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A REVIEW ANALYSIS OF SELF SUPPORTED STEEL CHIMNEY WITH GEOMETRY VARIATION AS PER INDIAN STANDARD

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ABSTRACT

The majority of industrial steel chimneys have circular cross-sections and are towering structures. Wind-exit vibration is prone to such slender, lightly damped structures. Self-supporting steel chimney geometry affects its structural behaviour when subjected to lateral dynamic loading. This is because the stiffness parameters of the chimney are mostly determined by geometry. The height, diameter at exit, and other basic dimensions of an industrial self-supporting steel chimney, on the other hand, are usually derived from the surrounding environmental circumstances. The geometry (top-to-base dia. ratio and ht.-to-base dia. ratio) must meet many requirements to ensure a desired failure mode design code (IS-6533: 1989 Part 2) is met. The goal of this research is to justify code requirements for basic dimensions of industrial steel chimneys.

For this study, a total of 66 self-supporting steel flared unlined chimneys were investigated. For all of the scenarios, the chimney thickness was kept constant. Using MathCAD software, Max. B.M. and stress for all chimneys were computed for dynamic wind load according to the procedure outlined in IS 6533: 1989 (Part 2). The results were also confirmed using ANSYS and finite element analysis. For these calculations, a wind speed of 210 km/h is used, which corresponds to the coast of Orissa. As a function of top-to-base dia ratio and ht.-to-base dia ratio, max base moments and corresponding steel stresses were displayed. The findings of this investigation don't match the coding criteria.

1. INTODUCTION

Chimneys, also known as stacks, are significant industrial structures that allow toxic gases to be emitted to a greater elevation, away from the surrounding atmosphere. These constructions are tall, slender, and have circular cross-sections in general. Chimneys are made of different materials, including concrete, steel, and masonry. Steel chimneys are appropriate for process operations that require a quick heat-up time and limited thermal capacity. Steel chimneys are also cost-effective at heights up to 45 metres. A photograph of self-supporting steel chimneys in an industrial plant is shown in Figure 1.

Fig. 1: Self-supporting Steel Chimney

For designing self-supporting industrial steel chimneys, a variety of standards are available, including Indian Standard IS 6533: 1989 (Part-1 and Part-2), International Committee on Industrial Chimneys CICIND 1999 (rev 1), and others.

Its geometry affects its structural behaviour when subjected to lateral dynamic loading. This is just because of stiffness parameters of the chimney are mostly determined by geometry.

2. LITERATURE REVIEW

A survey of the literature on the design and analysis of steel chimneys is conducted, with a focus on geometrical restrictions. Despite the fact that there are numerous publications on the design and analysis of steel chimneys, there are only two that deal with the geometrical features of steel chimneys. This section contains a summary of the literatures examined as part of the study.

Menon and Rao (1997) examines the international code processes for evaluating RC chimneys' across-wind response. This research uses a reliability technique to investigate discrepancies in the codal estimations of across wind moments as well as load factor specifications. This research suggests that, under certain conditions, it is vital to design for across wind loading.

Chmielewski, *et. al.* (2005) Natural frequencies and natural modes of a 250-meter-high multi-flue industrial RC chimney with soil flexibility were investigated. The analysis in this paper was done with the finite element method. Additionally, using two geophone sensors, experimental work is carried out to explore the free vibration response, and the experimental results are compared to analytical data. The findings demonstrate that the soil flexibility beneath the foundation has a significant impact on the chimney's natural modes and natural periods.

Ciesielski, *et. al.* (1996) Cross vibrations on a steel chimney were discovered as a result of an aerodynamic phenomenon. This research demonstrates how specifically designed turbulizers and mechanical dampers can significantly reduce cross vibrations.

Ciesielski, *et. al.* (1992) provides information on the response of towers and steel chimneys to vortex excitation caused by cross wind. The greatest displacement of the chimney at the top due to cross wind is calculated using a model, and the findings are stated to be very close to the observed maximum top displacement.

Flaga and Lipecki (2010) The lateral reaction of steel and concrete chimneys with circular cross-sections was explored due to vortex excitation. A mathematical model of vortex shedding is developed for determining the maximum displacement of the chimney at the top due to vortex shedding.

Gaczek and Kawecki (1996) Steel chimneys with spoilers have their cross-wind behaviour discussed. This study describes a 3-start helical strake system with 5D pitch strakes. A chimney's top displacement is also stated to be influenced by the excitation parameter.

Galemann and Ruscheweyh (1992) presented the findings of wind-induced vibrations in a steel chimney experiment. The dynamic response as well as the vertical coherence of the wind speed were used to determine the aerodynamic admission function for along-wind vibration. The strouhal frequency and the natural frequency of the chimney interact to produce a new exciting frequency that is lower than the strouhal frequency, according to research.

Hirsch and Ruscheweyh (1975) A steel chimney that had collapsed owing to wind-induced vibrations was also examined. Cross-wind oscillations of steel stacks with provided structural data were examined in the analysis (such as natural frequencies and log decrements). This research also shows how a hydraulic automobile shockabsorber can reduce vortex-induced oscillations.

Kareem and Hseih (1986) carried out a wind-loading reliability analysis on concrete chimneys Safety requirements are taken into account in this research. Excessive deflection at the top of the chimney and exceeding the ultimate moment capacity of the chimney cross-section at any level were both failure criteria. A formula for wind-induced load effects in both the along-wind and across-wind directions is developed using probabilistic structural dynamics. To create a particular description of fluctuating wind load effects on chimneys, the covariance integration approach is applied. Structural resistance factors and load effects are handled as random variables. The wind environment and meteorological data, as well as characteristics describing wind-structure interactions and structural properties, are all random variables.

Kawecki and Zuranski (2007) The damping qualities of the steel chimney were measured due to cross-wind vibrations, and several ways to calculating relative amplitude of vibration at tiny scruton numbers were compared. They also considered the weather conditions during vibrations. They also provided a more accurate description of cross-wind vibrations using the Eurocode and CICIND model codes.

Ogendo, *et. al*. (1983) A resilient damping layer at the base of a large class of steel chimney designs can assist reach a sufficiently high overall damping level to block considerable vortex-induced vibrations, according to a theoretical analysis. In addition, full-scale investigations show that the system damping level can be enhanced by up to three times.

Pallares, *et. al.* (2006) The seismic behaviour of an unreinforced masonry chimney is discussed. To determine lateral displacements, crack pattern, and failure mode, a 3D finite element non-linear analysis is performed, combining cracking and crushing processes. The greatest earthquake that the chimney can withstand in terms of peak ground motion is also determined.

Verboom and Koten (2010) reveals that the stress differences between the design requirements for cross-wind vibrations for steel chimneys supplied by DIN 4133 and the CICIND model code can be as much as a factor of 6 or more. The Vickery-Basu model is used to design chimneys. This work proposes a design rule for calculating the stresses in industrial chimneys caused by vortex excitation more precisely. It has been demonstrated that the results achieved using this formulation are superior to those obtained using the DIN 4133 or CICIND model codes.

Wilson (2003) conducted An earthquake response of a tall reinforced concrete chimney is demonstrated using an experimental programme. The inelastic response of a tall concrete chimney subjected to earthquake excitation is evaluated using a non-linear dynamic analytical approach. Experiments show that relying on the development of ductility in reinforced concrete chimneys to prevent brittle failure modes is a good idea.

Kiran (2001) Provided concrete chimney design and analysis in accordance with several codes such as IS 4998, ACI 307, CICIND, and others. There are several published works on steel and concrete chimneys, as evidenced by the literature review presented above. On the behaviour of tall chimneys subjected to wind and seismic force, experimental and theoretical research are provided. The majority of chimney research studies focus on its response to vortex shedding, according to our findings. However, there is relatively little research on the geometric limits of the design code when it comes to steel chimneys.

Rekadi Rama Suvarna Varma1, VLD Prasad Reddy (2016) Using self-supported and guyed steel chimneys at various heights of 54m, 72m, and 90m, respectively, at varying wind speeds of 33m/s, 44m/s, and 50m/s, an attempt has been made to analyse the industrial steel chimney for established wind forces and seismic forces. The maximum lateral displacements and maximum stresses for the above-mentioned heights and wind speeds are compared using the software package STAAD.Pro.V8i.

Harshal Deshpande, Roshni John (2015) This research looks at the relationship between geometrical configuration and the dynamic response of short self-supported steel stacks subjected to dynamic wind and seismic loads. IS 6533(part 2) and IS 1893 are used to identify and analyse 42 steel stack configurations for seven distinct stack heights (part 4). The relationship between dynamic reaction and the stack's governing geometry is discovered. For analysis, Excel sheets and STAAD PRO software are used.

Kalpesh Dhopat et al (2018) : This paper summarises the effects of height to base diameter ratio and top to base diameter ratio on the behaviour of self-supported steel chimneys. In compliance with Indian regulations (IS: 6533 part2) and IS 1893, a total of 49 steel chimneys with seven different heights and top diameters were chosen and tested for wind and seismic loads (part 4). The effect of geometric parameters on a self-supported steel chimney is calculated using STAAD pro.

LOAD EFFECTS ON STEEL CHIMNEY: Steel chimneys that are self-supporting are subjected to a variety of loads in both vertical and lateral directions. Apart from self weight, loads from the attachments, and imposed stresses on the service platforms, a steel chimney is frequently subjected to wind, earthquake, and temperature loads. Because steel chimneys are often quite tall buildings, wind effects on them play a major part in their safety. Under wind load, the circular cross section of the chimney is subjected to aerodynamic lift.

Again, because the chimney is considered a natural load, seismic load is a crucial factor. In most cases, this load is dynamic. According to the code, quasi-static methods are employed to evaluate this load, and it is recommended that the normalised response of the chimney be amplified by a factor that varies depending on the soil and the magnitude of the earthquake.

The bulk of the time, high-temperature flue gases are expelled inside a chimney. As a result, a temperature gradient develops with regard to the ambient temperature outside, causing tensions in the cell. As a result, temperature effects must be taken into account while designing a steel chimney.

The effects of wind and seismic loads on self-supporting steel chimneys are discussed in this chapter.

2.1 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,

i. Along-wind effect

ii. Across -wind effect

iii. The sum of quasi-static and dynamic load components exerted at any point on a chimney can be termed the wind load. The static-load component is the force that wind will impose if it blows at a constant mean (time-average) speed and causes a steady displacement in a structure. The dynamic component, which can cause a structure to oscillate, is produced for the following reasons:

iv. Gusts

v. Vortex shedding

vi. Buffeting

Along Wind Effects

Along wind effects are happened by the drag component of the wind force on the chimneyWhen wind blows directly on the structure's face, it causes direct buffeting. To estimate such loads, the chimney must be modelled as a cantilever that is attached to the ground. The wind load acts on the exposed face of the chimney in this model, causing dominating moments. However, there is a difficulty in that the wind does not always blow at the same speed. As a result, the corresponding loads should be dynamic. The chimney is represented as a bluff body with turbulent wind flow to evaluate along wind loads. The similar static approach is used to estimate these loads in numerous regulations, including IS: 6533: 1989. 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.

Across wind effects

Across wind effect is not fully solved and it is required a considerable research work on it. Indian standards are silent on the design of self-supporting steel chimneys. However, it is referenced in IS 4998 (part 1): 1992 and ACI 307-95, both of which are exclusively relevant to concrete chimneys. Also, the CICIND code ignores these consequences and instead relies on IS 4998 (part 1): 1992 and ACI 307-95.

Generally, tall chimney-like structures are referred to as bluff bodies, as opposed to streamlines. The bluff body separates the wind from the streamlined body when it creates the oncoming wind flow. Negative regions emerge in the wake zone behind the chimney as a result of this. This wake zone generates a lot of turbulence and develops vortices, which are high-speed eddies. These vortices alternately create lift forces that act perpendicular to the direction of the incident wind. Due to the lift forces, the chimney oscillates in a direct line perpendicular to the wind flow.

2.3 WIND LOAD CALCULATION

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

$$V_z = V_b K_1 K_2 K_3 \qquad (2.1)$$

Where

Vz = design wind speed z m/s at any height

K1 stands for the likelihood factor (risk coefficient)

K2 refers to the size of the terrain, the height of the structure, and the size of the structure itself.

K3 refers to the topographical factor.

2.4 STATIC WIND EFFECTS

On a bluff body like a chimney, a static force known as drag obstructs an air stream. The shape and direction of wind incidence determine the distribution of wind pressure. Circumferential bending occurs as a result of this, which is more noticeable for bigger diameter chimneys. Along-wind S.F. and B.M. are also created by drag force.

a) Drag

The drag force on a single stationary bluff body is,

$$F_d = 1/2\ C_d . A\ \rho_a\ \bar{U}^2 \qquad (2.2)$$

2

Where

F_d = drag force, N

C_d = Drag coefficient

A = area of section normal to wind direction, sq. m

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

b) Circumferential bending

Re affects the radial distribution of wind pressure on a horizontal portion. Shear force s created in the structure generally counteracts the resultant force of along wind. The shear forces are expected to change sinusoidally along the chimney cell's perimeter.

c) Wind load on liners

Metal liners are utilised in both single-flue and multi-flue chimneys, however they are not in direct contact with or exposed to the wind. They are, however, intended to withstand wind stresses transferred through the chimney cell. Consider the liner as a beam with variable M.I. acted on by a transverse load at the top, and deflection is calculated at the top of the cell to estimate the size of the force.

2.5 DYNAMIC-WIND EFFECTS

The wind load consists of both a constant and a variable component. The wind load fluctuates in magnitude due to the turbulence effect.

$$F(t) = K\left(\overline{U} + \rho_u\right)^2$$

$$= K\left(\overline{U}^2 + 2\overline{U}\rho_u\right) \text{, for small values of } \rho_u$$

$$K = \tfrac{1}{2} C_d . A . \rho_a$$

(a) Gust loading

Wind load is unpredictable in nature due to variations. This burden can be expressed as follows

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

(b) 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;

$$A_n = \frac{1}{\left(1 + \frac{8Hn}{3U_t}\right)\left(1 + \frac{10nD_{CO}}{U_t}\right)} \qquad (2.4)$$

Where An is the aerodynamic admittance at the structure's natural frequency n, Hz, and t is the mean wind speed at the top of a chimney, in metres per second.

Because it allows response modification due to spatial wind-turbulence features, this coefficient must always be multiplied with the reaction of a structure due to wind loads.

(c) Vortex formation

When wind flows through a circular cross section like chimney vortices are formed. At regular pressure intervals, these vortices induce a pressure drop over the chimney. A lateral force perpendicular to the wind direction is formed as a result of this shift in pressure. It depends on Reyonld’s number which has a range such as sub-critical (R_e<3× 10^5), ultra-critical (R_e >3× 10^5) and super-critical (3×10^5 to 3× 10^6).

(d) 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. The maximum reaction is obtained when the vortex shedding frequency is close to a chimney's inherent frequency (when its motion is near sinusoidal). The energising force should be interpreted as follows:

$$F_L = 1/2\,\rho_a A\overline{U}^2 \sin \omega t c_L^{-} \qquad – \qquad (2.5)$$

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 liftingforce coefficient with a range of frequencies close to the natural frequency ω_o of the structure

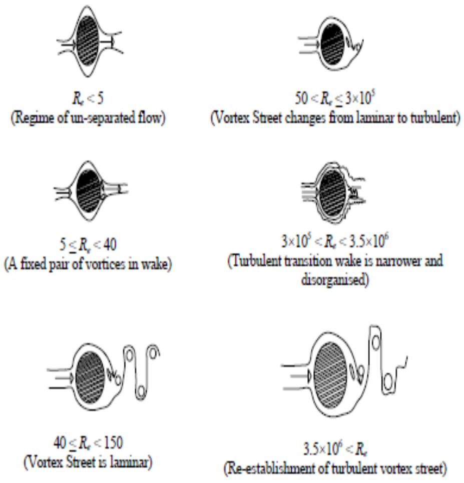

Fig. 2.1: Regimes of fluid flow across circular cylinders

(ii) In super-critical R_e range

In this range both frequency and magnitude are random in nature. The response of the structure here is determined by the power input. The power spectrum of the lift-force should be described as, if we plot the power –input density function S' (St) versus non-dimensional frequency St.

$$S_l = \left[\frac{1}{2}\rho_a A\overline{U}^2 \sqrt{\overline{C_L^2}}\right].S_l'(S_t) \qquad (2.6)$$

If the period of natural oscillation for a self-supported chimney is greater than 0.25 seconds, the design wind load must take into account the dynamic effect of thrust pulsation caused by wind velocity in addition to the static wind load, according to the NFPA (IS-6533 part-2:1989). The basic period of vibration of the chimney determines this.

3. SEISMIC EFFECTS

The chimney is subjected to an additional load as a result of seismic activity. Because the chimney is a tall and slender structure, it is considered susceptible. For a short length of time, seismic force is predicted to be cyclic. When a chimney is subjected to cyclic loading, friction with air, friction between the particles that make up the structure, friction at structural element connections, and yielding of structural components diminish the amplitude of motion of a vibrating structure and bring it back to normal over time. The structure is said to be severely damped when the friction completely dissipates the structural energy during motion.

It is vital to examine the structural reaction to ground motion and compute the corresponding shear force and bending moments when constructing earthquake-resistant constructions. As a result, ground motion is a critical aspect in seismic evaluation. It is dependent on soil-structure interaction, structural stiffness, damping, and other factors to forecast exact future ground motion and its corresponding response of the structure.

For the purposes of analysis, the chimney is treated as a cantilever beam with flexural deformations. According to the IS codal clause, analysis is carried out using one of the techniques,

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 short chimney, response spectrum methodis used.

Response-spectrum method

It’s having three faces-

i. Fundamental period
ii. Horizontal seismic force

iii. Determine design shears and moments

Fundamental period determined by,

$$T = C_T \sqrt{\frac{W_t.h}{E_s.A.g}} \tag{2.7}$$

Here, C_t = coefficient depending on slenderness ratio of the structure

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

A = Cross- sectional area at the base of the structural shell

h = ht. of structure above the base

E_s= modulus of elasticity of material of the structural shell

g= Gravity

The flared chimney is roughly twice as stiff as the prismatic chimney. As a result, for this self-supporting steel chimney, a conservative estimate of natural time period will be:

$T_{emprical}$ = T/2

Horizontal seismic force

Its calculated according to IS 1893 (Part 1): 2002 as follows:

$$A_h = \frac{\left[\frac{Z}{2}\right]\left[\frac{S_a}{g}\right]}{\left(R/I\right)} \tag{2.8}$$

Here, Z= Zone factor

I denotes the importance of the zone.

R stands for "response reduction factor." For rock and soil locations, the ratio must not be less than 1.0

Sa/g= spectral acceleration coefficient.

SHEAR AND MOMENT

Base moment and base shear can be calculated as follows

$$P_{dyn} = \int_0^h dp_{dyn}$$

$$M_{dyn} = \int_0^h x \times dp_{dyn}$$

According to IS 6533 (Part-2): 1989, the inertia force, dP, for ith mode at a ht. x from the base of the chimney is as follows:

$$dP_{dyn} = dm \times \xi_i \times \eta_i \times v$$

Here,

dm is mass of the chimney at height x from the base of the chimney for an infinitesimal height dx

£$_I$ is (T_iV_b) / 1200 is the dynamic coefficient for the ith mode of vibration

T is the ith mode's period.

Vb is the fundamental wind speed in m/s,

v is the space coefficient.

TEMPERATURE EFFECTS:

The chimney's shell should be able to withstand the impacts of thermal gradient. Vertical and circumferential stress are created as a result of the thermal gradient, and these values are measured by the magnitude of the thermal gradient under steady state conditions.

SUMMERY:

The effects of wind and seismic load on self-supporting steel chimneys are discussed in this chapter. It also briefly explains how to compute static wind, dynamic wind, and seismic force in accordance with Indian Standard IS 6533 (Part-2):1989.

The primary goal of this research was to demonstrate the significance of geometrical constraints in the design of a self-supporting steel chimney. Current study on wind engineering, design, and analysis of steel and concrete chimneys, a thorough literature survey is conducted. Wind impacts (both along and across the wind), vortex shedding, vibration analysis, and gust factor are all investigated. On the effect of geometry on the design of chimneys.

Through example calculations, the design of chimney according to IS 6533 (Parts 1 and 2): 1989 is discussed. MathCAD software is used to build the relationship between geometrical parameters and related moments and shear. This study looked at two parameters: I top-to-base dia ratio (ii) height-to-base diameter ratio. A number of chimneys were investigated for dynamic wind loads. A total of 66 self-supporting steel flared unlined chimneys were examined for dynamic wind loads generated by wind velocity pulsation. Two chimney models, one with and one without inspection manhole, are considered to describe the effect of inspection manhole on the behaviour of self-supporting steel chimneys. The finite element programme ANSYS is used to analyse these models.

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