Effect of Buckling on Analysis of Hyperbolic Cooling Towers

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Abstract- **The Present paper deals with the study of buckling effect on hyperbolic cooling towers. Three cooling towers CT 1 (143.50m), CT 2 (150.67m), CT 3 (157.85m) with different heights and shell thicknesses are considered for the analysis. Eigen buckling analysis is carried out for three cooling towers using FEA based ANSYS software. Cooling towers are modeled considering top end free and bottom end fixed. . The material properties to model the cooling tower considered are young's modulus 39GPa, Poisson's Ratio 0.2 and density of RCC 25 kN/m$^{3.}$ Eigen buckling analysis has been carried out using 4 noded SHELL 181 element by Block lanczos method. The finite shell element and mesh size considered in the analysis are obtained by carrying out detailed convergence study. Three cases are considered in the analysis in order to study the effect of height of cooling tower and shell thickness. Case 1- Height is kept constant and shell thickness is varied from 200mm to 600mm. Case 2- Height is varied and shell thickness is kept constant. Case 3- Both height and shell thickness of cooling tower is varied.**

The Behavioral changes due to stress concentration of cooling towers are analyzed using ANSYS 10 (SHELL 181) element with varying its height and thickness for first 5 buckling modes. Maximum Deflection, frequencies, Maximum Principal Stresses and strain, Maximum Von Mises stress, strains are obtained. The Variation in Max principal stress v/s SHELL thickness, Max Principal stress v/s height, and Frequencies v/s selected modes, Frequencies v/s SHELL thickness is plotted graphically.

Keywords: Cooling tower, Frequency, shell element, stress, strain

I. INTRODUCTION

Natural Draught Hyperbolic cooling towers are most effective measures for cooling of thermal power plants by minimizing the need of water and avoiding thermal pollution of natural water bodies. Thus they are able to balance environmental factors, investments and operating costs with demands of reliable energy supply. Natural draught cooling tower (NDCT) is the characterizing landmarks of power stations. They contribute both to an efficient energy output and to a careful balance with our environment. Hyperbolic shape of cooling tower is usually preferred due to its strength and stability. In modern construction practices and techniques available in hand has made great impact in designing such towers with very small thickness.

II. INTRODUCTION TO FINITE ELEMENT ANALYSIS

In solving engineering problems, it is necessary to obtain approximate numerical solutions rather than exact closed-form solutions which are very difficult to obtain, or in a lot of cases, unobtainable. The finite element (FE), boundary element (BE), finite difference (FD), finite volume (FV) and spectral methods are examples of numerical method used to obtain approximate solutions. However, in modern engineering analysis it is rare to find a project that does not require some type of finite element analysis (FEA). The finite element method has become more popular now a day, with the advancement of computers and development of various efficient programming languages.

Finite element analysis is one of the powerful numerical techniques to solve the complex physical phenomenon that are governed by the differential equations. During last two decades, the practical advantages of FEA in stress analysis, structural dynamics and thermal analysis have made it a standard solution tool.

A. ANSYS

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.

ANSYS is one of the most popular finite element analysis and computer aided engineering software. It markets two suites of products. Simulation technology (Structural Mechanics, Multiphysics etc) and workflow technology (Workbench platform, High-Performance computing etc).

B. Analysis of Buckling behavior

Linear buckling analysis (LBA) is typically used to find the critical buckling load of a structure. This type of analysis solves the eigenvalue problem and produces a set of eigenvalues and their associated vectors. In practical terms, this analysis produces a set of buckling modes each containing a buckling shape, and a load factor. The lowest of these theoretical load factors should cause the structure to fail in buckling.

C. Linear Buckling Analysis

The geometry and load is linked from the static linear module to the buckling module. The Block lanczos solver is used as it is currently available in ANSYS software. Lanczos algorithm is an iterative energy method to find eigen values and eigen vectors of a square matrix.

III. OBJECTIVES OF PRESENT STUDY

The Present paper discusses the effect of buckling on analysis of hyperbolic cooling towers. The objective of present study is to find the variation in stresses and frequency obtained from eigen buckling analysis. The height and shell thickness of cooling tower is varied considered for the analysis. The eigen buckling analysis is carried out for three cases with varying different parameters, in order to study the effect of LBA.
The shell thickness is varied from 200mm, 300mm, 400mm, 500mm and 600mm.

- Case 1- Height is kept constant and shell thickness is varied from 200mm to 600mm.
- Case 2- Height is varied and shell thickness is kept constant.
- Case 3- Both height and shell thickness of cooling tower is varied.

A] Selection of finite shell element

Convergence study of finite shell elements available in ANSYS software is carried out, in order to validate the proper shell element. The linear static analysis of hyperbolic cooling tower is carried out using different shell elements. The Maximum principal stress, deflection etc are obtained from the analysis, the optimum mesh size and finite shell element was obtained from convergence study.
The mesh ratio/element edge length was varied from 50000 to 1000 (coarse to finer). From convergence study 4 node SHELL 181 element showed convergence for mesh ratio of 15000 and 20000. 4 node SHELL 181 element is used for linear analysis.

4 node SHELL 181 element
SHELL 181 is suitable for analyzing thin to moderately thick shell structure. SHELL 181 is well suited for linear large rotation and/or large strain non linear applications. SHELL 181 may be used for layered applications for modeling laminated composites shells or sandwich construction. The element has six degrees of freedom at each node, translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes. The element is defined by four nodes, four thicknesses.
Geometry: Triangular option (Not recommended)
Output Data: Nodal Displacement included in the overall nodal solution.

Table 1- Different types of shell elements

1)	4 node SHELL 63
2)	4 node SHELL 181
3)	4 node SHELL 41
4)	Elastic 4 node SHELL 63
5)	8 node SHELL 93
6)	8 node SHELL 91
7)	Plastic 4 node SHELL 143
8)	Hyper 4 node SHELL 181
9)	Plastic 4 node SHELL 43

B] Pre-defined properties/Material Properties

The Material properties used for modeling of cooling tower for linear buckling analysis chosen from referred paper.
Nasir A. M, Thambiratnam D.P, Butler D, Austin P. (2002) "Dynamics of axisymmetric hyperbolic shell structures", Thin-Walled Structures, ELSEVIER, pp no 665–690.

1] Young's modulus- E=39Gpa

2] Poisson's ratio- μ=0.2

3] Density of RCC- 25 kN/m^3

4] SHELL element- 4 node SHELL 181.

5] Boundary condition- Top end free and bottom end fixed.

6] Mesh size-15000

IV. MODELS OF COOLING TOWER-1 (143.50 M)

The Characteristics models of cooling tower 1 are as shown in (figure 1 to 15) for 200mm SHELL thickness using 4 noded SHELL 181 element. The models for cooling tower CT 2, CT 3 are also developed with varying thicknesses of 200mm, 300mm, 400mm, 500mm and 600mm.

Table no 2- Geometric details of hyperbolic cooling towers

Sl no	Description	Symbols	Parametric Values		
			CT 1(m)	CT 2 (m)	CT 3(m)
1	Total Height	H	143.50	150.67	157.85
2	Height of Throat	Hthr	107.75	113.13	118.525
3	Diameter at top	Dt	63.6	66.78	69.96
4	Diameter at bottom	Db	110	115.5	121.0
5	Diameter at throat level	Dth	61.0	64.05	67.10
6	Column height	Hc	9.2	9.66	10.12

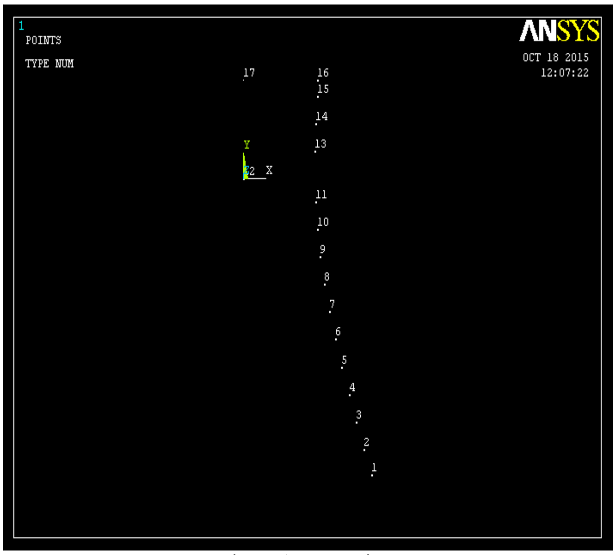


Figure 1: Key points

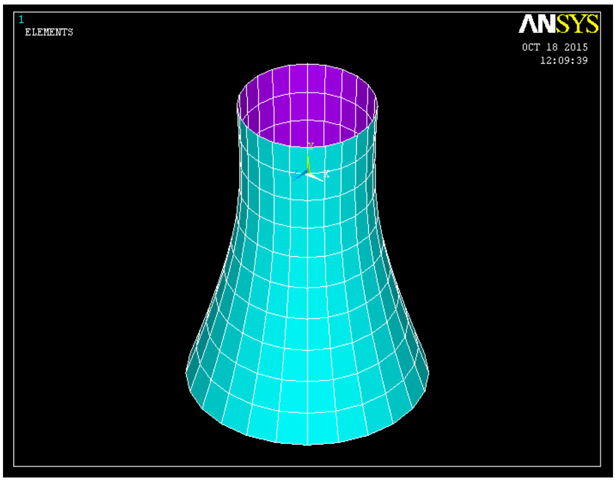


Figure 2: Meshing of cooling tower

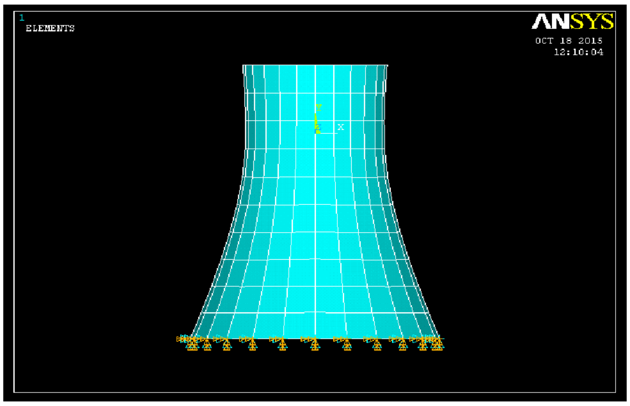


Figure 3: Boundary condition

Characteristics Models of CT 1 for Deflection and Maximum principal stresses in modes 1, 2, 3, 4, 5 for 200mm shell thickness

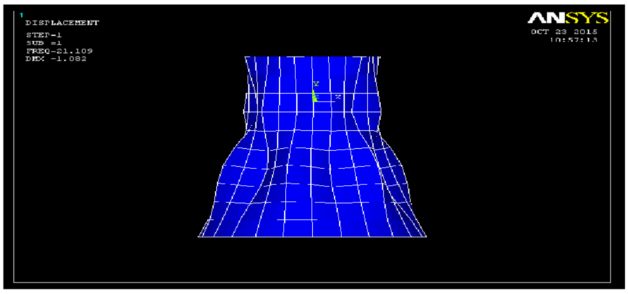


Figure 4: Deflection of CT 1 (Buckling Mode 1)

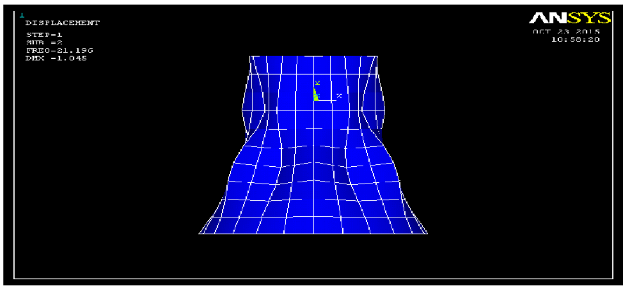


Figure 5: Deflection of CT 1 (Buckling Mode 2)

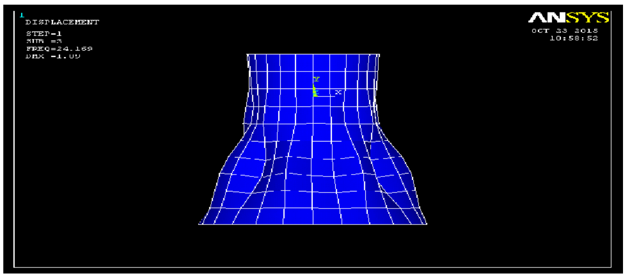


Figure 6: Deflection of CT 1 (Buckling Mode 3)

Table no 3- ANSYS Software Results of Frequency, Maximum Deflection & Maximum Principal Stress Values for 200mm SHELL thickness for selected Buckling modes

Buckling Modes	CT 1 (143.50 m)			CT 2 (150.67 m)			CT 3 (157.85m)		
	Frequency Hz	Maximum Deflection (mm)	Max Principal Stress (Mpa)	Frequency Hz	Maximum Deflection (mm)	Max Principal Stress (Mpa	Frequency Hz	Maximum Deflection (mm)	Max Principal Stress (Mpa
Mode 1	21.189	1.082	0.081626	20.294	1.06	0.086177	18.124	1.058	0.075131
Mode 2	21.196	1.045	0.077953	20.294	1.06	0.086177	18.124	1.058	0.075131
Mode 3	24.169	1.09	0.086075	20.769	1.063	0.088703	18.414	1.061	0.08162
Mode 4	24.169	1.09	0.086075	20.788	1.041	0.085241	18.428	1.038	0.078422
Mode 5	25.108	1.16	0.069945	21.436	1.062	0.074496	19.091	1.06	0.067335

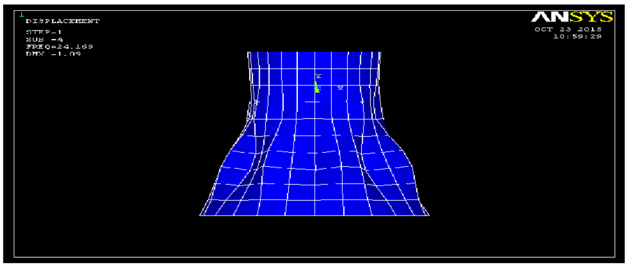


Figure 7: Deflection of CT 1 (Buckling Mode 4)

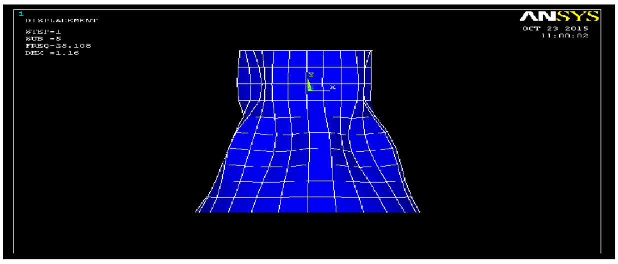


Figure 8: Deflection of CT 1 (Buckling Mode 5)

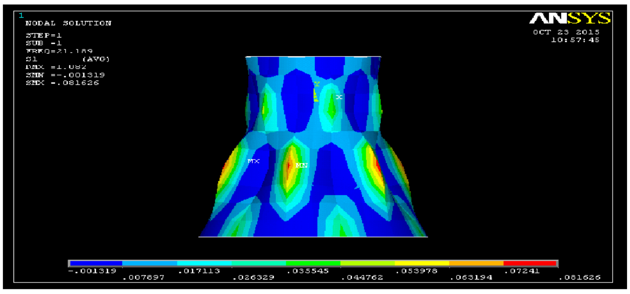


Figure 9: Max principal stress for CT 1 (Buckling Mode 1)

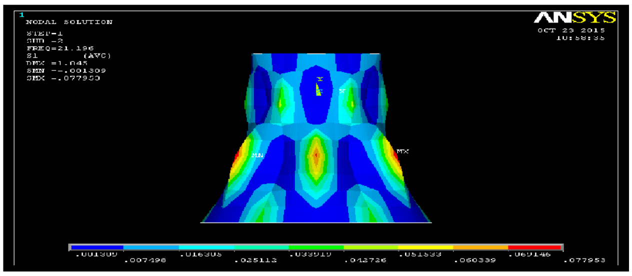


Figure 10: Max principal stress for CT 1 (Buckling Mode 2)

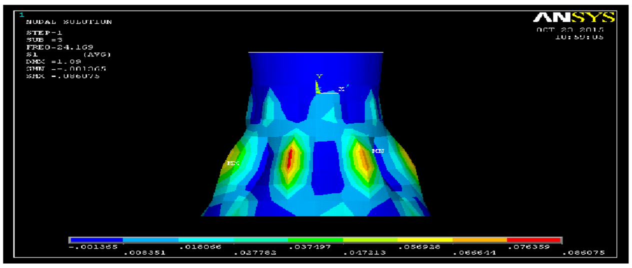


Figure 11: Max principal stress for CT 1 (Buckling Mode 3)

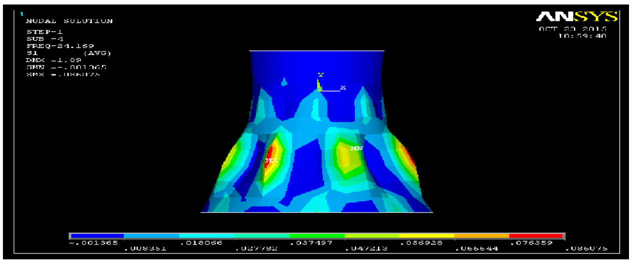


Figure 12: Max principal stress for CT 1 (Buckling Mode 4)

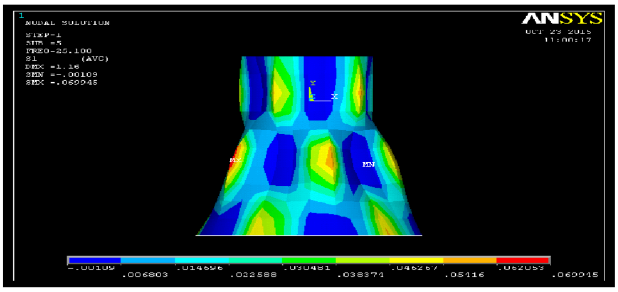


Figure 13: Max principal stress for CT 1 (Buckling Mode 5)

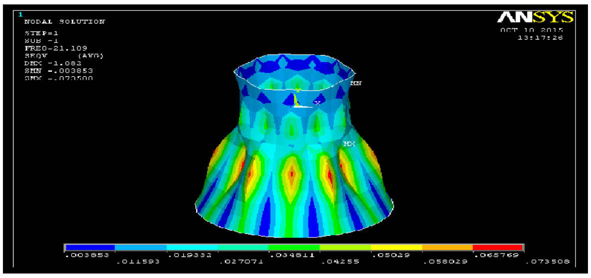


Figure 14: Maximum Von Mises Stress for CT 1

V. TABULATION & RESULTS

A. Block Lanczos (default)

This method is used to extract modes and frequencies. In Eigen buckling 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.

1) Eigen value Extraction method used- Block Lanczos

2) Number of modes to extract-50

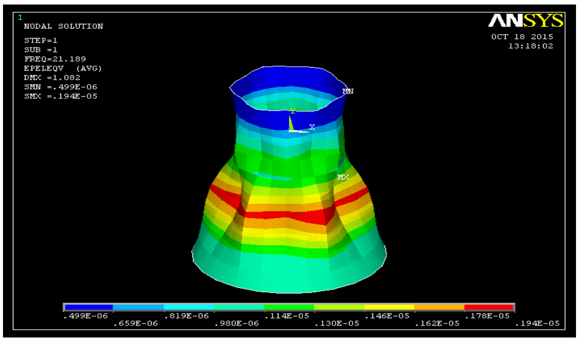
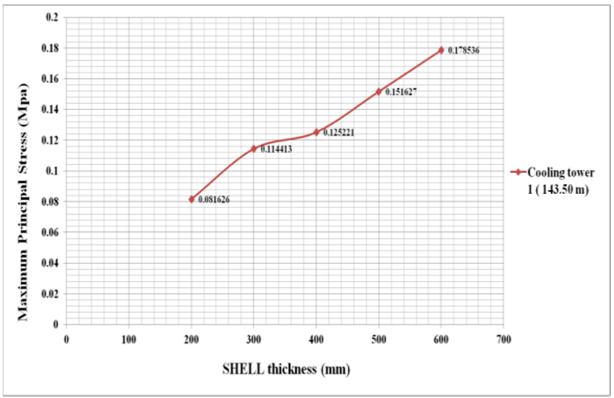
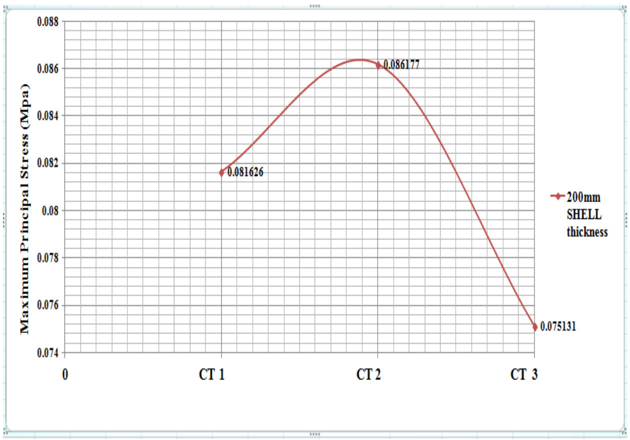


Figure 15: Maximum Von Mises Strain for CT 1

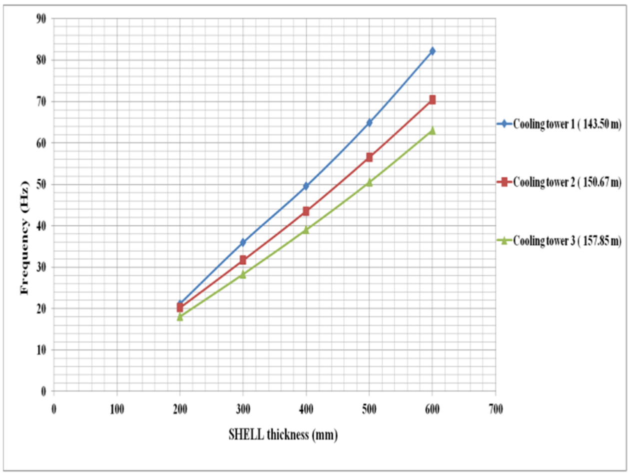
VI. GRAPHICAL REPRESENTATIONS



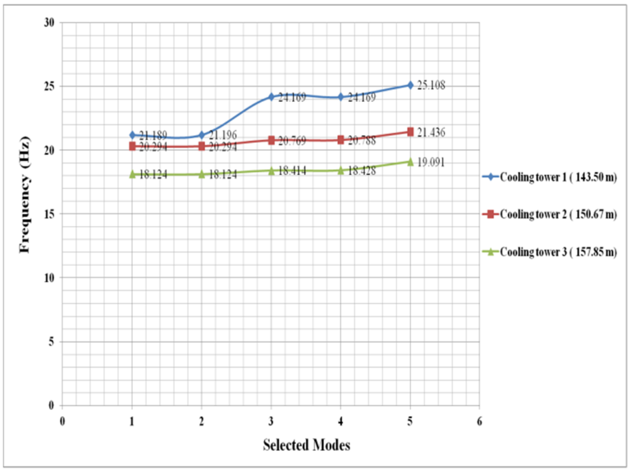
Graph no 1- Graphical Representation of Stress v/s shell thickness for cooling tower 1 (Mode 1)



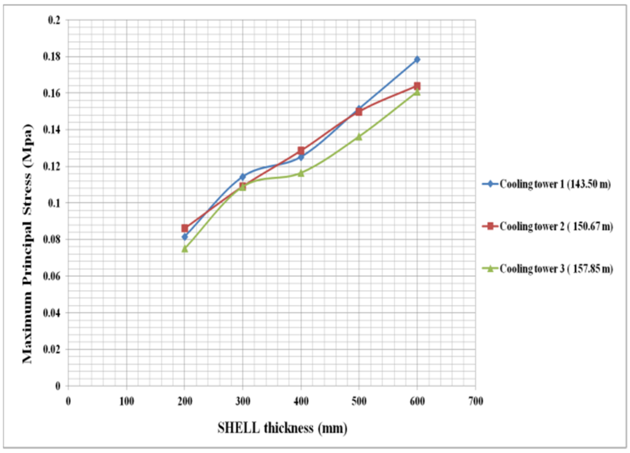
Graph no 2- Graphical Representation of Stress v/s heights for cooling tower 1, 2, 3 (Mode 1) for 200mm shell thickness



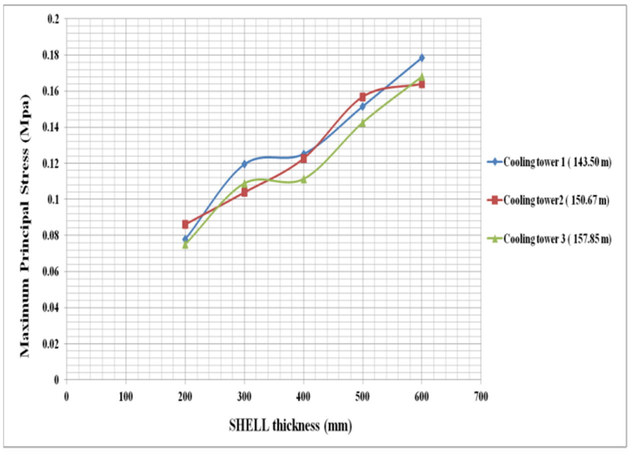
Graph no 3- Graphical Representation of frequency v/s shell thickness for cooling tower 1, 2, 3 (Mode 1)



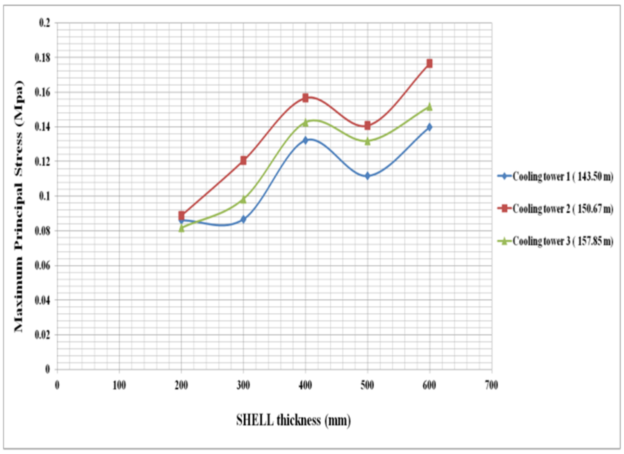
Graph no 4- Graphical Representation of frequency v/s selected modes for cooling tower 1, 2, 3 for 200mm shell thickness



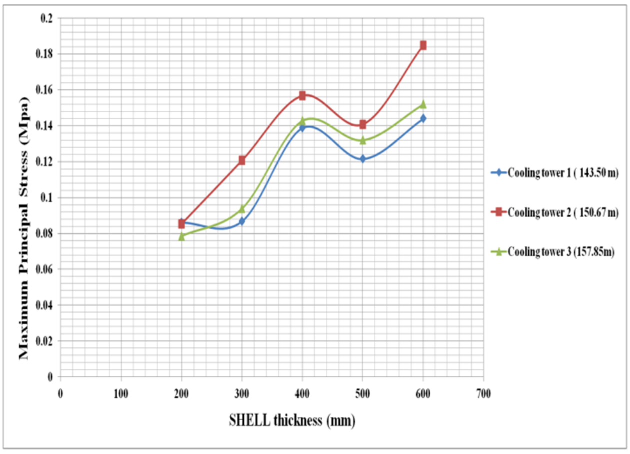
Graph no 5- Graphical Representation of Maximum principal stress v/s shell thickness for cooling tower 1, 2, 3 (Mode 1)



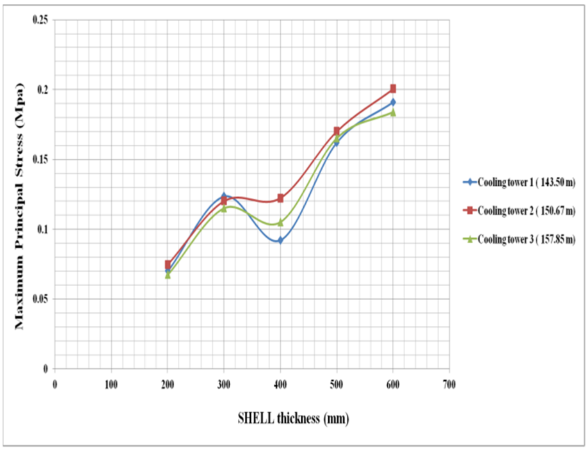
Graph no 6- Graphical Representation of Maximum principal stress v/s shell thickness for cooling tower 1, 2, 3 (Mode 2)



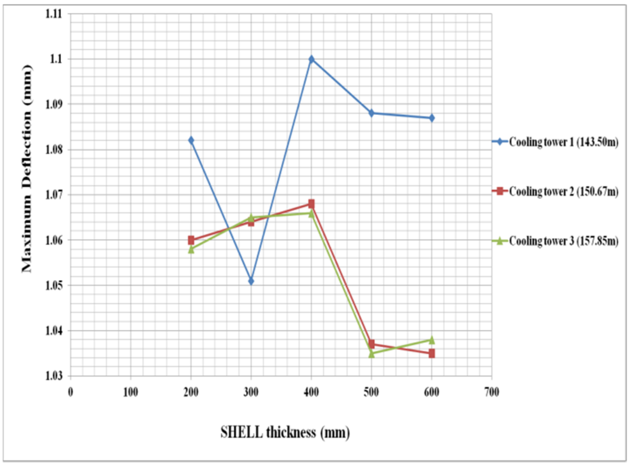
Graph no 7- Graphical Representation of Maximum principal stress v/s shell thickness for cooling tower 1, 2, 3 (Mode 3)



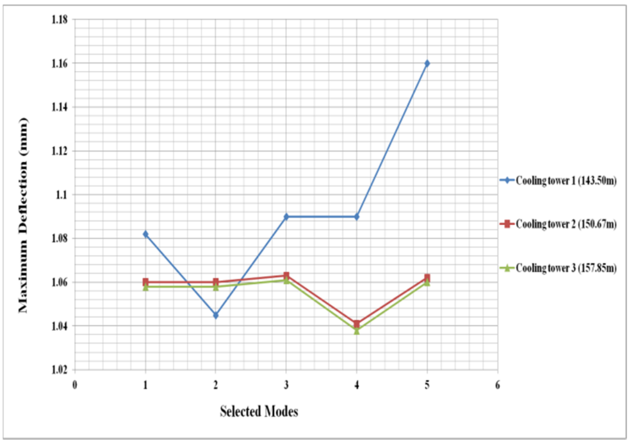
Graph no 8- Graphical Representation of Maximum principal stress v/s shell thickness for cooling tower 1, 2, 3 (Mode 4)



Graph no 9- Graphical Representation of Maximum principal stress v/s shell thickness for cooling tower 1, 2, 3 (Mode 5)



Graph no 10- Graphical Representation of Maximum deflection v/s shell thickness for cooling tower 1, 2, 3 (Mode 1)



Graph no 11- Graphical Representation of Maximum deflection v/s selected modes for cooling tower 1, 2, 3 for 200mm shell thickness

VII. RESULTS & DISCUSSIONS

Eigen value buckling analysis predicts the theoretical buckling strength of an ideal elastic structure. It computes the structural eigen values for the given system loading and constraints. This is known as classical Euler buckling analysis. Buckling loads for several configurations are readily available. However, in real-life, structural imperfections and nonlinearities prevent most real world structures from reaching their eigen value predicted buckling strength. It over-predicts the expected buckling loads. Eigen-value buckling analysis generally yields un conservative results, and should usually not be used for design of actual structures. 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).

The procedure of eigen-value buckling analaysis is as follows.

- Building the model
- Obtaining the static solution
- Obtaining the eigen value buckling solution
- Expanding the solution
- Reviewing the results

Two techniques are available in the ANSYS Multiphysics, ANSYS Mechanical, ANSYS Structural, and ANSYS Professional programs for predicting the buckling mode shape of a structure: Non-linear buckling analysis, and Eigen value (or linear) buckling analysis. Because the two methods can yield dramatically different results. Eigen value buckling analysis is used for the analysis. The concrete shell thickness is generally governed by buckling considerations resulted by self weight and wind loads, and a factor of safety of 5 is provided under service load condition.

VIII. SUMMARY & CONCLUSIONS

An attempt has been made in buckling analysis of hyperbolic cooling towers, in order to study the effect of buckling on analysis of hyperbolic cooling tower with varying its height and thicknesses. From the analysis of Eigen buckling analysis following conclusions could be drawn.

On comparing cooling towers (CT 1, CT 2, CT 3) with varying height and thickness for following cases considered

- Case 1- Height is kept constant and shell thickness is varied from 200mm to 600mm.
- Case 2- Height is varied and shell thickness is kept constant.
- Case 3- Both height and shell thickness of cooling tower is varied.

1] The Maximum Principal Stress value gradually increases upon increasing shell thickness for cooling towers (CT 1, CT 2, and CT 3) considered individually. (Height is kept constant). Refer graph no-1

2] The Maximum Principal Stress value gradually decreases for increasing heights of cooling towers for constant shell thickness (i.e. 200mm, 300mm, 400mm, 500mm, and 600mm). (Shell thickness is kept constant). Refer graph no-02

3] The Frequency value increases for increasing shell thickness for CT 1, CT 2, and CT 3 for selected modes, where as the value decreases for increasing heights of cooling towers. Refer graph no- 3 & 4.

4] The Maximum Principal Stress value gradually increases for increasing shell thickness for CT 1, CT 2, and CT 3 for selected buckling modes. Whereas principal stress value shows least value for 500mm shell thickness in modes 3, 4, and 400mm shell thickness in mode 5. Refer graph no- 5 to 9.

5] The Maximum deflection due to buckling of cooling towers depends upon shell thickness and height of tower. CT 2 and CT 3 show almost same deflection for increasing shell thickness for selected modes. Refer graph no 10 &11.

6] The Influence of shell height, thickness on buckling analysis structure has been studied. Height (of the shell structure) is seen to have greatest influence on buckling response, with the increase of height significantly decreases the buckling frequency in different modes of buckling.

7] The Maximum deformation due to buckling of RC hyperbolic cooling towers can be optimized by providing ring stiffeners. The stiffeners rings will considerably affect the structural buckling stability of cooling tower. Stiffening rings increases the buckling resistance of concrete shell. Depending upon the dimensions of the stiffening rings the ring will behave flexible or rigid

IX. ACKNOWLEDGMENT

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