International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2015): 6.391

Analysis of Tall RC Chimney as per Indian Standard Code

Amitha Baiju[1], Geethu S[2]

[1]Student, Sree Buddha College of Engineering, Pathanamthitta, India

[2]Associate Professor, Sree Buddha College of Engineering, Pathanamthitta, India

Abstract: ***Reinforced chimneys are used in Power plants to take the hot and poisonous flue gas to a great height. They are tall and slender structures, designed mainly to resist the lateral forces like wind and earthquake as well as the thermal stressesof the flue gas. An attempt is done to understand the variation of lateral deflection at the top of the chimney, by varying the height of chimney above 275 m. CED 38:7892 Code of practice for design of reinforced concrete chimney (Third revision of IS 4998:1992 [Part I]) is used for the analysis. The location selected for the study is Bellary in Karnataka. Along wind and temperature are only considered for this study. Sufficient amount of reinforcement is provided to resist the bending moment in the vertical direction and horizontal loops are provided to cater for the horizontal shear and temperature gradient. A totalof five models are selected for five different heights and the analysis and design are done. ANSYS software was used to do the analysis. All the models were analyzed and the lateral deflectionwas calculated.***

Keywords: R C Chimney, Wind Analysis, Thermal Analysis, Lateral Deflection

1. Introduction

Owing to the increase in population and technological progress, it requires a large supply of power for the smooth running of our modern world, thus leading to the increase in the number of power plants. The flue gas produced contains an increased concentration of compounds like oxides of nitrogen, sulphur and carbonetc.

As per Environment Protection Actand pollution control standards, this flue gas is to be taken to a considerably greater height for them to diffuse into the external atmosphere where it will not cause any ill effects to the eco system. Taking into account this aspect, the height of the chimneys used in power plants are generally very high of the order of 200-400m.

In this paper, a parametric study on RC chimneys of height range of 275 m to 315 m at an interval of 10 m is considered. The height-to-base diameter ratios considered is 12 and the taper of the chimney is 1 in 50.A total of 5 models where considered for the study. The code used for the analysis is CED 38:7892 (Third revision of IS 4998:1992 [Part I]). [8]
All the models are considered as uniformly tapered single flue circular chimney with brick lining. The thickness of the concrete shell is also varied, for the bottom two-third height of the chimney, the thickness is constant. And for the top one-third height of the chimney, even though the thickness is constant it is lesser than the thickness provided in the bottom portion. The shell thickness is calculated as per the code.

The effect of along-wind load and temperature stressesare only considered for the analysis in this study. The chimneys are designed considering a particular location, Bellary in Karnataka. This location is selected because there is already a thermal power plant in this district having a 275 m high chimney. Bellary is located in the Wind zone region II having a basic wind speed of 39m/s and Seismic zone II. The manual calculations are done using MS Excel spread sheet and the finite element analysis is done by ANSYS software.

1.1 Literature Review

A literature review is done on the design and analysis of RC chimneys with special interest on effects of geometric parameters on various load actions. The following literatures were available on RCC Chimney design.

Veena R N, Suresh S (2016) discusses about the limit state of serviceability of an RC chimney under different wind and earthquake conditions. This paper suggests that the moment due to earthquake in Zone III is almost equal to the combined moment due to wind speed of 55m/s.

Bashar Faisal AbdulKareem (2016) discusses the thermal analysis of chimneys on chimney shell thickness. The thermal loads considered are based on actual field measurements of temperature variation in Al-Dora chimney-Baghdad. Thermal analyses were done as per ACI-307-08 provisions, and STAAD.Pro-V8i (3D – plate element). This paper suggests that, increasing the thickness of shell chimney doesn't lead to smaller thermal stresses. Also winter time is found to be more critical since it gives higher temperatures gradient.

Amit Nagar, M. Shiva Shankar, et al (2015) discusses the effects of various profiles of chimney elevation i.e., uniform chimney, tapered chimney and uniform-tapered chimney. The dynamic behaviour of chimney due to wind load in wind zone I and seismic analysis were studied. Height was varied from 150 to 300 m for this study. It was found that uniform-tapered was the best section considering the wind and seismic analysis.

1.2 Importance and Need of study

As per the Environment (Protection) Rules, 1986, the thermal power plant having a power generation capacity of greater than 500MW should have a height of at least 275m.If this code is revised in the future and the height range is increased, then the effect of height, on the lateral deflection

Licensed Under Creative Commons Attribution CC BY

at the top of the chimney have to be studied, which is the main concern of this paper.

Due to design and construction problems, lots of chimneys havefailed structurally in the past few decades causing a heavy blow on the power production sector.

RC Chimneys being tall and slender need to be treated as a special structure during its design and construction stages, since their behavior under loading conditions is different from other structures. The considerations of various load combinations having static and dynamic effects make the analysis and design of RC Chimney complicated. Each of these casesis to be treated specifically, depending on the height of the chimney, its location, type of plant and therefore typical design are not feasible.

1.3 Objective and Scope

The main objective of this study is to understand the variation of maximum lateral deflection at the top of the chimney with the increase in the height.

Design and analysis is done considering the load combination Dead Load+ Wind load+ Temperature Load only.

The height range considered for this study is in the range 275m to 315 m. Single flue Circular chimney having brick lining is considered for this analysis.

1.4 Methodology

To achieve the above objective following step-by-step procedures are followed:

- Carry out literature study to find out the objectives of the project work.
- Understanding the design procedure of a concrete chimney as per third revision of Indian standard code IS 4998 (part 1):1992.
- Analyze all the selected chimney models.
- Evaluate the analysis results.

2. Design Methodology

2.1 Meteorological Data of Bellary, Karnataka.

Basic Wind Speed = 39 m/s
Seismic Zone = II
Maximum temperature = 45^{o}C
Minimum Temperature = 25^{o}C

Table 1: Description of Models

Model No.	*Height (m)*	*Outer Dia. at top(m)*	*Outer Dia. at bottom (m)*	*Thickness of shell at top (m)*	*Thickness of shell at bottom (m)*
1	275	11.92	22.92	0.198	0.291
2	285	12.35	23.75	0.202	0.298
3	295	12.78	24.58	0.205	0.305
4	305	13.22	25.42	0.209	0.312
5	315	13.65	26.25	0.213	0.319

Other details of the chimney are as follows:
1) Height-Base diameter ratio = 12
2) Slope (taper) or batter of the chimney = 1 in 50
3) Thickness of brick lining at the top = 0.2032 m
4) Thickness of brick lining at bottom = 0.3048 m
5) Grade of Concrete = M30
6) Foundation type = RCC Annular pile
7) Maximum flue gas temperature = 1000^{o}C

Description of Loading:
Density of various materials considered for design,
Concrete – 25kN/m^3
Acid Proof Brick Lining – 22kN/m^3
Structural steel – 78.5kN/m^3

Wind load:
The following wind parameters are followed in accessing the wind loads on the structure
Basic wind speed – 39m/s
Terrain category – 1
Class of structure – C
Risk coefficient k_1 – 1
Topography factor k_3– 1
K_2 factor taken from Draft Code CED 38(7892):2013 (third revision of IS 4998(part 1):1992).

3. Loads acting on RC Chimney

Loads which prevail over the R C tall Chimneys are:

- Self-weight
- Imposed loads
- Earthquake load
- Wind load
- Temperature effects
- Circumferential pressure effects

Dead load of an RC chimney includes weight of chimney shell, liners and its supports, insulation material if provided, load of ash and soot.The self-weight of the chimney and lining depends mainly upon the geometric parameters such as shape, size and the height of the chimney.

Imposed load on RC chimney is mainly by the internal platform and hood of multi-flue chimney, also the loads of framework during the construction stage.

Seismic force acts as a cyclic load for a short period of time. For earthquake resistant design of structures, it is important to calculate the structural response to ground motion and respective shear force and bending moments.

Seismic force acts as a cyclic load for a short period of time. For earthquake resistant design of structures, it is important to calculate the structural response to ground motion and respective shear force and bending moments.

Loads due to temperature effects depend on individual requirements for which a chimney is put to use. The main effect of increased temperature variation or uncontrolled fire in an RC chimney is the decrease of concrete strength. This leads to a reduction of the load carrying capacity and service life of a chimney. Elevated temperature causes cracking and

Licensed Under Creative Commons Attribution CC BY

spalling. Spalling is critical for the integrity of a structure. To avoid these, the concrete shell is lined using a lining material, like brick, FRP, insulated steel, insulated aluminium etc., having good temperature resistant properties. Sometimes, insulation materials like mineral wool, rock wool, slag wool etc., are provided in the gap between the concrete shell and lining material.

3.1 Importanceof Chimney Lining

- Liners protect the chimney shell from the corrosive by products of combustion. If the flue gases were allowed to penetrate to the chimney shell, the result would be a reduction in the usable life of the chimney.
- As Lining reduces thermal stresses and the chance of fire.
- Lining keeps the shell away from the chemical effect of flue and acids vapors.

3.2 Circumferential Pressure Effects

The code CED 38 (7892), 2013 only discusses design of a chimney having hollow circular cross section; it is to be designed to resist the loads caused by the circumferential pressure distribution. Under the circumferential pressure effects, two types of loads are considered, they are (i) the circumferential ring moment due to wind and (ii) circumferential ring moment due to temperature effects. To calculate this, horizontal strip at any level of chimney shell be designed as a horizontal beam resisting the circumferential ring moment.

4. Calculation of Loads

4.1 Along-wind load effects

Grade of concrete used is M_{30}
Dynamic modulus of elasticity for M30 concrete,

$$E_{ck} = 3.35 \quad 10^{10} N/m^2$$

Natural frequency of chimney in I mode of vibration,

$$f_1 = 0.2\left(\frac{d_0}{H^2}\right)\sqrt{\frac{E_{ck}}{\rho_{ck}}}\left(\frac{t_0}{t_H}\right)^{0.3} \qquad (1)$$

Natural frequency of chimney in II mode of vibration,

$$f_2 = 6 f_1\left[\frac{d_H t_H}{d_0 t_0}\right]^{0.2} \qquad (2)$$

Structural damping as a fraction of critical damping $\beta$is taken as 0.016 for along-wind loads.
Design hourly mean wind speed, taken as the reference wind speed at a height, *z*,

$$\bar{V}_{(z)}(\text{in m/s}) = V_b\ k_1 \bar{k}_2\ k_3 \qquad (3)$$

$\bar{k}_2$isobtained from the equation,

$$\bar{k}_2 = 0.1423\left[\ln\left(\frac{z}{z_0}\right)\right] {z_0}^{0.0706} \qquad (4)$$

Here z_0 is the aerodynamic roughness height, taken as 0.002 m for terrain category 1.
$\bar{V}_{(10)}$ – MeanHourly wind speed at 10m ht. above GL
Size Reduction Factor,

$$S = \left\{1 + 5.78\left(\frac{f_1}{\bar{V}_{(10)}}\right)^{1.14} H^{0.98}\right\}^{-0.88} \qquad (5)$$

Measure of available energy in the wind at the natural frequency,

$$E = \frac{\left\{123\left(\frac{f_1}{\bar{V}_{(10)}}\right)H^{0.21}\right\}}{\left\{1+\left(330\frac{f_1}{\bar{V}_{(10)}}\right)^2 H^{0.42}\right\}^{0.83}} \qquad (6)$$

Background factor indicating the slowly varying component of wind load fluctuations,

$$B = \left\{1 + \left(\frac{H}{265}\right)^{0.63}\right\}^{-0.88} \qquad (7)$$

Effective cycling rate × Sample period taken as 3600 sec,

$$\nu T = \frac{3600 f_1}{\left(1+\frac{B\beta}{SE}\right)^{1/2}} \qquad (8)$$

Twice the turbulence intensity at the top of the chimney,

$$r_t = 0.622 - 0.178 \log_{10} H \qquad (9)$$

Peak factor, ratio of expected peak value to RMS value of fluctuating load,

$$g_f = \sqrt{2 \ln \nu T} + \frac{0.577}{\sqrt{2 \ln \nu T}} \qquad (10)$$

Gust response factor,

$$G = 1 + g_f r_t \sqrt{B + \left(\frac{SE}{\beta}\right)} \qquad (11)$$

Design wind pressure due to hourly mean wind speed at a height of 10 m above GL,

$$\bar{p}_{(10)} = \frac{1}{2}\rho_a \{\bar{V}_{(10)}\}^2 \qquad (12)$$

Here mass density of air (ρ_a) is taken as 1.2 kg/m^3.
Mean along-wind load at 10 m height,

$$\bar{F}_{(10)} = \bar{C}_D d_{(10)} \bar{p}_{(10)} \qquad (13)$$

where$\bar{C}_D$ is mean drag coefficient taken as 0.8
$d_{(10)}$is the outer diameter of chimney at height 10 m above GL. Fluctuating component of along-wind load at 10 m height, $F'_{(10)}$ (in N/m)

$$F'_{(z)} = 3\frac{(G-1)}{H^2}\left(\frac{z}{H}\right)\int_0^H \bar{F}_{(z)}\, z\, dz \qquad (14)$$

Along-wind load, $F_{(z)}$ per unit height at a height z m above GL is,

$$F_{(z)} = \bar{F}_{(z)} + F'_{(z)} \qquad (15)$$

4.2 Across-wind load effects

$$\text{Reference height, } z_{ref} = \frac{5}{6}H \qquad (16)$$

$\bar{V}_{(ref)}$ –Mean hourly wind speed at reference height above GL
Critical wind speed for across-wind loads corresponding to fundamental mode I,

$$V_{(cr)} = \frac{f_1 d}{S_t} \qquad (17)$$

Strouhal number,

$$S_t = 0.25 F_{1A} \qquad (18)$$

Strouhal number parameter,

$$F_{1A} = 0.333 + 0.206 \ln\left(\frac{H}{d}\right) \qquad (19)$$

The value of F_{1A} shall be between 0.6 and 1.0.
Critical wind speed for across-wind loads corresponding to fundamental mode II,

$$V_{(cr)} = 5 f_2 d \qquad (20)$$

Licensed Under Creative Commons Attribution CC BY

According to the IS code, across-wind loads due to vortex shedding in the first and second modes shall be considered in the design of all chimney shells when the critical wind speed V_{cr} is between $0.5\bar{V}_{(z_{ref})}$ and $1.3\bar{V}_{(z_{ref})}$. Across-wind loads need not be considered outside this range.

For the five models selected, the across wind effects are not considered as the critical wind speed was outside the range specified by the code.

4.3 Stresses due to Temperature Effects

Max vertical stress due to temperature in concrete (at inside of shell),

$$f'_{CTV} = \alpha_{te}\, c\, T_x E_c \quad (21)$$

Max vertical stress due to temperature in steel (at inside of shell),

$$f'_{STV} = \alpha_{te}(c - 1 + \gamma_2) T_x E_s \quad (22)$$

Max vertical stress in the vertical steel, due to temperature (at outside face of shell),

$$f_{STV} = \alpha_{te}(\gamma_2 - c) T_x\, E_s \quad (23)$$

where T_x –Temperature drop across the concrete shell
E_c –Modulus of Elasticity of concrete
E_s –Modulus of Elasticity of steel
n–Modular ratio of Elasticity
ρ – Ratio of area of outside face vertical reinforcement to total area of concrete shell
γ_1 –Ratio of area of inside face vertical reinforcement to area of outside face vertical reinforcement
γ_2 –Ratio of distance between inner surface of chimney shell and outside face vertical reinforcement to total shell thickness
α_{te} – Thermal coefficient of expansion of concrete and of reinforcing steel

$$c = -\rho n(\gamma_1 + 1) + \sqrt{[\rho n(\gamma_1 + 1)]^2 + 2\rho n[\gamma_2 + \gamma_1(1 - \gamma_2)]} \quad (24)$$

5. Geometric Details of the chimney

A total of 30 Single-flue Circular RC Chimneys of Brick lining is used in this paper. All the models are considered as uniformly tapered single flue circular chimney with brick lining. The shell of the chimney is modeled as a shell type element of 3D 4 node shell 181. The grade of concrete mix adopted in this paper is M 30.The dynamic modulus of elasticity value, corresponding to the grade of concrete mix is taken from the code. The Poisson's ratio of concrete is in the range of 0.15 – 0.2(0.2 is taken in this paper). Fireclay acid proof bricks are considered for lining. The thickness of the chimney is varied. The thickness is constant for the bottom 2/3rd of height and a lesser value of thickness is provided as a constant value in the top 1/3rd. Due to this variation in thickness the temperature stresses were calculated separately for these two sections.

5.1 Design Assumptions

- The wind pressure varies with the height. It is zero at the ground and increase as the height increases.
- Imposed loads are not considered for the overall design of chimney shell and foundation.
- Earthquake and wind forces are not considered as acting simultaneously.
- Chimney is designed as shell having no openings.
- For the basic wind speed of the location selected, the critical wind speed was lower to produce any across-wind effects. Hence only along-wind effects were only considered.
- Circumferential pressure effects are not considered in this design.
- The load combination selected for the design of chimney shell is Dead loads + wind loads + loads due to temperature effects.

Wind load is provided as force on nodes and Temperature is provided as pressure (Fig. 1 and Fig 2). The chimney structure is divided into 28 sections along the height for the advantage of giving the load, as wind load varies with respect to the height.

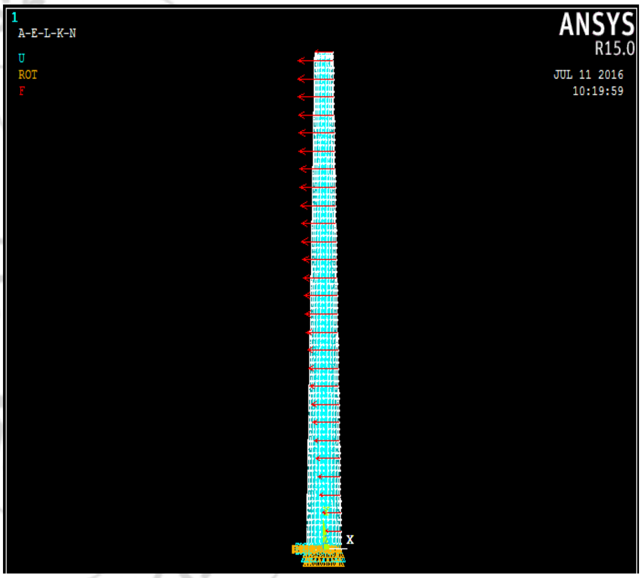

Figure 1: Wind Load applied on chimney

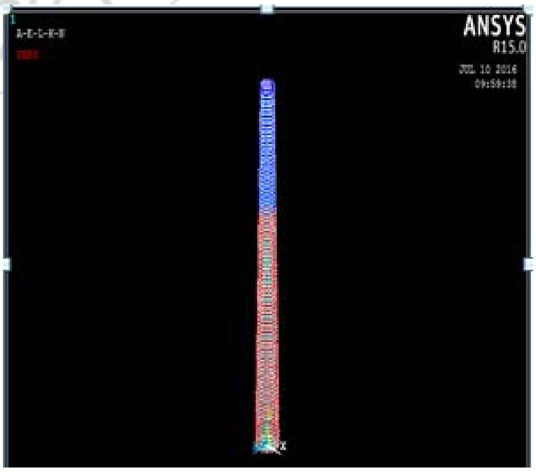

Figure 2: Temperature Load applied on chimney

6. Results and Discussions

As per the code, CED38 (7892):2013, the limiting deflection allowed at the top of chimney should be limited to H/500.

Licensed Under Creative Commons Attribution CC BY

For a particular height to base diameter ratio of 12 and slope 1in 50, the peak deflection was found to increase with increase in the height of the chimney.Table 2 shows the maximum lateral deflection at the top of chimneys for height varying from 275 m to 315 m.

Comparing the results for a chimney profile having height-to-base diameter ratio 12 and slope 1 in 50 the lateral deflection at top was found to increase by 5.48%, 11.45%, 18.62% and 25.90%, when the height is increased from 305 m to 315 m, 295 m to 315 m, 285m to 315m and 275m to 315m respectively.

Table 2: Max lateral deflection at the top of chimney

	Height of chimney (m)				
	275	285	295	305	315
Limiting Deflection (m)	0.55	0.57	0.59	0.61	0.63
Max. Lateral deflection at top (m)	0.34408	0.36520	0.38872	0.41070	0.43322

7. Conclusion

- At small wind speed regions, along-wind effects are the governing factor for the design of RC chimney.
- From the wind load and temperature load calculated it is clear that the wind effects are major constituent compared to Temperature effects.
- It was also found that the lateral deflection at top of chimney increases with the increase in height of the slender structure.

References

[1] Alok David John, Ajay Gairola, "Design Wind Loads on Reinforced Concrete Chimney – An Experimental Case Study," Procedia Engineering, Elsevier, Issue 14, 2011.

[2] Bashar Faisal Abdul Kareem, "Thermal analysis of chimneys by Finite Element",Al-Mansour Journal, Issue 25, 2016.

[3] B. Siva Konda Reddy, V.RohiniPadmavathi, Ch. Srikanth, "Study of Wind Load Effects on Tall RC Chimneys", International Journal of Advanced Engineering Technology, Volume 3, Issue 2, 2012.

[4] K.Anil Pradeep, C.V.Siva Rama Prasad, "Governing Loads for Design of a 60m Industrial RCC Chimney", International Journal of Innovative Research in Science, Engineering and Technology, Vol. III, Issue 8, 2014.

[5] Veena R N, Suresh S, "Analysis and Design of R C Chimney",International Journal of Mechanical Engineering and Information Technology,Volume 04, Issue 01, 2016.

[6] Manohar, S.N., "Tall Chimneys", Tata McGraw-Hill Publishing Company Limited, New Delhi, 1985.

[7] Draft copy CED 38(7892):2013 (Third revision of IS 4998(part 1):1992), "Criteria for design of reinforced concrete chimneys", Bureau of Indian standards, New Delhi, 2013.

[8] IS: 4998 (Part 1):1992, "Criteria for the Design of Reinforced Concrete Chimneys," Bureau of Indian standards, New Delhi, 1992.

[9] IS: 875 (Part 3) - 1987 "Code of Practice for Design Loads (Other Than Earthquake) for *Buildings and Structures – Wind Loads*," Bureau of Indian standards, New Delhi, 1987.

Licensed Under Creative Commons Attribution CC BY