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Linear and Nonlinear Performance Evaluation and Design of Cooling Tower at Dahej

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Abstract: *Water using as coolant in refineries can be cooled using a cooling tower of various types. This project deals with natural draft type in which, hot water comes in direct contact with the natural cool air, due to its hyperbolic shape. In this project, software modeling, analysis, design and estimation of a cooling tower was done for a site in gas fired power plant for M/S Torrent Energy at Dahej, Gujarat. Study of effect of variations in the tower height and shell thickness on the structural behavior, study of comparison between different seismic analysis methods such as Equivalent static, Response spectrum and Time history, and its result evaluation and interpretation were also performed. Structures were modeled using STAAD Pro V8i and analysed using SAP 2000NL*
Keywords – *Cooling tower, modeling, Time history, Response spectrum, Pushover.*

I. Introduction

A cooling tower is a heat rejection device, which extracts waste heat from a water stream to the atmosphere and cools the water to a lower temperature. It is difficult to design and analyze the structure for forces as it is a shell structure. Earthquake and wind loads are two important parameters to be considered which makes things more complex. There occurred many attempts to formulate design and analysis methods for cooling tower and many modeling studies were also occurred even from very early times. In this study design, analysis of structure for forces and estimation were done manually and also, design, analysis, modeling and drafting were done using software. Three analysis methods done and compared were Time history, Response spectrum and pushover. Also effect of variation of parameters such as height and thickness was studied. This paper gives an idea of design and analysis of a cooling tower, its modeling, limit states that should be considered for design, and optimum height and thickness that can be adopted.

II. Literature Review

The natural draft or hyperbolic cooling tower makes use of the difference in temperature between the ambient air and the hotter air inside the tower. As hot air moves upwards through the tower, fresh cool air is drawn into the tower through an air inlet at the bottom. The hyperbolic shape is made because of following reasons. More packing can be fitted in the bigger area at the bottom of the shell, the entering air gets smoothly directed towards the centre because of the shape of the wall, producing a strong upward draft, and greater structural strength and stability of the shell is provided by this shape. Concrete is used for the tower shell with a height of up to 200 m. These cooling towers are mostly only for large heat duties because large concrete structures are expensive.

III. Objectives

The main objectives of our project are:

- To analyze and design the cooling tower for prevailing wind load and dead load
- To model cooling tower using STAAD Pro and to analyze and design cooling tower using SAP2000NL
- To evaluate the performance of cooling tower by varying the parameters such as thickness and height of tower shell and to study the effect of these parameters on structural behaviour of cooling tower
- To study and analyze cooling tower using the seismic analysis methods such as Equivalent static, Response spectrum and Time history and the comparison between its results and their interpretation. Time history analysis will be doing with El-Centro earthquake excitation.

IV. Methodology

4.1 Plotting of Wind Pressure Distribution And Tower Profile

As per IS 875 part III, (clause 5.3): $Vz = V_b\, k_1\, k_2\, k_3$ Basic wind speed V_b = 44 m/s at Dahej, Gujarat. Wind pressure as per (clause 5.4): $Pz = 0.6\, Vz^2$ Wind pressure was calculated at each section at an interval of 1m from the bottom and was plotted as Fig. 4.1. From the basic equation of hyperboloid: $[(r_0^2/a^2)-(Z^2/b^2)] = 1$, the radius of each sections of shell was calculated and was plotted as Fig. 4.2.

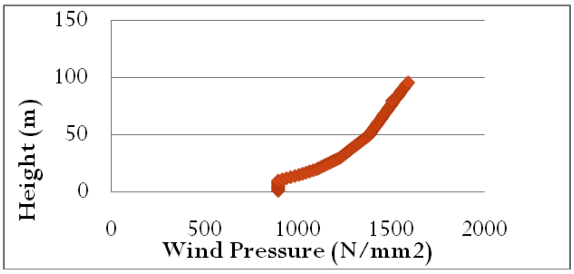

Fig. 4.1 Wind pressure distribution

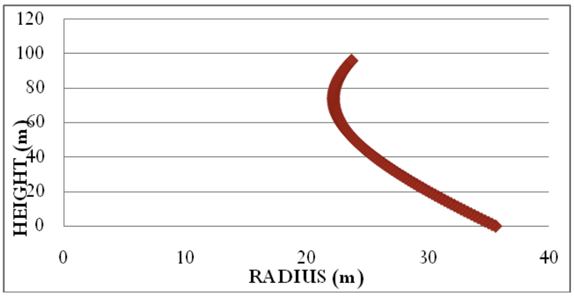

Fig. 4.2 Tower profile

4.2 Analysis and Design of Cooling Tower Shell

As per membrane theory, circumferential force:

$N_\theta = -[(ga^2)/\sqrt{(a^2+b^2)}][\xi/\sqrt{(1-\xi^2)}]$ and Meridional thrust $N_\theta = -[(gb^2)/4].[b^2\sqrt{(a^2+b^2)}].[(1-\xi^2)/(a^2+b^2-a^2\xi^2)].\ [f(\xi)-f(\xi_0)]$ (1)

Where:

$f(\xi) = [(\{2\xi\}/\{1-\xi^2\})+(\log\{(1-\xi)/(1+\xi)\})]$ (2)

g - Density of concrete

$b = [(a\, Z_t)/\sqrt{(t^2-a^2)}]$ = 59.196m

a - Radius at throat section= 22.25m

Z_t - Distance of top section from throat=22.1m

t - Radius at top section= 23.75m

<u>Case 1 : By considering only self weight of shell</u>

For base section :_ N_θ = -253.144kN/m and $N\phi$ = -657.68 kN/m

For top section :_ N_θ = -74.94kN/m and $N\phi$ = 0

<u>Case 2 : By considering only wind load</u>

For base section :_N_θ = -38.07kN/m and $N\phi$ = -222.825 kN/m

4.3 Design of Cooling Tower Shell

As per elastic theory, design parameters are:

- f_c = compressive strength of concrete = 4000psi, M25
- f c'= compressive working strength of concrete = 1800psi
- f_y = ultimate strength of steel =60000psi
- f_s = working strength of steel = 24000psi
- t = shell thickness = 180mm min
- N_Φ = meridional stress resultant in lb/in = 5027.81 lb/in
- N_θ = circumferential stress resultant in lb/in = 1662.87 lb/in

Codal provisions are:

- Steel in any direction > 0.35% of the C/S area (Cl 6.3.6, IS 11504) $A_{smin} = 3062.8\ mm^2/m$
- The Steel < 7.2t .f_c/ f_y OR 29000 t/ f_y , $A_{smax} = 35001.2\ mm^2/m$ OR $35242.5\ mm^2/m$
- Max spacing of bars = 2 × shell thickness = 0.36 m (Cl 6.3.6, IS 11504)
- Min spacing of bars As per IS 456:2000

Circumferential steel requirement: $A_{creq} = N_{\theta/} f_s = 0.832\ in^2/ft$. But Min steel as $1.447\ in^2/ft = 3062.8\ mm^2/m$ provided. Meridional steel requirement: $A_{mreq} = N_{\Phi} / f_s = 2.514\ in^2/ft = 5321\ mm^2/m$. Assume diagonal steel as 'X' at an angle 10^0 with horizontal. Vertical component: X Sin(10) × 2 = $5321\ mm^2/m$.

Thus X = $15321.2\ mm^2/m$, Horizontal component: 15321 × Cos(10) × 2 = $30176\ mm^2/m > 3062.8\ mm^2/m$. Hence OK. We can provide 25mm diameter bar at 320mm c/c along an inclined direction at 10^0 with the horizontal in both directions.

For bottom ring beam, $\theta = 73.59244^o$, Hoop tension: H = $N_\theta \times \cos\theta \times$ Radius =2944.86 KN. Area of steel = H/ stress = $12803.74mm^2$. We can provide 30 nos of 25 mm dia bar. For top ring beam, Min steel is provided as it does not take any load from shell. Min reinforcement = 0.6% of c/s = $1824\ mm^2$. We can provide 20 nos of 12 mm dia bars.

4.4 Estimation and Drafting of Cooling Tower Shell

Each horizontal s/c of very small height of 1m s/c can be reduced to aconical frustum having lateral surface area: $S = \pi \times (r_1 + r_2) \times \sqrt{((r_1 - r_2)^2 + h^2)}$ Volume = S x thickness of section. And total concrete volume = $8096.45\ m^3$. Total length of all bars along 1 direction = 49175.35 m. Area of 1 bar = $490.87\ mm^2$. Volume of bars = $48.28\ m^3$. For bottom ring beam, volume of concrete = $297.54\ m^3$ and volume of steel $3.338\ m^3$. For top ring beam, volume of concrete = $48.154\ m^3$and volume of steel $0.35\ m^3$. Thus total volume of concrete = $8442.15\ m^3$. Rate of M25 in India = 2900 /m^3. Total steel = $51.97\ m^3$. As density of steel is 77 kN/m^3, total weight = 4001.69 kN. Cost of steel = 4060/kN. Thus total cost of material= 4.07 Crore Indian rupees.

4.5 Validation of Modeling of Cooling Tower in STAAD Pro v8i

As per a validation problem from internet, dimensions of the Cooling Tower modeled for validation of modeling are as follows:

- Bottom diameter - 83.49 m
- Throat diameter - 51.21 m
- Top diameter- 53.28 m
- Height of shell - 100.58 m
- Thickness of shell - 0.18 m
- Distance from throat to shell top-18.29m
- Division along height - 24m
- Division along circumference - 20 m

Table 4.1 describes the loading. After analysis, the results were compared with that of validation example and a small error of 3% to 5% was obtained. Hence we concluded that our modeling method is correct for the further proceeding of the work.

Table 4.1 Loading of The Tower Shell

θ degrees	Pressure lb/ft^2	θ degrees	Pressure lb/ft^2
0	+151.726	180	+21.244
15	+134.641	195	+20.661
30	+82.338	210	+21.286
45	+13.165	225	+20.883
60	-47.142	240	+22.840
75	-66.998	255	+14.908
90	-27.801	270	-27.801
105	+14.908	285	-66.998
120	+22.840	300	-47.142
135	+20.883	315	+13.165
150	+21.286	330	+82.338
165	+20.661	345	+134.641

4.6 Modeling of Cooling Tower

Modeling of cooling tower of actual cooling tower was done as per the following dimensions.
Bottom diameter - 71.60 m
Diameter at throat - 44.500 m
Top diameter - 47.500 m
Height of shell - 96.182 m
Thickness of shell at bottom- 875mm, at throat-180mm, top-400mm
Distance from throat to top of shell top - 22.1 m

Two ring beams were provided at the top and bottom having dimensions 0.4m × 0.8m and 0.875m × 1.5m. Fixity is provided at the bottom of the shell. The entire shell is divided into finite elements of dimension 0.5m × 4m. The varying thickness of shell is also encountered in the model by assigning the interpolated thickness values. All the elements were assigned with the material property as concrete. Fig. 4.3 shows the actual STAAD Pro model.

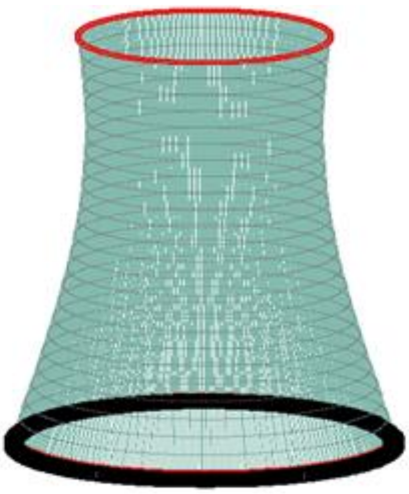

Fig. 4.3 STAAD Pro model of actual cooling tower

4.7 Analysis of Actual Model Using Sap2000

Following load combinations are considered as per IS 456:2000, IS 1893:2002 and IS 13920:1993.

Limit State of Collapse

1.5 (DL + LL)	1.2 (DL+LL+WLx)
1.2 (DL+LL+EQx)	1.2 (DL+LL+WL-x)
1.2 (DL+LL+EQ-x)	1.2 (DL+LL+WLy)
1.2 (DL+LL+EQy)	1.2 (DL+LL+WL-y)
1.2 (DL+LL+EQ-y)	1.5 (DL+WLx)
1.5 (DL+EQx)	1.5 (DL+WL-x)
1.5 (DL+EQ-x)	1.5 (DL+WLy)
1.5 (DL+EQy)	1.5 (DL+WL-y)
1.5 (DL+EQ-y)	0.9 DL +1.5WLx
0.9DL + 1.5 EQx	0.9 DL +1.5WL-x
0.9DL + 1.5 EQ-x	0.9 DL +1.5WLy
0.9DL + 1.5 EQy	0.9 DL +1.5WL-y
0.9DL + 1.5 EQ-y	

Limit State of serviceability

DL+LL	DL+0.8LL+0.8WLx
DL+0.8LL+0.8EQx	DL+0.8LL+0.8WL-x
DL+0.8LL+0.8EQ-x	DL+0.8LL+0.8WLy
DL+0.8LL+0.8EQy	DL+0.8LL+0.8WL-y
DL+0.8LL+0.8EQ-y	DL+WLx
DL+EQx	DL+WL-x
DL+EQ-x	DL+WLy
DL+EQy	DL+WL-y
DL+EQ-y	

V. Analysis Outcomes

5.1 Comparison of analysis methods

The analysis results are shown in Fig. 5.1

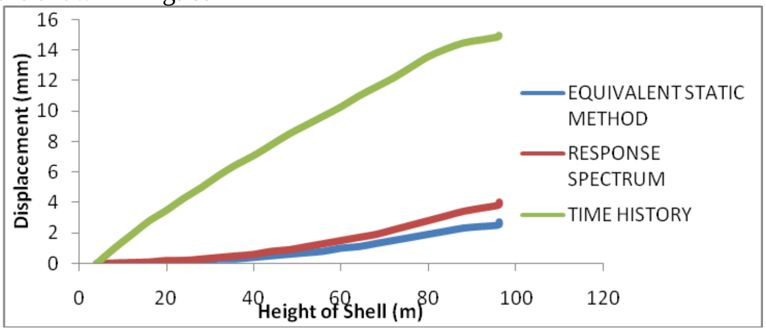

Fig. 5.1 Analysis results of actual model

5.2 Study of Effect of Shell Height and Thickness

Height and thickness of shell were selected as parameters for studying their influence on tower performance. Table 5.1 shows variation of parameters selected for study. Fig. 5.2 and Fig. 5.3 illustrates displacements of various thickness and heights obtained from different analysis.

Table 5.1 Description of Variation in Model

Constant Parameters	Varying Parameters						
Height	Thickness	180mm	210mm	240mm	270mm	300mm	485mm
Thickness	Height	76m	96m	116m	136m		

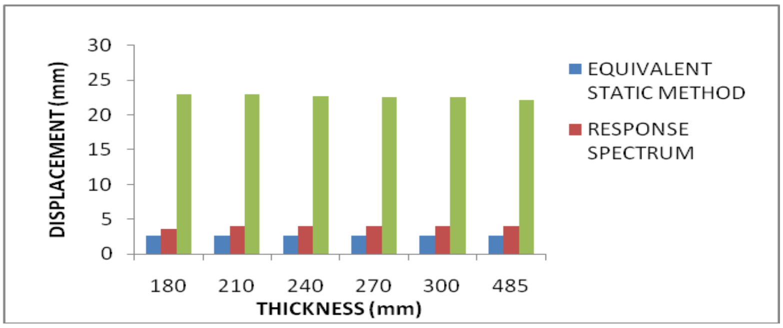

Fig. 5.2 Illustration of displacement for various shell wall thickness obtained for different analysis methods

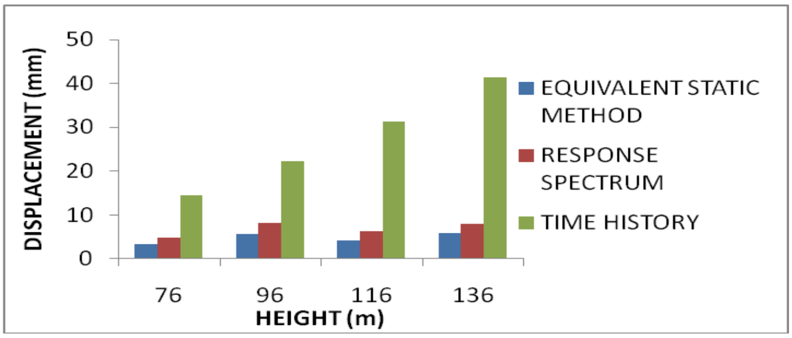

Fig. 5.3 Illustration of displacement for various shell heights obtained for different analysis methods

VI. Conclusions

The safety of hyperbolic cooling towers is important to the continuous operations of a power plant. Depending upon the site, wind and earthquake may govern the design of the tower. During comparison of different analysis methods, the behavior of structure under El-Centro earth quake using nonlinear dynamic time history analysis showed higher nodal drift when compared to other two. Percentage variation b/w ES & RS, RS & TH, ES & TH obtained are 30%, 63%, and 73% respectively. From the above study it can be concluded that time history analysis predicts the structural responses more accurately in comparison with equivalent static method and response spectrum method as it incorporate P-Δ effect and material and geometric nonlinearity which is true in real structure.

During study of influence of shell height and shell thickness, height is seen to have the greatest influence on the free vibration response, with increase height significantly increasing displacements. In case of shell thickness variation, it does not affect the top node displacement significantly. So we can infer that shell thickness does not have much effect in overall displacement of shell but, have effect in the local stiffness of the shell.

References

[1]. Hsue-Bin Chen, *Analysis and Design of a Hyperbolic Cooling Tower,* Taiwan Provincial College of Marine and Oceanic Technology Manhattan, 1976
[2]. J. Almasi, *Approximate Determination of Cooling Tower Dimensions*, Department of Reinforced Concrete Structures Technical University Budapest, August 1980

[3]. Dr. S. N. Tande and Snehal S. Chougule, Linear and Nonlinear Behaviour of R. C. Cooling Tower under Earthquake Loading, *International Journal of Latest Trends in Engineering and Technology, 2(4),* 2013, 370-379

[4]. Shailesh S. Angalekar and Dr. A. B. Kulkarni, Analysis of Natural Draught Hyperbolic Cooling Towers by Finite Element Method Using Equivalent Plate Concept, *International Journal of Research and Applications, 1(2),* 144-148

[5]. V.S.N. Raju, *Analysis of Hyperbolic Shell Natural Draught Cooling Towers Using MSC/NASTRAN,* Dept of civil Engineering A.P.S.E. Board Hyderabad

[6]. M. Diver and A. *C.* Paterson, Large cooling towers the present trend, *The Structural Engineer*, *55*, 431-445

[7]. Saeid Sabouri-Ghomi, Mehdi Hadj Karim Kharrazi, and Payman Javidan, Effect of stiffening rings on buckling stability of R.C. hyperbolic cooling towers, *Thin-Walled Structures, 44*, 2006, 52–158

[8]. Kopenetz ludovic gheorghe and catarig alexandru, Practically Structural Analysis of Large Cooling Towers, *Journal of applied engineering sciences, 1(4),* 2011, 39-44

[9]. Dieter Busch, Reinhard Harte, Wilfried B. Kra¨tzig andUlrich Montag, New natural draft cooling tower of 200 m of height, *Engineering Structures, 24*, 2002, 1509–1521

[10]. P.L. Gould and W.B. Kratzig, Cooling Tower Structures (Chen Wai-Fah), *Structural Engineering Handbook*, (Boca Raton: CRC Press LLC, 1999)

[11]. Hyuk Chun Noh, Nonlinear behavior and ultimate load bearing capacity of reinforced concrete natural draught cooling tower shell, *Engineering Structures, 28*, 2006, 399–410

[12]. N. Krishnaraju, *Advanced Reinforced Concrete Design (*CBS Publishers,2005)

[13]. IS 875 *Indian Standard Code of Practice For Design Loads (Other Than Earthquake) For buildings and structures,* (Part 3) *Wind loads,* - 1987

[14]. IS 11504 *Indian Standard Criteria For Structural Design of Reinforced Concrete Natural Draught Cooling Towers–* 1985

[15]. IS 1893 *Indian Standard Criteria For Earthquake Resistant Design of Structures Part 1 General Provisions And Buildings*-2002

[16]. IS *13920 Indian Standard Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces -Code Of Practice*-1993