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Static and Dynamic Analysis of Transmission Line Towers under Seismic Loads

Siddu Karthik C S
CADS (M.Tech)4th sem, Dept. of CIVIL
Sri Siddhartha Institute of Technology
Tumkuru, India

G. V. Sowjanya
Assistant Professor, Dept. of CIVIL
Sri Siddhartha Institute of Technology
Tumkuru, India

***Abstract* - Transmission line towers carry heavy electrical transmission conductors at a sufficient and safe height from ground. In addition to their self-weight they have to withstand all forces of nature like a strong wind, earthquake and snow load. Therefore, transmission line towers should be designed considering both structural and electrical requirements for a safe and economical design.**

This report introduces different types of transmission tower and its configuration as per Indian Standard IS-802. A typical type of transmission line tower carrying 220kV single circuit conductors is modelled and analyzed using SAP2000 considering forces like wind load, dead load of the structure, breaking load of the conductors and earthquake load as per Indian Standard IS1893: 2000 (part 1). Here we have considered optimally designed tower, which has the height of 30m which includes the ground clearance (h1), maximum sag of the lower most conductors wire (h2), vertical spacing between the conductor wires (h3) and vertical distance of earth wire from the uppermost conductor wire (h4). The earth wire or ground wire is always located at the top of the transmission tower. It has a square base width of 4.46m.

The type of transmission tower considered here is square based tower having no deviation located on a plain landscape with minimal obstacles. It is located at the wind zone 1 with the basic wind speed of 33m/s. The wind pressure on the tower depends on the gust response factor (GT) which increases with height.

Comparison is made between the transmission towers of different type of bracings and situated at different seismic zones such as Zone II. And the tower is analyzed both statically and dynamically.

The members are designed for maximum Tension and Compression load for the most critical load combination as per code IS802. The Seismic behaviour of the tower for zone 2 has been tabulated and the deflections, axial forces, modal time period and base shear of both types of towers are noted and compared to know which of these is safe.

1. INTRODUCTION

India has a large population residing all over the country and the electricity supply need of this population creates a requirement of a large transmission and distribution system. The use of electric power has become an increasingly important part of the economy of industrial countries. The advancement in electrical engineering shows needs for supporting heavy conductors which led to existence of towers. Towers are tall structures, their height being much more than their lateral dimensions. These are space frames built with steel sections having generally an independent foundation under each leg. The height of the tower is fixed by the user and the structural designer has the task of designing the general configuration, member and the joint details. Electric power generated at power plants is transmitted through Transmission lines supported by transmission line towers. The transmission Lines towers cost about 35 – 45 percent of the total cost of the transmission System. Hence utmost economy has to be exercised in their design and installation.

A transmission line tower is a space –frame and a high order indeterminate structure. Its cost is influenced by its weight. The weight in turn Is influenced by the designer's diligence and his efficient application of the governing specifications. Given the same code in respect of material, ruling Dimension loads, unit stresses, etc., any two competent engineers could produce Designs resulting in structures which are strikingly similar in weight. This similarity is only possible if designers aim at selecting the most economical configuration for the tower and the choice of the various sections is done with the uppermost thought of conserving every kg of steel possible, within the limitations of the specifications consistent with reliability.

The main supporting unit of overhead transmission line is transmission tower. Transmission towers have to carry the heavy transmission conductor at a sufficient, safe height from ground. In addition to that, all towers have to sustain all kinds of natural calamities. So transmission tower designing is an important engineering job where all three basic engineering concepts, civil, mechanical and electrical engineering concepts are equally applicable.

1.1 Objectives

To Find:

- Deflection and Member forces
- Fundamental Time period
- Natural frequency.
- Base shear

Comparison:

- For different bracing of the structure.

Seismic behavior:

- To check the behavior of the tower in seismic zones.

1.2Methodology

- Modeling is done by using SAP-2000
- Seismic analysis
  - Static analysis

    Equivalent static method
  - Dynamic analysis

    Time history method

2. LITERATURE REVIEW

1. Faruq M. A. Siddiqi and John F. Fleming gave a universal routine for calculating the dynamic response of electric transmission cable systems when one or more wires suddenly break, A computer program for doing a time history analysis for the nonlinear system has been broken. The program will compute the wire tensions, the arm loads and the ground line moments at the base of the support structures. A comparison is drawn between the computed solutions and the experimental solutions for a small scale laboratory model. Psychoanalysis of a full scale transmission line system shows that the shock factor as high as 4.5 can be expected due to the dynamic effects. (1)

2. Francis L. Ehasz, in this report presents the results of a study of the distribution of shear and torque in steel transmission towers. In conformity with the request of officials of fabricated Steel construction in the Bethlehem Steel Company, an analytical study of the problem was fixed and checked experimentally at the Fritz Engineering Laboratory of Lehigh University. Four preliminary frames four feet high, and a twenty one foot full sized model tower were investigated and preliminary stresses obtained by various methods from the experimental results were compared with the analytical stresses. (2)

3. G.Visweswara Rao, Worked on “Optimum Designs For Transmission Line Towers” in this a method for the development of optimized tower designs for extra high-voltage transmission lines is presented in the paper. The optimization is with reference to both tower weight and geometry. It is achieved by the control of a chosen set of key design parameters. Fuzziness in the definition of these control variables is also included in the design process . A derivative free method of nonlinear optimization is integrated in the program, especially trained for the configuration, analysis and design of transmission line towers. A few interesting result of both crisp and fuzzy optimization, relevant to the figure of a typical double circuit transmission line tower under multiple loading condition, are presented. (3)

4. Li Tian, Hongnan Li, and Guohuan Liu, in this paper analyzed the conduct of power transmission tower-line system subjected to spatially varying base excitations. The transmission towers are modeled by beam elements while the transmission lines are modeled by cable elements that account for the nonlinear geometry of the lines. The real multi station data from SMART-1 are used to dissect the system response subjected to spatially varying ground motions. The seismic input waves for vertical and horizontal ground motions are also generated based on the Code for Design of Seismic of Electrical Installations. Both the incoherency of seismic waves and wave travel effects are accounted for. The nonlinear time history, analytical method is employed in the analysis. The effects of boundary conditions, ground motion, spatial variations, the incident angle of the seismic wave, coherency loss, and wave travel on the system are looked into. The outcomes prove that the uniform ground motion at all supports of system does not provide the most critical case for the response calculations. (4)

5. Y. M. Ghugal , U. S. Salunkhe worked on “Analysis and Design of Three and Four Legged 400KV Steel Transmission Line Towers. The four legged lattice towers are most usually used as transmission line towers. Three legged towers only used as telecommunication, microwaves, radio and guyed towers, but not employed in the power sectors as transmission line towers. In this study an attempt is cleared that the three legged towers are planned as 400 KV double circuit transmission line tower. The present study describes the analysis and blueprint of two self-supporting 400 KV steel transmission line towers via three legged and four legged models using common parameters such as constant height, bracing system, with an angle sections system are posted out. In this study constant loading parameter including wind forces as per IS: 802 (1995) are brought into account. After analysis, the comparative study is presented with respective to slenderness effect, critical sections, forces and deflections of both three legged and four legged towers. A saving in steel weight up to 21.2% resulted when a three legged tower is compared with a four legged type. (5)

3. GENERAL ANALYSIS REQUIREMENTS OF TRANSMISSION TOWERS

3.1 Loads Acting On Towers:

The rafts on a transmission line tower consist of three mutually perpendicular system of loads acting vertically, normal to the centring of the communication channel and parallel to the centring of the business. In practice it is more beneficial to standardize the manner of loading as given hereunder:

1. Transverse load
2. Longitudinal load
3. Torsional shear
4. Self weight
5. Wind load

3.1.1 Transverse Loads:

The transeverse load consists of loads of the points of a conductor and ground wire support in a direction parallel to the axis of the cross-arms, plus a load distributed over the transeverse face of the structure due to the wind load on the tower. The conductor and ground wire support point loads are built up of the following elements:

i. Wind on the bare conductor/ground wire over the wind span and wind on insulator string

ii. Angular component of cable tension due to an angle in the line

3.1.2 Longitudinal Loads:

Whenever the conductor or ground wire breaks, its force will be to cause unbalanced pull normally in the longitudinal direction which the construction has to withstand. This unbalanced longitudinal pull is called longitudinal load

3.1.3 Vertical Loads:

Vertical load is applied to the ends of the cross arms and on the ground wire peak and consists of the following vertical downward components

1. Weight of bare or ice covered conductors as specified over the governing weight span.
2. The weight of insulators, hardware, etc., embraced with ice if applicable.
3. Arbitrary load to assume care of the weight of a man with tools.

3.1.4 Torsional Shear:

Torsional shear or torsional loads are made when there is unbalanced tension in the conductor on the two sides. This is due to broken wire or due to dead ending of the conductor on single circuit lines and thus causing twisting moments about the central axis of the column.

3.1.5 Wind Load:

Wind loads on all the towers are calculated separately by developing excel programs by following Indian Standards. For determining the drag coefficients for the members of triangular tower, the solidity ratio is derived from Table 30 –IS-875 (part 3)-1987 in the similar fashion as dictated in the IS- 826 (part-1/sec1) -1995.

4. TOWER CONFIGURATION

In present study 220KV ‘A’ type single circuit tower of K type and X type bracing are considered. The following figures shows the 2 different type of towers considered.

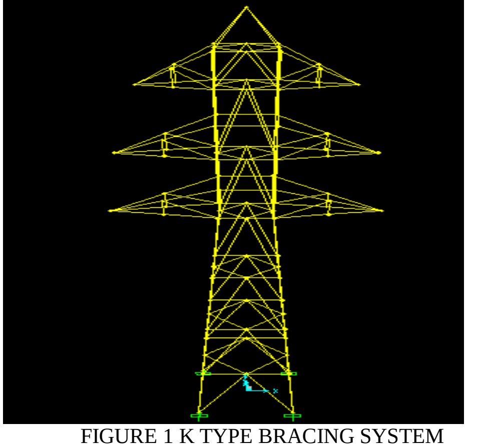


FIGURE 1 K TYPE BRACING SYSTEM

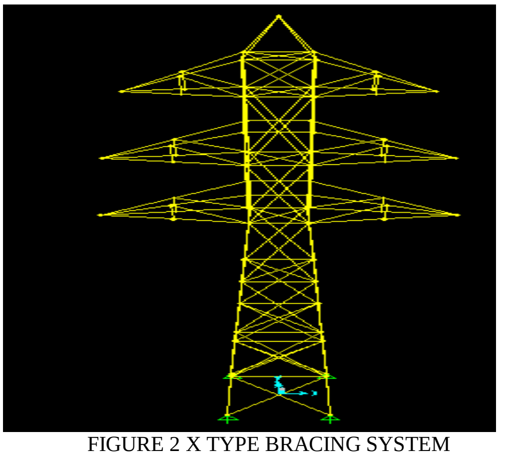


FIGURE 2 X TYPE BRACING SYSTEM

TABLE-1 TOWER DIMENSIONS :

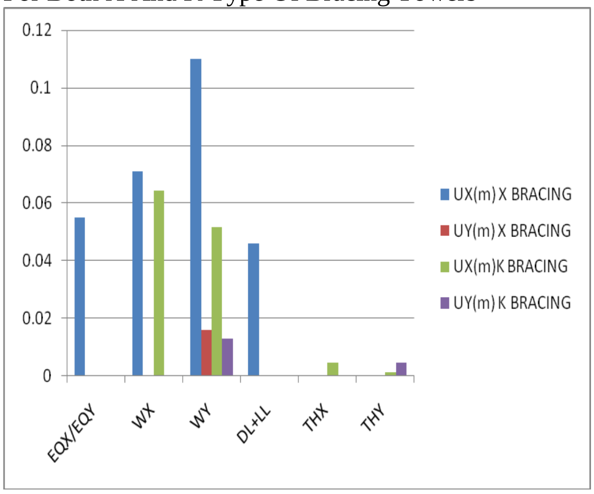
TOWER TYPE	**SQUARE TOWER (K-BRACING)**	**SQUARE TOWER (X-BRACING)**
Base Width	4.46m	4.46m
Hamper Width(L.C.A)	2.00m	2.00m
Hamper Width(U.C.A)	2.00m	2.00m
Height Till (L.C.A)	18.20m	18.20m
Height Till (U.C.A)	28.10m	28.10m
Total Tower Height	30.00m	30.00m

TABLE 2: LOAD CASES CONSIDERED

LOADING CASES NUMBER	TYPE OF LOADING CASES
1	(DL+LL)
2	(DL+LL+W_X)
3	(DL+LL+W_Y)
4	(TIME HISTORY)
5	(DL+LL+EQ_X)
6	(DL+LL+EQ_Y)

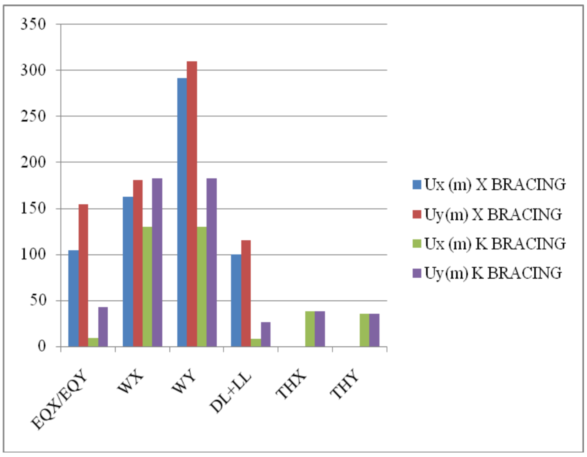
5.RESULTS AND DISCUSSIONS

Figure 3 : Graph Showing Deflections Versus Load Cases For Both X And K Type Of Bracing Towers



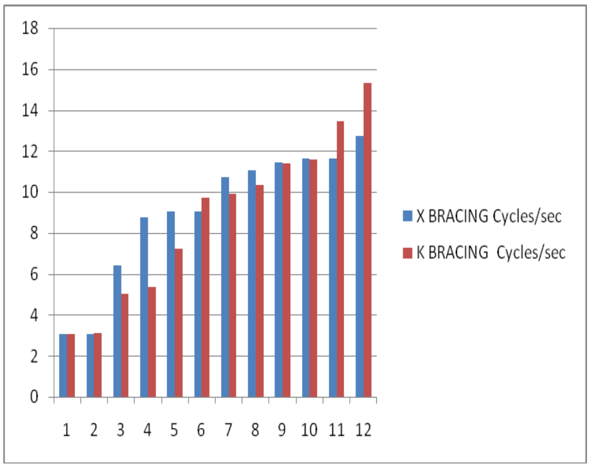
Deflection v/s Load Cases

Figure 2 : Graph Showing Axial Load Versus Load Cases For Both X And K Type Of Bracing Towers



Axial load v/s Load Cases

Figure 5: Graph Showing Frequency Versus Node Number For Both X And K Type Of Bracing Towers



Frequency v/s Mode Number

Table 3:Base Shear Values For K Bracing Type Tower

OUTPUT CASE	GLOBAL FX	GLOBAL FY	GLOBAL FZ
	KN	KN	KN
TH X	0.253	7.797E-07	4.665E-07
TH X	-0.097	-0.000001024	-3.585E-07
TH Y	2.985E-07	0.189	0.000001252
TH Y	-2.685E-07	-0.053	-0.000001437
1.5(DL+LL)	-49.56	-1.415E-12	42
1.2(DL+LL+WX)	-89.333	-2.188E-12	50.4
1.2(DL+LL+WY)	-118.944	-29.877	50.4
1.2(DL+LL+EQX)	-59.472	-1.706E-12	142.811
1.2(DL+LL+EQY)	-59.472	-1.706E-12	142.811

Table 4:Base Shear Values For X Bracing Type Tower

OUTPUT CASE	GLOBAL FX	GLOBAL FY	GLOBAL FZ
	KN	KN	KN
TH X	0.253	7.797E-07	4.665E-07
TH X	-0.097	-0.000001024	-3.585E-07
TH Y	2.985E-07	0.189	0.000001252
TH Y	-2.685E-07	-0.053	-0.000001437
1.5(DL+LL)	-49.56	-1.415E-12	42
1.2(DL+LL+ WX)	-89.333	-2.188E-12	50.4
1.2(DL+LL+ WY)	-118.944	-29.877	50.4
1.2(DL+LL+E QX)	-59.472	-1.706E-12	142.811
1.2(DL+LL+E QY)	-59.472	-1.706E-12	142.811

6.CONCLUSION

1.Study of different load cases on structure is very important to recognize the case that will cause larger deflection in tower model and to say which case will be optimized. Although we have analyzed for seismic conditions , the deflection is governed by wind load case.

2.The towers are provided with angle sections of x and k type bracings where k type bracing tower gives lesser deflections when compared with x type bracing tower.

3.Tower structure with least weight is directly proportional in reduction of the cost. K type bracing tower when completely assigned with steel angles to its members gives least weight comparing x bracing tower.

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