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STATIC AND DYNAMIC ANALYSIS OF HYPERBOLIC COOLING TOWER

Sachin Kulkarni[1], Prof A. V. Kulkarni[2]

[1]P.G Student, Dept of Civil Engineering, BLDEA'S V.P Dr P.G Halakatti College of Engineering & Technology Bijapur-586101, VTU Belgaum, Karnataka, India

[2]Associate Professor & Academic Coordinator, Dept of Civil Engineering, BLDEA'S V. P Dr P.G Halakatti College of Engineering & Technology, Bijapur-586101, VTU Belgaum Karnataka, India

ABSTRACT

Natural Draught hyperbolic cooling towers are the characterizing land marks 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 thermal power plants by minimizing the need of water & avoiding thermal pollution of water bodies.

This paper deals with the study of static and dynamic analysis of hyperbolic cooling towers (i.e. self weight, seismic load, wind load). Two existing cooling towers are chosen from Bellary thermal power station (BTPS) as case study. The boundary conditions considered are Top end free and Bottom end fixed. The material properties of the cooling tower are young's modulus 31GPa, Poisson's Ratio 0.15 and density of RCC 25 kN/m^3. Static analysis has been carried out using 8 noded SHELL 93 element and 4 noded SHELL 63.The behavioral changes due to stress concentration of cooling tower is analyzed using ANSYS 10 (SHELL 93) element with varying height & thickness. The objective is to obtain the optimal height, with low stress concentration. Seismic & wind analysis has been carried out for two existing cooling tower using (FEA), SHELL 93 element. The Seismic loads are carried out for 0.5g, 0.6g, 0.7g, ground acceleration in accordance with IS 1893(part I)-2002 & IS 1893(part IV)-2005 by modal & Response Spectrum method. Wind loads on these cooling towers have been calculated in the form of pressure by using design wind pressure co efficient given in IS 11504-1985 code & design wind pressure at different levels as per IS 875 (Part 3)-1987 code. Eigen buckling analysis has been carried out for both existing cooling towers. Maximum deflection, Maximum principal stress & strain, Maximum Von Mises stress, strains are obtained. The variation in max principal stress v/s thickness, maximum deflection v/s thickness is plotted graphically.

Key words: Cooling Tower, FEA, SHELL Element, Seismic and Wind Load, Stress, Mises.

1. INTRODUCTION

Hyperbolic Reinforced concrete cooling towers are effectively 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 are subjected to self-weight and dynamic load such as an earthquake motion and wind effects. In the absence of earthquake loading, wind constitutes the main loading for the design of natural draught cooling towers. Reinforced concrete (RC) cooling towers, which comprise of a thin concrete shell of revolution, are common place in civil engineering infrastructure that is concerned with the generation of electric power. The analysis of these towers is an interesting and challenging to any structural engineer in view of their size and shape.

2. LITERATURE SURVEY

Research works have been reported in the literature on seismic &wind load on cooling tower [1] to [5]. G. Murali, [1] Response of cooling tower to wind load. This paper deals with the study of two cooling towers of 122m and 200m high above ground level. Meridional forces and bending moments has been calculated. A. M. El Ansary [2], Optimum shape and design of cooling tower, study is to develop a numerical tool that is capable of achieving an optimum shape and design of hyperbolic cooling towers based on coupling non-linear finite element model developed in-house and a genetic algorithm optimization technique. Shailesh S Angalekar, Dr. A. B. Kulkarni [3], software package utilized towards a practical application by considering the problem of natural draught hyperbolic cooling towers. The main interest is to demonstrate that the column supports to the tower could be replaced by equivalent shell elements so that the software developed could easily be utilized. Prashanth N, Sayeed sulaiman [4] This paper deals with study of hyperbolic cooling tower of varying dimensions and RCC shell thickness, for the purpose of comparison an existing tower is considered, for other models of cooling tower the dimensions and thickness of RCC shell is varied with respect to reference cooling tower. N.Prabhakar (Technical Manager) [5] 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 both to design and construct.

2.1 Description of the Geometry of the Towers

Bellary thermal power station (BTPS) is a power generating unit near Kudatini village in Bellary district, Karnataka state. Two existing cooling towers are considered as case study as shown in Fig 1 & 2. BTPS is geographically located at 15º11’58” N latitude and 76º43’23” E longitude.

Details of existing cooling towers

1) The total height of the tower is 143.5 m. The tower has a base, throat and top radii of 55 m, 30.5 m and 31.85 m respectively, with the throat located 107.75 m above the base. (Unit No- 2 cooling tower in BTPS)
2) The total height of the tower is 175.5 m. The tower has a base, throat and top radii of 61 m, 34.375 m and 41.00m respectively, with the throat located 131.60 m above the base (Unit No- 3 cooling tower in BTPS).
The geometry of the Hyperboloid revolution

$$\frac{R_o^2}{a_o^2} - \frac{Y^2}{b^2} = 1 \qquad \text{......... (3)}$$

In which Ro horizontal radius at any vertical coordinate, Y origin of coordinates being defined by the center of the tower throat, a_o radius of the throat, and b is some characteristic dimension of the hyperboloid.

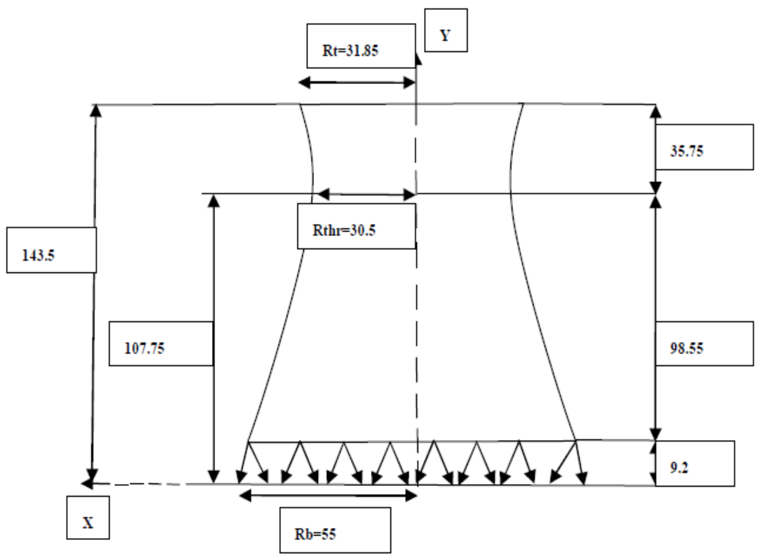


Figure 1: Geometry of existing cooling tower (BTPS)

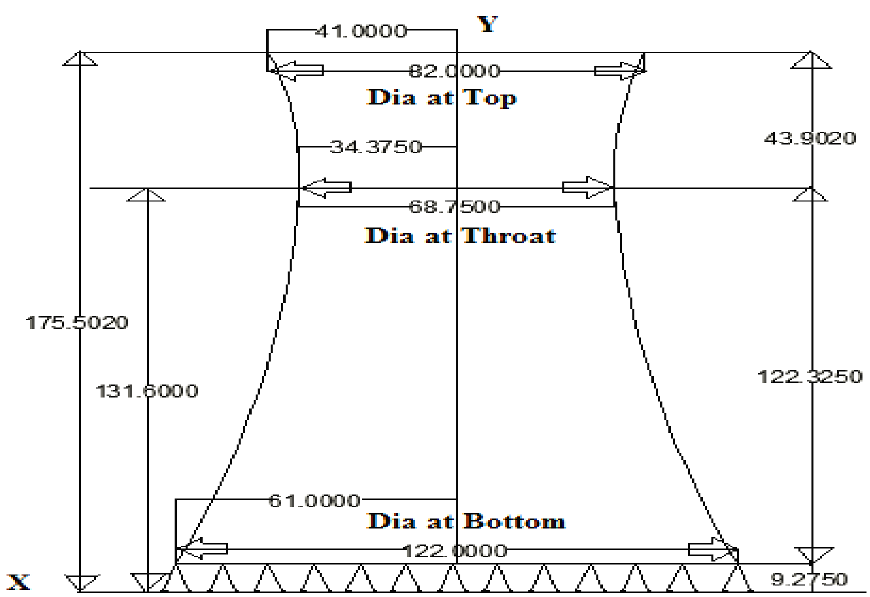


Figure 2: Geometry of existing cooling tower (BTPS)

Table 1: Geometric Details of Cooling Towers

SL NO	DESCRIPTION	SYMBOLS	PARAMETRIC VALUES				
			CT 1 Existing CT(Reference)	CT 2	CT 3	CT 4	CT 5 Existing CT
1	Total height	H	143.5m	150.67m	157.85m	165.025m	175.50m
2	Height of throat	Hthr	107.75m	113.13m	118.525m	123.91m	131.60m
3	Diameter at top	Dt	63.6m	66.78m	69.96m	73.14m	82.00m
4	Diameter at bottom	Db	110m	115.5m	121.00m	126.50m	122.00m
5	Diameter at throat level	Dthr	61.0m	64.05m	67.10m	70.150m	68.750m
6	Column Height	Hc	9.20m	9.66m	10.12m	10.580m	9.275m

Table 1 shows geometric details of cooling towers. CT 2, CT3, CT4 are intermediate cooling towers obtained between two existing cooling towers i.e. CT1 & CT5. CT 2, CT 3, CT 4 are obtained by increasing 5%, 10%, 15% all the dimensions of CT 1, which is considered as reference cooling tower. Thickness is varied from 200mm, 250mm, 300mm, 350mm, 400mm, 450mm, and 500mm.

2.2 Earthquake Forces

The seismic analysis is carried out for two existing cooling towers (CT 1& CT5) in accordance with IS: 1893 by modal analysis of the hyperbolic cooling towers, the earthquake analysis of the shell and for the fill supporting structures (RCC frames) is carried out by response spectrum method. For the Calculation of the Design Spectrum, the following Factors were considered as per IS 1893 (part I) 2002 Zone factor: For Zone III = 0.16 Importance factor (I) = 1.75 Response reduction factor (R) = 3.00 Average response acceleration coefficient Sa/g =Soft soil site condition. The design horizontal seismic coefficient Ah for 0.5g, 0.6g & 0.7g of a structure shall be determined. Maximum considered Earthquake (MCE) of 2% probability.

2.3 Wind loads

The wind pressures on two existing cooling towers CT 1& CT 5 at a given height [Pz] are computed as per the stipulations of IS: 875 (part 3)-1987. For computing the design wind pressure at a given height the basic wind speed (Vb) will be taken as Vb=39 m/s at 9.2m height above mean ground level. For computing design wind speed (Vz) at a height z, the risk coefficient k1=1.06 will be considered. For coefficient k2 terrain category 2 as per table 2 IS: 875 (part-3)-1987 will be considered. The wind direction for design purpose will be the one which would induces worst load condition. Coefficient k3 will be 1 for the tower under consideration. The wind pressure at a given height will be computed theoretically in accordance with the IS codal provision given as under $Pz=0.6\ Vz^2\ N/m^2$. Where Vz =Vb x k1 x k2 x k3 Computation of wind pressure (Pz) along the wind direction by Gust factor method.

2.4 Finite Element Modeling

Due to the complexity of the material properties, the boundary conditions and the tower structure, finite element analysis is adopted. The finite element analysis of the cooling towers has been carried out using ANSYS V.10. The analysis has been carried out using 8-node shell element (SHELL 93). In the present study, only shell portion of the cooling towers has been modeled and fixity has been assumed at the base.

2.5 ANSYS V.10

ANSYS is a commercial FEM package having capabilities ranging from a simple, linear, static analysis to a complex, non linear, transient dynamic analysis. It is available in modules; each module is applicable to specific problem. Typical ANSYS program includes 3 stages Pre processor, Solution & General Post processor.

2.6 Material Properties for Analysis of CT

- Young's modulus: 31Gpa.
- Poisson's Ratio: 0.15.
- Density of RCC: 25 kN/m^3.

3.0 TABULATION & RESULTS

3.1 Static Analysis

A) Comparison of cooling towers (CT 1, CT 2, CT 3, CT 4, and CT 5) with varying heights and thicknesses (200mm, 250mm, 300mm, 350mm, 400mm, 450mm, and 500mm).
B) Comparison between two existing cooling towers (CT 1 & CT 5) for different element types (4 noded SHELL 63 & 8 noded SHELL 93).
Models of Deflection, Maximum principal stress, Max principal strain, von Mises stress & strain for cooling tower 1 for static analysis & for 200mm shell thickness are shown below (Refer Fig no: 3 to 11).

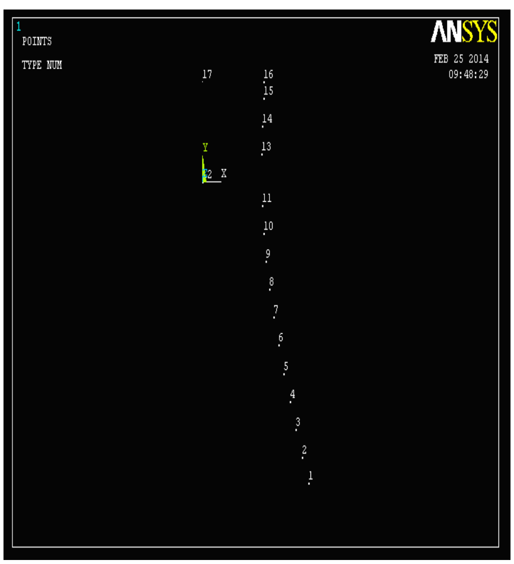


Fig 3: Key points

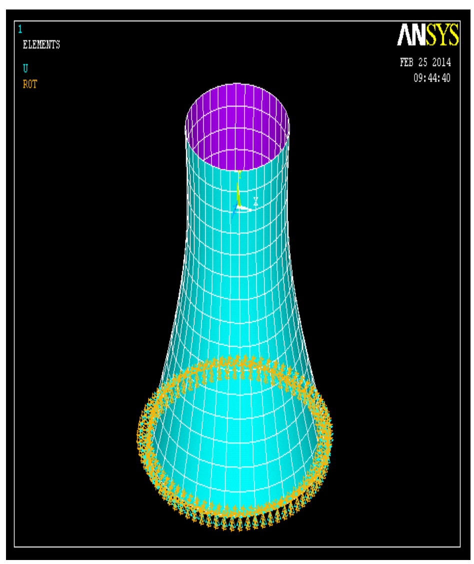


Fig 4: Boundary conditions

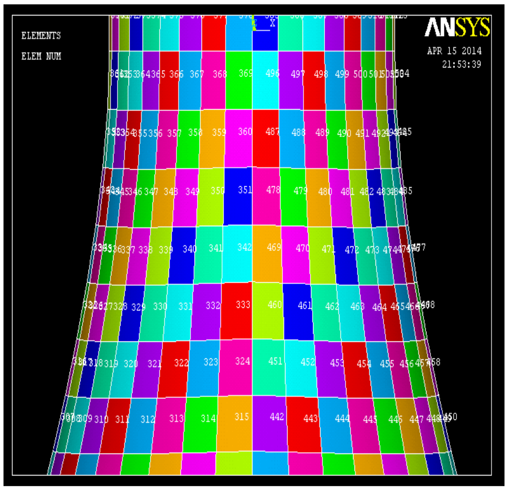


Fig 5: Element numbers in model

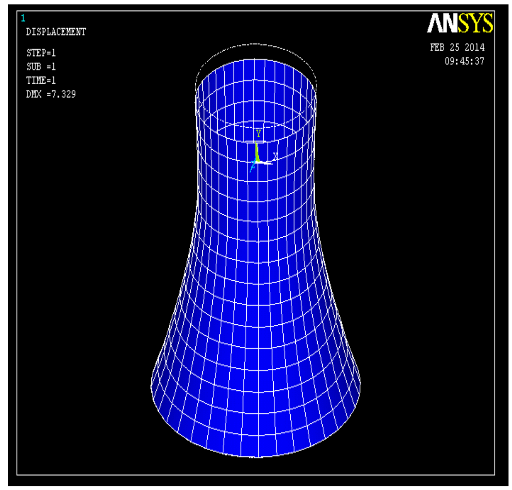


Fig 6: Deflection of CT 1 (200mm thickness)

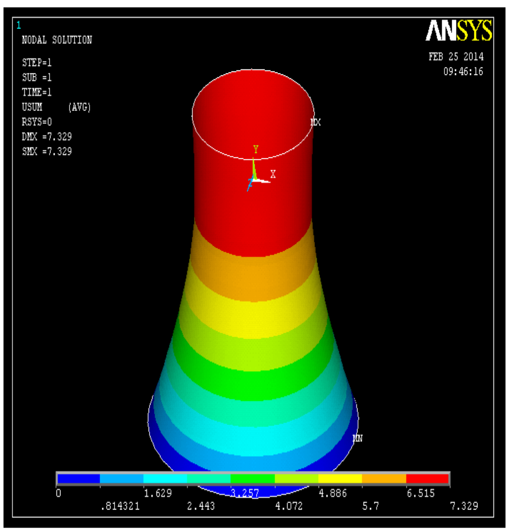


Fig 7: Displacement vector sum

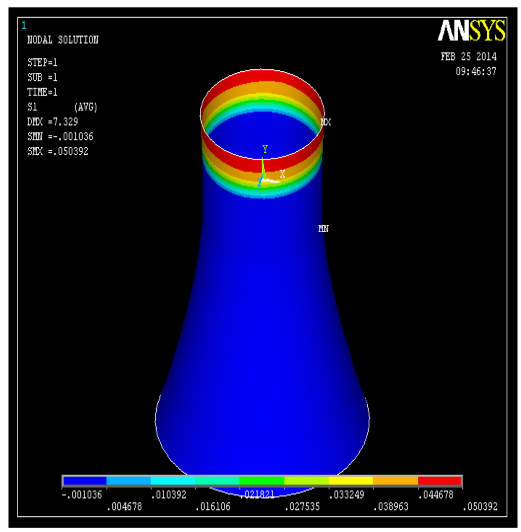


Fig 8: Maximum Principal Stress for CT1

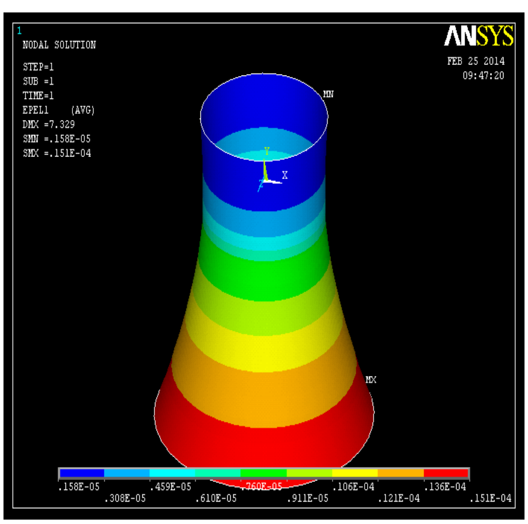


Fig 9: Maximum Principal Strain for CT 1

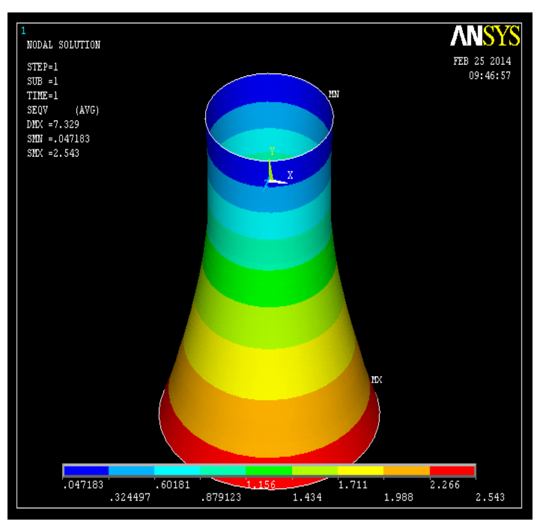


Fig 10: Von Mises Stress for CT 1

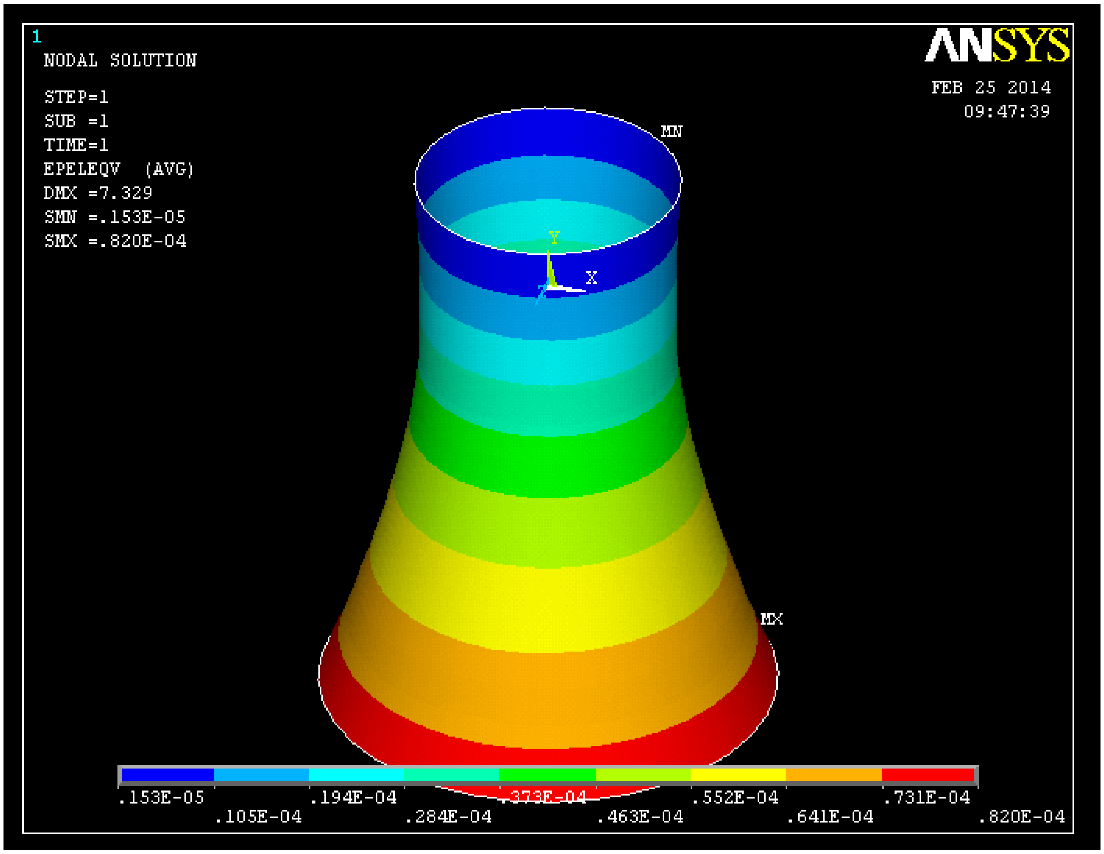
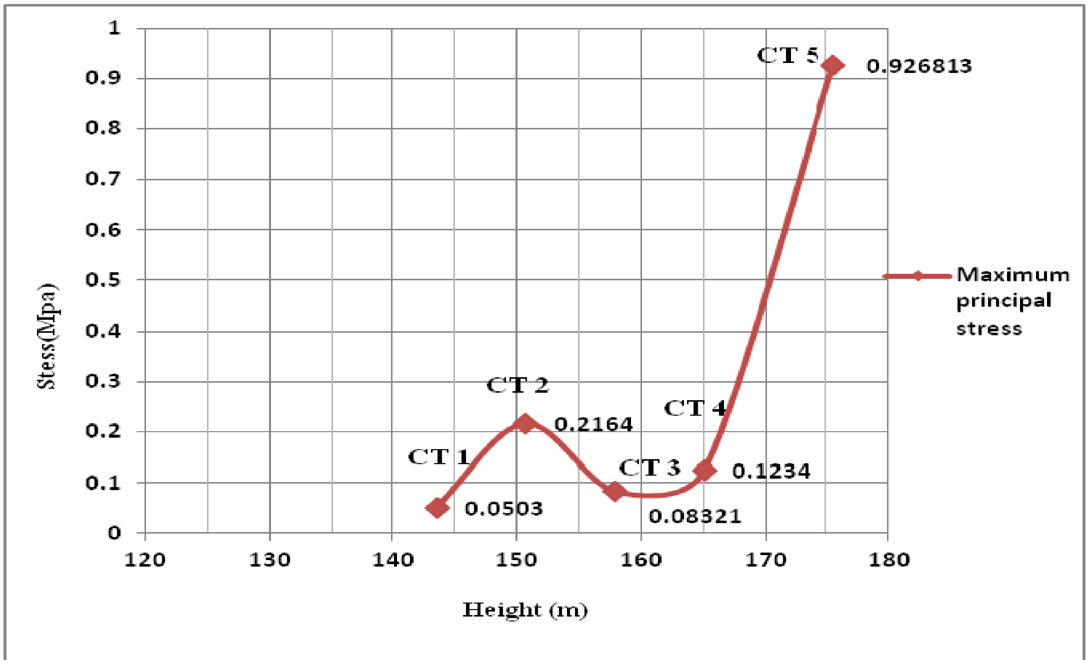
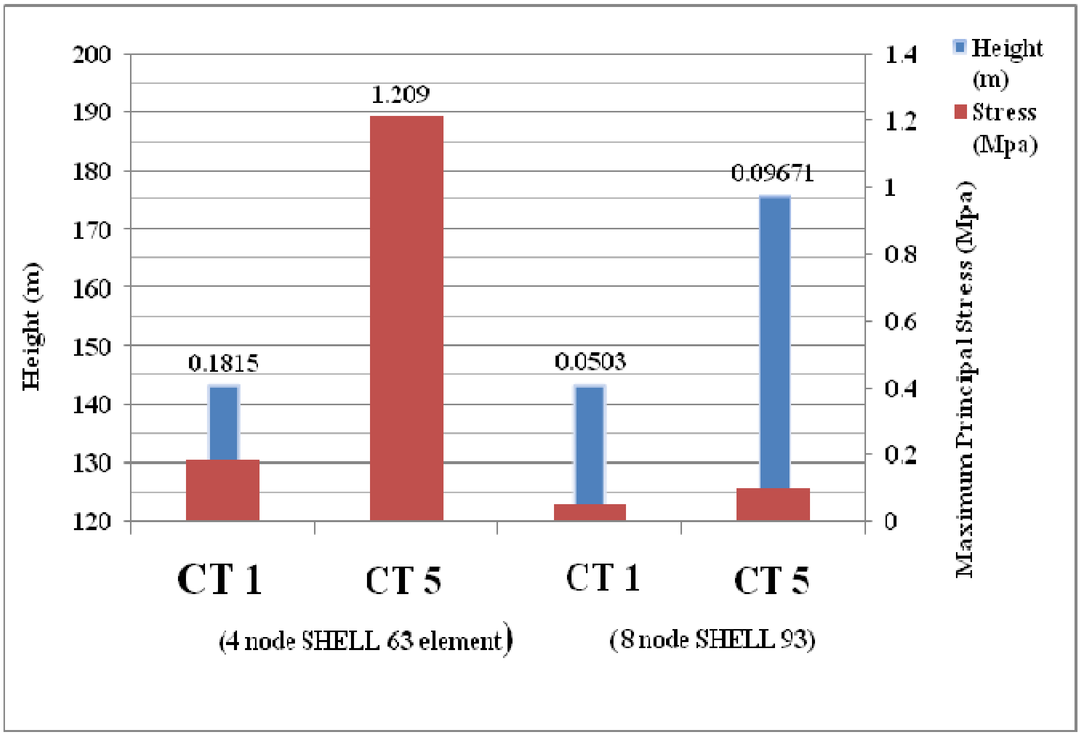


Fig 11: Von Mises Strain for CT 1



Graph 1: Graphical Representation of Stress v/s Height for Maximum principal stress for CT 1, CT 2, CT 3, CT 4, and CT5 for 200mm SHELL thickness



Graph 2: Graphical Representation of Height v/s Element type for various stresses for CT 1& CT5 for different element type for 200mm SHELL thickness

3.2 Modal analysis

Modal analysis is carried out for two existing cooling towers i.e. CT 1 & CT 5. This method is used to calculate Natural frequency and mode shapes. The Geometry of the model is created in ANSYS by using key points. By assigning the loads and boundary conditions to the model and selecting Modal analysis & giving number of modes to extract as 50 frequencies and solve the problem. The results are compiled in general post processor.

Characteristics of cooling tower 1 for 200mm thickness and Mode 1 for Modal analysis are shown below (Refer Fig no: 12 to 15).

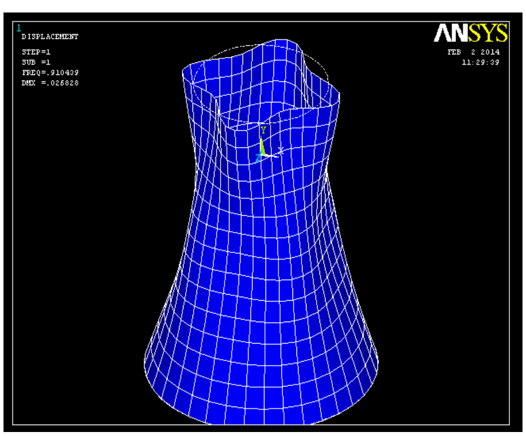


Fig 12: Deflection for CT 1 (Mode 1)

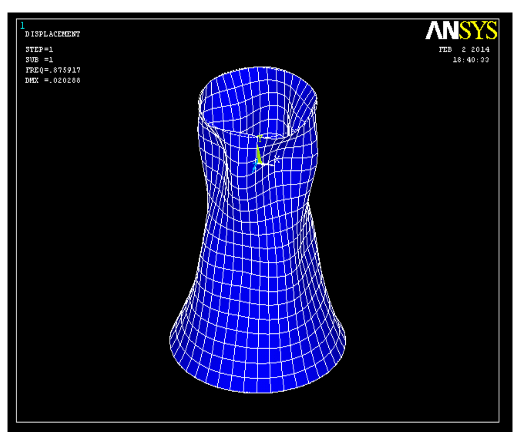


Fig 13: Deflection for CT 5 (Mode 1)

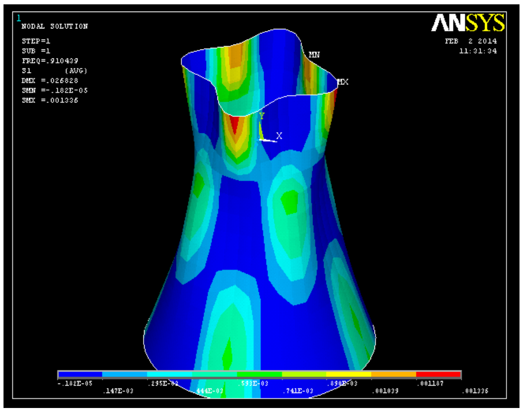


Fig 14: Max Principal Stress for CT 1

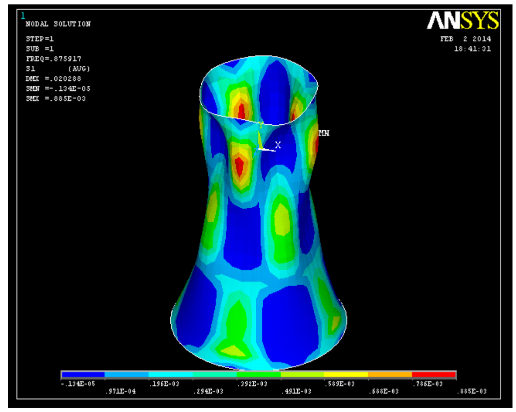


Fig 15: Max Principal Stress for CT 5

Table 2: Results of Modal Analysis for CT 1

Thickness (mm)	Modes	Frequency (HZ)	Maximum Principal stress (Mpa)
200	1	0.8759	0.885×10^{-3}
	5	1.005	0.924×10^{-3}
	10	1.087	0.952×10^{-3}
250	1	0.93833	0.964×10^{-3}
	5	1.057	0.00143
	10	1.132	0.865×10^{-3}
300	1	1.009	0.001048
	5	1.085	0.717×10^{-3}
	10	1.205	0.001526
350	1	1.058	0.755×10^{-3}
	5	1.088	0.679×10^{-3}
	10	1.245	0.989×10^{-3}
400	1	1.081	0.718×10^{-3}
	5	1.165	0.001194
	10	1.31	0.001054
450	1	1.095	0.623×10^{-3}
	5	1.249	0.001218
	10	1.382	0.001114
500	1	1.10	0.601×10^{-3}
	5	1.293	0.791×10^{-3}
	10	1.458	0.001167

Table 3: Results of Modal Analysis for CT 5

Thickness (mm)	Modes	Frequency (HZ)	Maximum Principal stress (Mpa)
200	1	0.8759	0.885×10^{-3}
	5	1.005	0.924×10^{-3}
	10	1.087	0.952×10^{-3}
250	1	0.93833	0.964×10^{-3}
	5	1.057	0.00143
	10	1.132	0.865×10^{-3}
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	10	1.31	0.001054
450	1	1.095	0.623×10^{-3}
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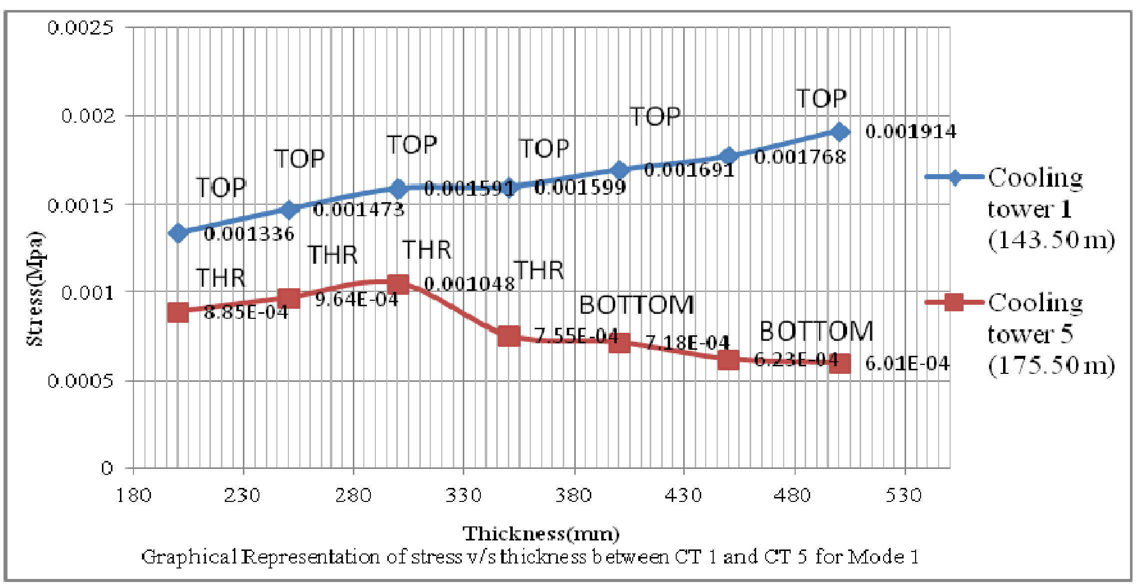
500	1	1.10	0.601×10^{-3}
	5	1.293	0.791×10^{-3}
	10	1.458	0.001167



Graph 3: Graphical Representation of Stress v/s thickness for CT 1& CT5 in (Mode 1)

3.3 Response Spectra Analysis: 0.5g, 0.6g & 0.7g

Response spectrum analysis is carried out for 0.5g, 0.6g & 0.7g for two existing cooling towers i.e. CT 1 & CT 5. The Geometry of the model is created in ANSYS by using key points & input material models, shell element & make mesh to model in Pre processor. By assigning the loads & boundary conditions to the model and before Spectrum analysis, modal analysis is carried out, after that select spectrum analysis & apply all input data's such as frequencies, seismic co-efficient, square root sum of squares (SRSS) method and solve the problem in solution & read the results in General post processor. Models of cooling tower 1 & 5 for deflection, maximum principal stress are as shown below. (Refer Fig 16 to 19).

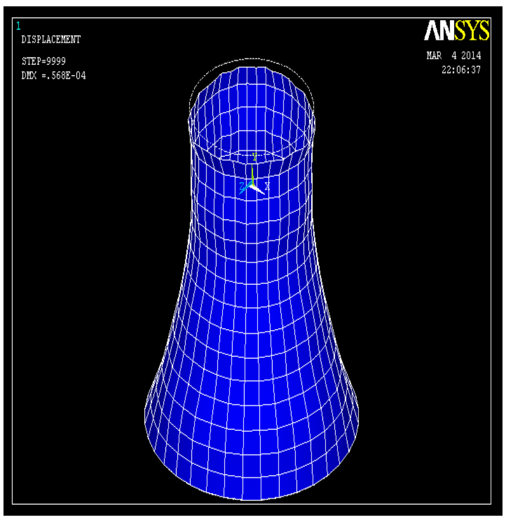


Fig 16: Deflection at 0.5g for CT 1

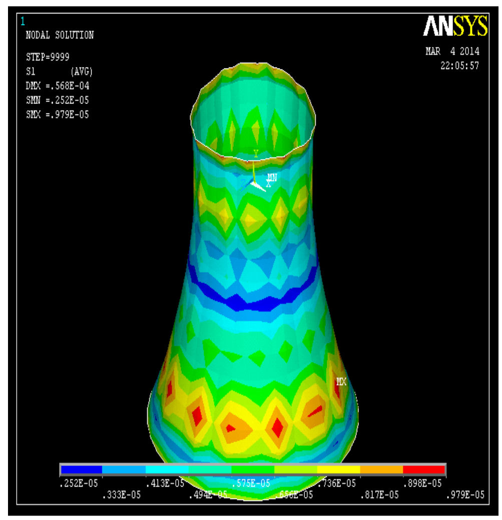


Fig 17: Max Principal Stress for CT 1 (0.5g)

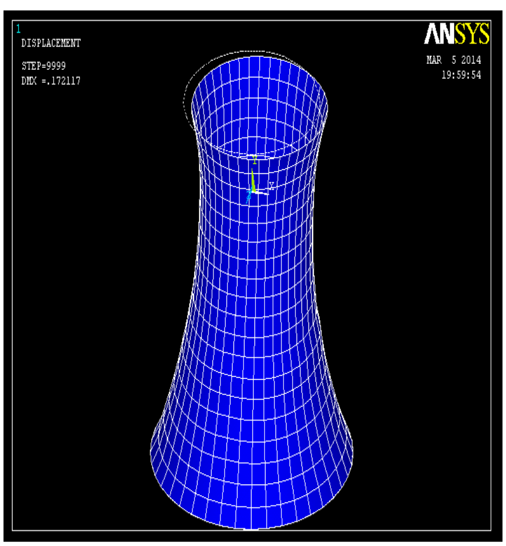


Fig 18: Deflection at 0.5g for CT 5

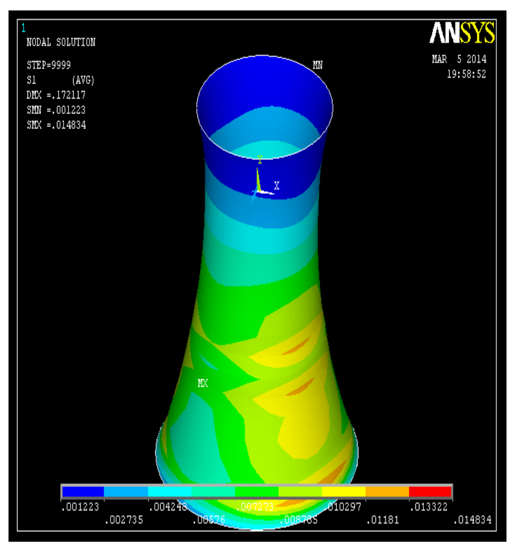
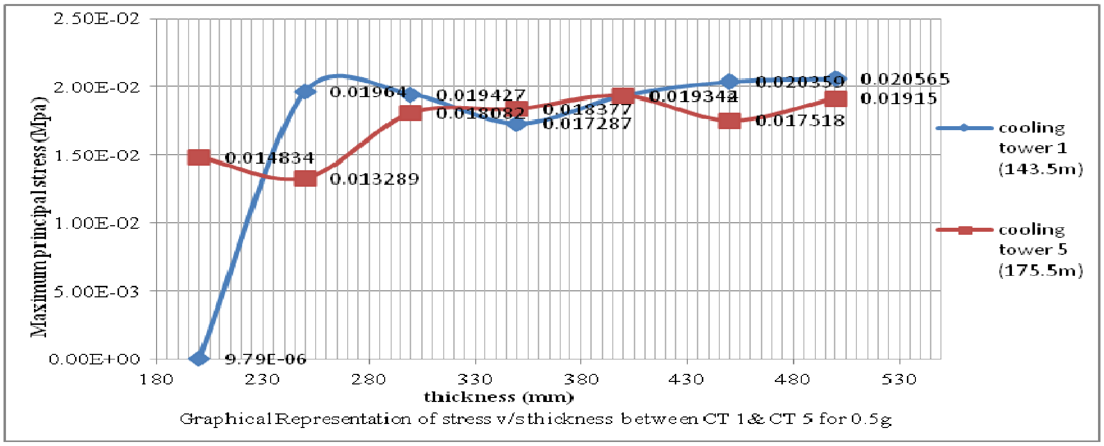
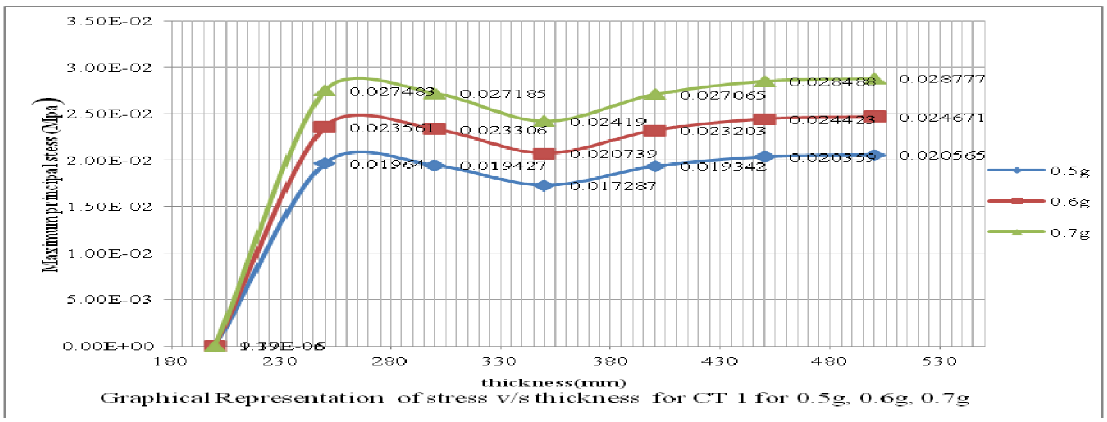


Fig 19: Max Principal Stress for CT 5 (0.5g)



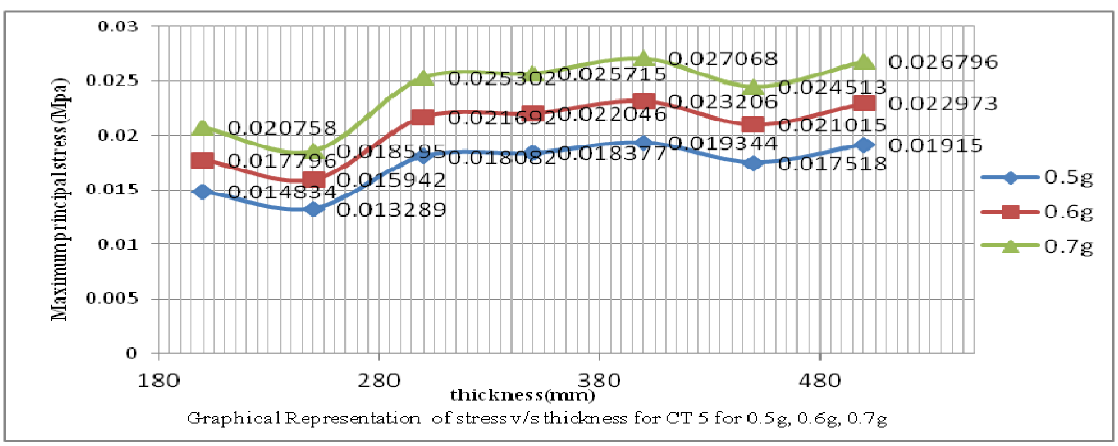
Graphical Representation of stress v/s thickness between CT 1& CT 5 for 0.5g

Graph 4: Graphical Representation of Stress v/s thickness between CT 1& CT 5 for 0.5g



Graphical Representation of stress v/s thickness for CT 1 for 0.5g, 0.6g, 0.7g

Graph 5: Graphical Representation of Stress v/s thickness for CT 1(0.5g, 0.6g, 0.7g)



Graphical Representation of stress v/s thickness for CT 5 for 0.5g, 0.6g, 0.7g

Graph 6: Graphical Representation of Stress v/s thickness for CT 5 (0.5g, 0.6g, 0.7g)

3.4 Wind Analysis

Wind analysis is carried out for two existing cooling towers i.e. CT 1 & CT 5. Geometry of the model is created in ANSYS by using key points & input material models, shell element & make mesh to model 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. Models of CT 1 & CT 5 for Deflection, Maximum principal stress are shown below (Refer Fig no 20 to 25).

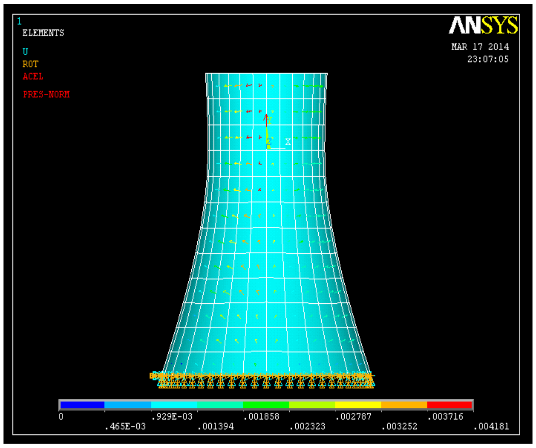


Fig 20: Wind Pressure applied for CT 1

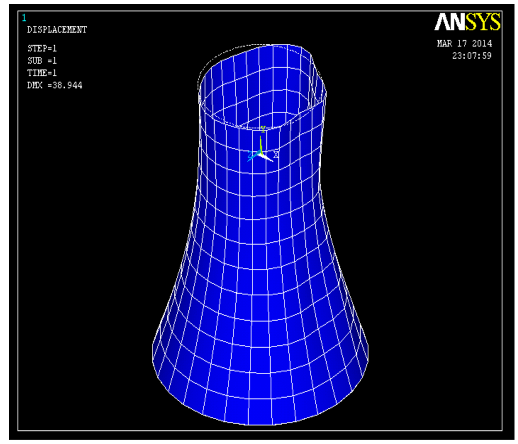


Fig 21: Deflection for CT 1

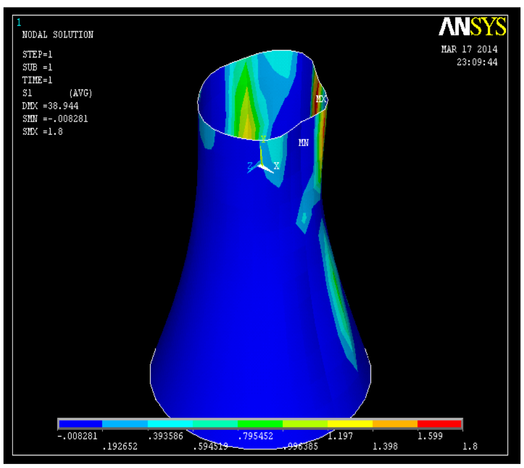


Fig 22: Max Principal Stress for CT 1

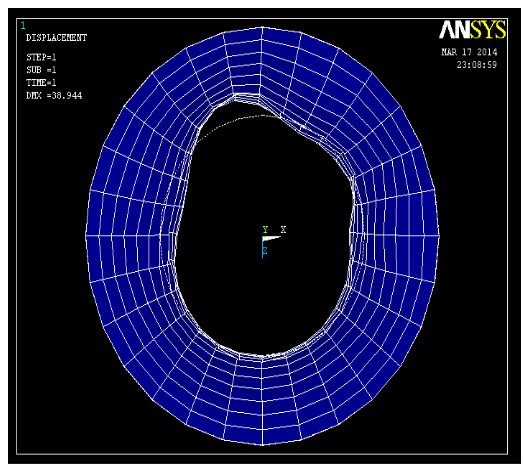


Fig 23: Deflection at Top for CT 1

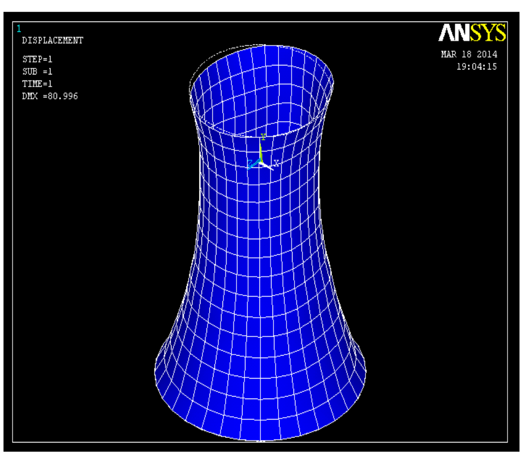


Fig 24: Deflection for CT 5

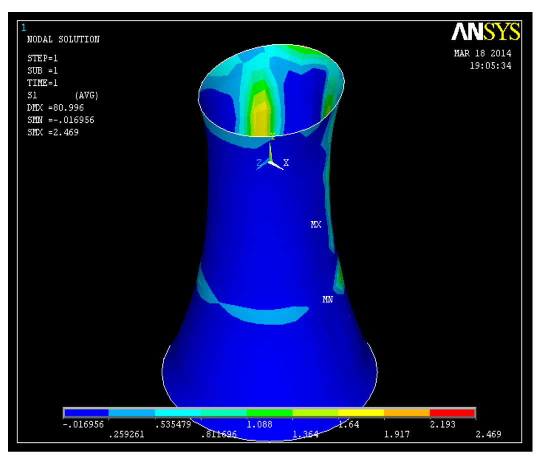
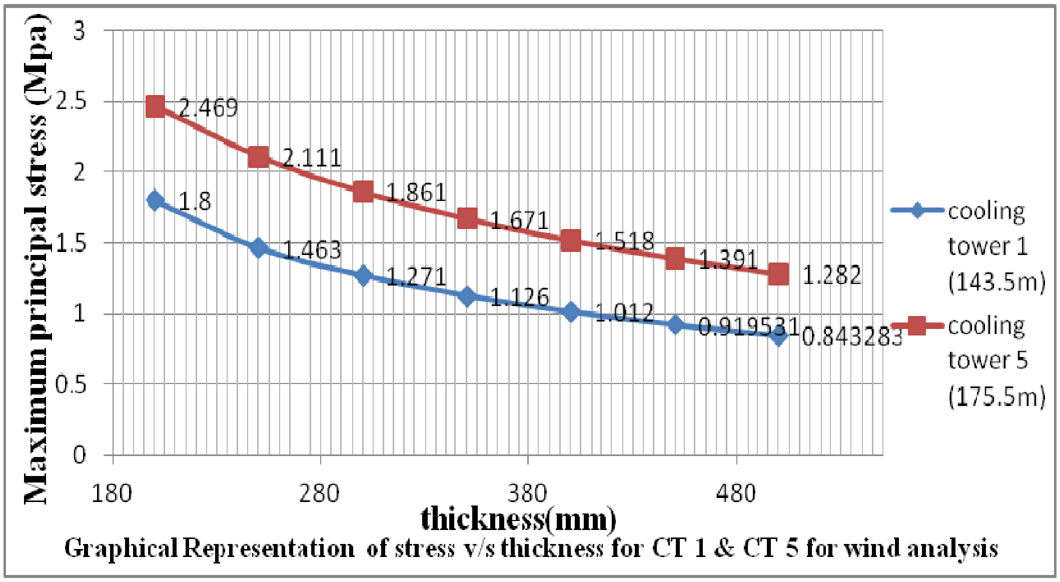


Fig 25: Max Principal Stress for CT 5



Graph 7: Graphical Representation of Stress v/s thickness for CT 1 & CT 5 for wind analysis

3.5 Buckling Analysis

Buckling Analysis is carried out for two existing cooling towers (CT 1& CT 5) due to its self weight & varying thicknesses. Eigen buckling analysis is a technique used to determine buckling loads (critical loads at which a structure becomes unstable) and buckled mode shapes (the characteristic shape associated with a structure's buckled response).

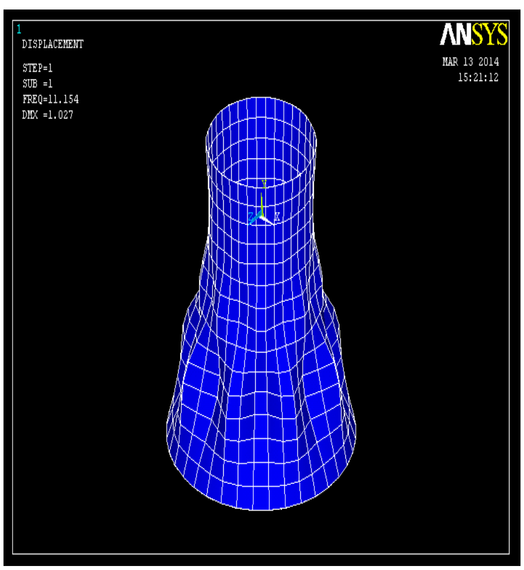


Fig 27: Deflection for CT 1

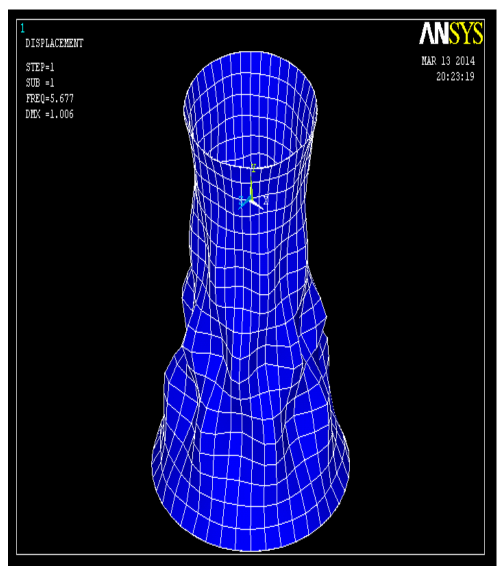


Fig 28: Deflection for CT 5

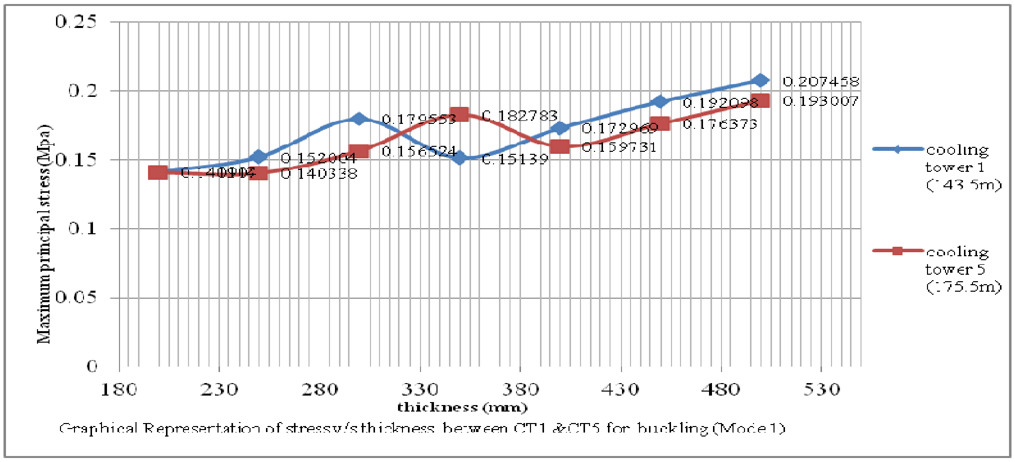
(Buckling mode 1) for 200mm SHELL thickness

Table 4: Results of Buckling analysis for CT 1

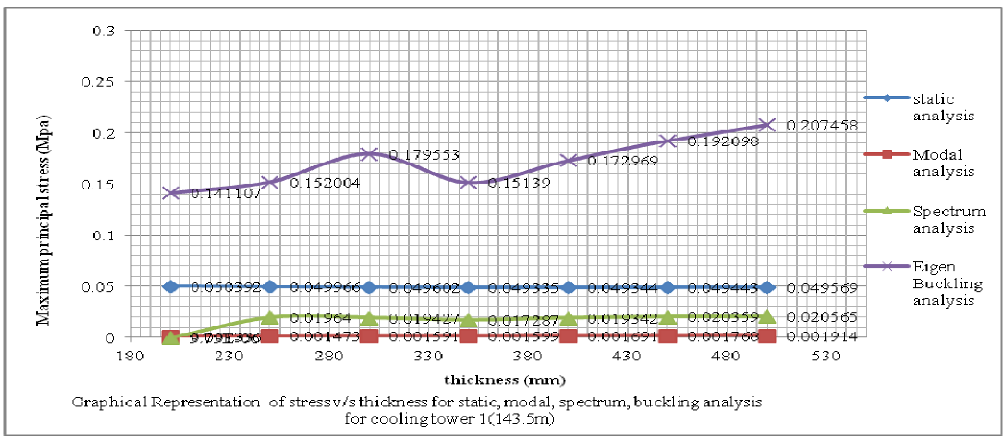
Thickness (mm)	Modes	Frequency (HZ)	Maximum Principal stress (Mpa)
200	1	11.154	0.141107
	3	11.589	0.121869
	5	11.645	0.152701
250	1	15.062	0.152004
	3	15.177	0.176925
	5	15.272	0.111382
300	1	19.013	0.179553
	3	19.046	0.129468
	5	19.806	0.211512
350	1	23.131	0.15139
	3	23.44	0.192193
	5	24.961	0.227134
400	1	27.508	0.172969
	3	28.32	0.212251
	5	29.343	0.12819
450	1	32.172	0.192098
	3	33.495	0.139156
	5	33.616	0.238148
500	1	37.118	0.207458
	3	37.896	0.154163
	5	39.279	0.263028

Table 5: Results of Buckling analysis for CT 5

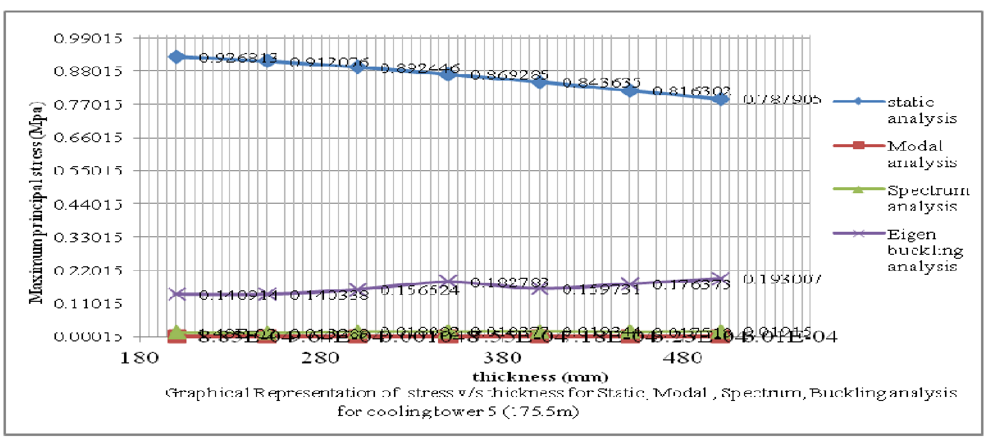
Thickness(mm)	Modes	Frequency (HZ)	Maximum Principal stress (Mpa)
200	1	5.677	0.140914
	3	6.349	0.170463
	5	7.144	0.105226
250	1	7.55	0.140338
	3	8.597	0.166921
	5	8.701	0.110335
300	1	9.645	0.156524
	3	10.406	0.126587
	5	11.152	0.191002
350	1	11.992	0.182783
	3	12.291	0.143113
	5	14.033	0.233165
400	1	14.372	0.159731
	3	14.603	0.209092
	5	17.242	0.256321
450	1	16.654	0.176373
	3	17.484	0.227851
	5	20.773	0.288999
500	1	19.143	0.193007
	3	20.638	0.249987
	5	23.365	0.150298



Graph 8: Graphical Representation of Stress v/s thickness for CT 1& CT 5 for buckling mode 1



Graph 9: Graphical Representation of Stress v/s thickness for CT 1 for static, modal, spectrum, buckling analysis



Graph 10: Graphical Representation of Stress v/s thickness for CT 5 for static, modal, spectrum, buckling analysis

4.0 CONCLUSIONS

1) On comparing all cooling towers (i.e. CT 1, CT 2, CT 3, CT 4, CT 5) in static analysis (self weight of tower), CT 3 & CT 4 shows least maximum principal stress among all cooling towers and prove to be the optimum cooling towers for shell thickness of 200mm.(Refer graph 1).
2) The Maximum principal stress for two existing cooling towers (CT 1 & CT 5) shows higher value on using 4 noded SHELL 63 element as compared to 8 noded SHELL 93 element. (Refer graph 2).
3) In free vibration analysis for both existing cooling towers.

   a) As thickness of shell increases, stress goes on increasing for CT 1 at TOP region in mode 1.
   b) As thickness of shell increases, stress gradually decreases from throat to bottom region for CT 5 in and TOP remains minimum.(Refer graph 3)

4) In Modal analysis, On comparing CT 1 & CT 5 cooling towers, CT 5 shows less maximum principal stress with increasing thickness in mode 1 and stress shifts from throat to bottom region.
5) In Modal analysis, the natural frequencies for CT 1 are more as compared to CT 5 with increasing thickness in selected modes i.e. Mode1, Mode 5 and Mode 10. (Refer table 2).
6) In Response spectrum analysis for 0.5g, 0.6g, 0.7g ground acceleration.

   a) The variation of Maximum Principal Stress for CT 1 of 200mm and 250mm thicknesses are minimum and maximum respectively whereas, CT 5 behaves conversely. (Refer graph 4).
   b) The variation of Maximum Principal Stress for CT 1 of 300mm, 350mm thicknesses are maximum & minimum respectively whereas, CT 5 behaves conversely. (Refer graph 4).

7) In Response spectrum analysis maximum principal stress for CT 1& CT 5 are same for 400mm thickness and shows optimality. (Refer graph 4).
8) In wind analysis, as thickness increases, deflection & maximum principal stress decreases for both existing cooling towers CT 1 & CT 5. (Refer graph 7).
9) In wind analysis, the degree of distortion increases with height of tower, hence deflection is maximum in CT 5.
10) In Buckling analysis, the buckling of CT 1 is maximum as compared to CT 5, CT 5 shows less buckling due to its size, symmetric geometry of shell for increasing thickness. (Refer Fig 27 & 28).
11) In Dynamic analysis, wind loads are dominating as compared to earthquake forces in zone III.
12) On Comparing CT 1 & CT 5, CT 5 gives optimum results for all analysis and is best suited cooling tower. (Refer graph 9 & 10).

5.0 REFERENCES

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