Seismic Analysis of Hyperbolic Cooling Towers Considering Different Geometrical Parameters

Dilip Sharma*, Akhil Nema*, K. K. Pathak**

*PG Student, Dept. of Civil and Env. Engineering, NITTTR Bhopal, India 462002

**Professor, Dept. of Civil Engineering, IIT(BHU) Varanasi, India 221005

***Abstract* - Cooling tower is a structure which is cylindrical in shape and used in power, nuclear and other plants to cool the hot water liberated from them. Cooling tower is very useful to increase performance and efficiency of power plants. Being such an important structure, structural behavior of cooling tower is very important. In this study, 108 cases of cooling tower structures are analyzed under the seismic force using STAAD.Pro software. The parameters considered are: diameter, height and thickness of cooling tower and earthquake zones. Results are analysed is terms of max.von Mises stress, max. principal stress, max. shear stress and max. displacement.**

Keywords: **Cooling tower, Earthquake, Stress, Deflection, Shear stress.**

I. INTRODUCTION

Hyperbolic cooling tower is a tall, open-topped, hyperboloidal concrete tower device which is simply used for cooling the water escapes out from power plants, air conditioning plants, chemical plants etc. Now-a-days chemical plants, electric power plants etc. are the few major need of society. One can't think to live more industrious and prosperous without them. But the plants have property that there is large unwanted heat in their procedures. Plants produce hot water but it is possible that the hot water acquired from these plants is absorbed by relatively cold air by using the scheme of cooling tower. Converted cold water then recycled through the system and the waste heat is rejected to the air.

Cooling tower is a large size structure. Its structural performance should be ensured under different kind of loads. Earthquake is the major governing parameter for the design of cooling towers with geometrical parameters like height, diameter and shell thickness of cooling tower. Being a structure of such an importance, its safety against earthquake loading must be ensured.

II. PREVIOUS WORK

Some of the prominent literature on the topic are as follows-

Akhil Nema, K.K.Pathak (2016), analyzed 64 cases of cooling tower under seismic forces under different geometrical parameters like diameter of cooling tower, height of cooling tower and different earthquake zones. They concluded their results in terms of max. von Mises stress, max. principal stress, max. shear stress and max. displacement. Akhil Nema, K.K.Pathak (2016), analyzed the 64 cases of cooling tower under seismic forces and 96 cases in wind forces under different geometrical parameters using software STAAD.Pro and compared them with artificial neural networks and they concluded that artificial neural network offers a powerful tool to analyze the natural draught hyperbolic cooling tower under wind and earthquake loading in absence of costly software. D. Makovicka (2016),analyzed and compared the performance of a unit of cooling tower under seismic loading and the envelops of dead, operational, live loads, wind and temperature actions. They considered the earthquake loading with ground motion of 0.3g and ductile properties of a somewhat rigid structure and assessed it as the decrease in seismic load. They concluded that the leading effect on the structure on the basis of maximum displacements, extreme stress state should be assessed by the temperature effect together with the design wind load. N. Prashanth, Sayeedsulaiman, M.U. Aswath (2013), analyzed two cooling tower under seismic and wind load and for this they considered 8-noded 93 shell element with varying dimension and R.C.C. shell thickness. They applied seismic load of 0.5g, 0.6g and 0.7g according to IS: 1893 (part1)-2002 by using modal analysis. Wind loads on cooling towers was applied as pressure according to IS: 875 (Part 3) – 1987 and IS: 11504-1985. They analyzed two cooling towers having fixed base and compared with one of the power plant, and concluded their results in terms of maximum deflection, maximum principal stress and strains, maximum von Mises stresses and strains. S.N.Tande, Snehal S. Chougule (2013) carried out linear dynamic analysis of cooling tower. They used time history modal analysis method and used SAP software for analysis. They considered the material non-linearity out of two geometric and material non-linearity. It was concluded that the displacement is more in non-linear analysis than linear analysis so the structure becomes more flexible in nonlinear analysis. They also observed that in non-linear analysis the stiffness reduces and hence base shear decreases. C.R. Athira, K.R. Rahul, R. Sivan Reshma, Seethu Vijayan, V. Sabu Nithin (2016) modeled, analyzed and designed a cooling tower for a site in gas fired power plant for M/S Torrent Energy at Dahej, Gujarat. In this paper they studied the effect of variations in the tower height and shell thickness on the structural behavior and compared the same for different seismic analysis methods such as equivalent static, response spectrum and time history. For this study they used the software STAAD.Pro and SAP 2000NL. They concluded that the behavior of structure under El-Centro earthquake using nonlinear dynamic time history analysis gave higher nodal drift when compared to other two. They also showed that height have the greatest effect on the free vibration response, increase in height significantly increases displacements. In case of shell thickness variation, it does not affect the top node displacement considerably.

In this study, 108 cases of cooling towers structure are analyzed under the seismic force using STAAD.Pro. The parameters considered are: diameter, height and thickness of cooling tower and earthquake zones. Analysis results are analysed is terms of max.von Mises stress, max.principal stress, max.shear stress and max. displacement.

III. PROPOSED METHODOLOGY

(A). Load case details

(a) Dead load (IS 875: 2007 Part 1)

These are the external loads which acts vertically downward and arises due to the self-weight of the structure. Dead loads include weight of the structural member such as beams, columns, slabs etc. as well as that of non-structural elements such as floor coverings, false ceilings etc. Dead load is calculated as per its cross sectional area multiply with the density of material used.

(b) Seismic Loads (IS 1893: 2002)

When a structure is subjected to ground motion, it responds in shaking fashion. The random motion of structure is possible in all possible directions mainly in horizontal (X) and vertical (Y) directions. This motion causes the structure to vibrate in all three directions. This seismic forces must be evaluated as per IS: 1893:2002.

(B) Geometrical Cases

Three thicknesses considered are 0.3 m, 0.4 m, 0.5 m.

Three heights considered are 100 m, 110 m, 120 m.

Three diameters considered are 60 m, 65 m, 70 m.

Four seismic zones of India are II, III, IV, and V.

Total number of cases =108.

(C) CASE DETAILS

Case details for thickness 0.3m are as below:

1. (height1- 100 m)X (diameter1 – 60 m)X (zone - II) = AaII
2. (height1- 100 m)X (diameter1 – 60 m)X (zone - III) = AaIII
3. (height1- 100 m)X (diameter1 – 60 m)X (zone - IV) = AaIV
4. (height1- 100 m)X (diameter1 – 60 m)X (zone - V) = AaV
5. (height1- 100 m)X (diameter2 – 65 m)X (zone - II) = AbII
6. (height1- 100 m)X (diameter2 – 65 m)X (zone - III) = AbIII
7. (height1- 100 m)X (diameter2 – 65 m)X (zone - IV) = AbIV
8. (height1- 100 m)X (diameter2 – 65 m)X (zone - V) = AbV
9. (height1- 100 m)X (diameter3 – 70 m)X (zone - II) = AcII
10. (height1- 100 m)X (diameter3 – 70 m)X (zone - III) = AcIII
11. (height1- 100 m)X (diameter3 – 70 m)X (zone - IV) = AcIV
12. (height1- 100 m)X (diameter3 – 70 m)X (zone - V) = AcV
13. (height2- 120 m)X (diameter1 – 60 m)X (zone - II) = BaII
14. (height2- 110 m)X (diameter1 – 60 m)X (zone - III) = BaIII
15. (height2- 110 m)X (diameter1 – 60 m)X (zone - IV) = BaIV
16. (height2- 110 m)X (diameter1 – 60 m)X (zone – V) = BaV
17. (height2- 110 m)X (diameter2 – 65 m)X (zone - II) = BbII
18. (height2- 110 m)X (diameter2 – 65 m)X (zone - III) =BbIII
19. (height2- 110 m)X (diameter2 – 65 m)X (zone - IV) = BbIV
20. (height2- 110 m)X (diameter2 – 65 m)X (zone - V) = BbV
21. (height2- 110 m)X (diameter3 – 70 m)X (zone - II) = BcII
22. (height2- 110 m)X (diameter3 – 70 m)X (zone - III) = BcIII
23. (height2- 110 m)X (diameter3 – 70 m)X (zone - IV) = BcIV
24. (height2- 110 m)X (diameter3 – 70 m)X (zone - V) = BcV
25. (height3- 120 m)X (diameter1 – 60 m)X (zone - II) = CaII
26. (height3- 120 m)X (diameter1 – 60 m)X (zone - III) = CaIII
27. (height3- 120 m)X (diameter1 – 60 m)X (zone - IV) = CaIV
28. (height3- 120 m)X (diameter1 – 60 m)X (zone - V) = CaV
29. (height3- 120 m)X (diameter2 – 65 m)X (zone - II) = CbII
30. (height3- 120 m)X (diameter2 – 65 m)X (zone - III) = CbIII
31. (height3- 120 m)X (diameter2 – 65 m)X (zone - IV) = CbIV
32. (height3- 120 m)X (diameter2 – 65 m)X (zone - V) = CbV
33. (height3- 120 m)X (diameter3 – 70 m)X (zone - II) = CcII
34. (height3- 120 m)X (diameter3 – 70 m)X (zone - III) = CcIII
35. height3- 120 m)X (diameter3 – 70 m)X (zone - IV) = CcIV
36. (height3- 120 m)X (diameter3 – 70 m)X (zone - V) = CcV.

Total no. of cases = 36

Same as above all other cases have been analyzed for other two thicknesses (0.4 m and 0.5 m) so the no. of cases analyzed are 108.

(D) MATERIAL PROPERTIES

Following material properties have been considered in the modeling-

Density of R.C.C. = 25 kN/m3

Poisson ratio= 0.20.

(E) SUPPORT CONDITION

As the structure is restrained at the bottom, therefore bottom ends at the ground level is considered to be fixed.

(F) EARTHQUAKE LOADING DETAILS

All the towers are analyzed for 4 seismic zones.

The earthquake loads are derived for following seismic parameters as per IS: 1893(2002).

Seismic zones - II,III,IV,V.

Response reduction factor - 5

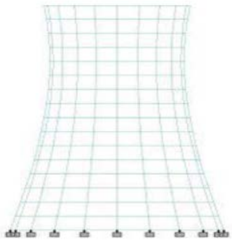
Importance factor - 1.5

Damping - 5%

Soil type - hard soil.

(I) STRUCTURAL MODELING

Structural modeling has been carried out using STAAD.Pro software (Ref.10) using 4- noded elements. There are 400 elements for different models. FE models are shown in Figure 4.1 and 4.2.



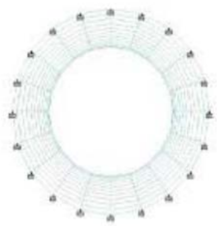


Fig. 3.1**:**Elevation of cooling tower Fig. 3.2: Plan of cooling tower

Earthquake loading in X and Z direction are shown in Fig. 4.3 and 4.4.

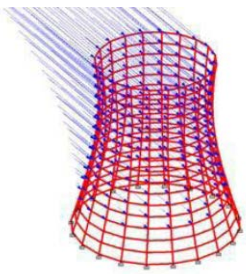


Fig. 3.3: Loading diagram for earthquake loading in +X direction

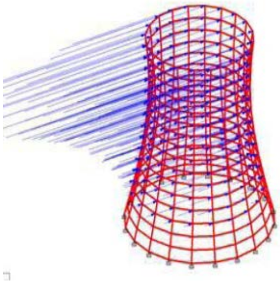


Fig. 3.4: Loading diagram for earthquake loading in +Z direction

IV. SIMULATION/EXPERIMENTAL RESULTS

Results obtained from STAAD.Pro analyses can be presented graphically under following heads –
(A). Seismic analysis for thickness-1(0.3m)
(a) Top diameter = 60m

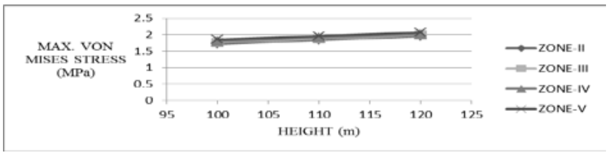


Fig.4.1: Max. von Mises stress for all seismic zones with respect to height

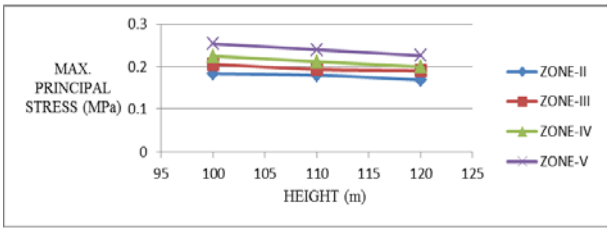


Fig. 4.2: Max. principal stress for all seismic zones with respect to height

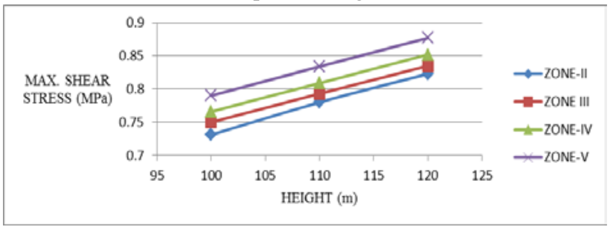


Fig. 4.3: Max. shear stress for all seismic zones with respect to height

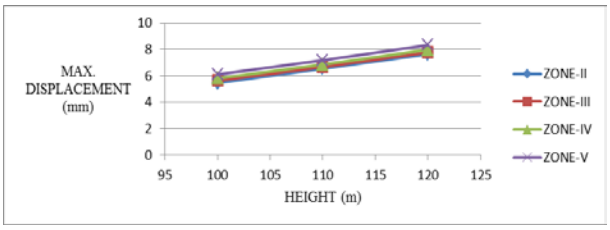


Fig. 4.4: Max. displacement for all seismic zones with respect to height

(b)Top diameter =65 m

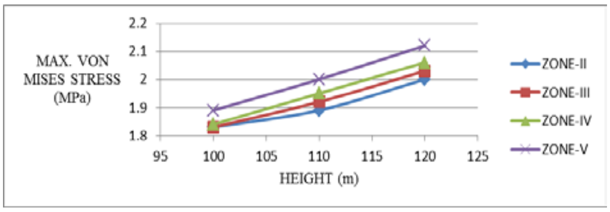


Fig.4.5: Max. von Mises stress for all seismic zones with respect to height

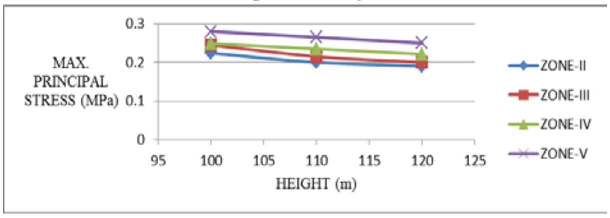


Fig.4.6: Max. principal stress for all seismic zones with respect to height

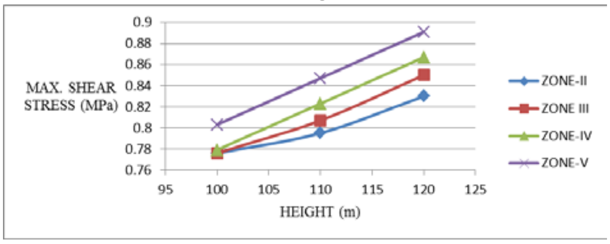


Fig.4.7: Max. shear stress for all seismic zones with respect to height

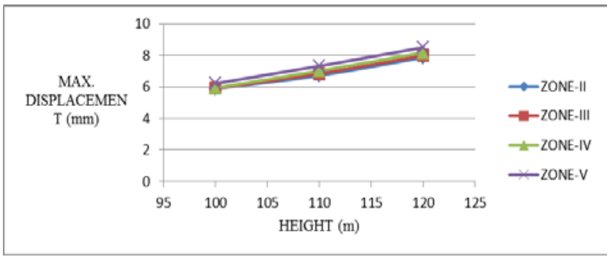


Fig.4.8: Max. displacement for all seismic zones with respect to height

(c)Top diameter =70 m

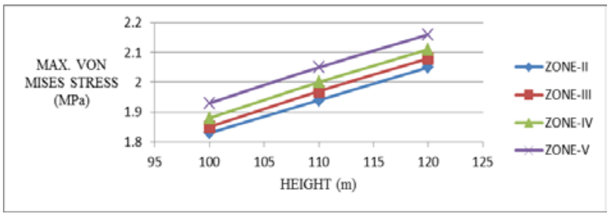


Fig.4.9: Max. von Mises stress for all seismic zones with respect to height

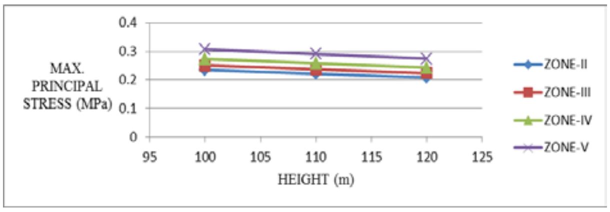


Fig.4.10: Max. principal stress for all seismic zones with respect to height

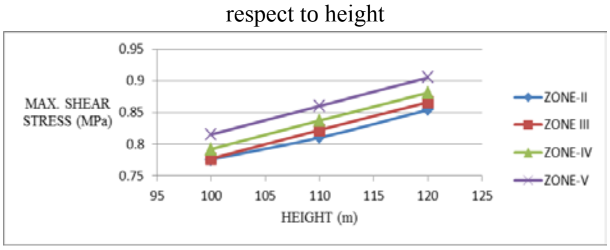


Fig.4.11: Max. shear stress for all seismic zones with respect to height

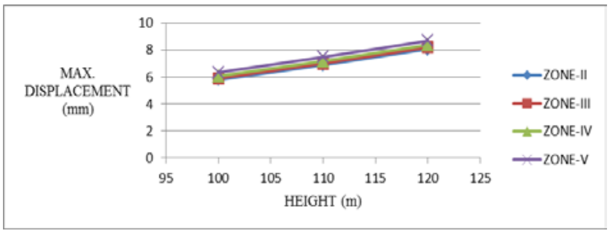


Fig.4.12: Max. displacement for all seismic zones with respect to height

(B). Seismic analysis for thickness-2(0.4m)

(a) Top diameter = 60m

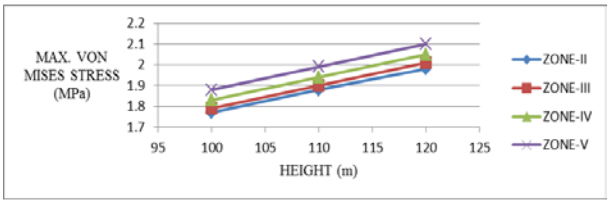


Fig.4.13: Max. von Mises stress for all seismic zones with respect to height

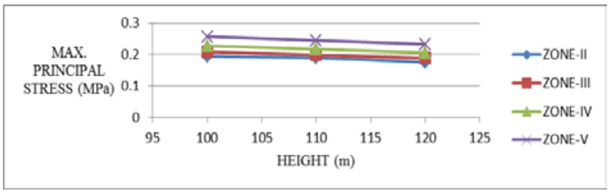


Fig.4.14 Max. principal stress for all seismic zones with respect to height

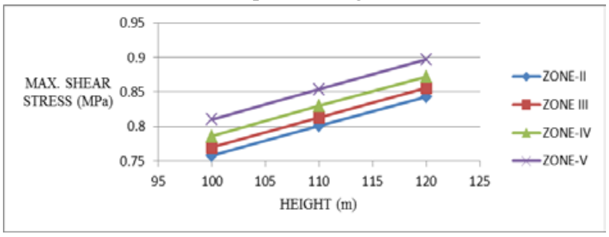


Fig.4.15: Max. shear stress for all seismic zones with respect to height

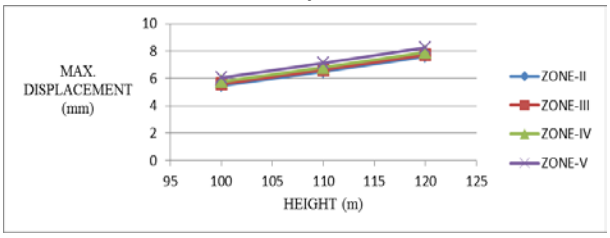


Fig.4.16: Max. displacement for all seismic zones with respect to height

(b)Top diameter = 65m

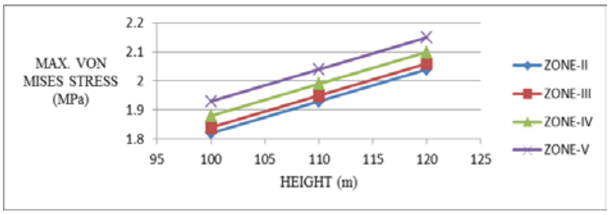


Fig.4.17: Max. von Mises stress for all seismic zones with respect to height

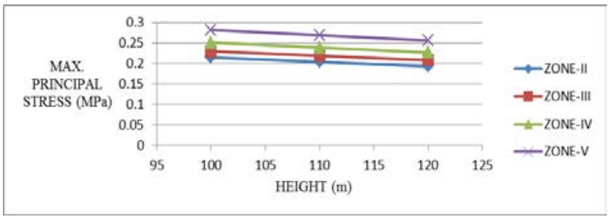


Fig.4.18: Max. principal stress for all seismic zones with respect to height

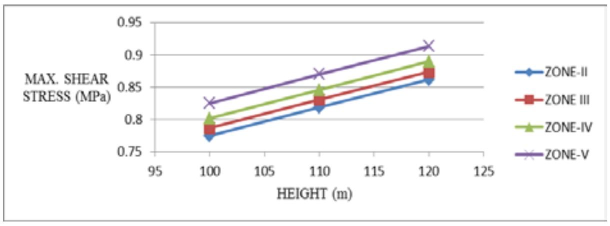


Fig.4.19: Max. shears stress for all seismic zones with respect to height

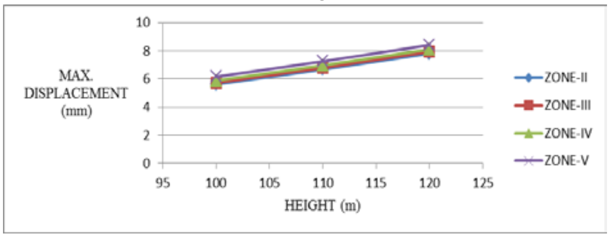


Fig.4.20: Max. displacement for all seismic zones with respect to height

(c)Top diameter=70 m

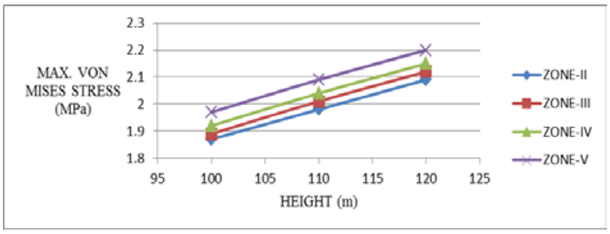


Fig.4.21: Max. von Mises stress for all seismic zones with respect to height

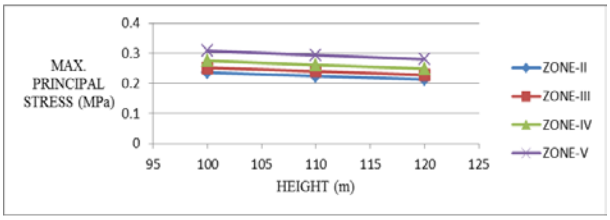


Fig.4.22: Max. principal stress for all seismic zones with respect to height

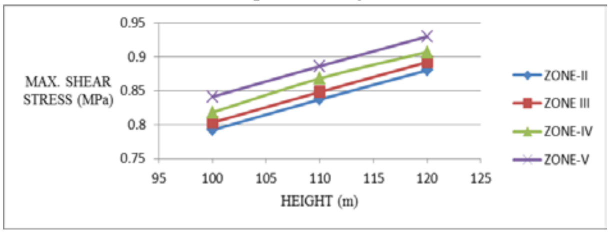


Fig.4.23: Max. shear stress for all seismic zones with respect to height

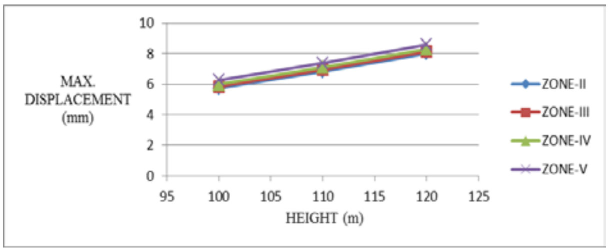


Fig.4.24: Max. displacement for all seismic zones with respect to height

(C). Seismic analysis for thickness-3(0.5m)

(a) Top diameter = 60m

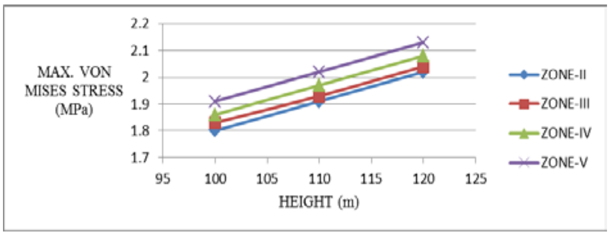


Fig.4.25: Max. von Mises stress for all seismic zones with respect to height

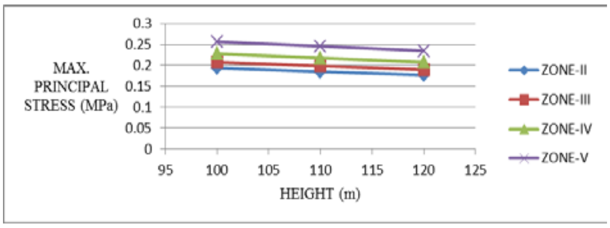


Fig.4.26: Max. principal stress for all seismic zones with respect to height

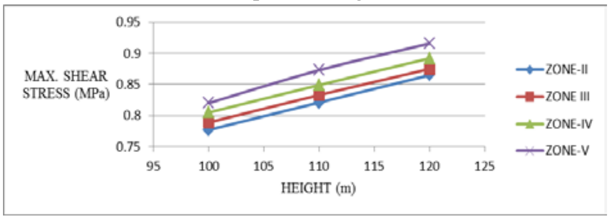


Fig.4.27: Max. shear stress for all seismic zones with respect to height

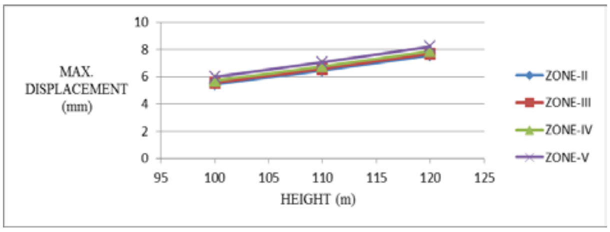


Fig.4.28: Max. displacement for all seismic zones with respect to height

(b) Top diameter=65 m

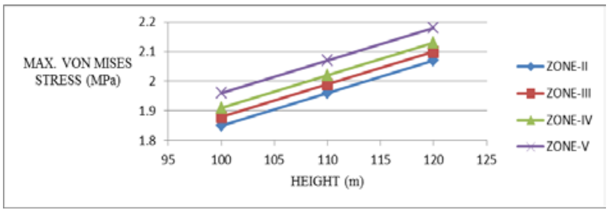


Fig.4.29: Max. von Mises stress for all seismic zones with respect to height

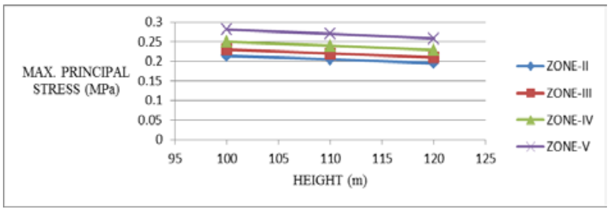


Fig.4.30: Max. principal stress for all seismic zones with respect to height

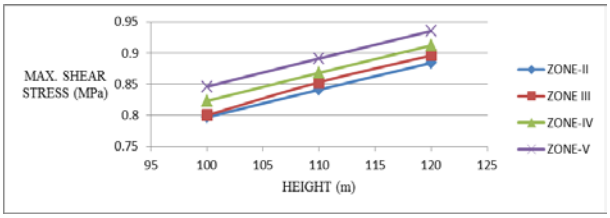


Fig.4.31: Max. shear stress for all seismic zones with respect to height

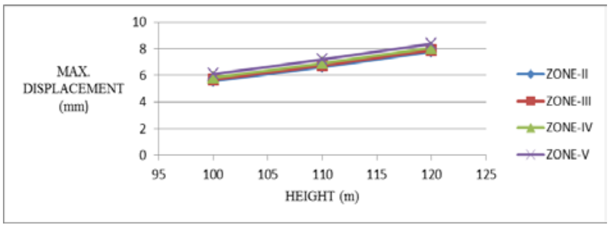


Fig.4.32: Max. displacement for all seismic zones with respect to height

(c) Top diameter = 70 m

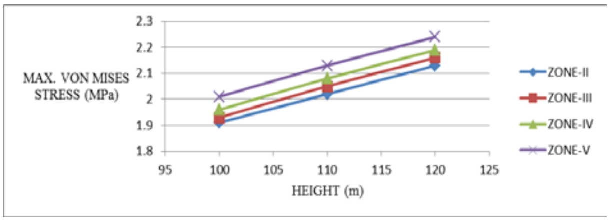


Fig.4.33: Max. von Mises stress for all seismic zones with respect to height

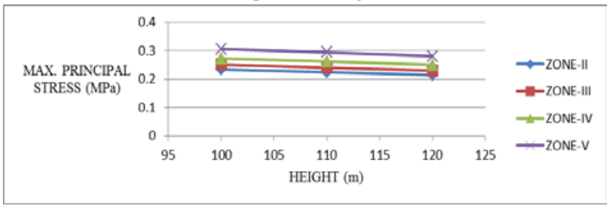


Fig.4.34: Max. principal stress for all seismic zones with respect to height

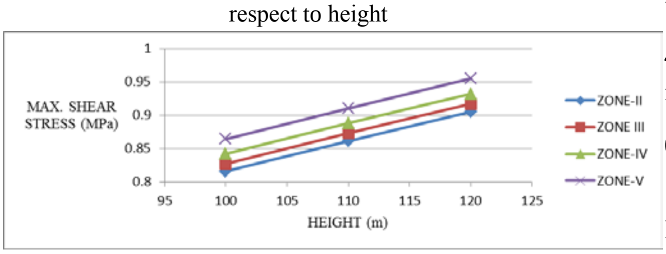


Fig.4.35: Max. shear stress for all seismic zones with respect to height

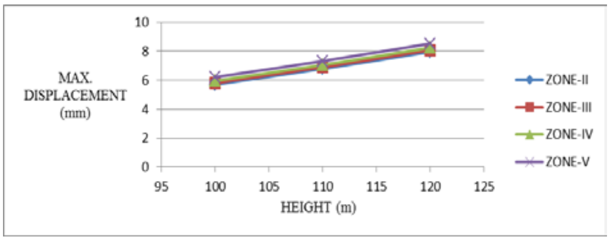


Fig.4.36: Max. displacement for all seismic zones with respect to height

V.CONCLUSION

The conclusions of this study on seismic analysis of hyperbolic cooling tower under different geometrical parameters are given below:

(A). Maximum von Mises Stress

1. Max. von Mises stress increases considerably with increase in height for all earthquake zones, diameters and thicknesses.

2. Max. von Mises stress increases considerably with increase in diameters for all earthquake zones, heights and thicknesses.

3. Thickness have very little effect on max. von Mises stress however max. von Mises stress increases with increase in thickness for all earthquake zones, heights and diameters.

4. Rate of increment is constant with respect to zone number.

(B). Maximum principal Stress

1. Max. principal stress decreases considerably with increase in height for all earthquake zones, diameters and thicknesses.

2. Max. principal stress increases considerably with increase in diameters for all earthquake zones, heights and thicknesses.

3. Thickness has very little effect on max. principal stress however max. principal stress increases with increase in thickness for all earthquake zones, heights and diameters.

4. Rate of decrement is constant with respect to zone number.

(C). Maximum shear Stress

1. Max. shear stress increases considerably with increase in height for all earthquake zones, diameters and thicknesses.

2. Max. shear stress increases considerably with increase in diameters for all earthquake zones, heights and thicknesses.

3. Max. shear stress increases considerably with increase in thickness for all earthquake zones, heights and diameters.

4. Rate of increment is constant with respect to zone number.

(D). Maximum displacement

1. Max. displacement increases considerably with increase in height for all earthquake zones, diameters and thicknesses.

2. Max. displacement increases considerably with increase in diameters for all earthquake zones, heights and thicknesses.

3. Thickness have very little effect on max. displacement however max. displacement decreases with increase in thickness for all earthquake zones, heights and diameters.

4. Rate of increment is constant with respect to zone number.

VI. FUTURE SCOPES

1. In this study linear elastic material property has been considered. The same may be carried out by considering non-linear material property.

2. In this study STAAD.Pro software has been used considering 4 - noded plate element. The same may be carried out by other FEM software such as ANSYS, ABAQUS etc. using different types of plate elements.

REFERENCES

[1] Akhil Nema, K.K. Pathak, Parametric Earthquake Analysis of Natural Draught Hyperbolic Cooling Tower, International Journal of Engineering Research, Vol.5, Special Issue 1, pp. 143-148, (2016).

[2] Akhil Nema, K. K. Pathak, Wind and Earthquake Analysis of Natural Draught Hyperbolic Cooling Tower Using Artificial Neural Networks, Journal of Engineering Science & Management Education, Vol.9, No.1, pp.34-44,(2016).

[3] C.R. Athira, K.R. Rahul, R.Sivan Reshma, Seethuvijayan, V. SabuNithin, To Study Effect of Variations in the Tower Height and Shell Thickness on the Structural Behaviours, IOSR Journal of Mechanical and Civil Engineering, Special Issue 1, pp. 18-24, (2016).

[4] D. MakoviCka, Response Analysis of an RC Cooling Tower Under Seismic and Windstorm Effects, Acta Polytechnica, Vol. 46, No. 6, (2006).

[5] IS 11504 (1985), Indian Standard-Criteria for Structural Design of Reinforcement Concrete Natural Draught Cooling Towers, Beauro of Indian Standard.

[6] N. Krishna Raju, Advance Reinforced Cement Concrete Designs, CBS Publication (2014).

[7] N. Prashanth, Sayeed Sulaiman, M.U.Aswath, To Study Effect of Seismic and Wind Loads on Hyperbolic Cooling Tower of Varying Dimension and RCC Shell Thickness, The International Journal of Science & Technology, Vol.1, No. 3, (2013).

[8] Sachin Kulkarni, A. V. Kulkarni, Static and Dynamic Analysis of Hyperbolic Cooling Tower, International Journal of Civil Engineering and Technology, Vol.5, No.9, pp. 09-26, (2014).

[9] S. N. Tande, Snehal S. Chougule, Linear and Nonlinear Behavior of R. C. Cooling Tower under Earthquake Loading, International Journal of Latest Trends in Engineering and Technology (IJLTET), Vol. 2, No.4, (2013).

[10] User Manual STAAD.Pro, Bentley Software, (2013).