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Dynamic Analysis of Transmission Line Towers

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***Abstract*—**The transmission line towers are one of the important life line structures in the distribution of power from the source to the various places for several purposes. The predominant external loads which act on these towers are wind and earthquake loads. In this present study tower is analyzed using Indian Standards IS: 875:1987(Wind Load), IS: 802:1995(Structural steel), IS:1893:2002 (Earthquake) and dynamic analysis of tower has been performed considering ground motion of 2001 Bhuj Earthquake (India). The dynamic analysis was performed considering a tower system consisting two towers spaced 800m apart and 35m height each. This analysis has been performed using numerical time stepping finite difference method which is central difference method were employed by a developed MATLAB program to get the normalized ground motion parameters includes acceleration, frequency, velocity which are important in designing the tower. The tower is analyzed using response spectrum analysis.

***Keywords*—** Response Spectra, Dynamic Analysis, Central Difference Method, Transmission Tower.

I. Introduction

STUDIES from the 1995 Kobe (Japan) and the Northridge 1994 earthquake (California), mentioned transmission towers were damaged primarily due to seismic activity leading to the damage of system and foundation failures. These studies, state the importance of earthquake analysis for transmission line towers although they are wind predominant structures. In this present study, Bhuj 2001 earthquake ground motion which resulted in magnitude of 7.7 was considered for the dynamic analysis of the tower [4], [5]. The tower is modeled as per the Indian electricity rules for the clear spacing and various parameters [10]. Wind span of the structure is assumed to be 800m. The data which are considered for the analysis are mentioned and detailed in Tables I & II with the specification details. The tower leg members are connected by using XB bracing system [2]. The structure is modeled using angle sections, Leg members: 150x150x10mm, horizontal members: 110x110x12mm, bracings: 100x100x10mm [11].

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TABLE I
DETAILS OF THE STRUCTURE CONSIDERED

Type of tower	Tangent Tower
Load carrying capacity	132 kN
Type of circuit	Single Circuit
Conductor [8]	Panther ASCR 30/7
Ground wire [8]	Galvanized Steel (6/4.09 mm)
Ruling Design span	800m
Temperature Variation:	5 – 60o/C
Coefficient of linear expansion:	$17.8\text{x}10^{-6}$ deg/C
Sag length for 800m [3]-[9]	7.26m

II. Clearances between the Components of Tower (Elevation)

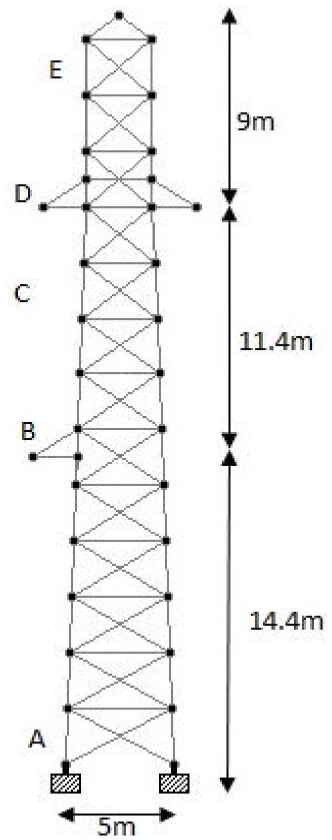

Fig. 1 Geometry of the Transmission Tower Considered in the Present Study

TABLE II
WIND AND EARTHQUAKE DATA CONSIDERED

Wind Data	Earthquake Data
Tower location: Bhuj, Gujarath, India.	Tower location: Bhuj, Gujarath, India
Wind speed: 50 m/s[7]	Ground Motion : 2001 Bhuj Earthquake
Design wind Pressure : 995.224N/m^2	Zone & Zone factor: V, 0.36 [12]

III. Analysis

In this analysis the various loads such as vertical loads which includes weight of tower structure, fittings, power conductors, ground wire and lateral loads like wind and earthquake loads, Longitudinal loads are due to unbalanced pull due to broken conductor, ground wire were considered. For dynamic analysis, the finite difference approximation method such as central difference method (CDM) is employed considering the time step interval of 0.02sec [1]. Using the algorithm of CDM, MATLAB [14] program has been written for the time derivatives of displacement such as Acceleration and Velocity. The normalized ground motion of 2001 Bhuj earthquake ground motion were plotted and obtained as shown in Fig. 2. Transmission tower analysis has been performed using the standard software package STAAD. Pro [13] by inputting generated acceleration. Using the dynamic equation of motion [1],

$$m\ddot{u}_i + c\dot{u}_i + ku_i = p_i \quad (1)$$

and substituting equations given below are considered for dynamic analysis to generate acceleration of the ground motion.

Refer to (1), where

$$\ddot{u}_i = \frac{u_{i+1} - 2u_i + u_{i-1}}{(\Delta t)^2} \quad (2)$$

$$\dot{u}_i = \frac{u_{i+1} - u_{i-1}}{2\Delta t} \quad (3)$$

where displacement at each incremental step,

$$u_{i+1} = \frac{\hat{p}_i}{\hat{k}} \quad (4)$$

$$\hat{p}_i = p_i - au_{i-1} - bu_i$$

$$\hat{k} = \frac{m}{(\Delta t)^2} + \frac{c}{2\Delta t}$$

where a, b represents constants in time stepping

$$a = \frac{m}{(\Delta t)^2} - \frac{c}{2\Delta t}$$

$$b = k - \frac{2m}{(\Delta t)^2}$$

Initial acceleration at time step 0 represented by $\ddot{u}_0$,

$$\ddot{u}_0 = \frac{p_0 - c\dot{u}_0 - ku_0}{m} \quad (5)$$

Displacement,

$$u_{-1} = u_0 - \Delta t\, \dot{u}_0 + \frac{(\Delta t)^2}{2}\, \ddot{u}_0 \quad (6)$$

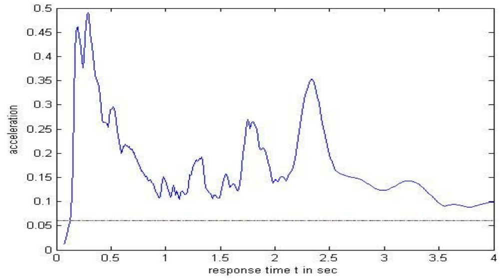

Fig. 2 Acceleration Spectra Bhuj (2001) ground motion

IV. Results

TABLE III
WIND FORCE ON WINDWARD AND LEEWARD SIDE OF THE STRUCTURE [6]

Height (m)	Wind Force on member on windward side (kN)	Wind Force on member on Leeward side (kN)
2.6	3.41	2.39
5.2	3.31	2.32
7.8	3.21	2.25
10.4	3.13	2.19
13	3.14	2.2
15.6	3.15	2.20
18.2	3.16	2.21
20.8	3.13	2.19
23.4	3.05	2.14
26	2.97	2.08
28.6	2.95	2.07
31.2	2.97	2.09
33.8	3.17	2.21
35	0.78	0.55

TABLE IV
DETAILS OF WIND, BREAKING, VERTICAL LOAD ON CONDUCTOR AND GROUND WIRE

Level (m)	Wind Load on conductor (KN)	Wind Load on Ground Wire (KN)	Breaking Load (KN)	Vertical Load (KN)
15.6	28.26	22.84	89.67	9.74
26	31.2	25.23	89.67	9.74
35	32.86	26.56	29.91	3.94

Using central difference method, forces obtained by performing dynamic results in the various members are listed considering the typical sections at A, B, C, D, E of the transmission tower shown in Fig. 1 are tabulated in Table V.

TABLE V
FORCES CONSIDERING BREAKING LOAD AND WITHOUT BREAKING LOAD

Section	Axial Force (kN) Breaking Load	Axial Force (kN) without breaking Load
A	1600	522.83
B	147.20	42.49
C	416.26	164.77
D	57.62	39.77
E	42.06	23.74

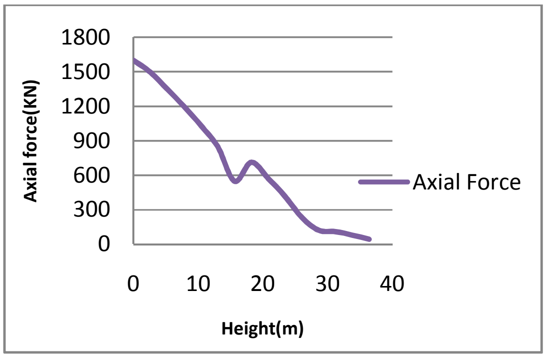

Fig. 3 Axial force considering Breaking Load

The frequency, time period of the structure for the first 6 modes are listed in Table VI and also the mode shapes are represented in Fig. 4.

TABLE VI
TIME PERIOD AND FREQUENCY

Mode Number	Time period(sec)	Frequency (cycles/Sec)
1	0.810	1.23
2	0.375	2.66
3	0.219	4.54
4	0.090	11.01
5	0.088	11.36
6	0.054	18.25

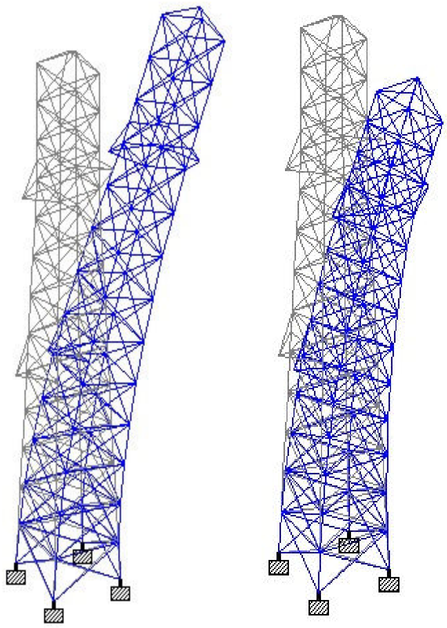

Fig. 4 (a) Mode1 Fig. 4 (b) Mode 2

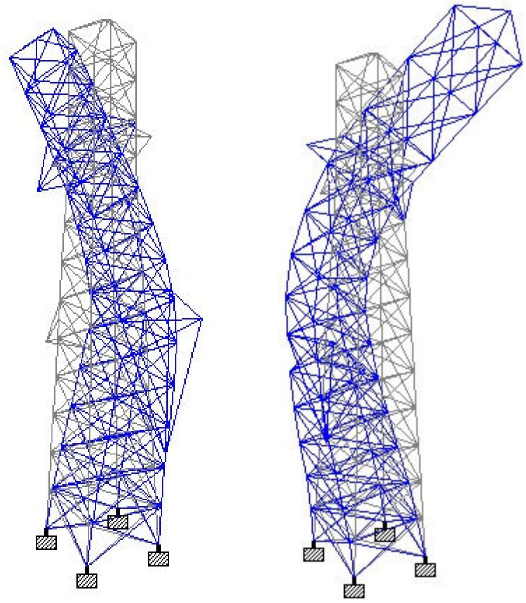

Fig. 4 (c) Mode3 Fig. 4 (d) Mode 4

Fig. 4 Mode Shapes of Transmission Tower

V. CONCLUSION:

In this present study, the analysis is carried out considering all the different loads such as vertical loads, lateral loads and longitudinal loads with the combinations specified as per Indian standards, resulting breaking load as the critical combination among the forces developed in the structure. Studies on the transmission tower also stated that the failure of leg members makes the structure more susceptible to damage. So, from this analysis it observed that the maximum axial force in the leg members is 1600kN considering the breaking load combination and the axial force is reduced to 522.382kN without considering breaking load. As the tower is assumed to be in the central span of equal distances between the adjacent towers, the breaking load will not be the major criteria for design of elements. Though dynamic analysis is performed, wind is the predominant load on these tall structures.

NOTATIONS

$\ddot{u}_I$ = acceleration at time i
$\dot{u}_I$ = velocity at time i
u_i = displacement at time i
Δt = time step
$k\hat{}$ =stiffness parameter
i = incremental time step

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