Optimality Study in Linear Static Analysis of Hyperbolic Cooling towers with different SHELL Elements

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Abstract— **The Present paper deals with the study of Optimality in linear static analysis of hyperbolic cooling towers with different SHELL elements. Four cooling towers with varying heights and thicknesses are analysed using different SHELL elements. The SHELL elements are grouped into Type A, Type B, Type C elements. The linear static analysis is carried out using FEA based ANSYS software. 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 characteristics & behavioural changes of cooling towers for max principal stress is analysed using different SHELL elements. The objective is to obtain optimum height & shell element for low stress concentration. A comparative study is carried out for Type A, Type B, Type C SHELL elements. Maximum deflection, Maximum principal stress & strain, Maximum Von Mises stress, strains are obtained. The variation in max principal stress v/s SHELL thickness is plotted graphically.**

Keywords— Cooling towers, FEA, SHELL, Stress, Strain, Element

I. INTRODUCTION

Natural Draught cooling towers are constructed for a wide range in power plants. The construction of taller cooling towers requires thicker concrete shells, which results in larger dead loads. To decrease the dead load, the concrete shell has to be designed thinner & slender, which will cause buckling instability problems in the RC shell due to wind & dead loads. Hyperbolic cooling towers have driven the engineer's towards the design of tall & thin shell towers which have considerable high slenderness aspect ratio. As a result the height to shell thickness or slenderness aspect ratio, of the cooling towers has been significantly increased. Such slender shell structures, which are distinguished as extreme slender reinforced concrete shell structures.

This paper studies the optimality of hyperbolic cooling towers with different SHELL elements available in ANSYS software (FEA). The behavioural changes due to stress concentration using different type of SHELL elements are analyzed. The characteristics behaviour of SHELL elements for variation in maximum principal stresses is observed in linear static analysis. The height & shell thickness of hyperbolic cooling tower is varied.

II. INTRODUCTION TO FINITE ELEMENT METHOD

Finite element method is one of the powerful numerical techniques to solve the complex physical phenomenon that are governed by the differential equations. Many of the practical engineering problems such as structural, thermal, magnetic, acoustic etc can be solved by the finite element method. Moreover, the finite element method is an increasingly common tool for engineering design.

A] ANSYS

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

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.

B] SHELL Structures

Shells, a derivative of the Latin *scalus*, describe a broad spectrum of natural objects ranging from the shell of a nautilus to the carapace of a turtle. The word has been adapted to describe human made structures commonly associated with a finite curvature and vanishing thickness.

When designed properly, shell structures exhibit incredible strength. As they carry a large portion of the load through membrane action, their thickness can be much less that of plate structure spanning the same area. Nature has utilized the inherent strength of shells through evolution and produced strong and beautiful structures such as egg shells, sea shells, blood cells and other shapes that surround us.

Thin shells are often the structure of choice when the design is weight critical. They inherently have excellent strength to weight ratio; this attribute for much thinner designs than that of other types of structures. Experienced designers realize that the rigidity of shells prevents them from giving ample warning before catastrophic failures. Unlike traditional constructions where the structure would deform visibly a long time prior to collapse, shells typically exhibit no such behavior. These failures are often attributed to buckling instabilities.

III. OBJECTIVES OF PRESENT STUDY

1) To Study the optimality of shell elements used in analysis of hyperbolic cooling towers.

2) To Study the Linear static analysis of cooling towers with variation in heights and shell thicknesses.

3) To Study the characteristics behavior of SHELL elements available in ANSYS software.

4) To Study the variation in maximum principal stress for increasing shell thickness and height for different type of SHELL elements.

5) To Study the deflection, stresses & strains for hyperbolic cooling towers.

IV. DESCRIPTION OF GEOMETRY OF COOLING TOWERS

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

Details of Existing cooling tower considered

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.

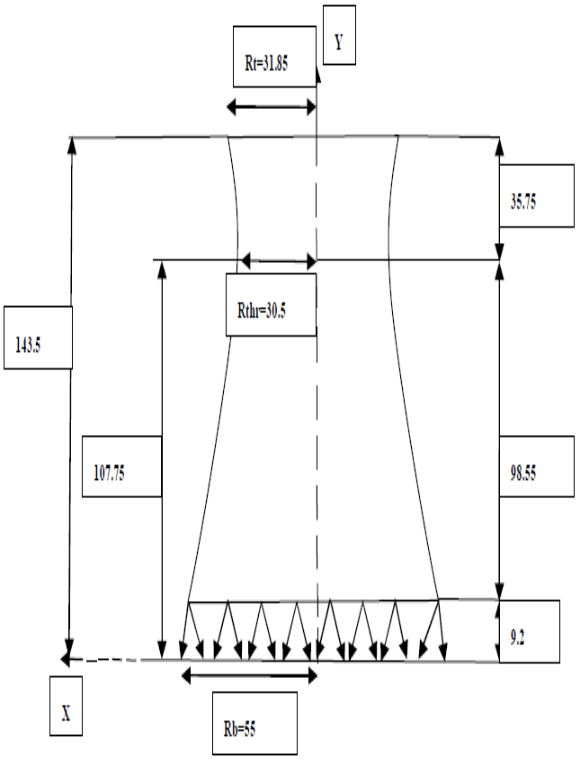


Fig-1. Geometry of Existing cooling tower 143.50m (BTPS)

Table no 1- Notations and description of cooling towers

Cooling tower no	Height (m)	Description
CT 1	**143.50**	Existing cooling tower (Reference cooling tower)
CT 2	**150.67**	Increasing 5% of all the dimensions of reference cooling tower
CT 3	**157.85**	Increasing 10% of all the dimensions of reference cooling tower
CT 4	**165.025**	Increasing 15% of all the dimensions of reference cooling tower

Table no 2- Geometric details of hyperbolic cooling towers

Sl no	Description	Symbols	Parametric Values			
			CT 1	CT 2	CT 3	CT 4
1	Total Height	H	143.50 m	150.67 m	157.85 m	165.025 m
2	Height of Throat	Hthr	107.75 m	113.13 m	118.525 m	123.91 m
3	Diameter at top	Dt	63.6 m	66.78 m	69.96 m	73.140 m
4	Diameter at bottom	Db	110 m	115.5 m	121.0 m	126.50 m
5	Diameter at throat level	Dth	61.0 m	64.05 m	67.10 m	70.150 m
6	Column height	Hc	9.2 m	9.66 m	10.12 m	10.580 m

V. TYPES OF SHELL ELEMENTS

Table no 3- Different types of SHELL elements

Type A	1) 4 node SHELL 63
	2) 4 node SHELL 181
	3) 4 node SHELL 41
	4) Elastic 4 node SHELL 63
Type B	1) 8 node SHELL 93
	2) 8 node SHELL 91
Type C	1) Plastic 4 node SHELL 143
	2) Hyper 4 node SHELL 181
	3) Plastic 4 node SHELL 43

The above mentioned shell elements are available in element library (ANSYS Software). The SHELL elements are categorized depending on the nodes. 4 noded shell elements belong to type A, 8 noded SHELL elements belong to type B; Plastic and Hyper 4 noded SHELL elements belong to type C. These SHELL elements are used in linear static analysis of hyperbolic cooling towers. The SHELL thicknesses are varied from 200mm, 250mm, 300mm, 350mm, 400mm, 450mm, and 500mm. The Deflection, maximum principal stress & strains, maximum von mises stress & strains are computed.

VI. DESCRIPTION OF SHELL ELEMENTS

1) 4 node SHELL 63 element

SHELL63 has both bending and membrane capabilities. Both in-plane and normal loads are permitted. 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. Stress stiffening and large deflection capabilities are included. A consistent tangent stiffness matrix option is available for use in large deflection (finite rotation) analysis.
The element is defined by four nodes, four thicknesses, an elastic foundation stiffness, and the orthotropic material properties. Orthotropic material directions correspond to the element coordinate directions. The element coordinate system orientation is as described in Coordinate Systems. The element x-axis may be rotated by an angle THETA (in degrees).

Geometry: Triangular option
Output Data: Nodal Displacement included in the overall nodal solution.

2) 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.

3) 4 node SHELL 41

SHELL 41 is a 3-D element having membrane (in-plane) stiffness but no bending (out of plane) stiffness. It is intended for shell structure where bending of the elements is of secondary importance. The element has variable thickness. Stress stiffening, large deflection. The element is defined by four nodes, four thicknesses and has 3 degree of freedom at each node, translations in the nodal x, y and z directions.

Geometry: Triangular option
Output Data: Nodal Degree of freedom results in the overall nodal solution.

4) 8 node SHELL 93

SHELL93 is particularly well suited to model curved shells. 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 deformation shapes are quadratic in both in-plane directions. The element has plasticity, stress stiffening, large deflection, and large strain capabilities. The element is defined by eight nodes, four thicknesses, and the orthotropic material Properties.

Geometry: Triangular option
Output Data: Nodal Displacement included in the overall nodal solution.

5) 8 node SHELL 91

SHELL 91 may be used for layered applications of a structural shell model or for modeling thick sandwich structures. 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 eight nodes, four layer thicknesses.

Geometry: Triangular option
Output Data: Nodal Displacement included in the overall nodal solution.

6) Plastic 4 node SHELL 143

SHELL 143 is well suited to model non linear, flat or warped, thin to moderately thick shell structures. The deformation shapes are linear in both in plane directions. For the out of plane motion, it uses a mixed interpolation of tonsorial components. 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
Output Data: Nodal Displacement included in the overall nodal solution.

7) 4 node Hyper SHELL 181

SHELL 181 is suitable for analyzing thin to moderately thick shell structures. 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 and four thicknesses.

Geometry: Triangular option (Not recommended)
Output Data: Nodal Displacement included in the overall nodal solution.

8) 4 node Plastic SHELL 43

SHELL 43is well suited to model linear warped, moderately thick-shell structures. 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 and four thicknesses.

Geometry: Triangular option
Output Data: Nodal Displacement included in the overall nodal solution.

A] Material Properties for Analysis of Cooling tower

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

VII. MODELS OF COOLING TOWER-1 (143.50 m)

The Characteristics models of cooling tower 1 are as shown in (figure 2 to 11) for 200mm SHELL thickness using 4 noded SHELL 41 element. The models for cooling tower CT 2, CT 3 & CT 4 are also developed for all type of SHELL elements with varying thicknesses of 200mm, 250mm, 300mm, 350mm, 400mm, 450mm and 500mm.

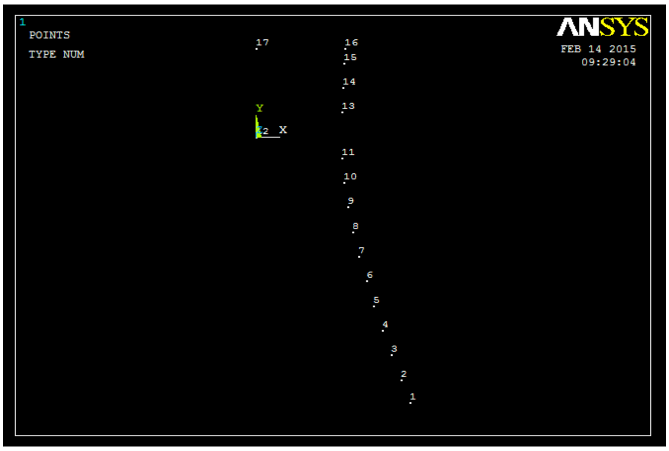


Fig-2. Key points

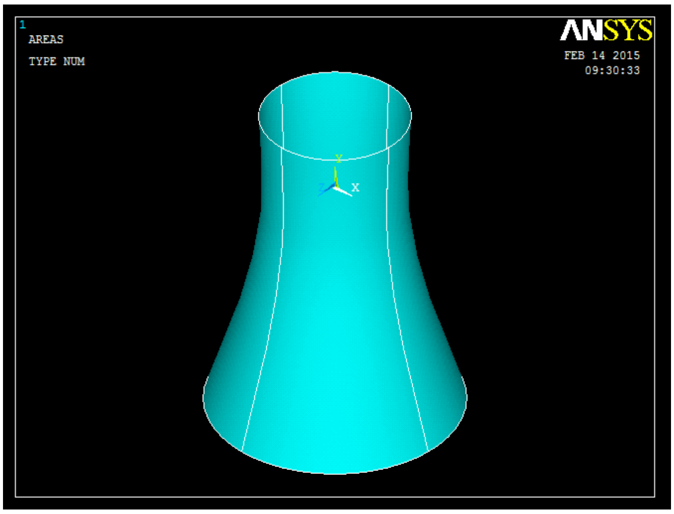


Fig-3. Model of cooling tower

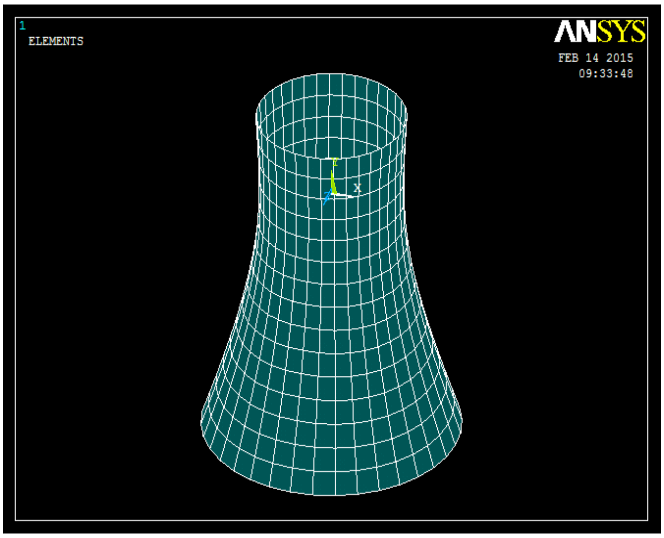


Fig-4. Meshing of cooling tower

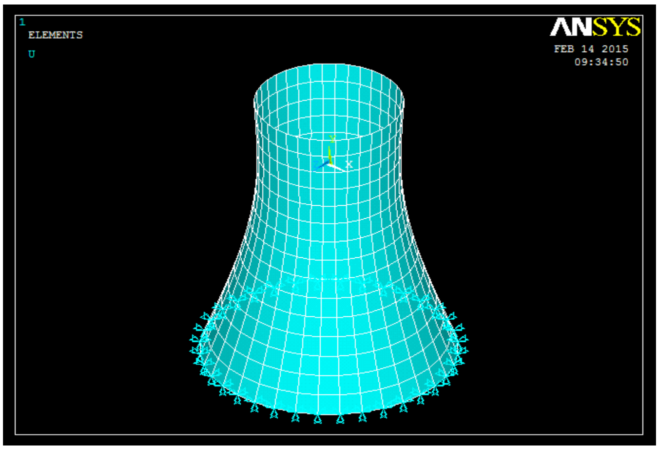


Fig-5. Boundary conditions in CT

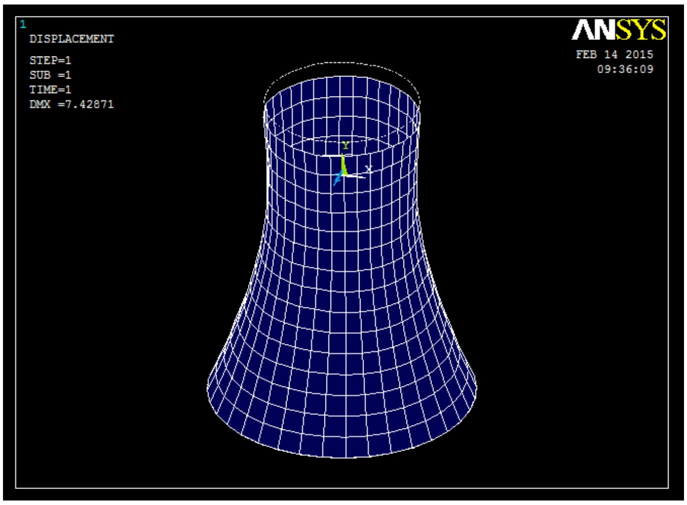


Fig-6. Maximum Deflection in CT 1

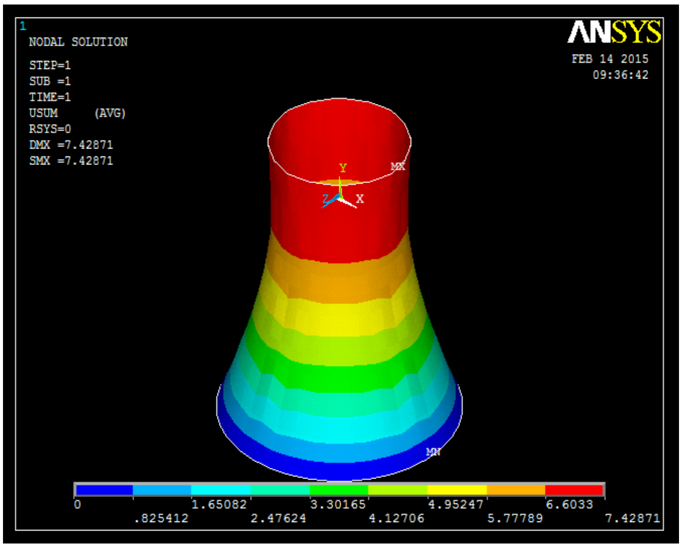


Fig-7. Displacement Vector sum for CT 1

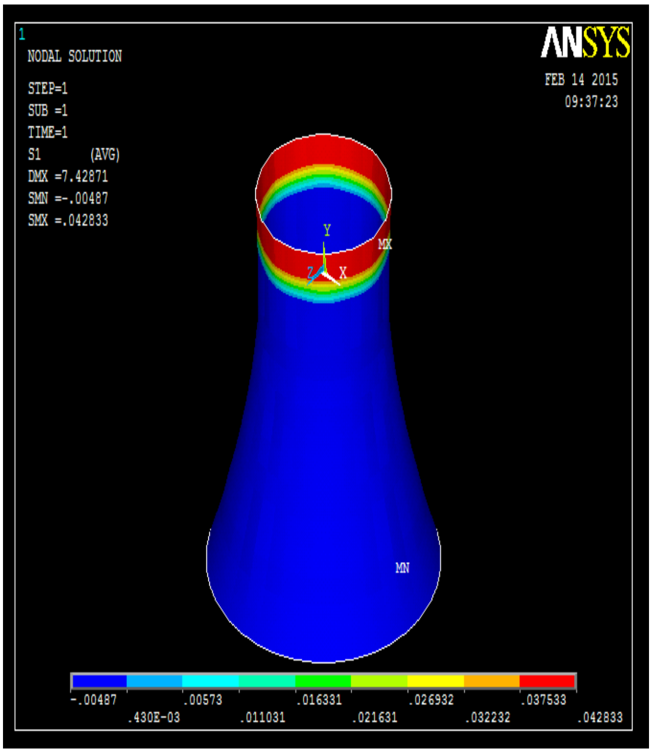


Fig-8. Maximum Principal Stress for CT 1

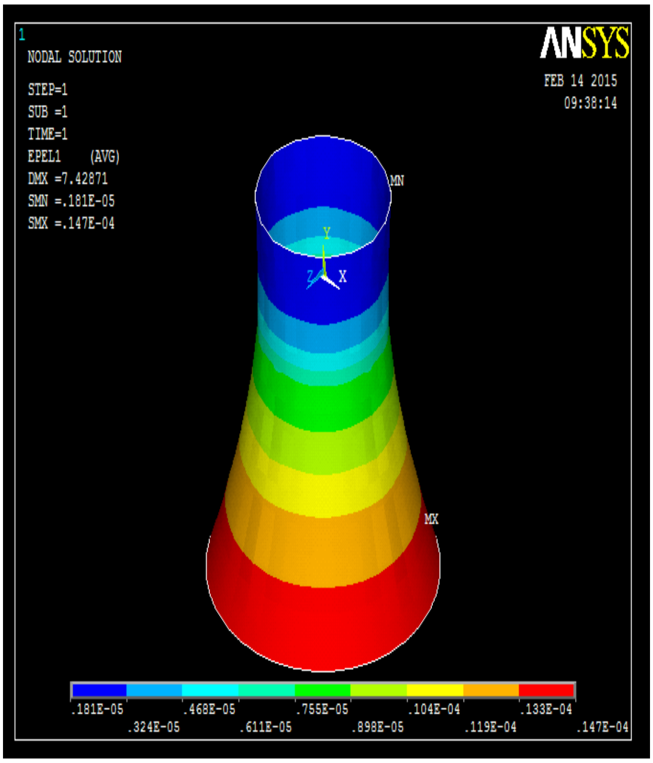


Fig-9. Maximum Principal Strain for CT 1

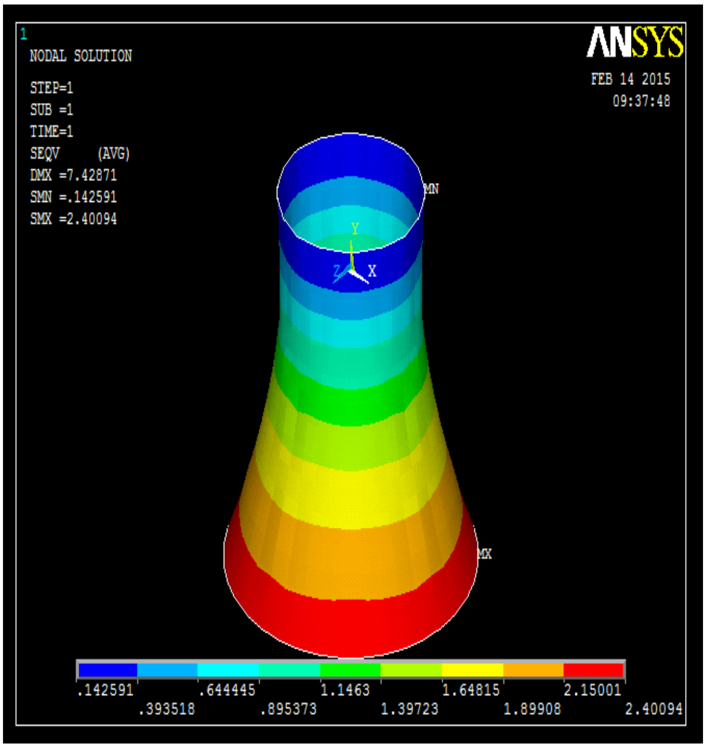


Fig-10. Maximum Von mises stress for CT 1

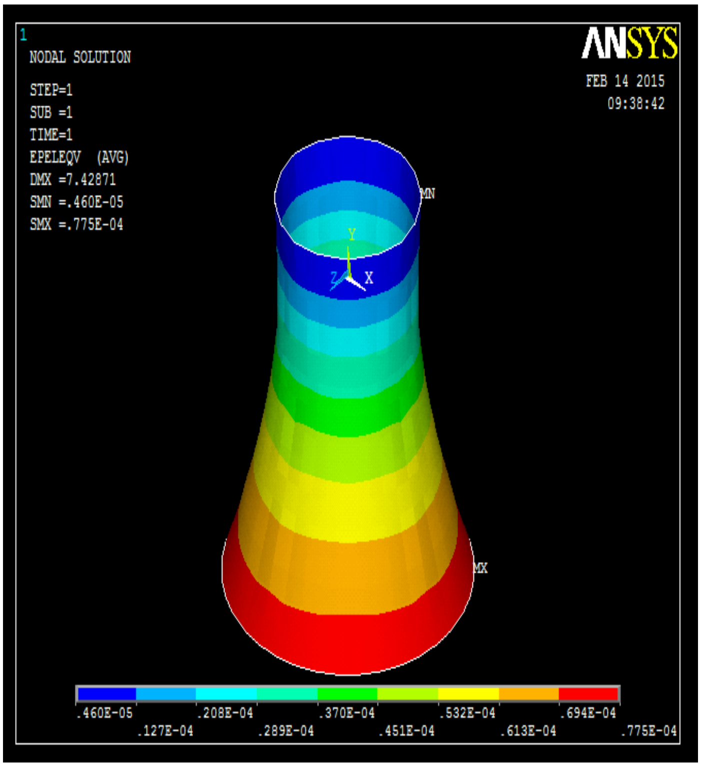


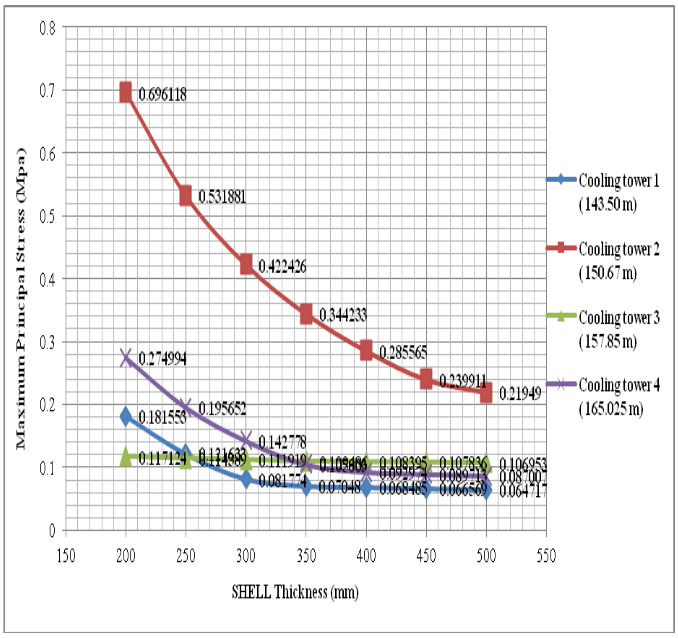
Fig-11. Maximum Von mises Strain for CT 1

VIII. RESULT AND DISCUSSIONS

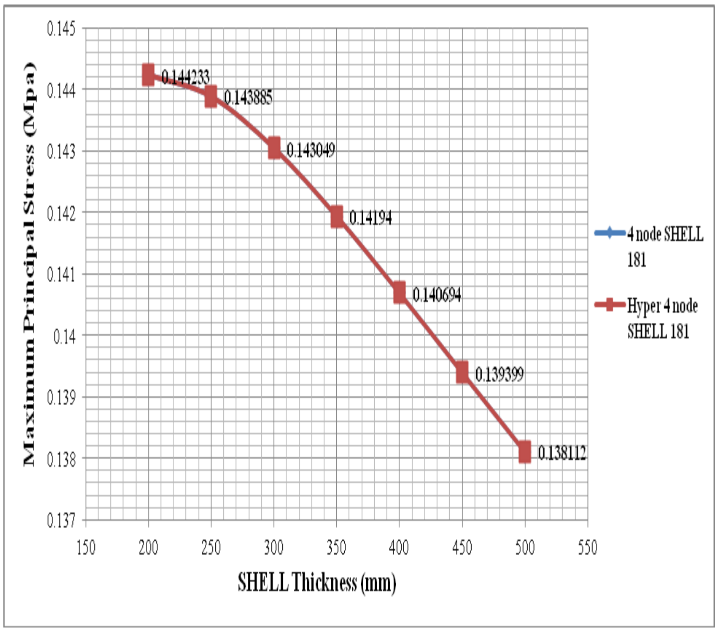
ANSYS Software Results of Maximum Deflection & Maximum Principal Stress Values for 200mm SHELL thickness

Sl no	SHELL Elements	CT 1		CT 2		CT 3		CT 4	
		Deflection (mm)	Stress (Mpa)	Deflection (mm)	Stress (Mpa	Deflection (mm)	Stress (Mpa	Deflection (mm)	Stress (Mpa
1	4 node SHELL 63	7.33996	0.181553	8.21302	0.696118	8.97089	0.117124	9.64917	0.274994
2	4 node SHELL 181	7.357	0.059505	8.362	0.144233	8.991	0.063996	9.664	0.07551
3	4 node SHELL 41	7.42871	0.042833	8.91215	0.234253	9.04478	0.096361	9.79002	0.094676
4	Elastic 4 node SHELL 63	7.340	0.181553	8.213	0.696118	8.971	0.117124	9.649	0.274994
5	8 node SHELL 93	7.329	0.050392	8.234	0.216416	8.972	0.083216	9.683	0.123455
6	8 node SHELL 91	7.329	0.050393	8.234	0.216425	8.972	0.083214	9.683	0.123464
7	Plastic 4 node SHELL 143	7.345	0.054603	8.223	0.231458	8.972	0.106857	9.641	0.09409
8	Hyper 4 node SHELL 181	7.357	0.059506	8.362	0.144233	8.991	0.063996	9.664	0.07551
9	Plastic 4 node SHELL 43	7.345	0.054246	8.223	0.231476	8.972	0.106476	9.642	0.094094

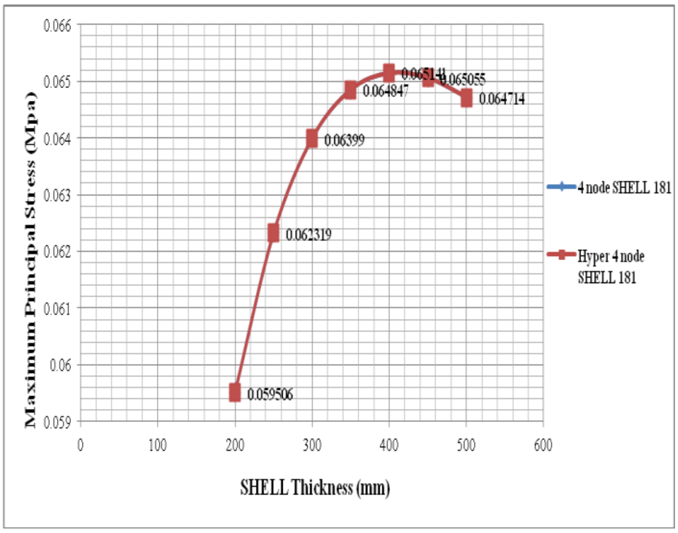
IX. GRAPHICAL REPRESENTATIONS



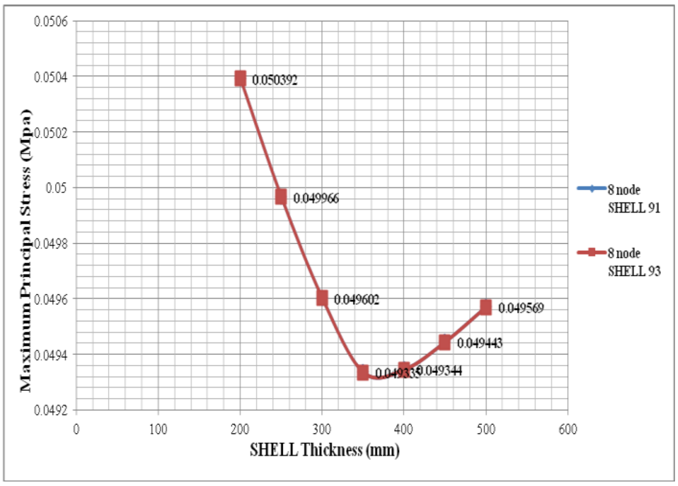
Graph 1- Graphical Representation of Stress v/s shell thickness for CT 1, CT 2, CT 3, CT 4 on using 4 node SHELL 63 & Elastic 4 node SHELL 63 element



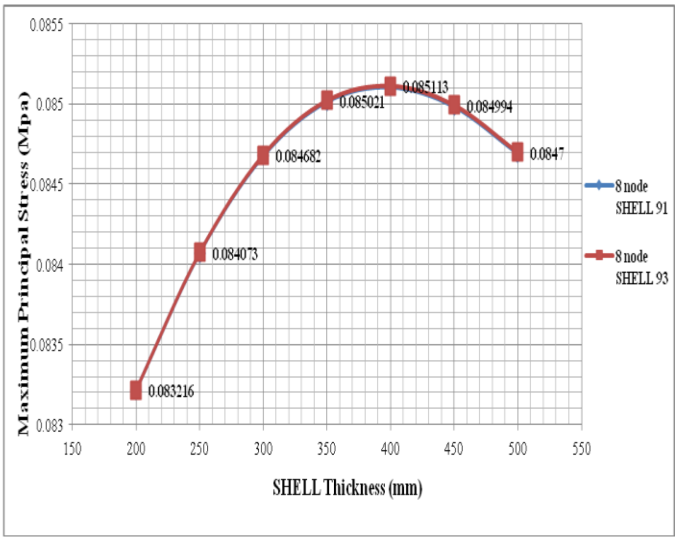
Graph 2- Graphical Representation of Stress v/s shell thickness for CT 2 on using 4 node SHELL 181 element



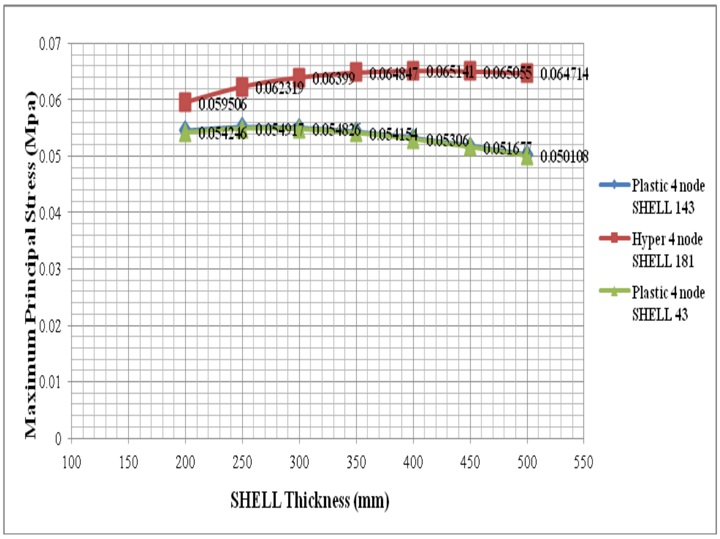
Graph 3- Graphical Representation of Stress v/s shell thickness for CT 1 on using 4 node SHELL 181 element



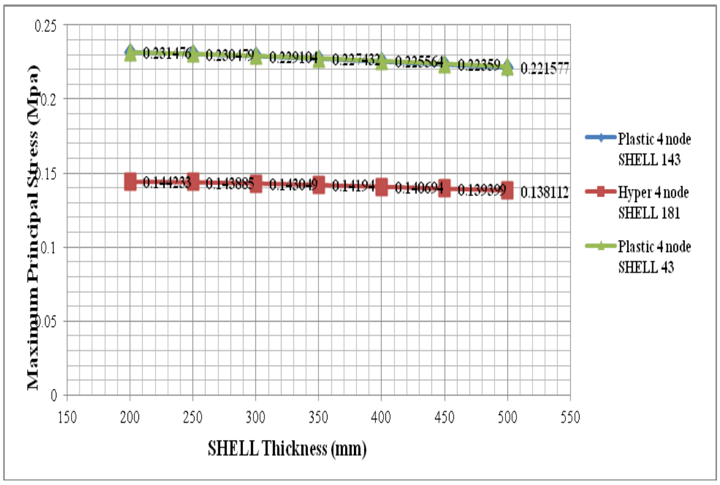
Graph 4- Graphical Representation of Stress v/s shell thickness for CT 1 on using 4 node SHELL 93 element



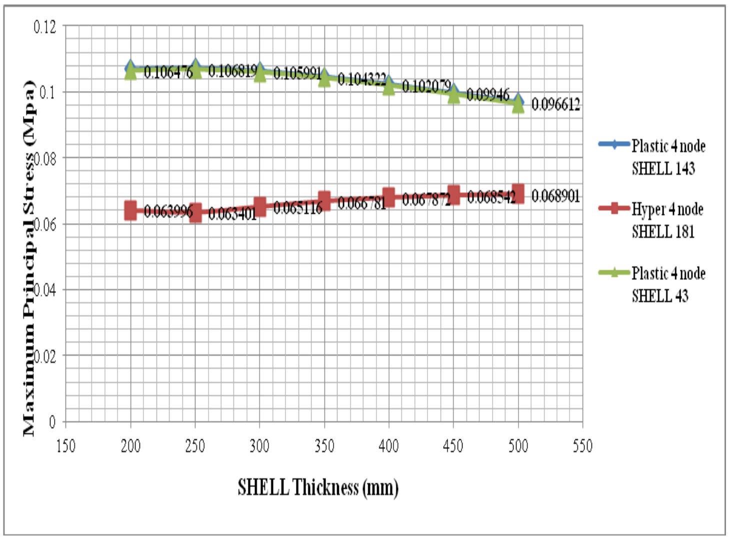
Graph 5- Graphical Representation of Stress v/s shell thickness for CT 3 on using 4 node SHELL 93 element



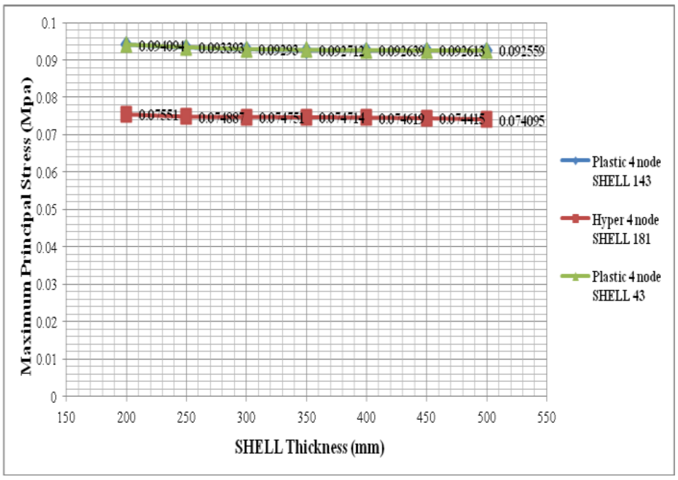
Graph 6- Graphical Representation of Stress v/s shell thickness for CT 1 on using Hyper 4 node SHELL 181 element



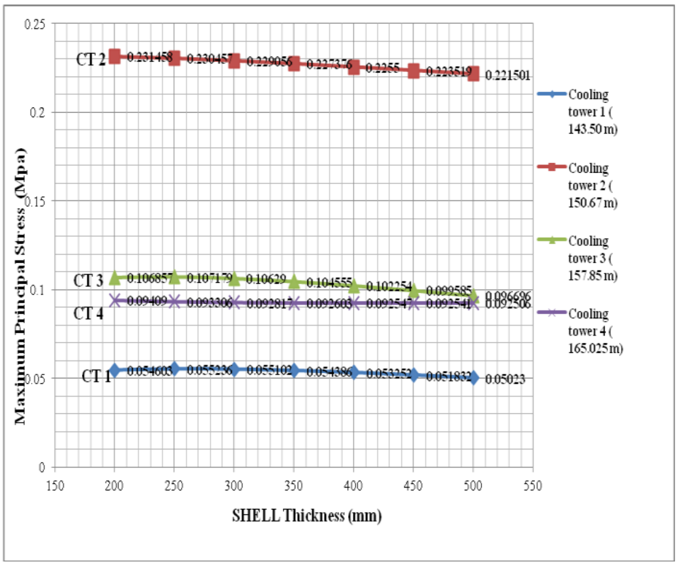
Graph 7- Graphical Representation of Stress v/s shell thickness for CT 2 on using Hyper 4 node SHELL 181 element



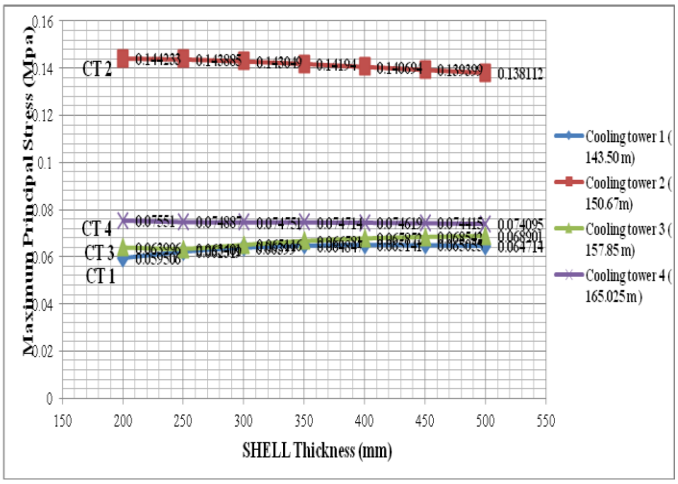
Graph 8- Graphical Representation of Stress v/s shell thickness for CT 3 on using Hyper 4 node SHELL 181 element



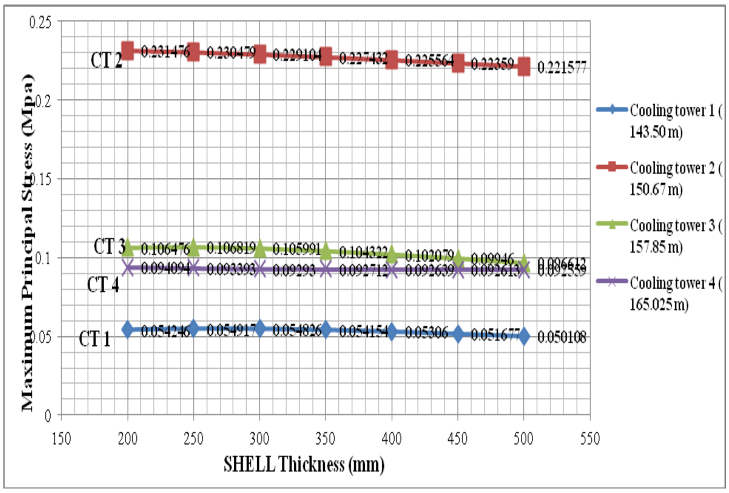
Graph 9- Graphical Representation of Stress v/s shell thickness for CT 4 on using Hyper 4 node SHELL 181 element



Graph 10- Graphical Representation of Stress v/s shell thickness for CT 1, CT 2, CT 3, CT 4 on using Plastic 4 node SHELL 143 element



Graph 11- Graphical Representation of Stress v/s shell thickness for CT 1, CT 2, CT 3, CT 4 on using Hyper 4 node SHELL 181 element



Graph 12- Graphical Representation of Stress v/s shell thickness for CT 1, CT 2, CT 3, CT 4 on using Plastic 4 node SHELL 43 element

X. SUMMARY & CONCLUSIONS

An attempt has been made in linear static analysis of hyperbolic cooling towers using different SHELL elements available in the software. The behavior of SHELL elements differs from each other, and they mainly depend on their characteristics.

On comparing all cooling towers (CT 1, CT 2, CT 3, and CT 4) for different type of SHELL elements, following conclusions could be drawn from linear static analysis.

1) Cooling towers CT 1 & CT 3 shows least value of principal stress and prove to be the optimal cooling towers.

2) The characteristics behavior of SHELL elements depends upon nodes, degree of freedom, geometry and applicability.

3) The Maximum Principal Stress value gradually decreases for increasing shell thickness on using 4 node SHELL 63 element, but remains same on using 4 node SHELL 41 element. Elastic 4 node SHELL 63 element and 4 node SHELL 63 element shows similar behavior (i.e Deflection and stress value remains same). (Refer graph-1)

4) The Maximum Principal stress value gradually decreases for CT 2 & CT 4 (behaves conversely for CT 1 & CT 3) on using 4 node SHELL 181 element and Hyper 4 node SHELL 181 element. The behavior of both elements remains almost similar. (Refer graph 2 & 3)

5) The Maximum Principal Stress value gradually decreases for CT 1, CT 2, CT 4 for increasing shell thickness, Above 400mm shell thickness the stress value increases in CT 1 (CT 3 behaves conversely to CT 1) on using 8 node SHELL 93 element. (Refer graph 4 & 5)

6) The behavior of 8 node SHELL 91 element and 8 node SHELL 93 element remains same, in same nature plastic 4 node SHELL 143 element and plastic 4 node SHELL 43 element behaves.

7) The Maximum Principal Stresses for CT 1 are maximum on using Hyper 4 node SHELL 181element compared with plastic 4 node SHELL 143 & plastic 4 node SHELL 43 element. CT 2, CT 3, CT 4 behaves conversely with CT 1. (Refer graph 6 to 9)

8) The Maximum Principal Stresses for CT 2 are maximum on using Hyper 4 node SHELL 181 element, plastic 4 node SHELL 143 & plastic 4 node SHELL 43 element individually. (Refer graph 10 to 12)

XI. ACKNOWLEDGMENT

The author thank the guide Prof A.V. Kulkarni, Associate Professor & Academic Coordinator, Department of Civil Engineering, BLDEA'S V.P Dr. P.G. Halakatti College of Engineering & Technology Bijapur, for the continued support and cooperation in carrying out this research study.

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