© 2017 IJSRSET | Volume 3 | Issue 5 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Response Study of Support Systems of Hyperbolic Cooling Towers

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ABSTRACT

This paper deals with the study of hyperbolic cooling towers having a total height of 175 m supported on 'I', 'V' and 'H' Geometrical Column systems. The modelling of the column was carried out in STAAD-Pro software for wind load, seismic load, self-weight, dynamic loading and harmonic loading. The tower was divided into 4-noded shell elements. Finite element analysis was used for carrying out the analysis of the cooling towers. The study of the different support systems for various aspects like reinforcement, linear elastic response, and elasto-plastic analysis was carried out to make a comparative conclusion for the optimum design of the cooling towers.

Keywords: Natural Draught Hyperbolic cooling Towers, wind load, seismic load, self weight, dynamic loading, harmonic loading, 4-noded shell elements

I. INTRODUCTION

A cooling tower is a heat rejection device that rejects waste heat to the atmosphere through the cooling of a water stream to a lower temperature. Common applications include cooling the circulating water used in oil refineries, petrochemical and other chemical plants, thermal power stations and HVAC systems for cooling buildings. Cooling towers vary in shape and size like circular, rectangular and hyperboloid.

Why is hyperbolic shape preferred?

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The most common sight, especially in power plants and nuclear plants, is hyperboloid-shaped cooling towers. The hyperboloid shape impacts the strength of the entire structure. Since cooling towers are supposed to cool the working fluid down to a low temperature, they release vapours into the atmosphere through the opening at the top of the tower. Therefore, these towers have to be sufficiently tall (they can be as tall as 200 meters), or else the released vapour may cause fogging or recirculation. To support such a high structure, it is extremely important that the base is considerably consolidated and spread over a large area so that it can support the tall, heavy structure above it. This is why cooling towers have a large, circular base.

Hyperbolic shape helps in facilitating aerodynamic lift and ensures faster and more efficient diffusion in to the atmosphere. There are also some other reasons behind the usage of this shape. For example, a wide base not only provides strength to the whole structure, but also offers ample space for the installation of machinery. From a logistical standpoint, this shape is easier to build, as it employs a lattice of straight beams to erect the tower. Also, this type of structure is more resistant to external natural forces than straight buildings.

Types of Support:

- Inclined support/V support- supporting columns are placed equidistant and the adjacent top of the column are connected.
- Vertical Support/I support- Supporting columns are placed equidistantly.
- Vertical Support with bracing/ H support- Supporting columns are placed equidistantly with bracings provided at mid-height of the column.

II. HYPERBOLIC COOLING TOWER MODEL

A. Introduction

The towers in practice are supported either by I column system, V column system or H column system. In reference, a tower of 175m high has been considered with this alternative supporting system. It is obvious that by taking up the investigation of these towers an additional benefit occurs in the manner of comparison of the relative effectivity of these alternative support systems. In view of this, the data pertaining to these towers has been used herein for investigations.

B. Description of Towers:

The geometric configuration R/C cooling shells is defined as follows (Hara 2004):

$$\boldsymbol{r} = \Delta\boldsymbol{r} + \boldsymbol{a}\sqrt{\mathbf{1} + \frac{(\boldsymbol{z}-\mathbf{125})^2}{\boldsymbol{b}^2}} \qquad \textbf{.....(1)}$$

Where,
r = radius of the shell at height z (m)
Parameters a, b and Δr are shown in table 4.1
The radius and the thickness of R/C shell are presented in Table 4.2

Table 4.1 Configuration parameters

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

Table 4.2 Radius and Thickness of shell

	Lintel (m)	**Node (m)**	**Top (m)**
Height(z)	9.17	125	175
Radius(m)	58.7199	36.6	41.37924
Thickness(m)	1.05	0.245	0.2

Table 4.3 Mean Radius And Thickness Details

Height (m)	**Mean Radius (m)**	**Thickness (m)**
0	61.755	0.9 sq/cs
1.834	61.139	
3.668	60.528	
5.502	59.920	
7.336	59.318	
9.170	58.719	1.050
14.195	57.105	1.015
19.220	55.527	0.980
24.245	53.989	0.945
29.270	52.493	0.910
34.295	51.043	0.875
39.320	49.642	0.840
44.346	48.292	0.805
49.371	46.997	0.770
54.396	45.760	0.735
59.421	44.585	0.700
64.446	43.476	0.665
69.471	42.437	0.630
74.496	41.471	0.595
79.522	40.583	0.560
84.547	39.775	0.525
89.572	39.051	0.490
94.597	38.416	0.455
99.622	37.872	0.420
104.647	37.421	0.385
109.673	37.067	0.350
114.698	36.811	0.315
119.723	36.655	0.280
124.748	36.600	0.245
129.773	36.645	0.240
134.798	36.791	0.236
139.823	37.037	0.231
144.849	37.382	0.227
149.874	37.822	0.222
154.899	38.358	0.218
159.924	38.984	0.213
164.949	39.699	0.209
169.974	40.498	0.204
175	41.379	0.200

C. Finite Element Idealizations:

Employing both 4-noded plate elements develops the finite element idealization for both the towers. In this, 36 elements in hoop direction and 34 elements in meridional direction are provided. The height is 175m and the thickness of the shell changes from 105cms at the lintel level through 20cms at the top of tower. In the meridional direction, the model has the mean radii and the shell thicknesses at various elevations.

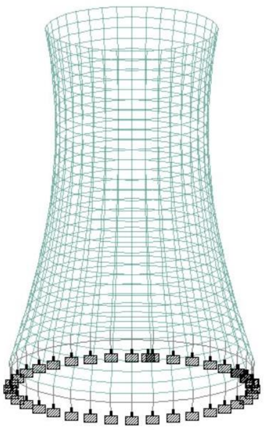

Fig. 1 ‘I’ Type Support

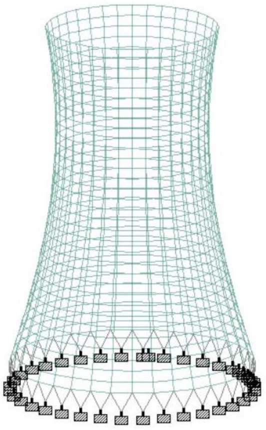

Fig. 2 ‘V’ Type Support

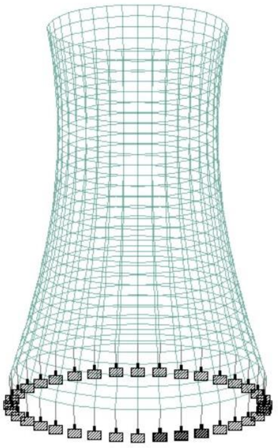

Fig. 3 ‘H’ Type Support

III. METHODOLOGY

The geometry is constructed in STAAD PRO. The height of the tower is 175m. The entire tower is divided in intervals of 5.02 m along its height. Also, it is divided in equal angle intervals of 10°**.** Beam elements are used to draw beams at the column height level. The Column height is 9.17m. 4-noded plate elements are used. Prismatic properties are specified. Columns are rectangular sections 300mm*300mm.

A. Loadings

The geometry is loaded with self-weight, Earthquake loads (Seismic) & wind.

1. Dead Load:

Self-weight of structure is considered in this type of loading. The dead load multiplier for the structure is taken as 1.5.

2. Earthquake load:

Loading is as per IS: 1893 2002.
Tower is located in Nagpur.
Damping ratio is taken as 5%. The tower is situated on hard strata. To find the base shear following equations are used:

$$Vb = W * Ah \qquad .... (2)$$

$$Ah = \frac{Sa * I * Z}{g * R * 2} \qquad ...(3)$$

Where,

$\frac{Sa}{g}$ = Average acceleration coefficient (Refer clause 6.4, pg no.16, IS: 1893-2002)
I = Importance Factor (refer clause 6.4.2, pg no.17 IS: 1893-2002)
R = Response Reduction Factor (refer clause 6.4.2, pg no.17 IS: 1893-2002)
Z= Zone Factor (refer clause 6.4.2, pg no.19, IS: 1893-2002)

In our case,

Ah= (0.1*1.5*1.1214/5*2) = 0.0168

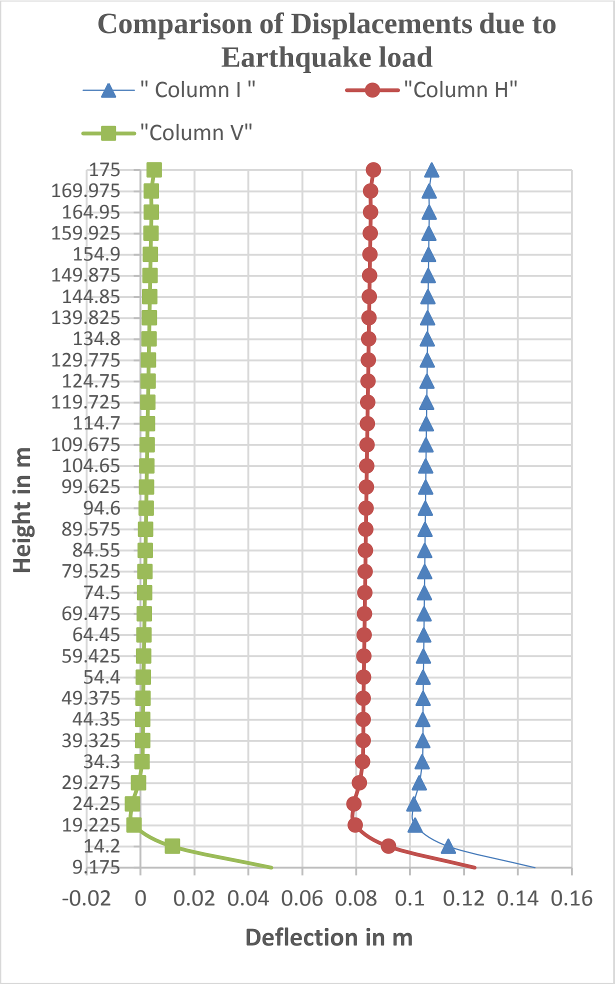

Fig. 4 Comparison of Displacements due to Earthquake Load

The profiles for the supports ‘I’, ‘V’ and ‘H’ are similar in nature. For seismic load combination the displacement is more in ‘I’ support model than ‘H’ and ‘V’ support models. The ‘I’ support cooling tower structure is more flexible structure compared to the ‘V’ and ‘H’ support cooling towers.

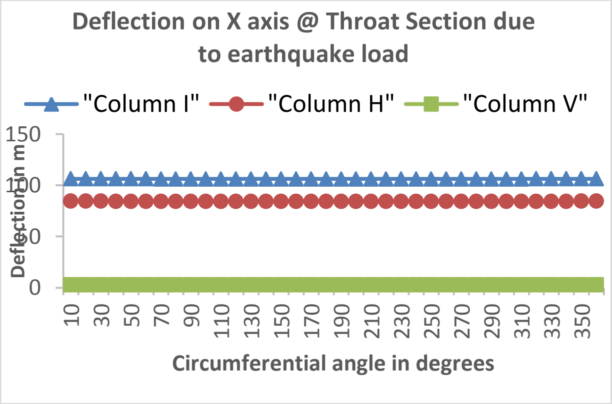

Fig. 5 Deflection on X axis at throat section due to Earthquake Load

The nature of the profiles for ‘I’, ‘V’, and ‘H’ support systems is similar. Comparing the displacements for seismic load combination at throat section for ‘I’, ‘V’, and ‘H’ support systems it is observed that displacement is maximum for ‘I’ support system.

3. Wind Load

Loading is as per IS: 875 part 3.
The hyperbolic cooling tower is located in Nagpur.
The following equation is used to find design wind speed (refer clause 5.3, pg. no.8, IS: 875 Part 3):

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

Where,

V_z = Design wind speed at any height z in m/s, (Cl.5.3, pg. no.8, IS: 875 Part 3);

V_b = Basic wind speed (refer Appendix A, Clause 5.2, pg. no.53, IS: 875 part 3);

k_1 = Probability factor (risk coefficient) (refer table 1, pg. no.11, IS: 875 part 3);

k_2 = Terrain, height and structure size factor (refer table 2, pg. no.12, IS: 875 part 3);

k_3 = Topography factor (refer Clause 5.3.3, pg. no.12, IS: 875 part 3).

In our case, design wind speed is:

$$V_z = 44*1.07*1.29*1$$

$$V_z = 60.7332 \text{ m/s.}$$

The following equation is used to find design wind pressure: (refer Clause 5.4, pg. no.12, IS: 875 part 3)

$$p_z = 0.6V_z^2 \qquad ...(5)$$

Where,

p_z = Design wind pressure in N/m^2 at height z; (refer Clause 5.4, pg. no.12, IS: 875 part 3)

In our case, design wind pressure is:

$$p_z = 0.6*(60.7332)^2$$

$$p_z = 2213.11\ N/m^2$$

The hyperbolic cooling tower is open only on one end. Hence internal pressure is not developed so the internal pressure coefficient is 0. The external pressure distribution coefficient is taken from Table 18, IS: 875 part 3. As Table 18 provides external pressure distribution coefficient for cylindrical structures, we changed the diameter in the equation of h/D for each section of height in our structure to get the external pressure distribution coefficient for that particular height. Areas for each section were taken from the STAAD Pro software.

The following equation is used to find wind load on each member (refer Clause 6.2.1, IS: 875 part 3):

$$F = (C_{pe} - C_{pi})Ap_z \quad ...(6)$$

Where,

F = wind load in N;

C_{pe} = External pressure coefficient; (Refer Table 18, pg. no.31, IS: 875- Part 3)

C_{pi} = Internal pressure coefficient;

A = surface area of structural element or cladding unit in m^2;

p_z = Design wind pressure in N/m^2 at height z

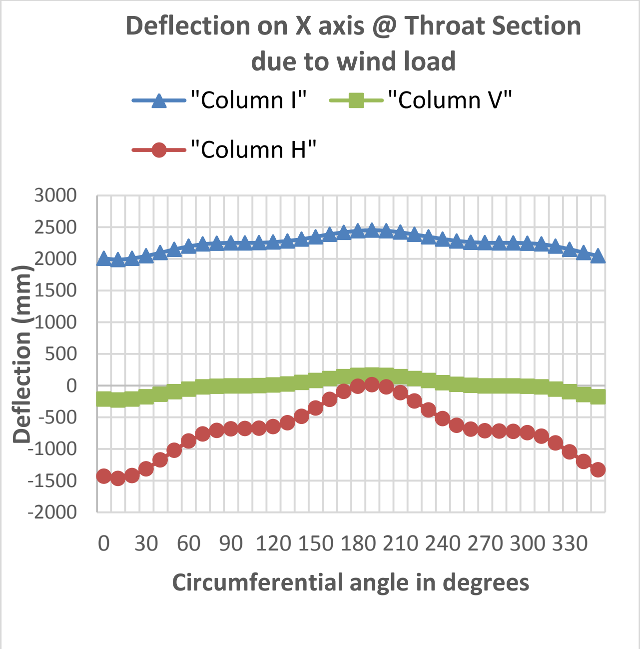

Fig. 6 Deflection on X axis at throat section due to Wind Load

The nature of the profiles for ‘I’, ‘V’, and ‘H’ support systems is similar. Comparing the displacements for wind load combination at throat section for ‘I’, ‘V’, and ‘H’ support systems it is observed that displacement is maximum for ‘I’ support system.

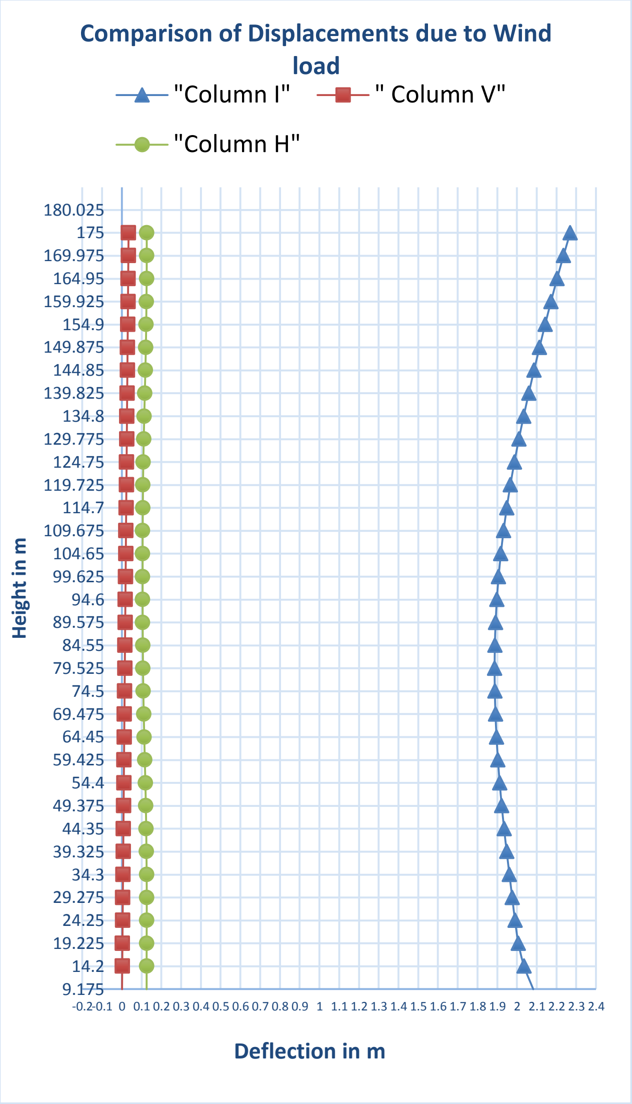

Fig. 7 Comparison of Displacements due to Wind Load

The profiles for the supports ‘I’, ‘V’ and ‘H’ are similar in nature. For wind load combination the displacement is more in ‘I’ support model than ‘H’ and ‘V’ support models. The ‘I’ support cooling tower structure is more flexible structure compared to the ‘V’ and ‘H’ support cooling towers.

IV. RESULTS

- Out of all the load combinations used, wind loads cause the maximum deflection.
- For all loading conditions the displacement is more in ‘I’ support model than ‘H’ and ‘V’ support models.
- The ‘I’ support cooling tower structure is more flexible structure compared to the ‘V’ and ‘H’ support cooling towers.
- The deflected profile patterns changes as the loading condition and support systems change.

- The deflection for ‘V’ support is 11.552% and ‘H’ support is 5.471% that of ‘I’ support at throat level of cooling tower for wind load combination.
- The deflection for ‘V’ support is 2.742% and ‘H’ support is 5.544% that of ‘I’ support at top level of cooling tower for wind load combination.

V. CONCLUSIONS

- As ‘I’ support is more flexible than ‘V’ and ‘H’ supports, it is more preferable in earthquake prone areas and where wind intensity is high.
- As the height of column increases intermediate bracings are required for additional stability, hence the ‘H’ columns are considered.
- Sometimes, the ‘V’ type support is preferred from structural point of view.

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