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RELIABILITY ASSESSMENT, STATIC AND DYNAMIC RESPONSE OF TRANSMISSION LINE TOWER: A COMPARATIVE STUDY

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ABSTRACT

The importance of Transmission Line Towers is never underestimated as it plays a very important role in power distribution to various places for several purposes. In this paper, the behavior of a three models of Transmission Towers subjected to both static and dynamic analysis was investigated in detail. A reliability assessment (or analysis) was performed using the "first Order Reliability Method, (FORM 5) to obtain the safest possible angle sections and their respective safety indices. This angle sections were then used to model the 1st transmission tower and the analysis was performed to observe its behavior. The 2nd and 3rd towers were modelled by replacing the angle sections of the 1st model with a similar Pipe and Tube sections having same cross-sectional areas respectively. The static analysis was observed under wind loading and conductor/earth wire load considering all possible parameters that play important role in the analysis. On the other hand, the Response Spectrum Analysis was adopted for the dynamic analysis. Frequencies & Time periods for different mode shapes as well as, spectral accelerations were obtained.

The analysis was carried out using STAAD.Pro and the Indian Standard was considered. The results obtained were critically observed then members were designed for the most economical sections i.e optimum design, considering the fact that the Transmission Line Tower constitutes 28 to 42% of the entire cost of the Transmission Tower.

Keywords: Response Spectra, Reliability Analysis, Dynamic Analysis, Transmission Line Tower.

I. INTRODUCTION

In performing the seismic analysis of transmission towers, the wires and the towers concerned are modelled, respectively, by using the efficient cable elements and the 3-D beam elements considering both geometric and material nonlinearities [1]. However, the increased demand in power supply and changing global weather patterns mean that these towers require upgrading to carry the resultant heavier loading. The failure of a single tower can rapidly propagate along the line and result in severe damage. [2]The supports of EHV transmission lines are normally steel lattice towers. The cost of towers constitutes about quarter to half of the cost of transmission line and hence optimum tower design will bring in substantial savings. [3] One assumption that is often made in transmission tower analysis is that the angle-to-angle bolted connections are pinned. If no rotation between connected members is expected, the joint is traditionally modelled as a rigid connection. In reality, however, the

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connection behaviour lies somewhere in between these two idealizations, possessing some degree of rotational stiffness as a function of the applied load. [4]In transmission line towers, the tower legs are usually set in concrete which generally provides good protection to the steel. However defects and cracks in the concrete can allow water and salts to penetrate with subsequent corrosion and weakening of the leg. [5]

In this paper, the following work has been done;

1. Reliability assessment using FORM 5 to obtain the safest possible angle sections for modelling the tower.
2. Dynamic response of those sections in the tower using 'Response spectrum analyses.
3. To perform the same dynamic analysis on a similar tower with same configuration and area using tube and pipe sections.
4. And finally make a comparative analysis.

II. METHODOLOGY

2.1 Reliability Analysis

The reliability assessment was performed to obtain the safest possible members or sections corresponding the required safety indices. This analysis was carried out using the "First Order Reliability Method (FORM)".

The method of probabilistic calculation in most cases is restricted to the comparison of two quantities, the resistance or strength R, and the load or action S.

The reliability function can be written as:

$$Z = R - S$$

III. COMPUTATION OF SAFETY INDEX

FORM program would be used to compute the safety indices for the Tower(s).

The sections obtained were used to model the tower in order to determine the dynamic response of the tower.

3.1 Stochastic Model Parameters

The stochastic model parameters for different angle sections which are used as inputs to generate the safety indices for each section. These sections should be used for modelling the transmission tower and afterwards, the dynamic analysis should be performed.

The table below gives the stochastic model parameters for L808018

S/NO	Parameter	Mean value (X)	Co-variance	Standard deviation	Statistical model
1.	Strength of steel	250N/mm^2	0.05	12.5 N/mm2	Log Normal
2	Load	12kN/m	0.05	0.6 kN/m	Log normal
3	Flange width	80mm	0.01	0.8mm	Normal
4	Flange thickness	18mm	0.01	0.18mm	Normal
5	Depth of web	80mm	0.01	0.8mm	Normal
6	Web thickness	18mm	0.01	0.18mm	Normal

There are 19 other tables of different angle sections

3.2 Modelling of Tower in Staad.Pro

The modelling of the transmission tower was done using STAAD.Pro software with the safest angle sections obtained from the reliability analysis. For easy comprehension, the following work has been done:

1. The sag tension calculation for conductor and ground wire using parabolic equation.
2. Towers are configured with keeping in mind all the electrical and structural constrains.
3. Loading format including reliability, security and safety pattern is evaluated. Now, the tower is modeled using STAAD.Pro.
4. The wind loading is calculated on the longitudinal face of the towers.
5. Then, the tower is analyzed for dynamic response as a three dimensional structure using STAAD.Pro

Response Spectrum Analysis

The analysis was used to generate the response frequencies, periods and spectral accelerations for the safest sections of the tower obtained from the reliability analysis.

3.3 Generation of Design Lateral Shear Force

The design lateral shear force at each mode is computed by the software in accordance with the IS: 1893 (part 1) 2002, equation 7.8.4.5c and 7.8.4.5d

$$Q_{ik} = A_k \times \varphi_{ik} \times P_k \times W_i$$

The software utilizes the following procedures to generate the lateral seismic loads:

1. User provides the value for $(Z/2) \times (I/R)$as factors for input spectrum.
2. Program calculates time periods for first six modes as specified by the user.
3. Program calculates $S_a/g$for each mode utilizing time period and damping for each mode.
4. The program calculates design horizontal acceleration, for different modes.
5. The program then calculates mode participation factor for different modes.
6. The peak lateral seismic force at each level in each mode is calculated.
7. All response quantities for each mode are calculated.
8. The peak response quantities are then combined as per method (SRSS or CQC) as defined by the user to get the final results.

Load Cases considered for the analysis

Figure 2: Load Case 1 for Self-weight and Conductor/Earth wire load

Figure 3: Wind Load on the Tower

Figure 4: Applied Seismic Load

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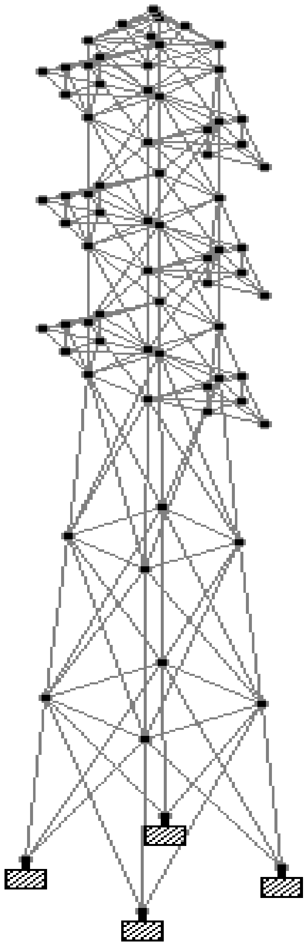

Fig. 1: A typical 3-D Model of a Transmission Line Tower

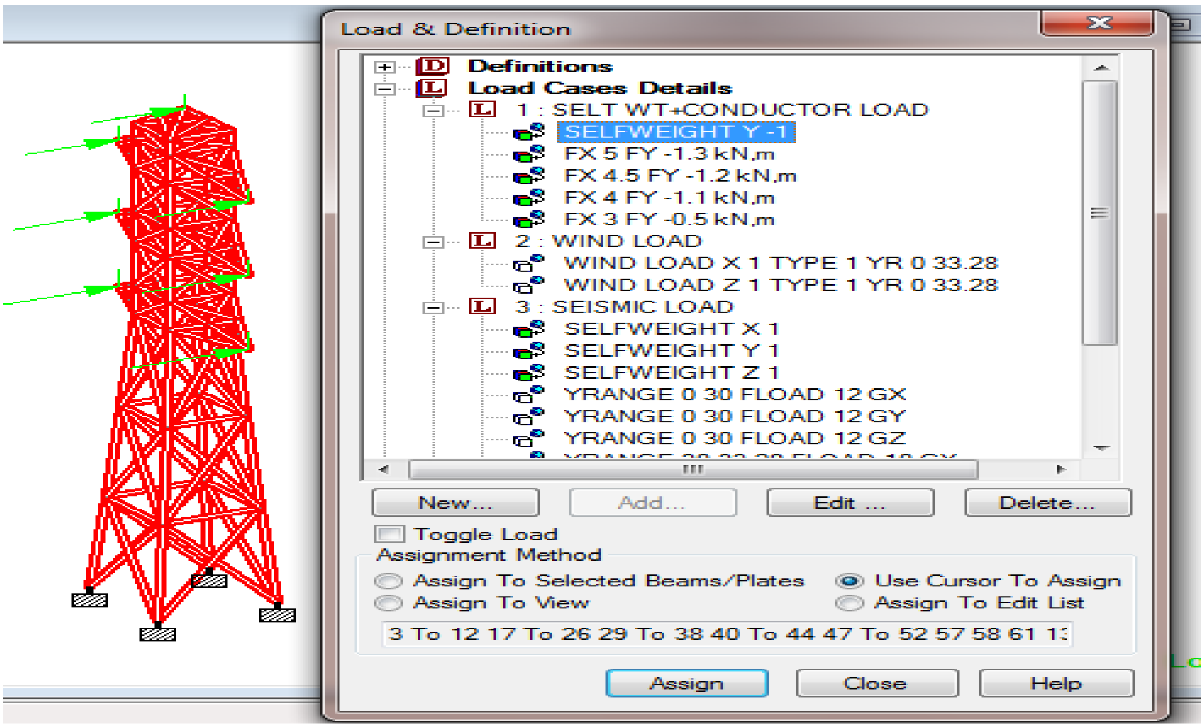

Fig.2: Self-Weight and Conductor/Earth Wire Load

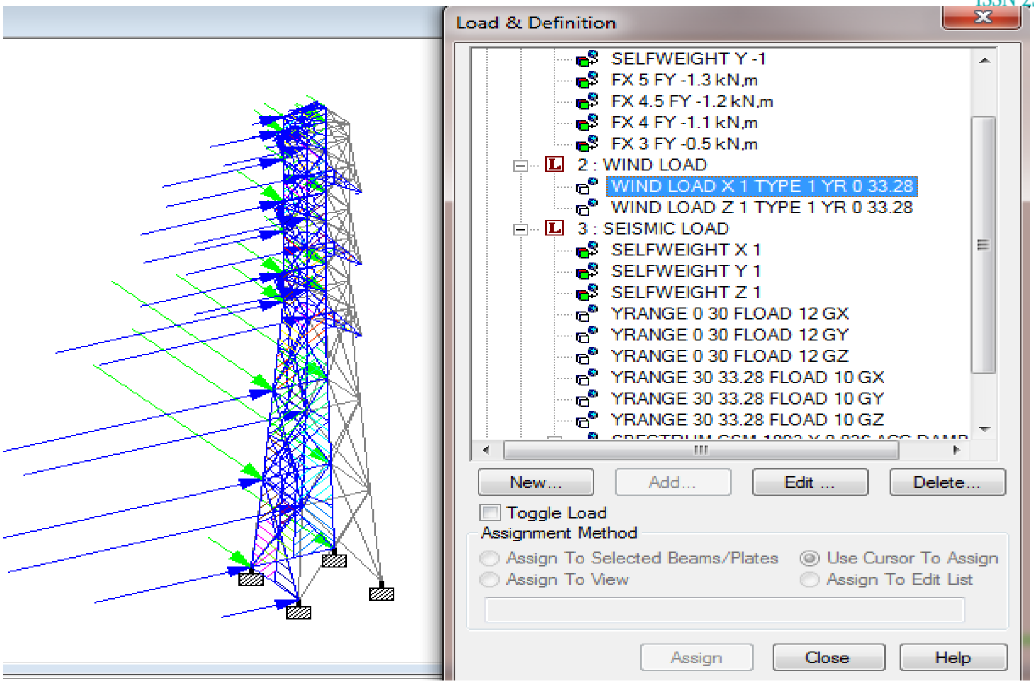

Fig. 2: Wind Load on the Tower

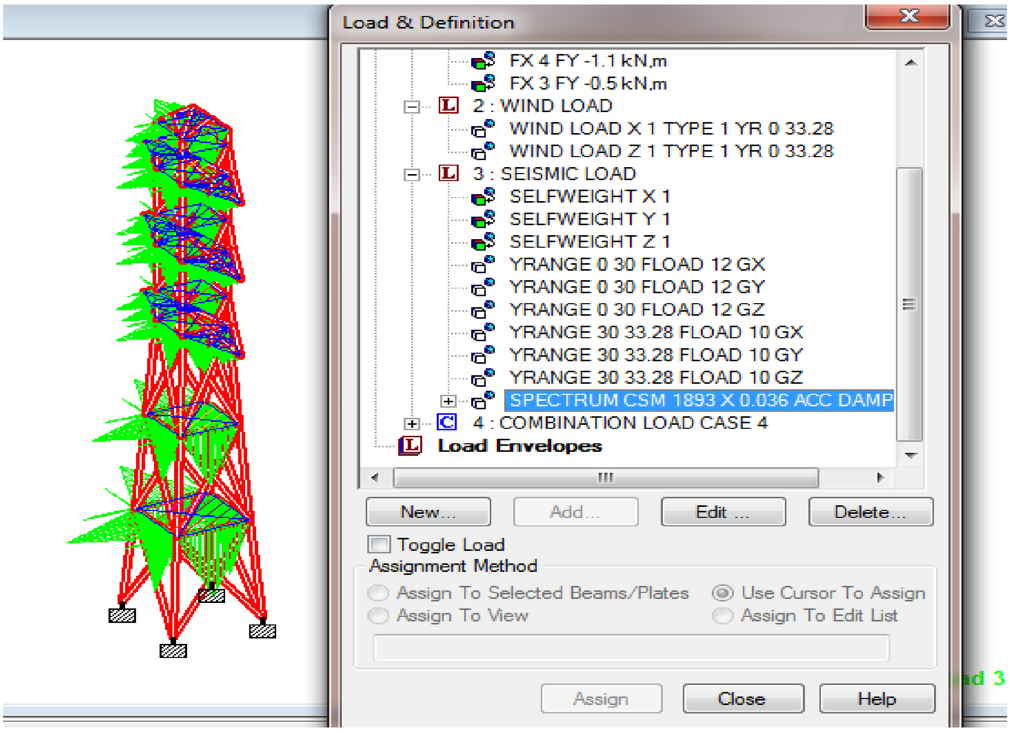

Fig. 4: Applied Seismic Load

IV. RESULTS AND DISCUSSIONS

Below are the results obtained from the reliability analysis and the response of the tower due to static and dynamic loading:-

i. Safest sections and their corresponding safety indices

ii. Maximum Node Displacements.

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iii. Response Frequencies and Periods.

iv. Spectral Acceleration.

v. Optimized weight of Towers

Table 1: Safest Angle Sections and their Corresponding Safety Indices

S/No.	Angle Sections	Safety Index, β
1	L25258	4.31
2	L50506	4.33
3	L35354	4.51
4	L50505	4.90
5	L30253	4.37
6	L40404	4.60
7	L25253	4.78
8	L30304	4.44
9	L35304	4.41
10	L40405	4.41
11	L50354	4.89
12	L60606	4.72
13	L40354	4.33
14	L30303	4.66
15	L25203	4.82
16	L25252	4.90
17	L30254	4.51
18	L50355	4.76
19	L25204	4.88
20	L20205	4.90
21	L20203	4.64
22	L20202	4.85
23	L25205	4.83
24	L60608	4.90
24	L80808	4.55
25	L808018	4.55
26	L808012	4.54
27	L80809	4.53
28	L808010	4.53

Table 2: Sections with their Corresponding Similar Cross-Sectional Areas

S/No.	ANGLE	PIPE	TUBE	AREA (cm2)
1	L25258	PIPS30	TUB25255	14.516
2	L50506	PIPX40	TUB50504	23.284
3	L35354	PIPX5	TUB25254	10.89
4	L50505	PIPS40	TUB45454	19.561
5	L30253	PIPX15	TUB20202	6.445
6	L40404	PIPS27	TUB25253	12.503
7	L25253	PIPX14	TUB20201	5.839
8	L30304	PIPS24	TUB20203	9.277
9	L35304	PIPX4	TUB20203	10.084
10	L40405	PIPS33	TUB35353	15.523
11	L50354	PIPS30	TUB30302	13.31
12	L60606	PIPS28	TUB60604	28.123
13	L40354	PIPS26	TUB20205	11.697
14	L30303	PIPX16	TUB20202	7.052
15	L25203	PIPS15	TUB20201	5.232
16	L25254	PIPX18	TUB20202	7.665
17	L30254	PIPX20	TUB20203	8.471
18	L50355	PIPS35	TUB35355	16.535
19	L25204	PIPX16	TUB20202	6.858
20	L20205	PIPX17	TUB20202	7.445
21	L20203	PIPS15	TUB15155	4.626
22	L20202	PIPS11	TUB15154	3.123
23	L25205	PIPX20	TUB20203	8.458
24	L60608	PIPS63	TUB80803	37.097
25	L80808	PIPS82	TUB80803	50.000
26	L808018	PIPS140	TUB80803	107.961
27	L808012	PIPS100	TUB80803	73.793
28	L80809	PIPS85	TUB80803	56.071
29	L808010	PIPS90	TUB80803	61.993

Table 3: Max. & Min. Nodal Displacements

	Nodal Displacements						
	Max X	Min X	Max Y	Min Y	Max Z	Min Z	Max Rst
	Node 94	Node 1	Node 86	Node 89	Node 94	Node 1	Node 94
Pipe	182.934	0	171.965	172.301	182.934	0	182.934
Tube	203.295	0	191.828	191.381	203.295	0	203.295
Angle	132.218	0	124.277	124.868	132.218	0	132.218

V. RESPONSE SPECTRUM ANALYSIS RESULTS

The diagrams and tables below give all possible response spectra results.

There are six different mode shapes developed for all the towers, but different results.

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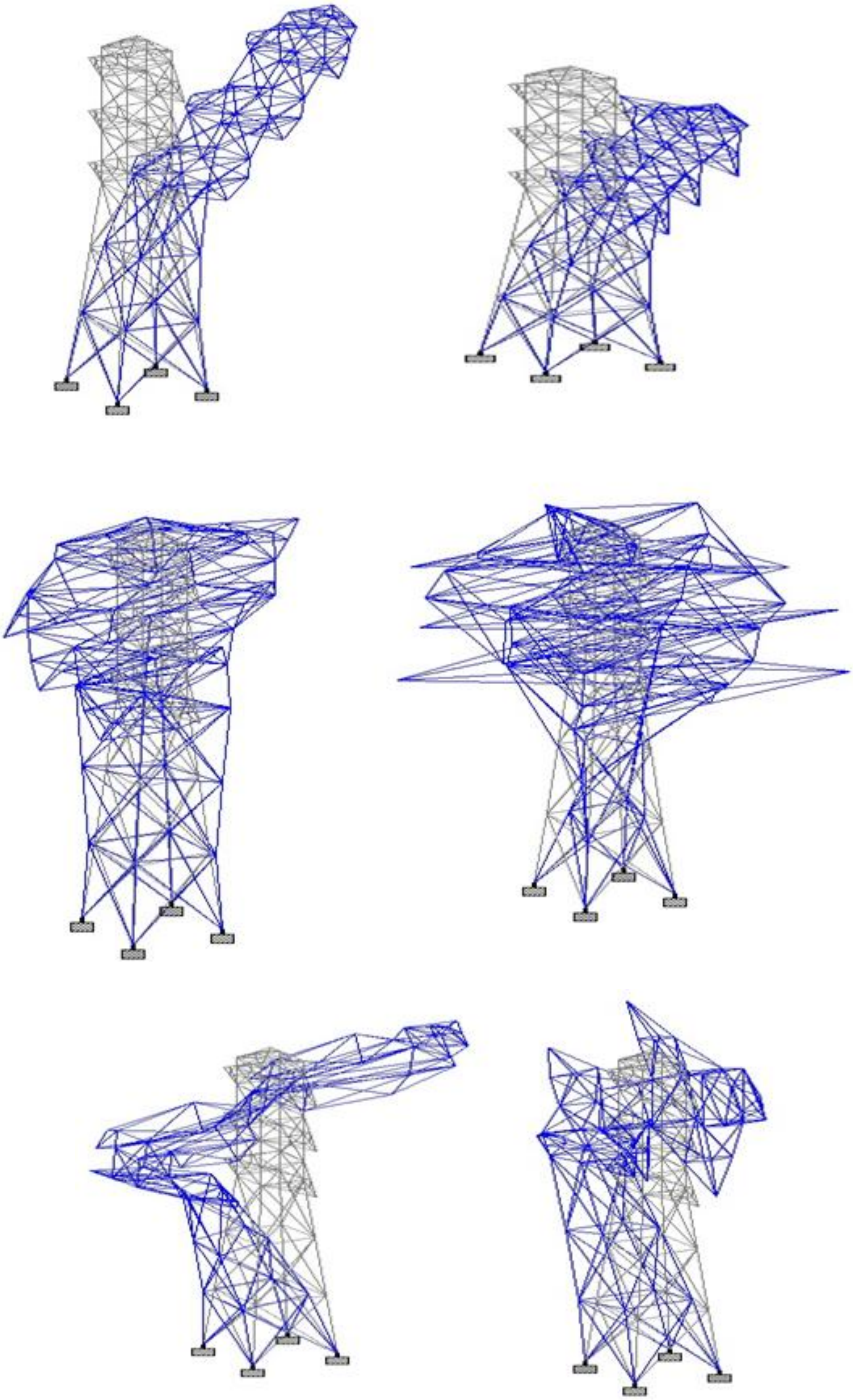

Table 4: Response Frequencies for all three Models of Towers

	Response Frequencies(cyc/sec)		
	Tube	Pipe	Angle
Mode 1	0.607	0.668	0.575
Mode 2	0.669	0.732	0.596
Mode 3	1.377	1.45	1.427
Mode 4	1.743	1.609	2.216
Mode 5	2.348	2.338	2.632
Mode 6	2.63	2.751	2.723

Table 5: Time Periods for all three Models of Towers

	Time Period (sec)		
	Tube	Pipe	Angle
Mode 1	1.6474	1.49603	1.73802
Mode 2	1.49572	1.36546	1.67772
Mode 3	0.72627	0.68951	0.70088
Mode 4	0.57358	0.62168	0.45127
Mode 5	0.42585	0.42776	0.38000
Mode 6	0.38026	0.36351	0.36724

Table 6: Spectral Accelerations for all three Models of Towers

	Spectral Acceleration		
	Tube	Pipe	Angle
Mode 1	0.82554	0.90907	0.7825
Mode 2	0.90926	0.996	0.81063
Mode 3	1.87257	1.97241	1.94043
Mode 4	2.37108	2.18763	2.50000
Mode 5	2.50000	2.50000	2.50000
Mode 6	2.50000	2.50000	2.50000

Table 7: Optimised Weight of Towers

	Optimized Weight of Towers		
Model	Pipe	Angle	Tube
Weight, kg	7889.4	7751.4	7818.1

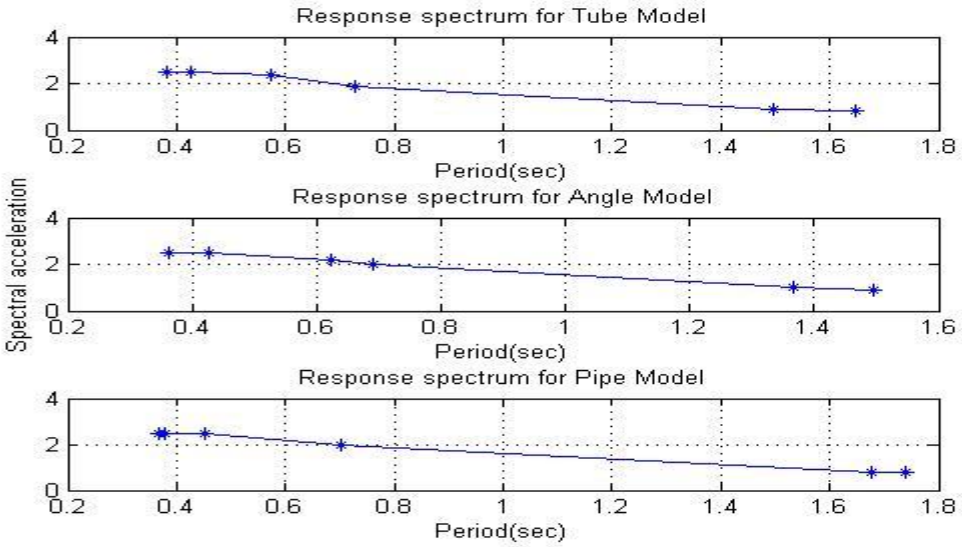

Fig. 6 Response Spectrum Graph

VI. DISCUSSION

The result in Table 1 shows the safest possible angle sections to be used in modelling the transmission tower. These sections have their corresponding safety indices which indicates the selection of that section.

Also available in Table 3 are the comparative results for is the maximum nodal displacements in all three towers indicating precedence in selection of a section over the other.

Additionally, dynamic response of all three towers are as indicted in Tables 4-7 comprising of the response frequencies, periods and spectral accelerations.

The optimized weight of all three towers is also represented in table 8.

Response spectra for all three towers is shown in Figure 4.13. There isn't any significant difference because it is mass dependent. The inertia force is very minimal due to small weight.

VII. CONCLUSION

From the reliability assessment and both static and dynamic analysis on the towers, the following conclusions can be deduced:

i. Angle sections in table obtained in the reliability analysis should be adopted while analyzing a transmission tower of such configuration. L808018, L808012, L808010, L80809, L80809 should be used for the bottom leg members and diagonal members. Some members do require back-back angle sections for rigidity but this should be adopted when there isn't enough space for wide base width.

ii. Angle sections L60606, L50505, L50355, and L40404 should be used for leg members and diagonal bracings just below the hamper level. The remaining sections should be utilized for the cross arms and L35355 should be sued for the diagonal bracing above hamper level.

iii. The nodal displacement as indicated in above shows that the tower with angle sections has the minimum displacements as compared to that of tube and pipe sections.

iv. The support reactions are more predominant in the Y-dr., as a result of the weight of the tower acting downwards. The tube section shows the critical support reaction due to weight.

v. The maximum member end forces are mostly predominant in the X-dr. as well as the tower with angle sections due to its lighter weight.

vi. All mode shapes generated from the dynamic response of the towers do not differ significantly. But nevertheless, however little the difference is, it should never be underestimated for safety.

vii. The response frequency and Period graphs show that the tower with angle sections having the lowest frequency at mode 1 as compared to tower with pipe and tube sections, lags in vibration at the start but increases significantly to the highest frequency i.e., the lowest period of vibration, which makes it more usually adopted than the other two. This implies that, the tower with angle sections absorbs and resists shock (its dynamic response) better than any other section.

viii. Another important conclusion to be deduced is the behavior of all three towers with respect to their respective spectral accelerations. From the chart and table, it can be noted that the spectral acceleration at the beginning of mode 1 started differently, with tower having pipe sections having the highest while that of angle sections having the least, but as it approaches mode 5, it became constant which indicates how it will not change for other mode shapes to be generated.

ix. For safety and economy, the angle section has once again proven its worth as it gives the least optimized weight and also more resistive to shocking from any form of vibration as earlier stated, as compared to the tower with pipe and tube sections.

Angle = 7751.4kg
Pipe = 7889.4kg
Tube = 7818.1kg

x. For construction purposes, the angle section is usually more user friendly, as it has more degrees of freedom due to its angle 90, which makes it to be climbed easily and can also be transported easily.

REFERENCES

[1] Chen, W., Lui, E. (1987). "Effects of Joint Flexibility on the Behavior of Steel Frames." Computers and Structures, 26(5), 7 19-73

[2] F. Albermani, M. Mahendran and S. Kitipornchai “Upgrading of Transmission Towers Using a Diaphragm Bracing System” International Journal Of Civil And Structural Engineering Volume2, No2, 2008.

[3] Gopi Sudam Punse “Analysis and Design of T.ransmission Tower”| IJMER | ISSN: 2249–6645| Vol. 4 | Iss. 1 | Jan. 2014 |116|.

[4] Knight, G. M. S., Santhakumar, A. R (1993). "Joints Effects on Behavior of Transmission Towers." Journal of Structural Engineering, 1 19(3), 698-7 12.

IJARSE
ISSN 2319 - 8354

[5] S.Christian Johnson 1 G.S.Thirugnanam "Experimental study on corrosion of transmission line tower foundation and its rehabilitation" International Journal Of Civil And Structural Engineering ISSN 0976 – 4399 Volume 1, No 1, 2010.

[6] ASCE. (1988). Guide for Design of Steel Transmission Towers, ASCE Manual 52, 2nd edition, New York.