Analysis of Steel Chimneys Considering Different Seismic Zones and Geometrical Parameters

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Abstract - Chimneys are tall and slender structures which are used to discharge waste gases. Chimney is sign of industrial growth in any country and while analysis and design of chimneys, proper care should be taken by the designers otherwise serious effects can be there on the surroundings. Being such an important structure, structural behaviour of chimney is very important. In this study, 36 cases of steel chimney structures are analyzed under the seismic force using STAAD. Pro software. The parameters considered are: diameter, height and thickness of steel chimney and earthquake zones. Results are analyzed is terms of max.von Mises stress, max. Principal stress, max. Shear stress and max. Displacement.

Keywords: Steel Chimney, Earthquake, Stress, Deflection, Shear stress.

I. INTRODUCTION

Chimneys or stacks are very important industrial structures for emission of poisonous gases to higher elevation such that the gases do not contaminate surrounding atmosphere. These structures are tall, slender and generally with circular cross-section. Different materials such as concrete, steel or masonry are used to build chimneys. Steel chimneys are ideally suited for process work where a short heat-up period and low thermal capacity are required. Steel chimneys are also economical, for height up to 45m. Although chimneys do not cause a great hazard to life and limb as buildings with high human capacity, damage to chimneys may result in shut down of plants and industries. The chimney may be self-supporting or guyed chimney. In this paper, an attempt has been made to analyze the self-supporting steel chimneys under the seismic forces.

II. PREVIOUS WORK

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

Rajkumar, B. Vishwanath Patil (2013), discusses the parametric study of RC chimney which is made by obtaining the results from software for different heights, diameter, earthquake zones, wind zones, types of soils and various load conditions. Because of changes in the dimensions of chimney, structural analysis such as response to earthquake and wind oscillations have become more critical to influence on response design of chimney. The minimum grade of concrete to be used for chimney should be greater than M25 since lower grades fail in permissible stresses. J.L.Wilson (2000), code references for the aseismic design of tall reinforced concrete chimneys, this paper presents results of recent investigational tests which indicate that reinforced concrete chimneys possess some ductility when subjected to cyclic loads. Based on these tests an inelastic procedure has been established for assessing the performance of reinforced concrete chimneys subject to severe earthquake ground shaking. This procedure has been used to analyse a number of chimneys, develop design recommendations and establish appropriate ductility factors. Tall reinforced concrete chimneys being highly tuned, profiled cantilevers respond in a complex manner to earthquake excitation, with the response dominated by higher mode effects, in both the elastic and inelastic range. J.L. Wilson (2003), conducted experimental program to show the earthquake response of tall reinforced concrete chimney. A non-linear dynamic analysis procedure is developed to evaluate the inelastic response of tall concrete chimney subjected to earthquake excitation. Based on experiments, the results encourage reliance on the development of ductility in reinforced concrete chimneys to prevent the formation of brittle failure modes. Doris Mehta, J. Nishant. Gandhi (2008), carried out time response study of tall chimneys, under the effect of soil structure interaction and long period earthquake impulse. This study is carried out using time history analysis considering Bhuj earthquake which is a long duration earthquake impulse. The main objective in using this earthquake was, to find out the effect on structure when hit by long duration and see how the response is modified, when soil effects are taken into the consideration. The analysis and results shows that the time period increases with increase in soil flexibility. It remarkably increases up to 9% for soft soil in fundamental mode and up to 80-85% for higher modes. The response of chimney is maximum at section 0.5h and h along the height of chimney for long duration earthquakes.

In this study, 36 cases of steel chimney structures are analyzed under the earthquake force using STAAD.Pro. The parameters considered are: diameter, height of Steel Chimney and earthquake zones. Analysis results are analyzed is terms of max.von Mises stress, max. principal stress, max. shear stress and max. Displacement.

III. PROPOSED METHODOLOGY

Load case details

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.

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.
3.2 Geometrical Cases
Three thicknesses considered is 0.016 m for whole chimney.
Three heights considered are 40m, 50 m, 60 m.
Three diameters considered are 2 m, 2.25 m, 2.5 m.
Four earthquake zones of India are II, III, IV, V.
Total number of cases =36.

Case Details

Case details are as below:

1. (height1- 40 m)X (diameter1 – 2 m)X (zone - II) =H_1D_1II
2. (height1- 40 m)X (diameter1 – 2 m)X (zone - III) =H_1D_1III
3. (height1- 40 m)X (diameter1 – 2 m)X (zone - IV) =H_1D_1 IV
4. (height1- 40 m)X (diameter1 – 2 m)X (zone - V) =H_1D_1V
5. (height1- 40 m)X (diameter2 – 2.25 m)X (zone - II) = H_1D_2II
6. (height1- 40 m)X (diameter2 – 2.25 m)X (zone - III) = H_1D_2III
7. (height1- 40 m)X (diameter2 – 2.25 m)X (zone - IV) = H_1D_2IV
8. (height1- 40 m)X (diameter2 – 2.25 m)X (zone - V) = H_1D_2V
9. (height1- 40 m)X (diameter3 – 2.5 m)X (zone - II) =H_1D_3II
10. (height1- 40 m)X (diameter3 – 2.5 m)X (zone - III) = H_1D_3III
11. (height1- 40 m)X (diameter3 – 2.5 m)X (zone - IV) = H_1D_3IV
12. (height1- 40 m)X (diameter3 – 2.5 m)X (zone - V) =H_1D_3V
13. (height2- 50 m)X (diameter1 – 2 m)X (zone - II) =H_2D_1II
14. (height2- 50 m)X (diameter1 – 2 m)X (zone - III) =H_2D_1III
15. (height2- 50 m)X (diameter1 – 2 m)X (zone - IV) =H_2D_1IV
16. (height2- 50 m)X (diameter1 – 2 m)X (zone – V) =H_2D_1V
17. (height2- 50 m)X (diameter2 – 2.25 m)X (zone - II) = H_2D_2II
18. (height2- 50 m)X (diameter2 – 2.25 m)X (zone - III) = H_2D_2III
19. (height2- 50 m)X (diameter2 – 2.25 m)X (zone - IV) = H_2D_2IV
20. (height2- 50 m)X (diameter2 – 2.25 m)X (zone - V) = H_2D_2V
21. (height2- 50 m)X (diameter3 –2.5 m)X (zone - II) =H_2D_3II
22. (height2- 50 m)X (diameter3 – 2.5 m)X (zone - III) = H_2D_3III
23. (height2- 50 m)X (diameter3 – 2.5 m)X (zone - IV) = H_2D_3IV
24. (height2- 50 m)X (diameter3 – 2.5 m)X (zone - V) =H_2D_3V
25. (height3- 60 m)X (diameter1 – 2 m)X (zone - II) =H_3D_1II
26. (height3- 60 m)X (diameter1 – 2 m)X (zone - III) =H_3D_1III
27. (height3- 60 m)X (diameter1 – 2 m)X (zone - IV) =H_3D_1IV
28. (height3- 60 m)X (diameter1 – 2 m)X (zone - V) =H_3D_1V
29. (height3- 60 m)X (diameter2 – 2.25 m)X (zone - II) = H_3D_2II
30. (height3- 60 m)X (diameter2 – 2.25 m)X (zone - III) = H_3D_2III
31. (height3- 60 m)X (diameter2 – 2.25 m)X (zone - IV) = H_3D_2IV
32. (height3- 60 m)X (diameter2 – 2.25 m)X (zone - V) = H_3D_2V
33. (height3- 60 m)X (diameter3 – 2.5 m)X (zone - II) =H_3D_3II
34. (height3- 60 m)X (diameter3 – 2.5m)X (zone - III) =H_3D_3III
35. (height3- 60 m)X (diameter3 – 2.5 m)X (zone - IV) = H_3D_3IV
36. (height3- 60 m)X (diameter3 – 2.5 m)X (zone - V) =H_3D_3V

Total no. of cases = 36

Material properties

Following material properties have been considered in the modeling-
Density of Steel = 76.8195 kN/m^3
Poisson ratio = 0.30.

Support condition

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

Earthquake loading details

All the chimney structures are analyzed for 4 earthquake zones.
The earthquake loads are derived for following seismic parameters as per IS: 1893(2002).
Earthquake zones - II, III, IV, and V.
Response reduction factor - 5
Importance factor - 1
Damping - 5%
Soil type - hard soil

Structural modeling

Structural modeling has been carried out using STAAD. Pro software (ref. 11) using 4- noded elements. There are 2160 elements in different models. FE models are shown in Fig.1 and 2.

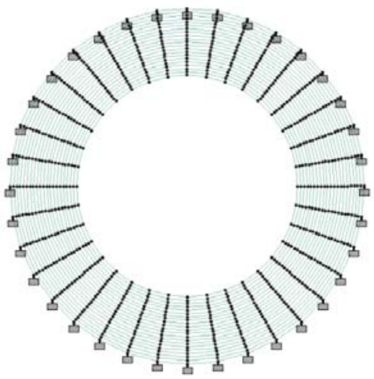

Fig.1**:** Plan of Chimney

Fig.2: Elevation of Chimney

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

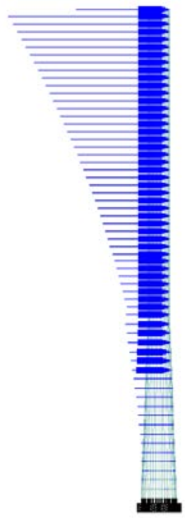

Fig.3: Loading diagram for earthquake loading in +x direction

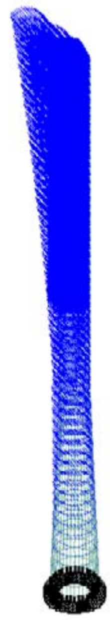

Fig.4: loading diagram for earthquake loading +z direction

IV. EXPERIMENTAL RESULTS

Results obtained from STAAD.Pro analyses can be presented graphically under following heads:-
(A)Top diameter = 2m
When the top diameter of steel chimney is 2m, the variation of maximum stresses and deflection for all earthquake zones and all three heights are shown in Fig. 5 to 8.

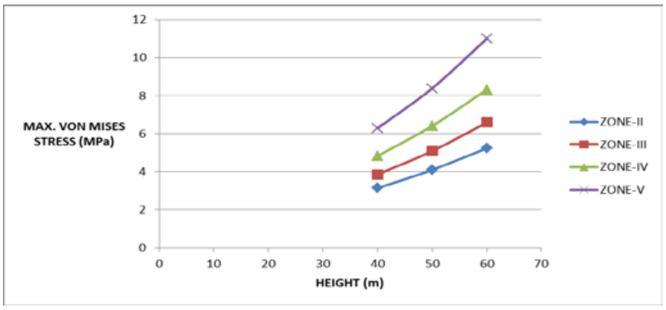

Fig.5: Max. von Mises stress for all seismic zones with respect to height

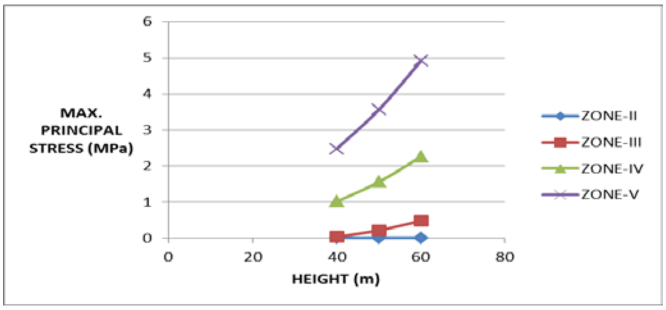

Fig.6: Max. Principal stress for all seismic zones with respect to height

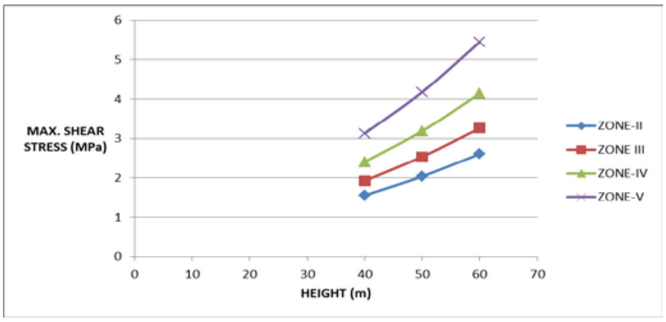

Fig.7: Max. shear stress for all seismic zones with respect to height

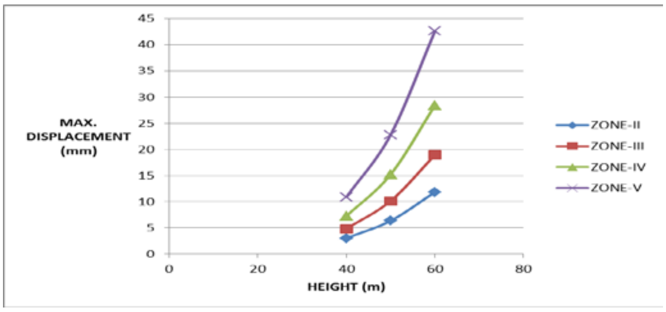

Fig.8: Max. displacement for all seismic zones with respect to height

(b)Top diameter =2.25 m

When the top diameter of steel chimney is 2.25m, the variation of maximum stresses and deflection for all earthquake zones and all three heights are shown in Fig. 9 to 12.

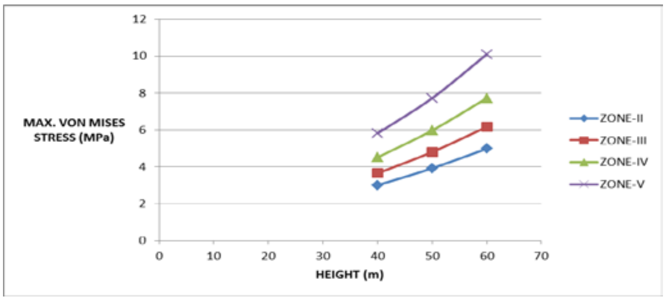

Fig.9: Max. von Mises stress for all seismic zones with respect to height

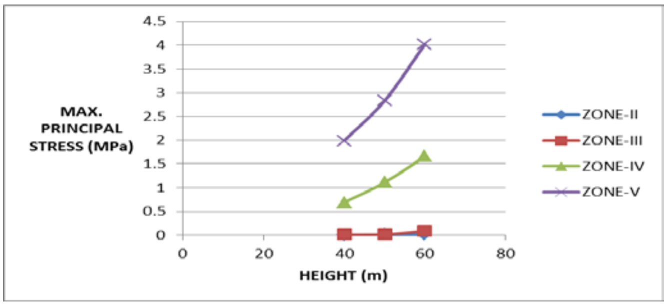

Fig.10: Max. principal stress for all seismic zones with respect to height

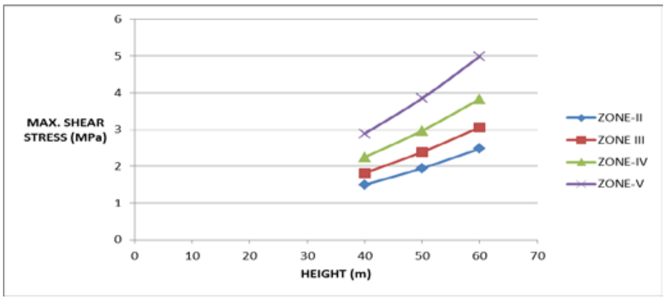

Fig.11: Max. shear stress for all seismic zones with respect to height

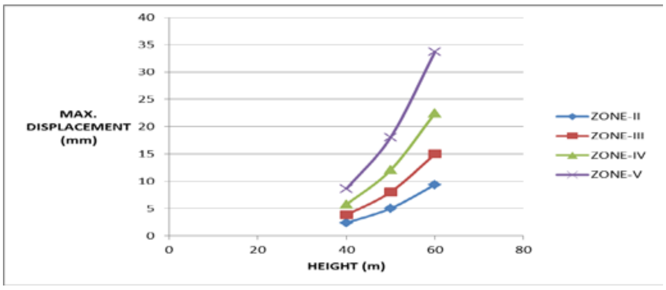

Fig.12: Max. displacement for all seismic zones with respect to height

(c)Top diameter =2.5 m

When the top diameter of steel chimney is 2.5m, the variation of maximum stresses and deflection for all earthquake zones and all three heights are shown in Fig. 13 to 16.

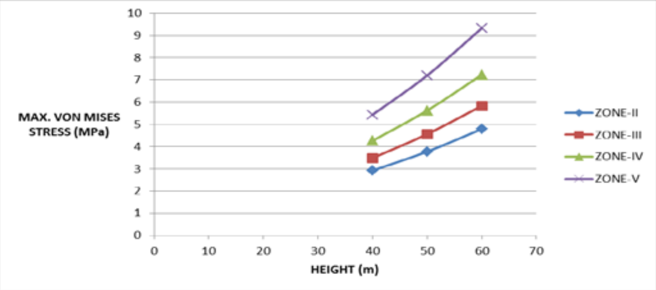

Fig.13: Max. von Mises stress for all seismic zones with respect to height

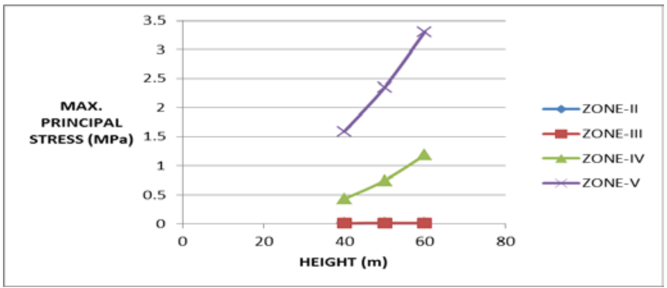

Fig.14: Max. principal stress for all seismic zones with respect to height

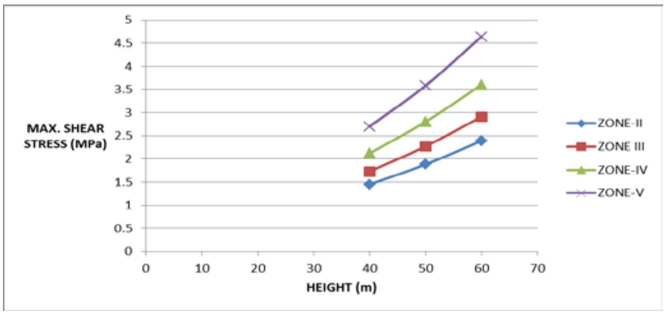

Fig.15: Max. shear stress for all seismic zones with respect to height

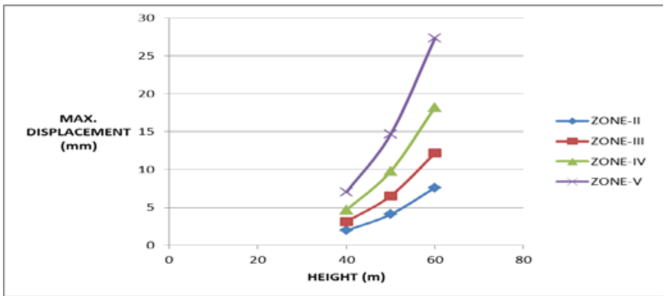

Fig.16: Max. displacement for all seismic zones with respect to height

V. CONCLUSION

Based on above results conclusions of this study about seismic analysis of chimney under different geometrical parameters are given below –

(A) Maximum von Mises Stress

1. Max. von mises stress increases with increase in height for all diameter and for all seismic zones.
2. Max. vonmises stress decreases with increase in diameter for all heights and for all seismic zones.
3. Rate of increment and decrement is constant with respect to zone number.

(B) Maximum principal Stress

1. Max. Principal stress increase with increase in height for all diameter and for all seismic zones.
2. Max. Principal stress decreases with increase in diameter for all heights and for all seismic zones.
3. Rate of increment and decrement is significant with respect to zone number.

(C) Maximum shear Stress

1. Max. shear stress increase with increase in height for all diameter and for all seismic zones.
2. Max. shear stress decreases with increase in diameter for all heights and for all seismic zones.
3. Rate of increment and decrement is constant with respect to zone number.

(D) Maximum displacement

1. Max. displacement increase with increase in height for all diameter and for all seismic zones.
2. Max. displacement decreases with increase in diameter for all heights and for all seismic zones.
3. Rate of increment and decrement is significant with respect to zone number and height.

VI. FUTURE SCOPES

1. This study has been carried out by considering equivalent load method, for more realistic results, time history analysis may be carried out.
2. In this study linear elastic material property has been considered. The same may be carried out by considering non-linear material property.
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.
4. In this study effect of thickness has been considered. In future study effect of thickness may also be considered.

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