Analysis of a Transmission Tower Near Coastal Area

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Abstract - The principal objective of this project is to analyze and design a Steel Transmission Tower near coastal areas using STAAD Pro software. The analysis would involve load calculations manually and analyzing the whole structure by STAAD Pro. STAAD Pro has a very interactive user interface that allows the users to draw the frame and input the load values and dimensions. Then according to the specified criteria assigned it analyses the structure and. Our work will involve some 2D & 3D frames under various load combinations. Our final work will be the proper analysis of the Steel Transmission towers near any coastal under various load combinations. In the post-processing mode after the completion of the analysis, we can work on structure and study bending moment and shear force values with generated diagrams. We may also check the Deflections of various members under the given loading combinations. In a nutshell, we are creating a transmission tower by analyzing the various forces in members and understanding their member properties as a quarter to half of the cost of the transmission line is dependent upon the design of the tower.

Keywords – Analysis, Transmission Tower, load, values, wind, Staad.Pro.

I. INTRODUCTION

India has a large population residing all over the country and the electricity supply need of this population creates the requirement for a large transmission and distribution system. The supporting structure types used in transmission lines 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 about a quarter to half of the cost of transmission lines and hence optimum tower design will bring in substantial savings. To Design the structure, we first need to analyze it and this analysis has been performed in this paper for a 45 meters high and 20 meters broad transmission tower. In the coastal region, the most predominant load is the wind load. Wind blow at high speeds and may collapse the structure, so this structure has been carefully analyzed for all the possible combination of wind loads. Structure components are also explained using different sources. Also, different research papers were reviewed on similar topics and relevant information was picked up from them to make this paper more informative. The information on transmission tower and tower components is taken from Google and the images of the tower .and tower components are picked from Google Images. The images of the Yield Strength of steel used in the tower are depicted in the form of a screenshot from Staad.Pro. The model of the tower in Staad.Pro has also been shown, 4 different images of winds from different directions, i.e., +Z, -Z, +X, and -X acting on a tower have also been shown. Every tower is in a different kind of terrain and is exposed to different kinds of conditions, so detailed tables from Staad. Pro software has been taken which shows what these different exposure conditions and categories signify. At last, a screenshot of the results of the tower analysis is shared and a graph below it shows that all the values of the tower are within permissible limits and the cases where the tower might fail. This graph is taken from [1] '*Analysis and Design of Three and Four-Legged 400KV Steel Transmission Line Towers: Comparative Study* 'by Y. M. Ghugal and U.S. Salunkhe. Also, a table has been presented which shows the effect of wind at different angles striking the tower. A study [5] also referred to understanding the role of vertical and horizontal members of transmission towers and which one of them is more important from the stability perspective. The foundation is as important as the tower. From [7] Chemical and electrochemical parameters, studied on transmission line tower stubs excavated from inland and coastal areas have been presented. A methodology for rehabilitation of transmission tower stubs has been discussed.

II. LITERATURE REVIEW

After carefully analyzing a lot of research papers we can study the behavior of a transmission tower under various kinds of loads. In this case, however, we are concerned with the wind load as our structure is situated in a coastal region. Through a rigorous review, we have studied the performance of 3-legged and 4-legged towers under loads and the performance of the foundation and the entire structure for wind load in coastal regions. Also, a comparison between the

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analysis from different codes for the same tower was studied. A lot of relevant information was gathered in advance through various other research papers to build this project. From [4] *"Analysis and Design of 220 kV Transmission Line Tower (A conventional method of analysis and Indian Code based Design)" by D.B.Sonowal1, J.D.Bharali2, M.K.Agarwalla3, N. Sarma4, P. Hazarika5, we know that* he transmission line tower is a statically indeterminate structure and the manual analysis of such a structure is very complex. A rigorous analysis considering three-dimensional space actions is quite difficult. The development and application of computer analysis opened new and practically unlimited possibilities for the exact solution of these statically indeterminate structures with precise static analysis of their three-dimensional performance. However, the adopted method of analysis presented in this paper considering linear behavior with two-dimensional approaches gives satisfactory results which should be further verified with advanced software like STAAD Pro, Ansys, etc. As per the design concern, all sections we consider are found safe against the worst condition. In summary, the study presented here would certainly be useful for Design Engineers basically for the new learners for a better understanding of the behaviors and the method of analysis and design of the transmission tower as per Indian Standard Codes of practice in a very simple and easy manner.

From [2] the *"study on the Limited Values of Foundation Deformation for a Typical UHV Transmission Tower" by Fengli Yang, Jingbo Yang, Junke Han, and Zifu Zhang,* we know that the working load cases of 90-degree wind, 60-degree wind, 10-mm accreted ice load, as well as the installation load cases, the limited values of foundation settlement, inclination, and slip under 60 wind load are the minimum. The 60-degree wind load case is the control case of foundation deformation.

From [3] "*Comparison on Wind Load Prediction of Transmission Line between Chinese New Code and Other Standards" by JIANG, Qia*†˙DENG, Hongzhou,* we know that In this paper, the wind load definition in the Chinese new code is compared with that in the ASCE standards, IEC60826, BS8100 and a 500 kV transmission line are taken as an example for comparison. The return periods defined in the Chinese new code are smaller than those in ASCE standards and IEC60826. Based on the same solidity ratio, the shape factor in the Chinese new code is lower than that in other standards. The height factor for terrain Category B in the Chinese new code is close to that in IEC60826, larger than that in ASCE standards, and smaller than that in BS8100. For a 50-year return period, the wind loads acting on conductors and ground wires are larger than values predicted by other standards. For towers with a total height above 60 m, the gust response factor, magnified from bottom to top, results in the increase of the wind loads in the Chinese new code. Therefore, the Chinese new code is conservative for towers in heights more than 60 m. For towers with a total height below 60 m, a constant gust response factor is used in the Chinese new code, and the wind load prediction is close to that in other standards. In general, the Chinese new code improves the reliability and safety of design and is validated to be reliable in comparison with other standards.

From "Analysis and Design of Three and Four-Legged 400KV Steel Transmission Line Towers: Comparative Study" by Y. M. Ghugal and U.S. Salunkhe, we know that. The axial forces are increased by 77.81% in three-legged tower support components as compared to four-legged tower support components. The moments are increased by 60% in three-legged tower components as compared to four-legged towers. Triangular tower deflection is found to increase by 27.4% in normal conditions compare with a square tower. A saving in steel weight of 21.2% resulted when using a three-legged tower as compared with a four-legged type with an angle section. In addition, 3.05 % area saving in the three-legged towers can be achieved as compared to a four-legged tower.

From [6] we can infer that a comprehensive analytical and experimental program for the analysis and design of pultruded FRP structural profiles to be used as a replacement for rolled steel angle sections in transmission line towers is investigated. The analysis is limited to linear-elastic response including buckling considerations. The experimental studies discussed in this paper predict that the deflections and strains are in close agreement with the experimental results and finite element analysis. The buckling mode of individual members and full-scale panels are in close agreement with the experiment and FE analysis. The result of this study indicates that the building of a power transmission line tower with FRP pultruded structural sections with a suitable joining technique is feasible.

From [8] we understand that this work attempts to optimize the transmission line tower structure for a 132KV double circuit with respect to configuration and different materials as variable parameters. Optimization of tower geometry with respect to member forces, the tower configuration having 3 panels and base width of 6.05metres is concluded as safe with respect to geometry. The tower with a 45˚ angle section and K-bracing with 7833.41kg/m3 has the greatest reduction in weight optimization. Analysis of tower with STAAD PRO software is showing a transmission line tower with a height of 31.53metres with 132KV. Tower structures with less height are directly associated with the reduction of wind loading and also structure construction. A narrow-based steel lattice transmission tower structure plays a vital role in its performance, especially while considering eccentric loading conditions for high altitude as compared to other normal towers. Narrow-based steel lattice transmission tower considered in this can safely withstand the design wind load and actually load acting on the tower. The bottom tier members have more roles in the performance of the tower in taking axial forces and the members supporting the cables

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are likely to have localized role. The vertical members are more prominent in taking loads of the tower than the horizontal and diagonal members, the members supporting the cables at higher elevations are likely to have a larger influence on the behavior of the tower structure. The effect of the twisting moment of the intact structure is not significant.

The most obvious and visible owe type towers are :

1. Lattice structure

2. Tubular pole structure

Lattice structure

Lattice steel towers are made up of many different steel structural components connected together with bolts or welded. Many different types of lattice steel towers exist. These towers are also called self-supporting transmission towers or free-standing towers, due to their ability to support themselves. These towers are not always made of steel; they can also be made of aluminum or galvanized stee**l.**

Tubular Pole structure

Tubular steel poles are another of the major types of transmission towers. They are made up of hollow steel poles. Tubular steel poles can be manufactured as one large piece, or as several small pieces which fit together

Few of the Components of a transmission tower:

The transmission tower consists of the following parts:

1- Cage of transmission tower

2- Cross arm of transmission tower

3- Peak of transmission tower

4- Transmission tower body

The Cage

The area between the tower body and peak is known as the cage of the Transmission Tower. The main vertical section of any transmission tower is named a cage. Normally cross-section of the cage takes a square shape and the shape is also depending on the height of the transmission line.

Cross arm of transmission tower

Cross Arm is one of the key components of a transmission line and it holds the power conductor. Cross arms can vary due to the location and power carried by the transmission line. The number of cross arms depends on the number of circuits consisting in Transmission Line

The peak of transmission tower

The Peak of the transmission tower is mainly used for lay ground wire in suspension clamp and tension clamp in suspension and angle tower locations. The peak is a portion of the above vertical configuration of the top cross arm. We can simply say that Peak is the section above the boom in the case of the horizontal section of the tower. The peak height depends on the specific angle of the shield and clearance of the mid-span. All these components are depicted in **Fig.1 and Fig.2**

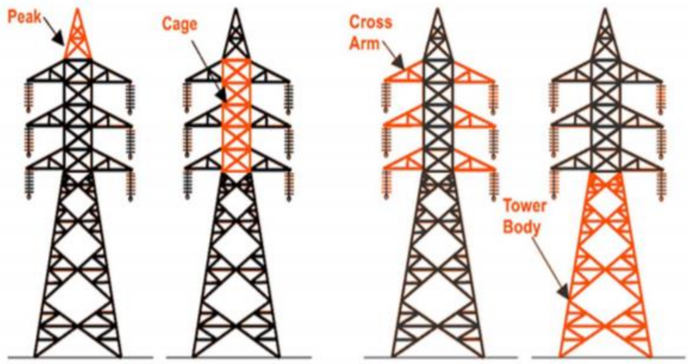

Fig 1- Tower Structure and its components

Fig 2- Images of Tower Structure

III. ANALYSIS OF TRANSMISSION TOWER

The Transmission tower modeled is a 45m high and 20m wide tower which lies in Category 1 and exposure condition B. **Fig 3** (yield strength of steel), As per the height and width of the structure. We concluded that the yielding strength of steel that is to be used in transmission tower must have a high yielding value so that factor of safety enhances and that's why the value of yielding is 500000 KN per sqr. Meter.

Fig 4 (giving tension values in sidearms) t the cable offers tension in the side arms of the transmission tower, this tension is high at the end node of the sidearm. From various types of transmission lines, it has been observed that a maximum of approx. 90KN value of tension is usually experienced by a tower in extreme conditions. The type of loads and results of the analysis are depicted in the screenshots below

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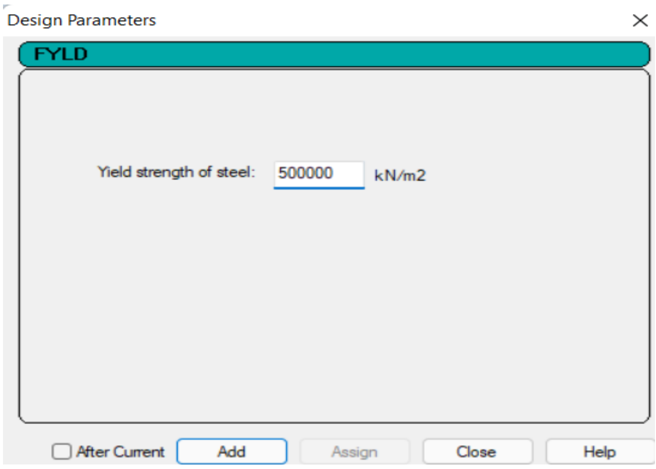

Fig 3-Yield Strength of Steel

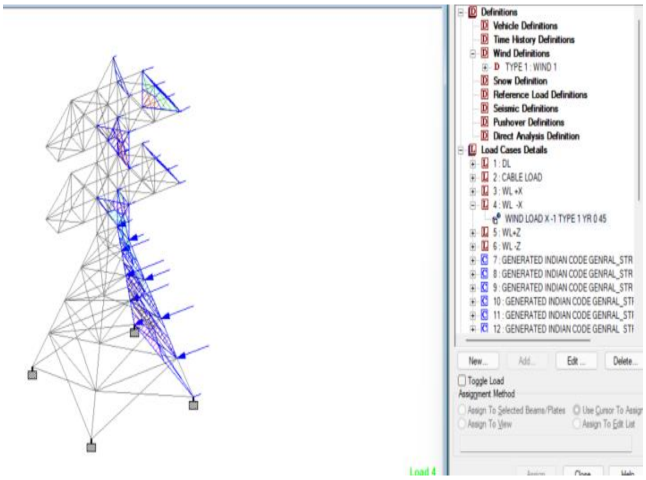

Fig 4(b)- Wind load(-X direction)

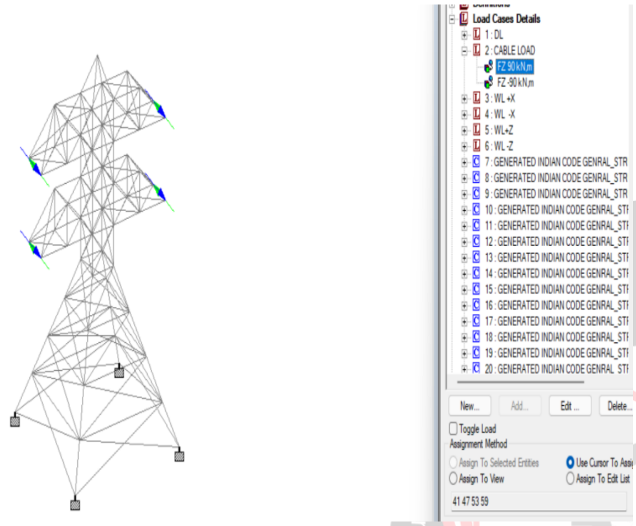

Fig 4-Cable Tension Loads

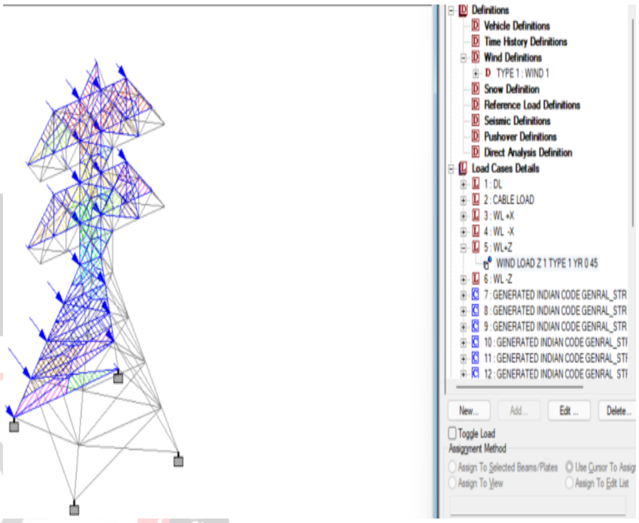

Fig 4(c)-Wind load (+Z direction)

(**Fig 4(a,b,c)** with WL+X WL -X WL +Z WL-Z) In wind analysis it was found that there are four directions in which wind strikes and directly affects the value of deflection and bending moment in which it is acting.

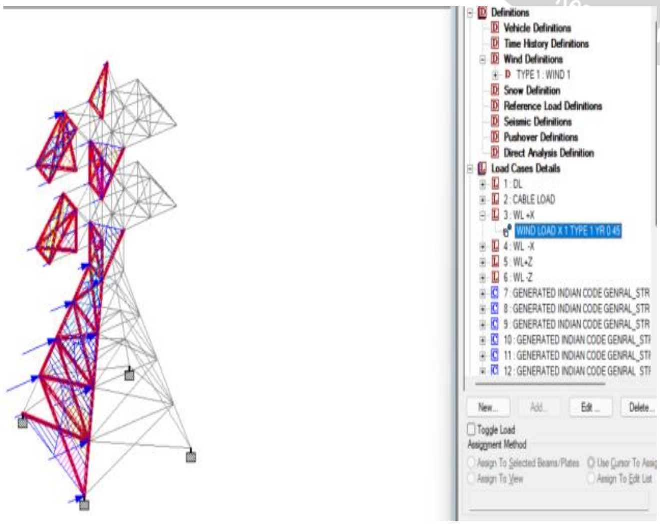

Fig 4(a)- Wind load(+X direction)

CATEGORY 1 - Exposed open terrain with few or no obstruction & in which the average height of any object surrounding the structure is less than 1.5 m.
CATEGORY 2 - Open terrain with well scattered structure obstruction having height generally b/w 1.5 to 10m.
CATEGORY 3 - Terrain with numerous closed spaced obstructions having size of building structures up to 10m in height.
CATEGORY 4 - Terrain with numerous large highly closely spaced obstructions above 25m.

EXPOSURE A - Max. dimensions (greatest horizontal or vertical dimension) should less than 20m.
EXPOSURE B - Max. dimensions (greatest horizontal or vertical dimension) should be in b/w 20-50m.
EXPOSURE C - Max. dimensions (greatest horizontal or vertical dimension) should greater than 50m

Table 1 Wind Category Description

Tables 1 and 2 (CATEGORY & EXPOSURE) Category denotes the obstruction's elevation and exposure denotes the height of the entity on which analysis is to be carried out. As our transmission tower is near coastal areas that clearly means the terrain will be plain with an open environment hence the obstruction's elevation will be less so the tower is of CATEGORY 1 here while our tower elevation is 45 m, hence EXPOSURE B

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EXPOSURE A - Max. dimensions (greatest horizontal or vertical dimension) should less than 20m.
EXPOSURE B - Max. dimensions (greatest horizontal or vertical dimension) should be in b/w 20-50m.
EXPOSURE C - Max. dimensions (greatest horizontal or vertical dimension) should greater than 50m

Table 2 -Exposure conditions

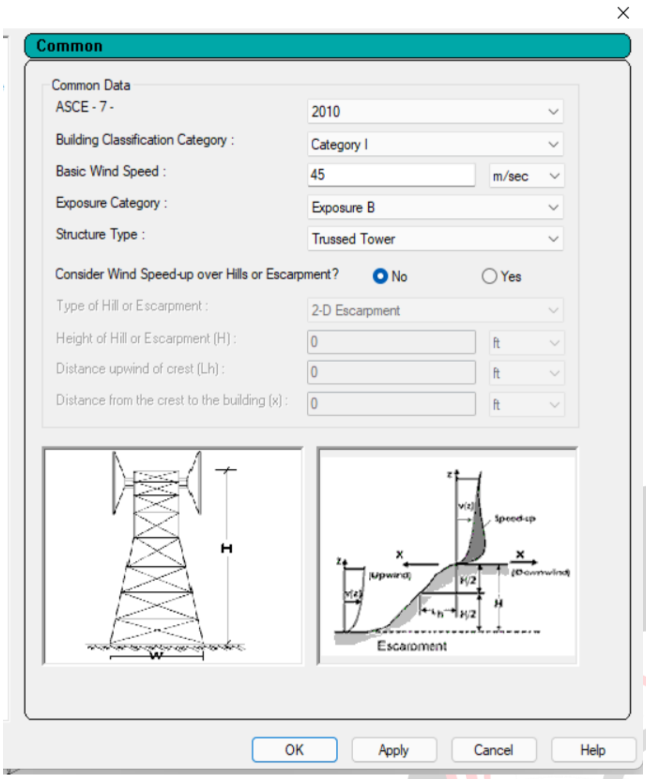

Fig 5 -Tower Specifications

Fig 5 It is the part where all the values from fig 4 along with details of towers are being entered

Table 3 After completing all analysis, the values of deflection for the dead load of the tower, cable load, wind load in all directions, and all load combinations individually

L/C	Length m	Max x mm	Dist m	Max y mm	Dist m	Max z mm	Dist m	Max mm	Dist m
1 DL	16.000	-0.001	8.000	-372.747	8.000	0.000	0.417	372.747	8.000
2 CABLE LO	16.000	-0.001	12.000	0.000	0.000	0.000	0.000	0.001	12.000
3 WL +X	16.000	-0.001	10.667	-0.042	4.000	0.004	0.250	0.042	4.000
4 WL -X	16.000	-0.001	12.000	-0.058	12.000	0.010	0.750	0.059	12.000
5 WL+Z	16.000	-0.001	8.000	-0.011	12.000	0.062	0.500	0.062	8.000
6 WL -Z	16.000	0.001	13.333	0.012	4.000	-0.066	0.500	0.066	8.000
7 GENERATE	16.000	0.001	9.333	-559.121	8.000	0.000	0.667	559.121	8.000
8 GENERATE	16.000	-0.002	12.000	-447.316	8.000	0.005	0.250	447.316	8.000
9 GENERATE	16.000	-0.001	8.000	-447.317	8.000	0.013	0.750	447.317	8.000
10 GENERAT	16.000	0.001	13.333	-447.304	8.000	0.075	0.500	447.304	8.000
11 GENERAT	16.000	0.001	13.333	-447.289	8.000	-0.079	0.500	447.289	8.000
12 GENERAT	16.000	-0.001	14.667	-447.278	8.000	-0.005	0.250	447.278	8.000
13 GENERAT	16.000	0.001	13.333	-447.276	8.000	-0.012	0.750	447.276	8.000
14 GENERAT	16.000	-0.001	12.000	-447.290	8.000	-0.074	0.500	447.290	8.000
15 GENERAT	16.000	-0.001	12.000	-447.305	8.000	0.079	0.500	447.305	8.000
16 GENERAT	16.000	-0.001	12.000	-447.297	8.000	0.000	0.500	447.297	8.000
17 GENERAT	16.000	0.001	14.667	-559.145	8.000	0.006	0.250	559.145	8.000
18 GENERAT	16.000	-0.001	12.000	-559.146	8.000	0.016	0.750	559.146	8.000
19 GENERAT	16.000	-0.001	14.667	-559.130	8.000	0.093	0.500	559.130	8.000
20 GENERAT	16.000	-0.002	14.667	-559.110	8.000	-0.099	0.500	559.110	8.000
21 GENERAT	16.000	-0.001	12.000	-559.097	8.000	-0.007	0.250	559.097	8.000
22 GENERAT	16.000	0.001	14.667	-559.095	8.000	-0.015	0.750	559.095	8.000
23 GENERAT	16.000	-0.000	13.333	-559.112	8.000	-0.093	0.500	559.112	8.000
24 GENERAT	16.000	-0.000	14.667	-559.131	8.000	0.099	0.500	559.131	8.000
25 GENERAT	16.000	-0.001	12.000	-335.472	8.000	0.000	0.583	335.472	8.000

Table 3-Result of Analysis

Cases		Relative direction to wind	Limited values in transverse direction(mm)	Limited values in longitudinal direction(mm)
Settlement	90-degree wind	Down wind	165	112
	90-degree wind	Against wind	68	112
	60-degree wind	Down wind	169	134
	60-degree wind	Against wind	65	80
	Accreted ice	/	129	116
	Installation	/	131	116
Inclination	90-degree wind	Down wind	1578	1703
	90-degree wind	Against wind	1705	1703
	60-degree wind	Down wind	1312	1274
	60-degree wind	Against wind	1661	1811
	Accreted ice	/	1750	1784
	Installation	/	1763	1806

Table 4- Effect of wind on the tower with respect to different angles

Table 4 This table is taken from [2] indicates the different angles of wind striking the tower and thus indicates the values of settlement and inclination for corresponding angles of wind. It can be noted that the 60 degrees of wind can be

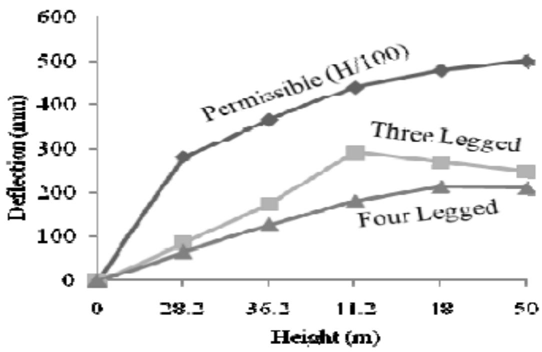

Fig 6- Height v/s Deflection graph

After working on both three-legged and four-legged towers the value difference between these types affects the value of deflection, the effect or difference varies with the elevation of the tower. In the graph, it has been observed that the deflection of the four-legged tower is comparatively less than the three-legged tower.

IV. RESULTS AND DISCUSSION

After designing a transmission tower with a height of 45m and a square base of side 20m each and with two side arms on each side as shown in (fig 1 &2). The designed tower is

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of steel with a yield strength of 500000 KN/m2.

After completing our design various loads (dead load, wind load, cable tension) which are the major factors responsible for the failure of a tower has also been applied to it. Fig. 3 shows the cable tension that has been applied to the nodes of the side arms of the transmission tower with a value of 90KN (in the global +Z & -Z direction). Fig. 4 shows the wind load that has been applied in all the four directions, the WL shows the wind load in the various directions-

WL +X shows wind load acting in positive X-direction.

WL -X shows wind load acting in negative X-direction.

WL +Z shows wind load acting in a positive Z-direction.

WL -Z shows wind load acting in negative Z-direction.

After defining all the wind loads the main thing is to give the properties to the wind load, as shown in fig. 5 firstly we have given the building classification value (Category 1), under this category, the terrain condition is taken as open terrain with few or no obstructions & in which the average height of any object surrounding the structure is less than 1.5m, now as our prime focus was to build a transmission tower near coastal areas and in coastal areas, the obstruction elevation is about 1.5m that's why we've selected category 1, after that we've specified wind speed as 45 m/s, as the wind speed near coastal areas is comparatively large with any other non-coastal areas after that exposure category has been selected (Exposure B), exposure category basically denotes the height of the structure and our tower height is 45m and exposure B is for buildings with height up to 45m that's why we've selected exposure B. And clearly, the tower comes under a trussed structure, that's why the structure type is selected as trussed.

Fig. 6 shows the table showing the deflection of the structure along all the axis due to all loads and combinations of loads.

Fig. 7 shows the table of deflection of foundation due to wind load on the transmission tower, the displaced value is comparatively less but the deflection held in both the directions (transverse and longitudinal), it's like they settled along with deflection which overall further resist the deflection in the foundation.

Fig. 8 shows a graph of the permissible value of deflection which is-

(H/100), H is the height of the transmission tower (in mm), and as our tower height is 45000mm so our permissible value of deflection will be 450mm, now along with it one more thing that the graph depicts and that is that the deflection in three-legged towers is larger as compared to the four-legged tower.

V. OUTCOME OF ANALYSIS

After analyzing transmission tower post-processing analysis it was noticed that the deflection of transmission tower is more due to the presence of wind speed which is high near coastal areas, also we've concluded that there is a slight increase in shear force with a major increment in bending moment. The foundation also has to be made in such a way that it can bear heavy moment that is caused by the wind effect on tower. The ratio of length by width ratio also affects the stability of tower, hence in our transmission tower this ratio is kept at 2.25 (less as possible), and in the end decrement in the value of shear force, bending moment, and deflection was observed.

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