Parametric Wind Analysis of Natural Draught Hyperbolic Cooling Towers

Akhil Nema[1], Shubhendra Mishra[1], K. K. Pathak[2]

[1]P.G. Student, [2] Professor

National Institute of Technical Teachers' Training and Research, Bhopal 462026 (MP)

Abstract - Hyperbolic cooling tower is a tall and hyperboloidal shaped device having open top which is used in power plants, nuclear and electrical plants to cool the water. Now-a-days the power plants are the major requirements of society but having a drawback, heat escapes out from the power plants in the form of water can be harmful to the environment. A survey says that only U S industries use approximately 500 billion gallons of water a day, so that hot water can either mix to the water streams or can be recycled. But if water recycled to the environment it can be harmful to the water species, and if the water is recycled to the power plants then it is not possible to convert the hot water into steam, so cooling tower is the right choice to cool the hot water and reuse the water. In this study, cooling tower is analyzed under the effect of wind forces using STAAD.Pro software. The parameters considered are top diameter and height of cooling with constant thickness under different wind zones of India. Various parameters on the basis of which results are analyzed are- maximum von Mises stress, maximum principal stress, maximum shear stress and maximum deflection. Based on these results, salient conclusions are drawn.

Keywords: Cooling tower, Wind, stress, shear stress, deflection.

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 requirements. One can't think to live more productive and flourishing without them. But the plants are have property that there is large waste of heat in their operations. For example thermal power plants for electricity generation works on the heat obtained from the burning of the coal whereas nuclear power plant for the same purpose works on the heat obtained from the nuclear chain reaction. Some other plants give the hot water but it is possible that the hot water obtained from these plants is absorbed by comparatively cold air by using the device cooling tower. Converted cold water then recycled throughout the system and the waste heat is rejected to the atmosphere. Wind is the major governing parameter in the design of cooling towers. There have been several failures due to wind. Being a structure of such an importance, its safety against wind loading must be ensured.

In surveying of all major failures of cooling towers, we can establish some points about-

1. Margin for safety against the wind load was not sufficient, means the maximum wind speed was not adequate in their design data.
2. When there is number of cooling towers or a group of cooling towers than there will vortex shedding which can influence downstream cooling towers, which was neglected.
3. It is also found that the towers were having no upper edge members to withstand the wind forces.

II. PREVIOUS WORK

Some of the latest literature on cooling tower are given below-

Tejas G. Gaikwad, N. G. Gore, V. G. Sayagavi, Kiran Madhavi, Sandeep Pattiwar (2014) modeled the cooling tower using STAAD.Pro.V8i and analyzed it. They modeled the cooling tower by using bar type finite elements having three or four inner nodes offering an efficient vibration analysis giving us simplicity and acceptable accuracy for practical engineering. They used Gust method and Peak wind methods for applying wind load. It is concluded that the response of cooling tower is governed by vertical as well as circumferential wind distribution. They also found when the curvature of shellis changed, hoop stresses are greatly influenced. Sachin Kulkarni, A. V. Kulkarni (2014) analyzed the two hyperbolic cooling tower of height 143.50 m and 175.50 m from Bellary thermal power station (BTPS) as case study. They analyzed both cooling towers for wind forces using ANSYS software with 8 noded SHELL 93 element assuming the fixed base with uniform thickness. They applied the wind load as pressure on cooling tower shell by using IS: 875(Part-III):1987 and IS: 11504:1985. A. D. John, R. Foroughi, A. Gairola (2014) investigated the influence of interfering structures on deformation of cooling tower due to non-axisymmetric horizontal wind loads. First they studied the pattern of wind load distribution on cooling tower in a wind tunnel on 1:150 geometrical scale models with interfering structures, and then they studied the deformation pattern of cooling tower. They found in their research, in case of interference for a tilted approach wind, there is a significant increase in the magnitude of the net pressure coefficients on windward meridian. They also evaluated the deformation of the tower for both mean and fluctuating wind loads. They concluded that the throat level for isolated cooling tower will be the weakest portion of cooling tower when the magnitude of wind load increases but that will not be dangerous for interference condition. G. Murali, C. M. Vivek Vardhan and B. V. Prasanth Kumar Reddy (2012) analyzed two cooling towers of 122 m and 200 m high fixed at base using ANSYS software. They considered 8- noded shell element for analysis and applied the wind load on cooling tower shell as pressure calculated according to IS:875 (Part- III):1987 at different levels according to IS:11504:1985. They concluded their result in terms of meridional force and hoop force, and bending moments, viz., meridional moment and hoop moment.

From the literature survey it is observed that researches have worked on various aspects of cooling towers. However, effects of geometrical parameters on wind analysis have not been given due to considerations. In this study effect of top diameters and height of cooling tower on wind analysis have been studied.

III. PROPOSED METHODOLOGY

3.1 Load Case Details

3.1.1 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.

3.1.2 Wind loads (IS: 875: 2002 PART-3)

In general, wind speed in the atmospheric boundary layer increases with height from zero at ground level to a maximum at a height called the gradient height. There is usually a slight change in direction (Ekman effect). The variation with height depends primarily on the terrain conditions. However, the wind speed at any height never remains constant and it has been found convenient to resolve its instantaneous magnitude into an average or mean value and a fluctuating component around this average value. We must calculate this load from IS: 875:2002 (Part-3).

3.2 Geometrical Cases Considered in Wind Analysis

TYPE-1: for zone-I, 4 diameters x 4 heights = 16 cases,
TYPE-2: for zone-II, 4 diameters x 4 heights = 16 cases,
TYPE-3: for zone-III, 4 diameters x 4 heights = 16 cases,
TYPE-4: for zone-IV, 4 diameters x 4 heights = 16 cases,
TYPE-5: for zone-V, 4 diameters x 4 heights = 16 cases,
TYPE-6: for zone-VI, 4 diameters x 4 heights = 16 cases,
TOTAL CASES = 96.

1.3 Geometry Selection

For wind zone - I

(a) (Height = 75m) X (Top Diameter = 40m - Throat Diameter = 37 m)=CTIAa
(b) (Height = 75m) X (Top Diameter = 45m - Throat Diameter = 42m) = CTIAb
(c) (Height = 75m) X (Top Diameter = 50m - Throat Diameter = 47m) = CTIAc
(d) (Height = 75m) X (Top Diameter = 55m - Throat Diameter = 52m) = CTIAd
(e) (Height = 80m) X (Top Diameter = 40m - Throat Diameter = 37m) = CTIBa
(f) (Height = 80m) X (Top Diameter = 45m - Throat Diameter = 42m) = CTIBb
(g) (Height = 80m) X (Top Diameter = 50m - Throat Diameter = 47m) = CTIBc
(h) (Height = 80m) X (Top Diameter = 55m - Throat Diameter = 52m) = CTIBd
(i) (Height = 85m) X (Top Diameter = 40m - Throat Diameter = 37m) = CTICa
(j) (Height = 85m) X (Top Diameter = 45m - Throat Diameter = 42m) =CTICb
(k) (Height = 85m) X (Top Diameter = 50m - Throat Diameter = 47m) =CTICc
(l) (Height = 85m) X (Top Diameter = 55m - Throat Diameter = 52m) =CTICd
(m) (Height = 90m) X (Top Diameter =40m - Throat Diameter = 37m) =CTIDa
(n) (Height = 90m) X (Top Diameter = 45m - Throat Diameter = 42m) =CTIDb
(o) (Height = 90m) X (Top Diameter = 50m - Throat Diameter = 47m) =CTIDc
(p) (Height = 90m) X (Top Diameter = 55m - Throat Diameter = 52m) =CTIDd

TOTAL NO. OF CASES = 16

Same as above all cases considered for all six wind zones, which will become total 96 no. of cases.

3.4 Selection of Frame Section and Its Geometrical Properties -

Following material properties have been considered in modeling -

Density of RCC: 25 kN/m^3

Poisson ratio: 0.20.

3.5 Support Condition

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

3.6 Load Cases Definition

Following loading is adopted for analysis:-

3.6.1 Dead Loads

Self weight of the structure and the weight of all instrument and devices attached to the structure have been being considered in the analysis, which is automatically considered by software.

3.6.2 Wind Loads

We have applied the wind load on cooling tower as pressure on shell and the magnitude of pressure is calculated as per IS: 875:2002 (PART-III).

The calculation of wind load for all wind zones are as follows –

Wind pressure (Pz) = $0.6.Vz^2$

Where Vz = design wind speed

= $Vb*k_1*k_2*k_3$

Where

Vb = Basic wind speed = 33m/s (for wind zone - I)

= 39 m/s (for wind zone - II)

= 44 m/s (for wind zone - III)

= 47 m/s (for wind zone - IV)

= 50 m/s (for wind zone - V)

= 55 m/s (for wind zone - VI)

K_1 = Risk coefficient = 1.05 (for wind zone -I)

= 1.06 (for wind zone -II)

= 1.07 (for wind zone -III)

= 1.07 (for wind zone -IV)

= 1.08 (for wind zone -V)

= 1.08 (for wind zone -VI)

K_2 = Terrain, height and structure size factor = variable (terrain category – 2and class - c)

= 0.93 (for 10m height)

= 1.0 (for 20m height)

= 1.04 (for 30m height)

= 1.07 (for 40m height)

= 1.1 (for 50m height)

= 1.114 (for 60m height)

= 1.128 (for 70m height)

= 1.135 (for 75m height)

= 1.142 (for 80m height)

= 1.149 (for 85m height)

= 1.156 (for 90m height)

K_3 = Topography factor = 1.0

Using these data, wind pressure for different height and wind zones can be calculated.

3.7 Structural Modeling

Cooling towers are modeled using STAAD.Pro software. Four – noded quadrilateral elements have been used for modeling. There are 300 to 360 elements in the model in different cases. Elevation and plan of the modeled tower are shown in Figure 3.1 and 3.2. Typical loading diagram is shown in Figure 3.3.

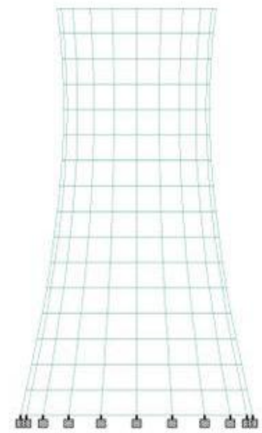

Figure 3.1: Elevation of Cooling Tower

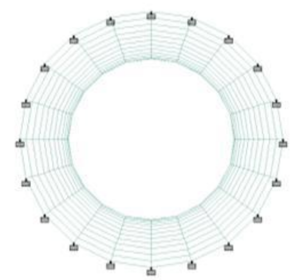

Figure 3.2: Plan of Cooling Tower

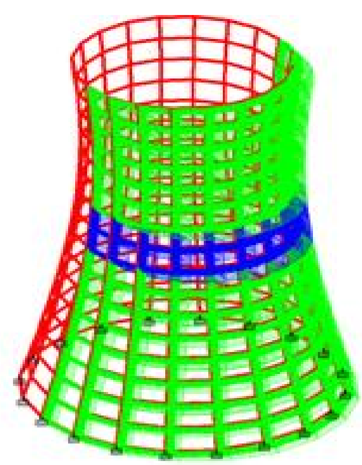

Figure 3.3: Loading Diagram for Wind Load

IV. EXPERIMENTAL RESULTS

The analysis results of all 96 cases of wind analysis are discussed below –

(A) Top diameter = 40 m

When the top diameter of cooling tower is 40m, the variation of maximum stresses and deflection for all wind zones and all four heights are shown in Figure 4.1 to 4.4.

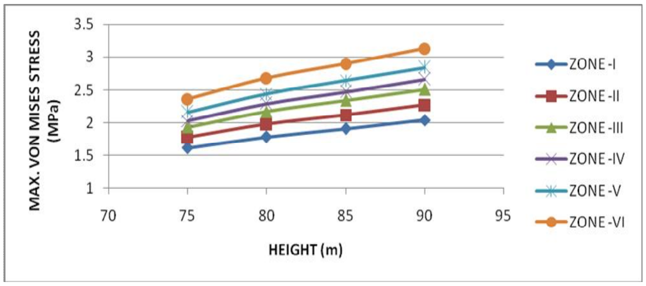

Figure 4.1: Max. von Mises stress for all wind zones with respect to height

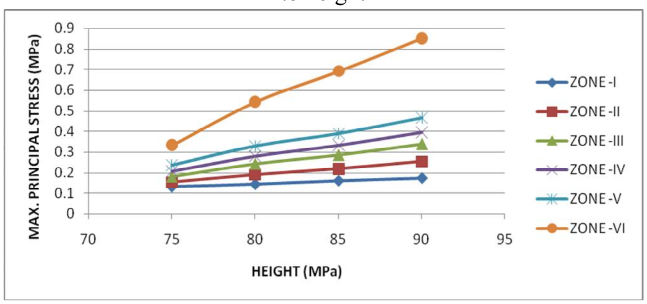

Figure 4.2: Max. Principal stress for all wind zones with respect to height

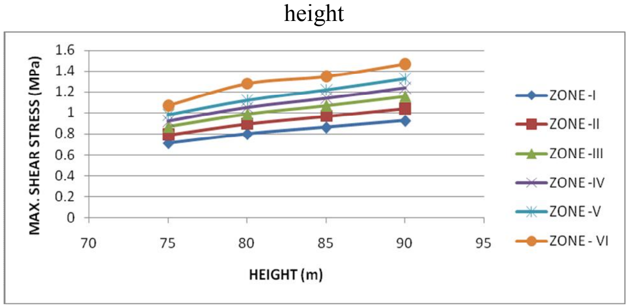

Figure 4.3: Max. Shear stress for all wind zones with respect to height

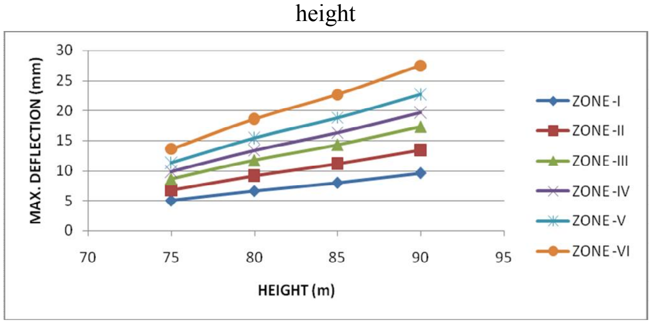

Figure 4.4: Max. Deflection for all wind zones with respect to height

(B) Top diameter = 45 m

When the top diameter of cooling tower is 45m, the variation of maximum stresses and deflection for all wind zones and all four heights are shown in Figure 4.5 to 4.8.

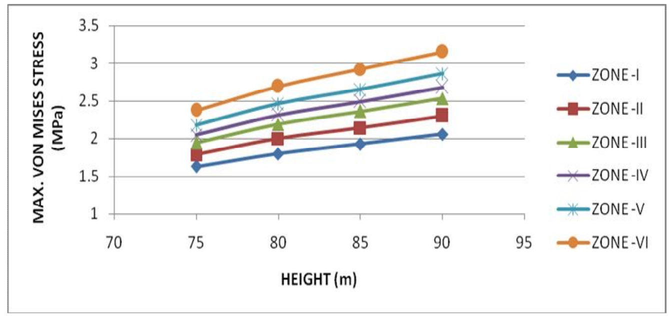

Figure 4.5: Max. von Mises stress for all wind zones with respect to height

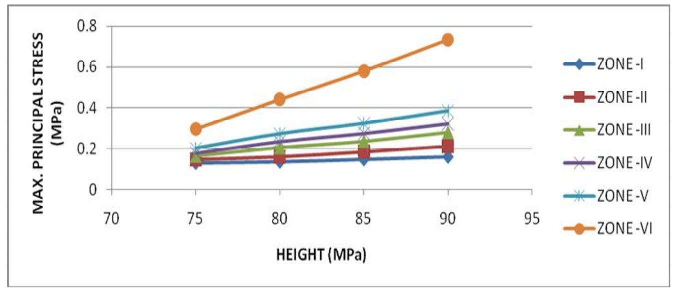

Figure 4.6: Max. Principal stress for all wind zones with respect to height

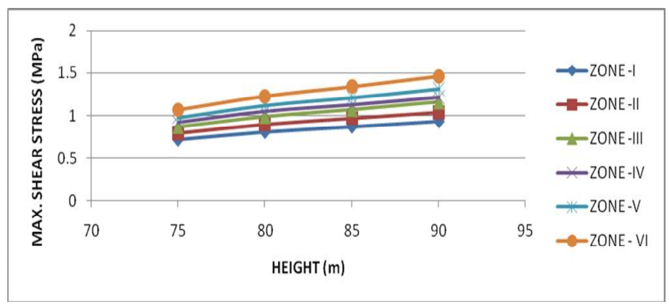

Figure 4.7: Max. Shear stress for all wind zones with respect to height

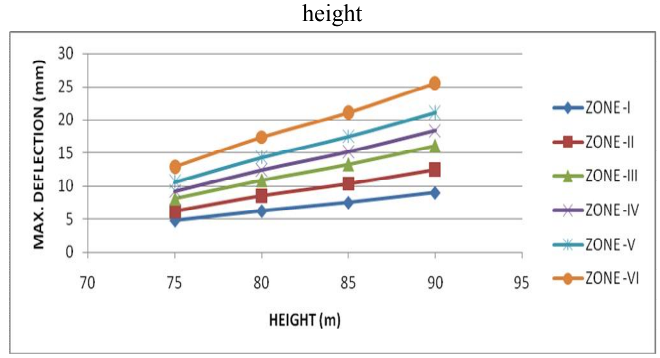

Figure 4.8: Max. Deflection for all wind zones with respect to height

(C) Top diameter = 50 m

When the top diameter of cooling tower is 50m, the variation of maximum stresses and deflection for all wind zones and all four heights are shown in Figure 4.9 to 4.12.

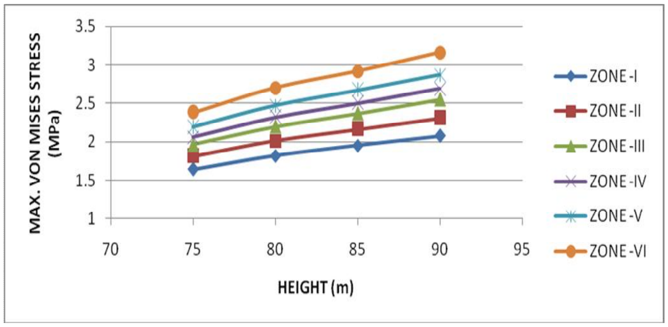

Figure 4.9: Max. von Mises stress for all wind zones with respect to height

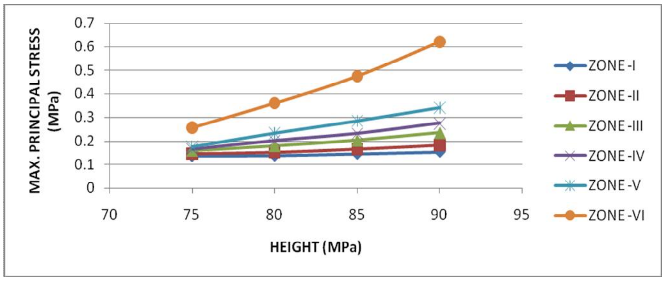

Figure 4.10: Max. Principal stress for all wind zones with respect to height

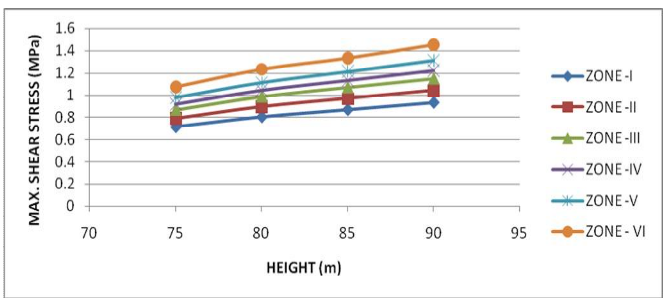

Figure 4.11: Max. Shear stress for all wind zones with respect to height

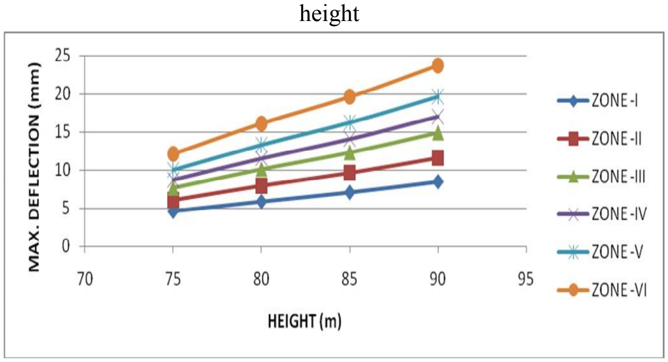

Figure 4.12: Max. Deflection for all wind zones with respect to height

(D) Top diameter = 55 m

When the top diameter of cooling tower is 55m, the variation of maximum stresses and deflection for all wind zones and all four heights are shown in Figure 4.13 to 4.16.

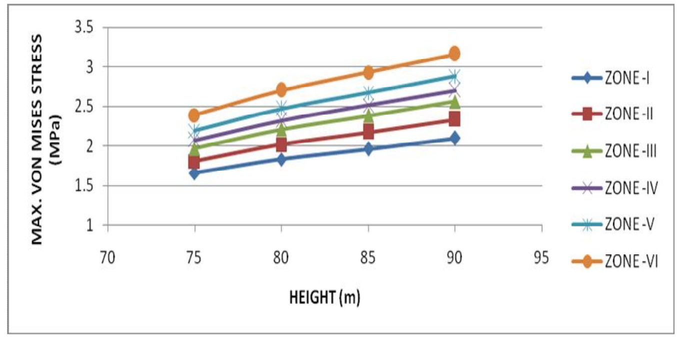

Figure 4.13: Max. von Mises stress for all wind zones with respect to height

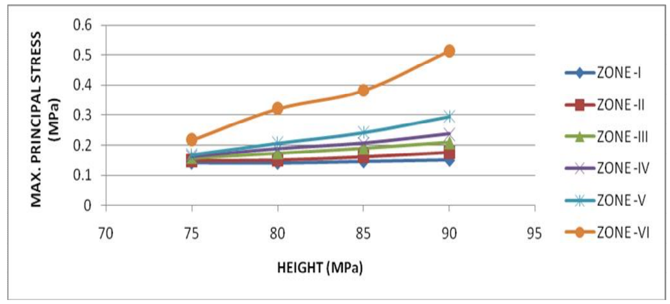

Figure 4.14: Max. Principal stress for all wind zones with respect to height

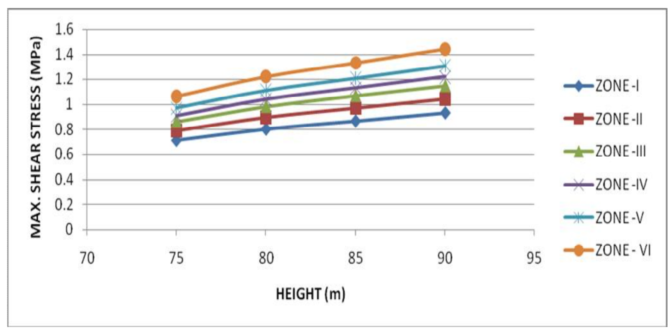

Figure 4.15: Max. Shear stress for all wind zones with respect to height

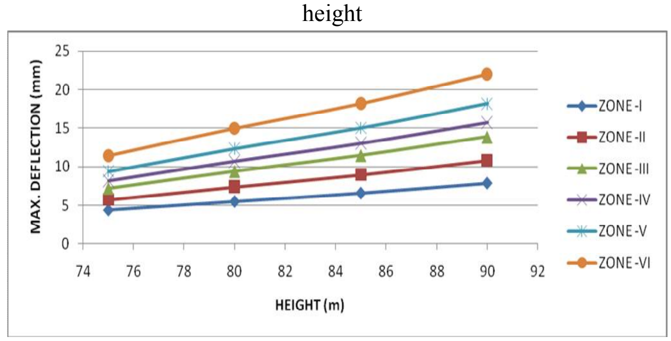

Figure 4.16: Max. Deflection for all wind zones with respect to height

V. CONCLUSION

Based on the results given above, following conclusions can be drawn-

(A) von Mises Stress

1. von Mises stress increases with increase in height and zone linearly for all the top diameters.
2. Diameters have very little effect on von Mises stress. However with increase in height von Mises stress increases considerably.
3. Rate of increment increases with increase in zone number.

(B) Principal stress

1. Principal stress increases with increase in height and zone linearly for all the top diameters.
2. With increase in diameter, principal stress decreases and with increase in height principal stress increases considerably.
3. Rate of increment increases with increase in zone number. The rate of increment for zone -VI is highest among all.
4. The principal stress for all the wind zones, are close at lower height but differs considerably with increase in height.

(C) Shear stress

1. Shear stress increases with increase in height and zone linearly for all the top diameters.
2. Diameters have very little effect on shear stress. However with increase in height shear stress increases considerably.
3. For shear stress, rate of increment increases with increase in zone number.

(D) Deflection

1. Deflection increases with increase in height and zone linearly for all the top diameters.
2. With increase in diameter, deflection decreases and with increase in height deflection increases considerably.
3. Rate of increment increases with increase in zone number.
4. The deflection for all the wind zones, are close at lower height but differs considerably with increase in height.

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 effect of thickness has not been considered. In future study effect of thickness may also be considered.
3. 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] A. D. John, R. Foroughi, A. Gairola, “Effect of Wind Loads on Structural Deformation of Cooling Tower “, International Journal of Structural Analysis & Design (IJSAD) Volume 1, Issue 3, (2014).

[2] G. Murali, C. M. Vivek Vardhan and B. V. Prasanth Kumar Reddy “Response Of Cooling Towers To Wind Loads”, ARPN Journal of Engineering and Applied Sciences Vol.7, No.1, (2012).

[3] IS 875 (PART -3) (2002), “Indian standard code of practice for design loads (other than earthquake) for building and structures”, Part 3, Wind loads, Indian Standard Institution.

[4] IS 875 (PART -1) (2007), “Indian standard code of practice for design loads (other than earthquake) for building and structures”, Part 1, Dead loads, Indian Standard Institution.

[5] IS 11504 (1985), “Indian standard-Criteria for structural design of reinforcement concrete natural draught cooling towers”, Indian Standard Institution.

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

[7] Sachin Kulkarni, A. V. Kulkarni,” Wind and Buckling Analysis of Natural Draught Cooling towers using ANSYS”, ISRASE First International Conference on Recent Advances in Science & Engineering, (2014).

[8] Tejas G. Gaikwad, N. G. Gore, V. G. Sayagavi, KiranMadhavi, Sandeep Pattiwar “Effect of Wind Loading on Analysis of Natural Draught Hyperbolic Cooling Tower” International Journal Of Engineering And Advanced Technology (IJEAT) Volume-4,Issue-1, (2014).

[9] Users Manual, STAAD.Pro, Bentley software, (2013).