PARAMETRIC STUDY OF RCC CHIMNEY FOR DIFFERENT LOADING CONDITION

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Abstract : ***A chimney is a means by which waste gases produced due to industrial processes are discharged to the atmosphere. Height of the chimney is kept such that the gases get diluted due to atmospheric turbulence. Chimney is particularly susceptible to the wind pressures so it is important to correctly estimate the design wind loads. It is a vertical cantilevered shell pierced by openings where necessary and subjected to large temperature gradients. The prime focus of the present major project work is to study the behaviour of chimney structure under the effect of wind loads, earthquake loads and temperature gradients. Chimney has been modelled in STAAD.Pro V8i using the lumped mass modelling approach to calculate dynamic properties useful for seismic and wind analysis. BIS has published draft code IS 4998 in April 2013 for design of reinforced concrete chimney. The provisions of the Draft code IS 4998:2013 are studied and compared with the provisions of the Indian Standards IS 4998 (Part - 1) 1992. The effect of temperature gradient and stresses induced on chimney is carried out. Parametric study has also been carried out for an RCC chimney for different geometric variation in chimney.***

IndexTerms - RCC Chimney, Seismic effect, Along and across wind effect, Stresses, Draft code, Stack effect, STAAD.Pro

I. INTRODUCTION

A Chimney is a tall slender structure by means of which the waste gases are discharged into the outside atmosphere at a high enough elevation via stack effect. Chimneys are typically vertical or as near as possible vertical, to ensure that the gases flow smoothly, under the influence of what is known as stack or chimney effect. The space inside the chimney is called a flue. The height of the chimney greatly influences its ability to transfer flue gases to the external environment via stack effect. The function of a chimney is to convey and discharge combustion or flue gases away from the operating area of the industry as well as the human occupancy. The cross-section of the chimney is generally hollow circular, from aerodynamic considerations, and tapered, from considerations of structural economy and aesthetics. The chimney is subject to gust buffeting in the along-wind direction due to drag forces, and also to possible vortex shedding in the across-wind direction. Tall reinforced concrete chimneys form an important component of major industries and power plants. Damage to chimney due to wind or earthquake load may lead to shut down of power plants and important industries.

WORKING PRINCIPLE: Stack effect is the driving force responsible for conveyance and discharge of the flue gases. Stack effect is the movement of air into and out of building, chimneys, flue gas stacks and is driven by buoyancy. Buoyancy occurs due to difference in indoor to outdoor air density resulting from temperature or moisture differences. The result is either a positive or negative buoyancy force. The greater the thermal difference and the height of the structure the greater are the buoyancy force, and thus the stack effect. The combustion flue gases inside the chimney or stacks are much hotter than the ambient outside air and therefore less dense than ambient air. This causes the bottom of the vertical column of hot flue gases to have a lower pressure than the pressure at the bottom of the corresponding column of outside air. The higher pressure outside the chimney is the driving force that moves the required combustion air into the combustion zone and also moves the flue gas up and out of the chimney. The movement of air or flow of combustion air and flue gases is called stack effect.

Figure 1: RCC Chimneys

1.1 Lining in chimney

Early chimneys were unlined. Developments in boiler and fuel technology led to low flue gas temperatures which aggravated the corrosion problem and forced the introduction of protective lining. Initially, self-supporting, acid - resisting brickwork backed by an insulating medium was used as a lining, but soon insulating bricks were introduced in 1950. As a subsequent development, such a lining was supported from corbels of the concrete shell instead of being independent of the shell. However gases penetrating through the brick lining caused corrosion of the concrete shell and to overcome this deficiency. a ventilated air gap was introduced between the lining and concrete shell. At present steel liners are popular because they are impervious to gases and compared to bricks, and permit a higher gas velocity. Important components of an RCC chimney are as follows:

- Flue
- Flue Lining
- Flue ducts and insulation
- Staircase and/or elevators
- Corbel
- Landings and Platforms (internal or external) for inspection and maintenance

1.2 Governing Loads for Chimney Design

As per IS : 4998 the various loads to be taken in to account for design of chimneys shall be as follows:

- Dead loads
- Live loads
- Lateral and circumferential wind loads
- Effect of temperature both vertical and circumferential
- Earthquake loads

1.2.1 Dead Loads

The dead loads to be considered for design mainly comprises of the following:

- Flue ducts
- Lining together with brackets and Insulation
- Staircases and/or Elevators
- Concrete wind shield
- Platforms for inspection and maintenance

1.2.2 Wind Load

The wind load exerted at any point on a chimney can be considered as the sum of quasi-static and dynamic load component. The static load component is that force which wind will exert if it blows at a mean (time-average) steady speed and which will tend to produce a study displacement in a structure. The dynamic component which can cause oscillations of a structure. The effect of wind on these tall structures can be divided into two components, known respectively as Along-wind effect and Across-wind effect.

1.2.2.1 Along Wind Effects

Along-wind effect is due to the direct buffeting action, when the wind acts on the face of a structure. For the purpose of estimation of these loads the chimney is modeled as a cantilever, fixed to the ground. The wind is then modeled to act on the exposed face of the chimney causing predominant moments in the chimney. True evaluation of the along-wind loads involves modeling the concerned chimney as a bluff body having incident turbulent wind flow. However, the mathematical rigor involved in such an analysis is not acceptable to practicing engineers. Hence most codes use an equivalent static procedure known as the gust factor method. This process broadly involves the determining of the wind pressure that acts on the chimney due to the bearing on the face of the chimney, a static wind load. This is then amplified using the gust factor to take care of the dynamic effects. The gust response factor is computed as:

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

gf is the peak factor, defined as the ratio of expected peak value to root mean square value of the fluctuating load, given by:

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

Where

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

Where, v = effective cycling rate

T = sample period taken as 3600s

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

B is the background factor indicating the slowly varying component of wind load fluctuations, given by

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

E is a measure of available energy in the wind at the natural frequency, given by

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

S is the size reduction factor, given by

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

1.2.2.2 Across Wind Effects

Tall body like the chimney is essentially a bluff body as opposed to a streamlines one. The streamlined body causes the oncoming wind flow to go smoothly past it and hence is not exposed to any extra forces. On the other hand the bluff body causes the wind to separate from the body. This separated flow causes high negative regions in the wake region behind the chimney. The wake region is a highly turbulent region that gives rise to high speed eddies called vortices. These discrete vortices are shed alternately giving rise to lift forces that act in a direction perpendicular to the incident wind direction. These lift forces cause the chimney to oscillate in a direction perpendicular to the wind flow**.**

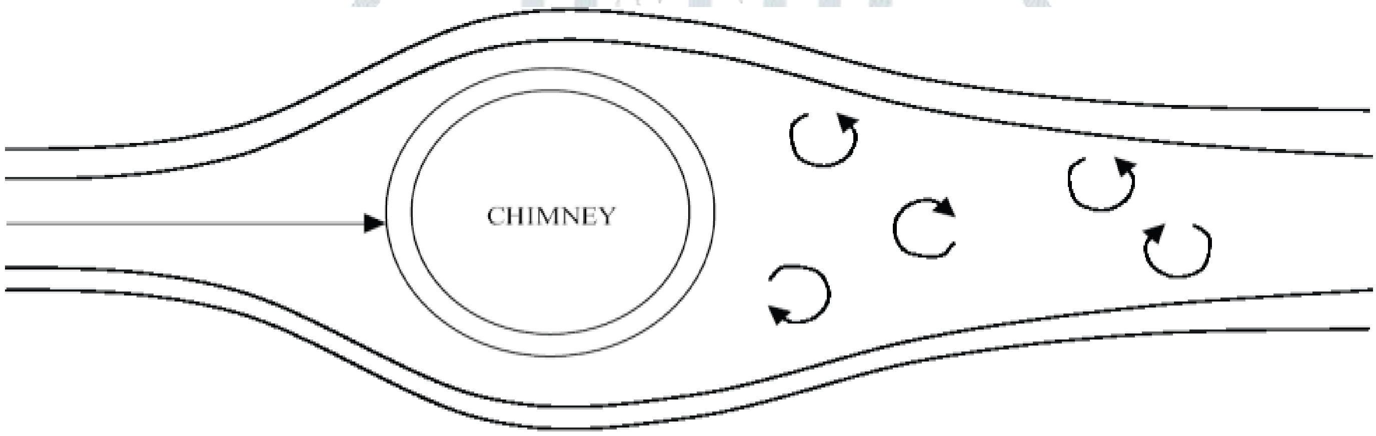


Figure 2: across wind effects

1.2.2.3 Dynamic Effects and the Gust Factor

All along-wind loads that act on the chimney are not due to the static wing bearing on the surface of the chimney alone. There is a significant change in the applied load due to the inherent fluctuations in the strength of wind that acts on the chimney. It is not possible of feasible to take the maximum load that can ever occur due to wind loads and design the chimney for the same. At the same time it is very difficult to quantify the dynamic effect of the load that is incident on the chimney. Such a process would be very tedious and time consuming. Most of the codes make use of the gust factor to account for this dynamic loading. To simplify the incident load due to the mean wind is calculated and the result is amplified by means of a gust factor to take care of the dynamic nature of the loading.

1.2.2.4 Vortex Shedding

The phenomena of alternately shedding the vortices formed in the wake region are called vortex shedding. This is the phenomena that give rise to the across-wind forces. This phenomenon was reported by Strouhal, who showed that shedding from a circular cylinder in a laminar flow is describable in terms a non-dimensional number Sn called the Strouhal number. The phenomena of vortex shedding and hence the across-wind loads depends on a number of factors including wind velocity, taper factors etc., that are specified by the codes. Codal estimation of the across-wind loads also involves the estimation of the mode-shape of the chimney in various modes of vibration.

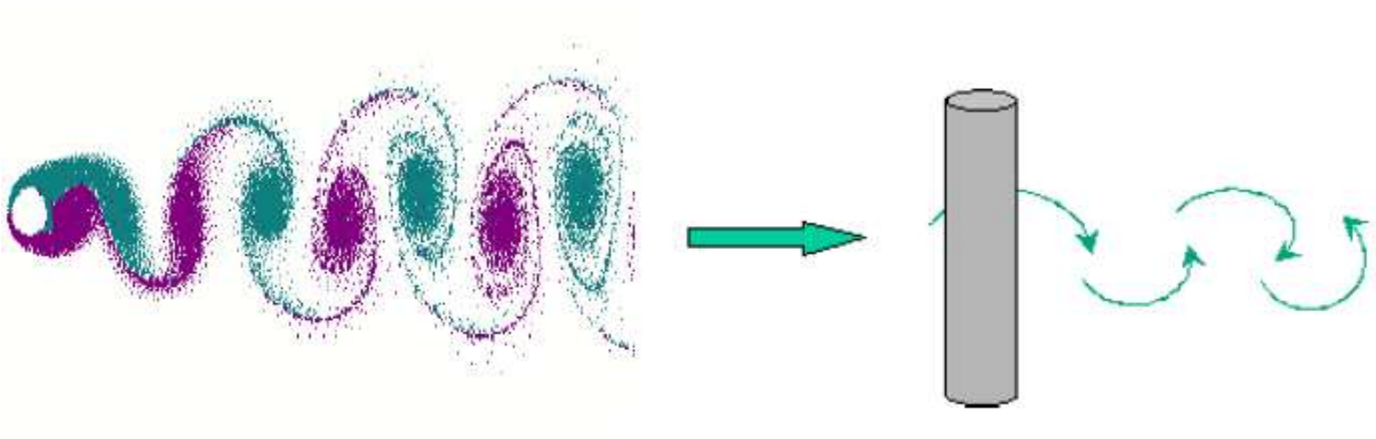


Figure 3: vortex shedding effect on chimney

1.2.2.5 Earthquake Load

Chimneys are particularly vulnerable to earthquake because they are tall slender structure. Therefore, such structure to very carefully designed to safely withstand the force likely to be imposed on them by ground motion. An earthquake resistant design essentially analysis of evaluating the structural response to an assumed likely ground motion and then calculation the corresponding shear force and bending moment which the structure need to safely resist. The characteristics of a likely ground motion depend on source mechanism, properties of the surface media transmitting seismic waves, reverberations in local layered geology and many other factor. Such excitation is random in nature which leads one to adopt design methods based on probability concepts and risk theories. Chimney vibration is essentially a dynamic problem of a transient nature for analysis, a chimney is treated as a cantilever beam with predominant flexural deformation and is analyses by one of the methods: Response spectrum method (First mode), Modal analysis technique (using response spectrum) and Time history response analysis.

1.2.2.6 Temperature Effects

Chimney structures are vertical cantilevered shells pierced by openings where necessary and subjected to large temperature gradients. The principle specialized problems concerning chimneys arise from the thermal and corrosive effects of the elevated temperatures and differential temperature movements between concrete and the insulating materials. High temperature flue gases give rise to insulation and movement problems, while low temperature gases induces difficulties due to acid condensation. These effects necessitate the protection of the concrete from elevated temperatures and differential temperature movements between concrete and the insulating materials. Temperature gradient induced vertical and circumferential stresses can be determined after establishing the magnitude of the thermal gradient.

II. ANALYSIS OF RCC SHELL

Details of the R.C.C. chimney are as follows:

1. Height of chimney above G.L. (H) = 90 m
2. Inside diameter of lining = 2.5 m
3. Velocity of flue gas exit = 20 m/s
4. Temperature of flue gas = 150 °C
5. Ambient temperature = 3 °C
6. Terrain category = 3
7. K2 = 1
8. Design life of chimney = 50 years
9. Number of boiler opening = (a)1 no. each 1.4 m wide at 8 m level (b) 1 no. 0.9 m wide at 0.0 m level for access
10. Number of R.C.C. platform full 360° = 3
11. Location = Lucknow
12. No. of proximity of other chimney= NO
13. Concrete grade = 25 N/mm²
14. Reinforcement grade = 500 N/mm²
15. Inner top diameter = 5.55 m
16. Thickness of lining = 0.115 m
17. Insulating material (mineral wool) = 0.05 m
18. GI flat = 0.01 m
19. Air gap = 0.1 m
20. Thickness of concrete shell at top = 0.2 m
21. Shell outer top diameter = 5.95 m
22. Inner bottom diameter = 5.55 m
23. Thickness of concrete shell at bottom = 0.3 m
24. Outer bottom dia. = 6.15 m
25. Approximate self weight of chimney P = 12399.1 kN
26. A = 5.5107 m²
27. P/A = 2250 kN/m²
28. Vb = 47 m/s
29. k1 = 1
30. k2 = 1
31. k3= = 1

32. Vz = Vb x k1 x k2 x k3 = 47 m/s
33. pz=0.6Vz² = 1.33 kN/m²
34. Wind load as UDL = 7.356 kN/m
35. Permissible stress in concrete=0.38*fck = 9500 kN/m²

III. PARAMETRIC STUDY

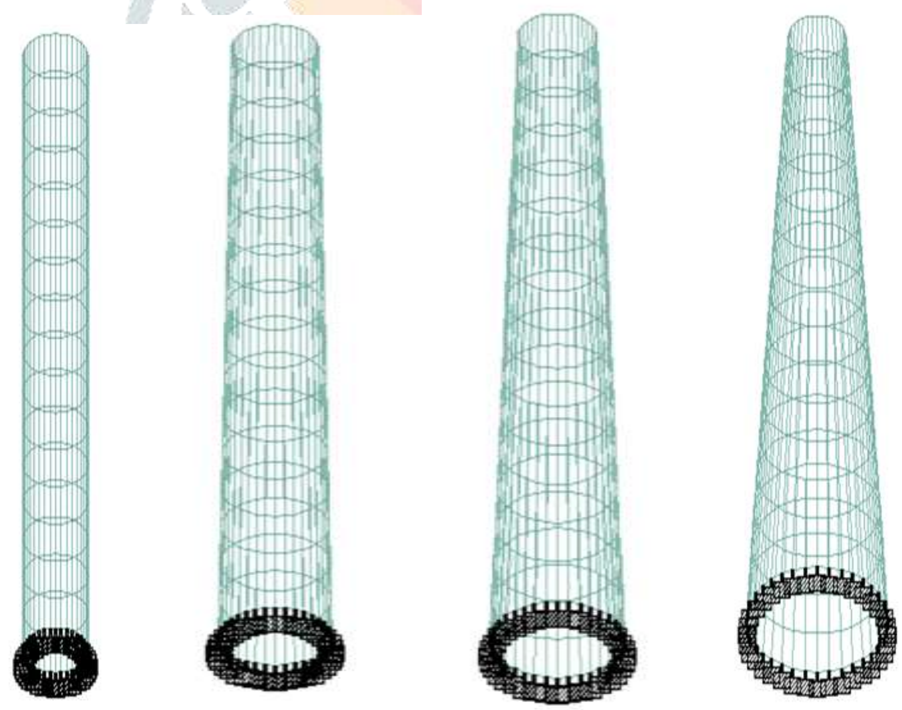
Chimneys are type of slender structure have different associated problems and therefore be treated separately from other forms of tower structures. Industrial structures present many unique problems compounded by their challenging environments. Prediction of the structural safety of these chimneys during strong winds requires the assessment of various uncertainties in the design procedure and then the calculation of the probability of failure. As chimneys are in majority of structure special codes are designed for design of chimneys. Designing of concrete chimney of basis of only codal provision does not suffice with the requirement. The chimney would behave different manner when they are changing the geometry for that two type of geometry is considered for the parametric study.

Case-I Tapered Chimney with Fixed Height and Different Slope

Height of chimney and slope of chimney are important parameters for tapered chimney. So that height ranging from 92.5 m to 160 m is considered when as for slope 1:20 to 1:90 are considered. The detailed typical geometry of 92.5 m heighted tapered chimney for all slopes is shown in table.

Table 1 : Detail properties of 92.5 m heighted tapered chimney

Height (m)	Taper Ratio	Outer Diameter		Inner Diameter		Thickness Of Shell (m)
		Top (m)	Bottom (m)	Top (m)	Bottom (m)	
92.5	1:20	5.95	14.40	5.55	14.00	0.2
92.5	1:30	5.95	12.40	5.55	12.00	0.2
92.5	1:35	5.95	11.20	5.55	10.80	0.2
92.5	1:40	5.95	10.40	5.55	10.10	0.2
92.5	1:45	5.95	10.10	5.55	9.70	0.2
92.5	1:50	5.95	9.85	5.55	9.45	0.2
92.5	1:60	5.95	9.00	5.55	8.60	0.2
92.5	1:70	5.95	8.50	5.55	8.10	0.2
92.5	1:85	5.95	8.10	5.55	7.70	0.2
92.5	1:90	5.95	7.90	5.55	7.50	0.2



Cylindrical Slope 1:90 Slope 1:45 Slope 1:20

Figure 4: Transformation of chimney from cylindrical to taper

Case-II Tapered Chimney+Prismetic Chimney with Same Height and Different Tapered Percentage

Height of chimney and tapered slope provided from base of the chimney are important parameters for tapered+prismetic chimney. So that height ranging from 92.5 m to 160 m is considered when as for tapered slope provided from base of chimney upto height ranging from 50% to 75% are considered. The detailed typical geometry of 92.5 m heighted tapered+prismetic chimney for all tapered slopes is shown in table.

Table 2 : Detail properties of 92.5 m tapered+prismetic chimney

Height (m)	Taper Height From Bottom (m)	Taper Height From Bottom (%)	Centre diameter at taper chimney		Centre diameter at top of the chimney (m)	Thickness of shell (m)
			Top (m)	Bottom (m)		
92.5	46.25	50	5.95	10.60	5.95	0.2
92.5	55.5	60	5.95	11.35	5.95	0.2
92.5	60.125	65	5.95	11.70	5.95	0.2
92.5	64.75	70	5.95	12.00	5.95	0.2
92.5	69.375	75	5.95	12.40	5.95	0.2

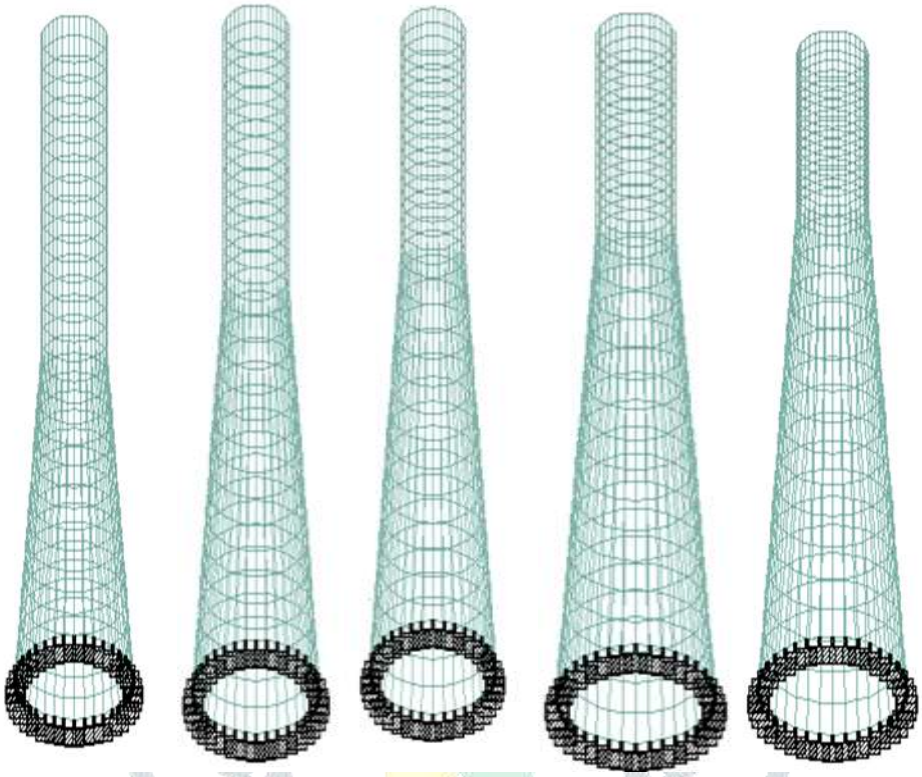


Figure 5: Tapered slope increased from base of chimney for tapered+prismatic chimney

IV. RESULTS AND DISCUSSION

Case-I Tapered Chimney with Fixed Height and Different Slope

Tapered chimney having a slope of 1:20, 1:30, 1:35, 1:40 to 1:90 was analysed in the STAAD.Pro V8i software. The summary of base reaction in term of base shear (FX) and moment (MY) for all slopes are shown in Charts:

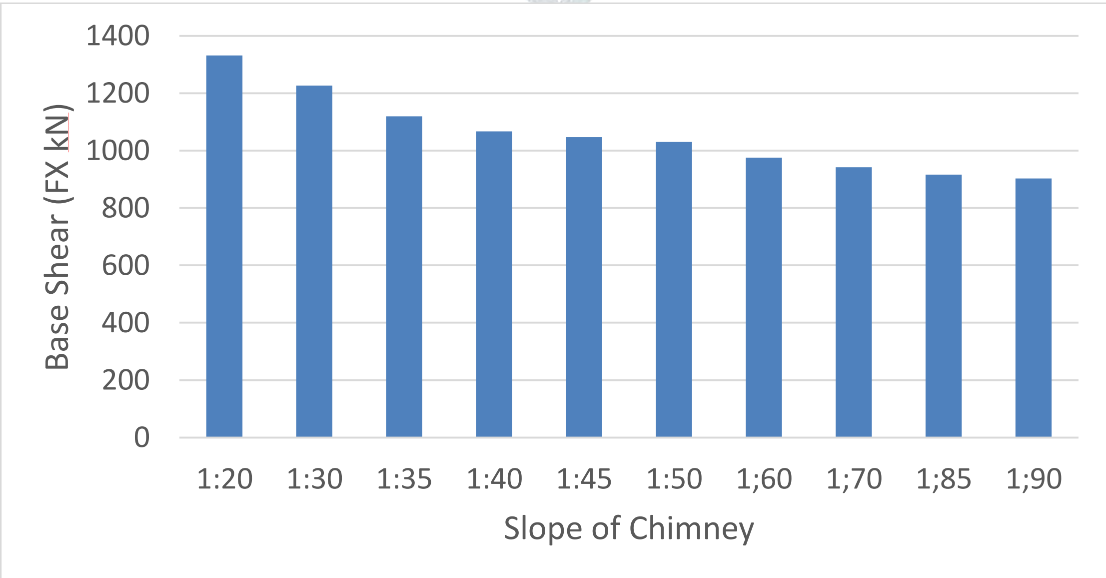


Chart 1: Base shear (FX) for 92.5 m tapered chimney

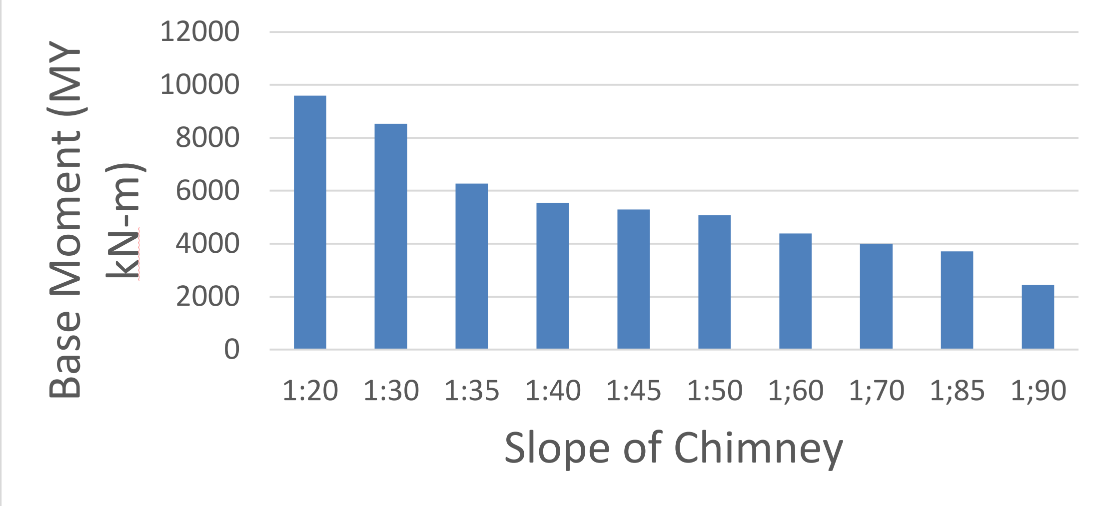


Chart 2: Base moment (MY) for 92.5 m tapered chimney

The results of global force at base shows that for a particular height when the slope of chimney changing from 1:20 to 1:90 the base shear (FX) and moment (MY) reduced. Also observed that for the slope of 1:20, 1:30 and 1:35 the reduction of base shear (FX) and moment (MY) is high but from slope 1:40 to 1:90 there is no significant difference in values.

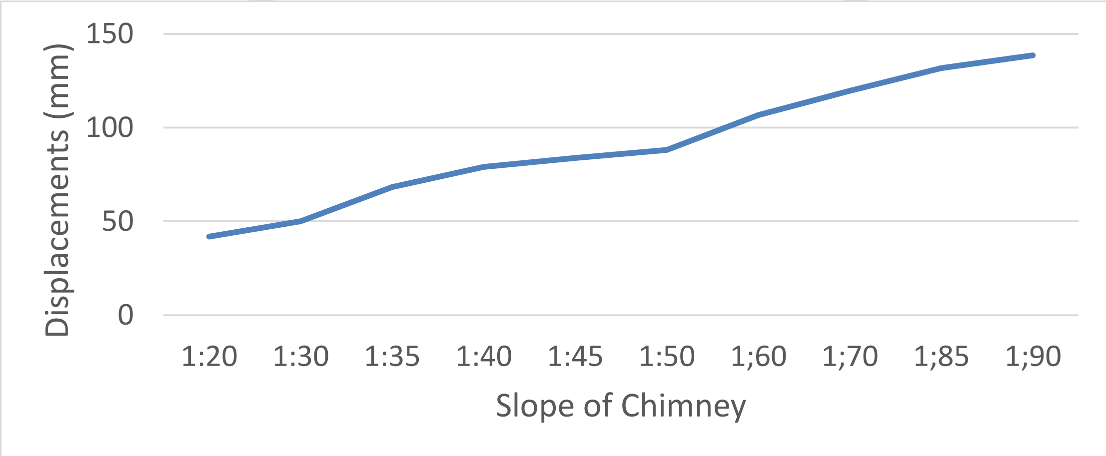


Chart 3: Displacements of 92.5 m tapered chimney

The displacement of chimney is shown in figure. It is observed that when the slopes change from 1:20 to 1:90 the displacement of chimney increases because geometry of chimney is converted from tapered to cylindrical.

Case-II Tapered Chimney+Prismetic Chimney with Same Height and Different Tapered Percentage

Geometry of chimney in this case is taken as tapered + prismatic. To create this geometry in chimney height up to 50%, 60%, 65%, 70% and 75% from the bottom is provide as a taper shape with slope of 1:50 and remaining height is provided as cylindrical. The results of base reaction in term of base shear (FX) and moment (MY) for all taper slopes are shown in figure. The results shows that when the chimney is transformed from cylindrical to taper like 50% to 75% tapered shape the base shear (FX) and moment (MY) increases because chimney is converted into conical shape and it attracts more force than cylindrical shape.

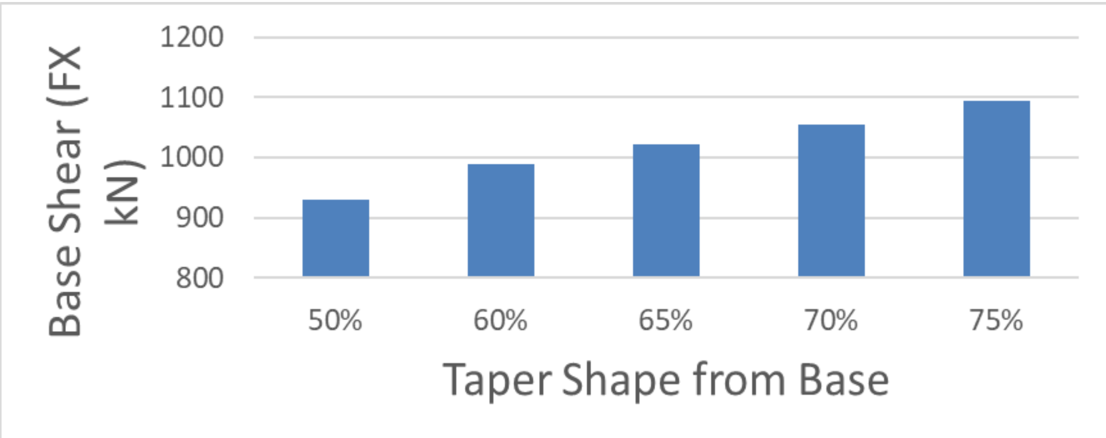


Chart 4: Base shear (FX) for 92.5 m Tapered + Prismatic Chimney

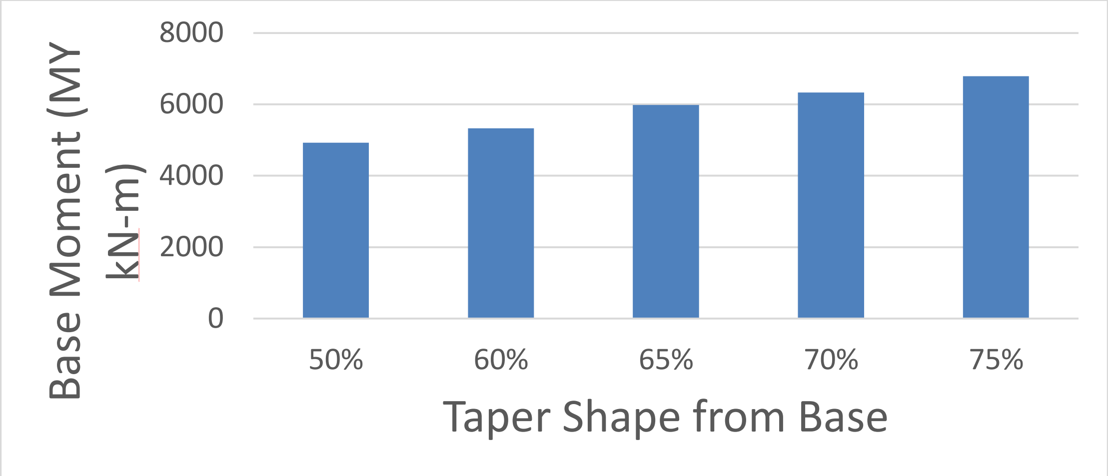


Chart 5: Base Moment (MY) for 92.5 m Tapered + Prismatic Chimney

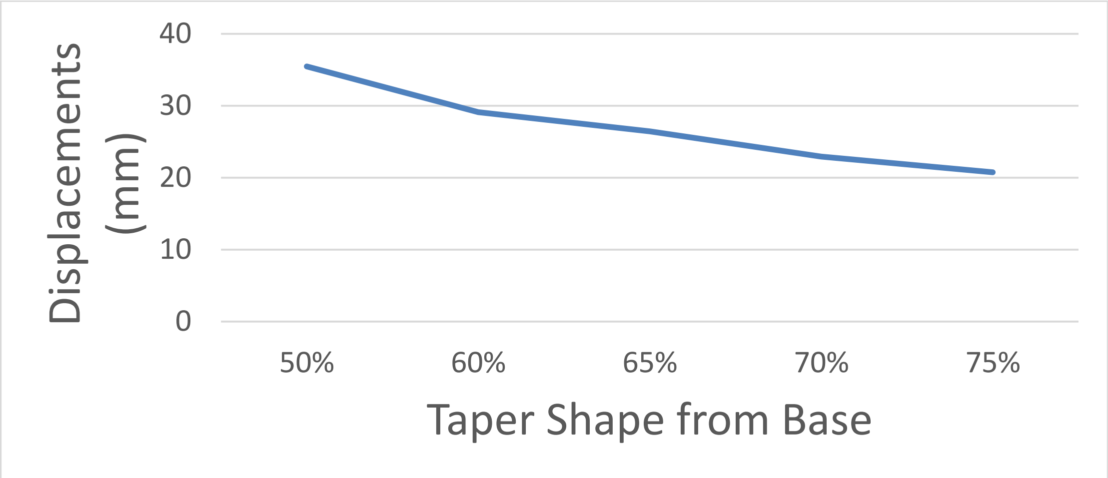


Chart 6: Displacements for 92.5 m Tapered + Prismatic Chimney

V. CONCLUSION

- Along wind Random Response method results are around 30% to 50% higher than results obtain by across wind simplified method.
- Along wind moments computed by random response method are higher in top portion of the chimney up to a certain height.
- Based on the observation of response of concrete chimney structure due to varying geometrical parameters the following concluding remarks have been arrived as:
- For the case of tapered chimney when the slope of chimney is changed from 1:20 to 1:90 the base shear and moment is reduced. The reduction in significant of base shear (6 to 10 %) and moment (15 to 18 %) for slopes ranging from 1:20 to 1:50. further change in slope from 1:50 to 1:90 does not result in any major reduction (1 to 3%).
- For the case of tapered chimney when the slope of chimney increased from 1:20 to 1:90 the principal stresses and lateral forces are increased. The reduction in significant of principal stresses (15 to 17%) at the base of structure for slopes ranging from 1:20 to 1:50. further change in slope from 1:50 to 1:90 does not result in any major reduction (2 to 4%). Because as slopes changing from 1:50 to1:90 the geometry of chimney transforms in taper to cylindrical.
- In case of tapered+prismatic transformed from cylindrical to more in taper like 50% to 75% taper shape the base reaction (FX) and moment (MY) increases but there is no significant difference.
- Displacement, principal stresses and lateral pressure are decreasing significantly (22 to 24%) when taper slope from 50% to 60%, then the decrement in displacement, principal stresses and lateral pressure are comparatively less for the taper slope 60% to 75% at the base of structure.
- The principal stress increase at the point where the chimney is transformed from tapered to cylindrical due to stress concentration at the transformation point.
- The displacement, principal stresses and lateral pressure are significantly less in tapered chimney slope of 1:50 than the tapered+prismatic chimney tapered slope upto 50%.

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