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MODAL ANALYSIS OF REINFORCED CONCRETE COOLING TOWERS

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Abstract: *This paper deals with the study of modal analysis of hyperbolic cooling towers. Two existing cooling towers are chosen from Bellary thermal power station (BTPS) as case study. FEA based ANSYS Software is used for the analysis. 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. The analysis is carried out using 8 noded SHELL 93 element. Natural frequencies, 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.*

Keywords— *Cooling tower, Element, FEA, Mises, Stress, Strain, SHELL,*

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 and stability and larger available area at the base. 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. Natural draughts cooling towers (NDCT) is the characterizing landmarks of power stations and are 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 are subjected to environmental loads such as Seismic and thermal gradients that is stochastic in nature. A series of a hyperbolic cooling tower is as shown in Fig-1

Fig-1: Group of Natural draught cooling towers

The present day hyperbolic cooling tower is exceptional structures in view of their shear size and complexities. The towers involve considerable amount of design work on structural aspect. The analysis of these towers is an interesting and challenging to any structural engineer in view of their size and shape.

II. INTRODUCTION TO MODAL ANALYSIS

Modal analysis is a method or a process or a technique to describe a structure in terms of its natural characteristics which are (its dynamic properties),

1) Natural frequency
2) Damping
3) Mode participation factors
4) Mode shapes

Modal analysis is a most fundamental of all the dynamic analysis types. Following are the benefits of modal analysis,
1) It allows the design to avoid resonant vibrations or to vibrate at a specified frequency (Speakers, for example).
2) It gives engineers an idea of how the design will respond to different types of dynamic loads.

Because a structure's vibration characteristics determine how it responds to any type of dynamic load, it is always suggested to perform a modal analysis first before performing any other dynamic analysis. Modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions. They are also required if you want to perform spectrum analysis or a mode-superposition harmonic or transient analysis.

III. FINITE ELEMENT PROGRAM (ANSYS)

Computer implementation of finite elements and solution procedures for engineering analysis is addressed. The end product is a general-purpose finite element analysis program. For such software to be used as an effective CAE tool, the programming should be hardware independent. The chosen finite elements and numerical methods must be accurate and reliable. The program should be executable on a given platform of choice - single processor, multiprocessor, parallel processor, etc. A general purpose FEA program consists of three modules: a preprocessor, a solver, and a postprocessor. Commercial FEA programs can handle very large number of nodes and nodal degrees of freedom provided a powerful hardware is made available. User's manual, theoretical manual, and verification problems manual, document a commercial FEA program. At present FEA programs are used rather than written. Understanding of the organization, capabilities, and limitations of commercial FEA programs is generally more important than an ability to develop or even modify a FEA code.

ANSYS is a complete FEA simulation software package developed by ANSYS Inc-USA. The company was founded in 1970 by Dr. JOHN SWANSON and originally named as Swanson Analysis systems; Inc. ANSYS is the original name for the commercial products. ANSYS have a big family of products, which are developed to deal with special purpose problems. ANSYS/Multiphysics is one of the product of ANSYS which covers most of the engineering disciplines such as structural, thermal, electromagnetic, and computational fluid dynamics.

IV. ANSYS SOFTWARE (PROCEDURE)

Several mode-extraction methods are available in ANSYS software

1) Block Lanczos method (default)
2) Sub space method
3) PCG Lanczos
4) Power Dynamics method
5) Reduced (Householder) method
6) Unsymmetric method
7) Damped method
8) QR damped method

1) Block Lanczos (default)
This method is used to extract modes and natural frequencies. In modal analysis by using Block Lanczos method, 50 numbers of modes are extracted. The block Lanczos eigenvalue solver is the default. It uses the Lanczos algorithm where the Lanczos recursion is performed with a block of vectors. This method is accurate as sub space method, but faster. The block lanczos method uses the spare matrix solver. The Block Lanczos method is especially powerful when searching for eigen frequencies in a given part of the eigen value spectrum of a given system. The convergence rate of the eigen frequencies will be about the same when extracting modes in the mid range and higher end of the spectrum as when extracting the lowest modes. Therefore, when you use a shift frequency (FREQB on MODOPT) to extract 'n' modes beyond the starting value of FREQB, the algorithm extracts the n modes beyond FREQB at about the same speed as it extracts the lowest n modes.

V. 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 143.50 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 175.50 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

$$\frac{R_o^2}{a_o^2} - \frac{Y^2}{b^2} = 1$$

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.

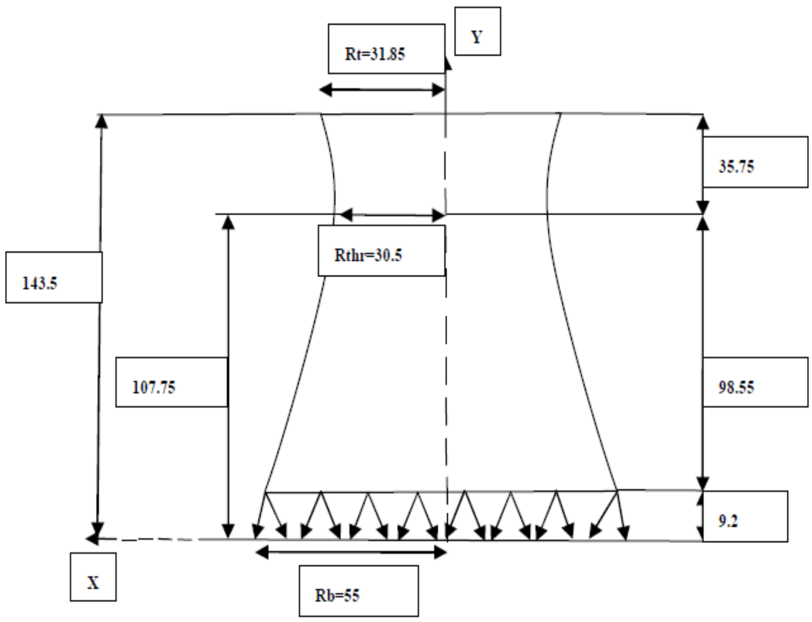


Figure 2: Geometry of Existing Cooling Tower (BTPS) CT 1 (143.50 m)

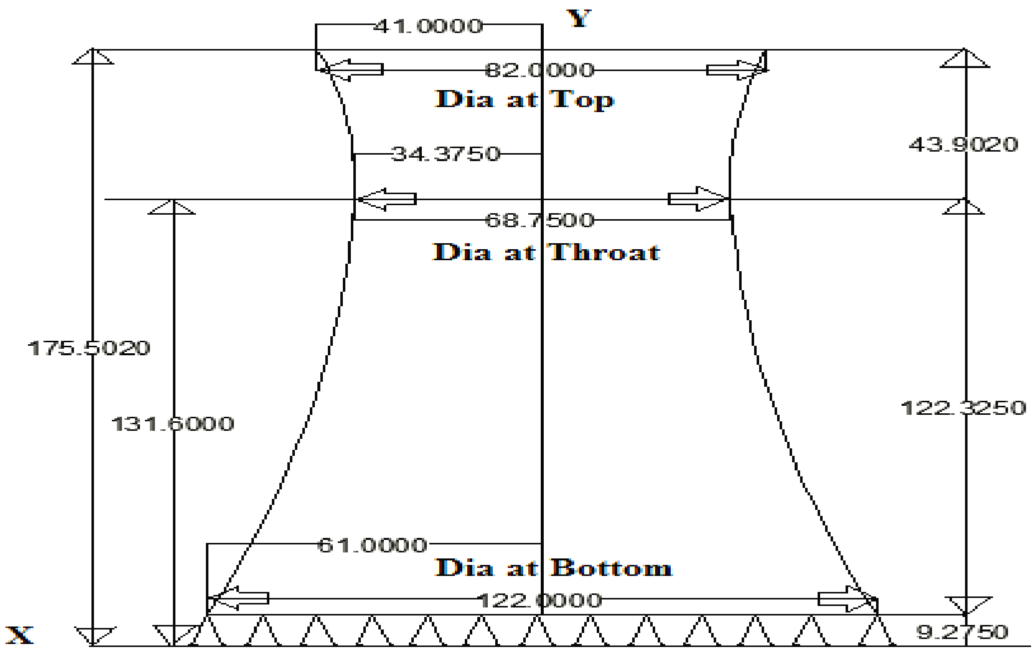


Figure 3: Geometry of Existing Cooling Tower (BTPS) CT 2 (175.50 m)

Table 1: Geometric Details of Cooling Towers

Sl no	Description	Symbols	Cooling tower 1 (CT 1)	Cooling tower 2 (CT 2)
1	Total height	H	**143.50m**	**175.50m**
2	Height of throat	Hthr	**107.75m**	**131.60m**
3	Diameter at top	Dt	**63.6m**	**82.00m**
4	Diameter at bottom	Db	**110m**	**122.00m**
5	Diameter at throat level	Dthr	**61.0m**	**68.750m**
6	Column Height	Hc	**9.20m**	**9.275m**
7	(Hthr/H) ratio		**0.750**	**0.749**
8	(Dthr/D) ratio		**0.554**	**0.563**

Analysis is carried out for uniform shell thickness from 200mm, 250mm, 300mm, 350mm, 400mm, 450mm, and 500mm.

VI. MATERIAL PROPERTIES FOR ANALYSIS OF COOLING TOWER (CT)

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

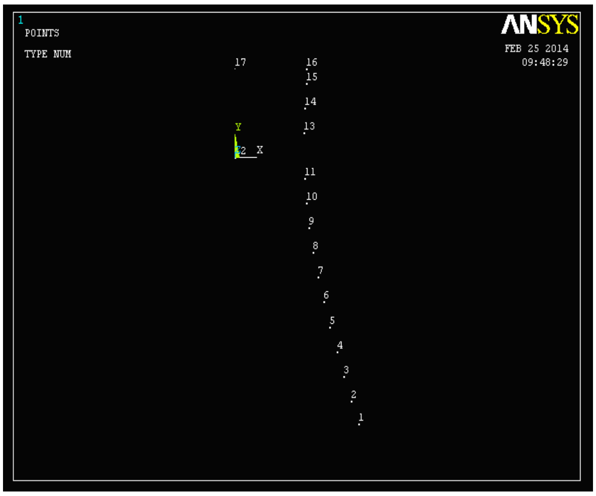


Fig 4: Key points to create Cooling tower

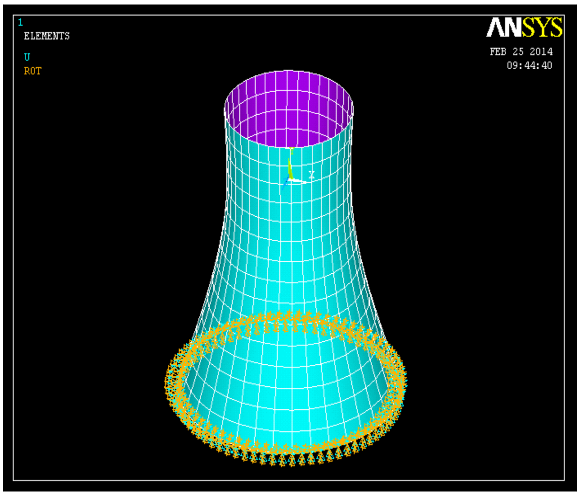


Fig 5: Boundary condition

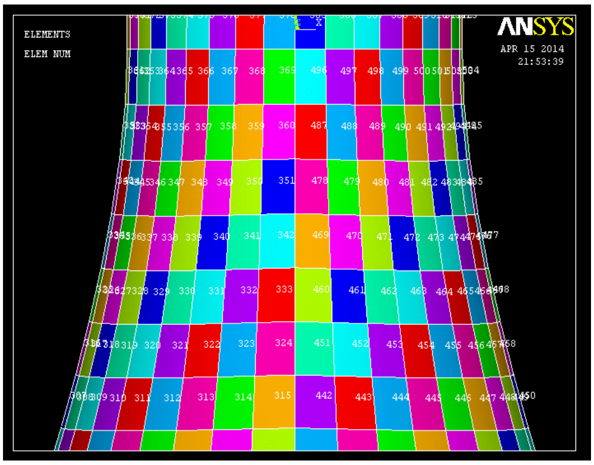


Fig 6: Element numbers in model

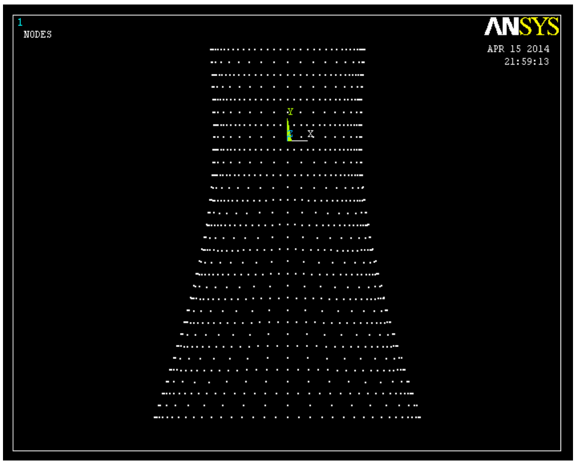


Fig 7: Nodes in model

Models of Cooling tower 1 (143.50 m) for 200mm thickness in Mode 1

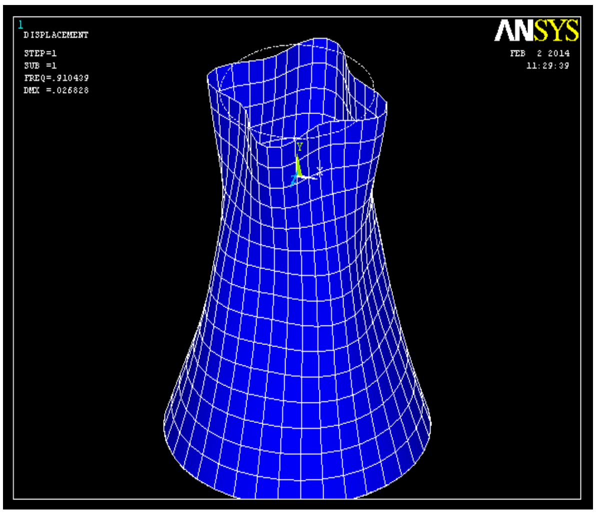


Fig 8: Deflection of CT 1 (Mode 1)

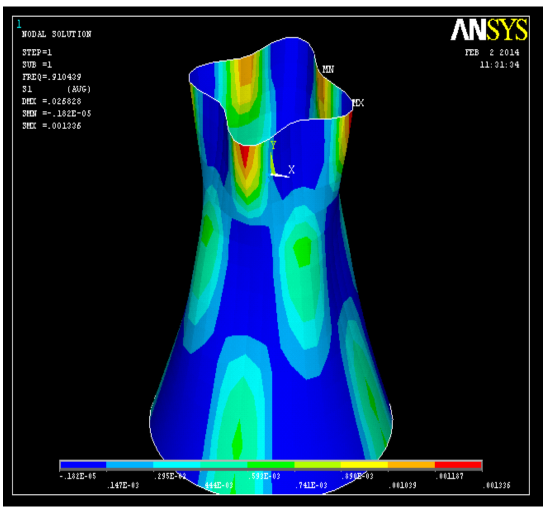


Fig 9: Maximum Principal Stress for CT 1 (Mode 1)

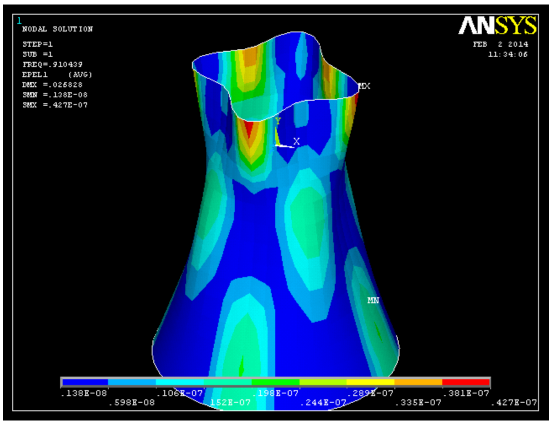


Fig 10: Maximum Principal Strain for CT 1

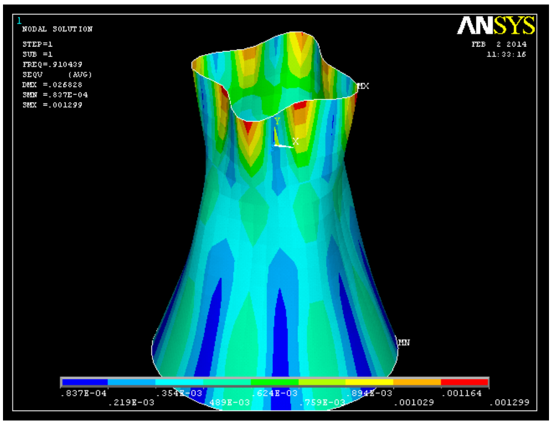


Fig 11: Von Mises stress for CT 1

The Characteristics Models for cooling tower 1 and cooling tower 2 for varying shell thickness of 200mm, 250mm, 300mm, 350mm, 400mm, 450mm and 500mm are developed in selected modes of 1, 5 and 10 mode. The Models of CT 1 for 200mm shell thickness in mode 1 is as shown in fig 8 to 11.

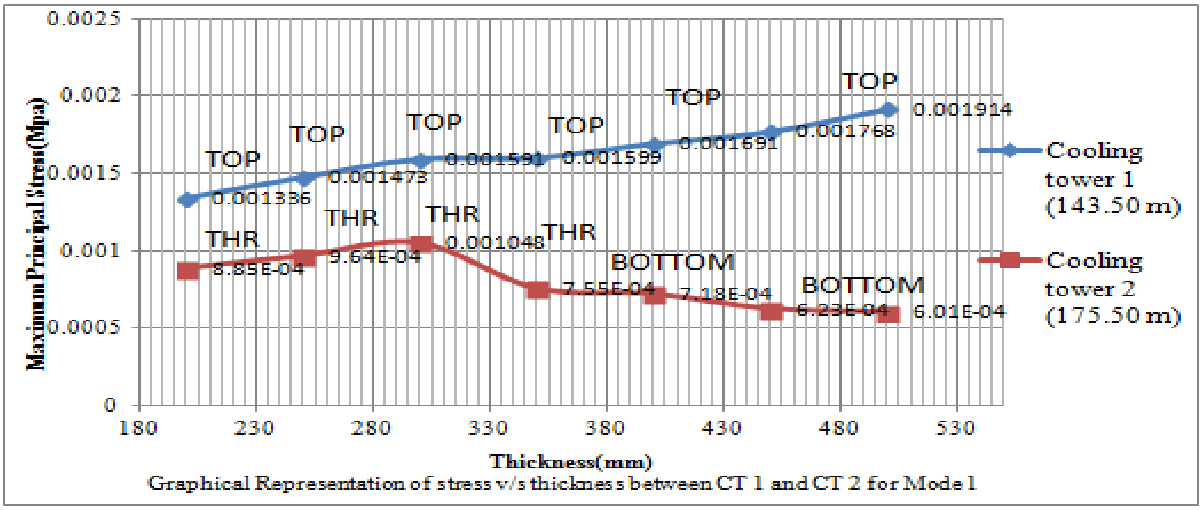
Table 2: Results of Modal Analysis for CT 1

Thickness (mm)	Modes	Frequency (HZ)	Maximum Principal Stress (Mpa)
200	1	0.91043	0.001336
	5	1.260	0.00169
	10	1.322	0.002749
250	1	0.98413	0.001473
	5	1.357	0.001154
	10	1.423	0.002071
300	1	1.067	0.001591
	5	1.376	0.001064
	10	1.531	0.920×10^{-3}
350	1	1.156	0.001599
	5	1.454	0.835×10^{-3}
	10	1.533	0.852×10^{-3}
400	1	1.251	0.001691
	5	1.476	0.775×10^{-3}
	10	1.626	0.001748
450	1	1.349	0.001768
	5	1.501	0.821×10^{-3}
	10	1.763	0.001597
500	1	1.449	0.001914
	5	1.528	0.853×10^{-3}
	10	1.891	0.001721

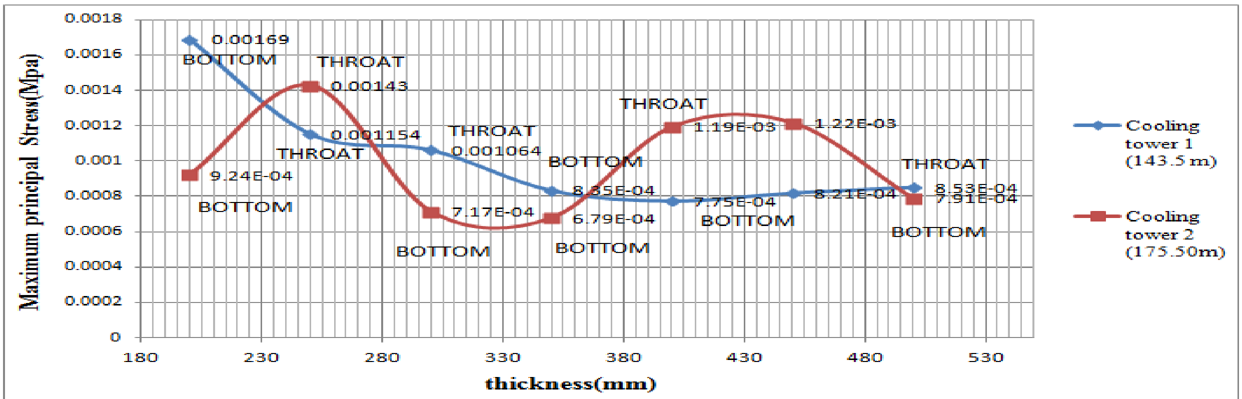
Table 3: Results of Modal Analysis for CT 2

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

VII. GRAPHS

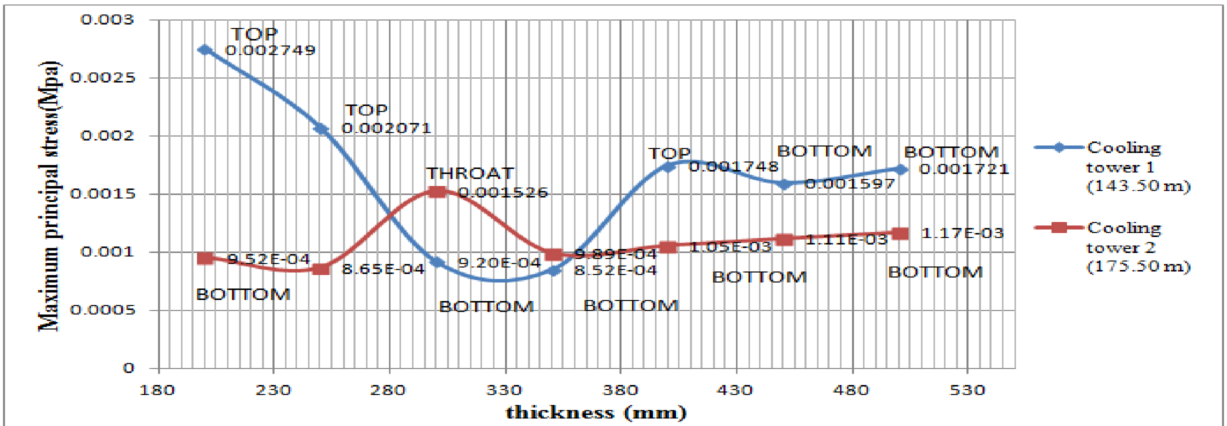


Graph 1: Graphical Representation of Stress v/s thickness between CT 1 and CT 2 (Mode 1)



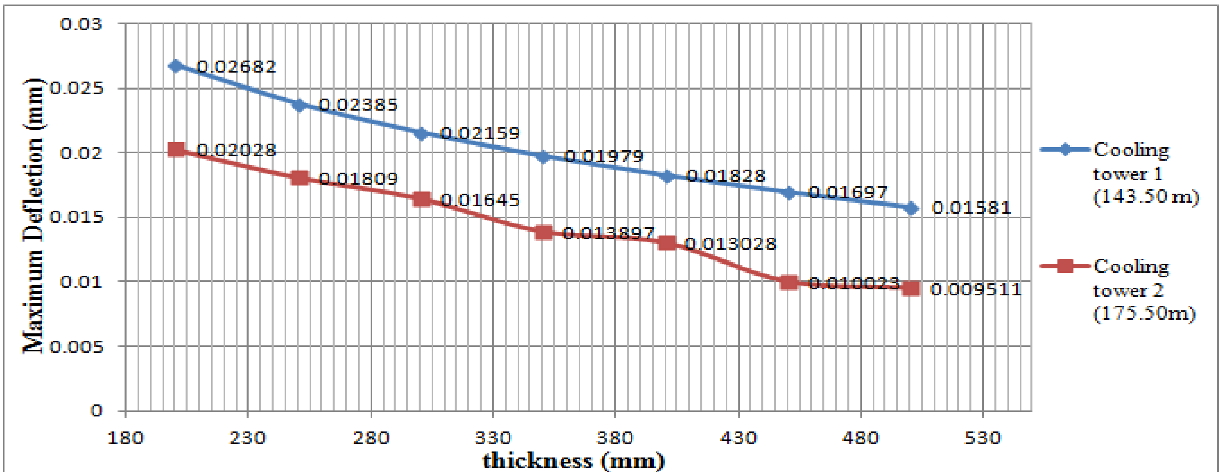
Graphical Representation of Stress v/s thickness between CT 1 & CT 2 for Mode 5

Graph 2: Graphical Representation of Stress v/s thickness between CT 1 and CT 2 (Mode 5)



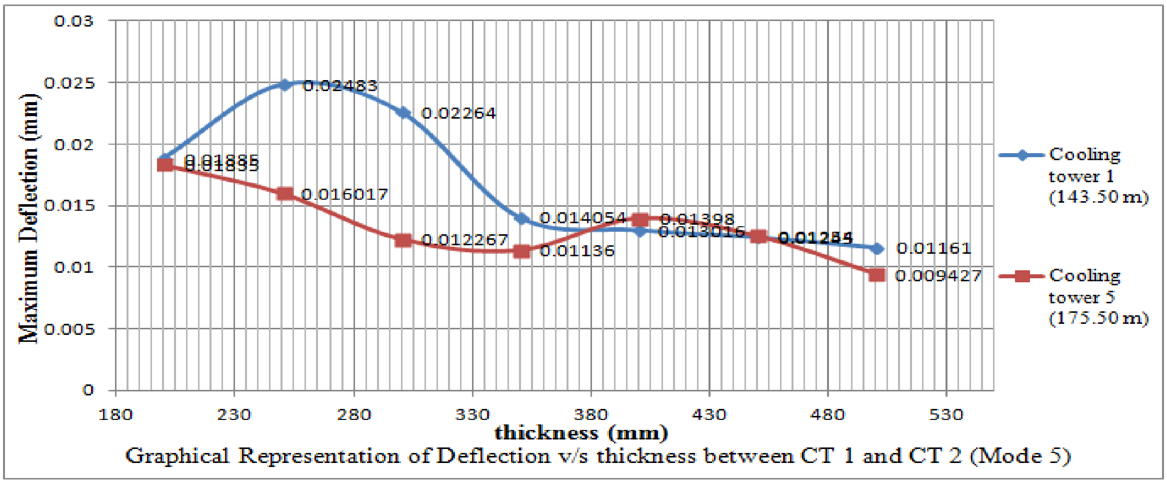
Graphical Representation of Stess v/s thickness between CT 1 & CT 2 for Mode 10

Graph 3: Graphical Representation of Stress v/s thickness between CT 1 and CT 2 (Mode 10)

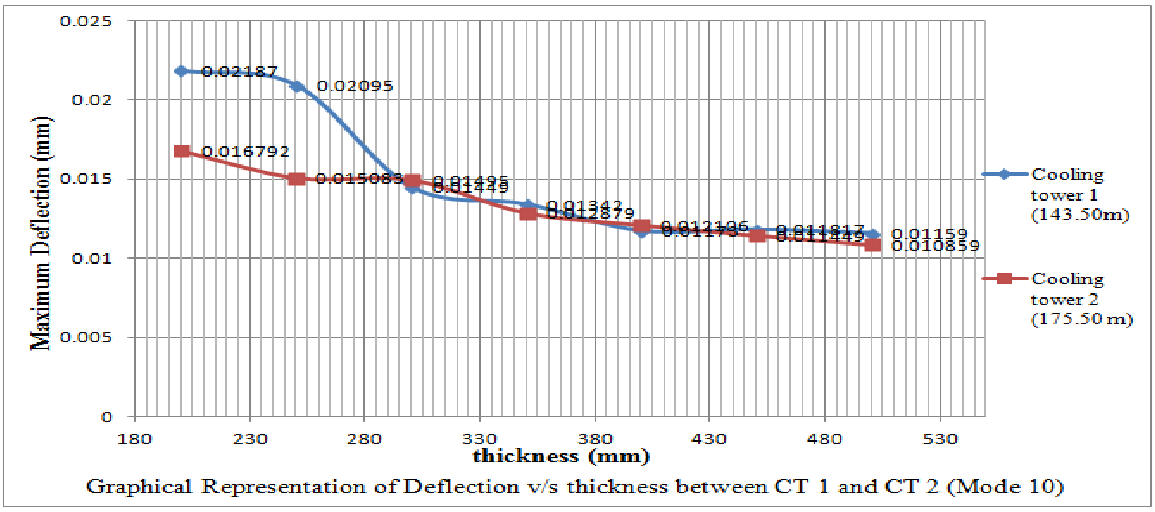


Graphical Representation of Deflection v/s thickness between CT 1 and CT 2 (Mode 1)

Graph 4: Graphical Representation of Deflection v/s thickness between CT 1 and CT 2 (Mode 1)



Graph 5: Graphical Representation of Deflection v/s thickness between CT 1 and CT 2 (Mode 5)



Graph 6: Graphical Representation of Deflection v/s thickness between CT 1 and CT 2 (Mode 10)

VIII. SUMMARY & CONCLUSIONS

A) From Graphical Representation of stress v/s thickness, it is evident that

1) In Mode 1

a) As thickness increases, Maximum Principal Stress goes on increasing for CT 1 at TOP region for Mode 1.

b) As thickness increases, Maximum Principal Stress decreases from THROAT to BOTTOM region for CT 2(Mode 1).

2) In Mode 5

a) As thickness increases, Max stress concentration shifts from BOTTOM to THROAT region respectively. However the value of Principal stress decreases in THROAT region as compared to BOTTOM region & remaining almost constant thereafter in CT 1.

b) As thickness increases, Max principal stress shifts from THROAT to BOTTOM region respectively. However the value of Principal stress decreases in BOTTOM region as compared to THROAT region and remaining almost constant thereafter in CT 2.

3) In Mode 10

a) As thickness increases, Max stress concentration shifts from TOP to BOTTOM region respectively. However the value of Principal stress decreases in BOTTOM region as compared to TOP region & remaining almost constant thereafter in CT 1.

b) As thickness increases, Max stress concentration shifts from BOTTOM to THROAT region respectively. However the value of principal stress decreases in THROAT region as compared to BOTTOM region & remaining almost constant thereafter in CT 2.

4) On Comparing CT 1 (143.5m) & CT 2 (175.50m) cooling towers, Maximum Principal Stress is decreasing for CT 2 in Mode 1 for increasing thickness.

B) From Graphical Representation of Deflection v/s thickness, it is evident that

1) As thickness increases, Deflection goes on decreasing for CT 1 & CT 2 in Mode 1.
2) As thickness increases, Deflection is minimum for CT 2 as compared to CT 1 till 350mm thickness respectively. For 400mm thickness it behaves conversely in Mode 5.
3) For shell thickness of 200mm, 380mm, 450mm deflection is almost same for CT 1 & CT 2 and shows optimality in Mode 5.
4) For shell thickness of 300mm, 350mm, 400mm, 450mm, 500mm, deflection is same for CT 1 & CT 2 and shows optimality in Mode 10.

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