Non-Linear Seismic Analysis of Reinforced Concrete Chimney

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Abstract

The chimney is a system for venting hot flue gases or smoke from a boiler or furnace to the outside atmosphere. They are typically almost vertical to ensure that the hot flue gases flow smoothly, drawing air into the combustion through the chimney effect. It is essential to determine the wind, seismic and temperature demands of chimney structures to prevent structural problems which lead to collapse of the structure. This study focused the effect of wind load, earthquake load as well as temperature effects on reinforced concrete (RC) chimneys. Wind analysis was carried out by along wind effects by using the Simplified method and seismic analysis by time history analysis for different heights varying from 275m to 400m with three different radius-thickness ratios and for different longitudinal sections such as tapered and partially tapered by using the software SAP2000v14. Analyses were conducted to study the variation of displacement and shell stress for the wind analysis, peak displacement for the seismic analysis and temperature effects. The results indicated that as the radius-thickness ratio increases the displacement values were decreasing. The RC chimney with more height and the partially tapered section will be critical compared to fully tapered chimney for the wind, seismic and temperature effects and fully tapered chimney structure exhibiting minimum displacement.

Keywords— *RC Chimney, Wind Analysis, Seismic Analysis, Temperature effects and SAP2000v14.*

I. INTRODUCTION

Tall chimneys are constructed as a result of the large-scale development of thermal power plant and industries. Tall chimneys are commonly used to discharge pollutants into the atmosphere at a higher elevation such that the pollutant which deemed harmful to the environment is kept within acceptable limits [1]. Now a day's to reduce the air pollution the chimneys are constructed as much as tall. That is the height of the chimney has been increasing since the last few decades [2]. Chimneys with height exceeding 150 m are considered as tall chimneys. However it is not only a matter of height but also the aspect ratio when it comes to classifying a chimney as tall [4]. Today, Reinforced Concrete is the dominant material used for the construction of tall chimneys [7]. Chimneys being tall slender structures, they have different associated structural problems and must therefore be treated separately from other forms of tower structure [9]. In order to prevent the collapse mechanism of the chimney structure seismic as well as the wind demands must be determined accurately. For this reason, many evaluations such as nonlinear analysis of chimney structures are proposed for the accurate determination of inelastic behavior and seismic demands of the chimney.

This paper discusses the behaviour of 30 chimney models with 5 different heights varying from 275m to 400m.

A. Objectives

- To determine the effect of radius-thickness ratio of tall RC chimneys
- To evaluate the response of chimney structures by wind analysis, seismic analysis and temperature effects for various deformation levels.
- To compare the behaviour of different chimney models

II. MODELING AND ANALYSIS

A. Modeling of the Structure

The chimneys are designed in this project are of five different heights. They are 275m, 300m, 325m, 350m and 400m. The normal height adopted for chimney in India is 275m. But thinking of stringent environmental constraints in future this height may not be sufficient for disposing the gaseous products as it will pose a serious threat causing air pollution. So increasing the height of the chimney would be better idea to meet out the environmental challenges. Considering chimney as a thin shell structure, varying the radius-thickness ratio for three different values such as 15, 20 and 25 the chimneys are modelling. The cross-section of the chimney used is circular. Two variations are shown in the profile such as 1.tapering from the bottom and become uniform at a height of one-third from the top of the structure.2.uniformly tapering from bottom to the top of structure. The shell thickness at the top of the structure is taken as 0.4m and the minimum bottom shell thickness is taken as 0.6m as per clause 6.4.1 in CED 38 (7892) (Draft Indian Standard Code of Practice for Design of Reinforced Concrete Chimneys). The diameter of the chimney is taken by considering the thickness and radius-thickness ratio. Totally in this project 30 models are considered. The chimney structure is modelling in SAP 2000 software. Material properties defined as M35 grade of concrete and Fe415 grade of steel. The elastic modulus considered is 35GPa and thermal loading depends upon the individual requirements of chimney as per IS 4998(Part 1):1982 (Criteria for design of reinforced concrete chimneys). The Poisson's ratio and density considered are 0.15 and 25lkN/m^3 respectively. The model of fully tapered 275m height chimney with radius-thickness ratio is 15 as shown in fig. 1.

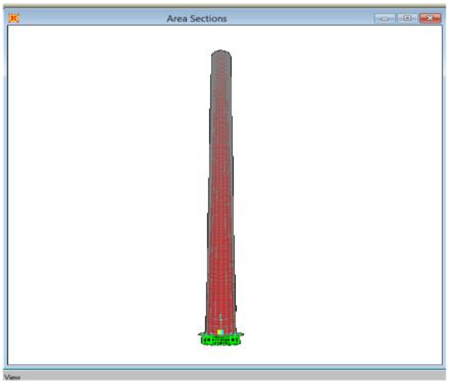

Fig. 1 Fully Tapered Model (H=275m, R/T=15)

B. Analysis of the Structure

Important loads that a RC chimney often experiences are wind loads, earthquake loads and temperature effects apart from self weight. Wind effects on chimney plays an important role on its safety as RC chimneys are generally very tall structures. The circular cross section of the chimney subjects to aerodynamic lift under wind load. Again seismic load is a major consideration for chimney as it is considered as natural load. This load is normally dynamic in nature. Here describes the wind load and seismic load considering temperature effects on RC chimney.

1) Wind Analysis: The concept of wind force calculation is given in design code IS: 875(Part 3)-1987. Using Simplified method along-wind load was computed for each 10m height according to IS: 4998 (Part 1)-1992.Static analysis has been carried out for wind load by considering chimneys were assumed to be located in terrain category 2, class c structure and subjected to a wind speed of 39m/s (by considering Trivandrum region) as per IS: 875(Part 3)-1987. IS: 875(Part 3)- 1987 code gives wind speed , pressure and forces on chimney structures.

From IS 875:1987 clause number 8.3

Force due to the wind pressure $F_z = C_d\, D_z\, P_z$

Where,

C_d - 0.8 (Drag coefficient)

D_z - diameter at height z m

P_z - calculated wind pressure at z m height

$P_z = 0.6\, V_z^2$

Where,

V_z – Design wind speed

$V_z = V_b\, k_1 k_2\, k_3$

Where,

V_b=basic wind speed

k_1= probability factor (risk coefficient)

k_2= Terrain, height and structure size factor

k_3= Topography factor

The value of Probability factor k_1=1 from Table 1of IS 875:1987

The Terrain or height factor k_2 is from Table 2 of IS 875:1987

Similarly Topography factor k_3 = 1 is from Table 3 of IS 875:1987

2) Seismic Analysis: Due to seismic action, an additional load is acted on the chimney. It is considered as vulnerable because chimney is tall and slender structure. For analysis purpose, chimney is behaved like a cantilever beam with flexural deformations.

The various parameters considered for seismic analysis is described. The chimney is located at level ground and soil condition is hard (type1). The chimneys are of more than 50m height so it is classified as class C structures. The zone in which the chimney is located is zone 3, Zone factor Z=0.16(Trivandrum region) as given in IS1893:2005, Importance factor, I=1.5 as given in IS1893:2005 and Response reduction factor, R=3.0 as given in 1893:2005 (part-4).

Time history analysis considering all the modes of the structure is assumed to give more accurate results when compared to other linear analysis procedures. This includes the step by step numerical time integration of equation of motion by expressing the relationship between the displacement and its time derivatives-velocity and acceleration. The Idukki earthquake was chosen for the analysis. Time histories in all three directions were available for this earthquake shown in fig. 2. The chosen accelerogram is Idukki earthquake, December 12th, 2000, Kerala, magnitude of 5 and depth is 7km.

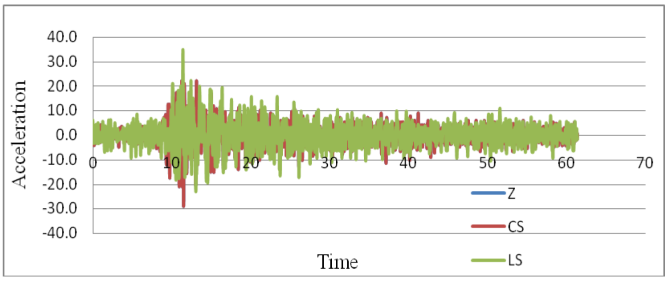

Fig. 2 Time History Motion Record

Consideration of thermal effects is important in chimney analysis. Thermal loading assigned to chimney structure depends upon the individual requirements of chimney as per IS 4998(Part 1):1982.Temperature provided varies 130°C to 230°C for 275m to 400m height thermal power plant chimney structures.

III. RESULTS AND DISCUSSIONS

A. *Wind Analysis Results*

Wind analysis of chimney model was conducted and results were taken to explain the performance of chimney structures by considering the output parameters like joint displacement and maximum shell stress.

1) *Comparison of Results by Considering Displacement:*

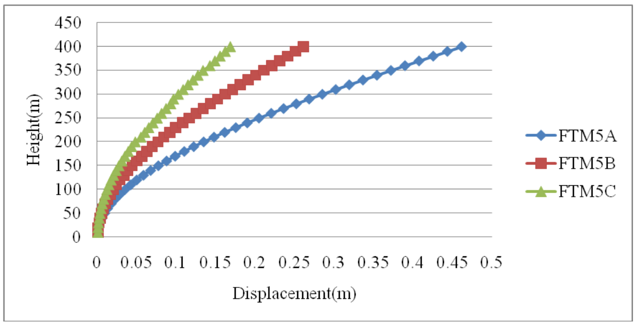

Fig. 3 Graph Of Displacement/Height For 400m Height Fully Tapered Chimney

Fig. 3 shows the displacement vs height relationship of chimney models, tapering from bottom to top which is having 400m height, the radius-thickness ratio for three different values such as 15, 20 and 25. The 400m height fully tapered chimney with R/T ratio is 15(FTM5A) has maximum displacement as 0.4618m. For 400m height fully tapered chimney with R/T ratio is 20(FTM5B) and for 400m height fully tapered chimney with R/T ratio is 25(FTM5C) have maximum displacement as 0.2612m and 0.1689m respectively. Joint displacement value was taken for each 10m height to plot the graph.

From the fig. 3 it was clear that FTM5A has high displacement values than that of FTM5B and FTM5C. The displacement value was decreased by 43% for FTM5B and 62% for FTM5C than that of FTM5A.

Partially tapered chimney also shows the same configuration.

From the graph we can conclude that the displacement of chimney models decreases with increase of radius thickness ratio.

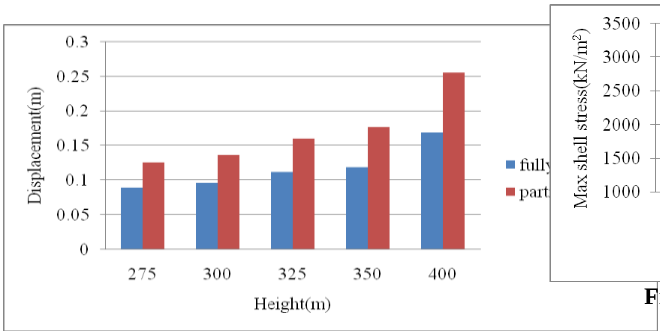

Fig. 4 Bar Chart For Displacement (Models With R/T=25)

Fig. 4 shows the bar chart for displacement at top of the chimney models, tapering from bottom to top and tapering from the bottom and becomes uniform at a height of one-third from the top of the structure, were having 275m,300m,325m,350m and 400m height and the radius-thickness ratio is 25.

From the fig. 4 it was observed that partially tapered chimneys with R/T ratio is 25 have 29% higher displacement values than that of fully tapered chimneys.

From the graph we can reach the conclusion that the chimney which is tapering from bottom to top has lesser displacement value than that of the chimney which is tapering from the bottom and becomes uniform at a height of one-third from the top of the structure. It also concluded that as the height increases displacement also increases for fully tapered and partially tapered chimneys.

1) *Comparison of Results by Considering Shell Stress:*

Fig. 5 Bar Chart For Maximum Shell Stress Of 400m Height Fully Tapered Chimney

Fig. 5 shows the bar chart for maximum shell stress of chimney models, tapering from bottom to top which is having 400m height, the radius-thickness ratio for three different values such as 15, 20 and 25.

From the fig. 5 it was clear that FTM5A has higher shell stress values than that of FTM5B and FTM5C. The shell stress value was decreased by 23% for FTM5B and 37% for FTM5C than that of FTM5A.

Obtained result for partially tapered chimney also have same pattern. From the graph we can conclude that shell stress in chimneys decreases with increase of radius thickness ratio.

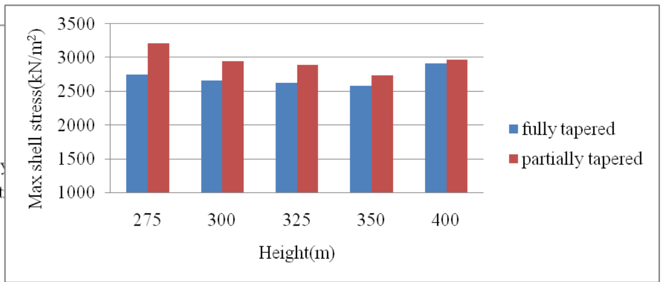

Fig. 6 Bar Chart For Maximum Shell Stress (Models With R/T=25)

Fig. 6 shows the bar chart for maximum shell stress of the chimney models, tapering from bottom to top and tapering from the bottom and becomes uniform at a height of one-third from the top of the structure, were having 275m,300m,325m,350m and 400m height and the radius-thickness ratio is 25.

From the fig. 6 it was observed that 275m height partially tapered chimney with R/T ratio is 25 has 14% higher shell stress value than that of fully tapered chimney. The 300m height partially tapered has 9.7% higher shell stress value than fully tapered chimney. For 325m height chimney it was 9.2% higher and 350m height chimney it was observed as 5.5% higher. Then obtained shell stress value for 400m height partially tapered chimney was 1.9% higher than that of fully tapered chimney.

From the graph it is seen that the chimney which is tapering from bottom to top has lesser shell stress value than that of the chimney which is tapering from the bottom and becomes uniform at a height of one-third from the top of the structure. It also concluded that as the height increases shell stress was decreases up to the height of 350m and for 400m height chimney it was increasing for fully tapered and partially tapered chimneys.

B. Seismic Analysis Results

Time history analysis of chimney models was conducted and results were taken to explain the performance of chimney structures by considering the output parameter joint displacement and temperature effects also considered for the analysis.

2) Comparison of Peak Displacement Values by Time History Analysis:

Time history analysis is carried out for different chimney models. The time and joint displacement plot function of 275m chimney which is tapering from bottom to top and the chimney which is tapering from the bottom and becomes uniform at a height of one-third from the top of the structure are shown in fig. 7 and fig. 8 respectively.

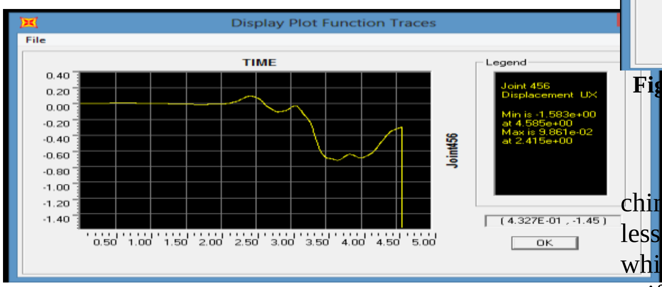

Fig. 7 Graph of Displacement/Time For 275m Height (R/T=25) Fully Tapered Chimney

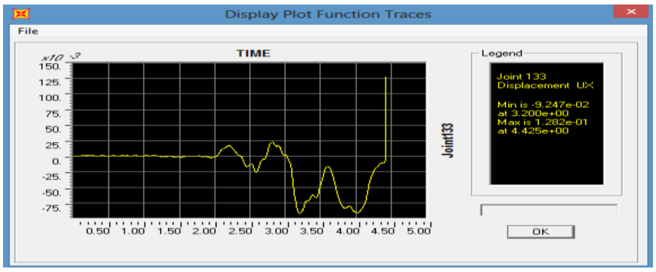

Fig. 8 Graph of Displacement/Time for 275m Height (R/T=25) Partially Tapered Chimney

Time history analysis is carried out for different chimney models. The time and joint displacement plot function of 400m chimney which is tapering from bottom to top and the chimney which is tapering from the bottom and becomes uniform at a height of one-third from the top of the structure are shown in fig. 9 and fig. 10 respectively.

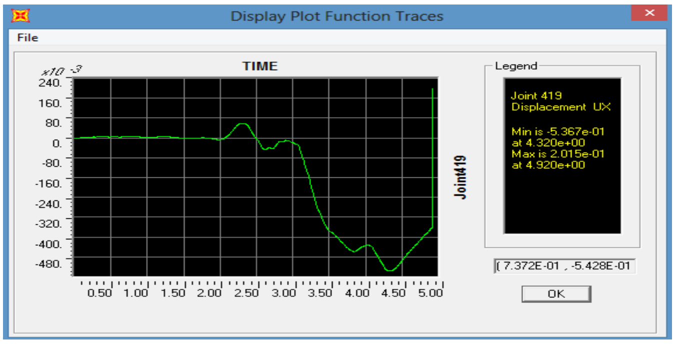

Fig. 9 Graph of Displacement/Time for 400m Height (R/T=25) Fully Tapered Chimney

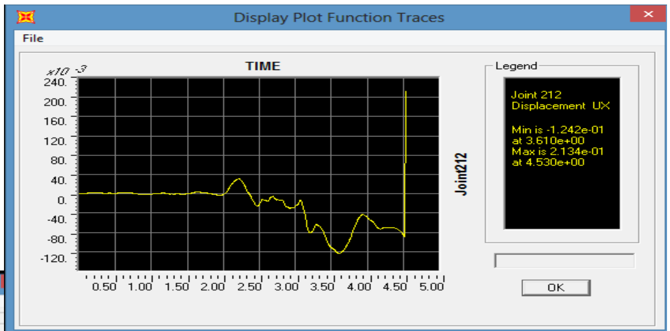

Fig. 10 Graph Of Displacement/Time For 400m Height (R/T=25) Partially Tapered Chimney

From these graphs it is concluded that the chimney which is tapering from bottom to top has lesser displacement value than that of the chimney which is tapering from the bottom and becomes uniform at a height of one-third from the top of the structure.

3) Comparison of Displacement (seismic load + Temperature Load):

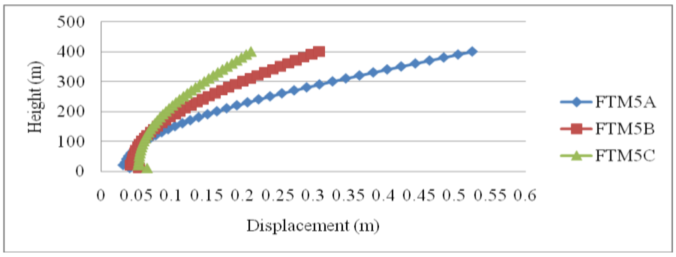

Fig. 11 Graph of Displacement/Height for 400m Height Fully Tapered Chimney

Fig. 11 shows the displacement vs height relationship of chimney models, tapering from bottom to top which is having 400m height, the radius-thickness ratio for three different values such as 15, 20 and 25.

From the fig. 11 it was clear that FTM5A has high displacement values than that of FTM5B and FTM5C. The displacement value was decreased by 43% for FTM5B and 62% for FTM5C than that of FTM5A.

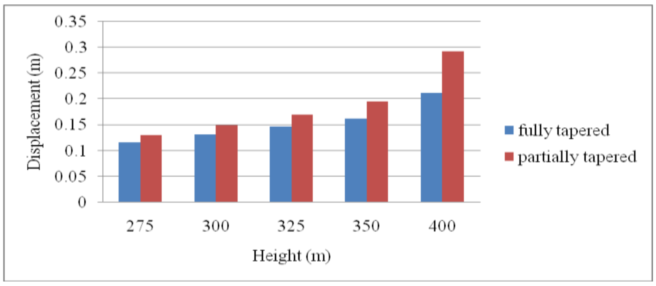

Fig. 12 Bar Chart for Displacement (Models With R/T=25)

Fig. 12 shows the bar chart for displacement at top of the chimney models, tapering from bottom to top and tapering from the bottom and becomes uniform at a height of one-third from the top of the structure, were having 275m,300m,325m,350m and 400m height and the radius-thickness ratio is 25.

From the fig. 12 it was observed that partially tapered chimneys with R/T ratio is 25 have 29% higher displacement values than that of fully tapered chimneys. From the graph we can reach the conclusion that the chimney which is tapering from bottom to top has lesser displacement value than that of the chimney which is tapering from the bottom and becomes uniform at a height of one-third from the top of the structure. It also concluded that as the height increases displacement also increases for fully tapered and partially tapered chimneys.

IV. CONCLUSIONS

Following are the major conclusions drawn from the analysis such as wind analysis and seismic analysis.

- The displacement of chimneys of different height decreases with increase of radius thickness ratio.
- The chimney which is tapering from bottom to top has lesser displacement value than that of the chimney which is tapering from the bottom and becomes uniform at a height of one-third from the top of the structure.
- The displacement of chimney structure is increases with the height.
- Shell stress in chimneys decreases with increase of radius thickness ratio.
- Fully tapered chimney structure has lesser shell stress value than that of partially tapered chimney.

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