DYNAMIC BEHAVIOUR OF TALL REINFORCED CONCRETE CHIMNEYS

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Abstract : The height of chimney influences the flow of flue gaeses to external environment. The higher the height, it is better for the environmental protection, but the reduced structual stability and increased construction cost with increasing the height.
The objective of this research paper is to perform a comparative design of a reinforced concrete chimney of 315m high, located at Hyderabad using BIS design codes of tall structures IS 875(Part 3):2015 and IS 875(Part3):1987. The detailed analysis revealed the effectiveness of IS 875(Part 3):2015 to have accurate wind pressure load consideration and it is observed 20% higher wind load with IS 875(Part 3):2015 at a location than that of older version.The second objective is to identify optimum height to diameter (H/D) ratio of chimney for different wind and seismic zones using Autodesk software and a parameteric study. The optimum H/D ratio for 315m chimney as measured as 13 for seismic zone 2, 3 and wind zone 1, 2, 3, in which zones Hyderabad is expected. Also the parameter study confirmed to continue the recommend usage of H/D ratio for the design of economical and safe Chimney.

***IndexTerms* - Industrial Chimney, IS 875(PART 3):1987, IS 875(PART 3):2015, Autodesk Software, Dynamic Behaviour Analysis**

I. INTRODUCTION

To cope with the exponential growth of population and the living index, there is a tremendous requirement of power consumption and thereby the increase in the production. The chimney becomes one of the fundamental elements of the power plant industries. It is essential to transfer the hot flue toxic gases at higher altitude to reduce pollution hazard. The efficient, cost effective chimneys are available with the codal provisions in IS: 875(Part 3). The environmental protection act mandates the minimum height of chimney as 220m and 275m for the power generation capacity less than 500MW and above 500MW respectively.
In this study, a Chimney of 315m height located at Hyderabad is chosen for the manual design. The design was performed using both the older version of code IS: 875(Part 3)-1987 and the newer version of code IS: 875(Part 3)-2015. The work is carried out to find the specific geometric parameters like diameter and thickness for the particular height of the chimney for the respective wind and seismic zone. There are many literatures available in this domain of study. A Bhaiju et.al. [1] conducted analysis on tall RC Chimney of height 275m and above, located at seismic and wind zone II ,using ANSYS software to understand the lateral deflection at the top of chimney. The paper identified that wind load effect is dominant when compared to seismic and temperature effects. Leonardo et.al. [2] invented a new simplified method to get the relation between the fundamental period of vibration, lateral displacement, shear force, bending moment and the parameters considered were H/D, radius ratio Rsup/Rinf, thickness ratio Esup/Einf are varied each one for all the 9 chimneys and their effect is observed. K.Anil Pradeep et.al. [3] analysed a 60m RC Chimney, measured shear force, bending moment, base shear and base moment sand concluded that the wind effect is significant when compared to seismic. It also recommends having the deflection criteria to be within limits as per the codal provisions.

In this study, the manual design of chimney was carried out and the design effectiveness of chosen chimney was analysed using Autodesk Robot Structural Professional Software. Section 2 and 3 of the paper describes the objectives, chimney configuration, input parameters and loading criteria considered. In Section 4, we present the design approach and analysis. In Section 5, results was analysed and reported. In Section 6 concludes with the summary of observations and recommendations.

Fig. 1 RC Chimney

II. OBJECTIVES OF THE PRESENT STUDY

• Examining the new wind design code for tall structures IS: 875 (Part 3) – 2015, which has been revised after 28 years with some add-ons to the older version i.e. IS: 875(Part 3) – 1987 in terms of terrain category factors, gust factor etc.

• A relation between the crude way of assumptions and the real life realities in the design with the design parameter H/D ratio was brought down.

• The variations in H/D ratio from 7-17 for different wind and seismic zones of India to understand the exact design ratio required as per design and analysis to safeguard and economize the structure.

• To incorporate new wind simulation design to enable the designers to test their designs in a virtual wind tunnel instantly to visualize surface pressures or generate wind loads to be used in design and analysis.

• The combination of virtual visualization and the design of chimney required to match up the real time problems and solve with the accurate results.

III. CHIMNEY CONFIGURATION AND ANALYSIS PARAMETERS

Table 1: Chimney configurations

Wind zones (WZ)	I, II, III, IV, V
Seismic zones (SZ)	II, III, IV, V
Heights considered	220m, 245m, 275m, 315m
H/D ratio	7-17 [4]
Tapering slope	1 in 50
Concrete grade	M30

The analysis is carried out by Autodesk Robot Structural Software. Robot structural is the latest wind simulation method which enables to test the designs in a virtual wind tunnel instantly to visualize surface pressures or generate wind loads to know the actual realistic behaviour of the structure. In order to identify the appropriate design ratio as well as to economise the construction the thickness is varied according to the particular H/D ratio for each model. A total of 99 models for each height are analysed, in total 396 tall RC Chimneys of 4 different heights are analysed. The configurations of the analysis are shown in the table 1. The bottom 2/3rd thickness of the chimney shell is constant and then decreasing the thickness for the next 1/3rdfor each chimney. The thickness calculations are as per IS 4998:1992 (Part 1).

IV. LOADS ON CHIMNEY

Design loads considered in the present study are:

- Dead load or self weight consists of the self weight of RC Chimney which includes the weight of chimney outer shell, liner insulation material. The self weight depends on the geometric parameters like height, base diameter, thickness of the RC Chimney.
- Live load or imposed load has less impact on the chimney as the accessible area is very less. The loads of formwork and construction elements during the construction stage are to be considered in the design.
- Wind loads are the predominant loads on Chimney due to its slenderness and height factor. It is mainly being classified as along wind and across wind loads. Along wind effects are caused mainly by gust buffeting action due to the dynamic behaviour along the direction of mean flow over the structures face. Across wind loads are mainly due to the respective 'lift' variable due to the phenomenon of 'vortex shedding'. Due to this effect, Chimney oscillates in the direction perpendicular to the wind.

- Seismic loads are the lateral loads acting on the structures in horizontal direction. The basis of seismic design IS: 1893-2000, specifies certain recommendations for tall slender structures like Chimney to adopt Response Spectrum method for the analysis. The effect of either wind and seismic which is predominant is considered in the analysis.
- Thermal loads are due to the effect of temperature on the structure due to the hot flue exhaustive gases. The lining of the concrete shell is as important in order to avoid cracking and to maintain the integrity of the structure. Insulation materials aluminium, mineral wool, expanded mineral etc., are provided in the gap between the concrete shell and lining to effectively reduce the temperature effect on the concrete shell.
- Circumferential force acting on the thin tapering cylinder is mainly due to the internal and external pressure i.e., due to temperature and wind effects respectively. The thickness of the chimney shell is the most critical to resist these circumferential loads against cracking, corrosion etc

V. DESIGN AND ANALYSIS

The work carried out in design phases :

(a) Design and Comparison Phase: The manual design of Chimney using the older version and newer version of code and the results were compared

(b) Analysis Phase: Analysis of the chimney using numerical software.

3.1 Design and Comparison Phase

The initial phase, the design of Chimney is carried out and the design change in the new wind analysis code IS: 875(Part 3)-2015 was identified and implemented. A comparison is made for the load and moment obtained from both the codes. The few specific changes in the design are compared in the table 2 [5, 6] below:

Table 2: Wind load calculations according to IS 875(Part3):1987 and 2015

IS:875 (Part 3) -1987	IS:875 (Part 3) - 2015
Along Wind Response: Fz = Cf*Ae*Pz*G Where, G = 1 + gt*r* $\sqrt{\left[B * (1+\emptyset)^2 + \frac{S*E}{\beta}\right]}$	Along Wind Response: Fz = Cf*Ae*Pz*G Where, G = 1 + r* $\sqrt{\left[g_v^2 * B_s(1+\emptyset)^2 + \frac{H_s*g_r^2*S*E}{\beta}\right]}$
To find out the factors of gust factor, charts are used given in the respective code	The gust factor parameters are calculated using specified formulas given in the respective code
Across Wind Response: not specified in IS:875 (Part 3) – 1987, RC Chimney design for across wind is calculated using IS 4998:1992 (Part 1)	Across Wind Response: Mc= 0.5*gh*ph*b*h2*(1.06-0.06k)* $\sqrt{\left[\frac{\pi*C_{fs}}{\beta}\right]}$ Fz,c= $\left(\frac{3*M_c}{h^2}\right) * \left(\frac{z}{h}\right)$

Seismic and temperature loads are calculated as per CED38 (7892):2013(3rd revision of IS 4998 (Part 1):1992) [7]

3.2 Analysis Phase

Wind loads are the predominant for tall structures especially Chimneys. In practical, wind has 8 directions, but in the design and analysis of a structure we consider only 2 directions i.e., X and Y. So due to the gap between the software developed model and the real structure, for tall and high rise buildings, there was a desperate need for wind tunnel testing which is time consuming as well as uneconomical. And many tall structures are not being tested before construction due to these constraints. So to overcome these cons, Autodesk has incorporated a new wind simulation tool in their Robot Structural product which enables to analyse the structural models in a virtual wind tunnel. However, this software can replace all the wind tunnel tests as supplement to validate and investigate wind tunnel testing which saves engineering time, reduced wind consultant costs and also reduce the overall economy of the project along with the number of test iterations. To accomplish this, the tool incorporates CFD (Computational Fluid Dynamics) into a streamlined workflow practical for design phase analysis. The most prevailing wind, seismic and temperature effects are considered for the design. RC Chimney model, wind patterns and wind application in Autodesk Robot Structural Analysis Software are shown in fig 1, 2 & 3 respectively.

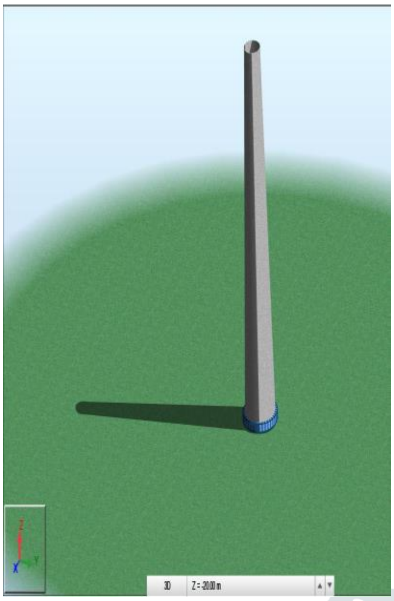

Fig 1: RC Chimney model

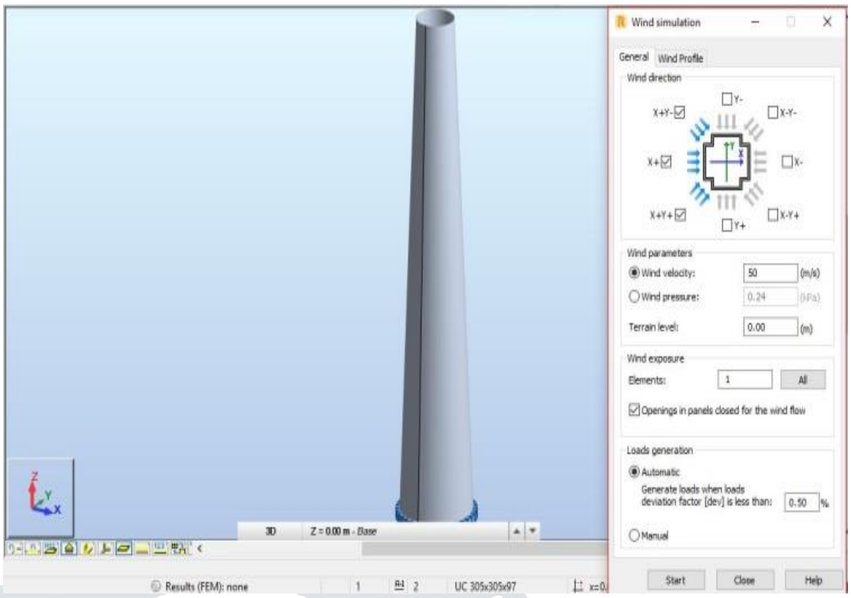

Fig 2: Applications of wind in 8 directions

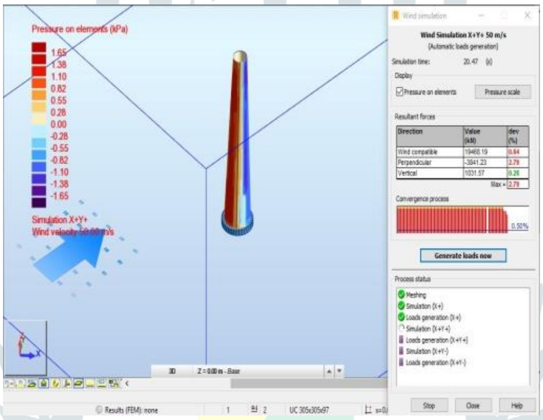

Fig 3: Wind application in specific direction

VI. RESULTS AND DISCUSSION

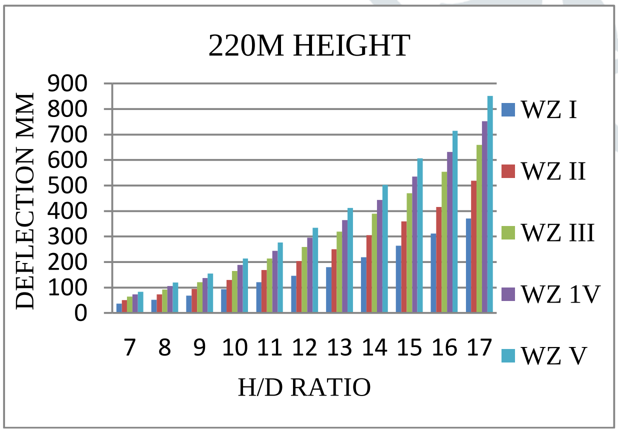

Fig 4: Graph for 220m height wind zones

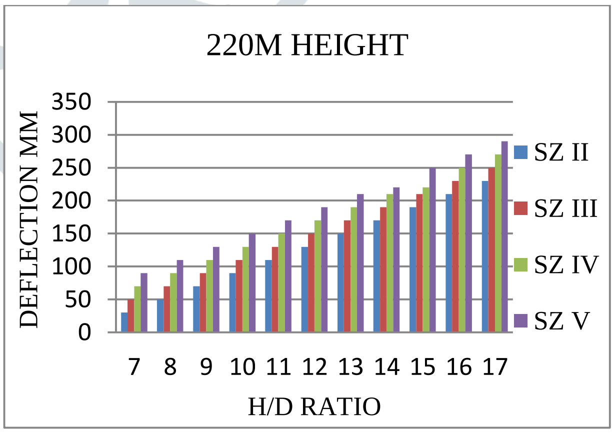

Fig 5: Graph for 220m height seismic zone

From the analysis, for 220m height chimney the H/D ratio 13 and 14 for the wind zones 1, 2, 3 and seismic zones 2 and 3 the deflections are within the limits. H/D ratio 13 and 14 cannot be provided in wind zone 4 and 5. The ratio beyond 14 cannot be considered for any zone.

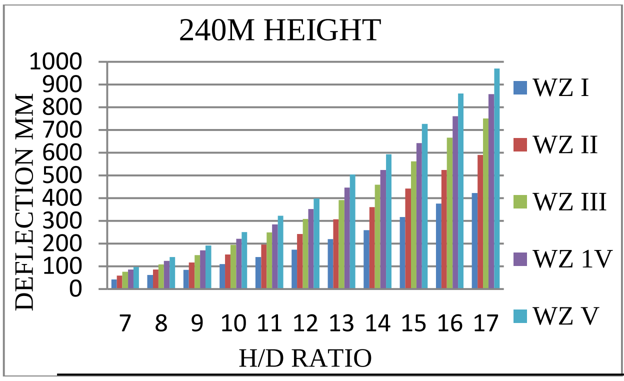

Fig 6: Graph for 240m height wind zones

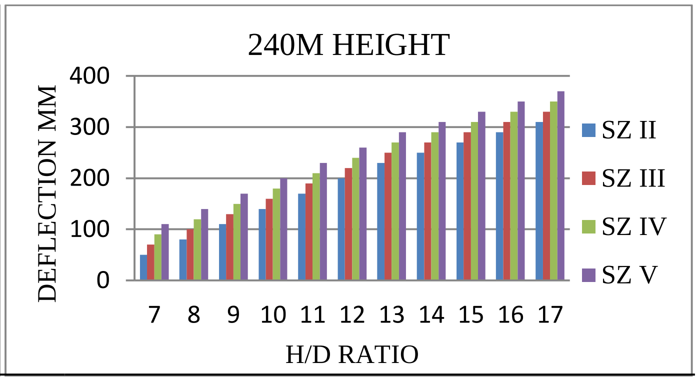

Fig 7: Graph for 240m height seismic zones

For 240m height chimney the H/D ratio 13 and 14 for the wind zones 1, 2, 3 and seismic zones 2, 3 respectively, the deflections are within the limits. H/D ratio 13 and 14 cannot be provided in 4 and 5 zone. The ratio beyond 14 cannot be considered for any zone.

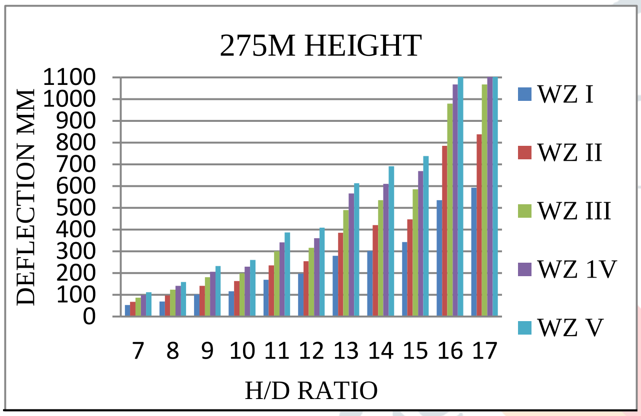

Fig 8: Graph for 275m height wind zones

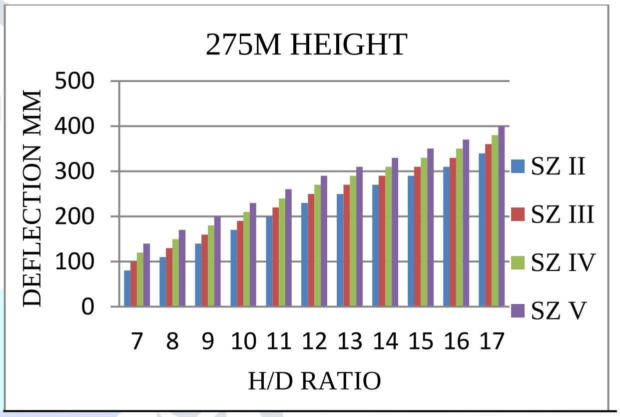

Fig 9: Graph for 275m height seismic zones

For 275m height chimney the H/D ratio 13 and 14 for the wind zones 1, 2, 3 and seismic zone 2, 3 the deflection is within the limits. H/D ratio 13 and 14 cannot be provided for zone 4 and 5. The ratio beyond 14 cannot be considered for any zone.

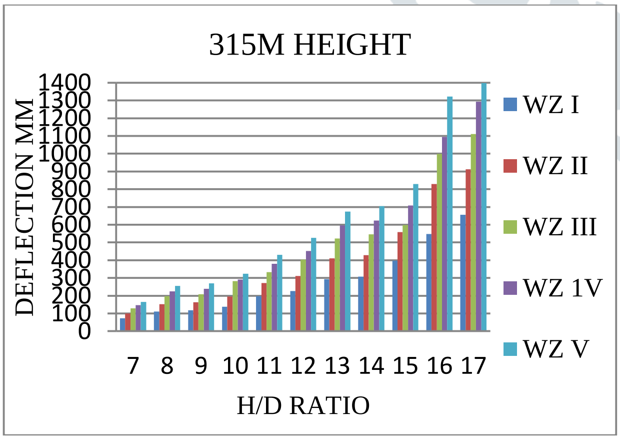

Fig 10: Graph for 315m height wind zones

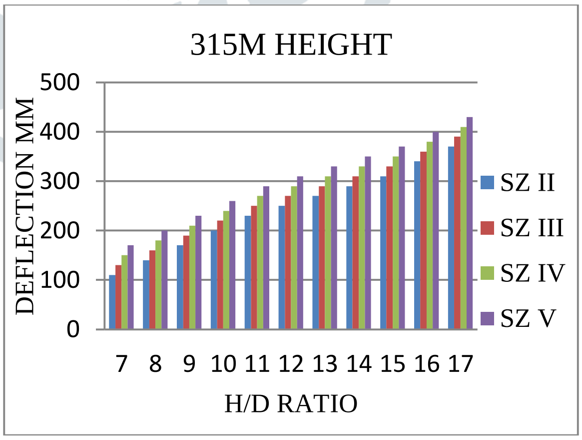

Fig 11: Graph for 315m height seismic zones

For 315m height chimney the H/D ratio 13 for the wind zones 1, 2, 3 and seismic zones 2, 3 the deflection is within the limits. H/D ratio 13 cannot be provided in wind zone 5. The ratio beyond 13 cannot be considered for any zone.

From the above figures, it can be examined that the critical H/D factor need not be assumed as 11 or 12. It can be calculated and measured as simple as the moment and shear force using easy and quick axis wind tunnel simulation tool, which provides insight into air flow behaviour and estimates the design loads resulting from wind. The tool serves as a practical means of testing/model optimization before time and money is invested in scale model wind tunnel testing that is often required for complex building projects. From the above charts, it can be seen that the deflection is directly proportional to height of the Chimney.

VII. CONCLUSION

- From the manual design calculations and comparison, it was interpreted that there was 20% increase in across and along wind load per unit height at height z as per new codal provision of wind IS: 875(Part 3)-2015. Hence it is recommended to use new codal provision.
- The parameter study confirmed to continue the recommend usage of H/D ratio for the design of economical and safe Chimney.
- The recommended H/D ratio as per the present study for 220m, 245, 275m height is 13 and 14 for wind zone 1, 2, 3 and seismic zone 2, 3. For wind zone 4, 5 and seismic zone 4, 5 it is advisable to provide H/D ratio as 11 or 12.
- From the study, for 315m chimney it is recommended to provide H/D ratio 13 for seismic zone II,III and wind zone I,II,III The deflection for the particular height of the chimney should always be within permissible limits as per the code.

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