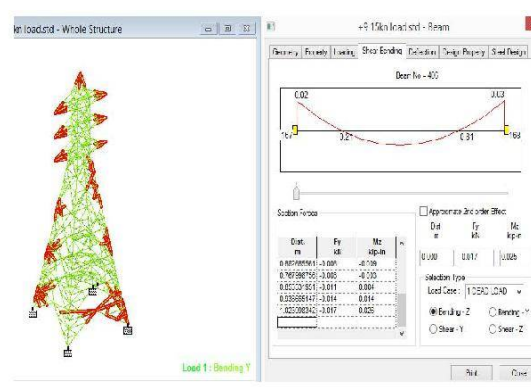
5	Bottom bracing	549	0.411
6	Top & cross arm bracing	334	0.633
7	Inclined member in cross arm	367	0.999

**Table 5.2.C** Maximum Displacement for channel section

S. No	Different Node Point	Beam No.	Displacement(mm)
1	Bottom leg	484	0.093
2	Top column	4	0.852
3	Bottom horizontal member	442	0.483
4	Top horizontal member	245	1.062
5	Bottom bracing	549	0.529
6	Top & cross arm bracing	334	0.700
7	Inclined member in cross arm	367	0.999



**Figure 5.2:** Maximum Displacement diagram of angular section



**Figure 5.3.**Maximum bending moment diagram of angular section

## DESIGN OF TOWER

The design is the process of section selection from the analysis results by using suitable design procedures in accordance with the code IS 800:2007.

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After assigning all the inputs such as member properties, loads etc., the design of structures was done using commands. These selected sections are added and then assigned to the structure as appropriate components. All the sections which are safe during analysis are suitable for using in the tower structure.

### III. RESULTS AND DISCUSSIONS

#### Maximum axial forces:

As the applied load increases, axial force also increases causing the member to become unstable and is said to have buckled.

**Maximum deflection:** As deflection increases, it causes aesthetic and functional problems, damage to structural and non structural element attached to the member. Excessive deflection causes objectionable sagging and hogging.

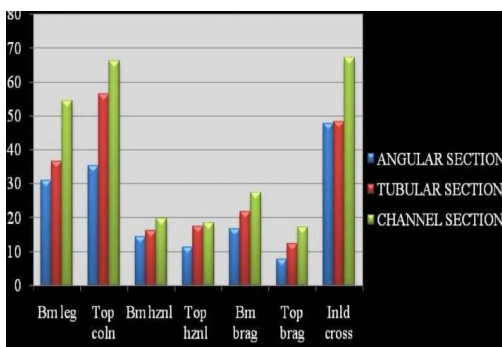


Figure 6.1 Bar Chart of Maximum Axial Force

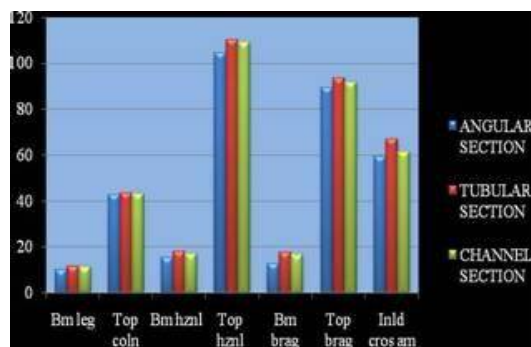


Figure 6.2 Bar Chart of Maximum Deflection

### IV. CONCLUSION

Considering the normal load conditions with Wind Zone V, the Angle/tension towers for 110KV Double circuit transmission line with 9m extension to have adequate vertical clearance between center line of railway track and bottom most conductor of the transmission line was analysed and designed for its safety, deflection, shear force and bending moments using STAAD Pro V8i.

The bottom tier members have more role in performance of the tower in taking axial forces and the members supporting the cables are likely to have localized role. The vertical members are more prominent in taking the loads of the tower than the horizontal and diagonal members, the members supporting the cables at higher elevations are likely to have larger influence on the behavior of the tower structure. The effect of twisting moment of the respective structure is not significant. The geometry parameters of the tower can efficiently be treated as design variables and considerable weight reduction can be achieved as a result of geometry changes.

Comparative analysis was done by considering angle, tubular and channel section of suitable sizes of members among which, the angle section is more safe in respect of displacement and axial force. Also, the tower with angle section and X-bracing has the greater reduction in weight after optimization.

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The properties of the angle members used to form a safe and economical structure are as below:

### STEEL TAKE-OFF

PROFILE	LENGTH (METRE)	WEIGHT (KN )
ST ISA150X150X16	91.38	32.082
ST ISA90X90X8	399.34	42.334
ST ISA45X45X5	169.00	5.556
ST ISA50X50X6	90.94	3.968
ST ISA130X130X12	15.16	3.483
ST ISA65X65X5	144.04	6.916
ST ISA100X100X10	12.27	1.800
ST ISA75X75X6	22.90	1.523
ST ISA100X100X8	123.59	14.621
LD ISA60X60X5	83.15	7.346
LD ISA90X90X8	65.33	13.851
TOTAL =		133.481

Thus, the total weight of the tower by optimum design is 13.50MT

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