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Finite element analysis of hyperbolic cooling tower by the concept of equivalent plate

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Abstract-*This paper deals with the study of hyperbolic cooling tower of 175m high above ground level. This cooling tower has been analyzed for wind load using ANSYS software by assuming fixity at the shell base. For this analysis a single case of the tower with alternative 'I' and 'V' supports is taken up. The wind load on this cooling towers has been calculated in the form of pressure by using the circumferentially distributed design wind pressure coefficients as given in IS: 11504-1985 code along with the design wind pressures at different levels as per IS:875 (Part 3)- 1987 code. The analysis has been carried out using & 4-noded shell element (SHELL181). The vertical distribution of membrane forces along* 0^0*and the circumferential distributions at base, throat and top levels have been studied for the cooling tower.*

Key words: cooling tower, wind loads, membrane forces, bending moments.

1. INTRODUCTION

The natural draught cooling tower is a very important and essential component in the thermal and nuclear power stations. Due to their complexities in geometry and the spectacular failure of cooling tower at Ferry Bridge in England in 1965, and at Ardeer in Scotland in 1973, have attracted attention of many researchers throughout the world. In the absence of earthquake loading, wind constitutes the main loading for the design of natural draught cooling towers. A lot of research work was reported in the literature on the wind load on cooling tower.

The finite element analysis of hyperbolic cooling tower under quasi-static wind load [1], using a constant meridional curvature element and semi-loof shell elements. Busch, *et al.*, [2] demonstrated the optimization of a 200m high natural draught cooling tower by varying the height of throat and inclination of the meridian in reducing the stress due to wind load. The load bearing behavior was observed to be best when the meridian curvature increases continuously from the bottom to the throat and by avoiding an abrupt change of curvature above the throat, as far as possible. The towers in practice are supported either by I column system or V column system. In reference [3], a tower of 175m height has been considered with this alternative supporting system. The analysis has been carried out using 8-noded shell element (SHELL 93) with 5 degrees of freedom per node [4], by using two cooling towers of 122m and 200m high above ground level. Comparative study of effect of wind load and seismic load on A-Frame and H-Frame column supported cooling tower is done [6] by plotting stress and strain contours.

2. DESCRIPTION OF TOWERS

The geometry configuration of cooling tower shell is defined by,

$$r = \Delta r + a\left[\sqrt{1+\frac{(z-125)^2}{b^2}}\right] \quad \text{………………} \ (1)$$

Where, r is radius of tower shell at a height 'z' (m). The parameters a, b, Δr are, as per table 1.

Table 1: Basic Data for Cooling Towers

Height (z)	9.17m-125m	125m-176m
a	51.9644	0.2578
b	113.9896	8.0293
Δr	-15.3644	36.3422

The profiles of the towers are as shown in fig.1.
All the elevational details i.e. height of tower, indicated in the following fig. 1, are in meters.
Material properties of concrete considered are:
Young's modulus (E) = 3.4 x 10^7 kN /m^2, Poisson's Ratio (ν) = 0.167, Density of RCC= 23 kN / m^3.

3. FINITE ELEMENT MODELING

The finite element analysis of the cooling towers has been carried out using ANSYS software. The shell element is the most efficient element for the solution of shells having the arbitrary geometry and it accounts for both membrane and bending actions. The analysis has been carried out using 4-noded shell element (SHELL 181). The height is 175m and the thickness of the shell changes from 105cms at the lintel level through 20cms at the top of tower. There are 18 column supports at the base of the tower. The c/s of the columns is 90cms x 90cms. In the present study, only shell portion of the cooling towers has been modeled and 18 columns are kept fixed for all the six degrees of freedom (u, v, w, θx, θy, θz) and the models of structural system has been analysed for its self weight and it has been analysed for the effect of wind load.

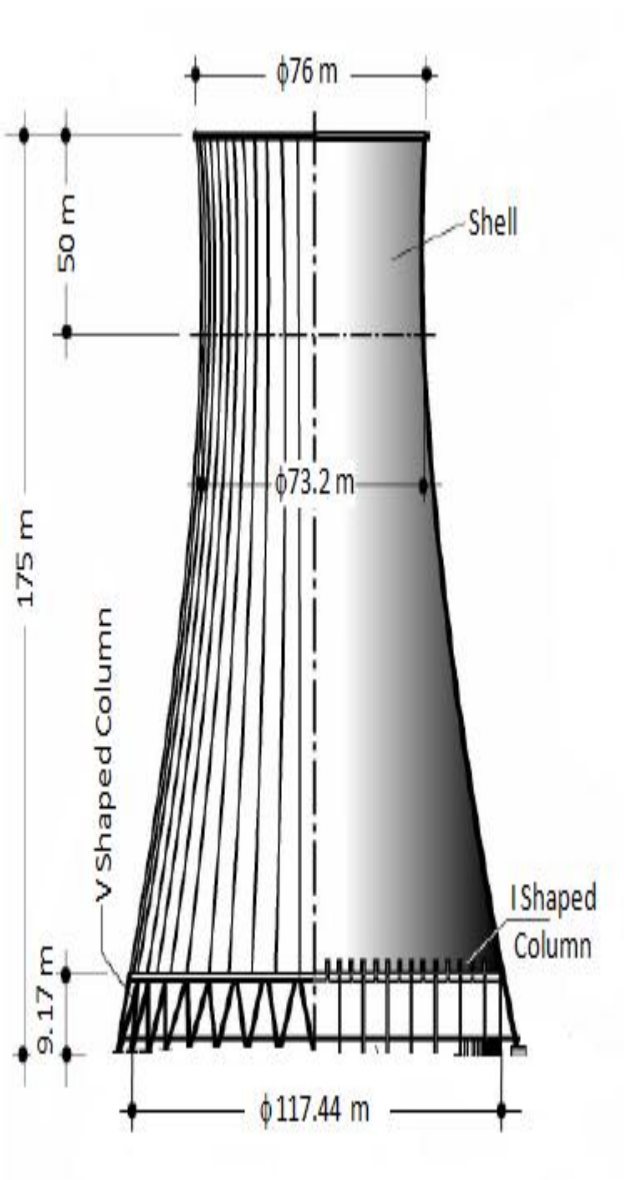

Fig.1: Profile of Cooling Tower

4. WIND LOAD

The wind pressure distribution on the outside of the shell is assumed to be symmetrical about the centre line in the direction of wind. The circumferential pressure distribution can be represented by a Fourier cosine series of the form as given below:

$$P' = \sum_{n=0}^{7} F_n \cos n\theta$$

$$= F_0 + F_1 \cos\theta + F_2 \cos 2\theta + \cdots + F_7 \cos 7\theta \text{...} \quad (2)$$

Where,

P' = pressure coefficient

n = harmonic number

θ = horizontal angle measured from the windward meridian and

F_n = harmonic constants = [0.00071, 0.24611, 0.62296, 0.48833, 0.10756, -0.09579, -0.01142].

The same distribution has been used at all the levels along the height of the tower. The design wind pressure at any height above ground level has been obtained by using the following relationship between wind pressure, $P_z(N/m^2)$, and the design wind velocity, $V_z(m/s)$:

$P_z = 0.6V_z{}^2$ .... (3)

The coefficient 0.6 in Eq. (3) is dependent on atmospheric pressure and ambient air temperature. The basic wind speed for the design of the cooling tower is obtained from the basic wind speed, V_b, and by including the following factors: (1) risk level, (2) terrain roughness, (3) height and size of structure and (4) local topography. It can be mathematically expressed as:

$V_z = V_b k_1 k_2 k_3$ .... (4)

Where,

V_b = basic wind speed which is specified for different zones of the country

k_1= Probability factor (risk coefficient) based on the statistical concepts which take into account the degree of reliability required and the time period of wind exposure i.e., the life of the structure

k_2 = The terrain height and structure size parameter that gives the multiplying factor by which the basic wind speed shall be multiplied to obtain the wind speed at different heights in each terrain category for different sizes of buildings and structures.

k_3 = The topography factor

5. CONCEPT OF EQUIVALENT PLATE THICKNESS

The equivalent plate thicknesses for the column supports are based upon a consideration that the vertical deflection at the top of the tower remains same as the once due to column support wherein only the influence of the self weight is considered. As the complete development of the software for analysis of various types of elements is employing exclusively the plate elements therefore it was considered more practical to transform the column supports in the towers for equivalent plates. For this the influence of the self weight was considered by analysing the tower structures with columns and plate combinations. The vertical displacement at the top was determined through this analysis. With this kind of idealizations numbers of trials are taken to arrive at the plate thickness which would produce the same vertical deflection as was found out for the column plate systems. In this manner the equivalent thickness 't' for the 'I' column supports was derived equal to 0.080m and for 'V' column support it was derived equal to 0.075m. To ascertain the validity of this kind of alternative formulation for carrying out the further kind of analysis the influence of the wind loads is examined for both the column plate system and the equivalent plate system. In the Fig.2.1 presented below 'x' axis indicates elevational height in meters, while 'y' axis indicates the displacement due to wind load in meters.

6. WIND ANALYSIS

For wind load analysis geometry of the model is created in ANSYS .V.14.0 by using key points. The material properties and element type assigned to model & mesh generation is done in Pre- processor. By assigning the loads & boundary conditions and input the Pressures alongside to the model and solve the problem in solution & read the results in General post processor.

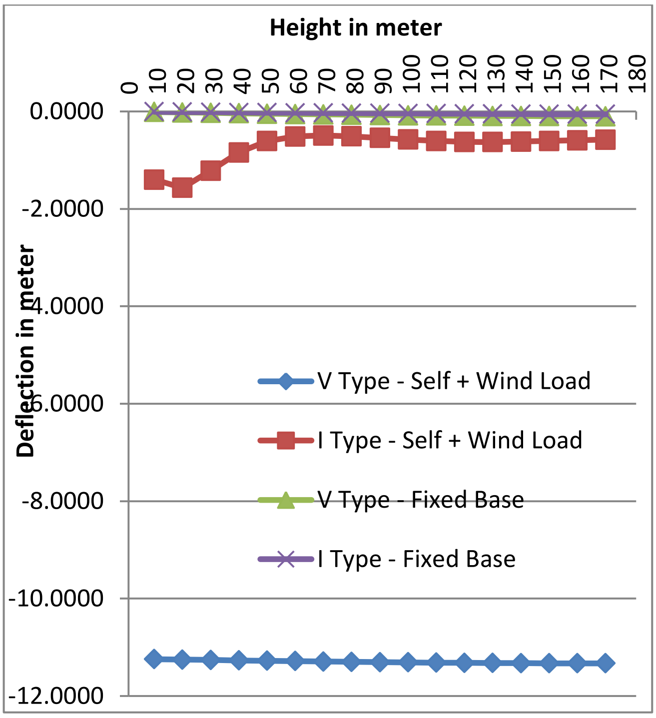

Chart-1: Comparison Of Defelction Due To Wind For Column & Eq. Plate System For Both 'I' & 'V' Support Types

Models of wind load analysis are,

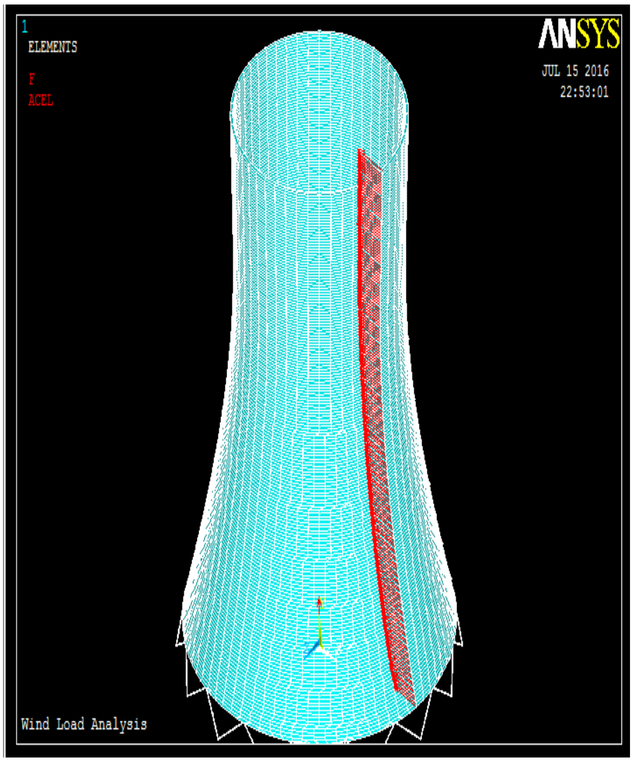

Fig.2: Wind Pressure Application

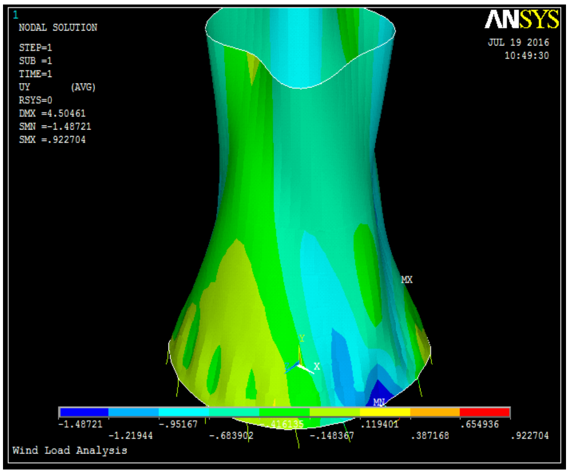

Fig.3: 'I' Support Self weight + Wind

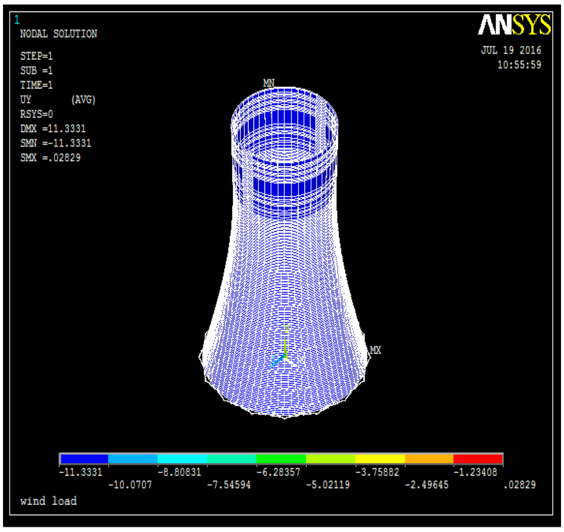

Fig.4: 'V' Support Self weight + Wind

7. SUMMARY AND CONCLUSIONS

1. For all loading conditions the displacement is more in 'V' support models than the 'I' support models.

2. The 'V' support cooling tower structure is more flexible structure compared to the 'I' supports cooling tower.

3. The Distortion is minimum at bottom part of shell due to fixed base & maximum at top part of shell.

4. The deflected profile patterns changes as the loading conditions and element changes.

5. The 'V' supports gives 90.89% more sway than 'I' supports at top level of the cooling tower in the case of column supports.

6. The 'V' supports gives 91.76% more sway than 'I' supports at throat level of the cooling tower in the case of column supports.

7. Equivalent plate thickness for 'I' support shell is 0.080m & for 'V' support is 0.075m.

8. The equivalent shells provide identical deflected profiles for the application of the wind loads, as those due to column supports, so the equivalent shell is proposed as an alternative structural system for the cooling towers having column supports.

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