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Self-supported steel chimney analysis as per Indian standard

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ABSTRACT

Most of the industrial steel chimneys are round cross-sections with column structures. Because of its frame behaviour under lateral dynamic loading Geometry of a self-supporting steel chimney shows an important role. It is primarily responsible for the stiffness parameters of the chimney this is because of geometry. However, basic dimensions of industrial self-supporting steel chimney are generally derived from the associated environmental conditions, such as height, diameter at the exit, etc. Design code (IS-6533: 1989 Part 2) imposes several criteria on the geometry (top-to-base diameter ratio and height-to base diameter ratio) of steel chimneys to ensure the desired failure mode. To justify the code criteria with regard to basic dimensions of industrial steel chimney is the objective of the present study.

Keywords: *Steel chimney, Design code, Frame behaviour.*

1. INTRODUCTION

For emission of poisonous gases to a higher elevation such that the gases do not contaminate surrounding atmosphere chimneys or stacks are very important industrial structures. To build chimneys different construction materials, such as concrete, steel or masonry, are used. For process work where a short heat-up period and low thermal capacity are required Steel chimneys are ideally suited. For height up to 45m, steel chimneys are also economical. For designing self-supporting steel chimneys two important IS-6533: 1989 recommended geometry limitations are as follows:

i) At the top minimum outside diameter of the unlined chimney should be one-twentieth of the height of the cylindrical portion of the chimney.

ii) At the base minimum outside diameter of the unlined flared chimney should be 1.7 times the outside diameter of the chimney at the top.

2. LITERATURE REVIEW

On the design and analysis of steel chimney with special interest on the geometrical limitations, a literature review is carried out. On the design and analysis of steel chimney, there are only two published literature found that deals with the geometrical aspects of steel chimney although a number of literature are available. On the literature reviewed as part of this project, this section presents a brief report.

To show the earthquake response of column reinforced concrete chimney Wilson (2003) conducted the experimental program. To evaluate the inelastic response of column concrete chimney subjected to earthquake excitation a non-linear dynamic analysis procedure is developed. The results encourage reliance on the development of ductility in reinforced concrete chimneys to prevent the generate of brittle failure modes Based on experiments.

By various codes generation such as IS 4998, ACI 307, CICIND, etc Kiran (2001) shows design and analysis of concrete chimney. Numbers of published works are there on steel and concrete chimneys the literature review showed above show that. On the behavior of column chimneys subjected to wind and seismic force experimental and theoretical studies are presented. The majority of the research papers on chimney are concentrated on its response to vortex shedding it is found. On the geometric limitations of the design code with regard to steel chimneys, a very less research effort is found.

3. OBJECTIVES

The objective of this study Based on the literature review express in the last section is defined as follows:

- For the construction of self-supporting steel, chimney assess the geometry limitations imposed by IS 6533:1989.

4. SCOPE

i) In this study, Self-supporting flared steel chimney is taken.
ii) Soil flexibility is not taken in this study. Chimneys took to be fixed at their own support.
iii) All chimneys are of a single-flue type selected here.
iv) During the complete height of the chimney, uniform thickness is selected.
v) For the construction of the chimney, only wind load and seismic load are selected.

5. METHODOLOGY

Following step-by-step procedures are followed to achieve the above objective:

- To find out the objectives of the project work carried out literature study.
- Of a self-supporting steel chimney as per Indian Standard IS 6533:1989 Understand the design procedure.
- Selecting and leaving code (IS 6533:1989) limitations select various chimney geometry.
- Using manual solutions (MathCAD) and finite element analysis (ANSYS) analyze complete the selected chimney models.
- Find the analysis results and verify the requirement of the geometrical limitations.

6. LOAD EFFECTS ON STEEL CHIMNEY

Wind loads, earthquake loads, and temperature loads apart from self-weight, loads from the attachments, imposed loads on the service platforms are the important loads that a steel chimney often experiences. As steel chimneys are generally very column structures wind effects on chimney plays an important role in its safety. Under wind load the circular cross-section of the chimney subjects to aerodynamic lift.

7. WIND ENGINEERING

Wind is selected as the main source of loads for self-supporting steel chimney. The load can be categorized into two components respectively such as,

i) Along-wind effect
ii) Across -wind effect
The sum of quasi-static and a dynamic-load component can be selected as the wind load exerted at any point on a chimney. a steady displacement in a structure which will tend to produce the static-load component is that force which wind will exert if it blows at a mean (time-average) steady speed. The dynamic component is generated which can cause oscillations of a structure due to the following reasons:
i) Gusts
ii) Vortex shedding
iii) Buffeting

Along with Wind Effects

By the drag component of the wind force on the chimney along wind effects are happening.

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

Across wind effects

It is essential a selectable experimental work on it, across wind result is not fully calculated. Indian standard stand silent about it for construction of self-supporting steel chimney. But it is shown in IS 4998 (part 1): 1992 and ACI 307-95 which is valid for concrete chimney only. It depends on IS 4998 (part 1): 1992 and ACI 307-95 and CICIND code do not mention this effects.

Generally to oppose a streamlines one chimney-like column structures are selected as the bluff body. The bluff body causes the wind to separate from the body when the streamlined body causes the oncoming wind flow. Due to this behind the chimney, negative regions are generated in the wake region. This wake region forms high-speed eddies called vortices and produces highly turbulent region. It acts in a direction perpendicular to the incident wind direction and these vortices alternatively form lift forces. Due to this lift forces, Chimney oscillates in a direct ion perpendicular to the wind flow.

Wind Load Calculation

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

$$Vp = Vb\ Ka\ Kb\ Kc$$

Where-
Vp= design wind speed at any height z m/s
Ka= probability factor (risk coefficient)
Kb= terrain, height and structure size factor
Kc= topography factor
Drag
The drag force on a single stationary bluff body is,

$$Fk = 1/2 Cd\ A\ \rho a\ U \quad (2.2)$$

Where Fk = drag force, N
Cd = Drag coefficient

Circumferential bending
The radial distribution of wind pressure on horizontal section depends on Re. 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 sinusoid ally along the circumference of the chimney cell.
Wind load on liners
In both single-flue and multi-flue chimneys metal liners are being used but these do 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 selecting the liner as a beam of the varying moment of inertia, acted upon by a transverse
load at the top and deflection is calculated at the top of the cell.

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. Gust loading due to fluctuations in wind load is random in nature. This load can be expressed as

$$F(t) = (K\ U + \rho u)^2$$

$$= K\ U^2 + 2U\rho, \text{ for small values of } \rho u$$

Where

$$K = ½\ Cd\ A\rho a$$

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

Seismic Effects

An extra load is acted on the chimney, due to seismic action. Chimney is a column and slender structure so it is selected as vulnerable. For a short period of time seismic force is estimated as cyclic in nature. 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 chimney subjected to cyclic loading. The structure is called critically damped when this friction fully dissipates the structural energy during its motion. It is necessary to evaluate the structural response to the ground motion for designing earthquake-resistant structures and calculate respective shear force, bending moments. Hence for seismic evaluation ground motion is the important factor. it depends on soil-structure interaction, structural Stiffness, damping etc to estimate exact future ground motion and its corresponding response of the structure. The chimney behaves like a cantilever beam with flexural deformations for analysis purpose.
According to the IS codal provision analysis is carried out by following one of the methods,
1. Response-spectrum method (first mode)
2. Modal-analysis technique (using response spectrum)
3. Time-history response analysis.
For chimneys which are less than 90m high called as a short chimney, response spectrum method is used.

Response-spectrum method

This method consists of three steps such as,
I. Fundamental period
II. Horizontal seismic force
III. Determine design shears and moments
The fundamental period of the free vibration is calculated as,

$$T = C\sqrt{\frac{Wt.h}{EAG}}$$

Where *C* = coefficient depending on slenderness ratio of the structure
W t= total weight of the structure including the weight of lining and contents above the base,
A = area of the cross-section at the base of the structural shell
h = height of the structure above the base
E= modulus of elasticity of the material of the structural shell
g= acceleration due to gravity

Shear and Moment

Base moment and base shear can be calculated as follows

$$Pdyn = \int dpdyn$$

$$Mdyn = \int x \times dpdyn$$

As per IS 6533 (Part-2): 1989 Inertia force, *dyn dP*, for *i*th mode for an infinitesimal height *dx* at a height *x* from the base of the chimney is as follows:

$$dpdyn = \times\xi \times\eta \times\nu\ dm$$

Where,
dm = mass of the chimney for an infinitesimal height *dx* at height *x* from the base of the chimney,
T = the period of *i*th mode
V = basic wind speed in m/s,
ν = coefficient which takes care of the space

8. EFFECT OF GEOMETRY ON THE DESIGN OF SELF SUPPORTING STEEL CHIMNEY

This Chapter deals with the analysis of steel chimneys. With a tubular cross-section for analysis, the chimney is idealized as cantilever column. The main loads to be selected during the analysis of chimneys are wind loads and seismic loads as explained in the previous chapter in addition to the dead loads. From the environmental selectation basic dimensions of a self-supporting steel chimney are generally obtained. Another important geometrical selectation is limited by design code IS 6533 (Part 1 & 2): 1989 to find a preferred mode of failure.
The different chimney geometry selected for this study is shown in section 4.2. Also, to understand the chimney behaviour with inspection manhole at the lower end of the chimney a study is carried out. The difference of chimney behavior with and without the inspection manhole shown in the last part of this chapter. Using MathCAD as well as finite element analysis using commercial software ANSYS analysis is carried out through manual calculations.

9. LIMITATIONS ON CHIMNEY GEOMETRY

Except at the bottom, Steel Chimneys are cylindrical in shape for the major portion where for better stability and for easy entrance of flue gases the Chimney is given a conical flare. The chimney generally varies from one fourth to one third of the total height of the chimney height of the flared portion. To its geometrical parameters, design forces in a chimney are very sensitive such as the height of the flare, base and top diameter of the chimney, thickness of the chimney shell and height of the chimney. To arrive at the thickness of Chimney shell design codes select two modes of failure: local buckling in compression and material yielding in tension and compression.
From environmental conditions height of the chimney is obtained. As per notifications of the Ministry of Environment and Forests (MEF Notification 2002), Govt. of India, the height of a self-supporting steel chimney should be as follows:

$$h = \max \begin{bmatrix} 14Q^{0.4} \\ 6m + \text{max buliding height of the location} \\ 33m \end{bmatrix}$$

Where Q = total SO2 emission from the plant in kg/hr and h = height of the steel chimney in m.

10. DESCRIPTION OF THE SELECTED CHIMNEYS

There is two important parameters that explains the geometry of a self-supporting chimney on the basis of discussions in the previous section it is clear that height-to-base diameter ratio and top-to-base diameter ratio are the two important parameters. In this study, we select a total of 65 numbers of Chimney with varying top-to-base diameter ratio and height-to-base diameter ratio. For all the cases the thickness and the diameter of the flared base of the chimney were kept constant. The region acceptable by the design code IS 6523 (Part 2): 1989 is represented by the shaded portion. Design code limits minimum base diameter as 1.5 times the top diameter of the chimney. This gives a maximum limit of top-to-base diameter ratio as 1.6 = 0.624. Also, as per IS 6533 (Part 2): 1989, the minimum top diameter of the chimney should be one-twentieth of the height of the cylindrical portion of the chimney, *i.e.*, (2h 3)×(1 20) = h 33 (selecting the flare height of the chimney as one-third of the total height).

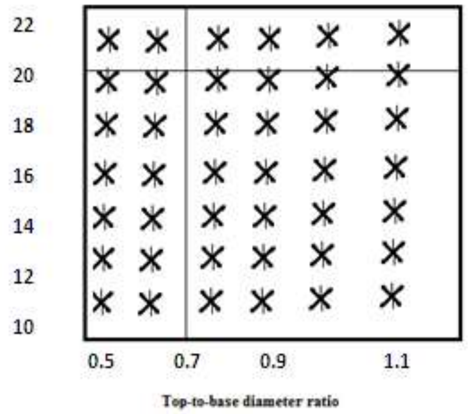

figure-4.1 considered chimney geometrical disturbance

11. CONCLUSIONS

In a self-supporting steel chimney, the maximum bending stress due to dynamic wind is a continuous function of the geometry (top-to-base diameter ratio and height-to-base diameter ratio) it is found from these analyses that maximum moment and load. For minimum top diameter to the height ratio of the chimney and minimum base diameter to the top diameter of the chimney, this study does not support the IS 6533 (Part-2): 1989 criteria.

In a self-supporting steel chimney inspection, manhole increases the von-mises stress resultant and top displacement. As evident from the modal analysis results, this is because manhole reduces the effective stiffness of a chimney. Design of self-supporting steel chimney and manhole opening in the analysis is important to select.

12. SCOPE FOR FUTURE WORK

i) Using finite element software ANSYS The effect of a cross-wind can be calculated through computational fluid dynamics.
ii) This study selects only self-supporting steel chimney. For guyed steel chimney as well as concrete chimney this study can be further enhanced.

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