SECOND ORDER ANALYSIS OF RCC CHIMNEY FOR DIFFERENT ELEVATION

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Abstract

Chimneys are tall slender structures which fulfill an important function of discharging hot gases over a greater height. Due to this greater height Chimneys are normally designed for critical loads produced by earthquake or wind or its self-weight. In the case of RCC Chimney wind load is more critical than earthquake load because as height of chimney increases the dead load and wind load increases and the earthquake load is negligible as compared to wind load. As the height of chimney increases it is necessary to analyze the second order effect produced due to the self-weight of the structure itself and the wind load acting on it. In this paper equation were developed using beam column theory and Loads considered were combination of wind load and dead load of the structure. Wind load has been calculated as per IS 4998 (Part 1): 1992. Across wind loads have been neglected as it is a part of dynamic analysis.

Keyword: RCC Chimney, Second order analysis, P-Delta analysis, beam-column theory, along wind effect.

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. Tall RC chimneys are commonly used to discharge pollutants at higher elevation. They are typically almost vertical to ensure that the hot gases flow smoothly, drawing air into the combustion through the chimney. Chimneys are tall to increase their draw of air for combustion and to disperse the pollutants in flue gases over a greater area in order to reduce the pollutant concentrations incompliance with regulatory or other limits. 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.

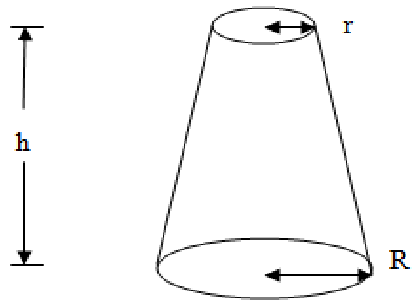
II. VARIOUS FORCES ON CHIMNEYS

The various forces acting on a chimney are as follows

1) Dead load of the chimney itself.
2) Imposed loads
3) Wind loads
4) Earthquake loads
5) Temperature effects

A Dead load

Dead loads shall include the weight of chimney shell, jiners, liner supports, other accessories and load of ash and soot as applicable. Unit weight of the materials shall be taken in accordance with IS 875 (Part1):1987. Dead load with the combination of wind load or earthquake load must be taken into consideration to find the most critical load for the design of chimney. For calculation of Dead load Frustum of cone method is used. A frustum of a cone or truncated cone is a result of cutting a cone by a plane parallel to the base and removing the part containing the apex.



Frustum of a cone

The slant height of the truncated cone is obtained by applying the Pythagorean Theorem for The Shaded triangle

$$s^2 = h^2 + (R - r)^2$$

Volume of Frustum of Cone is given by,

$$V = \frac{\pi h}{3}(R^2 + Rr + r^2)$$

B DESCRIPTION OF LOADING

Details of the parameters are as follows

1. Height of the chimney - 260 m
2. Outer diameter of bottom - 36.6 m
3. Outer diameter at top - 19.6 m
4. Thickness of shell - 0.8 m
5. Grade of concrete - M25
6. Seismic zone - III
7. Basic wind speed - 39 m/sec (for Solapur)
8. Foundation type - RCC circular mat
9. Density of concrete - 25 kN/m^3
10. Design life of structure - 100 years
11. Terrain category - 4
12. Probability factor - 1.06
13. Topography factor - 1
14. Class of structure - Class C

Total volume of Chimney considering thickness

$$V1 = \frac{\pi h}{3}(R^2 + Rr + r^2)$$

$$= \frac{\pi 260}{3}(18.3^2 + 18.3 * 9.8 + 9.8^2)$$

$= 166074.80\ m^3$

Volume of Chimney excluding thickness

$$V_2 = \frac{\pi h}{3}(R'^2 + R'r' + r'^2)$$

$$= \frac{\pi 260}{3}(17.5^2 + 17.5 * 9 + 9^2)$$

$=148244.633\ m^3$

$V = V_1 - V_2$

$=166074.80-148244.633$

$= 17830.17 m^3$

DL = Volume × Density of concrete

=17830.17 x 25

= 445754.25 KN

Table 1 Dead load

Height (m)	Dead Load(kN)
0	445754.4
20	401593.4
40	359077.8
60	318207.6
80	278982.7
100	241453.4
120	205513
140	171217.9
160	138568.2
180	107589
200	78223.68
220	50503.76
240	24429.2
260	0

C Wind load

When wind meets an obstruction, it exerts pressure on the obstruction. The intensity of pressure depends on the wind velocity, which in turn depends upon the elevation above ground. Hence, intensity of wind pressure depends on the height of the chimney. Two methods of estimating the wind load are given in IS code provisions.

1. Simplified Method
2. Random Response Method

For this research work simplified method has been considered for the wind load calculation.

Simplified Method:

Along Wind Load or Drag Force:

The Along wind load or drag force per unit height of the chimney at any level shall be calculated from the equation

$$Fz = Pz\ Cz\ dz$$

Where,

Pz= design wind pressure obtained in accordance with IS 875 (Part 3): 1987.

z= height of any section of the chimney in meter measured from top of foundation.

Cd = drag coefficient of the chimney to be taken as 0.8.

dz= diameter of the chimney at height z in meter.

III. First order analysis

It's the most basic method of analysis, in which the material is modeled as linear elastic and the equilibrium is expressed in terms of the geometry of the unreformed structure. In case of linearly elastic structure, relation between displacement and external force is proportional.

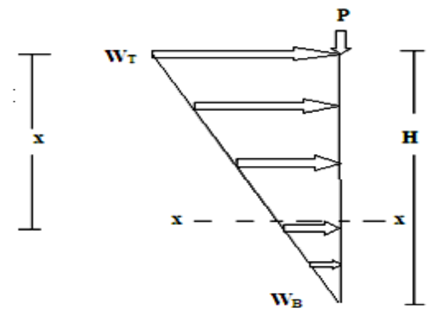
The first order elastic analysis is based on following assumptions:-
1) The material behave linearly and hence all yielding effects can be ignored
2) The members behave linearly, and the member instability effects such as those caused by axial compressions (these are called P-δ effects), which reduces the member's flexural stiffness, can be ignored.
3) The frame also behaves linearly, and the frame instability effects, such as those caused by the moments due to horizontal frame deflections and gravity loads acting on the displaced Structure (these are called P-Δ effects), can be ignored.

IV. SECOND ORDER ANALYSIS

P-Delta is a non-linear (second order) effect that occurs in every structure where elements are subject to axial load and lateral loads. It is a genuine effect that is associated with the magnitude of the applied axial load (P) and a displacement (delta). The magnitude of the P-delta effect is related to the:-
1) Magnitude of axial load P
2) Stiffness/slenderness of the structure as a whole.
3) Slenderness of individual elements.
In first-order analysis, the unknown deformations can be obtained in a simple and direct manner, whereas second-order analysis requires an iterative procedure to obtain the solutions. This is because the deformed geometry of the structure is not known during the formation of the equilibrium and kinematic relationship. Thus, the analysis proceeds in a step-by-step incremental manner, using the deformed geometry of the structure obtained from a preceding cycle of calculation. For most practical case, accurate second–order design forces can be obtained by applying the loads in one or two increments, and only a few iterations are required to converge to an accurate solution.

V. DIFFERENTIAL EQUATION BY USING BEAM COLUMN THEORY

A First Order Analysis of Chimney

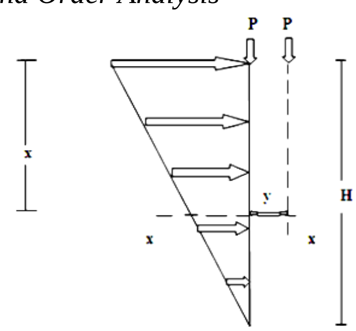


WT = Lateral load intensity at top of chimney
WB= Lateral load intensity at bottom of chimney
H = height of chimney
Wx= Lateral load intensity at general section 'x' on chimney
Take section $x - x$at distance x from *top.*

$$m_x = w_T \times \frac{x^2}{2} - \frac{(w_T - w_B)}{H} \times \frac{x^3}{6}$$

This is the first order equation for bending moment of chimney

B *Second Order Analysis*



WT = Lateral load intensity at top of chimney
WB= Lateral load intensity at bottom of chimney
H = height of chimney
Wx= Lateral load intensity at general section 'x' on chimney
Bending moment at general section x given by

$$Mx = Py - m_x \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Representation of moment curvature equation,

$$EI\,\frac{d^2y}{dx^2} = -\,m$$

y =complementary solution + particular solution

y_c = A$\cos\alpha x$ + B$\sin\alpha x$ and

$y_p = ax^3 + bx^2 + cx = d$

On solving above equation *we get,*

$$y_p = \frac{1}{p}\left[\frac{W_T x^2}{2} - \frac{k_w x^3}{6} - \frac{W_T}{\alpha^2} + \frac{k_w x}{\alpha^2} - \frac{k_w}{\alpha^2}\right]$$

Taking double derivative, we get

$$\frac{d^2y}{dx^2} = -A\,\alpha^2\cos\alpha x - B\,\alpha^2\sin\alpha x + \frac{1}{p}[w_T - k_w x]$$

Using boundary condition $x = 0, \frac{d^2y}{dx^2} = 0$, And when x=H, $\frac{dy}{dx} = 0$ we get

$$A = \frac{W_T}{P\alpha^2} \quad \text{and} \quad B = \frac{\left[\frac{W_T\alpha\sin\alpha H}{P\alpha^2} - \frac{1}{P}\left[\frac{W_T H}{2} - \frac{3H^2 h_{x}}{6} + \frac{h_{x}}{\alpha^2}\right]\right]}{\alpha\cos\alpha H}$$

The deflection equation is given by,

$$y = \frac{W_T}{P\alpha^2}\cos\alpha x + \frac{\left[\frac{W_T\alpha\sin\alpha H}{P\alpha^2} - \frac{1}{P}\left[\frac{W_T H}{2} - \frac{3H^2 h_{x}}{6} + \frac{h_{x}}{\alpha^2}\right]\right]}{\alpha\cos\alpha H}\sin\alpha x + \frac{1}{P}\left[\frac{W_T x^2}{2} - \frac{h_x x^3}{6} - \frac{W_T}{\alpha^2} + \frac{h_x x}{\alpha^2} - \frac{h_x}{\alpha^2}\right]$$

The moment equation is given by,

$$M_x = P\left(\frac{W_T}{P\alpha^2}\cos\alpha x + \frac{\left[\frac{W_T\alpha\sin\alpha H}{P\alpha^2} - \frac{1}{P}\left[\frac{W_T H}{2} - \frac{3H^2 h_{x}}{6} + \frac{h_{x}}{\alpha^2}\right]\right]}{\alpha\cos\alpha H}\sin\alpha x + \frac{1}{P}\left[\frac{W_T x^2}{2} - \frac{h_x x^3}{6} - \frac{W_T}{\alpha^2} + \frac{h_x x}{\alpha^2} - \frac{h_x}{\alpha^2}\right]\right) - W_T \times \frac{x^2}{2} - \frac{(W_T - W_B)}{H} \times \frac{x^3}{6}$$

Table 2 Results by Beam-Column theory

Height (m)	BM 1 (kNm)	BM 2 (kNm)	Y (mm)
0	175969.69	175970.56	0
60	114980.6	116827	16.919
180	21931.69	23042	42.607
240	1019.2	1555.5	48.81
260	0	52.876	49.658

VI. ALONG WIND EFFECT ON VARYING HEIGHT OF CHIMNEY

Following are the along wind effect on varying heights of chimney

A Static or along wind load with or without Aerodynamic Interference

When a cluster of chimney is present aerodynamic interference between them may increase the total wind load. Aerodynamic interference shall be consider for along wind only if the spacing between the center lines of chimney is less than 3 times the effective diameter of the largest chimney.

B *Unsteady force*

a) Periodic vortex shedding

b) Unsteady force caused by atmospheric turbulent

C *Ovalling oscillation*

Because of the relatively small thickness of chimney at the top compared to its diameter possibilities of Ovalling oscillations will have to be examined if the diameter of chimney exceeds 75 times the wall thickness at the top.

D *Buffeting*

The turbulence in the atmosphere around a mean wind speed consisting of fluctuations of large magnitude in velocity can also be a source of large deflection and stresses in chimney this is termed as atmospheric buffeting.

E *Galloping instability*

In all galloping oscillations the amplitude of the response continues to increase with wind speed and this can be highly dangerous.

VII. CONCLUSION

1. A Chimney is vertical cantilever, fixed at base and free at top so that maximum bending moment occurs at base of the chimney. As the section moves upward the bending moment decreases.
2. From table 1 it concludes that the dead load of the chimney decreases as the section moves upward i.e. height of chimney increases dead load decreases and finally zero at the top.
3. From table 2 it concludes deflection is directly proportional to height of chimney.
4. As height of chimney increase from bottom to top the deflection due to loading increases and maximum at the top of chimney.
5. As height increases the effect of second order affects the different parameters like, bending moment and displacement.

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