A Review of Wind Load Effects and Load Calculation on Tall Chimneys

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Abstract—In this paper deals with wind load effects on tall chimneys, Wind is essentially the large scale movement of free air due to thermal currents. It plays an important role in design of tall structures because it exerts static and dynamic loads whose effects on a slender structure, such as a chimney are significant. The wind load exerted at any point on a chimney can be considered as the sum of quasistatic and a dynamic load component. In order to effectively analyse a chimney's response, a deep knowledge of the basic wind engineering concepts is needed. The force exerted by wind on the chimney varies with the wind speed and its associated turbulence. A chimney is a vertical channel through which smoke and combustion gases pass out of a building. Chimneys are used to emit the exhaust gases higher up in the atmosphere so that diffusion of gases may take place. Chimney may be constructed of steel, R.C.C or masonry.

Key words: Chimney, Wind Load, Static Moment, Dynamic Moment Static Force, Dynamic Force

I. INTRODUCTION

They are typically almost vertical to ensure that the hot gases flow smoothly, drawing air into the combustion through the chimney effect. Chimneys are tall to increase their draw of air for combustion and to disperse the pollutants in flue gases over a greater area in order to reduce the pollutant concentrations in compliance with regulatory or other limits. The first industrial chimneys were built in the mid 17th century when it was first understood how they could improve the combustion of a furnace by increasing the draft of air into the combustion zone. As such, they played an important part in the development of refractory furnaces and a coal-based metallurgical industry, one of the key sectors of the early Industrial Revolution. Most 18th century industrial chimneys generally located adjacent to a steam-generating boiler or industrial furnace and the gases are carried to it with ductwork. Chimneys with height exceeding 150 m are considered as tall chimneys. However it is not only a matter of height but also the aspect ratio when it comes to classifying a chimney as tall. Today, Reinforced Concrete is the dominant material used for the construction of tall chimneys and for short chimneys precast concrete with or without pre stressing, Modern industrial chimneys consists of a concrete windshield with a number of steel stacks on the inside. [1] Design and analysis of structures for wind loads is usually limited to a static analysis using code prescribed wind loads. For special structures such as tall buildings wind loads are obtained from wind tunnel testing on a mock-up of the building and surrounding terrain in a laboratory. Wind tunnel test loads are frequently reported in the form of static loads which are more realistic in value and distribution over surfaces and height of the structure compared to code prescribed wind loads. Similar to earthquake loads, wind loads are dynamic in nature. However, performing a dynamic analysis is not cost effective and practical for regular structures. Structures whose heights are greater than 4 times their minimum effective width; structures with heights greater than 400 ft; flexible structures (with frequencies normally below 1Hz) and structures with low damping are susceptible to vibration during high wind events [2]. Wind is essentially the large-scale movement of free air due to thermal currents. It plays an important role in chimney design because of its capacity to transport and disperse pollutants and also because it exerts static and dynamic loads whose effects on a slender structure, such as a chimney, are significant. It is very difficult to predict wind effects precisely by analytical procedures because of winds uncertain variability and therefore a designer is forced to use approximate design techniques.[3]

II. ESTIMATION OF WIND LOAD EFFECTS ON A CHIMNEY:

A. Along Wind Effects:

Long-wind loads are caused by the 'drag' component of the wind force on the chimney. This is accompanied by 'gust buffeting' causing a dynamic response in the direction of the mean flow. 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 modelled as a cantilever fixed to the ground. The wind is then modelled to act on the exposed face of the chimney causing predominant moments in the chimney. Additional complications arise from the fact that the wind does not generally blow at a fixed rate.

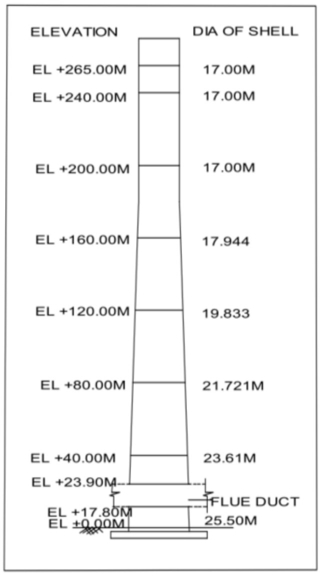

Fig. 1: Section showing 275m tall RCC chimney modelled in Staad Pro**.**

Wind generally blows as gusts, this requires that the corresponding loads and hence the response be taken as dynamic. True evaluation of the along-wind loads involves modelling 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 (GFM). This helps in simplifying the incident load due to the mean wind. The actual wind load is calculated and the results are amplified by means of a gust factor to take care of the dynamic nature of the loading. The gust factor is defined as the ratio of the expected peak load to the mean load.[4]

B. Across Wind Effects:

Across wind loads are caused by the corresponding 'lift' component of the wind force on the chimney. This is associated with the phenomenon of 'vortex shedding' which causes the chimney to oscillate in a direction perpendicular to the direction of wind flow. The across wind response of a chimney occurs mainly due to vortex shedding and velocity dependent forces. The across-wind response of tall slender structures in atmospheric turbulence involves a number of complex fluid-structure interaction phenomena. The principal source of excitation arises from vortex shedding, but if the motion induced is significant, other velocity dependent forces begin to play an important role. Further, the longitudinal and lateral fluctuations in the approaching flow give rise to a cross-wind buffeting forces. The shedding of vortices is fairly regular in the sub critical range when Reynolds number (Re) <3x105 and ultra-critical range (Re>3x106), whereas it is random in the supercritical range (3x105<Re<3x106). Normally for chimneys, Re is sub critical and this permits design to be based on an assumption that the excitation is periodic. When Re is super- critical, excitation is random and the response being small, this case does not generally control design. Across wind analysis of chimney is required only if the critical wind speeds for any mode of oscillation is less than the mean design wind speed. [1][4]

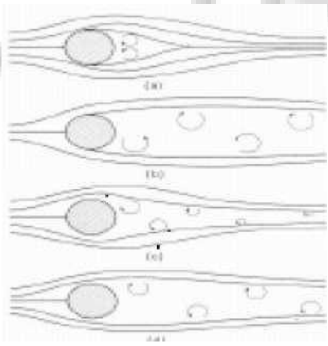

Fig. 2: Vortex Formation Due To Wind

III. CALCULATION OF WIND LOADS

A. Wind Loads

The wind load on chimney depends upon its location and height. As the wind pressure varies with height, the stack is divided into parts and the wind load in each part is calculated. The wind pressure over each part is considered as uniform and resultant is assumed to be acting at mid-height of that portion. The wind loading causes bending moment in steel stack. The design wind pressure at any height above ground level has been obtained by using the following relationship between wind pressure, Pz (N/m²), and the design wind velocity, Vz (m/s):

$$P_z = 0.6V_z^2 \text{ .... (1)}$$

The coefficient 0.6 in Eq. (1) depends upon a number of factors and primarily on the atmospheric pressure and air temperature. The design wind velocity at any height for the chosen structure is obtained from the basic wind speed, Vb, and by including the following factors: (1) risk level, (2) terrain roughness, (3) Height and size of structure and (4) local topography. It can be mathematically expressed as:

$$V_z = V_b \, k_1 \, K_2 \, k_3 \text{ .... (2)}$$

Where

Vb = basic wind speed which is mentioned for different zones of the country.

k1 = probability factor (risk coefficient) based on the statistical concepts which take into account the degree of reliability required and the time period of wind exposure i.e. the life of the structure.

k2 = the terrain height and structure size that gives the multiplying factor by which the basic wind speed shall be multiplied to obtain the wind speed at different heights in each terrain category for different sizes of buildings and structures. k3 = the topography factor.[5] [6]

B. Static Force

Static shear is obtained by the product of design wind pressure, shape factor, height of each zone and the inner diameter of chimney. It can be expressed as follows.

Static shear= p*Cp*h*ϕ .... (3)

Where p=0.6*Vz2

Cp= From IS code 6533-1971

P=design wind pressure

Cp=shape factor

H=height of each zone

Φ=inner diameter of chimney

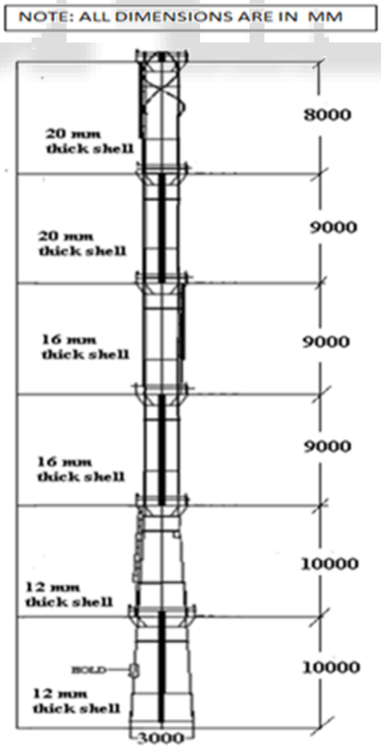

Fig. 3; dimension off chimney

C. Static Moment:

Static moment is obtained by the product of static shear of the zone and the zone height of the chimney.

D. Dynamic Force:

Dynamic shear is obtained by the product of dynamic load, shape factor, height of each zone and the inner diameter of chimney. It can be expressed as follows.

Static shear= P dyn*cp*h*ф …………… (4)

Where, P dyn= mj*ξ1*ηij*v …………….. (5)

P dyn= Dynamic load
Mj= Mass of jth zone in kg connected at its centre
ξ1= Co-efficient of dynamic influence for steel chimney
ηij= Deduction acceleration in m/s2 of centre of jth zone
v= Co-efficient which takes care of spare correlation of wind pulsation speed according to height and vicinity of building structure
Cp= Shape factor
H= Height of each zone
Ф= Inner diameter of chimney [6]

IV. CONCLUSION

This work describes simulation of multi body dynamic systems in the product development process. The papers presented describe how computer tools are used in product development and how multibody dynamic analysis can be applied to applications within vehicle dynamics. The approach has been .to identify the process of multibody dynamics simulation and make it more efficient by structuring of the simulation, simulation models and their usage. Previous work has concentrated on developing faster calculation methods and more specialized simulation software. Efforts have been made to clarify how computer tools and multibody dynamic analysis methods are used in product development in industry today. The different stages of the MBS process are discussed and insight into non-linear analysis is given. Insight into the knowledge domains of product development and multi body Dynamic is given together with an introduction to the area of distributed simulation and modularization techniques. The performed work is to be seen as cross-functional work in order to bring different domains together for the sake of a better total product development.

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