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Governing Loads for Design of A tall RCC Chimney

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Abstract: *Design of tall chimneys requires dynamic analysis for loads due to self weight, earthquake and wind. Because of changes in the dimensions of chimney, structural analysis such as response to earthquake and wind oscillations have become more critical. The present paper discusses analysis of reinforced concrete tall chimney. The main focus is to compare the wind analysis result with that due to seismic one. Wind analysis is done for along wind by peak factor method as well as by gust factor method and for across wind by simplified method as well as by random response method (shell completed case). The results obtained in above cases are compared. The seismic analysis is performed using response spectrum method. Finally, the maximum values obtained in wind analysis and seismic analysis are then compared for deciding the design values.*

Key words - *Chimney, Seismic Analysis, Wind Loading, Wind Analysis*

I. INTRODUCTION

As large scale industrial developments are taking place all around, a large number of tall chimneys would be required to be constructed every year. The primary function of chimney is to discharge pollutants into atmosphere at such heights and velocities that the concentration of pollutants deemed harmful to the environment are kept within acceptable limits at ground level. Due to increasing demand for air pollution, height of chimney has been increasing since the last few decades, and these are valid reasons to believe that this trend towards construction of taller chimneys will continue. However, chimneys being tall slender structures, they have different associated structural problems and must therefore be treated separately from other forms of tower structure.

Construction of such tall chimneys needs the better understanding of loads acting on them and of the structural behavior, so that with the help of modern construction equipment and technique such as slip form, reinforced concrete, the most favored material for chimney construction, could be used efficiently. The proper design and construction of such chimneys will create self standing structures to resist wind load and other forces acting on them. It is a common practice to consider the effects of wind and earthquake separately in the design. The present paper discusses analysis of reinforced concrete tall chimney. The main focus is to compare the wind analysis result with that due to seismic one. Wind analysis is done for along wind and across wind (shell completed case) and the results so obtained are compared with seismic analysis for deciding the design criteria.

II. HEADINGS

1. Description of Structure: A single flue reinforced concrete chimney is considered for the analysis situated in seismic zone III. The flue gas emission point will be 220 m above the finished floor level. The liner is essentially constructed from structural steel and shall be hung from the liner support platform near the chimney top. The liners are provided with resin bonded wool type thermal insulation; there will be several internal platforms of structural steel provided along the height of the chimney. Except for the roof platform, all the other internal platforms will have steel grillage of beams covered with galvanized gratings; internal platforms are provided for enabling access to various elevations of the chimney and provide restraint to the steel liners. External concrete platforms are supported by the chimney shell. The chimney roof shall however comprise of a reinforced concrete slab supported over a grid of structural beams. The roof slab shall be protected by layer of acid resistant tiles. The grade level slab shall be of reinforced concrete. An internal structural steel staircase supported from the floor at the bottom with a guide support from shell is considered up to the support platform. There shall be rack and pinion elevator. Both the elevator and staircase will provide access to all internal and external platforms.

The chimney height and top diameter are governed by exit velocity of gas and dispersion of effluent to a larger area within specified limits of ground level concentration ref [1]. It is known by test that downwash can be avoided if efflux velocity is greater than 1.5 times the wind speed for this reason, the chimney flue at top is based on minimum exit velocity between 15 to 25m/sec, and the Indian code IS: 4998 gives an empirical formula to calculate the chimney height. The external profile of the chimney shell is derived from the structural consideration of the super structure and the foundation. The top portion to the extent possible is kept cylindrical followed by linear slopes. The diameter of the chimney shell at the top is kept minimum possible allowing for accommodation of the flue, staircase and the elevator. The bottom diameter of chimney is normally governed by structural requirements, for single flue chimney an outside batter of 1 in 50 or 60 and a ratio of height to base diameter in the range of 12 to 15 is provided.

Single flue of structural steel is provided to discharge the flue gases and is hung from the liner support platform near the chimney top. The shell rests on R.C.C. mat foundation of circular shape.

1.1 Details of the chimney are as follows

1.	Height of chimney	-	220 m
2.	Outer dia at bottom	-	18.36 m
3.	Outer dia at top	-	6.082 m
4.	Thickness of shell at bottom	-	0.5 m
5.	Thickness of shell at top	-	0.275 m
6.	Grade of concrete	-	M30
7.	Exit velocity of gas at top	-	25.0 m/sec
8.	Flue gas volume from the flue		340 cum/sec
9.	Maximum flue gas temperature		135 degree centigrade.
10.	Seismic Zone	-	III
11.	Basic wind Speed	-	44 m/sec (for Koradi)
12.	Foundation Type	-	RCC circular mat

2. Description of Loading

2.1 Dead Load

Density of various materials considered for design

Concrete	:	25 kN/m^3
Insulation	:	1 kN/m^3
Soil	:	18 kN/m^3
Structural steel	:	78.5 kN/m^3

2.2 Live Load

5 kN/m^2 will be considered for the design of internal and external platforms.

2.3 Wind Load

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

Basic wind speed = 44 m/sec (for koradi as per IS: 875 (part3) 1987 ref [5])

Terrain category = 2

Class of structure = C

Risk coefficient $k_1 = 1.07$

Topography factor $k_3 = 1.00$

k_2 factors shall be suitably taken along the height as given in Table – 2 and Table – 33 as per IS: 875 part-3 according to the method of analysis as per IS: 4998 (part1) 1992 ref [3].

Drag coefficient = 0.8 (for the unstraked region)

3. Earthquake Force Data

Earthquake load for the chimney has been calculated as per IS: 1893 Part-1 2002 ref[4]. Accordingly the relevant parameters are as follows:

Zone factor (Z) = 0.16

Seismic zone = III

Importance factor (I) = 1.75

Reduction factor (R) = 3

Therefore seismic coefficient (A_h) = $\frac{Z}{2}\frac{I}{R}\left(\frac{S_a}{g}\right)$

Max horizontal seismic coefficient $A_h = \frac{0.16}{2}\times\frac{1.75}{3}\times\frac{S_a}{g} = 0.047\times\frac{S_a}{g}$

Horizontal seismic coefficient $A_h = 0.047\ \frac{S_a}{g}$

Accordingly a seismic coefficient value of 0.047 is considered and the $\frac{S_a}{g}$ Values corresponding to hard soil are taken from Figure-2 of ref [4], Dynamic modulus of elasticity considered = 3.35 kN/m^2 as per IS: 4998 part - 1 1992, Poisson ratio considered for concrete = 0.15

III. INDENTATIONS AND EQUATIONS

1. Analysis

The analysis of R.C.C. chimney is carried out when it is subjected to wind forces and earthquake forces, at various sections along its height as shown in the following figure.

The wind analysis is carried out as per methods given in IS 4998 (Part1) 1992 for *along wind* by Peak Factor Method and Gust Factor Method, for *across wind* by Simplified Method and Random Response Method.

2. Analysis Procedure for Wind Load as per IS 4998 (Part 1) 1992

2.1 Peak Factor Method for Calculation of Wind Load

The along wind load or drag force per unit height of the chimney at any level is calculated from the equation $F_z = P_z C_D D_z$ where P_z is design wind pressure obtained in accordance with IS 875 (Part 3): 1987, Z is height of any section of the chimney in m measured from top of foundation, C_D is drag coefficient of the chimney to be taken as 0.8, and D_z is diameter of chimney at Z height.

The chimney is divided into twenty eight no of sections along its height and the lateral load due to wind at any section is calculated by suitably averaging the loads above and below it. The moments are calculated from the sectional forces treating the chimney as a free standing structure.

2.2 Simplified Method for Response of Chimney

2.2.1 The amplitude of vortex excited oscillation, perpendicular to the direction of wind for ith mode of oscillation is calculated by the formula:

$$(1): \eta_{oi} = \left\{ \frac{\int_0^H d_z \phi_{zi} d_z}{\int_0^H \phi^2{}_{zi} d_z} \right\} \times \frac{C_L}{4\pi S^2{}_n K_{si}}$$

where η_{oi} = peak tip deflection due to vortex shedding in the ith mode of vibration in m, C_L = peak oscillatory lift coefficient to be taken as 0.16 H = height of chimney in m, K_{si} = mass damping parameter for the ith mode of vibration, S_n = Strouhal number to be taken as 0.2, Φ_{zi} = mode shape function normalized with respect to the dynamic amplitude at top of the chimney in the ith mode of vibration.

2.2.2 The sectional shear force (F_{zoi}) and bending moment (M_{zoi}) at any height zo, for the ith mode of vibration, are calculated from the following equations:

$$(2): F_{zoi} = 4\,\pi^2 f_1{}^2 \eta_{oi} \int_{z0}^{H} m_z \phi_{zi} d_z$$

$$(3): M_{zoi} = 4\,\pi^2 f_1{}^2 \eta_{oi} \int_{z0}^{H} m_z \phi_{zi} (z - z_0) d_z .$$

where f_1 = natural frequency of the chimney in Hz in the ith mode of vibration, m_z = mass per unit length of the chimney at section z in kg/m.

Periodic response of the chimney in the ith mode of vibration is very strongly dependent on a dimensionless mass damping parameter k_{si} calculated by the formula:

$$(4): K_{si} = \frac{2 m_{ei} \delta_s}{\sigma . d^2}$$

where m_{ei} = equivalent mass per unit length in kg/m in the ith mode of vibration as defined, δ_s = logarithmic decrement of structural damping = $2\pi\beta$, β = structural damping as a fraction of critical damping to be taken as 0.016, σ = mass density of air to be taken as 1.2 kg/m^3, d = effective diameter taken as average diameter over the top 1/3rd height of chimney in m.

2.2.3 The equivalent mass per unit length in ith mode of vibration (m_{ei}) is calculated by the formula:

$$(5):\ m_{ei} = \frac{\int_0^H m_z \phi^2_{zi}.d_z}{\int_0^H \phi^2_{zi}.d_z}$$

2.3 Gust Factor Method for Calculation of Wind Load

The along wind response of a chimney is also calculated by the gust factor method. The use of the gust factor method requires knowledge of hourly mean wind speed (HMW). Hourly mean wind speed at any height (z) is obtained as per IS 875 (part3) 1987.

The along wind load as per unit height at any height z on a chimney is calculated from the equation, $F_z = F_{zm} + F_{zf}$, where F_{zm} is the wind load in N/m height due to HMW at height z and is given by $F_{zm} = P_z\ C_D\ D_z$, F_{zf} is the wind load in N/m height due to the fluctuating component of wind at height z and is given by:

$$(6):\ F_{zf} = \frac{3(G-1)}{H^2} \times \left(\frac{z}{H}\right) \int_0^H F_{zm}.z.d_z$$

P_z = design pressure at height z, due to HMW is obtained as $0.6\ V^2\ z$ (N/m^2)

G is the gust factor which is calculated from the equation:

$$(7):\ G = 1 + g_f\, r \sqrt{\left\{B + \frac{SE}{\beta}\right\}}$$

where g_f = peak factor defined as the ratio of the expected peak value to RMS value of the fluctuating load:

$$(8):\ g_f = \frac{\sqrt{(2\log_e \nu T)} + 0.577}{\sqrt{(2\log_e \nu T)}}$$

$$(9):\ \nu T = \frac{3600\ f_1}{\left(1 + \frac{B\beta}{SE}\right)^{\frac{1}{2}}}$$

r = twice the turbulence intensity:

$$(10):\ r = 0.622 - 0.178 \log_{10} H$$

B = background factor indicating the slowly varying component of wind load fluctuation:

$$(11):\ B = [1 + (H/265)^{0.63}]^{-0.88}$$

E = a measure of the available energy in the wind at the natural frequency of chimney:

$$(12):\ E = \frac{\left[123 \frac{f_1}{\bar{V}_{10}} \times H^{0.21}\right]}{\left[1 + \left(\frac{330 f_1}{V_{10}}\right)^2 \times H^{0.42}\right]^{0.83}}$$

S = size reduction factor:

$$(13):\ S = \left[1 + 5.78\left(\frac{f_1}{\bar{V}_{10}}\right)^{1.14} H^{0.98}\right]^{-0.88}$$

V_{10} = hourly mean wind speed in m/sec at 10m above ground level = $V_b\ \bar{k}_2$ are as defined in IS 875 (part3):1987.

f_1 = natural frequency of chimney in the first mode of vibration in Hz.

The Shear Force due to wind at any section is calculated by suitably averaging the loads above and below it. The moments are calculated from the sectional forces treating the chimney as a free standing structure.

2.4 Random Response Method for Response of Chimney

Calculation of across wind load is made by first calculating the peak response amplitude at the first mode of vibration.

The top one-third height of chimney is cylindrical that is with no taper. Therefore the modal response at a critical wind speed $V_{cri} = f_1\, d / S_n$, is calculated by the formula.

$$(14):\ \eta_{oi} = \frac{\dfrac{1.25 C_L d \phi H_i}{\Pi^2 S^2{}_n} \times \dfrac{\sigma d^2 \sqrt{\left\{ \sqrt{\dfrac{(\Pi L)}{2}} (\cap + 2) \right\}}}{m_{ei}}}{\left[\dfrac{1}{H} \displaystyle\int_0^H \phi^2{}_{zi} d_z \right]^{\frac{1}{2}} \left(\dfrac{\beta - k_a \sigma d^2}{m_{ei}} \right)^{\frac{1}{2}}}$$

where $\cap$ = equivalent aspect ratio = H/d, C_L = RMS lift coefficient to be taken as 0.12, L = Correlation length in diameters which may be taken as 1.0 in the absence of field data, k_a = aerodynamic damping coefficient to be taken as 0.5.

The sectional shear force (F_{zoi}) and bending moment (M_{zoi}) at any height zo, for the i^{th} mode of vibration, are calculated from the following equations:

$$(15):\ F_{zoi} = 4\,\pi^2\, f_1{}^2\, \eta_{oi} \int_{z0}^{H} m_z \phi_{zi} d_z$$

$$(16):\ M_{zoi} = 4\,\pi^2\, f_1{}^2\, \eta_{oi} \int_{z0}^{H} m_z \phi_{zi} (z - z_0) d_z\,.$$

And seismic analysis of chimney is performed by Response spectrum in STAAD PRO 2007 software in which the chimney is modeled as vertical cantilever structure fixed at the base having varying cross section area, inertia mass along the height. The 220 m height of chimney is divided into 27 elements their masses lumped at their centre of gravity having one degree of freedom. The discretization of chimney is shown in the following figure Response spectrum analysis for the given acceleration response spectra for first five mode shape as shown in the following figure have been considered.

3. Results

Graphs are the presentations of the results obtained by these methods for the 220 m height RCC chimney, different graphs are prepared which show the variations as shown in fig 4 and 5 for different internal forces like bending moment and shear force.

IV. FIGURES AND TABLES

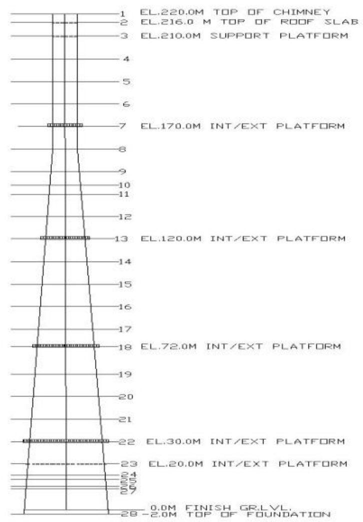

FIGURE: 1 SECTIONAL ELEVATION OF R.C.C CHIMNEY.

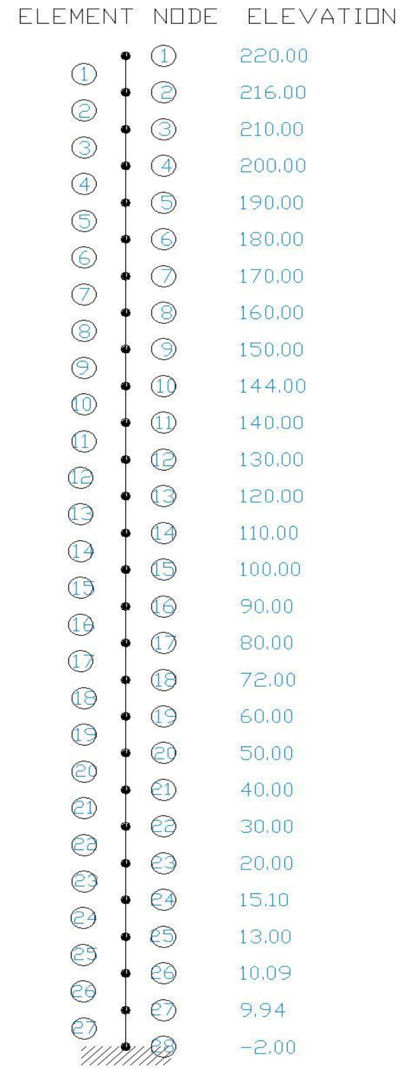

FIGURE: 2 STRUCTURAL IDEALIZATION

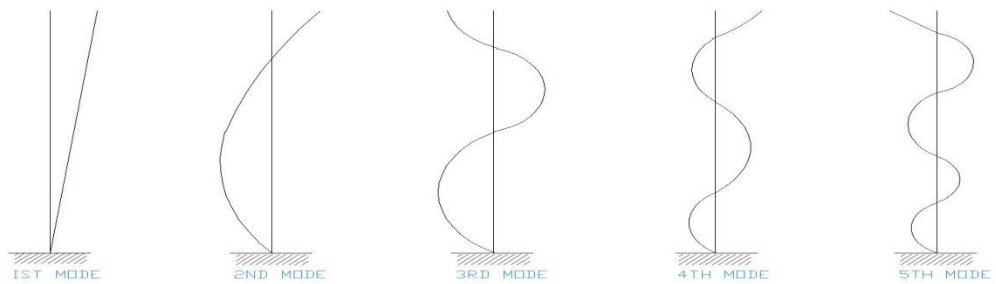

FIGURE: 3 NORMAL MODES OF THE R.C.C CHIMNEY FOR FIXED BASE

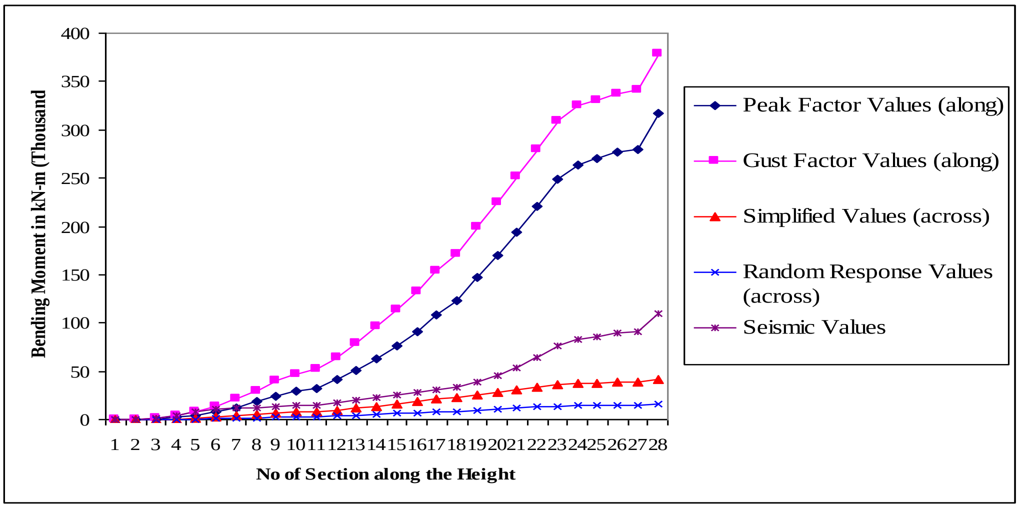

Fig 4: Variation of Bending Moment along the Height of Chimney

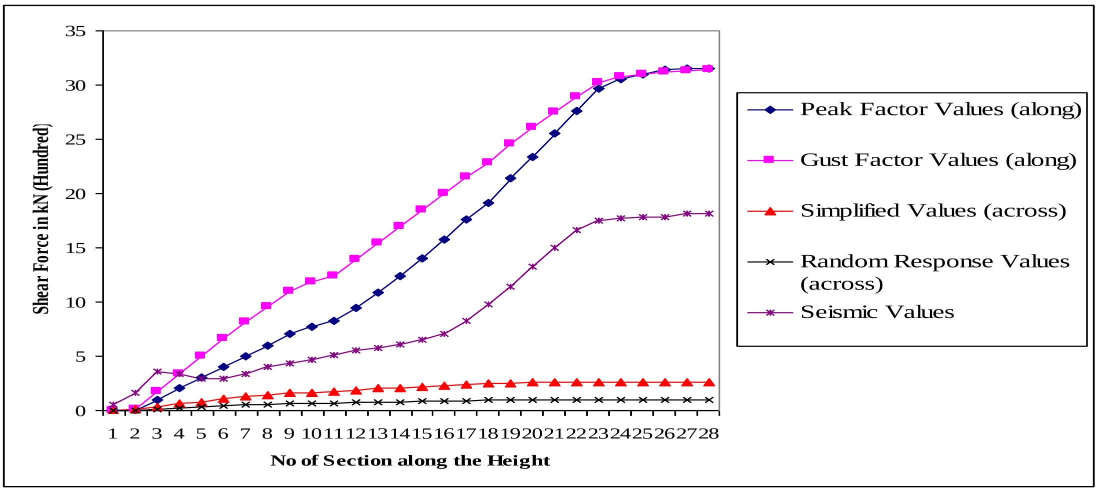

Fig5: Variation of Shear Force along the Height of Chimney

Table. Floor Weight Calculation at Different Platform level

Floor No (1)	Elevation (m) (2)	Diameter (m) (3)	Shell Thickness (m) (4)	Area (m^2) (5)	Deduction for flue (m^2) (6)	Net Floor Area (m^2) (7)=(5)-(6)	Unit wt for floor load calculation kN/m^2 (8)	Floor wt kN (9)=(8)x(7)	Liner wt kN (10)	External Platform kN (11)	Total kN (12)
7	215	6.082	0.275	24	12.5	11.5	9.0	103.5	-	-	104.0
6	210	6.082	0.275	24	12.5	11.5	4.0	46.0	2400.0	-	2450.0
5	170	6.082	0.275	24	12.5	11.5	2.0	23.0	-	100.0	123.0
4	120	9.59	0.339	62.5	12.5	50	2.0	100.0	-	150.0	250.0
3	72	13.54	0.412	127.5	12.5	1.5	2.0	230.0	-	200.0	430.0
2	30	17.483	0.484	214.4	12.5	201.9	2.0	410.0	-	260.0	670.0
1	20	17.921	0.492	225.5	12.5	213	2.0	430.0	-	-	430.0

V. CONCLUSION

The effect of wind forces is quite significant as compare to earthquake forces over 220 m height R.C.C chimney. The geometry of chimney has to be so chosen that the deflection of chimney at the top is within permissible limits. The presence of gust wind over a considerable height of chimney plays important role as the forces obtained by gust factor method are quite high along the sections considered except the top four sections where the forces obtained in seismic analysis are higher. Elsewhere, the effect of earthquake forces seems comparatively lesser along the height of the chimney. The cross wind analysis is taken care of by considering first mode of oscillation as the critical wind speed is well within the design wind speed for the first two modes. Having known this, a given tall reinforced concrete chimney can now be designed for respective wind and seismic forces obviating the need for empirical formulae.

REFERENCES

[1] S. N. Manohar,, *tall chimneys design and construction,* 1985, TATA McGraw – Hill Publishing Company Limited

[2] G. M. Pinfold, *reinforced concrete chimneys and towers,* A view point publication, UK, 1984

[3] I.S 4998 (Part1) – 1992, *Indian Standard Code of Practice for Criteria for Design of Reinforced Concrete Chimneys. Part 1: Assessment of Loads*. (Bureau of Indian Standard, New Delhi)

[4] IS 1893(Part1) – 2002, *Indian Standard Code of Practice for Criteria for Earthquake Resistant Design of Structures. Bureau of Indian Standard*, (New Delhi)

[5] IS 875 (Part3) – 1987, *Indian Standard Code of Practice for Criteria for Design Loads (Other than Earthquake) For Buildings and Structures.* (Bureau of Indian Standard, New Delhi)

[6] K. Suresh Kumar and G. N. V. Rao, Wind Loading over the Top Portions of Tall Stacks with and Without External Landing Platforms, *Journal of Wind Engineering and Industrial Aerodynamics, Vol. 51, Page 319-338, July 1993*

[7] Lawrence C Maugh and Wadi S. Rumman, Dynamic Design of Reinforced Concrete Chimneys, *ACI Journal, Vol. 64, No. 47, Page 560-567, September 1967*

[8] S. R. Joshi, N. S. Pendse, V. T. Patilkakad, Some Special Aspects of the Design and Analysis of Tall Chimneys, *Irrigation and Power Journal, Vol. 42, No. 1, January 1985*

[9] K. S. Babu Narayan, Subhash C. Yarogal, and Yukio Tamura, "Interaction Envelops For Limit State Design of Chimneys", Fourth International Symposium on Computational Wind Engineering, Yokohama, 2006

[10] J. L. Wilson, Code Recommendation for the aseismic Design of Tall Reinforced Concrete Chimneys, *CICIND's Report Australia, Bibao, Vol. 16, No. 2, September 2000*

[11] N. S. Pour, Indrajit Chowdhary, Dynamic Soil – Structure Interaction Analysis of Tall Multi flue Chimneys Under Aerodynamic and Seismic Force, *Twelfth International Conference of IACMAG India, Goa, Page 1-6, October 2008*