

Governing Loads For Design of a 60m Industrial RCC Chimney

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ABSTRACT: Industrial Chimneys are generally intended to support critical loads produced by seismic activity and wind. So it is essential to evaluate the dynamic response of chimney to seismic activity and wind loads. Response to Earthquake and wind are more critical as chimney is a slender structure. The present paper will analyse the 60m reinforced concrete chimney. Comparison has been made for wind and seismic analysis. Seismic analysis is done as per IS 1893(part 4): 2005 and wind analysis as per Draft Code CED38(7892):2013 (Third revision of IS 4998(part 1):1992). Further study continues on deciding the governing loads for chimneys for the loads considered.

KEYWORDS: RCC Chimneys, Earthquake loads, Wind loads, Combined design loads, Seismic analysis, Wind analysis, Draft code.

I. INTRODUCTION

Chimneys are the structures which are built to greater heights as tall slender structures. In early days, as household vents and over the years; they are popularly known as chimneys [1]. Chimneys or stacks are used as a medium to transfer highly contaminated polluted gases to atmosphere at greater heights. Over the years due to development of large scale industries, a large number of tall slender chimneys are required to be designed every year. The main function of chimney is to take highly poisonous gases which are not acceptable at ground level were taken to greater heights with sufficient velocities. Chimneys are more vulnerable to wind and earthquake loads which may cause severe problem in power plants and major industries. However, if they located in higher seismic zone with lower wind speeds, then, seismic forces may become analogous, if not more, than the wind loads. It is designed for both, along wind and across wind loads. In this paper procedure given by draft Code CED 38(7892):2013 (third revision of IS 4998(part 1):1992)[2] is being used to obtain the combined design loads. In this paper of 60m RCC chimney for design seismic loads and wind loads; both are compared to decide the governing loads for the design of chimney shell. By ensuring proper design and construction, chimneys will be treated as self-standing structures to resist earth quake forces and wind forces acting on them. It is a general method to reflect the effects of wind and earthquake distinctly in the design.

II. LITERATURE REVIEW

Present literature review is carried out on the analysis of RCC chimney for wind and seismic effects.

Menon and Rao(1997) reviews the code measures to estimate the across wind response of reinforced concrete chimney. In this paper, the difficulties in the codal evaluation of across wind moments and load factor provisions are examined through reliability approach. This paper mainly suggest that it is essential to design at certain conditions for the across wind loading[3].

K.R.C. Reddy, O.R. Jaiswal and P.N. Godbole (2011) discusses about wind and earthquake analysis of tall reinforced concrete chimney. In this paper two reinforced concrete chimneys are analysed for wind and earth quake loads. Earth quake analysis is done as per IS 1893 (part 4): 2005 and wind analysis is done as per IS 4998 (part 1): 1992. The combination of along & across wind loads of chimney is done as per ACI 307-98 code. Finally they computed the governing load for design of chimneys [4].

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 8, August 2014

B. SivaKonda Reddy, C.Srikanth, V.RohiniPadmavathi (2012) discusses about wind load effects on tall reinforced concrete chimneys. In this paper they considered 275m reinforced concrete lined chimney. The study of this paper is along & across wind effects on this RCC Chimney for I and VI wind zones of India. Finally they concluded that, for wind zone –I across wind loads are governing and for wind zone-VI along wind loads are governing rather than the across wind loads [5].

K.R.C. Reddy, O.R.Jaiswal and P.N.Godbole (2012) discusses about combined design moments of tall reinforced concrete chimneys. Combined design moments along and across wind response of chimneys are considered for the design as wind load governs the design of RC chimneys. The methods used for evaluation are IS 4998, ACI 307, AS/NZS11702&Menon&Rao [6].

M.G.Shaikh, Mie, H.A.M.I.khan discusses about governing loads for design of a tall RCC chimney. Generally, this type of design requires dynamic analysis for loads due to self-weight, earthquake and wind. The main focus is to compare the wind loads with seismic loads. For along wind, wind analysis is done by peak factor method and for across wind by random response method [7].

Based on literature review, most of the chimneys designed are based on IS 4998:1992 but in this paper response of chimney was evaluated based on draft Code CED 38(7892):2013 (third revision of IS 4998(part 1):1992)

Details of the chimney as follows,

1. Height of the chimney – 60m
2. Outer diameter of chimney at bottom – 5.455m
3. Outer diameter of chimney at top – 3.273m
4. Thickness of shell at bottom – 0.15m
5. Thickness of shell at top – 0.15m
6. Thickness of air gap – 0.08m
7. Thickness of fire brick lining – 0.1m
8. Grade of concrete – M25
9. Height to base diameter ratio – 11
10. Top diameter to base diameter ratio – 0.6
11. Basic wind speed – 55m/s
12. Foundation type – RCC circular mat

Description of loading:

Density of various materials considered for design,

Concrete – 25kN/m^3

Insulation – 1kN/m^3

Structural steel – 78.5kN/m^3

Live load – 5kN/m^3

Wind load:

The following wind parameters are followed in accessing the wind loads on the structure

Basic wind speed – 55m/s

Terrain category -2

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)

Earthquake force data:

Earthquake load for the chimney has been calculated as per IS 1893(par 4) : 2005

Zone factor – 0.16

Seismic zone – III

Importance factor (I) – 1.5

Reduction factor (R) - 3

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 8, August 2014

Analysis procedure for wind load as per Draft copy CED 38(7892):2013 (third revision of IS 4998(part 1):1992)

III. ESTIMATION OF WIND LOADS

In tall structures like industrial chimneys, wind forces usually govern the design. Wind effect can be divided into two components. Those are along wind and across wind effects. Due to drag force on chimney, along wind loads occur. Due to lift force on chimney, across wind loads occur. When wind forces act on the structure, buffeting effect is produced because of along wind loads. For the reason of evaluation of loads, the chimney is designed as a cantilever whose bases are fixed to the ground. Generally wind does not blow at a fixed rate. It blows at gusts. So this requires that the effects are taken in terms of equivalent loads. Here chimney is analysed as a bluff body having turbulent flow for the computation of along wind loads. Equivalent static procedure is used in codes known as gust factor method. Currently stipulated in all building codes and also in Draft Code CED 38(7892):2013 (third revision of IS 4998(part 1):1992). In this method wind pressure which is assumed to be acting on the face of the chimney, due to this wind pressures are considered as static wind loads. This is then improved using the gust factor to make sure of the dynamic effects. The following codes are used in estimation of along wind loads are:

- ✓ IS 875 (part 3):1987 - code practice for design loads for building and structures [8].
- ✓ Draft Code CED 38(7892):2013 (third revision of IS 4998(part 1):1992)

Design wind pressure:

The design wind speed, $V(z)$ can be calculated by multiplying basic wind speed, V_b with modification factors, k_1 , k_2 and k_3 .

$$\overline{V}(z) = V_b k_1 \overline{k_2} k_3$$

$$\overline{k_2} = 0.1423 \left[\ln \left(\frac{z}{z_0} \right) \right] (z_0)^{0.0706}$$

Where z_0 = aerodynamic roughness height

For terrain category-1 = 0.002

Terrain category-2 = 0.02

$$\text{Design wind pressure, } \overline{p}(z) = \frac{1}{2} \rho_a \{ \overline{V}(z) \}^2$$

Where, mass density of air = 1.2 kg/m³

Calculation of along wind loads:

By using the gust factor approach, along wind loads are calculated. Generally, chimney height is divided into number of segments. Each segment is not greater than 10 meters. Load can be calculated at any section by taking the average of loads above and below it. Considering the chimney like a cantilever structure, by using sectional forces, moments are evaluated [2].

The along-wind load, $F(z)$ can be calculated for unit height of chimney at any section, z is equal to the summation of the mean along-wind load, $\overline{F}(z)$ and the fluctuating component $F'(z)$ of along-wind load.

$$F(z) = \overline{F}(z) + F'(z)$$

The mean along-wind load $\overline{F}(z)$,

$$\overline{F}(z) = \overline{C_d} d(z) \overline{p}(z)$$

C_d = Mean drag coefficient = 0.8

$d(z)$ = Chimney outer diameter at each section.

Fluctuating component of along-wind,

$$F'(z) = 3 \frac{(G-1)}{H^2} \left(\frac{z}{H} \right) \int_0^H \overline{F}(z) z dz$$

Where,

G = Gust response factor

H = Height of chimney from base.

The gust response factor,

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 8, August 2014

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

g_f = peak factor,

$$g_f = \sqrt{2 \ln(vT)} + \frac{0.577}{\sqrt{2 \ln(vT)}}$$

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

v = Effective cycling rate

T = Sample period taken as 3600 seconds

r_t = Twice the turbulence intensity

$$r_t = 0.622 - 0.178 \log_{10} H$$

B = Background factor,

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

E = At natural frequency, Measure of available energy in the wind.

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

S = Size reduction factor

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

$\bar{V}(10)$ = Mean hourly wind speed from the base above 10 m height (m/s)

β = For along wind loads, Structural damping as a fraction of critical damping = 0.016.

f_1 = Natural frequency of stack (Hz).

Calculation of across wind load:

When opposed to a streamline flow a chimney is assumed to behave like a bluff body. When wind flows smoothly past the chimney no extra forces will act. A bluff body causes wind to disperse from the exposed surface. Due to this diverged flow behind the chimney wake regions are formed. In this region, wind is turbulent and eddies arise which are of high speeds called vortices. Vortices in turn will give rise to lift forces. These forces are acting in perpendicular to the wind direction [2].

Generally critical wind speed lies between $0.5 \bar{V}(z_{ref})$ and $1.3 \bar{V}(z_{ref})$. Across wind loads are not considered, when they are not within the specified limits. Across wind loads are evaluated as given below,

The peak moment at base, M_{ac}

$$M_{ac} = \left[g_{ac} S_s C_L \frac{\rho_a V_{cr}^2}{2} d H^2 \right] * \left[\frac{\pi}{4(\beta_s + \beta_a)} \right]^{0.5} * S_p * \left\{ \frac{2L}{\left(\left(\frac{H}{d}\right) + C_E\right)} \right\}^{0.5}$$

When $V_* \geq V(z_{ref})$, M_{ac} shall be multiplied by

$$\left\{ 1.0 - 0.95 \left[\frac{\bar{V}_* - \bar{V}(z_{ref})}{\bar{V}(z_{ref})} \right] \right\}$$

S_s = Mode shape factor = 0.57 (1st mode)
= 0.18 (2nd mode)

C_E = End effect factor = 3

g_{ac} = Peak factor = 4.0

RMS lift coefficient, C_L

**International Journal of Innovative Research in Science,
Engineering and Technology**

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 8, August 2014

$$C_L = C_{Lo} F_{1B}$$

RMS lift coefficient for local turbulence, C_{Lo}

$$C_{Lo} = -0.243 + 5.648 I_{ref} - 18.182 [I_{ref}]^2$$

Where

$$I_{ref} = \frac{1.0}{\ln\left(\frac{z_{ref}}{z_0}\right)}$$

z_{ref} = Reference height

$$z_{ref} = (5/6)H$$

$$F_{1B} = -0.089 + 0.337 \ln\left(\frac{H}{d}\right)$$

F_{1B} lies between 0.2 and 1.0

$$V_{cr} = \frac{f_1 d}{S_t}$$

f_1 = Natural frequency

$$S_t = 0.25 F_{1A}$$

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

F_{1A} lies between 0.6 and 1.0

$$\beta_s = 0.01 + \frac{0.10 [\bar{V}_* - \bar{V}(z_{ref})]}{\bar{V}(z_{ref})}$$

β_s lies between 0.01 and 0.04

$$\beta_a = \frac{K_a \rho_a d^2}{m_{ave}}$$

m_{ave} = Average mass in top one third of chimney per unit height (kg/m)

$$K_a = K_{ao} F_{1B}$$

$$K_{ao} = \frac{-1.0}{(1 + 5I_{ref}) \left[1 + \frac{|k-1|}{I_{ref} + 0.10}\right]}$$

$$k = \frac{\bar{V}_*}{V_{cr}}$$

$$S_p = \frac{k^{1.5}}{\sqrt{B_w} (\pi^{0.25})} \exp\left[-\frac{1}{2} \left(\frac{1-k^{-1}}{B_w}\right)^2\right]$$

B_{ow} = Band width parameter

$$B_w = 0.10 + 2 I_{ref}$$

L = Correlation length coefficient = 1.2

By using M_{ac} , Across wind load per unit height, $F_{ac}(z)$ in N/m, shall be evaluated with respect to the mode shape of the chimney.

$$F_{ac}(z) = \frac{M_{ac} m(z) \phi_i(z)}{\int_0^H m(z) \phi_i(z) z dz}$$

$m(z)$ = Mass per unit height of chimney (kg/m)

$\phi_i(z)$ = Mode shape with respect to i^{th} mode

Across wind bending moments $M_{ac(z)}$ shall be calculated by using the $F_{ac}(z)$.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 8, August 2014

Natural frequencies:

Natural frequency of first mode, f_1

$$f_1 = 0.2 \left(\frac{d_o}{H^2} \right) \sqrt{\frac{E_{ck}}{\rho_{ck}}} \left(\frac{t_o}{t_{zh}} \right)^{0.3}$$

Where

t_o = Bottom thickness of shell (m)

t_H = Top thickness of shell (m)

d_o = Bottom Centre line diameter of shell (m)

ρ_{ck} = Mass density of concrete (kg/m^3)

E_{ck} = Dynamic modulus of elasticity of concrete (N/m^2)

IV. ESTIMATION OF EARTHQUAKE LOADS

For the calculation of earthquake loads, there are two methods available in Indian standards. These two methods are used to evaluate the design forces. Earth quake analysis was carried out by using IS 1893 (part 4): 2005 [9]

Moment and Shear Force Calculation:

For evaluation of moment and shear force, the following are required.

1) The fundamental time period of the free vibration is,

$$T = C_T \sqrt{\frac{W_t h}{E_s A g}}$$

Where

C_T = Coefficient depending on slenderness ratio of the structure

W_t = Total weight of the structure including lining weight,

A = Area of cross-section at the base of the structural shell

h = Total height of the structure

E_s = Modulus of elasticity of material of the structural shell

g = Acceleration due to gravity

2) By using the fundamental time period T , the horizontal seismic coefficient A_h shall be evaluated.

$$A_h = \frac{Z}{2} * \frac{S_a}{g} * \frac{I}{R}$$

Where

A_h = Horizontal seismic coefficient

Z = Zone factor as given in IS 1893:2005 (Part I),

I = Importance factor as given in IS 1893:2005 (part-4)

R = Response reduction factor as given in IS 1893:2005 (part-4)

S_a/g = Spectral acceleration coefficient.

3.) Shear force V and Bending Moment M , can be computed using,

$$V = C_v A_h W_t D_v$$

$$M = A_h W_t h D_m$$

where

C_v = Coefficient of shear force depending on slenderness ratio

A_h = Horizontal seismic coefficient

W = Total weight of structure including lining weight

h = Height of centre of gravity of structure above base

D_v, D_m = Distribution factors for shear and moment

V.STAAD MODEL

For generating chimney model in STAAD, two types of models were considered, one with 8 node solid elements and other one with line element. Both the models were analysed and deflection was calculated. It is found that the deflection value for the 8 node solid element model and the linear model are same, so for making the model generation easy linear element was chosen. Mode shapes and frequencies are calculated using STAAD. A factor of 1.2 was multiplied to take in to account of accessories of chimney to its self-weight[10].



(a) STAAD model of chimney using 8 node solid elements

In the above figure (a) STAAD model of chimney using 8 node solid elements, shows 60m chimney having fixed supports assigned to base elements and the topmost elements are left free to ensure cantilever action. Under the calculated horizontal forces the displacement of this chimney was noted to compare it with chimney model generated using linear/ beam element.



(b) STAAD model of chimney using Line/Beam elements

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 8, August 2014

In the above figure (b) STAAD model of chimney using Line/Beam elements, shows 60m chimney having fixed support assigned to base node of the bottom most element. Cross sections were assigned using tapered tube element. For the same horizontal load mentioned above this model was analysed for deflection. It is found that both the deflection values are same. Hence, for modal analysis linear element model was adopted for easier evaluation and interpretation of results.

VI. EXPERIMENTAL RESULTS

Table 1: Free vibration characteristics of chimney

Chimney Height (m)	Natural frequency(Hz)		Time period(sec)	
	1 st mode	2 nd mode	1 st mode	2 nd mode
60	0.827	4.147	1.208	0.241

Table 1 represents Natural frequencies and corresponding time periods for the 60m chimney. These results correspond to modal analysis of linear model generated in STAAD as discussed above. The mode shapes for each frequency obtained were used in the wind analysis as per Draft Code CED 38(7892):2013 (third revision of IS 4998(part 1):1992).

Table 2: Results of earthquake analysis

S.No	Zone	Zone factor	Shear force(kN)	Bending moment(kN-m)
1	II	0.10	148.47	2989.38
2	III	0.16	238.09	4793.74
3	IV	0.24	357.14	7190.61

Table 2 represents Shear force and Bending Moment values obtained from the earthquake analysis for the zones II, III & IV. Analysis is carried out using IS 1893 (part 4): 2005. It is observed that there is at least 50% increase in moments in every zone when compared to its previous zone. These are the maximum moments obtained at the base of the chimney.

Table 3: Results of wind analysis

Chimney height (m)	Base shear(kN)			Base moment (kN-m)		
	Along wind	Across wind	Combined wind	Along wind	Acrosswind	Combined wind
60	19.26	158.40	159.65	585.00	7237.79	7261.38

Table 3 represents Shear force and Bending Moment values obtained from the wind analysis for the wind speed of 55 m/s as per Draft Code CED 38(7892):2013 (third revision of IS 4998(part 1):1992). The wind analysis consists of calculating along and across wind effects separately and combined effect is computed and presented. It is observed that the across wind effects are quite significant when compared to along wind effects.

VII. CONCLUSIONS

- On studying the results presented in the above tables, it shows that as the zone factor increases the values of shear force and bending moment increases.
- The effect of wind force for 55m/s wind speed is quite significant as compared with the earth quake forces in Zone II and Zone III.
- Moment due to earthquake in Zone III is almost equal to the Combined Moment due to wind speed of 55m/s.
- As per draft code the deflection at the free end of the chimney should be well within the permissible limits.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)



Vol. 3, Issue 8, August 2014

- For 60m RCC Chimney of chosen geometric proportions, wind forces governing the design.

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BIOGRAPHY

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