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Seismic Analysis and Design of a Hyperbolic Cooling Tower

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Abstract: Cooling towers are widely used for cooling large quantities of water in thermal power stations, refineries, atomic power plants, steel plants, air conditioning and other industrial plants. Cooling towers vary in size from small roof-top units to very large hyperboloid structures that can be up to 200 metres (660 ft.) tall and 100 metres (330 ft.) in diameter, or rectangular structures that can be over 40 metres (130 ft.) tall and 80 metres (260 ft.) long. This study is to determine the maximum height the cooling towers can be built by making it stable under the influence of the wind load as well as seismic loads. Different radius for the throat, height for the cooling towers and thickness for the plates has been used and the different models have been analyzed to determine the optimum measurements. The critical plate of the optimum model is designed manually. STAAD Pro v8i software was used for the purpose of analysis.

Keywords: Seismic, Hyperbolic Cooling Tower, STAAD Pro v8i.

I. INTRODUCTION

Cooling tower is a tall cylindrical concrete tower used for cooling water or condensing steam from an industrial process. It is a heat rejection device which extracts waste heat to the atmosphere through the cooling of a water stream to a lower temperature. It is generally of 2 shapes, hyperboloid or hyperbolic and rectangular. Hyperboloid cooling towers will be around 130-200m tall and 100 mm in diameter while the rectangular cooling towers will be around 40m tall and 80m long. Cooling tower is generally made of concrete and rebar. The type of foundation required for each cooling tower, e.g. individual foundations, ring foundation or piling, is determined according to the ground conditions. Applications of cooling tower include Oil refineries, petrochemical and other chemical plants, thermal power stations and HVAC systems for cooling buildings. The safety of hyperbolic cooling towers is important to the continuous operation of a power plant. Depending upon the site, earthquake may govern the design of the tower.

II. CLASSIFICATION OF COOLING TOWERS

Cooling towers can generally be classified by it's:

Use:

- Build
- Heat Transfer methods
- Air flow generation methods

Classification by Use: Heating, Ventilation and Air Condition (HVAC) Cooling towers.

A. Shape of a Cooling Tower

Cooling towers are generally of 2 shapes, hyperboloid or hyperbolic and rectangular. Rectangular cooling towers are generally small in size which are associated with small buildings such as residential buildings, small industries etc. Height of a rectangular cooling tower will be around 40-80m. In this study, 4 cooling towers of height 150m, 200m, 250m and 300 m with three different plate thicknesses of 200mm, 250mm and 300mm were modeled using STAAD Pro software. The radius of throat and base diameters were also varied according to different models. These models were analysed for wind load as well as seismic loads. Equivalent static analysis and Response Spectrum analysis were carried out for seismic loads. Nodal displacement, support reactions, mode shapes, base shear and plate stress of the models were compared and the optimum height of the plate and thickness of the plate were obtained. The critical plate was designed manually.

III. MODELLING

Modeling a building involves the modeling and assemblage of its various load carrying elements. The model must ideally represent the mass distribution, strength, stiffness and deformability. The first part of this chapter gives a summary of various parameters such as material properties, basic geometry required to define the model. Accurate modeling of the nonlinear properties of various structural elements is very important in nonlinear analysis. In this study, STAAD Pro v8i is used for the modeling and analysis of the structure.

A. Details of Modelling

The modelling of the structure is done in STAAD Pro. Four models of heights 150m, 200m, 250m and 300m were modelled and each model was assigned with three different thicknesses 200mm, 250mm and 300mm for the concrete plates used in the model. The models were analysed for both wind load as well as seismic load. The top edge of the cooling tower is free to translate and rotate in all directions, while the base is completely fixed.

B. Structural Details of the Models

The structural details of four different models created are given in Table1.

TABLE I: Structural Details of the Models

Sl No	Parameters	Model 1	Model 2	Model 3	Model 4
1	Height(m)	150	200	250	300
2	Base Diameter(m)	118	115	110	105
3	Top diameter(m)	60	65	70	90
4	Throat Diameter(m)	40	50	60	80
5	No of plates	5625	10000	15625	22500

IV. MATERIAL PROPERTIES

This section provides the properties of the material used for the modeling of the cooling tower. Reinforced concrete with a unit weight of 25 kN/m3, Poisson's ratio of 0.2, damping ratio of 5% and elastic modulus of 39 GPa were considered for the finite-element modeling of the cooling tower.

A. Loading

Dead load, wind load and seismic load were applied on the structure. Dead load shall be calculated on the basis of the unit weights taken in accordance with IS: 875 (part 1)-1987. Wind loads shall be taken as specified in IS: 875 (part 3)-1987. Seismic load shall be taken in accordance with IS: 1893 (part 1)-2002 .The instances where concentrated loads occur, special consideration should be given in analysis and design. Dynamic loads of interest include wind loads and seismic actions that are time dependent and asymmetric. The use of equivalent static loads simplifies the analysis, however, it does not account for interaction between the frequencies of the applied load and the characteristic natural frequencies of the structure and limited knowledge on the dynamic behaviour of structure. Parameters that are considered for wind loading according to IS875-Part 3 details are given in Table 2.

TABLE II: Wind Load Parameters

Sl No	Parameters	Values
1	Category of building	4
2	Class of building	C
3	Basic wind speed in m/sec	50
4	Force coefficient	1.2
5	Guest factor calculations	Applied

B. Earthquake Loads

Parameters for Earth quake loads according to IS 1893-2002 (Part 2) are given in Table 3.

TABLE III: Seismic Load Parameters

Sl No	Parameters	Values
1	Zone	III
2	Zone Factor	0.16
3	Importance Factor	1
4	Response Reduction Factor	3
5	Soil Type	I

V. RESULT

12 different models were analyzed for wind load and seismic loads. Seismic analyses included equivalent static analysis and response spectrum analysis. Maximum nodal displacement, support reactions and stress for each case was determined and compared to study the impact of the different load conditions for varying height and thickness of plate in a simulated model. Table 4 shows the maximum node displacements for wind load for the cooling tower model of height and table 5 shows the Support Reactions of all the models 150 m and varying plate thicknesses of 200mm, 250mm and 300 mm.

TABLE IV: Maximum Node Displacements for Wind Load

Sl No	Thickness of Plate(mm)	Max displacement(mm)
1	200	67.314
2	250	51.903
3	300	42.049

TABLE V: Support Reactions of All the Models

Height(m)	Thickness(mm)	Wind(kN)	ESA(kN)	RSA(kN)
150	200	3257.11	3328.09	9106.94
150	250	2943.79	2961.63	4666.53
150	300	2642.87	2092.01	3975.45
200	200	2786.046	2557.472	3005.85
200	250	2564.103	2208.38	3903.43
200	300	2350.066	1850.23	4686.75
250	200	2458.526	1700.575	2246.26
250	250	2304.855	1461.078	2997.58
250	300	2153.708	1216.747	3510.014
300	200	3228.64	2020.508	2840.05
300	250	3022.091	1729.904	3547.5
300	300	2820.721	1434.257	4145.81

VI. CONCLUSION

From the analysis results, it can be concluded that The nodal displacement of the structure increases by 30% as the height of the

- Cooling tower is increased while the nodal displacement can be reduced by around 20-25 % by increasing the thickness of the plate used for modeling the cooling tower.
- Mass participation of more than 75% is obtained for all the dominant modes.

- The variation in plate stress was found to be minimum (5%) with the increase in height of the model and thickness of the plate.
- The CQC shear of the increased by around 35% as the height of the tower and thickness of the plate is increased.

From the above results taking cost effectiveness into consideration, the optimum height for a cooling tower can be considered as 250m, optimum plate thickness as 300mm and optimum throat diameter as 60m.

VII. REFEREANCE

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