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Parametric Earthquake Analysis of Natural Draught Hyperbolic Cooling Tower

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Abstract : Hyperbolic cooling tower is a tall and hyperboloidal shaped device having open topped 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 that 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 earthquake forces using STAAD.Pro software. The parameters considered are top diameter and height of cooling with constant thickness under different earthquake 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, 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 requirements. One can't think to live more productive and flourishing without them. But the plants 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. Earthquake is the major governing parameter for the design of cooling towers. Being a structure of such an importance, its safety against earthquake loading must be ensured.

Some of latest prominent literatures on the topic are given below-

D. Makovicka (2006) 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 with 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, Sayeed Sulaiman, 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 with 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) analyzed the the 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. Sachin Kulkarni, A.V. Kulkarni (2014) analyzed two cooling tower from Bellary thermal power station (BTPS) as case study. They analysed the cooling towers statically and dynamically for wind and earthquake loadings using 8 noded SHELL 93 element and 4 noded SHELL 63 element with software ANSYS 10. They applied seismic load for 0.5g, 0.6g, 0.7g, ground acceleration in accordance with IS 1893(part I)-2002 & IS 1893(part IV)-2005 by modal & Response Spectrum method and for wind load they used IS 875 (part -III) 1987. Takashi Hara (2015) developed a mathematical format to examine the behavior of cooling tower structure under dynamic earthquake loading. For this work of research he considered two types of conventional column coordination that are V-column and I-column, Shell portion is reinforced and modeled using solid elements. It was concluded that stress concentration will be more dangerous when we provide shell with I- column than with V- column

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8 & 9 Jan 2016

Stress concentration will be at the junction of tower shell and columns.

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

II. Material and Methodology

2.1 Load case details

2.1.1 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.

2.1.2 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 from IS: 1893:2002.

2.2 Geometrical cases

Following four types and 64 cases of geometrics have been considered-

TYPE -I: for zone II, 4 diameters X 4 heights = 16 cases
TYPE -II: for zone III, 4 diameters X 4 heights = 16 cases
TYPE -III: for zone IV, 4 diameters X 4 heights = 16 cases
TYPE -IV: for zone V, 4 diameters X 4 heights = 16 cases.
Total cases = 64.

3. Experimental program

3.1 Geometry Selection

Following 16 cases have been considered-

(a) (Height = 75m) X (Top Diameter =40m -Throat Diameter=37 m)=CTEIIAa
(b) (Height = 75m) X (Top Diameter =45m -Throat Diameter=42m) = CTEIIIAb
(c) (Height = 75m) X (Top Diameter =50m -Throat Diameter=47m) = CTEIVAc
(d) (Height = 75m) X (Top Diameter =55m -Throat Diameter=52m) = CTEVAd
(e) (Height = 80m) X (Top Diameter =40m -Throat Diameter=37m) = CTEIIBa
(f) (Height = 80m) X (Top Diameter =45m -Throat Diameter=42m) = CTEIIIBb
(g) (Height = 80m) X (Top Diameter =50m -Throat Diameter =47m) = CTEIVBc
(h) (Height = 80m) X (Top Diameter =55m -Throat Diameter=52m) = CTEVBd
(i) (Height = 85m) X (Top Diameter =40m -Throat Diameter=37m) = CTEIICa
(j) (Height = 85m) X (Top Diameter =45m -Throat Diameter =42m) =CTEIIICb
(k) (Height = 85m) X (Top Diameter =50m -Throat Diameter =47m) =CTEIVCc
(l) (Height = 85m) X (Top Diameter =55m -Throat Diameter=52m) =CTEVCd
(m) (Height = 90m) X (Top Diameter =40m -Throat Diameter =37m) =CTEIIDa
(n) (Height = 90m) X (Top Diameter =45m -Throat Diameter=42m)=CTEIIIDb
(o) (Height = 90m) X (Top Diameter =50m -Throat Diameter=47m) =CTEIVDc
(p) (Height = 90m) X (Top Diameter =55m -Throat Diameter=52m) =CTEVDd

Total no. of cases = 16

Similar 16 cases have been framed for zone III, IV and V, making total 64 no. of cases.

3.2 Selection of frame section and its geometrical properties

Following material properties have been considered in modelling.

Density of R.C.C. = 25 kN/m^3
Poisson ratio: 0.20.

3.3 Support condition

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

3.4 Earthquake loading details

All the building frames are analysed for 4 seismic zones

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

Earthquake zones - II,III,IV,V.
Response reduction factor - 5
Importance factor - 1.5
Damping - 5%
Soil type - hard soil

3.5 Structural modeling

Structural modeling has been carried out using STAAD.Pro software (ref. 8) using 4- noded elements. There are 300 to 360 elements for different models. FE models are shown in Figure 1 and 2.

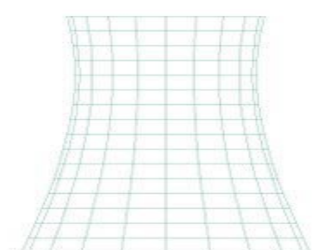

Figure 1 :Elevation of cooling tower

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8 & 9 Jan 2016

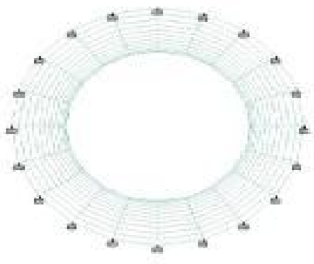

Figure 2: Plan of cooling tower

Earthquake loading in X and Z direction are shown in Figure 3 and 4.

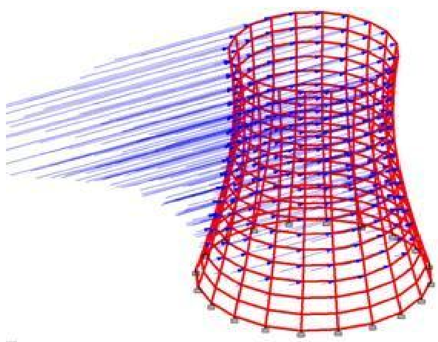

Figure 3: loading diagram for earthquake loading in +x direction

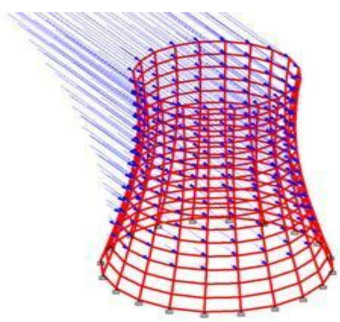

Figure 4: loading diagram for earthquake loading in +x direction

III. Results and Tables

The analysis results of all 64 cases of earthquake analysis are discussed below –

4.1 Top diameter = 40 m

When the top diameter of cooling tower is 40m, the variation of maximum stresses and deflection for all seismic zones and all four heights are shown in Figure 5 to 8.

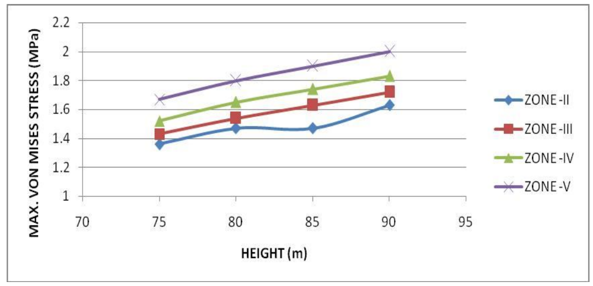

Figure 5: maximum von mises stress for all earthquake zones with respect to height.

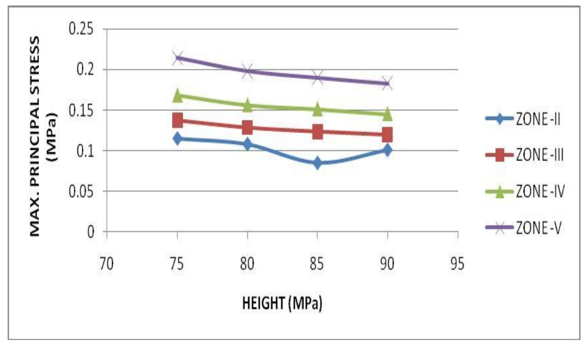

Figure 6: maximum principal stress for all earthquake zones with respect to height.

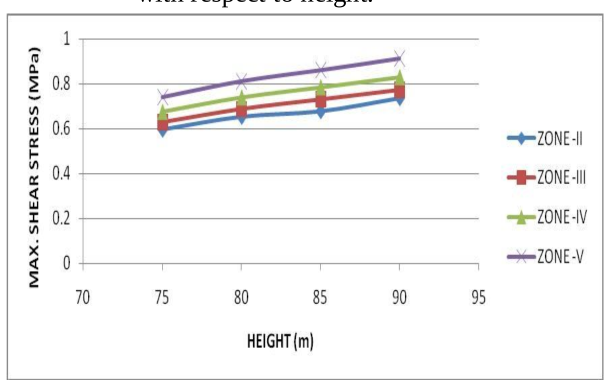

Figure 7: maximum shear stress for all earthquake zones with respect to height.

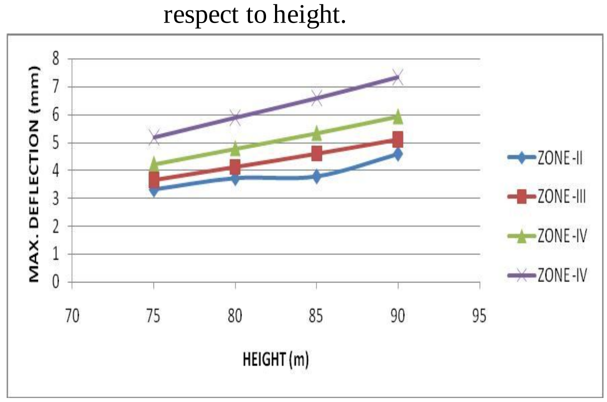

Figure 8: maximum displacement for all earthquake zones with respect to height.

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8 & 9 Jan 2016

4.2 Top diameter = 45 m

When the top diameter of cooling tower is 45m, the variation of maximum stresses and deflection for all seismic zones and all four heights are shown in Figure 9 to 12.

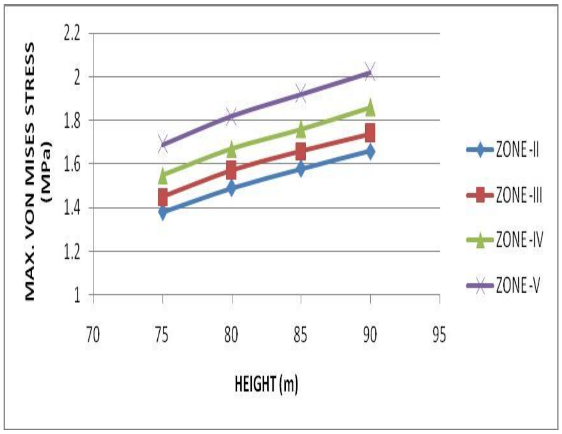

Figure 9: maximum von mises stress for all earthquake zones with respect to height.

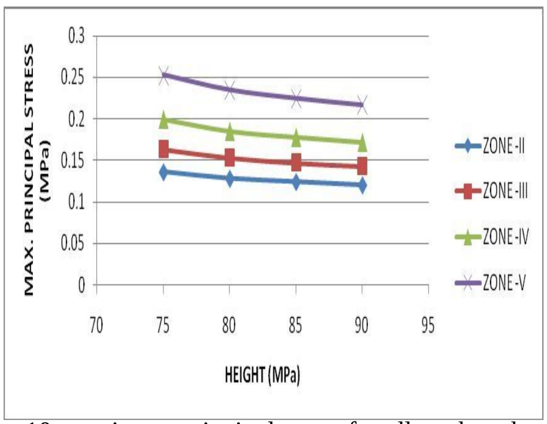

Figure 10: maximum principal stress for all earthquake zones with respect to height.

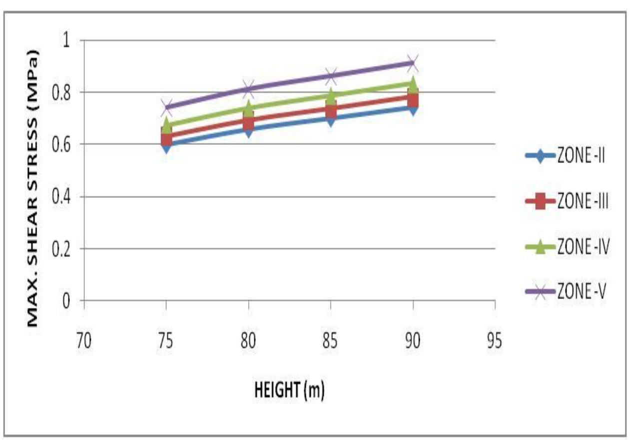

Figure 11: maximum shear stress for all earthquake zones with respect to height.

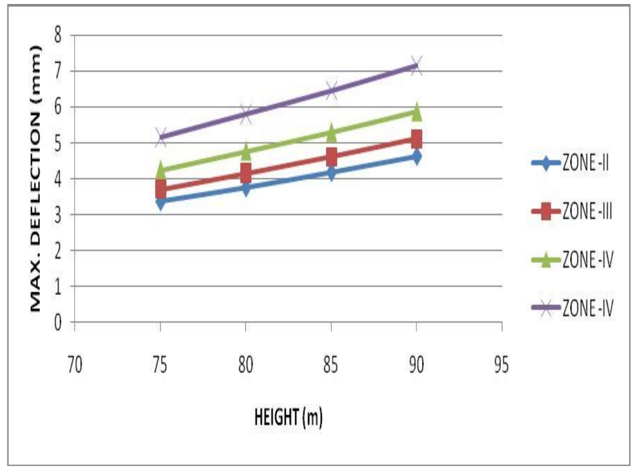

Figure 12: maximum displacement for all earthquake zones with respect to height.

4.3 Top diameter = 50 m

When the top diameter of cooling tower is 50m, the variation of maximum stresses and deflection for all seismic zones and all four heights are shown in Figure 13 to 16.

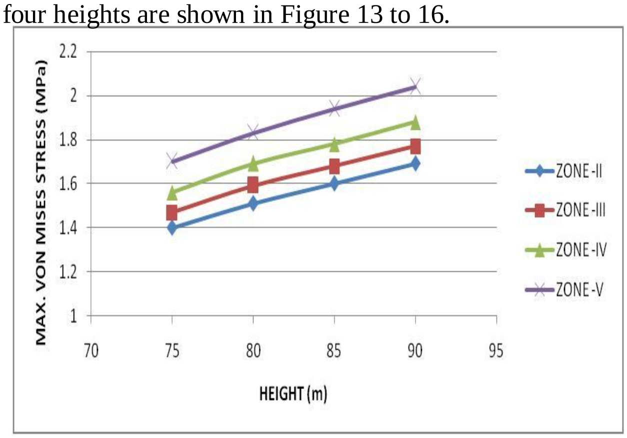

Figure 13: maximum von mises stress for all earthquake zones with respect to height.

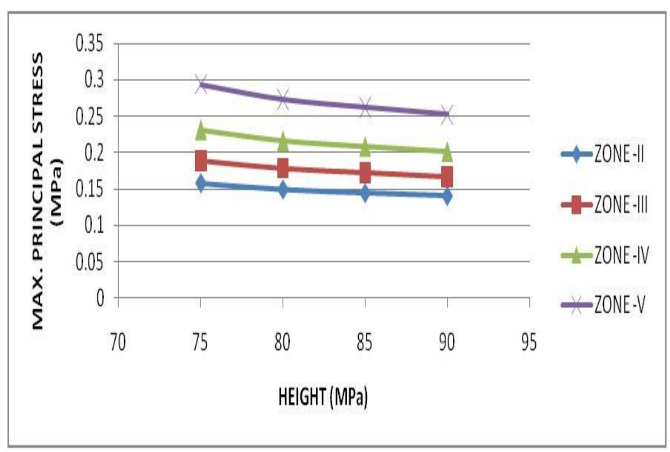

Figure 14: maximum principal stress for all earthquake zones with respect to height.

ISSN:2319-6890(online),2347-5013(print)
8 & 9 Jan 2016

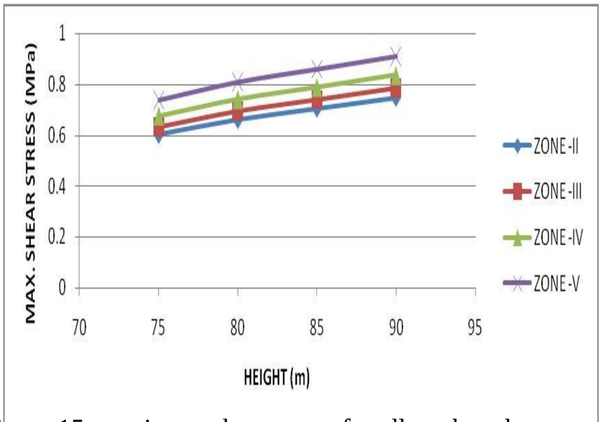

Figure 15: maximum shear stress for all earthquake zones with respect to height

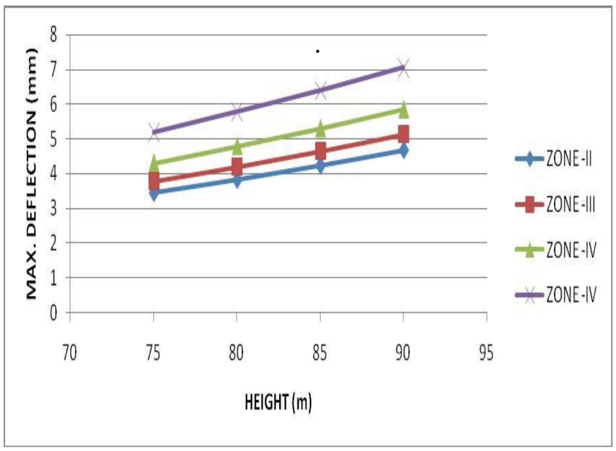

Figure 16: maximum displacement for all earthquake zones with respect to height.

4.4 Top diameter = 55 m

When the top diameter of cooling tower is 55m, the variation of maximum stresses and deflection for all seismic zones and all four heights are shown in Figure 17 to 20.

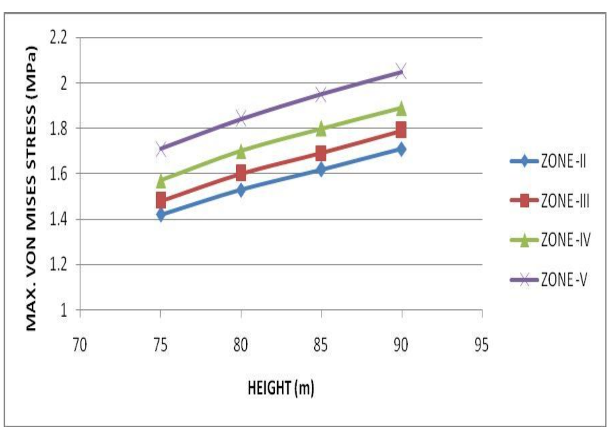

Figure 17: maximum von mises stress for all earthquake zones with respect to height.

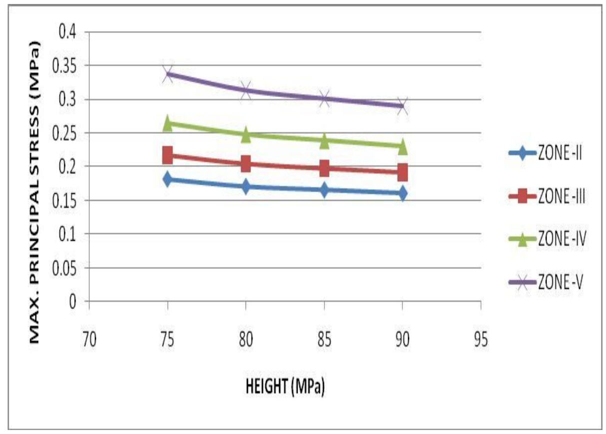

Figure 18: maximum principal stress for all earthquake zones with respect to height.

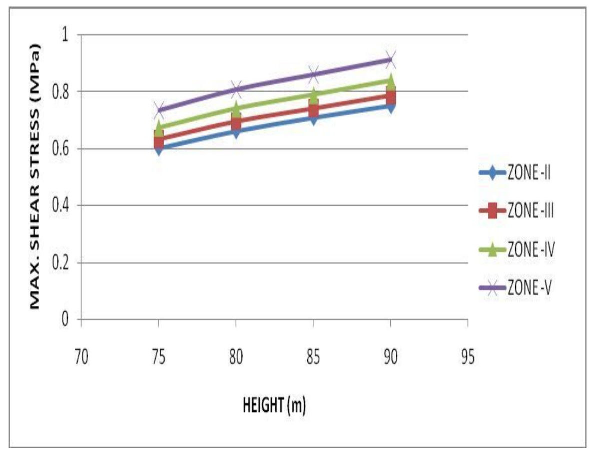

Figure 19: maximum shear stress for all earthquake zones with respect to height

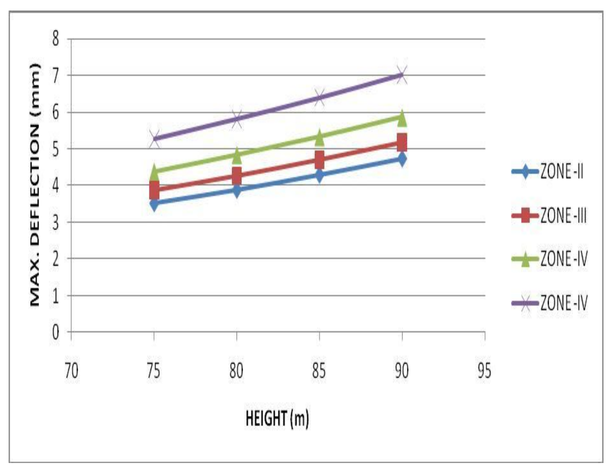

Figure 20: maximum displacement for all earthquake zones with respect to height.

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IV. Conclusion

From the results given above, following conclusions can be drawn-

5.1 von Mises Stress

a) von Mises stress increases with increase in height and zone linearly for all the top diameters.
b) Diameters have very little effect on von Mises stress. However with increase in height von Mises stress increases considerably.
c) Rate of increment increases with increase in zone number.
d) The von Mises stress is highest in zone -V for all heights.

5.2 Principal stress

a) Principal stress decreases with increase in height and zone linearly for all the top diameters.
b) With increase in diameters the principal stress increases and with increase in height principal stress decreases considerably.
c) Rate of decrement increases with increase in zone number.
d) The Principal stress is highest at zone -V for all heights.

5.3 Shear stress

a) Shear Stress increases with increase in height and zone linearly for all the top diameters.
b) Diameters have very little effect on shear stress. However with increase in height shear stress increases considerably.
c) For shear stress, rate of increment increases with increase in zone number.
d) The shear stress is highest at zone -V for all heights.

5.4 Deflection

a) Deflection increases with increase in height and zone linearly for all the top diameters.
b) With increase in diameters the deflection decreases, and with increase in height deflection increases considerably.
c) Rate of increment increases with increase in zone number.
d) The deflection is highest at zone -V for all heights.

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