Design of Steel Transmission Structure

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UNIVERSITY OF MANAGEMENT AND TECHNOLOGY LAHORE

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Abstract

In this project the performance of tower according to various loads such as wind load, will be observed. Wind load is actually a major force act on transmission line tower. The basic wind speed applied on tower, effects of tower height above the ground level. Design of wind speed, wind pressure, and wind forces will be explained and analyzed in software for design of members of transmission tower. Dead load of the tower is also considered in designing of transmission tower members. An analysis will be done on software to check the performance of tower and the member forces in all directions including diagonal members. Keeping in view the different load cases will be taken to work on the severe or critical phase of the tower, also applying different load combinations for taken critical situation on which members of the tower will be designed.

Keywords: Wind load, Load cases, Load Combinations, and Transmission Tower Steel Designs

UNDERTAKING

We certify that research work titled "*Design of Steel Transmission Structure*" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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ABBREVIATIONS

$\mathbf{A_g}$	Gross Area
$\mathbf{A_n}$	Net Area
BLC	Bottom Left Conductor
BRC	Bottom Right Conductor
BWC	Broken Wire Condition
$\mathbf{C_c}$	Column Slenderness ratio separating elastic and inelastic buckling
$\mathbf{C_f}$	Net Force Coefficient
D	Diameter
$\mathbf{F_a}$	Design Compressive Stress
$\mathbf{F_t}$	Design Tensile Stress
$\mathbf{F_u}$	Ultimate Tensile Strength
$\mathbf{F_v}$	Bolt Shear Capacity
G	Gust Factor
$\mathbf{K_d}$	Wind Directionality Factor
$\mathbf{K_e}$	Ground Elevation Factor
$\mathbf{K_z}$	Velocity Pressure Exposure Coefficient
$\mathbf{K_{zt}}$	Topographical Factor
L	Length
MLC	Middle Left Conductor
MRC	Middle Right Conductor
$\mathbf{N_c}$	Number of Conductors
OPGW	Optical Ground Wire
$\mathbf{P_a}$	Capacity of Compression member
$\mathbf{P_t}$	Capacity of Tension member
$\mathbf{P_u}$	Axial Force in member due to applied load
$\mathbf{Q_z}$	Velocity Pressure at Height z

TLC	Top Left Conductor
TRC	Top Right Conductor
V	Wind Speed

CHAPTER 1

Introduction

In modern times survival without electricity is nearly impossible; the capacity to produce and provide electricity to the people is a major determinant of progress of any country. The most common method of providing electricity from power station to cities, towns and villages through Conductors Suspended on transmission towers. A steel transmission tower is a tall structure, usually a steel lattice tower is used to support an overhead power line.

1.1 Overview of the project

It was proposed to design a 132KV steel transmission tower. The main objective of the project is to analyze the structural design of transmission tower under the loading criteria given by ASCE 7-16. The structural dimensions, weight of conductor and insulator were taken from NTDC (National Transmission and Dispatch Company). The modeling and calculations have been done manually and with the aid of software SAP2000, emphasis was laid on tower weight estimation and economic aspects of design.

Dimensions of structure are given below.

Table 1.1 Dimensions of structure

Voltage	132 KV
Length	25.3 ft.
Width	25.3 ft.
Height	93 ft.
Center-Center Distance between Adjacent Towers	328 ft.
Max Conductor Sag	8.2 ft.

1.1.1 Structural Drawings

The Following are structural drawings

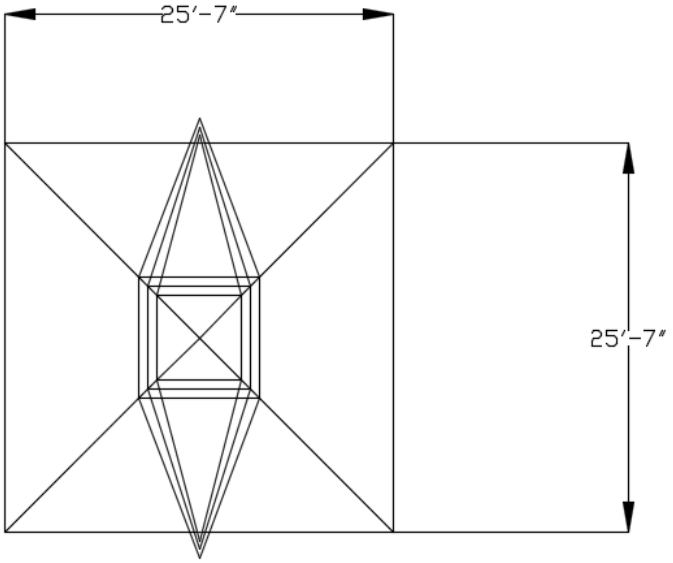


Figure 1.1 Plan view of tower

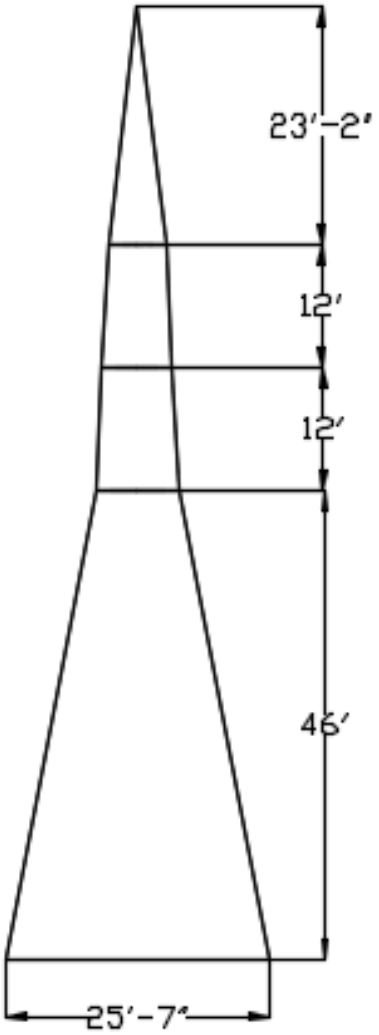


Figure 1.2 Front view of tower

1.2 Objective

To design the transmission tower according to applied wind load, dead load and make the transmission tower cost effective.

CHAPTER NO 2

Literature Review

The wind load calculations were done according to ASCE 7-16 Minimum Design Loads for Buildings and other Structures, 2016

Designing of members was done according to ASCE 10-15 Design of Latticed Steel Transmission Structure.

Selection of members was done from AISC Steel Design Aids

Bolt designing was done according to ASCE 7-16 Minimum Design Loads for Buildings and other Structures, 2016 and ASTM A394 Standard Specification for Steel Transmission Tower Bolts, Zinc-Coated and Bare

CHAPTER 3

Load Cases and Load Combinations

Load combinations are applied on the structure for the safety purposes, load combination on any structure will be used when one or more types of loads simultaneously or together act on a structure. For example, dead load, wind load etc.

Load cases are the loads that act on a structure on same time. While designing any structure load cases depend upon which type of structure has to be built. The project of transmission tower has major load cases of wind forces that act in different ways on power transmission tower. Keeping in view it is necessary to deal with almost all types of wind cases on which direction the wind will act on the tower and also depend upon the tower conductors either the transmission line tower is single line circuit tower or double line circuit tower

3.1 Load Combinations

Load combinations applied on power transmission tower is given below.

Table 3.1 Load Combinations

Load Combinations
1.4D
1.2D
1.2D + 0.5W
1.2D + 1.0W
0.9D + 1.0W
0.9D

D is the dead load
W is the wind load

3.2 Load Cases

Load cases used are defined below

3.2.1 Load Case 1

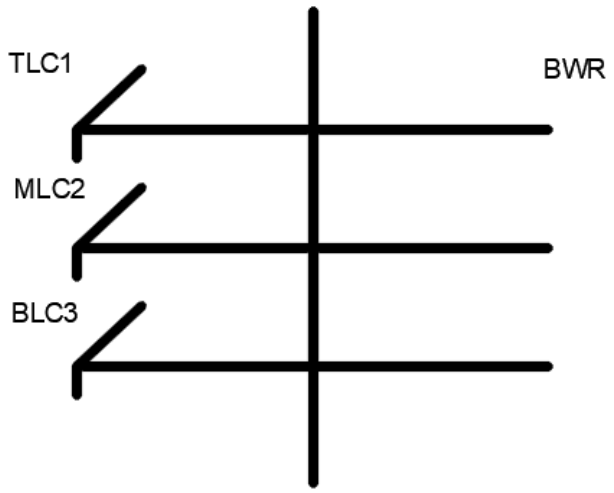


Figure 3.1 Conductors and insulators on left side

This load case shows broken wire condition (BWR) on right side of the power transmission line and the conductors or insulators on the left side of power transmission tower. This condition causes the tower to bend towards where the conductors and insulators hanged. This condition or load case is analyzed while designing the power transmission tower.

3.2.2 Load Case 2

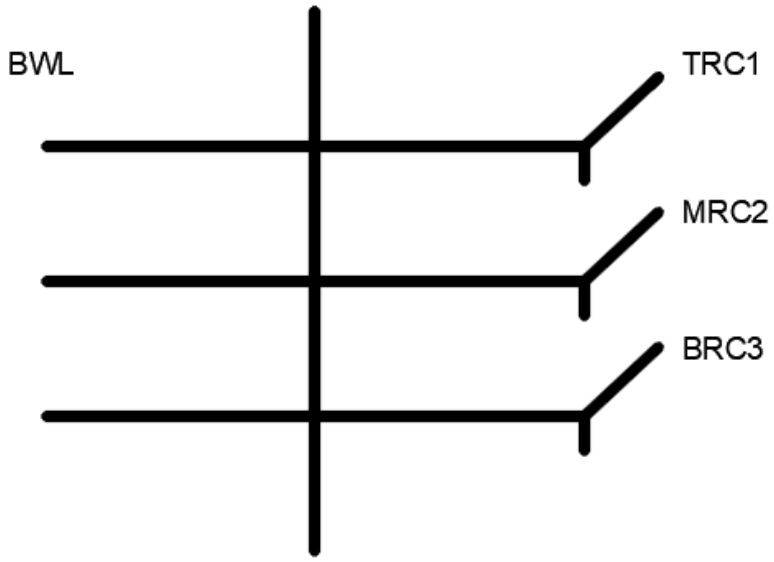


Figure 3.2 Conductors and insulators on right side

This condition shows the broken wire condition on left side of the power transmission tower and the conductors and insulators are on the right side of the tower. In this case the tower bends towards the right side where the conductors or insulators are hanged. This load case is also analyzed while designing the power transmission tower.

3.2.3 Load Case 3

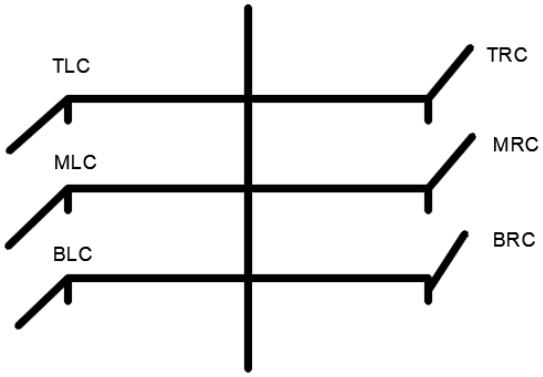


Figure 3.3 Conductors and insulators on both side or in opposite direction

This case shows conductors on both sides but in opposite direction. This will cause the transmission tower to twist. This load case is analyzed while designing the transmission tower.

The designing of members will be done on the basis of load combinations.

3.2.4 Load Case 4

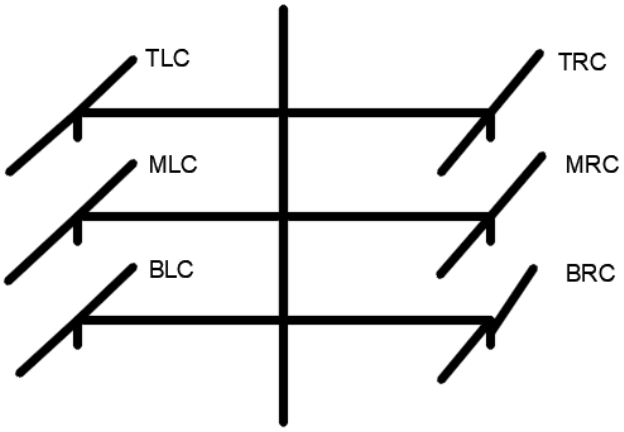


Figure 3.4 Conductors and insulators on all sides

This case shows conductors on all sides. There is no broken wire condition.

The designing of members will be done on the basis of load combinations

Different load combinations were applied on each load cases. Software simulated each load cases individually and gave result of each case.

CHAPTER 4

Wind Load Calculations

4.1 Wind Pressure on Tower Structural Members

$$Q_Z = 0.00256 K_d K_{zt} K_z K_e V^2 \ (psf) \qquad 4.1\text{-}1$$

$K_d = 0.85$

$K_{zt} = 1$

$K_z =$ Velocity Pressure Exposure Coefficient

$K_e = 1$

$V =$ 105 mi/hr.

Table 4.1 Wind Pressure according to height

Height	**Wind Pressure**
ft.	psf.
10.0	58.9
20.0	62.4
30.0	67.9
40.0	72.1
50.0	75.6
60.0	78.3
70.0	81.1
80.0	83.9
93.0	86.7

4.1.1 Graph

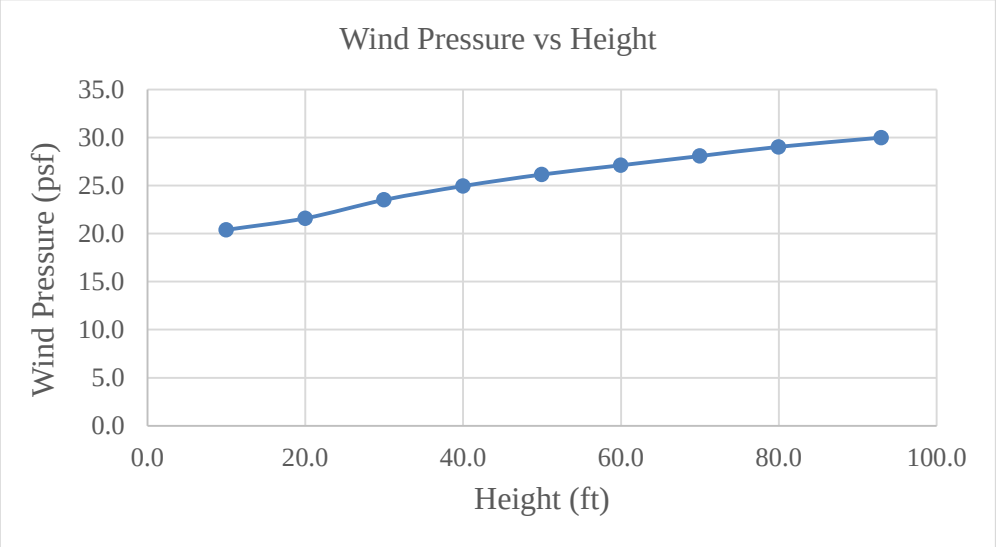


Figure 4.1 Wind Pressure vs Height

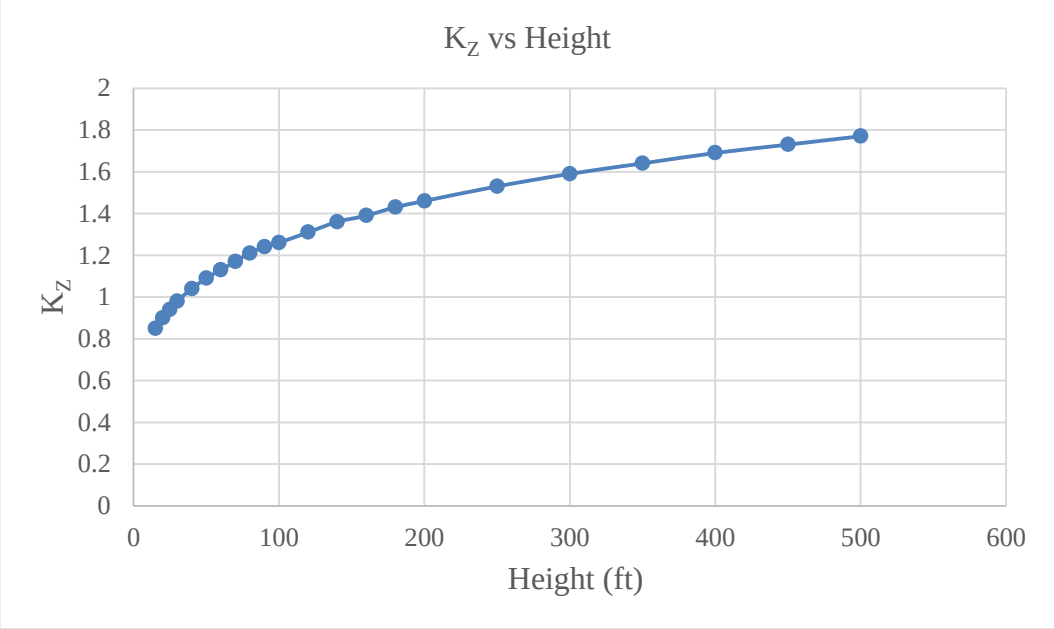


Figure 4.2 K_Z vs Height

4.2 Wind Force on Insulators

$$F = 0.00256 K_d K_{zt} K_z K_e V^2 G C_f A_i \qquad 4.2\text{-}1$$

$K_d = 0.85$

$K_{zt} = 1$

$K_z =$ Velocity Pressure Exposure Coefficient

$K_e = 1$

$V =$ 105 mi/hr.

$G =$ 0.85

$C_f =$ 3.4

$A_i =$ 40 ft^2

Table 4.2 Wind Force on Insulator

Insulator	**Height**	**Wind Force**
	ft.	lb.
Insulator of lower conductor	50.0	3022.9
Insulator of middle conductor	60.0	3133.8
Insulator of upper conductor	70.0	3244.7

4.3 Wind Force on Conductors

$$F = 0.00256 K_d K_{zt} K_z K_e V^2 G C_f N_c D_c L_c \quad 4.3\text{-}1$$

$K_d = 0.85$

$K_{zt} = 1$

$K_z =$ Velocity Pressure Exposure Coefficient

$K_e = 1$

$V =$ 105 mi/hr.

$G =$ 0.85

$C_f =$ 3.4

$N_c =$ 2

$D_c =$ 0.0923 ft

$L_c =$ 328 ft

Table 4.3 Wind Force on Conductor

Conductor	Height (ft.)	Wind Force (ft.)
Lower Conductor	50.0	4575.8
Middle Conductor	60.0	4743.7
Upper Conductor	70.0	4911.6

4.4 Wind Force on OPGW

$$F = 0.00256 K_d K_{zt} K_z K_e V^2 G C_f DL \qquad 4.4\text{-}1$$

$K_d = 0.85$

$K_{zt} = 1$

$K_z =$ Velocity Pressure Exposure Coefficient

$K_e = 1$

$V =$ 105 mi/hr.

$G =$ 0.85

$C_f = 3.4$

$L = 328$ ft

$D = 0.03937$ ft

Table 4.4 Wind Force on OPGW

	Height	**Wind Force**
	ft.	lb.
OPGW	93.0	1118.9

CHAPTER 5

Modeling

This project requires a 3d model to be prepared for the designing of members. The requirement of modeling is mandatory for calculation that will be applied on the structure for the analysis and designing.

This project is done on SAP2000 software for the analysis and designing of transmission tower. First the grids are defined in *x, y,* and *z* axes by putting the value of length, width and height which is taken from NTDC drawings

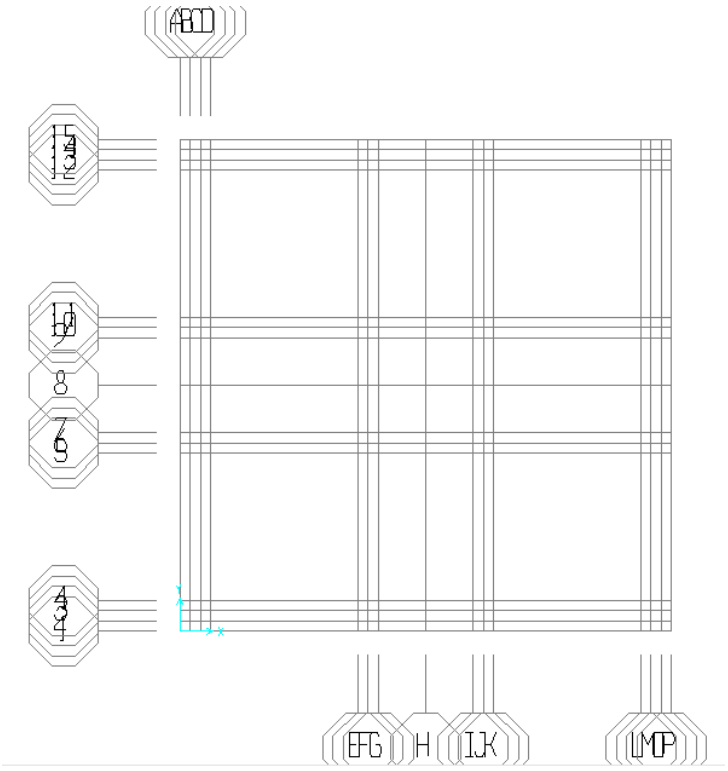


Figure 5.1 Grids of *x, y* coordinates

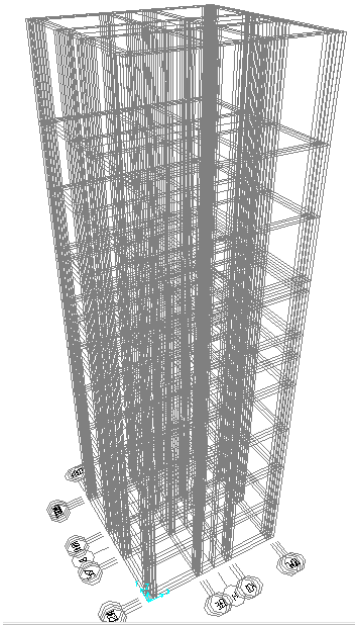


Figure 5.2 Grids of *x*, *y*, *z* Coordinates

After making a 3D model lines are joining further between the members according to distance for Bracings.

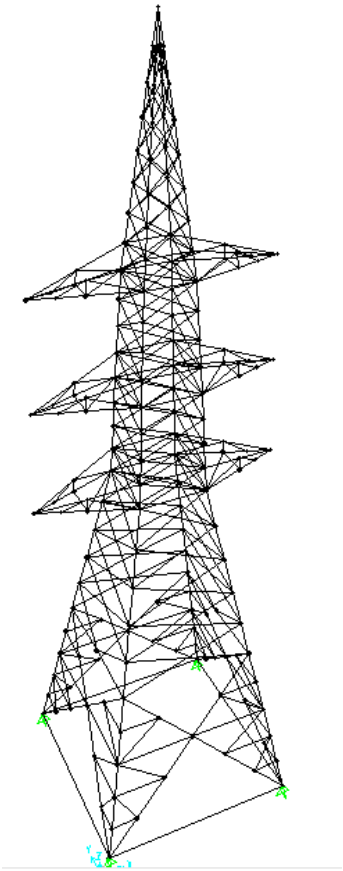


Figure 5.3 Complete Model with Bracings

CHAPTER 6

Equilibrium Check for Model Validation

Equilibrium check is necessary to check whether the sum of net forces is equal to zero, first the tower is cut from the base after cutting from the base there are leg sections and bracing that was cut in the plane. After this the tension and compression forces were taken from the model and applied on the members. These forces are on inclined members and the forces are divided into *x*, *y*, and *z* component. Then angles are calculated with x, y, and z components from top view and front view (*x*, *y* plane) (*x*, *z* plane). Checking was done by method of section. The load cases which are used for the validation of equilibrium check are dead loads which includes horizontal and vertical components of tension in conductors (reactions were calculated for horizontal and vertical components) and dead load of insulators. Load combination used was 1.2D.

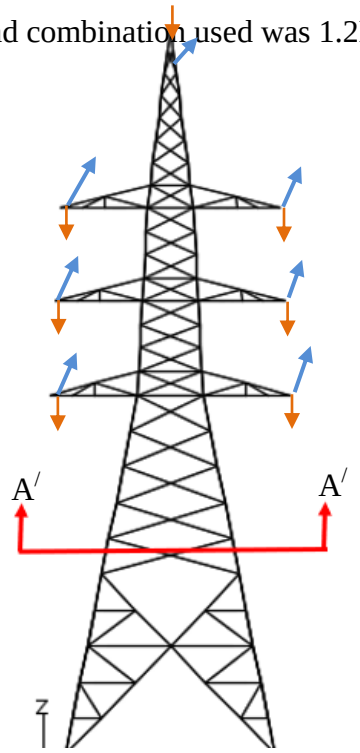


Figure 6.1 Front View

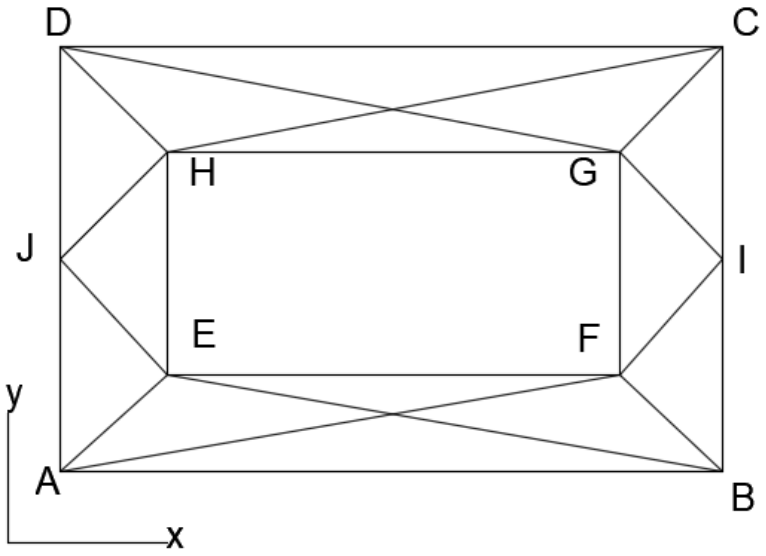


Figure 6.2 Plan View

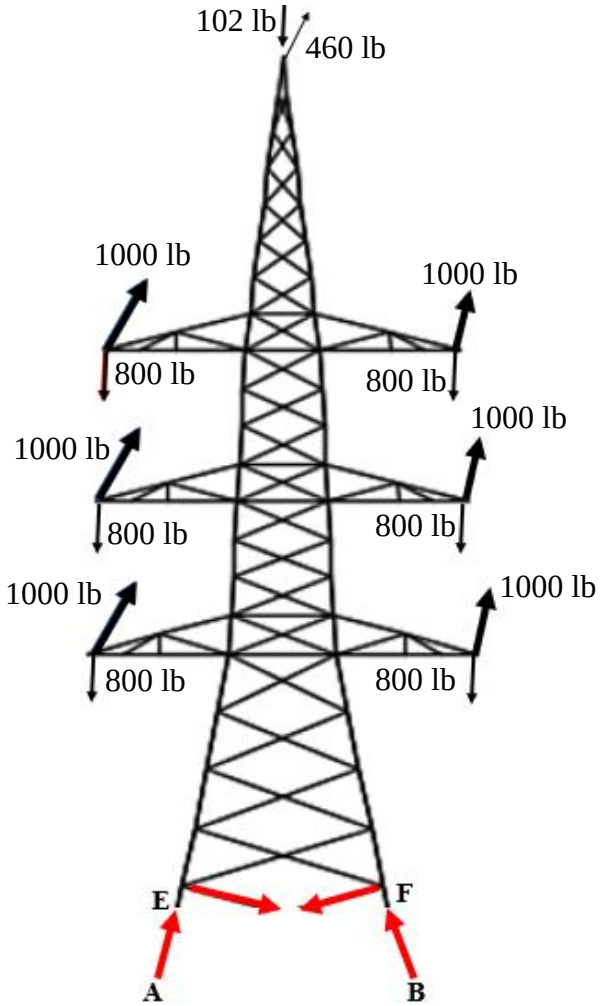
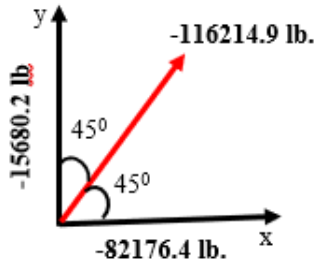
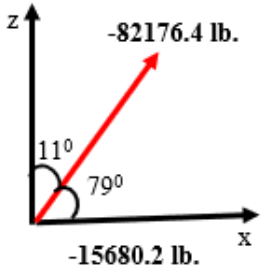


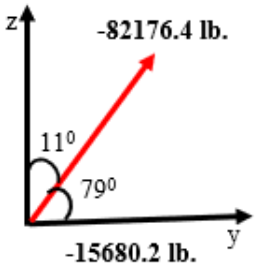
Figure 6.3 Free body diagram of section A/ - A/

6.1 Calculations with Method of Sections

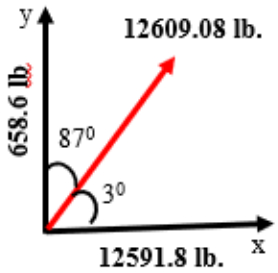
6.1.1 Leg Member AE

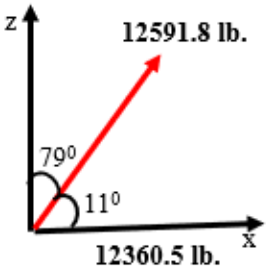


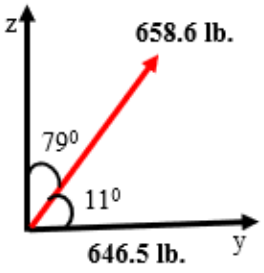




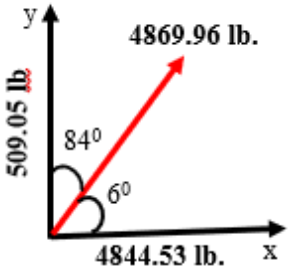
6.1.2 Bracing EB

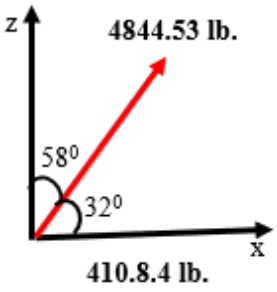


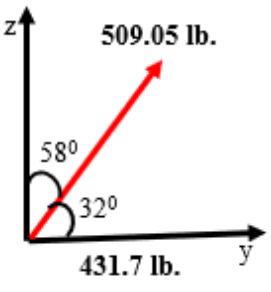




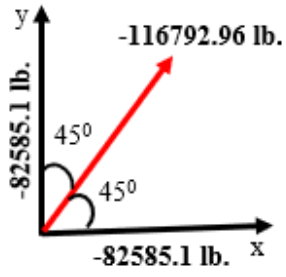
6.1.3 Bracing EJ

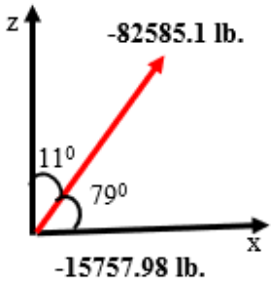


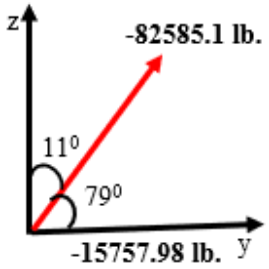




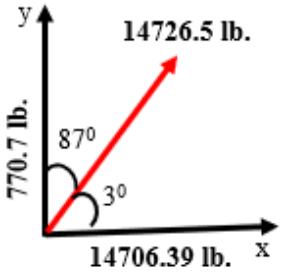
6.1.4 Leg Member BF

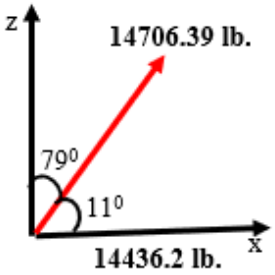


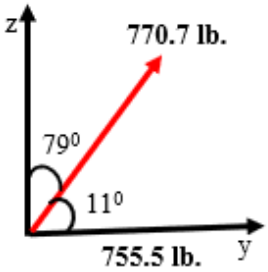




6.1.5 Bracing FA







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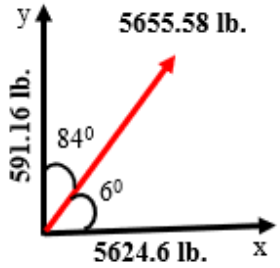
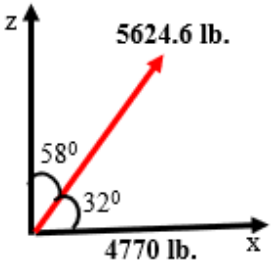
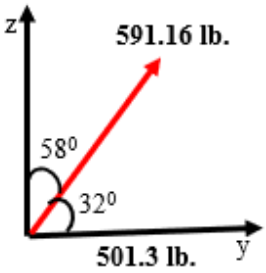
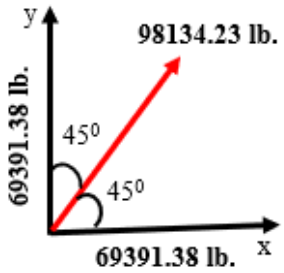
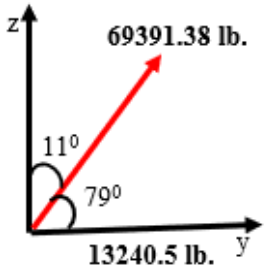




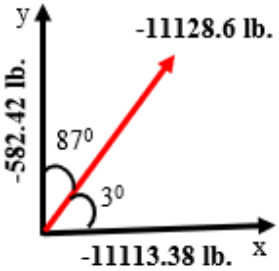


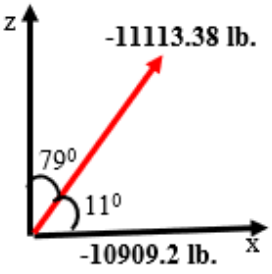
6.1.7 Leg Member CG



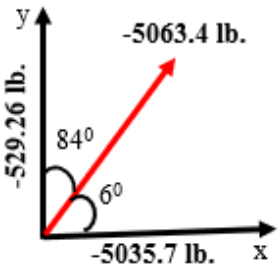


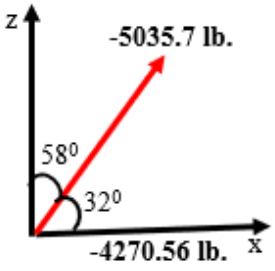
6.1.8 Bracing GD



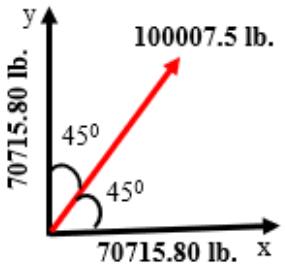


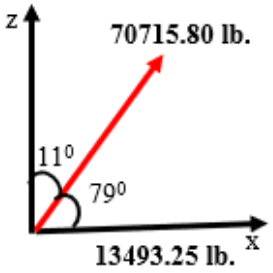
6.1.9 Bracing GI

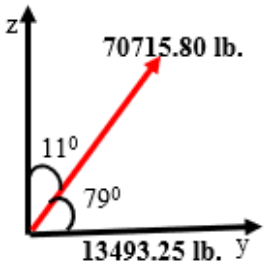




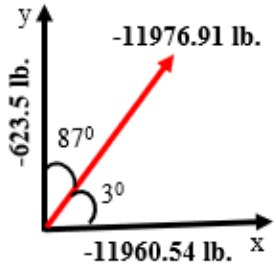
6.1.10 Leg Member DH

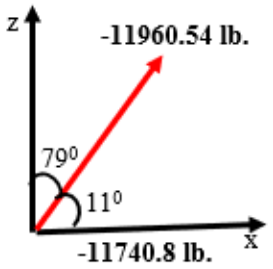


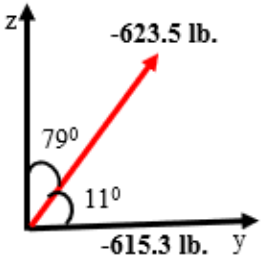




6.1.11 Bracing HC







6.1.12 Bracing HJ

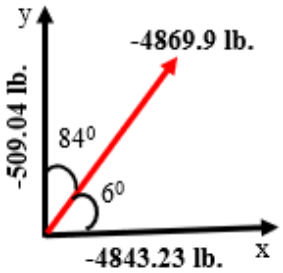


Table 6.1 Calculation of Equilibrium Check

Members	Angles	X-axis perpendicular to the conductors	Y-axis along conductors
	Degree	kip	kip
Leg AE	79	-15.6802	-15.6802
BRACING EB	11	12.3605	0.6465
BRACING EJ	32	4.1084	0.4317
Leg BF	79	-15.75798	-15.75798
BRACING FA	11	14.4362	0.7565
BRACING FI	32	4.77	0.5013
Leg GC	79	13.2405	13.2405
BRACING GD	11	-10.9092	-0.5717
BRACING GI	32	-4.27056	-0.44878
Leg DH	79	13.49325	13.49325
BRACING HC	11	-11.7408	-0.6153
BRACING HJ	32	-4.1073	-0.4316
Sum of member forces		-0.05719	-6.43581
Load applied on top		0	6.46
Total Sum		-0.05719	0.02419

CHAPTER 7

Design of Connection

The bolts are manually designed from the ASCE 10-15 Design of Latticed Steel Transmission Tower. The bolts designed on the value of tension member no 136. ASTM A394 bolts are used.

7.1 Bolt Shear Capacity

Bolt size = ½" (0.5")

Number of Bolts = 2

$$F_v = 0.62\, F_u \qquad 7.11$$

$A = \frac{\pi}{4}(d^2)$

= 0.196 in^2

$F_v = 0.62\ (17050)$

F_v = 10571*2*0.196

$F_v = 4038.1$ lb

$P_u = 1346.88 < 4038.1$ **OK**

7.2 End Distance

$$e = 1.2\ \frac{P}{F_u\, t} \qquad 7.21$$

$e = 1.2\ (\frac{1346.88}{65000 * 1.125})$

e = 0.022 in

$e = 1.2\ (d)$

e = 1.2 (0.5)

e = 0.65 in

$$e = t + \frac{d}{2} \qquad 7.22$$

$e = 1.125 + \frac{0.5}{2}$

e = 1.375 in

The value of end distance is e = 1.375 in

7.2.1 Center-Center Distance

$$S_{min} = 1.2\ \frac{P}{F_u\ t} + 0.6\ d \qquad 7.23$$

$S_{min} = 1.2\ \left(\frac{1346.88}{65000 * 1.125}\right) + 0.6\ (0.5)$

$\boldsymbol{S_{min} = 0.322\ in}$

7.2.2 Edge distance

$$f_{min} = 0.85\ e_{min} \qquad 7.24$$

$\boldsymbol{f_{min} = 0.0204\ in}$

CHAPTER 8

Designing of Members

The designing of members is according to ASCE 10-15 Design of Latticed Steel Transmission Tower. The designing of tower is done according to the selection of tower levels that are defined first in the SAP2000 software.

Table 8.1 Wind load calculation on SAP2000 for trial section

Member	Length	Width	Wind Force	Force	Joint Force
	ft.	ft.	psf.	lb.	lb.
1	5.5077	0.25	78.3	107.81	53.91
2	5.9689	0.08	86.7	43.13	21.56
3	8.3703	0.25	78.3	163.85	81.92
4	8.0984	0.25	78.3	158.53	79.26
5	4.7596	0.33	75.6	119.94	59.97
6	4.7596	0.33	75.6	119.94	59.97
7	4.7596	0.33	75.6	119.94	59.97
8	4.7596	0.33	75.6	119.94	59.97
9	4.7596	0.33	75.6	119.94	59.97
10	4.7596	0.33	75.6	119.94	59.97
11	4.7596	0.33	75.6	119.94	59.97
12	4.7596	0.33	75.6	119.94	59.97
13	4.7596	0.33	75.6	119.94	59.97

14	4.7596	0.33	75.6	119.94	59.97
15	4.7596	0.33	75.6	119.94	59.97
16	4.7596	0.33	75.6	119.94	59.97
17	4.7596	0.33	75.6	119.94	59.97
18	4.7596	0.33	75.6	119.94	59.97
19	4.7596	0.33	75.6	119.94	59.97
20	4.7596	0.33	75.6	119.94	59.97

After running the analysis, it is found out that many of the members in tower were failed than these members were adjust on the basis of width and thickness of L section. After selecting all these members, the wind load was changed, because we used the trial section first. The members select after applying wind load was again analyzed.

Table 8.2 Wind Load Calculation on SAP2000 after selecting the members

Member	Length	Width	Wind Force	Force	Joint Force
	ft	ft	psf.	lb.	lb.
1	5.5077	0.25	78.3	107.81	53.91
2	5.9689	0.16667	86.7	86.25	43.13
3	8.3703	0.33333	78.3	218.46	109.23
4	8.0984	0.33333	78.3	211.37	105.68
5	4.7596	0.83333	75.6	299.85	149.93
6	4.7596	0.66667	75.6	239.89	119.94
7	4.7596	0.66667	75.6	239.89	119.94

8	4.7596	0.66667	75.6	239.89	119.94
9	4.7596	0.66667	75.6	239.89	119.94
10	4.7596	0.66667	75.6	239.89	119.94
11	4.7596	0.66667	75.6	239.89	119.94
12	4.7596	0.66667	75.6	239.89	119.94
13	4.7596	0.66667	75.6	239.89	119.94
14	4.7596	0.66667	75.6	239.89	119.94
15	4.7596	0.83333	75.6	299.85	149.93
16	4.7596	0.66667	75.6	239.89	119.94
17	4.7596	0.66667	75.6	239.89	119.94
18	4.7596	0.66667	75.6	239.89	119.94
19	4.7596	0.66667	75.6	239.89	119.94
20	4.7596	0.66667	75.6	239.89	119.94

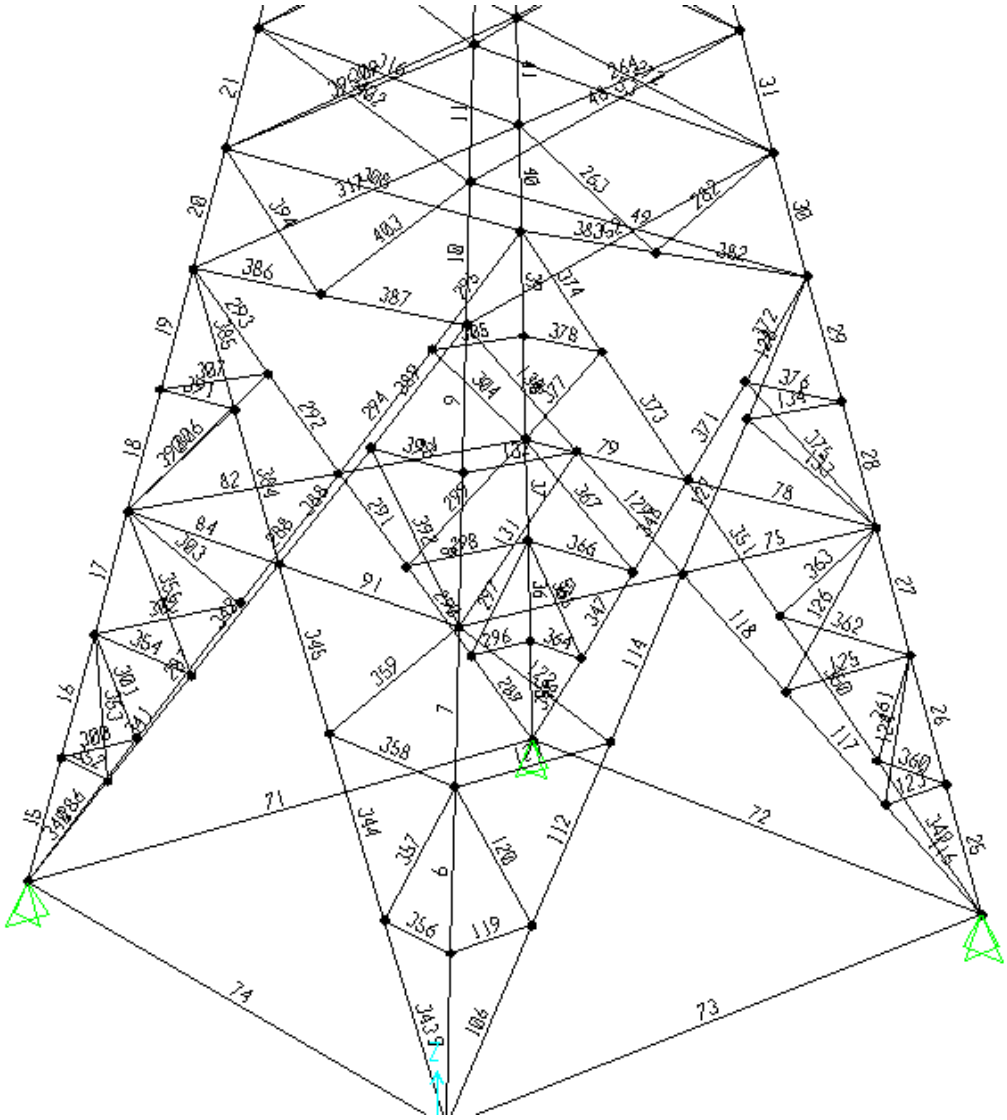


Figure 8.1 Member labels location

8.1 Drawings

The drawings of Transmission Tower are given below.

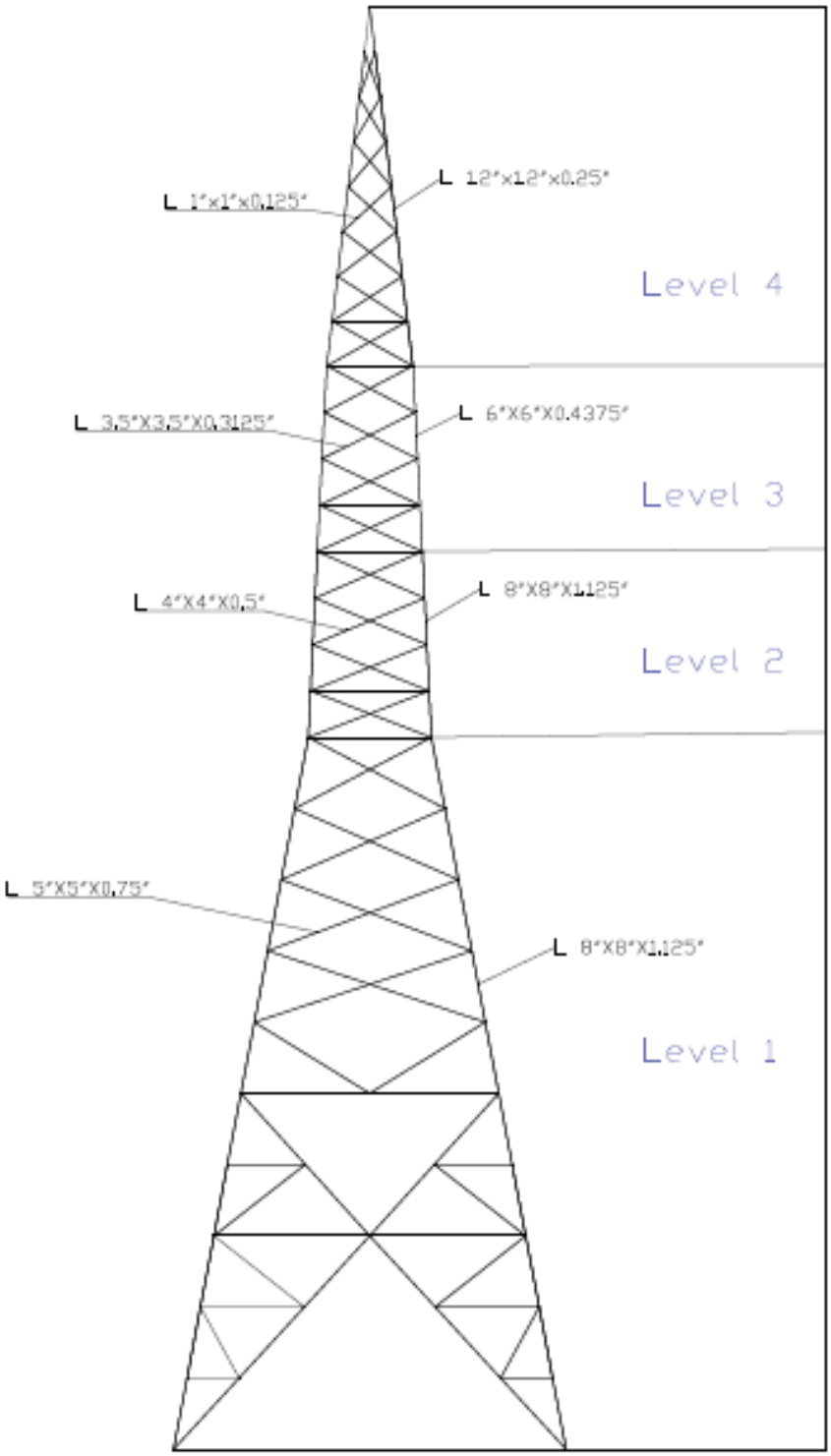


Figure 8.2 Side view of Tower Drawing

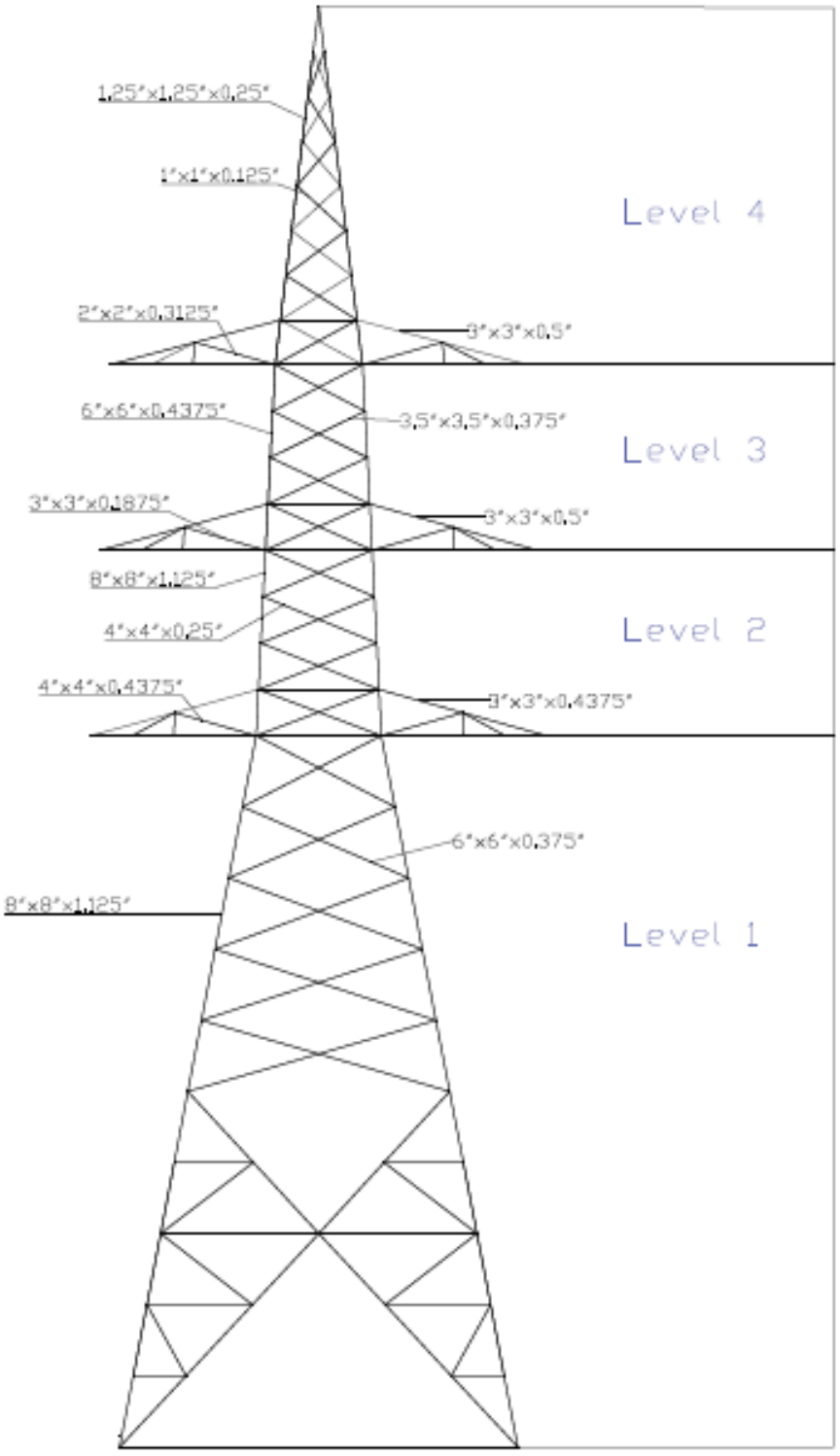


Figure 8.3 Front view of Tower Drawing

The Transmission tower has several members on which forces are applied but we have to observe the maximum positive and maximum negative force of the truss members on different levels.

8.2 Maximum Tension and Compression at level 1

The maximum positive tension value using load case 3 ($1.2D+1.0W_x$) is 62027.32 lb on member 10. The maximum negative compression value using load case 3 ($1.2D+1.0W_x$) is -68761.45 lb on member 30 on level 1.

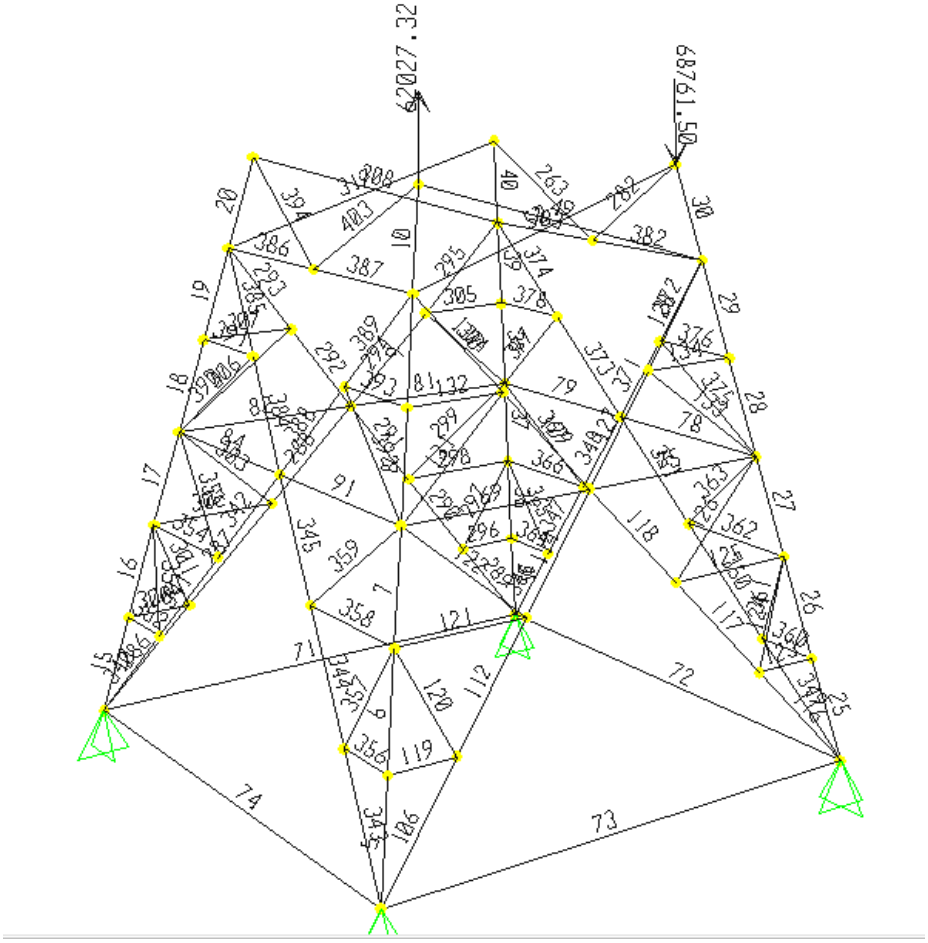


Figure 8.4 Maximum Tension and Compression at level 1

8.3 Maximum Tension and Compression at level 2

The maximum positive tension value using case 3 is 18339.846 lb on member 321. The maximum negative compression value using case 3 is -125274.8 lb on member 144 on level 2.

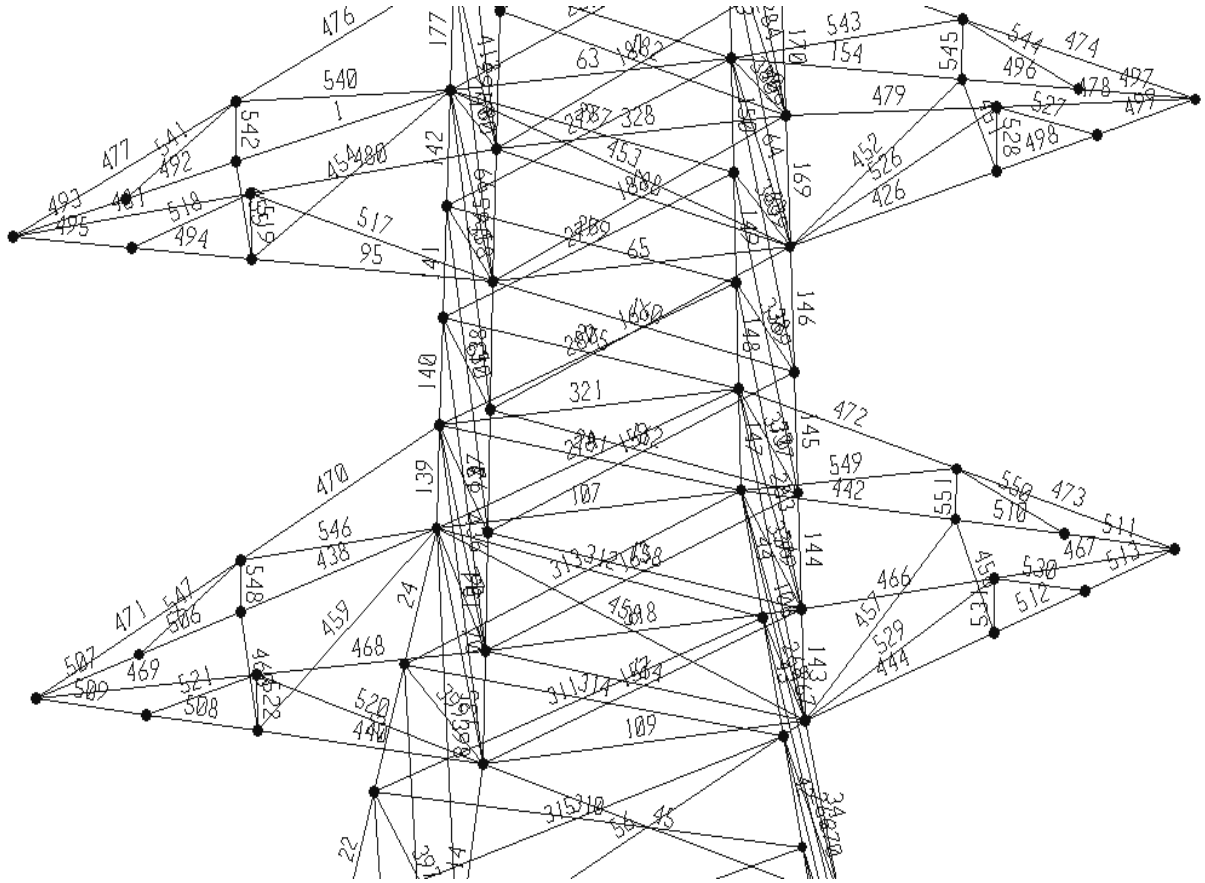


Figure 8.5 Maximum Tension and Compression at level 2

8.4 Maximum Tension and Compression at level 3

The maximum positive tension value using case 3 is 12058.98 lb on member 328. The maximum negative compression value using case 3 is -37836.60 lb on member 170 on level 3.

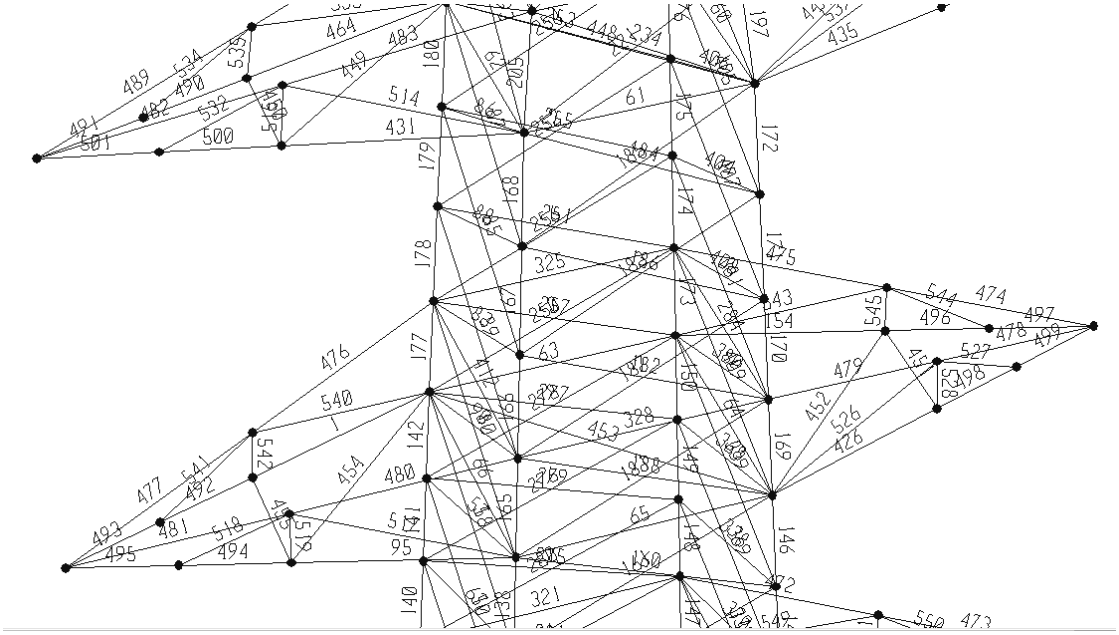


Figure 8.6 Maximum Tension and Compression at level 3

8.5 Maximum Tension and Compression at level 4

The maximum positive tension value using case 3 is 9053.74 lb on member 331. The maximum negative compression value using case 3 is -1460.89 lb on member 190 on level 3.

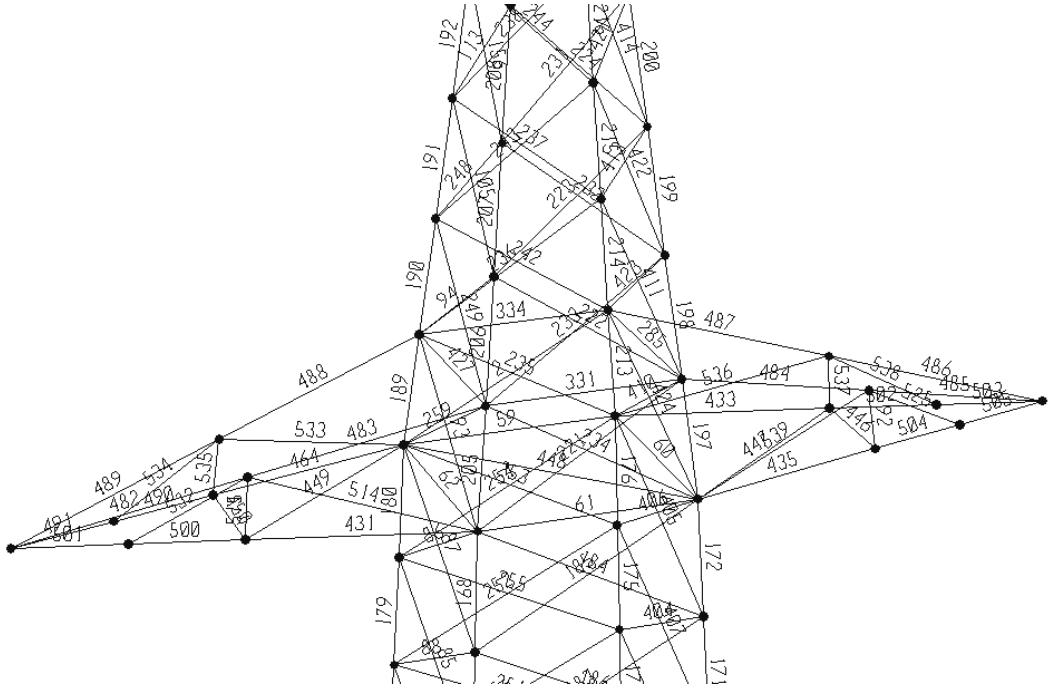


Figure 8.7 Maximum Tension and Compression at level 4

8.6 Validation of Member Design

Member 136 was selected for validation of design under compression and tension forces. The maximum force of tension is 1346.881 lb (load combination 1.2D, dead load case 3) and the maximum force of compression is 7546.76 lb. (load combination 1.2D, dead load case 2)

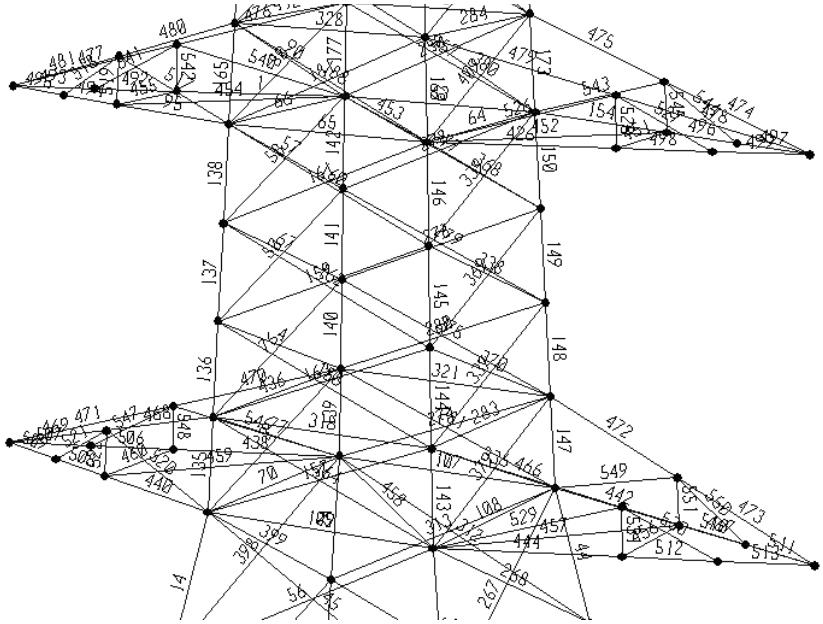


Figure 8.8 Validation of Member 136

8.6.1 Checking Member Strength in Compression

Column slenderness ratio separating elastic and inelastic buckling is C_c

$$C_c = \pi \sqrt{\frac{2E}{F_y}} \qquad 8.61$$

$E = 29{,}000{,}000$ psi

$F_y = 50{,}000$ psi

Putting the value in equation 8.6-1

$C_c = 106.9$

For members with normal framing eccentricities at both ends of the unsupported panel

$$\frac{kL}{r} = 60 + 0.5\,\frac{L}{r} \qquad 8.62$$

$\frac{kL}{r} = 60 + 0.5\,(\frac{36.069}{3.045})$

$= 67.6$

F_a is the allowed compressive stress

$$F_a = [\,1 - \frac{1}{2}\left(\frac{Kl/r}{C_c}\right)]^2\,F_y, \quad \frac{kL}{r} \leq C_c \qquad 8.63$$

$\frac{kL}{r} \leq C_c$

$67.6 \leq 106.9$

$F_a = [\,1 - \frac{1}{2}\left(\frac{65.9}{106.9}\right)]^2\,5x10^4$

$F_a = 23920.67\ psi$

$P_a = F_a A_g$

$P_a = 400288.49\ lb$

$P_u = 7546.76\ lb$

$P_a > P_u$ **OK**

$\frac{w}{t} = 13.7 < 25$ **OK**

8.6.2 Checking Member Strength in Tension

F_t is the design tensile stress

$$F_t = F_y A_n \quad 8.64$$

$A_n = A_g - n\,(d + 0.118)\,t$

$A_n = 16.734 - 2(0.5 + 0.118)\,(1.125)$

$A_n = 15.34\ in^2$

$F_t = 50{,}000\ (15.34)$

$F_t = 46842.55\ psi$

$P_t = F_t A_n$

$P_t = 767{,}000\ lb$

$P_u = 1346.881 < P_t$ **OK**

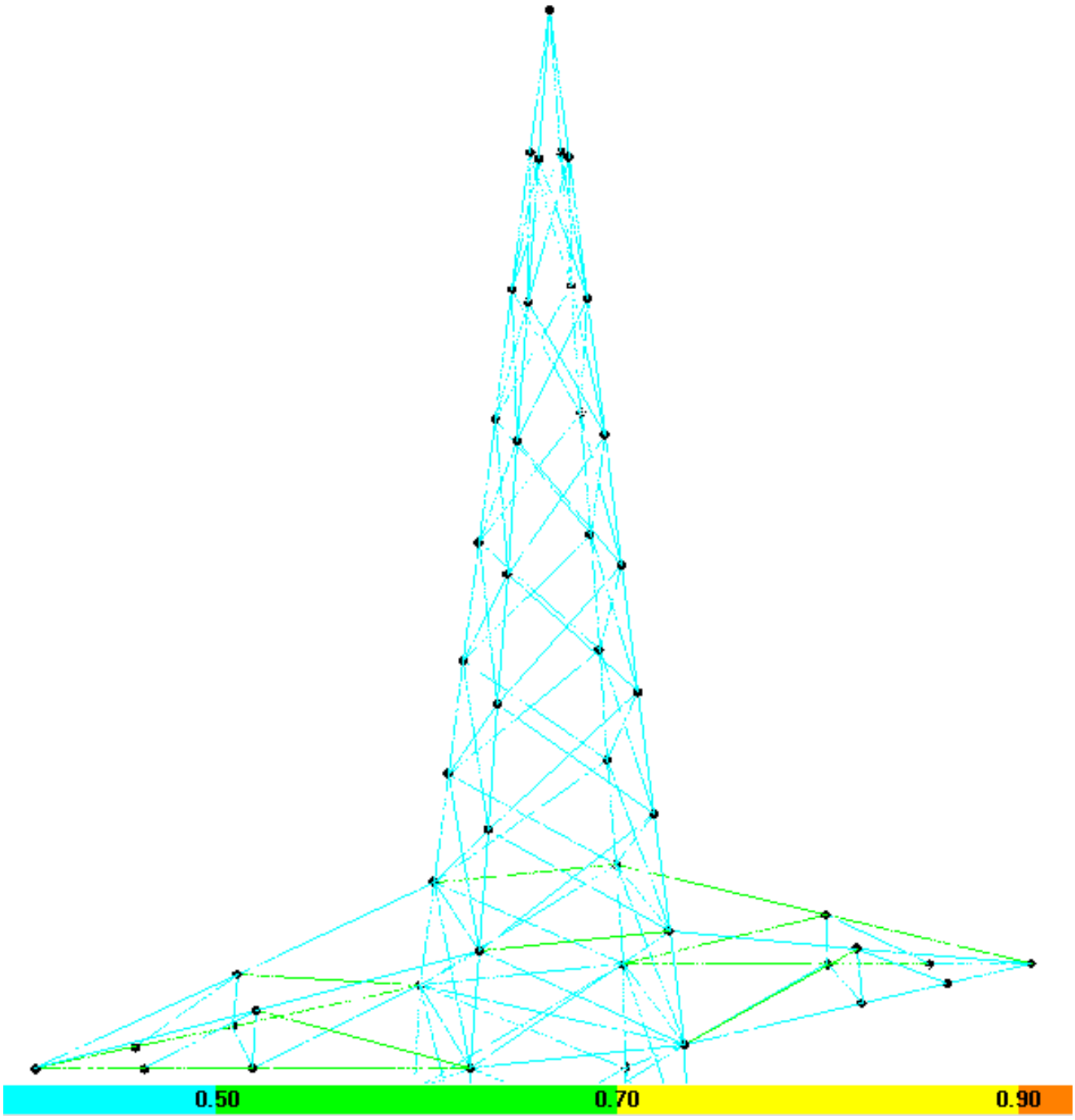


Figure 8.9 Member designed on SAP2000 (top part)

The status bar in different values shows the ratio of axial force in member to the strength of the member. If the ratio exceeds the value of 0.95 then the member will be considered to be at risk of failure.

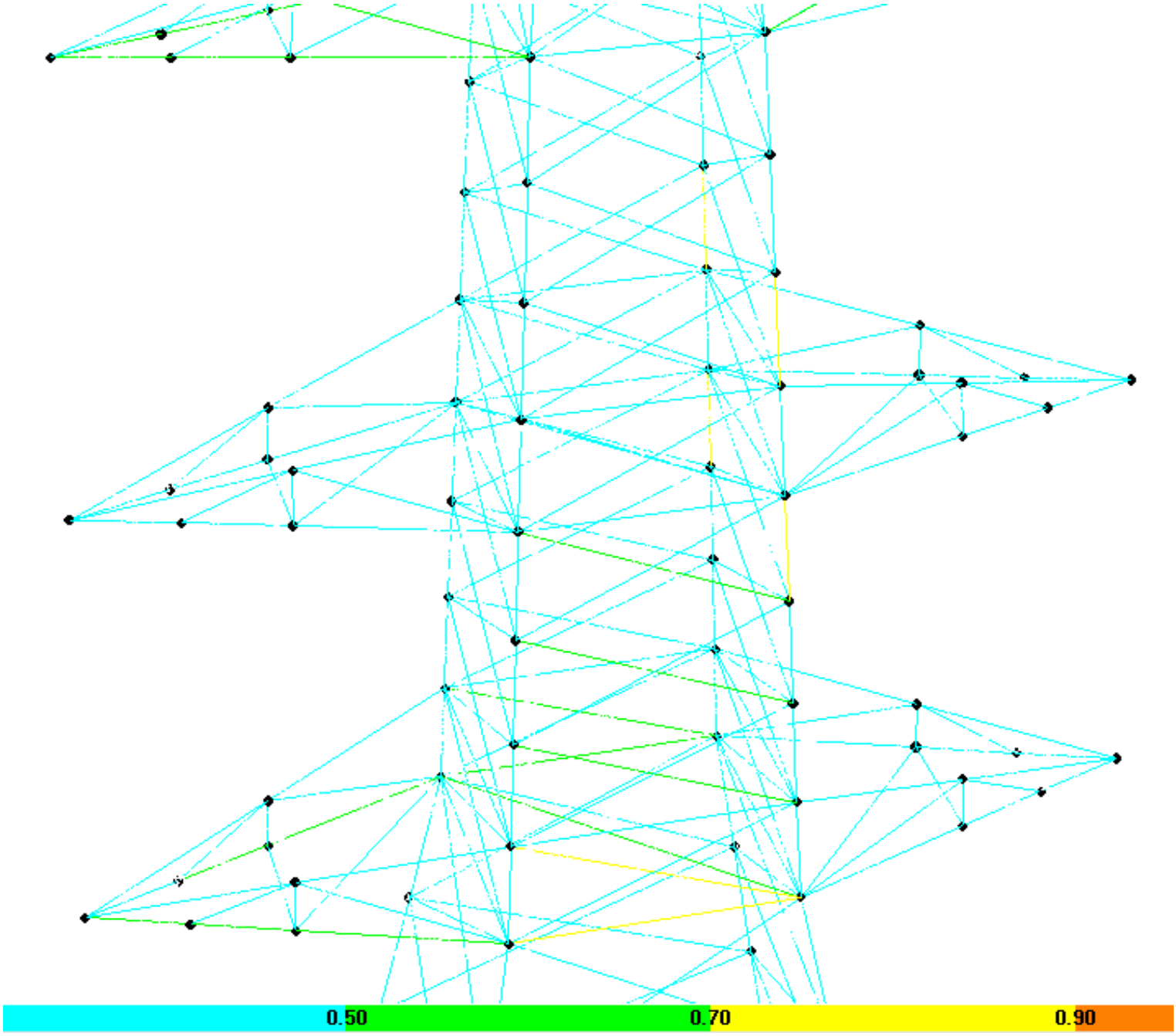


Figure 8.10 Member designed on SAP2000 (middle part)

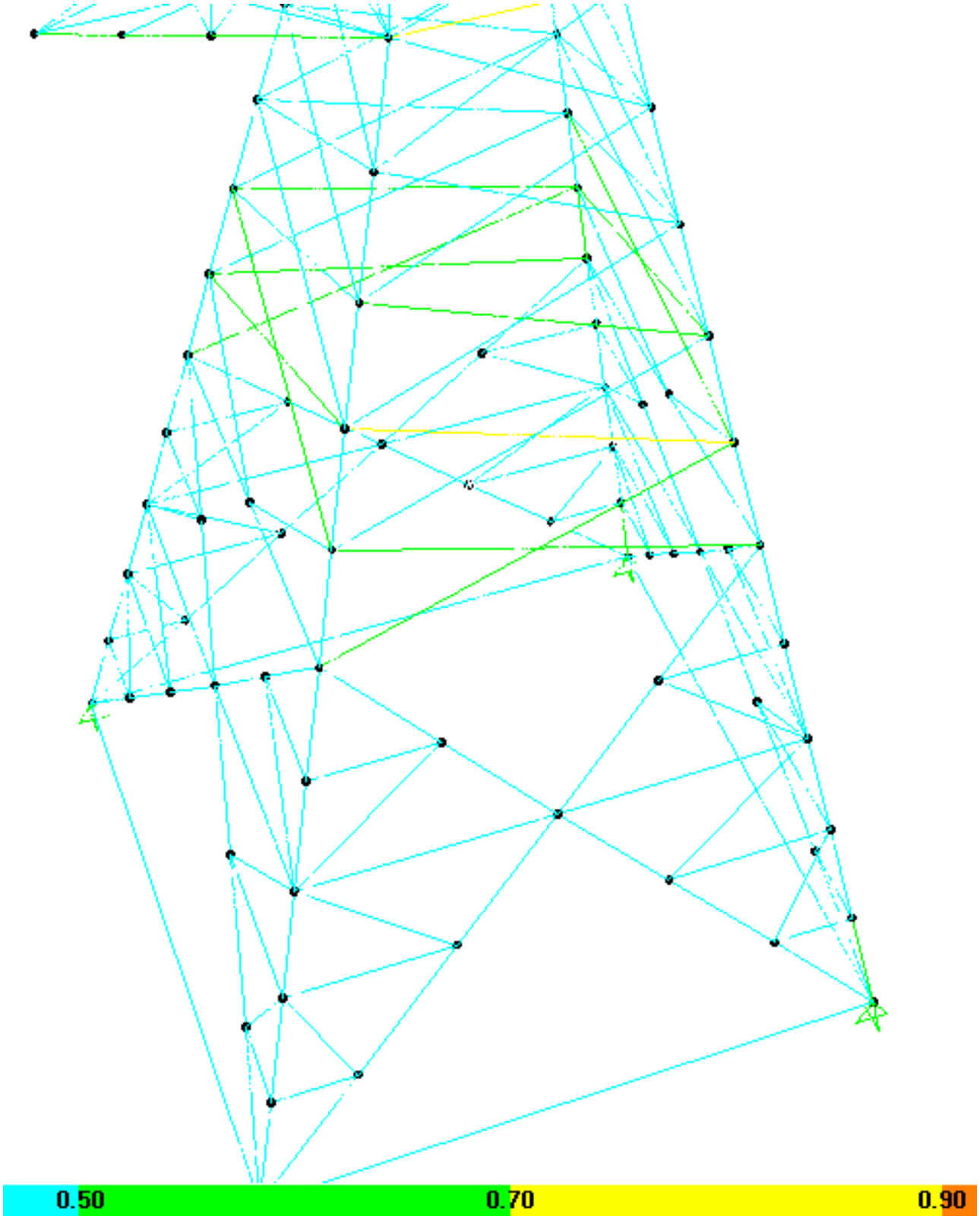


Figure 8.11 Member designed on SAP2000 (bottom part)

Conclusion

The objective of this project is to make the transmission tower cost effective. After designing the members, it is concluded that the weight of total steel members taken from NTDC is heavier than the weight of this designed transmission tower. The total weight of steel members of this project is 53413.63 lb.

References

1) ASCE. (2015). *10-15 Design of Latticed Steel Transmission Structures.* American Society of Civil Engineers.

2) ASCE. (2016). *7-16 Minimun Design Loads for Building and other Structures.* Amercian Society of Civil Engineers.