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Case Study of Seismic Effect on Hyperbolic Cooling Towers

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Abstract
This paper deals with the study of seismic 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. 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, Stress, Strain, SHELL

1. Introduction

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. Reinforced concrete cooling towers are effectively used for cooling large quantities of water in thermal power stations, refineries, and 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.

1.1 Introduction to Dynamic Analysis

Earthquakes are caused by faulting, a sudden lateral or vertical movement of rock along a rupture (break) surface. The surface of the Earth is continuous slow motion. This is plate tectonics--the motion of immense rigid plates at the surface of the Earth in response to flow of rock within the Earth. The plates cover the entire surface of the globe. Since they are all moving they rub against each other in some places, sink beneath each other in others, or spread apart from each other. At such places the motion isn't smooth the plates are stuck together at the edges but the rest of each plate is continuing to move, so the rocks along the edges are distorted (what we call "strain"). As the motion continues, the strain builds up to the point where the rock can't withstand any more bending. With a lurch, the rock breaks and the two sides move. An earthquake is the shaking that radiates out from the breaking rock. Unfortunately, timing of this natural phenomenon cannot be predicted scientifically. Historical records reveal the tendency of earthquakes to revisit regions after an interval of time. This random time interval is called RETURN PERIOD. This is the basis of the seismic zonation. There are four zones in the country and they are denoted as II, III, IV and V. Zone I which existed in the earlier versions of the code, has been upgraded to Zone II or higher. The higher the zone, the more vulnerable is that region to a major earthquake. The size of an earthquake is measured by the strain energy released along the fault. It is expressed as MAGNITUDE. The commonly used scale for expressing the magnitude is the Richter scale. Every unit increase in magnitude implies an increase of about 31 times the energy. Dynamic analysis may be performed either by the Time History Method or by the Response Spectrum Method. For cases where a more refined design analysis is desired, response spectra are used as the means for determining lateral forces. A Response spectrum for a particular earthquake shows in a relatively simple way the dynamic characteristics of a given earthquake.

1.2 Generation of Response Spectra

For the design of RC structures for seismic loading a design spectrum is obtained as per the recommendations of IS 1893 (Part1): 2002 titled "Criteria for Earthquake Resistant Design of Structures". The parameters considered are type of soil, type of construction, the dynamic behavior of the prototype structure and the appropriate seismic zone. The earthquake spectrum is an average smoothened plot of maximum acceleration as function of frequency or time period of vibration for a specified damping and for a site-specific condition. According to the code, India is classified into four seismic zones i.e. Zone II, Zone III, Zone IV and Zone V. The code specifies forces for analytical design of structures standing on rocks or soil for above four zones and different value of damping of the structure. For the purpose of design acceleration spectrum has been prepared for zone III assuming damping as 5% and the soft soil condition.

1.3 Description of Geometry of the Cooling 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

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

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.

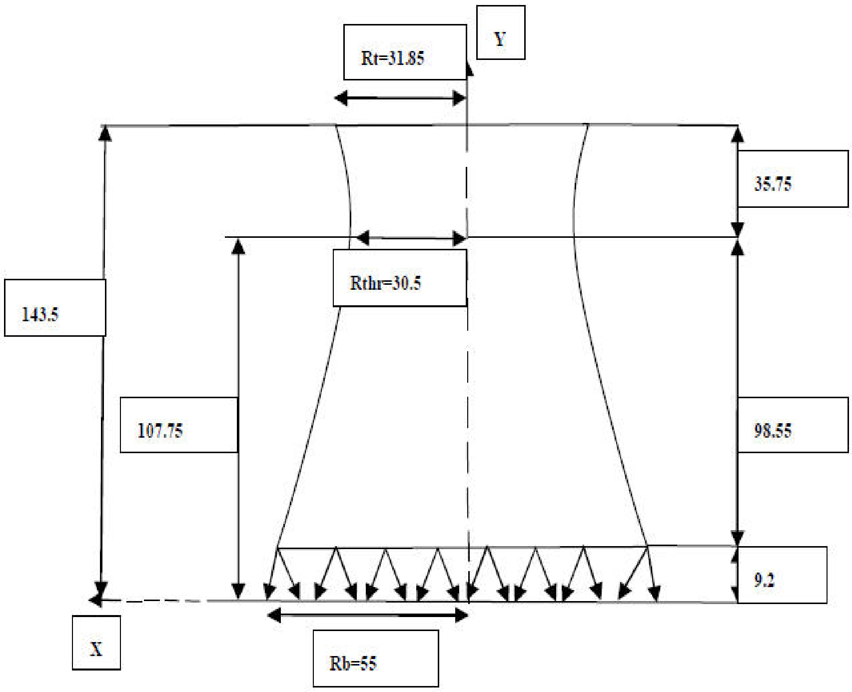

Figure 1: Geometry of Existing Cooling Tower (BTPS) CT 1 (143.50 m)

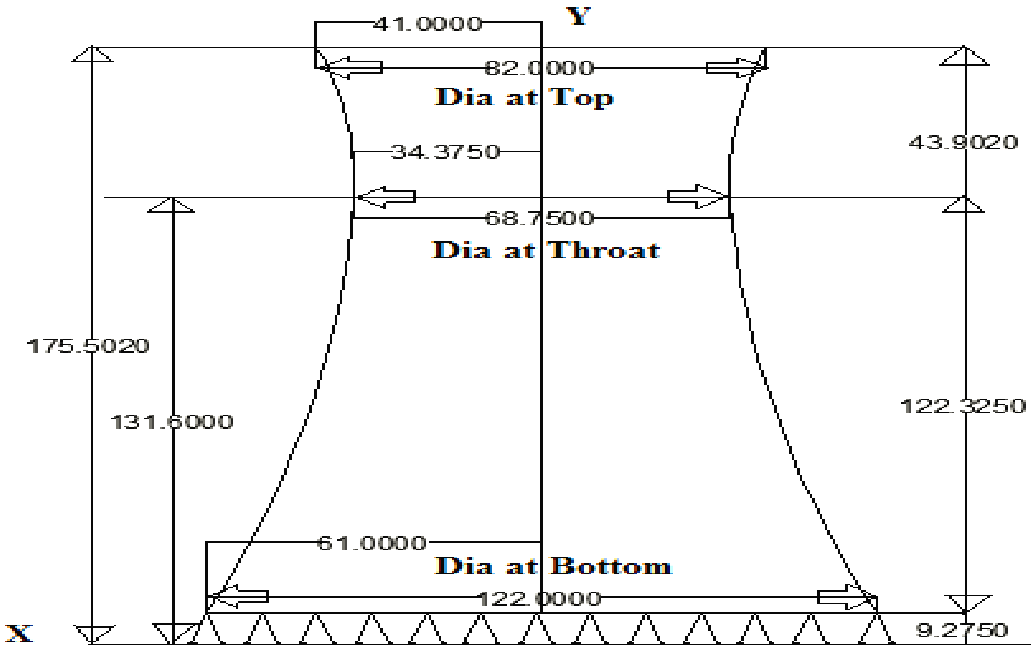

Figure 2: Geometry of Existing Cooling Tower (BTPS) CT 2 (175.50 m)

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.

2.0 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.

2.1 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.

3.0 Earthquake Forces

The seismic analysis is carried out for two existing cooling towers (CT 1 & CT 2) 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, IS 1893 (Part IV) 2005.

a) Zone factor: For Zone III Z = 0.16
b) Importance factor (I) = 1.75
c) Response reduction factor (R) = 3.00

d) Average response acceleration coefficient Sa/g =Soft soil site condition.
e) Damping Ratio= 5%
f) Mode Combination Method= SRSS

The design horizontal seismic coefficient Ah for 0.5g, 0.6g & 0.7g of a structure shall be determined. Maximum considered Earthquake (MCE) is 2% of probability.

3.1 Material Properties for Analysis of Cooling Tower

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

4.0 Design Spectrum

The design horizontal seismic coefficient *A*h for a structure shall be determined by the following expression

$$Ah = \frac{Z\ I\ Sa}{R\ g} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6.2)$$

Provided that for any structure with T ≤ 0.1 s, the value of *A*h will not be taken less than Z/2 whatever be the value of I/R.

Where

Z= Zone factor is for the Maximum Considered Earthquake (MCE) and service life of structure in a zone. The factor 2 in the denominator of Z is used so as to reduce the Maximum Considered Earthquake (MCE) zone factor to the factor for Design Basis Earthquake (DBE).

I = Importance factor, depending upon the functional use of the structures, characterized by hazardous consequences of its failure, post- earthquake functional needs, historical value, or economic importance.

R= Response reduction factor, depending on the perceived seismic damage performance of the structure, characterized by ductile or brittle deformations. However, the ratio (I/R) shall not be greater than 1.0. The values of R for buildings are given in the code.

Sa /g= Average response acceleration coefficient, In case design spectrum is specifically prepared for a structure at a particular project site, the same may be used for design at the discretion of the project authorities. For rock and soil sites and based on appropriate natural periods and damping of the structure. These curves represent free field ground motion.

The Design acceleration spectrum for vertical motions, when required, may be taken as two-thirds of the design horizontal acceleration spectrum

For Rocky or Hard soil sites

$$Sa/g = \begin{cases} 1+15T, & 0.00 \le T \le 0.10 \\ 2.50 & 0.10 \le T \le 0.40 \\ 1.00/T & 0.40 \le T \le 4.00 \end{cases}$$

For Medium soil sites,

$$Sa/g = \begin{cases} 1+15T & 0.00 \le T \le 0.10 \\ 2.50 & 0.10 \le T \le 0.55 \\ 1.36/T & 0.55 \le T \le 4.00 \end{cases}$$

For Soft soil sites

$$Sa/g = \begin{cases} 1+15T, & 0.00 \le T \le 0.10 \\ 2.50 & 0.10 \le T \le 0.67 \\ 1.67/T & 0.67 \le T \le 4.00 \end{cases}$$

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

Procedure: Response spectrum analysis is carried out for two existing cooling towers (CT 1 & CT 2) for 0.5g, 0.6g & 0.7g ground acceleration. 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 doing Spectrum analysis carry out Modal analysis, after that we have to select the spectrum analysis & apply all input data's such as frequencies, seismic co-efficient, and solve. Again select modal analysis and on expansion pass and run the solution. Last select spectrum analysis once again and select mode combination method as SRSS method and solve the problem in solution, read input file which is saved for modal analysis in jobname.mcom & read the results in General post processor.

Inputs given in spectrum analysis

1) Type of Response spectrum – Seismic Displacement
2) Scale factor- 1.0 (Applied to spectrum values)
3) [SED] Excitation Direction SEDX, SEDY, SEDZ- ………………… Coordinates of point that forms line to define excitation direction

1	0	0

4) Damping ratio for curves – 5% (0.05)
5) SIGNIF Significant threshold- 0.001
6) Mode combination method –SRSS (Modes for solutions Extracted-50)

4.2 Response Spectra Curves for 0.5g, 0.6g, 0.7g

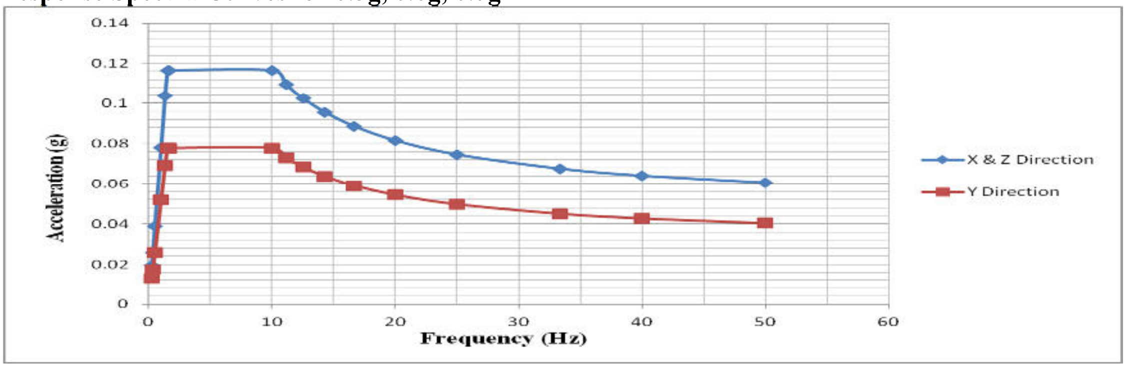

Fig 3: Response Spectra Graph for 0.5g

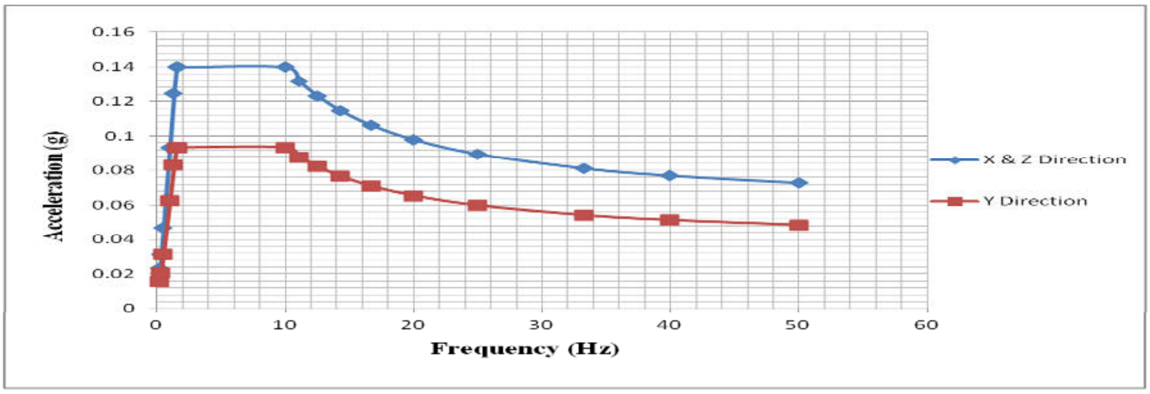

Fig 4: Response Spectra Graph for 0.6g

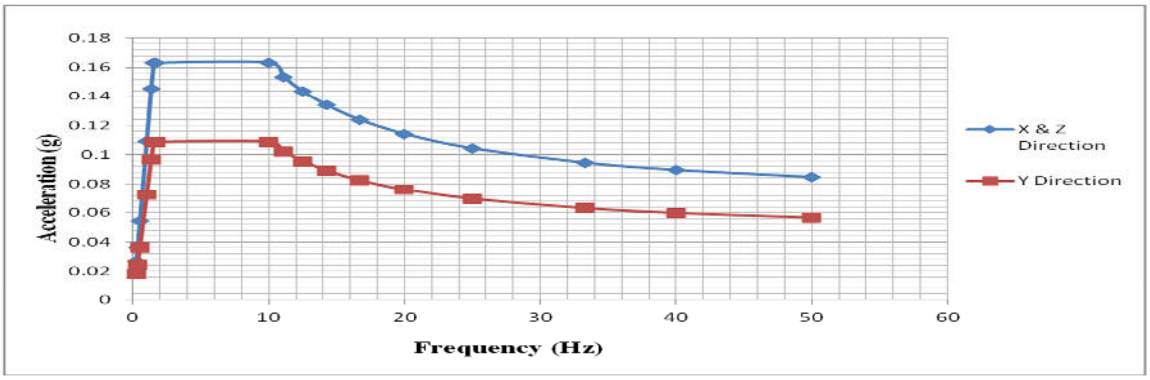

Fig 5: Response Spectra Graph for 0.7g

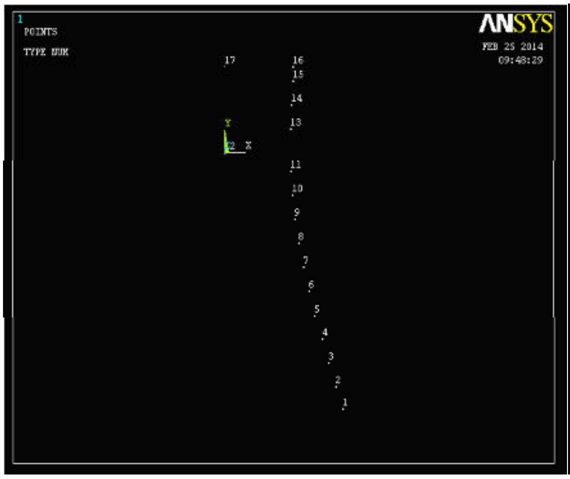

Fig 6: Key points to create cooling tower

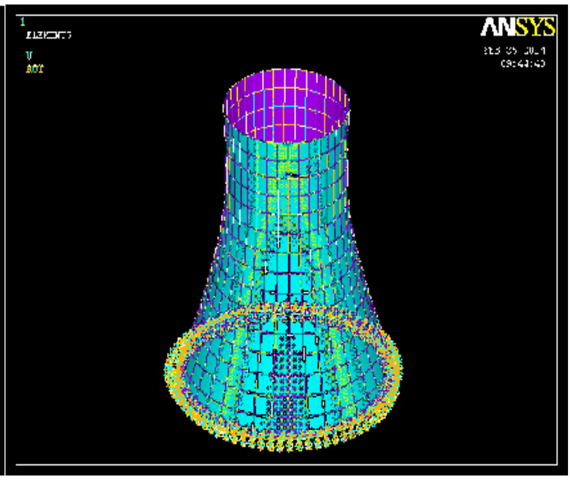

Fig 7: Boundary Condition

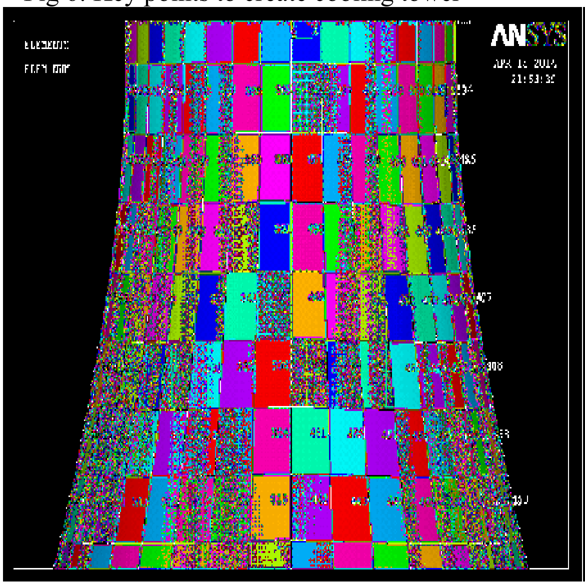

Fig 8: Elements number in model

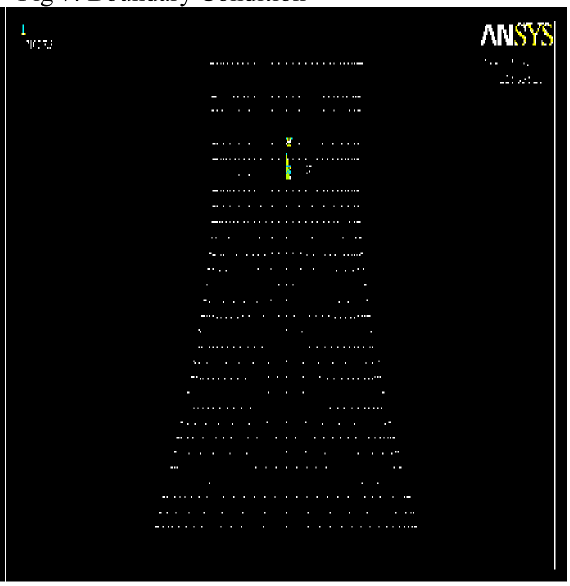

Fig 9: Nodes in Model

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 for 0.5g, 0.6g, 0.7g ground acceleration. The Models of CT 1 & CT 2 for 200mm shell thickness is as shown in fig 10 to 13.

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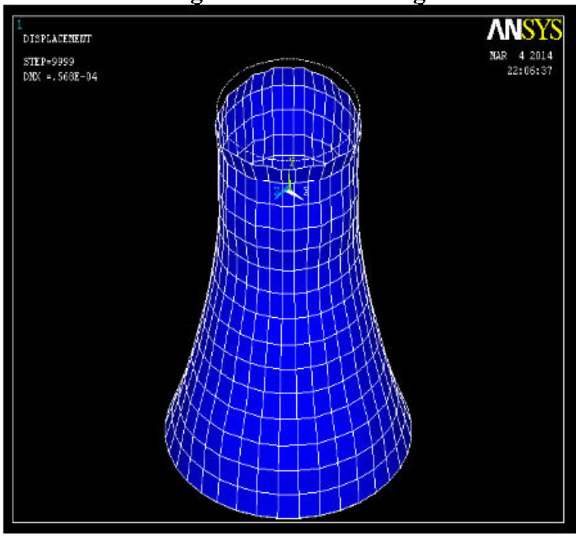
Models of cooling tower 1 & 2 at 0.5g for 200mm SHELL thickness



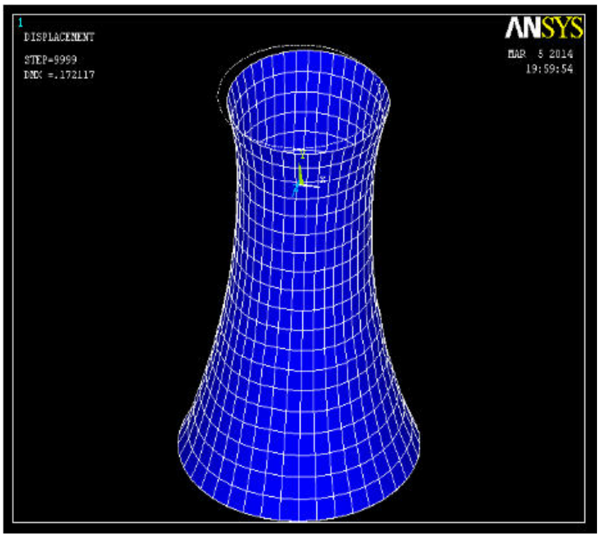


Fig 10: Deflection at 0.5g for CT 1 (200mm shell thickness) Fig 11: Deflection at 0.5g for CT 2

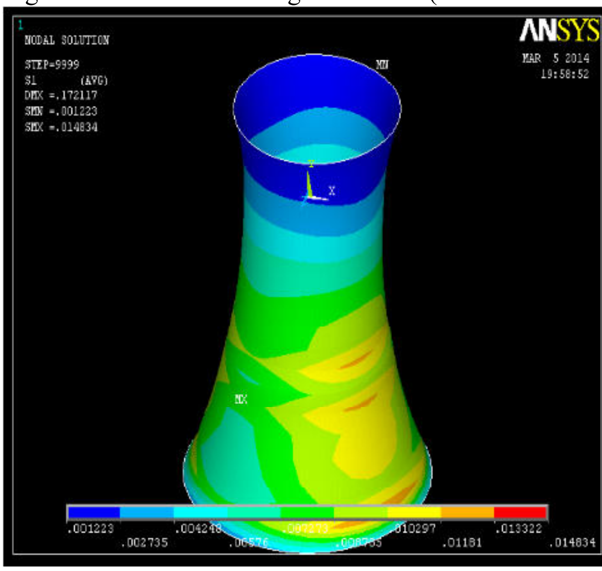


Fig 12: Max Principal Stress for CT 1

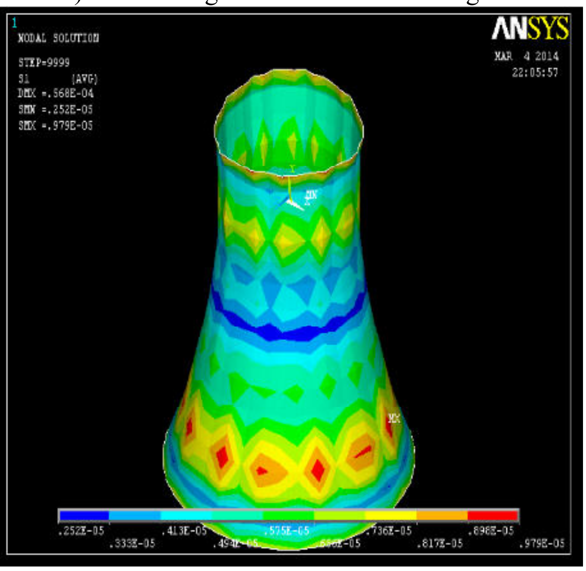
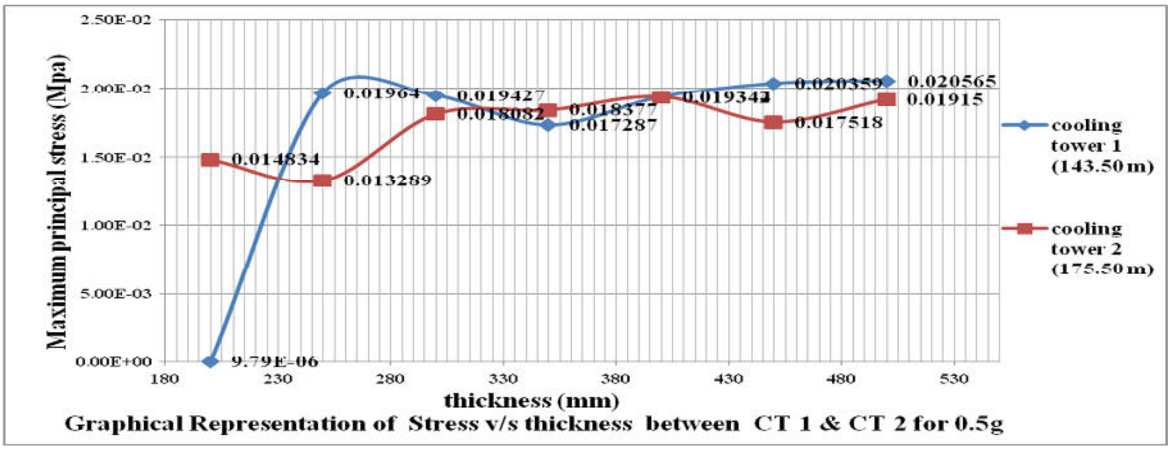
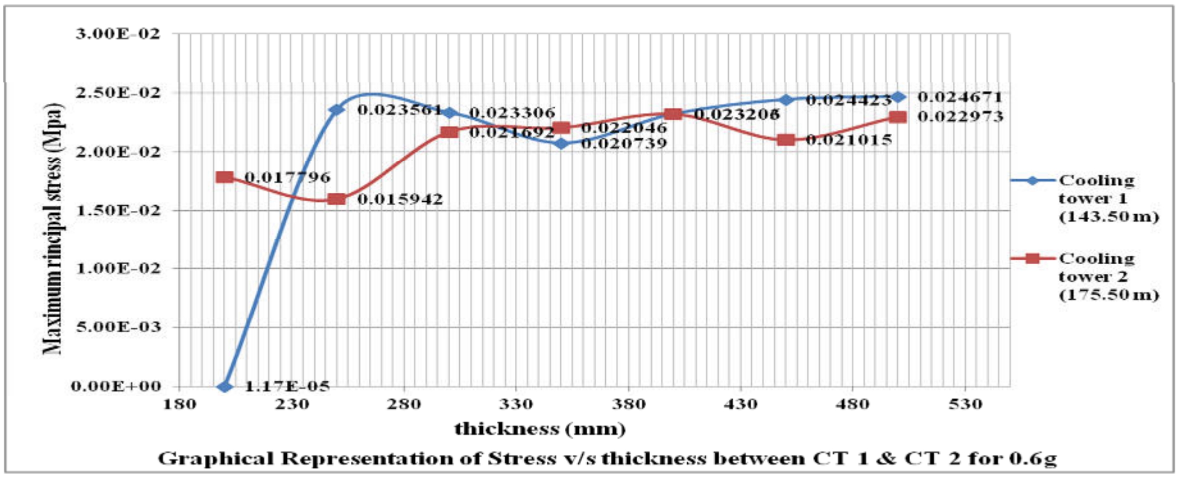


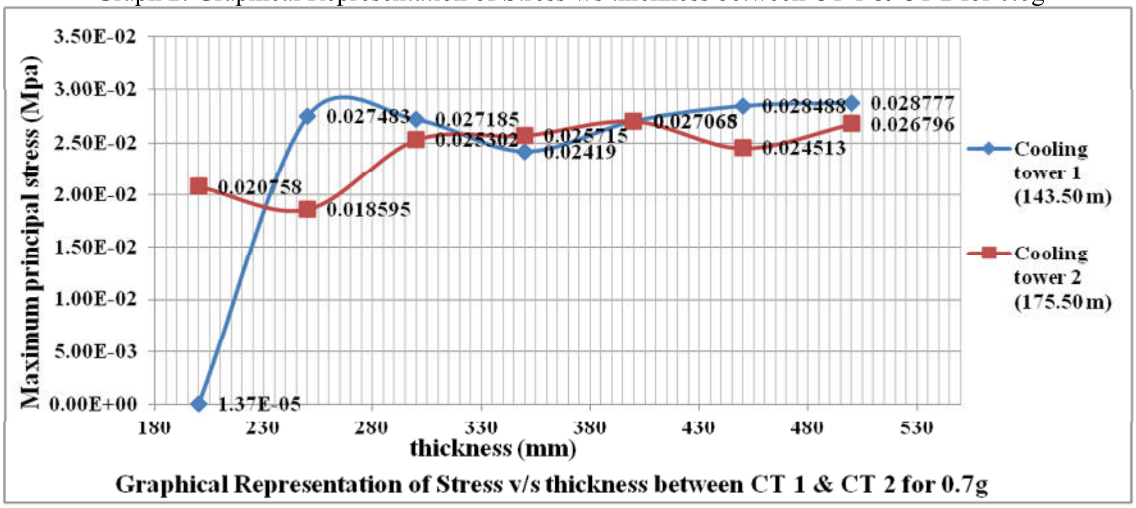
Fig 13: Max Principal Stress for CT 2



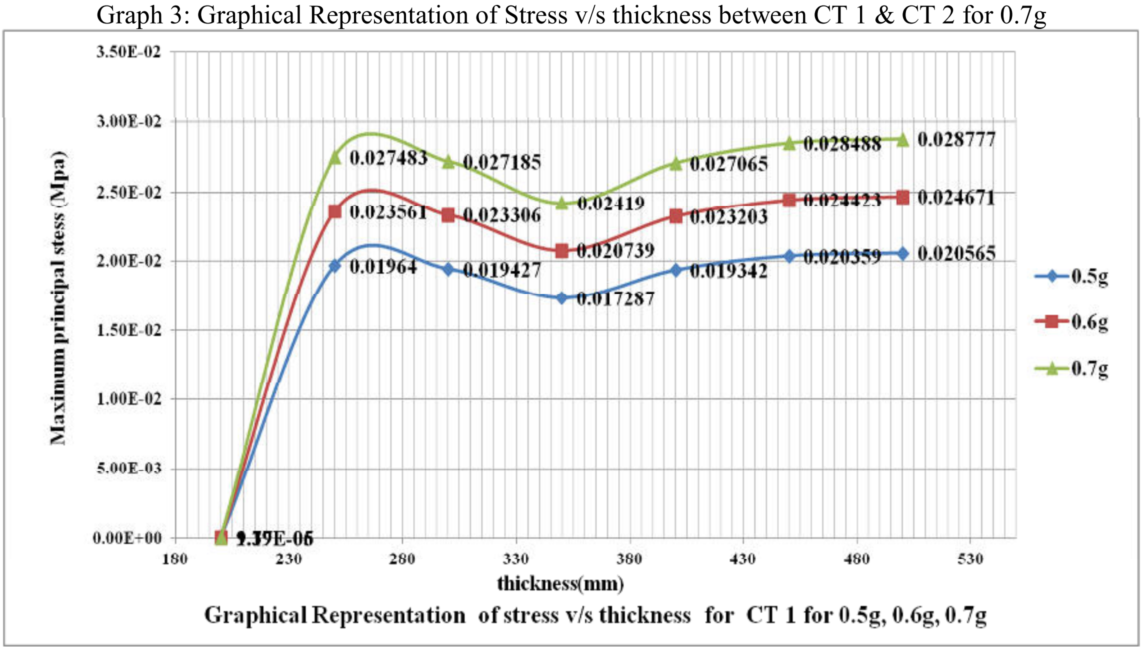
Graph 1: Graphical Representation of Stress v/s thickness between CT 1 & CT 2 for 0.5g



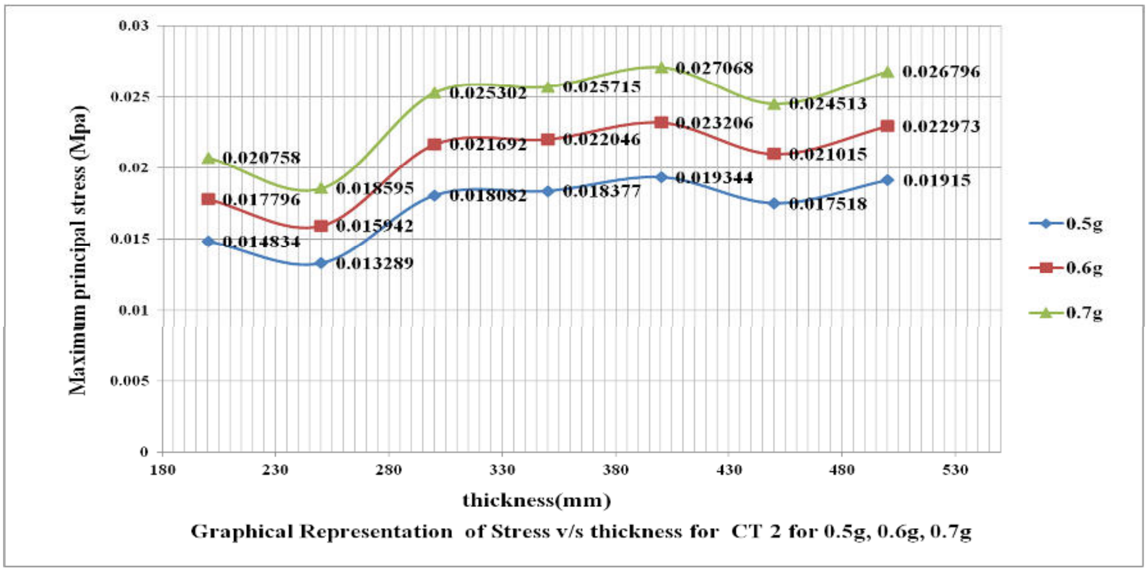
Graph 2: Graphical Representation of Stress v/s thickness between CT 1 & CT 2 for 0.6g



Graph 3: Graphical Representation of Stress v/s thickness between CT 1 & CT 2 for 0.7g



Graph 4: 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 2 for 0.5g, 0.6g, 0.7g

5.0 Summary & Conclusions

A) From Graphical Representation of Max Principal Stress v/s thickness for ground acceleration of 0.5g, 0.6g, 0.7g, it is evident that

1) On comparing CT 1 & CT 2 for Maximum Principal stress

a) The Maximum Principal stress for 200mm thickness is minimum & for 250mm thickness shows maximum stress for CT 1 respectively, whereas CT 2 behave conversely to CT 1 for same thicknesses.

b) The Maximum Principal Stress for 300mm thickness is maximum & for 350mm thickness shows least maximum stress for CT 1 respectively, whereas CT 2 behave opposite to CT 1 for same thicknesses.

c) The Maximum Principal Stress for thickness of 450mm & 500mm shows maximum for CT 1 as compared to CT 2.

d) On comparing CT 1 (143.50m) & CT 2 (175.50m); Initially CT 1 shows less value of stress for 200mm thickness and high value of stress for 500mm thickness respectively, but CT 2 behaves opposite to CT 1 for 200mm & 500mm thickness.

e) As Ground acceleration increases the stresses developed in shell reaches maximum and the stresses developed in shell portion depends upon the SHELL thickness.

2) The Maximum Principal Stress for CT 1 & CT 2 is same for 400mm SHELL thickness and shows optimality.

B) From Graphical Representation of Deflection v/s thickness for 0.5g, 0.6g, 0.7g, it is evident that

1) The Maximum Deflection for 200mm SHELL thickness is least for CT 1 as compared to CT 2, whereas for thickness of 250mm till 500mm thickness deflection for CT 1 is more as compared to CT 2.

2) The Damping factor used in dynamic loading is 5% of critical damping for maximum considered earthquake, the damping factor as given in IS 1893 Part 4: 2005 code for reinforced concrete is 7%. In Response Spectrum Analysis the 5% & 7% damping gives almost same results in the analysis.

6.0 References

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