Static and Dynamic Analysis of Natural Draught Hyperbolic Cooling Tower

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Abstract*- Natural Draught Hyperbolic Cooling towers are the characterizing landmarks of power station. They contribute both to an efficient energy output & to a careful balance with our environment. These structures are most efficient measures for cooling of thermal power plants by minimizing the need of water & avoiding thermal pollution of water bodies. Hyperbolic shape of cooling tower is usually preferred due to its strength & stability. In modern construction practices & techniques available in hand has made great impact in designing such towers with very small thickness.*

This Paper deals with the Study of Static and Dynamic analysis of hyperbolic cooling towers (i.e. self-weight, seismic load, wind load). Existing cooling towers are chosen from Bellary thermal power station (BTPS) as case study. Bellary thermal power station is a power-generating unit near Kudatini village in Bellary district, Karnataka state. Basic wind speed is 39 m/sec, risk co-efficient factor k_1 shall be taken as 1.06, terrain category shall be 2 and corresponding values shall be taken for k_2, risk co-efficient factor k_3 shall be taken as 1.0. The seismic zone is zone III, importance factor (I) is 1.75. The Boundary conditions considered are Top end free and Bottom end is fixed. The material properties of the cooling tower have young modulus 31 GPa, Poisson Ratio 0.15 and density of RCC 25 kN/m3. The behavioral changes due to stress concentration of cooling tower is analyzed using SAP 2000v18 element with actual height & thickness. Experimental model made with stainless steel sheet of 2 mm thickness with proportion of 1:500 actual cooling tower. The cooling tower model is tested with Shake table for earthquake analysis and wind tunnel for wind analysis. The objective is to obtain Maximum Deflection, Maximum Principal Stresses, & strain, Maximum Von Misses stress, strains.

Keywords- Natural draught hyperbolic cooling tower, SAP2000v18, Shake table, Wind tunnel.

I. INTRODUCTION

Hyperbolic cooling towers are large, thin shell reinforced concrete structures, which Contribute to power generation efficiency, reliability and to environmental protection. Natural draft cooling tower is one of the most widely used cooling towers. It works on the principle of temperature difference between the air inside the tower and outside the tower. Hyperbolic shape of cooling tower is usually preferred due to its strength, stability, and larger available area at the base.

Hyperbolic reinforced concrete cooling towers effectively used for cooling large quantities of water in thermal power stations, refineries, atomic power plants, steel plants, air conditioning, and other industrial plants. Natural draughts cooling tower is the characterizing landmarks of power stations and used as heat exchangers in nuclear power plants. They contribute both to an efficient energy output and to a careful balance with our environment. These shell structures subjected to environmental loads such as Seismic and thermal gradients that is stochastic in nature.

Reinforced concrete cooling towers, which comprise of a thin concrete shell of revolution, are commonplace in civil engineering infrastructure that is concerned with the generation of electric power. Large reinforced concrete, natural draught cooling tower structures can be as tall as or even taller than many chimneys, however due to their design and function, they have a very much larger surface area, with a much lower mass to surface area ratio. So study of Natural draught hyperbolic cooling tower is important with functional and environmental aspects.

II. OBJECTIVE

1. To Study the linear static analysis of existing cooling towers for maximum principal stress.
2. To Study the Free vibration analysis for existing cooling tower. To Study the Natural frequencies, Modes of vibration (selected modes) for both existing cooling tower and steel model.
3. To Study the frequencies, maximum principal stresses subjected to earthquake excitation.
4. To Study the deflection pattern, stress induced to wind load.

III. LITERATURE REVIEW

G. Murali et al. (2012) have studied response of cooling towers to wind loads. This study deals with the study of two cooling towers of 122 m and 200 m high above ground level. These cooling towers have been analyzed for wind loads using ANSYS software by assuming fixity at the shell base. The wind loads on these cooling towers have been calculated in the form of pressures 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 carried out using 8- noded shell element (SHELL 93) with 5 degrees of freedom per node.

Esmaeil Asadzadeh et al. (2012) did finite element analysis for structural response of cooling tower shell considering alternative supporting systems. This paper deals with the study of following kind of supports to the shell part of the tower. Such as Fixity at the base, I type of column support at the base, V type of column support at the base. With a view to compare the relative influence of the supports on the structural response offered by the shell for available case history Finite Element Analysis employing higher order Mind line formulation have been undertaken. The comparison has been made of the self-weight loading, static wind loading and pseudo static seismic activities the loads are calculated as per the recommendation of relevant IS codes. Based on various details presented in this paper broad conclusions have been drawn. In general it has been observed that I type of supports create higher flexibility at the base of the tower as compared to the V type of supports. In fact the V types of the supports behaves in a manner similar to fixed support at the base and provides truss action & provide more rigidity to the tower.

N. Prabhakar (1990) studied the various structural aspects of hyperbolic cooling tower. The present day hyperbolic cooling towers are exceptional structures in view of their sheer size and complexities. The towers involve considerable amount of design work on structural aspect. Besides providing suitable structural profile to meet the functional needs, the design requires consideration of external applied, ladings, both in static and dynamic. The Paper describes briefly salient structural features and current practices adopted in the structural design of hyperbolic cooling towers. Cooling towers are undoubtedly exceptional structures, which require special expertise to both design and construct. meridional form of the shell and proper assessment of wind loads are of considerable importance in arriving at stress resultant values and buckling safety factors. As the structure is sensitive to wind loads, shell reinforcement must be provide based on limit state approach.

Prashanth N et al. (2013) studied the effect of seismic loads and wind load on hyperbolic cooling tower of varying dimensions and RCC shell thickness. This paper deals with study of hyperbolic cooling tower of varying dimensions and RCC shell thickness, for the purpose of comparison a existing tower is consider, for other models of cooling tower the dimensions and thickness of RCC shell is varied with respect to reference cooling tower. The boundary conditions should consider, as been top end free and bottom end is fixed. The material properties of the cooling tower have young modulus 31 GPa, Poisson Ratio 0.15, and density of RCC 25 kN/m3. These cooling towers analyzed for seismic loads & wind load using Finite Element Analysis. The seismic load will be carried out for Bhuj earthquake in accordance with IS: 1893 (part 1) 2002 and by modal analysis and wind loads. On these cooling towers have been calculated in the form of pressures by using the design wind pressure coefficients as given in are IS: 11504-1985 code along with the design wind pressures at different levels as per IS 875: (Part 3)- 1987 code. The analysis carried out using 8-noded 93 shells Element. The outcome of the analysis is max deflection, max principal stress & strain, max von mises stress & strain.

A. M. El Ansary et al. (2011) analyzed the Optimum shape and design of cooling towers. The aim of the current study is to develop a numerical tool that is capable of achieving an optimum shape and design of hyperbolic cooling towers based on coupling a non-linear finite element model developed in-house and a genetic algorithm optimization technique. The objective function is set to be the minimum weight of the tower. The geometric modeling of the tower represented by means of B-spline curves. The finite element method applied to model the elastic buckling behavior of a tower subjected to wind pressure and dead load. The study divided into two main parts. The first part investigates the optimum shape of the tower corresponding to minimum weight assuming constant thickness. The study is extended in the second part by introducing the shell thickness as one of the design variables in order to achieve an optimum shape and design. Design, functionality, and practicality constraints are applied.

IV. RESEARCH METHODOLOGY

The cooling towers analyzed using FEA (Finite element analysis). SAP2000v18 software used for the analyze shell structures. Seismic analysis is carried out for ground acceleration in accordance with IS codes. Wind loads on these cooling towers have been calculated in the form of pressure by using the design wind pressure coefficient and design wind pressure at different levels as per IS codes. The proportionate steel model is also analyzed with same criteria. The experiment of Shake table carried out on horizontal shake table of 30 kg capacity having maximum frequency of 25 Hz. Results obtained from experiment also used for validation purpose. Here actual scaled down model is been considered. Scaling factor used to scale down the model is λ=1:500. With the help of scale down dimensions, the model required for experimentation fabricated. The Wind tunnel experiment is carried out with same model. The model of natural draught hyperbolic cooling tower placed in wind tunnel. Five pressure taps fixed on it to find out pressure on manometer with air velocity of 15 m/s. The room temperature was 27° C. The values of drag C_D plotted against lift coefficient C_L for angles of attack 0° to 360° with interval of 30° on a curve known as polar diagram.

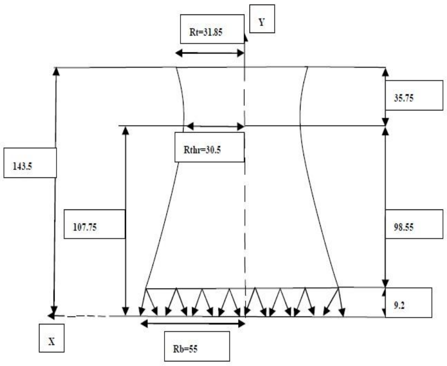
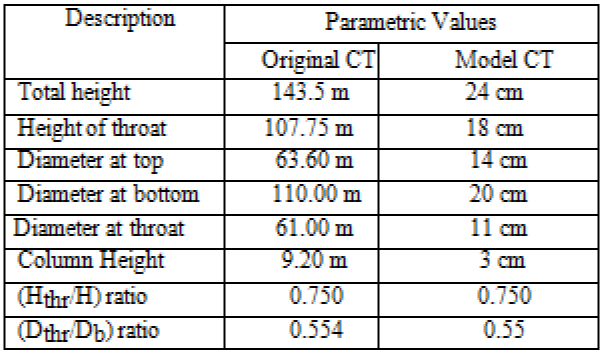


Figure 1: Geometry of Existing cooling tower

Table 1: Geometric details of cooling towers



Description	Parametric Values	
	Original CT	Model CT
Total height	143.5 m	24 cm
Height of throat	107.75 m	18 cm
Diameter at top	63.60 m	14 cm
Diameter at bottom	110.00 m	20 cm
Diameter at throat	61.00 m	11 cm
Column Height	9.20 m	3 cm
(H_{thr}/H) ratio	0.750	0.750
(D_{thr}/D_b) ratio	0.554	0.55

V. RESULT & DISCUSSION

Earthquake analysis

1) Static earthquake analysis -

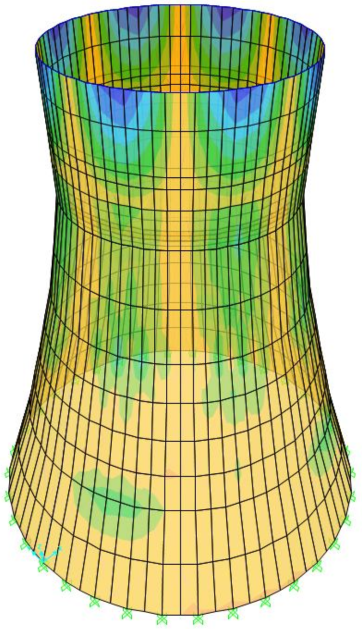


Figure 2: 1^{st} mode shape stresses on the existing cooling tower

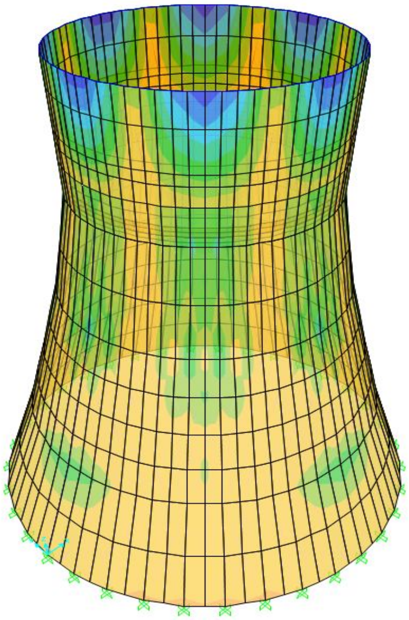


Figure 3: 1^{st} mode shape stresses on the experimental cooling tower

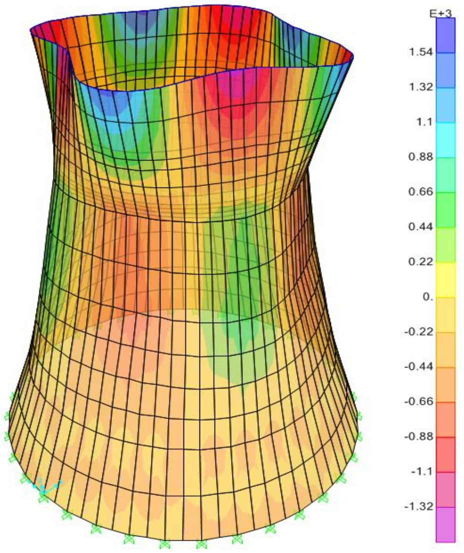


Figure 4: Stresses for first mode shape in existing cooling tower

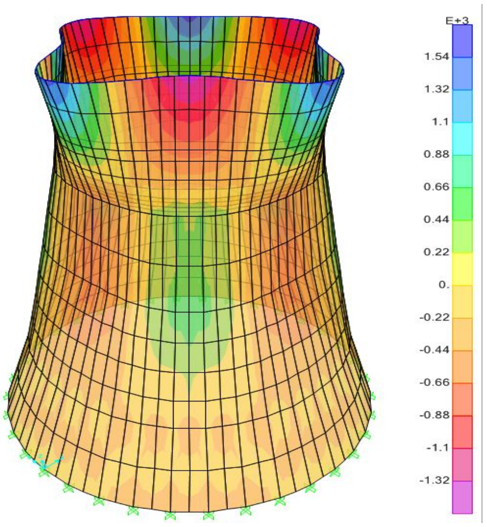


Figure 5: Stresses for first mode shape in experimental cooling tower

2) Von misses stresses –

If Dimension (Height) is less, deflection is also less and vice versa. As Deflection increases, stress also increases and thickness of shell increases, deflection and stress decreases.

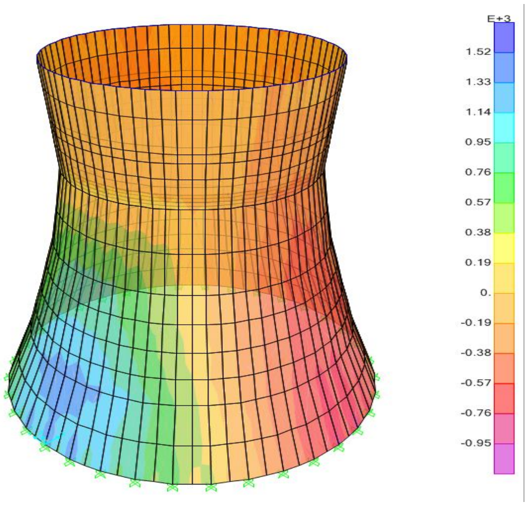


Figure 6: Von misses stresses for existing cooling tower

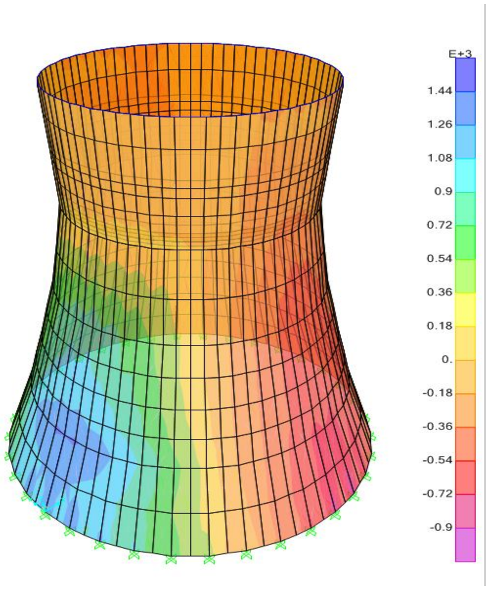


Figure 7: Von misses stresses for experimental cooling tower

3) Time history analysis -

The time history analysis of Natural draught hyperbolic cooling tower investigated for Bhuj Earthquake. Bhuj earthquake is one of the hazardous earthquake occurred in India. These analyses carried out in the finite element method or by the analytical methods.

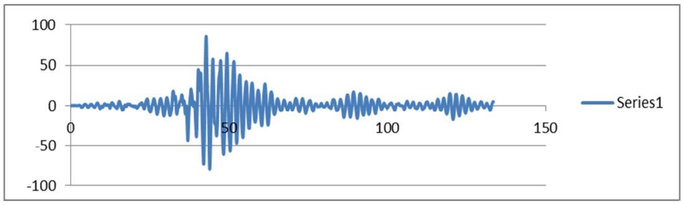


Figure 8: Time against acceleration graph for Bhuj earthquake for existing cooling tower

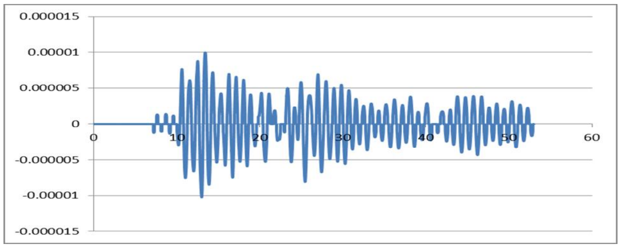


Figure 9: Time against acceleration graph for Bhuj earthquake for experimental cooling tower

Table 2: Stresses developed in existing and experimental CT

Thickness (mm)	Mode	Maximum deflection (mm)	maximum principal stress	Maximum von misses stress
250 (Existing CT)	1	20.03	1.01	0.003764
	2	17.03	1.03	0.00491
	3	24.83	1.7	0.00747
2 (Experimental CT)	1	2.3	2.31	0.312
	2	1.2	1.25	0.412
	3	0.98	1.9	0.328

Table 3: Stresses developed in experimental CT (Comparison of experimental and analytical analysis)

H of cooling tower	External Freq. (Hz)	Acceleration (m/s^2)		Displacement (m)	
		Experimental	Analytical	Experimental	Analytical
3 cm Bottom	2.5	0.01926	0.00233	0.000	0.00
	5.0	0.05928	0.06229	0.000	0.00
24 cm Top	2.5	0.01695	0.01480	0.049	0.052
	5	0.05539	0.05818	0.060	0.069

Wind analysis –

1) Wind analysis in SAP2000v18

First we must create the geometry of the model in SAP2000v18 by using key points & we have to input material models, shell element & make mesh to model in Preprocessor. By assigning the loads and input the Pressures, alongside to the model and solve the problem in solution & read the results in General post processor. The graphs below represent the variation of the stresses in the shell element around the periphery of the model. The variation of stresses around the shell is varying symmetrically varying. It observed that the stresses at perpendicular direction to the wind force seem to be a minimum. The variation in stress along height of the shell is varying non-linearly as wind force is purely horizontal. C_{P1} (4cm), C_{P2} (7cm), C_{P3} (12cm), C_{P4} (20cm), C_{P5} (23cm) are the points which are connected to manometer at certain height of cooling tower to find wind pressure in wind tunnel experiment.

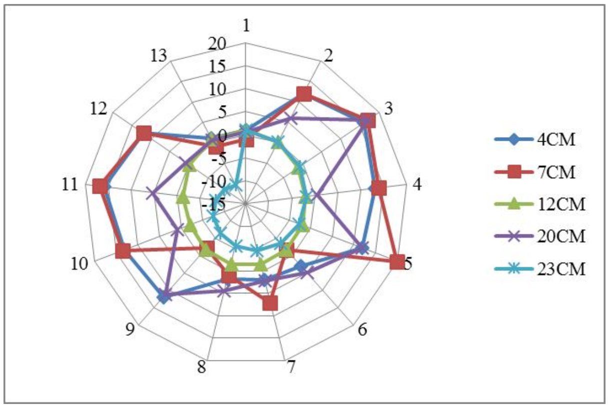


Figure 10: C_p distribution along the periphery polar plot at 0^0 in SAP2000v18 for experimental model

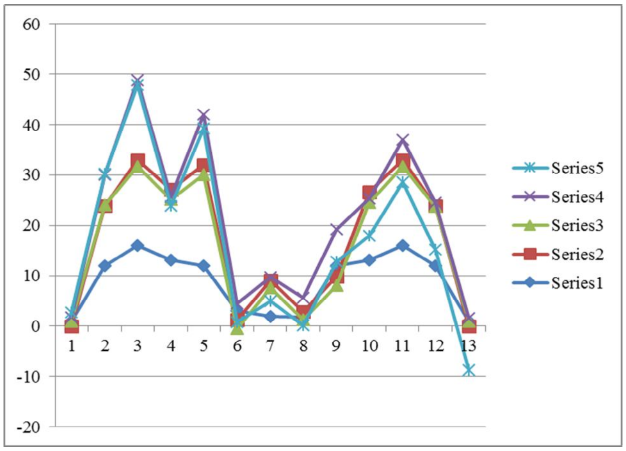


Figure 11: C_p distribution along the periphery in X-Y plot in SAP2000v18

Table 4: Wind pressure at various pressure tap

Angle	C_{P1} (4cm)	C_{P2} (7cm)	C_{P3} (12cm)	C_{P4} (20cm)	C_{P5} (23cm)
0	1	-1	1.04	0.7	1.05
30	12	12	0.104	6.00	0.10
60	16	17	-1.236	17	-0.84
90	13.1	14	-1.938	0.6	-1.79
120	12	20	-1.9089	12	-2.74
150	3	-1.75	-1.7472	5	-3.68
180	2	7	-1.4382	2.13	-4.63
210	1.8	1.03	-1.554	4.43	-5.58
240	12	-2.17	-1.82	11.2	-6.52
270	13.1	13.58	-2.058	0.8	-7.47
300	16	16.98	-1.2827	5.35	-8.42
330	12	12	-0.1785	0.8	-9.36
360	1	-1	0.95893	0.6	-10.31

2) Experimental wind analysis –

Experimental Details-
Wind velocity -15 m/s
Wind density - 1.2 kg/m^3

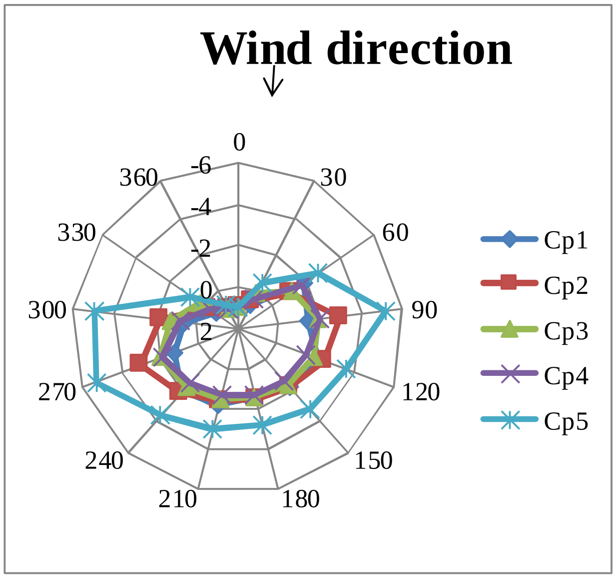
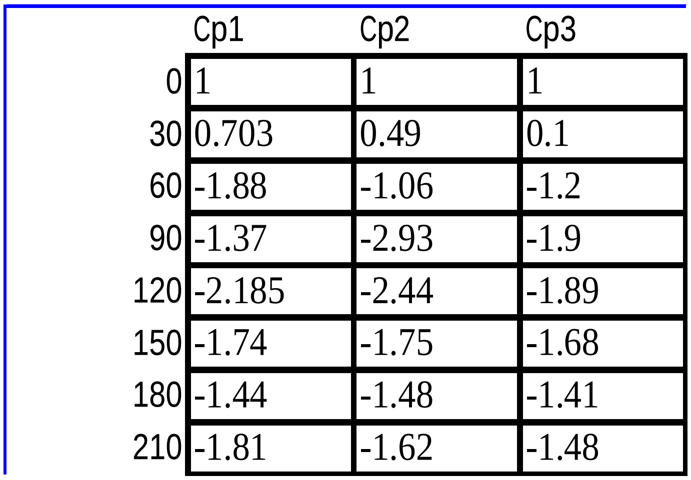


Figure 12: C_p distribution along the periphery polar plot at 0^0 in Wind tunnel experiment

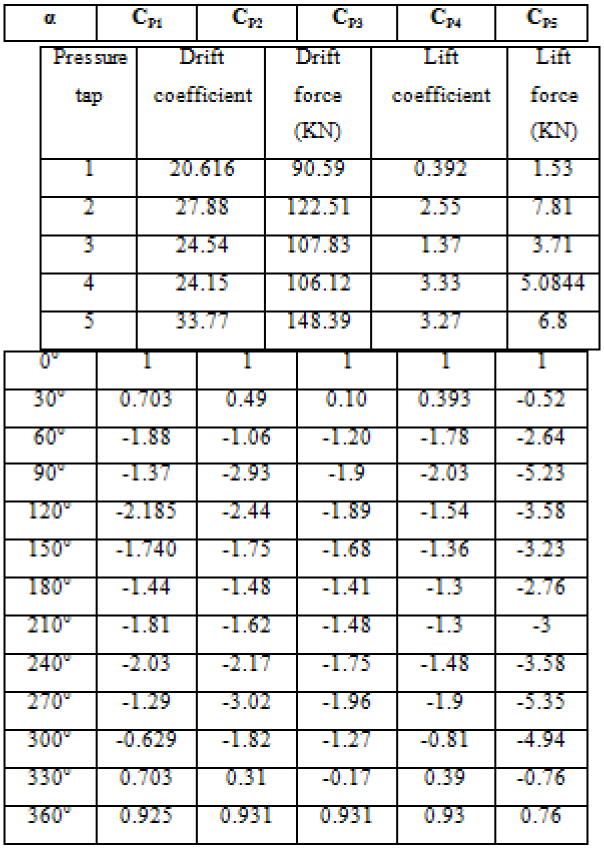


	Cp1	Cp2	Cp3
0	1	1	1
30	0.703	0.49	0.1
60	-1.88	-1.06	-1.2
90	-1.37	-2.93	-1.9
120	-2.185	-2.44	-1.89
150	-1.74	-1.75	-1.68
180	-1.44	-1.48	-1.41
210	-1.81	-1.62	-1.48

Figure 13: C_p distribution along the periphery in X-Y plot in wind tunnel experiment

Table 5: Wind pressure at various pressure tap in wind table experiment

Pressure tap	Drift coefficient	Drift force (KN)	Lift coefficient	Lift force (KN)
1	20.616	90.59	0.392	1.53
2	27.88	122.51	2.55	7.81
3	24.54	107.83	1.37	3.71
4	24.15	106.12	3.33	5.0844
5	33.77	148.39	3.27	6.8



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3	24.54	107.83	1.37	3.71
4	24.15	106.12	3.33	5.0844
5	33.77	148.39	3.27	6.8

α	C_{P1}	C_{P2}	C_{P3}	C_{P4}	C_{P5}
0°	1	1	1	1	1
30°	0.703	0.49	0.10	0.393	-0.52
60°	-1.88	-1.06	-1.20	-1.78	-2.64
90°	-1.37	-2.93	-1.9	-2.03	-5.23
120°	-2.185	-2.44	-1.89	-1.54	-3.58
150°	-1.740	-1.75	-1.68	-1.36	-3.23
180°	-1.44	-1.48	-1.41	-1.3	-2.76
210°	-1.81	-1.62	-1.48	-1.3	-3
240°	-2.03	-2.17	-1.75	-1.48	-3.58
270°	-1.29	-3.02	-1.96	-1.9	-5.35
300°	-0.629	-1.82	-1.27	-0.81	-4.94
330°	0.703	0.31	-0.17	0.39	-0.76
360°	0.925	0.931	0.931	0.93	0.76

VI. CONCLUSION

1) In free vibration analysis for existing cooling tower as thickness of shell increases, Maximum Principal Stress goes on increasing at top region in mode 1.
2) In Modal analysis, cooling tower shows less maximum principal stress with increasing thickness, and stress shifts from throat to bottom region.
3) In Wind analysis, as thickness increases, deflection & maximum principal stress decreases for both existing cooling towers.
4) In Wind analysis, the degree of distortion increases with height of tower.

5) In Dynamic analysis, wind loads are dominating as compared to earthquake forces in zone III.

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