TRANSMISSION TOWER DESIGN IN STAAD PRO

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Abstract

Transmission towers are critical structures in power transmission networks, designed to support overhead power lines and maintain the necessary clearance from the ground. The structural integrity of these towers is paramount, given their exposure to various environmental loads such as wind, ice, and seismic forces. This study presents a detailed approach to designing a transmission tower using STAAD.Pro, a powerful structural analysis and design software. The process involves the creation of a 3D model, the application of loads, including dead, wind, and seismic loads, and the optimization of the tower's structural components to ensure safety, stability, and cost-effectiveness. The study also examines the importance of complying with relevant design codes and standards to achieve a reliable and efficient tower design. The analysis results provide insights into the load distribution, member forces, and overall behavior of the tower under various load combinations, ultimately leading to a design that meets both structural and economic requirements.

Keywords
Transmission tower, STAAD.Pro, structural analysis, wind load, seismic load, steel design, optimization, power transmission, structural integrity, design codes.

INTRODUCTION

India has a large population residing all over the country and the electricity supply need of this population creates requirement of a large transmission and distribution system. Also, the disposition of the primary resources for electrical power generation viz., coal, hydro potentialis quite uneven, thus again adding to the transmission requirements. 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 cost of the line and they play an important role in the reliable power transmission. They are designed and constructed in wide variety of shapes, types, sizes, configurations and materials. The supporting structure types used in transmissionlines generally fall into one of the three categories: lattice, pole and guyed. The supports of EHV transmission lines are normally steel lattice towers. The cost of towers constitutes aboutquarter to half of the cost of transmission line and hence optimum tower design will bring in substantial savings. 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 and member and joint details. The goal of every designer is to design the best (optimum) systems. But, because of the practical restrictions this hasbeen achieved through intuition, experience and repeated trials, a process that has worked well.

Objectives of the Present Work

- To design transmission tower with three different configurations (on the basis of different Bracing Systems) for a given scenario and selecting the most economical design.
- Towers in plain and hilly regions will be considered, in two separate stages.
- Parameters for comparison are :
    - Weight of Tower
    - Various Stresses
    - Foundation
    - Cost (Member cost, Joint cost, Labour cost)

Introduction to STAAD.pro

Before the availability of computers and specialized analysis and design programs, towers were often designed by graphical methods. It was considered prudent to test new designs that would be used repeatedly on a transmission line, thereby confirming the design assumptions with a full-scale test. Today's analysis tools allow engineers to refine designs to an unprecedented degree, and as a result, many utilities feel testing is not warranted. However, while great strides have been made in the analysis and design of latticed steel transmission towers, differences between analysis results and full-scale tests still occur.

STAAD.Pro features a state-of-the-art user interface, visualization tools, powerful analysis and design engines with advanced finite element and dynamic analysis capabilities. From model generation, analysis and design to visualization and result verification, STAAD.Pro is the professional’s choice for steel, concrete, timber, aluminum and cold- formed steel design of low and high-rise buildings, culverts, petrochemical plants, tunnels, bridges, piles and much more. The following key STAAD.Pro tools help simplify ordinarily tedious tasks:

- The STAAD.Pro Graphical User Interface incorporates Research Engineers' innovative tabbed page layout. By selecting tabs, starting from the top of the screen and heading down, you input all the necessary data for creating, analyzing and designing a model. Utilizing tabs minimizes the learning curve and helps insure you never miss a step.
- The STAAD.Pro Structure Wizard contains a library of trusses and frames. Use the Structure Wizard to quickly generate models by specifying height, width, breadth and number of bays in each direction. Create any customizable parametric structures for repeated use. Ideal for skyscrapers, bridges and roof structures.

Features of STAAD.Pro

- "Concurrent Engineering" based user environment for model development, analysis,design, visualization and verification
- Full range of analysis including static, P-delta, pushover, response spectrum, time history, cable (linear and non-linear), buckling and steel, concrete and timber design included with no extra charge
- Object-oriented intuitive 2D/3D graphical model generation
- Pull down menus, floating tool bars, tool tip help
- Quick data input through property sheets and spreadsheets

Load Types and Generation

- Categorized load into specific load group types like dead, wind, live, seismic, snow, user-defined, etc. Automatically generate load combinations based on standard loading codes such as ASCE etc.
- One way loading to simulate load distribution on one-way slabs
- Patch and pressure loading on solid (brick) elements
- Element pressure loads can be applied along a global direction on any imaginary surface without having elements located on that surface
- Automatic wind load generator for complex inclined surfaces, irregular panels and multiple levels also taking into consideration user-defined panels
- Loading for Joints, Members/Elements including Concentrated, Uniform Linear, Trapezoidal, Temperature, Strain, Support Displacement, Priestess and Fixed-endLoad

Introduction to Excel VBA

- The Windows version of Excel supports programming through Microsoft's Visual Basic for Applications (VBA), which is a dialect of Visual Basic. Programming with VBA allows spreadsheet manipulation that is awkward or impossible with standard spreadsheet techniques. Programmers may write code directly using the Visual Basic Editor (VBE), which includes a window for writing code, debugging code, and code module organization environment. The user can implement numerical methods as wellas automating tasks such as formatting or data organization in VBA and guide the calculation using any desired intermediate results reported back to the spreadsheet.
- A common and easy way to generate VBA code is by using theMacro Recorder. The Macro Recorder records actions of the user and generates VBA code in the form of a macro. These actions can then be repeated automatically by running the macro. The macros can also be linked to different trigger types like keyboard shortcuts, a command button or a graphic. The actions in the macro can be executed from these trigger types or from the generic toolbar options. The VBA code of the macro can alsobe edited in the VBE. Certain features such as loop functions and screen prompts by their own properties, and some graphical display items, cannot be recorded, but must be entered into the VBA module directly by the programmer. Advanced users can employ user prompts to create an interactive program, or react to events such as sheetsbeing loaded or changed.
- VBA code interacts with the spreadsheet through the Excel Object Model a vocabulary identifying spreadsheet objects, and a set of supplied functions or methodsthat enable reading and writing to the spreadsheet and interaction with its users (for example, through custom toolbars or command bars and message boxes). User- created VBA subroutines execute these actions and operate like macros generated using the macro recorder, but are more flexible and efficient.

TRANSMISSION TOWERS

Details of Tower

In the present section, the tower has been detailed for its location, type and kind of constituent members.

Introduction to Tower

A tower or mast is a tall skeleton structure with a relatively small cross-section, which has a large ratio between height and maximum width. A tower is a freely standing self supporting structure fixed to the base or foundation.

In developed countries the environmental impact of the traditional transmission towers is no longer accepted. Currently available design solutions with acceptable appearance are not employed in the developing countries, mainly for cost reasons. In the developing countries the use of the traditional lattice transmission towers will continue employing steel angles. A comparison of the available design specifications for steel angles in transmission towers is presented.

Generally towers are made up of a material called steel. Steel towers (short, medium and tall) are normally used for the following purposes:

(i) Electric power transmission
(ii) Microwave transmission for communication
(iii) Radio transmission (short and medium wave wireless)
(iv) Television transmission
(v) Satellite reception
(vi) Air traffic control
(vii) Flood light stand
(viii) Metrological measurements
(ix) Derrick and crawler cranes
(x) Oil drilling masts
(xi) Over head tanks

Further classification of towers depending upon their heights is as follows:

The height of towers for electric power transmission may vary from 10 to 45 m while those for flood lights in stadiums and large flyover intersections may vary from 15 to 50m. The height of television towers may vary from 100 m to 300 m while for those for radio transmission and communication networks the height may vary from 50 to 200m.

Depending upon the size and type of loading, towers are grouped into two heads:

(a) Towers with large vertical loads
(b) Towers with mainly horizontal wind loads

Towers with large vertical loads (such as those of over head water tanks, oil tanks, metrological instrumentation towers etc.) have their sides made up of vertical or inclined trusses.

The towers, falling under the second category and subjected predominantly to wind loads, may be classified in to two types:

(1) Self-supporting towers
(2) Guyed towers

(1) Self-supporting towers

Self-supporting towers or free standing towers are known as lattice towers. These are generally square in plan and are supported by four legs, fixed to the base.

These towers act as vertical cantilever trusses, subjected to wind and/or seismic loads.Free standing towers are commonly used for T.V., microwave transmission, power transmission, flood light holding.

The free standing towers for power transmission have arms to both the sides of the centre line, to carry power transmission lines.

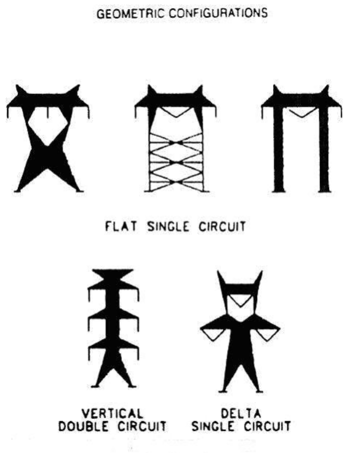


Figure 1: Self Supporting Towers

(2) Guyed towers

Guyed towers are hinged to the base**,** and are supported by guy wires attached to it at various levels, to transmit the wind forces to the ground. Due to this reason, guyed tower of the same height is much lighter than a self-supporting tower. However, it requires much larger spacein plan, to accommodate the placement of guy ropes. Guyed towers are mostly known as masts, having three or four legs and triangular or rectangular configuration in plan.

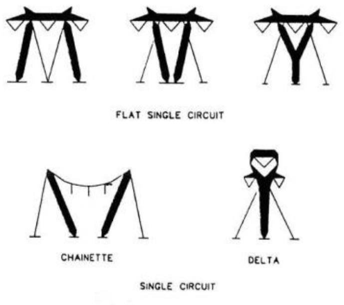


Figure 2: Guyed Towers

Lattice tower

The self supporting towers, subjected predominantly to wind loads, are called lattice towers. Such towers are square or rectangular in plan. The width b of the side face at the base may vary between 1/8 to 1/12 of the height H of the tower. The top width of towers is kept between 1.5 to 3m or more, depending upon the requirement. There are ten types of bracing systems for a lattice tower configuration. Those ten types are as follows:

1.**Single diagonal bracings:** this is the simplest form of bracing. The wind shear at any level is shared by the single diagonal of the panel. Such bracing is used for towers upto 30m height.

2.**X-X bracing:** this is a doublediagonal system without horizontal bracing, used for towers upto 50m height. It is a statically determinate structure.

3.**X-B bracing:** this is a double diagonal system with horizontal bracings. Such bracings are quite rigid, and may be used for towers upto 50m height. The structure is statically indeterminate. The horizontal members are redundant members and carry only nominal stresses.

4.**K-bracing:** such a bracing gives large head room, and hence K-bracing can be used in lower panels where large head room is required. The structure is statically determinate. Such bracing can be used for towers of 50 to 200m height. In most of the transmission line towers, the lower panels is either K- or Y- braced and upper panels are X-braced or XB- braced.

5.**X B X bracing:** this is a combination XX and XB bracing where horizontal members are provided only at the level of crossing of diagonals. The structure is statically indeterminate.However, the length of the diagonal is reduced. The system is suitable for towers 50 to 200m height.

6. W-bracing: this system uses a number of overlapping diagonals. The system is statically indeterminate. However, the effective length of diagonals is reduced the system is quite rigid and may be used for towers of 50 to 20m height.

7. Y-bracing: this system gives larger head room can be used for lower panels. The system is statically determinate. In most of the transmission line towers, lower panels are either Y- braced on k-braced and upper panels are X-B braced or X-braced.

8. Arch bracing: such a bracing can be adopted for wider panels. This system also providesgreater head room. The system is statically determinate.

9. Subdivided V-bracing: such a bracing are used for tall towers of communication systems,radio and TV transmission etc; for heights between 50 to 200m.

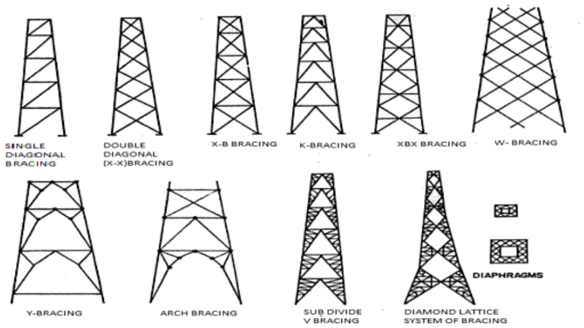
10. Diamond lattice system: A typical diamond lattice system is used for towers of 100 to 200m height. The base width is kept at 1/5 to 1/6 of the height. Rigid horizontal diaphragmsare used at top and at intermediate sections, preferably at intervals of 25 to 30m, to increasethe torsional stiffness of the cross-arm.

Figure 3: Lattice tower cofigurations with Bracing syste ms.

PROBLEM DEFINITION AND METHODOLOGY

Problem Definition

In the problem three different towers in two different wind zones, i.e, Himachal Pradesh (39 m/s) and Haryana (47 m/s) have been considered. Different loads considered to be acting on these towers are:



1. Self-weight of tower
2. Weight of conductor
3. Wind load (x and z directions)
4. Wind load on conductor and ground wire
5. Broken wire load (security considerations)
6. Linemen with tools (safety considerations).

Analysis and optimum design of towers has been done for the following requirements andconfiguration:

- Transmission tower for 220 kV-3 phase-single-circuit.
- Suspension and Tangent tower (0° – 2°)
- Height = 28.2 m, Base width = 4.72 m
- Batter width = 1.5 m
- Deviation angle= 79° (40°-90°)
- Shielding Angle = 30°
- Sag = 8 m
- Wind speed = 39m/s and 41m/s(IS-802 (Part 1)-1995)
- Conductor Wire ACSR ZEBRA (Properties in Table No. 1)
- Earth wire (Properties in Table No. 2)

Table 1: Conductor wire electrical and mechanical properties

Voltage Level	220kV
Code Name of Conductor	ACSR “ZEBRA”
No. of conductor/ Phase	ONE
Stranding/ Wire diameter	54/3.18mm AL + 7/3.18mm steel
Total sectional area	484.5 mm2
Overall diameter	28.62 mm
Approx. Weight	1621 Kg/ Km
Calculated D.C resistance at 20 0C	0.06915 ohm/Km
Min.UTS	130.32 kN
Modulus of elasticity	7034 Kg/mm2
Co – efficient of linear expansion	19.30 x 10-6/ 0C
Max. Allowable temperature	750C

Table 2: Earth Wire Electrical and Mechanical Properties

Voltage Level	220kV
Code Name of Conductor	ACSR “ZEBRA”
No. of conductor/ Phase	ONE
Stranding/ Wire diameter	54/3.18mm AL + 7/3.18mm steel
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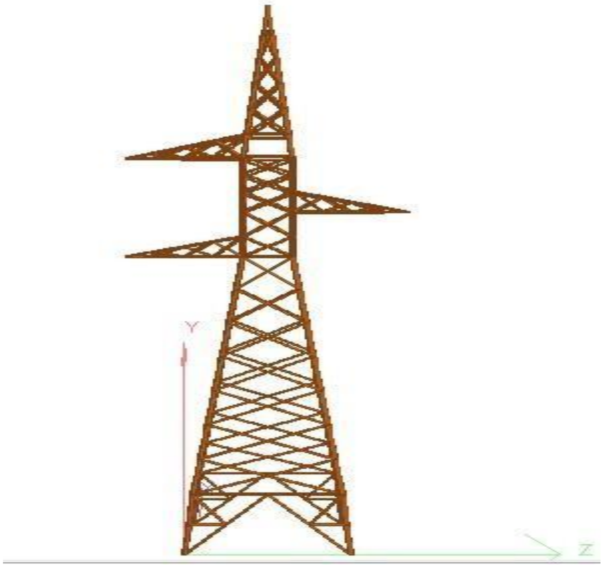


Figure 4: X-X Bracing

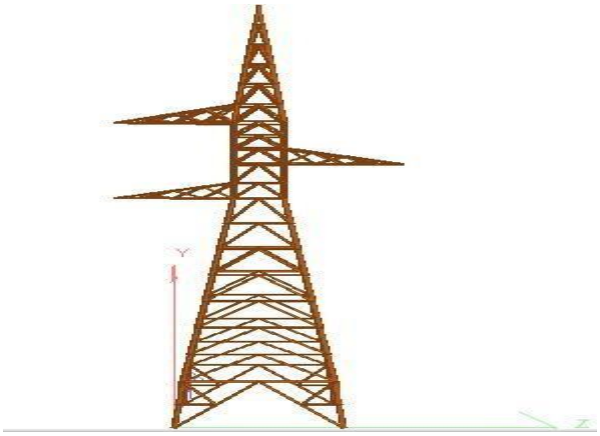


Figure 6 :K Bracing

LOAD CALCULATIONS AND ANALYSIS

Load Calculation

Self weight

The self weight is precisely considered as the dead load of the structure as these loads ***neither***change their position ***nor do they*** vary their magnitude. Actually, according to IS 1911:1967, the density of steel is 7850 kg/m^3 but we have assumed the self weight of both super and substructure of the tower as 1 kn/m^2 in downward direction.

Figure 7: Self Weight

Wind Load

Theterm wind denotes almost exclusively to horizontal wind. Wind pressure, therefore, actshorizontally on the exposed surfaces of towers.

Here, we have followed Design wind speed as per IS: 875-1987. The design wind speed(V_z) is obtained by multiplying the basic wind speed (V_b) by the factors k_1, k_2 and k_3

$$V_z = V_b \times k_1 \times k_2 \times k_3$$

where,

V_b = the basic wind speed in m/s at 10 m heightk_1 = probability factor (or risk coefficient)
k_2 = terrain, height and structure size factork_3 = topography factor.

The basic wind speed of Shimla is taken as 39 m/s as per IS-875:1987 Part-III.

Probability factor (or risk coefficient) k_1

The factor k_1 is based on statistical concept which take account of degree of reliability required a period of time in years during which there will be exposure to wind. In actual practice the factor $k_1$depends on type and importance of structure, design life of structure and basic wind speed in the region.

Table 3 Values of Factor k_1

Class of structure	Mean probable design life of Structure (years)	k_1 factor for basic design wind speed					
		33	39	44	7	50	55
1. All general buildings and structures	50	1.0	1.0	1.0	1.0	1.0	1.0
2. Temporary sheds and structures Under Construction	5	0.82	0.76	0.73	0.71	0.70	0.67
3. Buildings and structures presenting a low degree of hazard to life andproperty in event of failure	25	0.94	0.92	0.91	0.90	0.90	0.89
4. Important buildings and structuressuch as hospitals an communication buildings (tower, power plant structures etc.)	100	1.05	1.06	1.07	1.07	1.08	1.08

Terrain, height and structure size factor k_2

This factor takes into account terrain roughness, height and size of structure for determining k_2. Terrains are classified in to four categories and structures according to their heights into three classes.

Categories of structure
There are mainly four categories of structure for terrain, height and structure size which areas follows:
Category 1:
This represents exposed open terrain with few or no obstructions i.e. open sea coasts and flattreeless plains.
Category 2:
This represents open terrain with well scattered obstructions having height between 1.5 to 10m., i.e. air fields, under developed built-up outskirts of towns and suburbs.
Category 3:
This represents terrain with numerous closely spaced obstructions. This category includeswell wooded areas, shrubs, towns and industrial areas fully or partially developed.
Category 4:
This represents terrain with numerous large high closely spaced obstructions above 25m., i.e.large city centers.

Classes of structure
There are mainly three Classes of structure are as follows:
Class A: Structures having maximum dimension less than 20m. *Class* B:
Structures having maximum dimension between 20 to 50m.*Class* C: Structures
having maximum dimension greater than 50m

Table 4 Values of factor k_2.

Height (m)	Terrain Category 1			Terrain Category 2			Terrain Category 3			Terrain Category 4		
	Class			Class			Class			Class		
	A	B	C	A	B	C	A	B	C	A	B	C
10	1.05	1.03	0.99	1.0	0.98	0.93	0.91	0.88	0.82	0.80	0.76	0.67
15	1.09	1.07	1.03	1.05	1.02	0.97	0.97	0.94	0.87	0.80	0.76	0.67
20	1.12	1.10	1.06	1.07	1.05	1.0	1.01	0.98	0.91	0.80	0.76	0.67
30	1.15	1.13	1.09	1.12	1.10	1.04	1.06	1.03	0.96	0.97	0.93	0.83
50	1.20	1.18	1.14	1.17	1.15	1.10	1.12	1.09	1.02	1.10	1.05	0.95
100	1.26	1.24	1.20	1.24	1.22	1.17	1.20	1.17	1.10	1.20	1.15	1.05

150	1.30	1.28	1.24	1.28	1.25	1.21	1.24	1.21	1.15	1.24	1.20	1.10
200	1.32	1.30	1.26	1.30	1.28	1.24	1.27	1.24	1.18	1.27	1.22	1.13
250	1.34	1.32	1.28	1.32	1.31	1.26	1.29	1.26	1.20	1.28	1.24	1.16
300	1.35	1.34	1.30	1.34	1.32	1.28	1.31	1.28	1.22	1.30	1.26	1.17
350	1.37	1.35	1.31	1.36	1.34	1.29	1.32	1.30	1.24	1.31	1.27	1.19
400	1.38	1.36	1.32	1.37	1.35	1.30	1.34	1.31	1.25	1.32	1.28	1.20
450	1.39	1.37	1.33	1.38	1.36	1.31	1.35	1.32	1.26	1.33	1.29	1.21
500	1.40	1.38	1.34	1.39	1.37	1.32	1.36	1.33	1.28	1.34	1.30	1.22

Note: Intermediate values may be obtained by linear interpolation. It is permissible to assume constant wind speed between two heights, for simplicity.

Topography factor k_3

The value of $k_3$is varies from 1 to 1.4, depending upon the topography; for plain lands, k_3=1. Wind speed is affected by local topographic features such as hills, valleys, cliffs escarpments,or ridges. Hence while calculating design wind speed topography of the region is considered especially when the upwind slope (θ) is greater than 3^0 (below that $k_3$is taken as1.0) otherwise

$$k_3 = 1 + C \times s$$

C depends upon slopes as:

SLOPE	VALUE OF C
$> 17^o$	0.36
$3^o < \theta < 17^o$	1.2 (Z/L)

where,

Z = Height of crest or hill

L = Projected length of upwind zone

Design Wind pressure

The design wind pressure at any height above mean ground level is obtained by the followingrelationship:

$$p_z = 0.6\, V^2$$

where,

p_z = design wind pressure in N/m^2 at height z

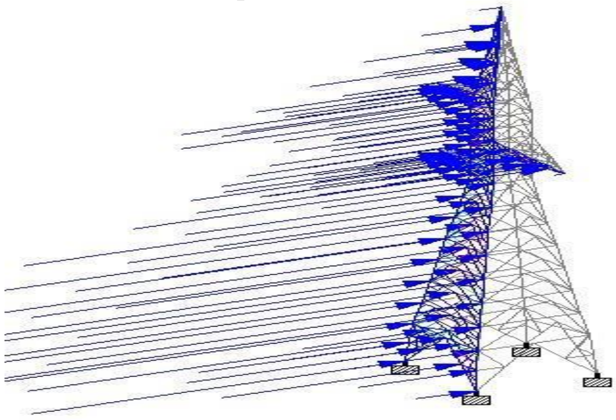


Figure 8: Wind Load

Others loads

- Weight of conductor and ground wire
- Line man with tools
- Broken wire Load

Load Combination

Load combinations are developed on the basis of the guidelines given in the codeIS802 (Part 1/Sec1):1995 considering the reliability, security and safety.

Reliability:

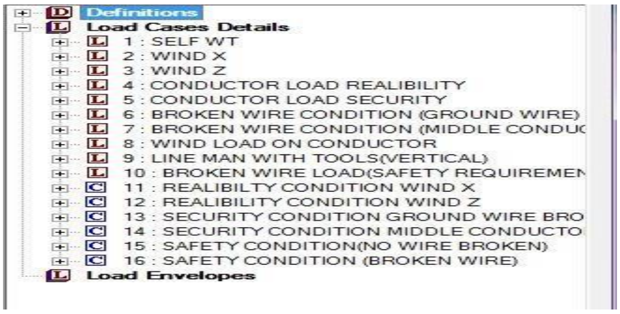
- Self Weight + Wind Load(X Direction) + Weight of Conductors
- Self Weight + Wind Load(Z Direction) + Weight of Conductors + WindLoad on Conductor

Security:

- Self Weight + Reduced Conductor Weight + Broken Wire Load(MiddleConductor)
- Self Weight + Reduced Conductor Weight + Broken Wire Load(GroundWire)

Safety:

- Self Weight + Conductor Weight + Load of lineman with tools



Definitions
Load Cases Details
1 : SELF WT
2 : WIND X
3 : WIND Z
4 : CONDUCTOR LOAD REALIBILITY
5 : CONDUCTOR LOAD SECURITY
6 : BROKEN WIRE CONDITION (GROUND WIRE)
7 : BROKEN WIRE CONDITION (MIDDLE CONDU
8 : WIND LOAD ON CONDUCTOR
9 : LINE MAN WITH TOOLS(VERTICAL)
10 : BROKEN WIRE LOAD(SAFETY REQUIREME
11 : REALIBILTY CONDITION WIND X
12 : REALIBILITY CONDITION WIND Z
13 : SECURITY CONDITION GROUND WIRE BRO
14 : SECURITY CONDITION MIDDLE CONDUCTO
15 : SAFETY CONDITION(NO WIRE BROKEN)
16 : SAFETY CONDITION (BROKEN WIRE)
Load Envelopes

Figure 9: Load combinations

Structural Analysis

Data Input for Analysis with STAAD.pro

STAAD.pro requires data input in some form like graphical or text. The following data wasfed to STAAD.pro graphically:

1. Member lengths and locations
2. Mutual Connectivity of members
3. Type of Supports
4. Assigning type and properties of members
5. Assignment of loads

Following data were inserted as text:

1. Load List for Analysis
2. Load Combination
3. Desired analysis results like Nodal displacements, Support reactions etc

Member forces and nodal displacement values from analysis

In this section, the analysis results for various cases considered are presented.

Zone 1, Himachal Pradesh (Basic Wind Speed = 39 m/sec)X-X

Bracing

Table 5: Max and min Member Forces (X-X Bracing)

	Beam	L/C	Node	FxkN	FykN	FzkN
Max Fx	9	12REALIBILITY CONDITION WIND Z	3	238.188	0.738	-0.498
Min Fx	35	12REALIBILITY CONDITION WIND Z	41	-193.970	-0.259	-0.190
Max Fy	25	15SAFETY CONDITION(NOWIRE BROKEN)	15	-44.475	4.875	10.266
Min Fy	27	15SAFETYCONDITION(NO WIRE BROKEN)	83	-10.163	-3.752	8.154
Max Fz	25	15SAFETY CONDITION(NOWIRE BROKEN)	15	-44.475	4.875	10.266
Min Fz	26	15SAFETY CONDITION(NOWIREBROKEN)	14	26.114	4.559	-10.697

K Bracing

Table 11: Max and Min forces in members (K bracing)

	Beam	L/C	Node	FxkN	FykN	FzkN
Max Fx	3	12 REALIBILITY CONDITION WIND Z	5	201.807	0.490	1.910
Min Fx	141	12 REALIBILITY CONDITION WIND Z	33	-168.626	0.210	-0.321
Max Fy	194	15 SAFETY CONDITION(NO WIRE BROKEN)	67	44.876	13.499	1.615
Min Fy	340	15 SAFETY CONDITION(NO WIRE BROKEN)	68	-13.529	-4.277	-0.174
Max Fz	151	15 SAFETY CONDITION(NO WIRE BROKEN)	13	60.155	0.557	4.826
Min Fz	3	15 SAFETY CONDITION(NO WIRE BROKEN)	5	71.440	-0.207	-2.738

Table 12: Nodal Displacement (K bracing)

			Horizontal	Vertical	Horizontal	Resultant
	Node	L/C	X mm	Y mm	Z mm	Mm
Max X	99	11 REALIBILTY CONDITION WIND X	44.454	-0.235	4.649	44.697

Min X	82	16 SAFETY CONDITION (BROKEN WIRE)	-10.307	1.068	0.377	10.369
Max Y	79	12 REALIBILITY CONDITION WIND Z	6.948	28.563	55.591	62.885
Min Y	88	12 REALIBILITY CONDITIONWIND Z	2.445	-25.189	37.076	44.890
Max Z	99	12 REALIBILITY CONDITION WIND Z	10.848	2.305	107.633	108.203
Min Z	167	2 WIND X	1.233	0.501	-4.225	4.429

Table 13: Support reactions (K Bracing)

			Horizontal	Vertical	Horizontal	Moment		
	Node	L/C	FxkN	FykN	FzkN	MxkNm	My kNm	MzkNm
Max Fx	9	12 REALIBILITY CONDITION WIND Z	13.785	-192.742	-31.737	-0.601	-0.567	0.948
Min Fx	5	11 REALIBILTY CONDITION WIND X	-22.718	152.283	-12.717	1.029	-0.065	0.777
Max Fy	5	12 REALIBILITY CONDITIONWIND Z	-16.509	230.147	-36.581	-1.158	-0.003	-1.374
Min Fy	9	12 REALIBILITY CONDITION WIND Z	13.785	-192.742	-31.737	-0.601	-0.567	0.948
Max Fz	1	2 WIND X	-22.392	-130.625	11.197	-1.000	0.715	1.380
Min Fz	5	12 REALIBILITY CONDITIONWIND Z	-16.509	230.147	-36.581	-1.158	-0.003	-1.374
Max Mx	5	15 SAFETY CONDITION(NOWIRE BROKEN)	-21.771	86.743	-2.054	1.739	0.309	2.065

Min Mx	1	12 REALIBILITY CONDITION WIND Z	11.940	171.862	-25.773	-1.169	0.123	1.366
Max My	1	2 WIND X	-22.392	-130.625	11.197	-1.000	0.715	1.380

Zone 2, Haryana (Basic Wind Speed = 47 m/sec)X-X Bracing

Table 14: Max and Min Member Forces(X-X Bracing)

	Beam	L/C	Node	FxkN	FykN	FzkN
Max Fx	11	12 REALIBILITY CONDITION WIND Z	4	281.015	0.924	1.970
Min Fx	152	12 REALIBILITY CONDITION WIND Z	24	-231.711	0.371	-1.548
Max Fy	25	15 SAFETY CONDITION(NO WIRE BROKEN)	15	-43.323	7.347	9.685
Min Fy	27	15 SAFETY CONDITION(NO WIRE BROKEN)	83	-16.480	-6.016	9.551
Max Fz	25	15 SAFETY CONDITION(NO WIRE BROKEN)	15	-43.323	7.347	9.685
Min Fz	28	15 SAFETY CONDITION(NO WIRE BROKEN)	16	55.010	-5.584	-10.725

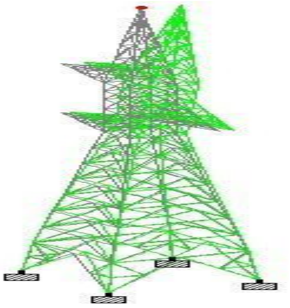
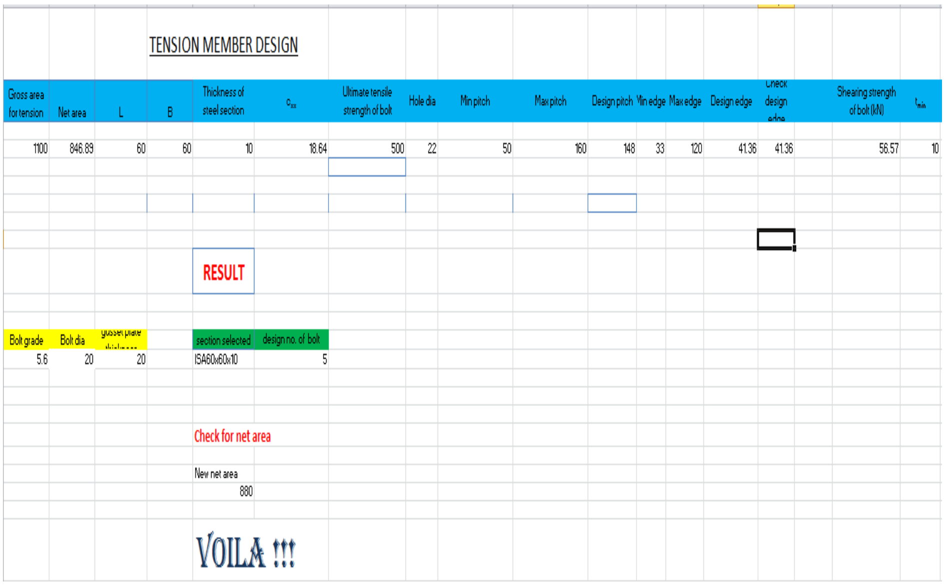


Figure 10: Deflected Shape of Tower



TENSION MEMBER DESIGN

Gross area for tension	Net area	L	B	Thickness of steel section	c_{xx}	Ultimate tensile strength of bolt	Hole dia	Min pitch	Max pitch	Design pitch	Min edge	Max edge	Design edge	Check design edge		Shearing strength of bolt (kN)	t_{min}
1100	846.89	60	60	10	18.64	500	22	50	160	148	33	120	41.36	41.36		56.57	10

RESULT

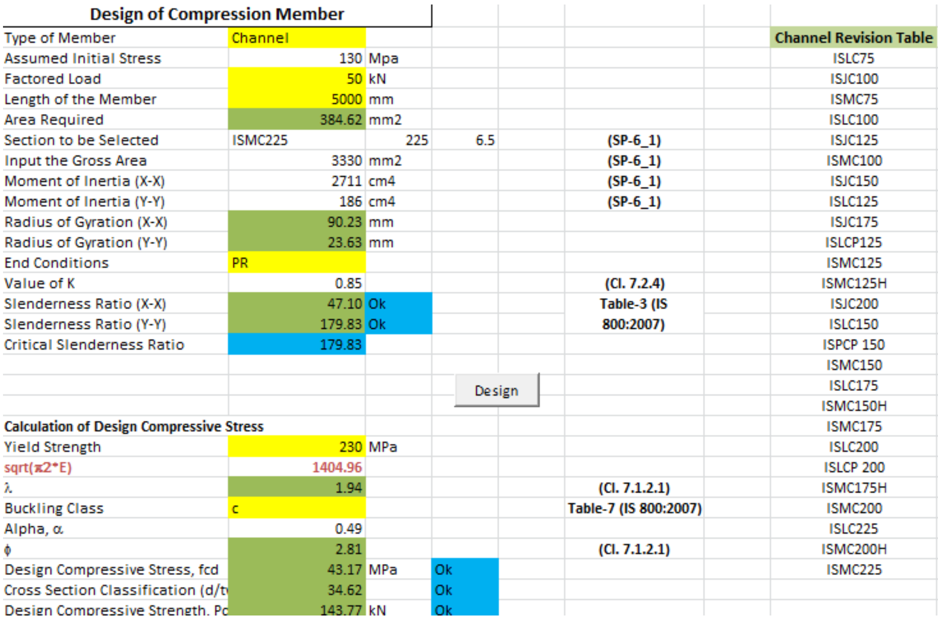
Bolt grade	Bolt dia	gusset plate		section selected	design no. of bolt
5.6	20	20		ISA60x60x10	5

Check for net area

New net area
880

VOILA !!!

Figure 14: Tension Member Excel Sheet



Design of Compression Member

Type of Member	Channel					Channel Revision Table
Assumed Initial Stress	130	Mpa				ISLC75
Factored Load	50	kN				ISJC100
Length of the Member	5000	mm				ISMC75
Area Required	384.62	mm2				ISLC100
Section to be Selected	ISMC225	225	6.5		(SP-6_1)	ISJC125
Input the Gross Area	3330	mm2			(SP-6_1)	ISMC100
Moment of Inertia (X-X)	2711	cm4			(SP-6_1)	ISJC150
Moment of Inertia (Y-Y)	186	cm4			(SP-6_1)	ISLC125
Radius of Gyration (X-X)	90.23	mm				ISJC175
Radius of Gyration (Y-Y)	23.63	mm				ISLCP125
End Conditions	PR					ISMC125
Value of K	0.85				(Cl. 7.2.4)	ISMC125H
Slenderness Ratio (X-X)	47.10	Ok			Table-3 (IS	ISJC200
Slenderness Ratio (Y-Y)	179.83	Ok			800:2007)	ISLC150
Critical Slenderness Ratio	179.83					ISPCP 150
						ISMC150
			Design			ISLC175
						ISMC150H
Calculation of Design Compressive Stress						ISMC175
Yield Strength	230	MPa				ISLC200
sqrt(π2*E)	1404.96					ISLCP 200
λ	1.94				(Cl. 7.1.2.1)	ISMC175H
Buckling Class	c				Table-7 (IS 800:2007)	ISMC200
Alpha, α	0.49					ISLC225
ϕ	2.81				(Cl. 7.1.2.1)	ISMC200H
Design Compressive Stress, fcd	43.17	MPa	Ok			ISMC225
Cross Section Classification (d/t	34.62		Ok			
Design Compressive Strength, Pc	143.77	kN	Ok			

Figure 15: Compression Member Excel Sheet

FOUNDATION DESIGN

Introduction

For more structures including buildings, bridges, earth fills, earth and concrete dams, it is the earth that provides the ultimate support. The behavior of the supporting ground is invariably asoil (sound rocky stratum being very rare) which is weaker than any construction material like wood, concrete, steel or masonry. Hence, compared to structural members made out of these materials, a large area or mass of soil is necessarily involved in carrying the same load. Structural foundations are the substructure elements which transmit the structural load to the earth in such a way that the supporting soil is not overstressed and not undergo deformations that would cause excessive settlement of the structure. Hence, the properties of the supportingsoil must be expected to affect vitally the choice of the type of structural foundation suitable for a structure.

The various types of structural foundations can be broadly grouped into two categories, namely,

- Shallow foundations
- Deep foundations

Due to the presence of large uplift load the only foundation we find suitable for that type ofcondition is:-

- Under-reamed pile foundations

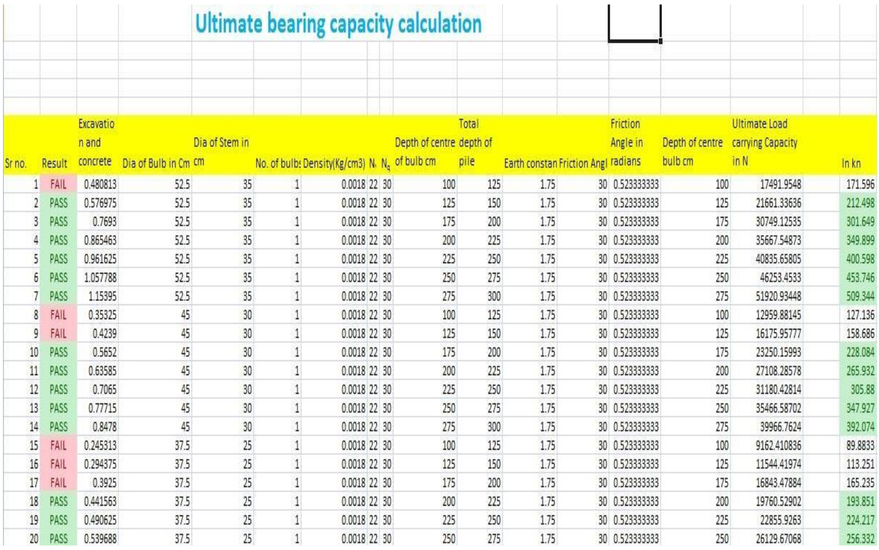
Methodology

Microsoft Excel spreadsheets were used for the foundation design of the transmission tower. Foundation design was based on the recommendation of IS, foundation was designed for two main conditions:

- Ultimate Bearing Capacity
- Uplift Load

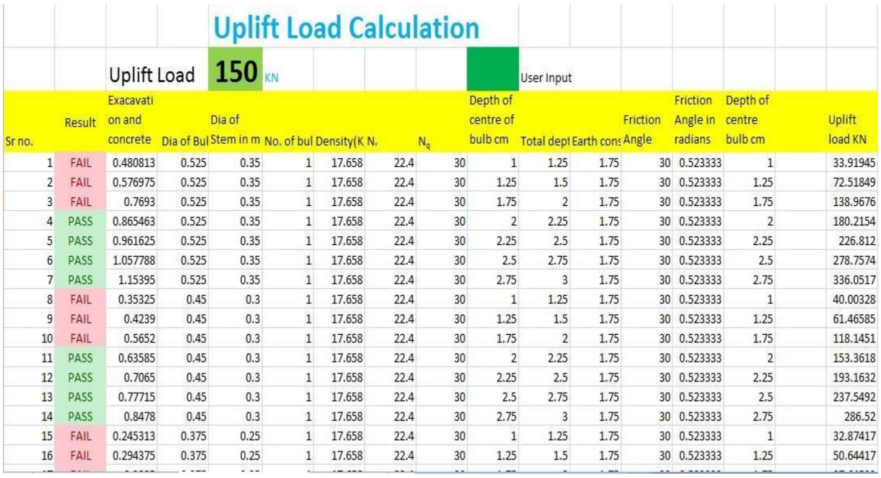
Spreadsheet takes input from the user in form of Ultimate downward load and Uplift load, Microsoft Excel spread sheet then compare these loads with the various combinations of under-reamed piles. It provides result in the form of pass and fail for both the load cases, and gives opportunity to the user to select best under reamed pile on the basis of least excavation and concreting.

Figure 16: ultimate load bearing capacity Excel Sheet



Ultimate bearing capacity calculation

Sr no.	Result	Excavation and concrete	Dia of Bulb in Cm	Dia of Stem in cm	No. of bulb:	Density(Kg/cm3)	N.	N_q	Depth of centre of bulb cm	Total depth of pile	Earth constan	Friction Angl	Friction Angle in radians	Depth of centre bulb cm	Ultimate Load carrying Capacity in N		In kn
1	FAIL	0.480813	52.5	35	1	0.0018	22	30	100	125	1.75	30	0.523333333	100	17491.9548		171.596
2	PASS	0.576975	52.5	35	1	0.0018	22	30	125	150	1.75	30	0.523333333	125	21661.33636		212.498
3	PASS	0.7693	52.5	35	1	0.0018	22	30	175	200	1.75	30	0.523333333	175	30749.12535		301.649
4	PASS	0.865463	52.5	35	1	0.0018	22	30	200	225	1.75	30	0.523333333	200	35667.54873		349.899
5	PASS	0.961625	52.5	35	1	0.0018	22	30	225	250	1.75	30	0.523333333	225	40835.65805		400.598
6	PASS	1.057788	52.5	35	1	0.0018	22	30	250	275	1.75	30	0.523333333	250	46253.4533		453.746
7	PASS	1.15395	52.5	35	1	0.0018	22	30	275	300	1.75	30	0.523333333	275	51920.93448		509.344
8	FAIL	0.35325	45	30	1	0.0018	22	30	100	125	1.75	30	0.523333333	100	12959.88145		127.136
9	FAIL	0.4239	45	30	1	0.0018	22	30	125	150	1.75	30	0.523333333	125	16175.95777		158.686
10	PASS	0.5652	45	30	1	0.0018	22	30	175	200	1.75	30	0.523333333	175	23250.15993		228.084
11	PASS	0.63585	45	30	1	0.0018	22	30	200	225	1.75	30	0.523333333	200	27108.28578		265.932
12	PASS	0.7065	45	30	1	0.0018	22	30	225	250	1.75	30	0.523333333	225	31180.42814		305.88
13	PASS	0.77715	45	30	1	0.0018	22	30	250	275	1.75	30	0.523333333	250	35466.58702		347.927
14	PASS	0.8478	45	30	1	0.0018	22	30	275	300	1.75	30	0.523333333	275	39966.7624		392.074
15	FAIL	0.245313	37.5	25	1	0.0018	22	30	100	125	1.75	30	0.523333333	100	9162.410836		89.8833
16	FAIL	0.294375	37.5	25	1	0.0018	22	30	125	150	1.75	30	0.523333333	125	11544.41974		113.251
17	FAIL	0.3925	37.5	25	1	0.0018	22	30	175	200	1.75	30	0.523333333	175	16843.47884		165.235
18	PASS	0.441563	37.5	25	1	0.0018	22	30	200	225	1.75	30	0.523333333	200	19760.52902		193.851
19	PASS	0.490625	37.5	25	1	0.0018	22	30	225	250	1.75	30	0.523333333	225	22855.9263		224.217
20	PASS	0.539688	37.5	25	1	0.0018	22	30	250	275	1.75	30	0.523333333	250	26129.67068		256.332



Uplift Load Calculation

Uplift Load 150 KN

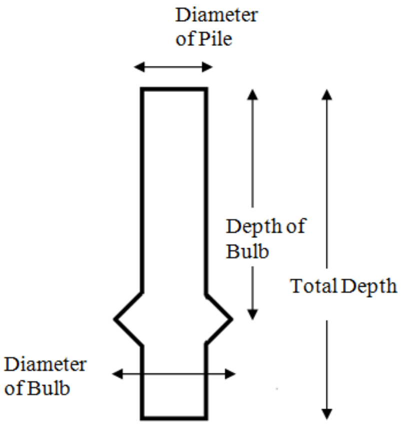
🟩 User Input

Sr no.	Result	Exacavation and concrete	Dia of Bul	Dia of Stem in m	No. of bul	Density(K	Nᵧ	N_q	Depth of centre of bulb cm	Total dept	Earth cons	Friction Angle	Friction Angle in radians	Depth of centre bulb cm		Uplift load KN
1	FAIL	0.480813	0.525	0.35	1	17.658	22.4	30	1	1.25	1.75	30	0.523333	1		33.91945
2	FAIL	0.576975	0.525	0.35	1	17.658	22.4	30	1.25	1.5	1.75	30	0.523333	1.25		72.51849
3	FAIL	0.7693	0.525	0.35	1	17.658	22.4	30	1.75	2	1.75	30	0.523333	1.75		138.9676
4	PASS	0.865463	0.525	0.35	1	17.658	22.4	30	2	2.25	1.75	30	0.523333	2		180.2154
5	PASS	0.961625	0.525	0.35	1	17.658	22.4	30	2.25	2.5	1.75	30	0.523333	2.25		226.812
6	PASS	1.057788	0.525	0.35	1	17.658	22.4	30	2.5	2.75	1.75	30	0.523333	2.5		278.7574
7	PASS	1.15395	0.525	0.35	1	17.658	22.4	30	2.75	3	1.75	30	0.523333	2.75		336.0517
8	FAIL	0.35325	0.45	0.3	1	17.658	22.4	30	1	1.25	1.75	30	0.523333	1		40.00328
9	FAIL	0.4239	0.45	0.3	1	17.658	22.4	30	1.25	1.5	1.75	30	0.523333	1.25		61.46585
10	FAIL	0.5652	0.45	0.3	1	17.658	22.4	30	1.75	2	1.75	30	0.523333	1.75		118.1451
11	PASS	0.63585	0.45	0.3	1	17.658	22.4	30	2	2.25	1.75	30	0.523333	2		153.3618
12	PASS	0.7065	0.45	0.3	1	17.658	22.4	30	2.25	2.5	1.75	30	0.523333	2.25		193.1632
13	PASS	0.77715	0.45	0.3	1	17.658	22.4	30	2.5	2.75	1.75	30	0.523333	2.5		237.5492
14	PASS	0.8478	0.45	0.3	1	17.658	22.4	30	2.75	3	1.75	30	0.523333	2.75		286.52
15	FAIL	0.245313	0.375	0.25	1	17.658	22.4	30	1	1.25	1.75	30	0.523333	1		32.87417
16	FAIL	0.294375	0.375	0.25	1	17.658	22.4	30	1.25	1.5	1.75	30	0.523333	1.25		50.64417

Figure 17: Uplift load Excel Sheet

Figure 18: Pile foundation

Table23: Foundation Design (Zone-1)



Type of Bracing system	*Diameter of pile(Cm)*	*Diameter of bulb(Cm)*	*Depth of pile(Cm)*	*Depth of centreof bulb(Cm)*
X-X	30	45	300	275
X-B	25	37.5	300	275
K	30	45	275	250

Table 24 : Foundation Design (Zone-2)

Type of Bracing system	*Diameter of pile(Cm)*	*Diameter of bulb(Cm)*	*Depth of pile(Cm)*	*Depth of centre of bulb(Cm)*
X-X	35	52.5	250	225
X-B	35	52.5	300	275
K	35	52.5	300	275

SECTION 7RESULTS AND DISCUSSIONS

The results obtained in the previous sections are presented in this section and discussed.

- The parameters of this study are maximum compressive and tensile stresses in the tower members, axial forces in the members and maximum deflection of the nodes in x, y, z directions and the above parameters are compared in zones 1 and 2 with the wind speed 39 m/s and 47 m/s respectively.
- Table 6, 9 and 12 represent the maximum axial deflections of node in x,y and z direction of X-X , X-B , K bracing system in zone 1 and Table 15,18 and 21 represent the maximum axial deflections of node in x,y and z direction of X-X , X-B , K bracing system in zone 2.
- Table 5,8 and 11 represent the maximum and minimum axial forces in X-X, X-B and K bracing system respectively in zone 1 and Table 14,17 and 20 represent the maximum and minimum axial forces in X-X, X-B and K bracing system respectively in zone 2.
- Table 7, 10, 13 represents the support reactions of X-X , X-B and K bracing systems respectively in zone 1 and table 16,19,22 represents the support reactions of X-X , X- B and K bracing systems respectively in zone 2.
- The maximum deflections of top node of different bracing system in different zones are mentioned in Table 23.

Table 25: DEFLECTION

Zone 1		**Zone 2**	
BRACING SYSTEM	HORIZONTAL DEFLECTION(mm)	BRACING SYSTEM	HORIZONTAL DEFLECTION(mm)
X-X	88.69	X-X	65.19
X-B	52.33	X-B	55.95
K	44.45	K	42.08

Table 26: ZONE 1- X-X Bracing

PROFILE	**LENGTH (m)**	**WEIGHT(N)**
ISA 130x130x16	158.78	47814
ISA 60x60x6	298.60	15690
ISA 100x100x8	196.84	23286
	TOTAL	86790

Table 27: ZONE 1 X-B Bracing

PROFILE	**LENGTH (m)**	**WEIGHT(N)**
ISA 130x130x16	149.64	45061
ISA 60x60x6	404.34	21246

ISA 100x100x8	201.51	23839
	TOTAL	90146

Table 28: ZONE 1 K Bracing

PROFILE	**LENGTH (m)**	**WEIGHT(N)**
ISA 130x130x16	10.85	3267
ISA 60x60x6	512.18	26912
ISA 100x100x8	153.04	18104
	TOTAL	48284

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Table 29: ZONE 2 X-X Bracing

PROFILE	**LENGTH (m)**	**WEIGHT(N)**
ISA 130x130x16	132.14	39792
ISA 60x60x6	342.20	17983
ISA 100x100x8	179.88	21280
	TOTAL	79053

Table 30: ZONE 2 X-B Bracing

PROFILE	**LENGTH (m)**	**WEIGHT(N)**
ISA 130x130x16	134.80	40593
ISA 60x60x6	434.17	22813
ISA 100x100x8	186.51	22065
	TOTAL	85472

Table 31: ZONE 2 K Bracing

PROFILE	**LENGTH (m)**	**WEIGHT(N)**
ISA 130x130x16	10.85	3267
ISA 60x60x6	518.81	27267
ISA 100x100x8	146.40	17319
	TOTAL	47847

Table 32: No. of Joints

Type of bracing system	**Number of Joints**
X-X	146
X-B	132
K	203

CONCLUSIONS

This work attempts to optimize the transmission line tower structure for a 220 KV threephase single circuit, with respect to configuration and different site condition as a variable parameters. Due to multiple loading conditions, each member subjected to maximum stress under any of these loading conditions is assigned an angle size section. This work has focused on techno economical analysis and design of transmission line tower structure. Also the focus is on saving time and cost when optimization of tower for different configurations are considered.

Based upon results and discussions presented in the report, the following are the general observations and conclusions drawn.

- Optimization of tower geometry with respect to member forces. The K-bracing tower with base width 4.72 m is concluded as the optimum tower configuration with respect to geometry for both the zones.
- As far as the deflection criterion is concerned, the K bracing tower has the least deflection under the same load cases for both the zones.
- The tower structure with the least weight is directly associated with the reduction of the foundation cost.
- The cost of the tower is directly proportional to the number of joints required because of increased number of bolts, gusset plates, and man-hours.
- Difference in the foundation parameters is not substantial, therefore this does not affect the total cost to a large extent.

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