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Analysis of Cantilever Steel Chimney As Per Indian Standards

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ABSTRACT
Chimneys are tall and slender structures which are used to discharge waste/flue gases at higher elevation with sufficient exit velocity such that the gases and suspended solids(ash) are dispersed in to the atmosphere over a defined spread such that their concentration , on reaching the ground is within acceptable limits specified by pollution control regulatory authorities. This paper summarizes the analysis and design concepts of chimneys as per Indian codal provisions incorporation was also made through finite element analysis. Effect of inspection manhole on the behavior of Cantilever steel chimney, two chimney models one with the manhole and other without manhole were taken into consideration. These models are analyzed by finite element software STAAD Pro, emphasis also placed on effect of geometric limitations on the design aspects in designing chimney.

I. INTRODUCTION

Chimneys or stacks are very important industrial structures for emission of poisonous gases to a higher elevation such that the gases do not contaminate surrounding atmosphere. These structures are tall, slender and generally with circular cross-sections. Different construction materials, such as concrete, steel or masonry, are used to build chimneys. Steel chimneys are ideally suited for process work where a short heat-up period and low thermal capacity are required. Also, steel chimneys are economical for height up to 45m. Fig. 1.1 shows a cantilever steel chimneys located in an industrial plant.

Fig. 1.1: Cantilever Steel Chimney

Two important IS-6533: 1989 recommended geometry limitations for designing Cantilever steel chimneys are as follows:

i. Minimum outside diameter of the unlined chimney at the top should be one twentieth of the height of the cylindrical portion of the chimney.

ii. Minimum outside diameter of the unlined flared chimney at the base should be 1.6 times the outside diameter of the chimney at top.

Present study attempts to justify these limitations imposed by the deign codes through finite element analyses of steel chimneys with various geometrical configurations.

1.1. Objectives

Based on the literature review presented in the previous section the objective of the present study is defined as follows:

- To formulate the base moment of the steel chimney as a function of top-to-base diameter ratio.
- To predict the variation of bending stress as a function of geometry of steel chimney.
- To assess the geometry limitations imposed by IS 6533:1989 in the design of Cantilever steel chimney.

II. LOAD EFFECTS OF STEEL CHIMNEY

2.1 Overview

Cantilever steel chimneys experience various loads in vertical and lateral directions. Important loads that a steel chimney often experiences are wind loads, earthquake loads, and temperature loads apart from self weight, loads from the attachments, imposed loads on the service platforms. Wind effects on chimney plays an important role on its safety as steel chimneys are generally very tall structures. The circular cross section of the chimney subjects to aerodynamic lift under wind load.

Again seismic load is a major consideration for chimney as it is considered as natural load. This load is normally dynamic in nature. According to code provision quasi-static methods are used for evaluation of this load and recommend amplification of the normalized response of the chimney with a factor that depending on the soil and intensity of earthquake. In majority of the cases flue gases with very high temperature released inside a chimney. Due to this a temperature gradient with respect to ambient temperature outside is developed and hence caused for stresses in the cell. Therefore, temperature effects are also important factor to be considered in the steel design of chimney.

This section describes the wind load and seismic load effects on cantilever steel chimney.

2.2 Wind engineering

For self-supporting steel chimney, wind is considered as major source of loads. This load can be divided into two components respectively such as,

- Along - wind effect.
- Across - wind effect.

The wind load exerted at any point on a chimney can be considered as the sum of quasi-static and a 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 steady displacement in a structure. The dynamic component, which can cause oscillations of a structure, is generated due to the following reasons:

- Gust
- Vortex shedding
- Buffeting

2.3 Along Wind Effects

Along wind effects are happened by the drag component of the wind force on the chimney. When wind flows on the face of the structure, a direct buffeting action is produced. To estimate such type of loads it is required to model the chimney as a cantilever, fixed to the ground. In this model the wind load is acting on the exposed face of the chimney to create predominant moments. But there is a problem that wind does not blow at a fixed rate always. So the corresponding loads should be dynamic in nature. For evaluation of along wind loads the chimney is modeled as bluff body with turbulent wind flow. In many codes including IS: 6533: 1989, equivalent static method is used for estimating these loads. In this procedure the wind pressure is determined which acts on the face of the chimney as a static wind load. Then it is amplified using gust factor to calculate the dynamic effects.

2.4 Across wind effects

Across wind effect is not fully solved and it is required a considerable research work on it. For design of Cantilever steel chimney, Indian standard remain silent about it. But it is mentioned in IS 4998 (part 1): 1992 and ACI 307-95 which is applicable for concrete chimney only. Also CICIND code does not mention this effects and depends on IS 4998 (part 1): 1992 and ACI 307-95.

Generally chimney-like tall structures are considered as bluff body and oppose to a streamlines one. When the streamlined body causes the oncoming wind flow, the bluff body causes the wind to separate from the body. Due to this a negative regions are formed in the wake region behind the chimney. This wake region produces highly turbulent region and forms high speed eddies called vortices. These vortices alternatively forms lift forces and it acts in a direction perpendicular to the incident wind direction. Chimney oscillates in a direct ion perpendicular to the wind flow due to this lift forces.

2.5 Wind Load Calculation

According to IS 875 (part 3):1987 basic wind speed can be calculated,

$$V_z = V_b K_1 K_2 K_3$$

Where , V_z= design wind speed at any height z m/s
K_1= probability factor (risk coefficient)
K_2= terrain, height and structure size factor
K_3= topography factor

2.6 Static Wind Effects

A static force called as drag force, obstructs an air stream on a bluff body like chimney. The distribution of wind pressure depends upon the shape and direction of wind incidence. Due to this a circumferential bending occurs and it is more significant for larger diameter chimney. Also drag force creates along-wind shear forces and bending moments.

2.6.1 Drag

The drag force on a single stationary bluff body is,

$$F_d=0.5\ C_d\ A\ \rho_a\ \bar{U}_2$$

Where F_d = drag force, N
C_d = Drag coefficient
A = area of section normal to wind direction, m^2

The value of drag coefficient depends on Reynolds number, shape and aspect ratio of a structure.

2.6.2 Circumferential bending

The radial distribution of wind pressure on horizontal section depends on R_e. normally the resultant force of along wind is counteracted by shear force s which is induced in the structure. These shear forces are assumed to vary sinusoidal along the circumference of the chimney cell.

2.6.3 Wind load on liners

In both single-flue and multi-flue chimneys metal liners are being used but these are not directly contact or exposed to wind. But they are designed for wind loads which are transmitted through the chimney cell. The magnitude of the force can be estimated by considering the liner as a beam of varying moment of inertia, acted upon by a transverse load at the top and deflection is calculated at the top of the cell.

2.7 Dynamic-wind effects

Wind load is a combination of steady and a fluctuating component. Due to turbulence effect the wind load varies in its magnitude.

2.7.1 Gust loading

Due to fluctuations wind load is random in nature. This load can be expressed as

$F(t) = K (\bar{U} + \rho_u)^2 = K (\bar{U}^2 + 2 \bar{U} \rho_u)$, for small values of ρ_u

Where $K=0.5 C_d A \rho_a$

In the above expression ($K \bar{U}^2$) is quassi-static and $\bar{U}$ is the mean velocity.

2.7.2 Aerodynamic Effects

In wind engineering there is a term called “aerodynamic admittance coefficient” which depends on spatial characteristics of wind turbulence. Spatial characteristics relates to structure’s response to wind load, at any frequency. This coefficient is expressed as;

This method has various advantages following are.

$$A_n = \frac{1}{\left(1+ \frac{BHn}{3\bar{U}_t} \right) \left(1+ \frac{10nD_{co}}{\bar{U}_t} \right)}$$

Where

A_n = aerodynamic admittance at the structure’s natural frequency n, Hz

$\bar{U}_t$ = mean wind speed at top of a chimney, m/s

Always this coefficient has to be multiplied with response of a structure due to wind loads because it allows response modification due to spatial wind-turbulence characteristics.

2.7.3 Vortex formation

When wind flows through a circular cross section like chimney vortices are formed. These vortices cause a pressure drop across the chimney at regular pressure intervals. Due to this change in pressure, a lateral force perpendicular to wind direction is created. It depends on Reynolds's number which has a range such as sub-critical ($R_e < 3\times10^5$), ultra-critical ($R_e > 3\times10^5$) and super-critical (3×10^5 to 3×10^6).

2.7.4. Vortex excitation

The alternate shedding of vertices creates a transverse forces called as lift. According to practical design purpose it is divided into two forms, such as

(i) In sub-critical and ultra-critical Re range

The frequency of lift force is regular, but magnitude is random. When frequency of vortex shedding is close to natural frequency of a chimney (when its motion is near sinusoidal), maximum response is obtained. The exciting force should be taken as,

$$F_L = 0.5 \rho_a A \bar{U}^2 \sin \omega_t C_L$$

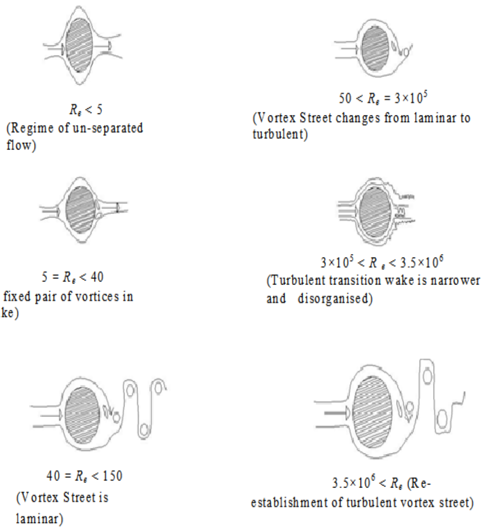
The response of the structure depends on the time-average energy input from the vortex shedding forces. In the expression C_l has the time-average value rms value of the lifting force coefficient with a range of frequencies close to the natural frequency ω_o of the structure.

(ii) In super-critical R_e range

In this range both frequency and magnitude are random in nature. Here structure’s response depends on the power input. If we plot power –input density function S_l' (St) against non-dimensional frequency St, then the power spectrum of the lift-force should be expressed as,

$$S_l = \{ 0.5 \rho_a A \bar{U}^2 \sqrt{C_L^2} \} S_l' (S_t)$$

According to the (IS-6533 part-2:1989), if period of natural oscillation for the cantilever steel chimney exceeds 0.25 seconds, the design wind load take into consideration the dynamic effect due to pulsation of thrust caused by the wind velocity in addition to the static wind load. It depends on the fundamental period of vibration of the chimney.



$R_e < 5$ (Regime of un-separated flow)

$50 < R_e = 3\times10^5$ (Vortex Street changes from laminar to turbulent)

$5 = R_e < 40$ (A fixed pair of vortices in wake)

$3\times10^5 < R_e < 3.5\times10^6$ (Turbulent transition wake is narrower and disorganised)

$40 = R_e < 150$ (Vortex Street is laminar)

$3.5\times10^6 < R_e$ (Re-establishment of turbulent vortex street)

Fig. 3.1 Regimes of fluid flow across circular cylinders

2.8 Seismic Effects

Due to seismic action, an additional load is acted on the chimney. It is considered as vulnerable because chimney is tall and slender structure. Seismic force is estimated as cyclic in nature for a short period of time. When chimney subjected to cyclic loading, the friction with air, friction between the particles which construct the structure, friction at the junctions of structural elements, yielding of the structural elements decrease the amplitude of motion of a vibrating structure and reduce to normal with corresponding to time. When this friction fully dissipates the structural energy during its motion, the structure is called critically damped.

2.8.1. Response-spectrum method

$$T= \quad C_t \quad \mathrm{SQRT} \left[\frac{W_t h}{E_S A g} \right]$$

Where

C_t = coefficient depending on slenderness ratio of the structure

W_t= total weight of the structure including weight of lining and contents above the base,

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

h = height of the structure above the base

E_s= modulus of elasticity of material of the structural shell

g = acceleration due to gravity

2.8.2. Horizontal seismic force

$$Ah= \frac{Z\ I\ Sa}{2\ R\ g}$$

Where

Z= zone factor

I= importance factor

R= response reduction factor. The ratio shall not be less than 1.0

$S_{a/g}$= spectral acceleration coefficient for rock and soil sites

2.9 Temperature Effects

The shell of the chimney should withstand the effects of thermal gradient. Due to thermal gradient vertical and circumferential stress are developed and this values estimated by the magnitude of the thermal gradient under steady state condition.

III. DESIGN OF STEEL CHIMNEY

This section presents procedures to design self-supported steel chimney as per Indian Standard IS 6533 (Part 1 & 2):1989 through an example calculation. A typical chimney to be located at coastal Odisha for an exit flue discharge of 100000 m^3/s is taken for the example. The chimney is first designed for static wind load and then the design is checked against dynamic wind load, possible resonance and seismic load.

3.1 Introduction

The design of steel chimney can be done as two types:

- Cantilever steel chimneys
- Guyed steel chimneys
- stayed chimney (on a supporting column)
- Bracketed chimney (on a nearby building).

There are also several types of Cantilever chimney

- bare steel shell
- double-skin chimneys in which the steel is internally covered with a liner
- Multi-flue chimneys in which the steel shell contains several liners.

3.2 Design Aspects of Steel Chimney

The design aspects of steel chimney consists of two aspects, they are;

3.2.1. Mechanical aspects

This part covers design, construction maintenance and inspection of steel stacks. This also includes lining materials, draft calculations, consideration for dispersion of pollutants into atmosphere and ash disposal.

3.2.2 Structural aspects

It covers loadings, load combinations, materials of construction, inspection, maintenance and painting of both Cantilever and guyed steel stacks (with or without lining) and their supporting structures.

3.3 Applicable Codes for Design

Various national and international codes and guidelines are available for designing the chimneys, they are.

3.3.1. IS 875 (Part-3):1987

Code of practice for design loads other than earthquake for buildings and structures (wind loads). This Indian standard IS: 875 (Part-3) was adopted by bureau of Indian Standards after the draft finalized by the structural safety sectional committee had been approved by the civil engineering division council. This part covers

a. Wind loads to be considered when designing buildings, structures and components.
b. It gives the basic wind speeds for various locations in India.
c. Factors to be considered while estimating the design wind speed/pressure.

3.3.2 IS 6533 (Part-1): 1989

Indian standard design and construction of steel stacks-code of practice (Mechanical aspects).

This includes

a. Determination of inside diameter.
b. Determination of stack height based on pollution norms and dispersion of gases into the atmosphere.
c. Estimation of draft losses.
d. General requirements for materials of construction, insulation, lining and cladding.

3.3.3 IS 6533 (Part-2): 1989

This is Indian Standard Code of practice for design and construction of steel chimneys (structural aspect). This includes

a. Material of construction for bolts, plates, rivets and welding
b. Loadings and load combinations
c. General design aspects covering minimum thickness of shell. Allowable stresses, allowable deflection, determination of dynamic force and checking for resonance.

Typical ladder details, painters trolley, location of warning lamps and the flue opening details, inspection, maintenance and protective coatings.

3.4 Design Methodology

IS:6533 (Part-1 & 2): 1989, IS 875 (Part-3 & 4): 1987, and IS 1893 (Part-4):2005 will be used as the basis for design, which gives detailed procedure to determine static, dynamic and seismic loads coming on the structure.

3.4.1 Assumptions

Following assumptions are made

1. The wind pressure varies with the height. It is zero at the ground and increase as the height increases. For the purpose of design it is assumed the wind pressure is uniform throughout the height of the structure.
2. For the purpose of calculations, it is assumed that the static wind load (projected area multiplied by the wind pressure) is acting at the centre of pressure.
3. In calculating the allowable stresses both tensile and bending, the joint efficiency for butt welds is assumed to be 0.85.
4. The base of the stack is perfectly rigid and the effect of the gussets and stool plate on the deflection and the stresses in the stack is not considered. This is applicable only for manual calculations.
5. There are no additional lateral movements from the duct transferred to the stack; suitable arrangement has to be provided to absorb this movement from the duct.
6. Earthquake causes impulsive ground motions, which are complex and irregular in character, changing in period and amplitude each lasting for a small duration. Therefore resonance of the type as visualized under steady-state sinusoidal excitations will not occur, as it would need time to build up such amplitudes.
7. Earthquake is not likely to occur simultaneously with maximum wind or maximum flood or maximum sea waves..

3.4.2 Loadings

The followings loads are to be estimated while designing the steel chimney

1. Wind load
2. Earthquake load
3. Imposed load

3.4.3 Load combinations

As per IS: 6533 (Part 2), the following load causes are to be considered while designing the stack

1. Load case 1 = Dead load + wind load (along X direction) + Imposed load
2. Load case 2 = Dead load + wind load (along Y direction) + Imposed load
3. Load case 3 = Dead load + Imposed load + earthquake load

3.4.4 Design inputs of chimney

Burner capacity of the each dryer:	Q=600 sq. /hr.
Total no of dryer:	n= 2
Density of flue:	df = 0.9kg/l
Rates of emission	Ve = 27.78 cum/s
Basic wind speed	v_b =58.33m/s
Temperature	t=200^0 c
Min. height of chimney	h = 45m
Height of flare	h flare: =15m
Height of cylindrical portion	Ht − h flare =30m
Outside diameter on top	d top.min =2m
Outside diameter at base	d top.min =3.2m
Thickness of the shell	T= 14mm
Quantity of the gas	Q := n.capa = 55.556 cum/s

3.4.5 FEM Modeling

By the synthesis of 3D model of all structural parts, the 3D model of the chimney is set up and presented in Figure 4.1. The structure thickness is varying along the structure height. Thickness is modeled in accordance with the ultrasonic measurement of sheet metal thickness.

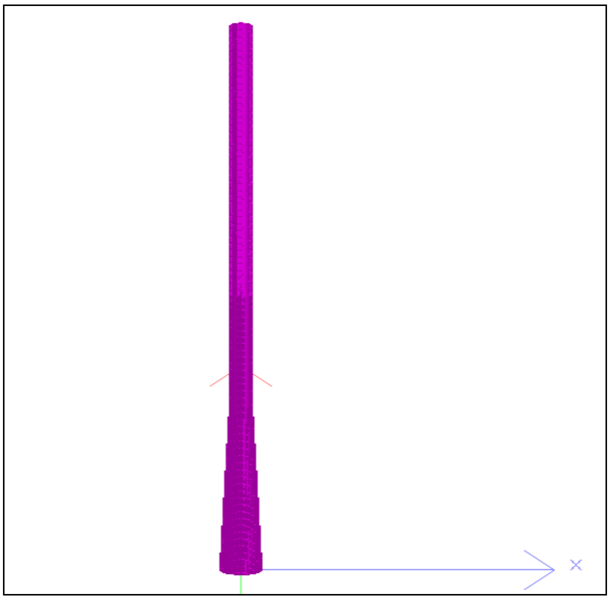


Fig. 4.1 3D Model of Steel Chimney of Rendered view

3D STAAD model of the structure was a starting point in creating finite element model. The model presents the continuum discretized by the 10-node parabolic tetrahedron elements in order to create FEM model. FEM model of the chimney structure consists of 14432 nodes. Figures 4.2 and 4.3 show details of the root section finite element model. The size of the elements varies depending on the local geometry of the structure

Fig. 4.2 FEM Model of Chimney

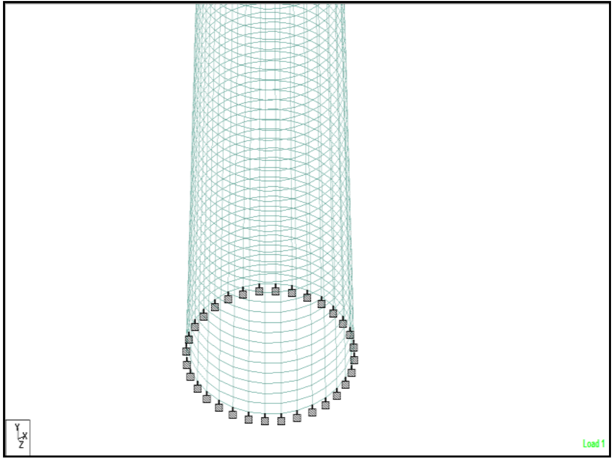


Fig. 4.3 FEM Model of Chimney's root section

External load:
The load analysis of the chimney is carried out according to the rules given in the international codes. Modeling of external loads and anchor connection between steel structure and concrete foundation simulated realistic boundary conditions of the structure of the chimney.

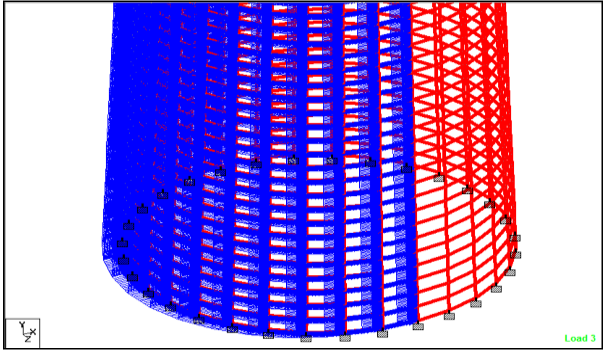


Fig. 4.4 Structure with a wind load [wall pressure]

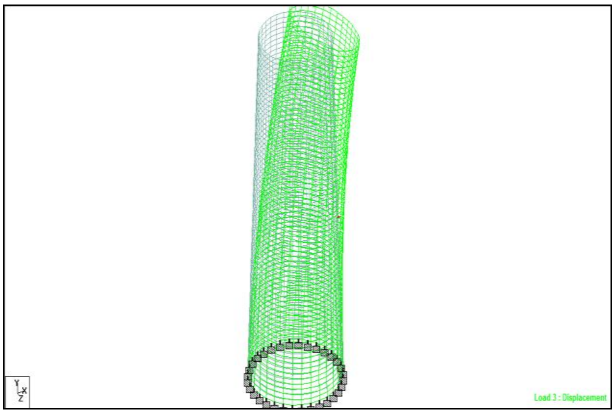


Fig. 4.5 Displacement of Chimney structure due to wind/seismic

Stress state of the structure: The uni-axial stress field obtained according to the Huber-Hencky-Von Mises hypothesis for the root section of the chimney is shown in Figure 4.6 and for the rest of the chimney structure. Maximum values of uni-axial stress are obtained at the chimney's root section in the zones next to the upper corners of the flue duct entries, Fig. 4.7. Chimney sections above the root section have evenly distributed uni-axial stress field without stress concentration locations.

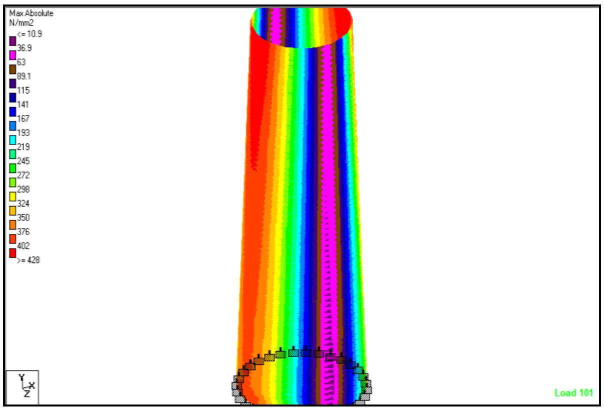


Fig. 4.6 Uni-axial stress field on the chimney's root segment

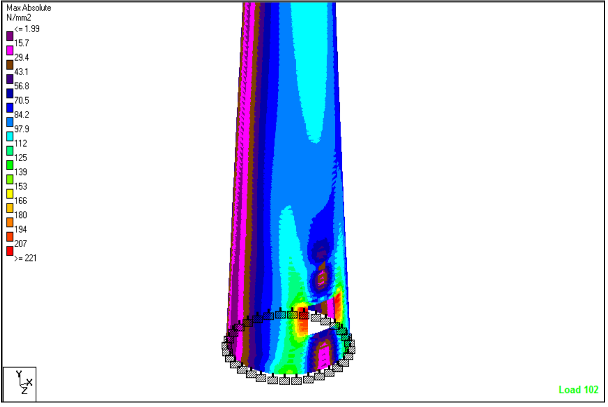


Fig. 4.7 Distribution of the uni-axial stress at the zone of flue duct upper corners

IV. Effect of Geometry on the Design of

Cantilever Steel Chimney

Geometric design of a chimney plays a major role in its performance.

4.1 Overview

This Section deals with the analysis of steel chimneys. The chimney is idealized as cantilever column with tubular cross section for analysis. As explained in the previous section the main loads to be considered during the analysis of chimneys are wind loads and seismic loads in addition to the dead loads. Basic dimensions of a Cantilever steel chimney is generally obtained from the environmental consideration. Other important geometrical considerations are limited by design code IS 6533 (Part 1 & 2): 1989 to obtained preferred mode of failure. Section 5.2 discusses the geometry limitations recommended by IS 6533 (Part 1 & 2): 1989. This section attempts to assess these limitations through analysis of different chimney geometries. Section 5.3 presents the different chimney geometry considered for this study. Also, a study is carried out to understand the chimney behavior with inspection manhole at the lower end of the chimney. Last part of this section presents the difference of chimney behavior with and without the inspection manhole. Analysis is carried out through manual calculations as well as finite element analysis using commercial software STAAD Pro.

4.2 Limitations on Chimney Geometry

Steel Chimneys are cylindrical in shape for the major portion except at the bottom where the chimney is given a conical flare for better stability and for easy entrance of flue gases. Height of the flared portion of the chimney generally varies from one fourth to one third of the total height of the chimney. Design forces in a chimney are very sensitive to its geometrical parameters such as base and top diameter of the chimney, height of the flare, height of the chimney and thickness of the chimney shell. Design codes consider two modes of failure to arrive at the thickness of chimney shell: material yielding in tension and compression and local buckling in compression. Height of the chimney obtained from environmental conditions.

It is clear that the height of the chimney and diameter of the chimney at top is completely determined from the dispersion requirement of the flue gases in to the atmosphere. Because of this IS 6533 (Part 2): 1989 limits the proportions of the basic dimensions from structural engineering considerations as follows:

1. Minimum outside diameter of the unlined chimney at the top should be one twentieth of the height of the cylindrical portion of the chimney.
2. Minimum outside diameter of the unlined flared chimney at the base should be 1.6 times the outside diameter of the chimney at top.

With this background this paper attempts to check the basis of design code limitations with regard to the basic dimensions of a Cantilever unlined flared steel chimney. Two parameters: (i) top-to-base diameter ratio and (ii) height-to-base diameter ratio were considered for this study. A numbers chimney with different dimensions analyzed for dynamic wind load.

4.3 Description of the Selected Chimneys

From the discussions in the previous section it is clear that top-to-base diameter ratio and height-to-base diameter ratio are the two important parameters that define the geometry of a Cantilever chimney. In the present study a total of 66 numbers of Chimney were selected with varying top-to-base diameter ratio and height-to-base diameter ratio. The thickness and the diameter of flared base of the chimney were kept constant for all the cases. Fig.5.1 presents the different parameters of the selected chimneys. The shaded portion in the figure represents the region acceptable by the design code IS 6533 (Part 2): 1989. Design code limits minimum base diameter as 1.6 times the top diameter of the chimney. This gives maximum limit of top-to-base diameter ratio as $1/1.6 = 0.625$. Also, as per IS 6533 (Part 2): 1989, minimum top diameter of the chimney should be one twentieth of the height of the cylindrical portion of the chimney, i.e., $(2h/3)\times(1/20)= h/30$

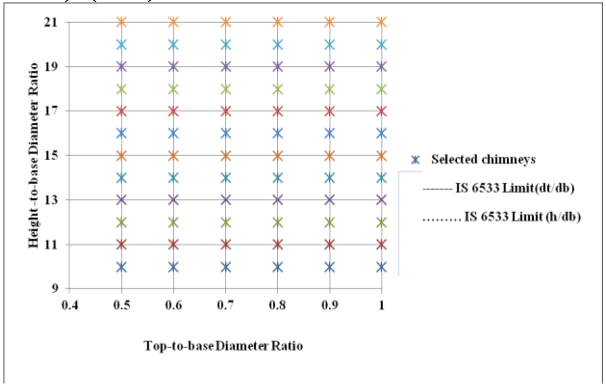


Fig. 5.1 Geometrical distribution of selected chimney models

Therefore the height-to-base diameter ratio as per the code limits to $30/1.6 = 18.75$ (for a maximum top-to-base diameter ratio of 0.625). This figure shows that the selected chimneys cover a wide range of geometry. Here, top-to-base diameter ratio is one means self-supporting chimney without flare. The chimney models were considered to be located at costal Orissa area with a basic wind speed of 210 km/h. Safe bearing capacity of the site soil at a depth

2.5m below the ground level is assumed to be 30 t/m^2. Fixity at the base of the chimney is assumed for the analysis.

4.4 Dynamic Wind Load As Per Is 6533 (Part-2): 1989

IS 6533 (Part-2): 1989 requires design wind load to consider dynamic effect due to pulsation of thrust caused by wind velocity in addition to static wind load when the fundamental period of the chimney is less than 0.25s. The fundamental period of vibration for a Cantilever chimney can be calculated as per IS-1893 Part-4:2005 as follows:

$$T = C_T \; SQRT \; \left(\frac{WTh}{E_s A_{base} g} \right)$$

Where,

C_T = Coefficient depending upon slenderness ratio,
W_T = Total weight of the chimney,
h = total height of the chimney.
E_s = Modulus of elasticity of the material of structural shell and
A_{base} = Area of cross section at base of chimney shell

Stiffness of the flared chimney is generally approximated as two times the prismatic chimney. Therefore a conservative estimate of fundamental period for flared chimney considered to be one half the period of given in the previous equation. Fundamental period of the chimney is also determined from finite element software STAAD-Pro and compared with that obtained from the empirical equation. Assuming the fundamental mode shape of the chimney is represented by second degree parabola whose ordinate at the top of the chimney is unity. So, the ordinate, y (in m) of the mode shape at a height 'x (in m) from the ground is as follows (where h = total height of the chimney in m).

$$y=(x/h)^2$$

This assumption holds good for the type of chimney considered in the present study. Fig. 5.2 shows the fundamental mode shape of a typical chimney as obtained Eigen value analysis using STAAD-Pro.

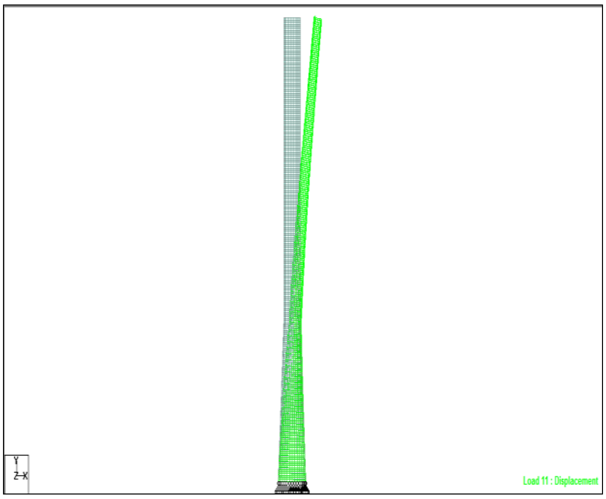


Fig. 5.2 Fundamental mode shape of a typical chimney as obtained from finite element analysis

Fig. 5.3 presents the comparison of the fundamental mode shapes of a typical chimney obtained from empirical equation and Eigen value analysis. This figure shows that the empirical equation for fundamental mode shape is closely matching the actual mode shape.

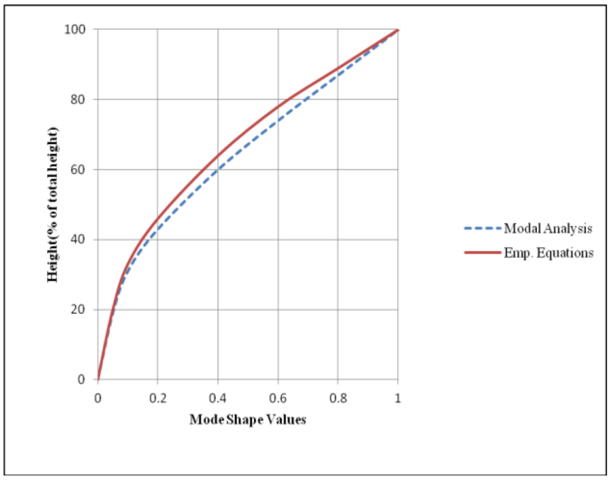


Fig. 5.3: Comparison of fundamental mode shape obtained different analysis

4.5 Results and Discussions

66 selected chimneys with different dimensions as explained in the previous section were analyzed for dynamic wind load as per IS 6533 (Part-2): 1989 using Excel Spread sheets to calculate base shear and base moment for each chimney as follows:

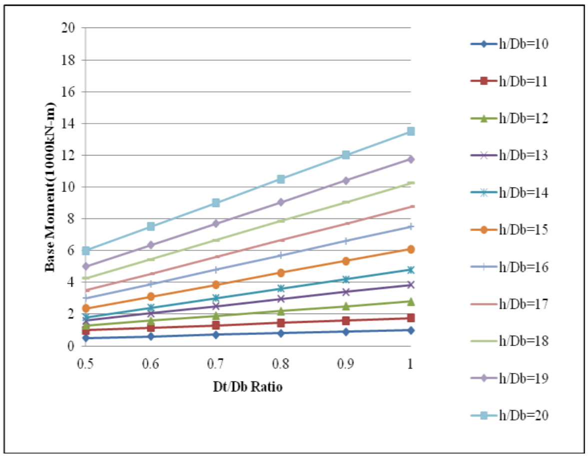


Fig. 5.4: Base moment of the chimney as a function of top-to-base diameter ratio.

Fig. 5.4 presents the bending moment at the base of the chimney for dynamic wind load as a function of top-to-base diameter ratio for different height-to-base diameter ratio. This figure shows that the base moment increases with the increase of top-to-base diameter ratio almost proportionally.

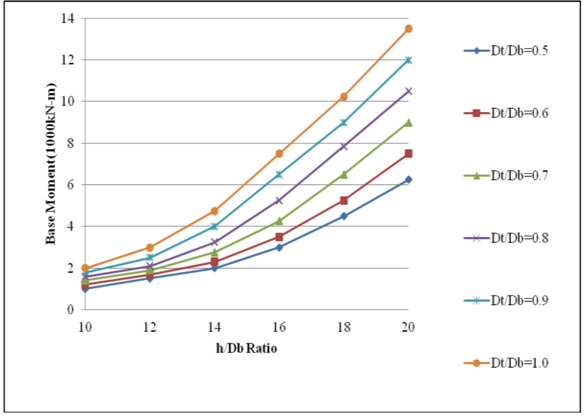


Fig. 5.5: Base moment of the chimney as a function of height-to-base diameter ratio

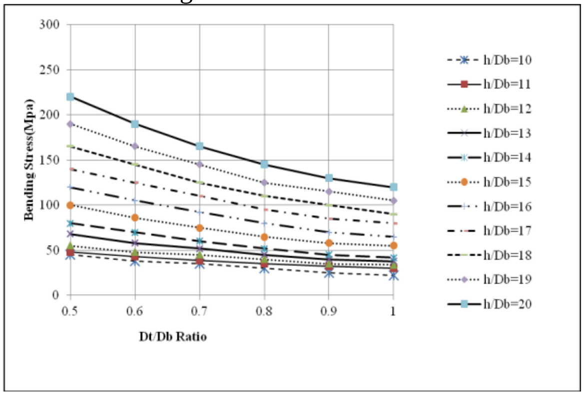


Fig. 5.6: Variation of bending stress as a function of geometry

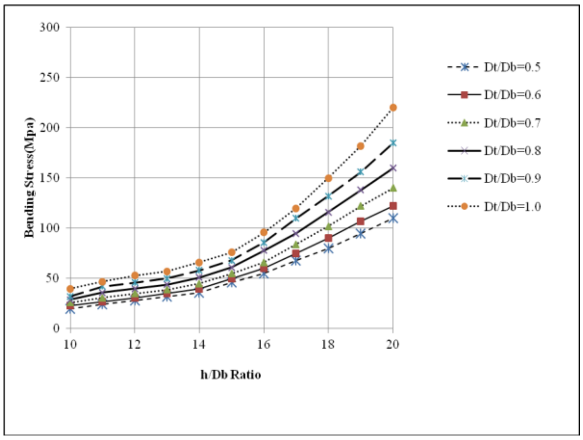


Fig. 5.7: Variation of bending stress as a function of geometry

Fig. 5.5 presents the base moment as a function of height-to-base diameter ratio for different top-to-base diameter ratio. This figure also shows similar results, i.e., that base moment increases with the increase of height-to-base diameter ratio. However, the rate of increase in base moment is slightly less for lower value of height-to-base diameter ratio. There is a sudden increase of the gradient of the base moment curve for height-to-base diameter ratio = 14. Maximum bending stresses in the chimney also calculated and presented in Fig. 5.6 for different height-to-base diameter ratio and top-to-base diameter ratio. a typical chimney model It is clear from these figures that base moment (maximum moment) and the maximum bending stress due to dynamic wind load are continuous function of the geometry (top-to-base diameter ratio and height-to-base diameter ratio). Therefore this study does not support the limitations imposed by IS 6533 (Part-2): 1989 with regard to the selection of basic dimensions of Cantilever steel chimneys.

4.6 Effect of Inspection Manhole on the Behavior of Cantilever steel Chimney

Manholes are generally provided at the bottom of the chimney for maintenance and inspection purpose. The standard dimension of the manhole is 500mm×800mm according to Indian standard IS 6533 (Part-2):1989. These manholes are at generally located at minimum suitable distance from the base of the chimney. Two chimney models, one with the manhole and other without manhole, are analyzed using finite element software STAAD Pro for static wind load. Fig. 5.7 presents the Von-Mises stress for chimney model without manhole whereas Fig. 5.8 presents the same for chimney with manhole. These results show that the maximum stress in the chimney with manhole is increased 55.6% as compared to the maximum stress in chimney without manhole.

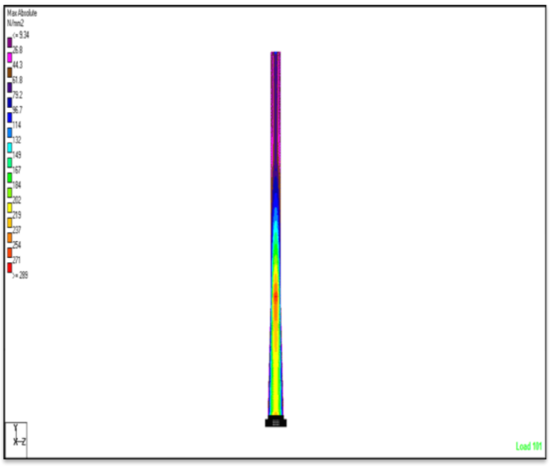


Fig.5.7: Stress for chimney without manhole

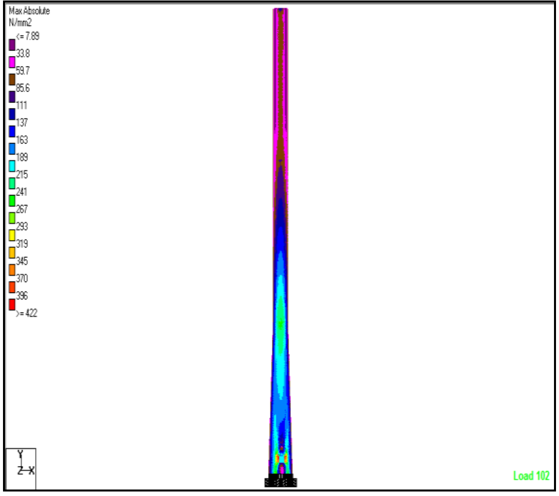


Fig.5.8: Stress for chimney with man hole

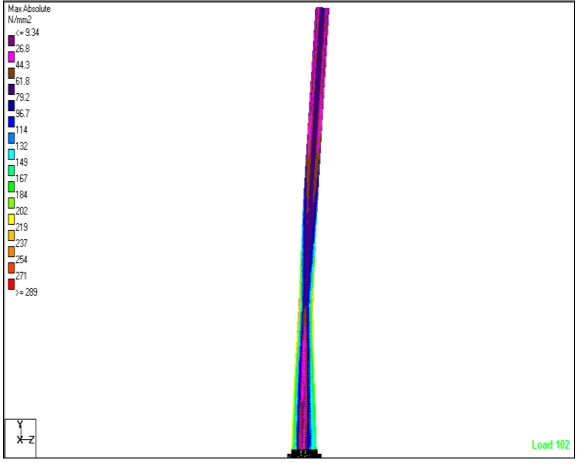


Fig.5.9: Top deflection of the chimney without manhole

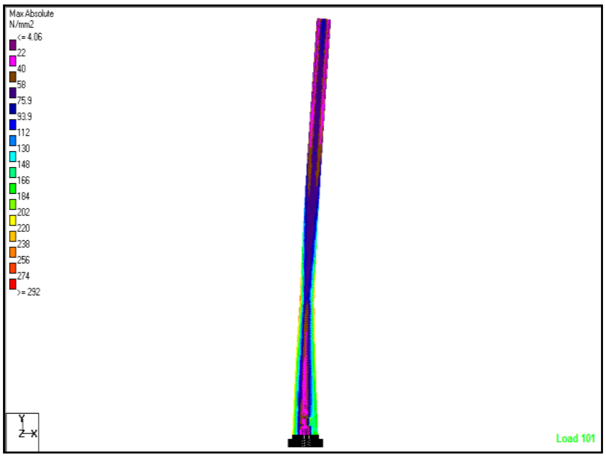


Fig.5.10: T op deflection of the chimney with manhole

Figs. 5.9 and 5.10 present the displacement response of the two chimneys under static wind force. These two figures show that higher deflection is occurred at the top of the chimney with manhole as compared to chimney without manhole.

Fig. 5.11 and 5.12 presents the fundamental mode shape of the two chimney models. Chimney without manhole is found to have higher fundamental frequency compared to the chimney with manhole. This is because chimney without manhole is stiffer than chimney with manhole.

Stress Diagrams of Cantilever Steel Chimney (FEM)

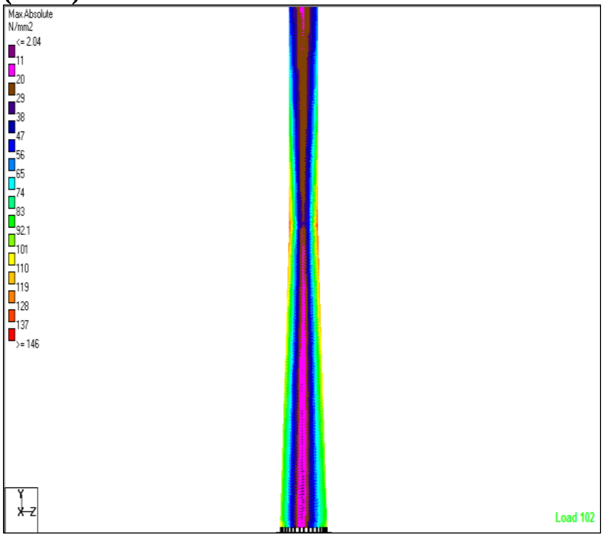


Fig.5.11: Stress at the base of the cantilever steel chimney (wind in x - direction)

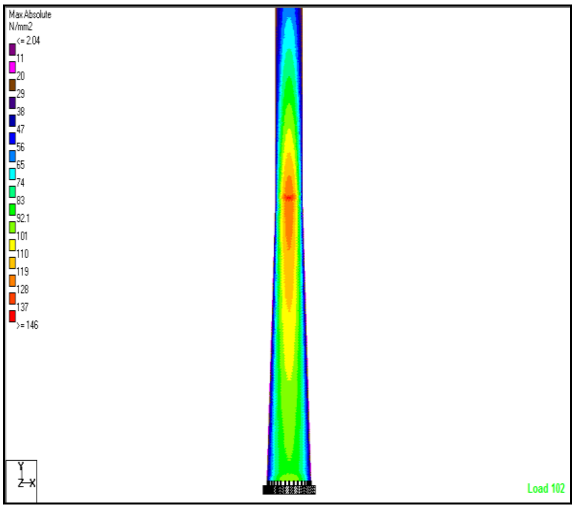


Fig.5.12: Stress at the flared portion of the chimney (wind in x - direction)

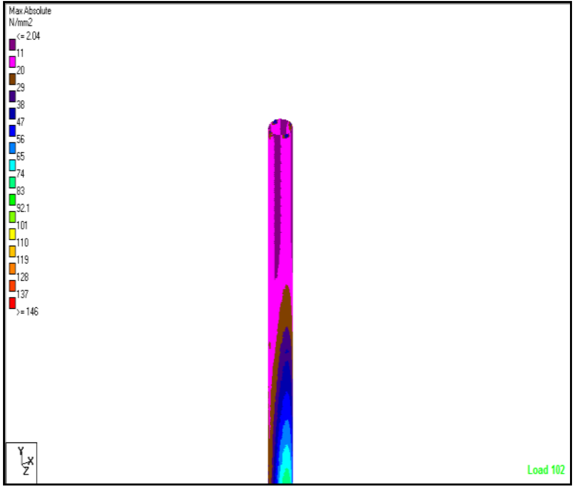


Fig.5.13: Stress at the top of the chimney (wind in x - direction)

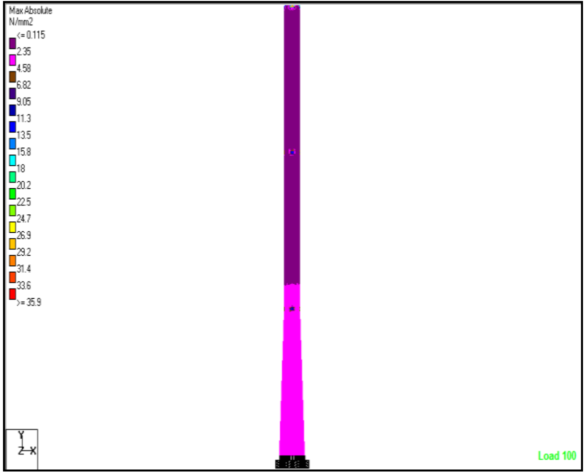


Fig.5.14: Stresses of the chimney wall for DL and LL condition

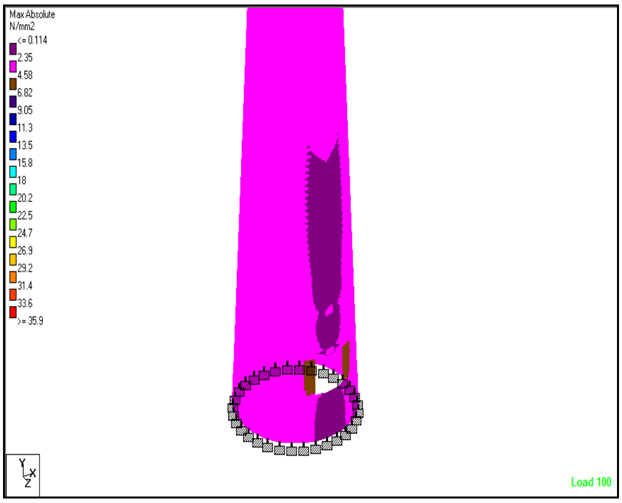


Fig.5.15: Stresses at the inspection manhole (DL and LL condition)

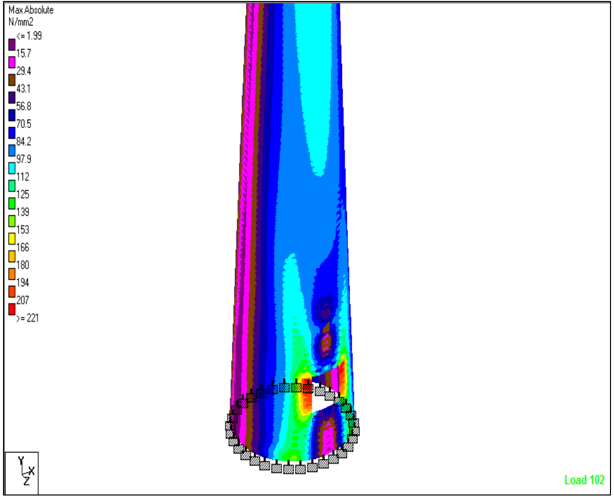


Fig.5.16: Stresses at the inspection manhole (wind load condition)

V. Conclusion

The main objective of the present study was to explain the importance of geometrical limitations in the design of cantilever steel chimney. A detailed literature review is carried out as part of the present study on wind engineering, design and analysis of steel chimney as well as concrete chimney. Estimation of wind effects (along wind & across wind), vortex shedding, vibration analysis, and gust factor are studied. There is no published literature found on the effect of geometry on the design of cantilever steel chimney.

Design of a cantilever steel chimney as per IS 6533 (Part-1 and 2): 1989 is discussed through example calculations. A study is carried out to understand the logic behind geometrical limitations given in Indian Standard IS 6533 (Part-1 and 2): 1989. The relation between geometrical parameters and corresponding moments and shear is developed by using EXCEL Spread sheets. Two parameters: (i) top-to-base diameter ratio and (ii) height-to-base diameter ratio were considered for this study. A numbers of chimneys with different dimensions analyzed for dynamic wind load. A total of 66 numbers Cantilever steel flared unlined chimneys were analyzed for dynamic wind load due to pulsation of thrust caused by wind velocity.

To explain the effect of inspection manhole on the behavior of Cantilever steel chimney, two chimney models one with the manhole and other without manhole are taken into consideration. These models are analyzed by finite element software STAAD Pro. It is found from these analyses that maximum moment and the maximum bending stress due to dynamic wind load in a Cantilever steel chimney are continuous function of the geometry (top-to-base diameter ratio and height-to-base diameter ratio). This study does not support the IS 6533 (Part-2): 1989 criteria for minimum top diameter to the height ratio of the chimney and minimum base diameter to the top diameter of the chimney.

Inspection manhole increases the stress resultant and top displacement in a Cantilever steel chimney. This is because manhole reduces the effective stiffness of a chimney as evident from the modal analysis results. Therefore it is important to consider manhole opening in the analysis and design of Cantilever steel chimney.

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