Analysis of Cantilever Reinforced Concrete Chimney with Variation in Geometry

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Abstract— Any structure needs to be withstanding for two issues, strength and stability. Structure requires a support system that has sufficient strength to bear loads and stability to transmit it safely to the ground. The paper shows the analysis of cantilever reinforced concrete chimney subjected to lateral loads like earthquake and wind loads by considering the variation in geometry. The previous investigations concluded that, height to diameter ratio and thickness of concrete shell are able to resist maximum part of lateral load on reinforced concrete chimney. The scope of present work is to analysis of cantilever reinforced concrete chimney with different height to base diameter ratio and top to base diameter ratio. The equivalent static analysis has been carried out by using STAD-PRO Software and maximum moment and stress calculated as per procedure given in IS 4998 (part -1)-1992. The models where examined for parameters like shear force, bending moment, bending stress, deflection and modal oscillation. The behaviour of reinforced concrete chimney will examine in this experimental work by analyzing it. In this experimental case we are going to assume the different base and top diameter and thickness of concrete shell maintaining the same height of reinforced concrete chimney. Based on the results analysis, the best reinforced concrete chimney is suggested for such consideration.

Key words: Reinforced Concrete Chimney, Cantilever, Lateral Load, Stad-Pro2007

I. Introduction

In recent constructions, the reinforced concrete structures are frequently designed. These are an inseparable structure which behaves separately as the design variables are changes. The design of such structure becomes perceptible and more composite. However, in most cases these are the congregation of several basic structural components likewise, shell, slab, beams, columns, walls and foundations. In the initial design stage, working with the structure in all its complexity have to be resolved and prove to be well ordered. At this instant, the superstructure response must be studied and designed for risk-free case. For ensuing to that, design load to be used for the model to capture the essentials of the structural performance which show the way the structure channels the applied loads into the foundations. Thus, models and numerical outcomes recognized from computerized primarily design are furthermost suitable in evaluate the reaction of structures. These attained values will furthermore apply to design the foundation work of specific models.

Chimneys or stacks are very significant industrial structures for creation of lethal gases to a greater promotion such that the gases do not pollute surrounding atmosphere. These structures are high, 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 reasonable for elevation up to 45m.Geometry of a self-supporting steel chimney plays an important role in its structural behaviour under lateral dynamic loading. This is because geometry is primarily responsible for the stiffness parameters of the chimney. However, the fundamental geometrical parameters of the steel chimney (e.g., overall height, diameter at exit, etc.) are associated with the consistent environmental conditions.

India has been striving to alleviate the electric power crisis, recently aggravated due to the economic boom in the country. Out of the two main sources of power, i.e. Hydro Power and Thermal Power, the latter has become more popular due to its adaptability towards larger production capability. Thermal power is obtained through burning coal, which is required to operate the steam boilers. When burnt, the coal produces polluting gases that need to be discharged at a high elevation enough to dilute the pollution and to keep it within acceptable limits at ground level. An adequately designed tall chimney serves this purpose. As the pollution norms have become stringent with time, the chimney heights have gone up progressively from 100m to 150m to 220m to 275m.In most thermal power plants, 275m tall concrete chimneys have now become the standard norm. It may be worthwhile mentioning here that a bi-product of burning of coal is fly ash, which is produced in the process line between boiler and chimney. This fly ash is extracted using electrostatic precipitators, which incidentally can be used in blended cement and as mineral admixture in concrete.

A. Background

Each structure is to be designed for strength, limiting deflection, and durability. The purpose and aesthetics of structures should keep in attention throughout getting this strength, distortion and durability. It may imaginable when the structural engineer had quite knowledge about architectural necessities. In case of high-rise structure, definite flops may arise due to lateral loads. The lateral loads are almost live loads, whose main horizontal force component acting on the different members of structure. The lateral force effects due to wind and earthquake loads are generally examined as an equivalent static load in most type of high-rise structure. These configurations are designed in such a way that its every component must resist two types of loads like vertical Load due to gravity and lateral load due to earthquake and wind. The component reinforce concrete chimney is shell, which transfer vertical load and lateral load to the foundation. The present study is an introductory report on the analysis of cantilever reinforced concrete chimney with variation in geometry and different orientation, when they are subjected to the lateral loads.

This report shows the certain design values for different configurations of chimney structures which may take consideration for foundation designing work. The effects of lateral force due to wind and earthquake loads are analyzed by an equivalent static load method. Also the lateral earth pressure on footing is also considered while analysis. The present study is carried for the region Pravaranagar, Loni, Ahmednagar, district of Maharashtra state in India. According to which wind load and earthquake load parameters were considered as per IS code. The present study is carried only to study the merits and demerits of these types of chimney configuration based on the results analysis, for such terrain conditions.

B. Exploration

On top of that design code (IS 4998 (Part 1): 1992) enforces several criteria on the geometry and design of reinforced concrete chimneys to ensure a desired failure mode. Two important IS- 6533: 1989 recommended geometry limitations for designing self-supporting chimneys are as follows:

- Minimum outside diameter of the unlined chimney at the top should be one twentieth of the height of the cylindrical portion of the chimney.
- Minimum outside diameter of the unlined chimney at the base should be 1.6 times the outside diameter of the chimney at top.
- Present study attempts these limitations imposed by the deign codes through finite element analyses of reinforced concrete chimneys with various geometrical configurations.

II. LITERATURE REVIEW

A. Kareem, J. Hsieh study the statistical analysis of the moment capacity of a tubular reinforced-concrete (R/C) section was performed. The moment capacity of the cross section was estimated utilizing a second-order stress-strain relationship for concrete. This study followed the American Concrete Institute (ACI) code in assuming that the ultimate moment-capacity limit state is reached when the concrete strain attains a value of 0.003.

Alok David John, Ajay Gairola, Eshan Ganju, and Anant Gupta study the wind load on reinforced concrete chimney, particular consideration has been given to bending moment due to across-wind vibration, because it has been found that across-wind vibration is more prevalent for the case of interloping at a 45 degree angle of wind incidence. Bending moment due to across-wind vibration for interference is found to be nearly twice compared to that of unconnected condition.

B. Siva Konda Reddy, V. Rohini Padmavathi, Ch. Srikanth proposes a single coherent formulation that delivers compact expression for evaluating along wind, cross wind, and torsional response generalized gust factor approach. It presents the wind -loading model and uses a generalized equivalent spectrum technique to derive closed form solutions of the 3D wind excited response of slender structures and structural elements. This encompasses a solution previously obtained for along-wind vibration to the cross-wind and torsional response. Numerical examples are provided that clarified the simplicity and precision of this method. Because of this simplicity and precision, the method is suitable for use in design offices as a mean of providing rapid estimates of the dynamic response of slender structure to gust buffeting actions.

C.M. Cheng, Ahsan Kareem discussed the across wind response of isolated reinforced concrete chimneys of circular cross-section is studied using wind tunnel tests, full-scale measurements and response predictions based on semi-empirical methods. Three chimneys with available full scale response interpretations were selected for this study to compare their measured and expected responses. The wind tunnel experiments occupied measurements of unsteady aerodynamic loads on rigid models of circular cross-section and aero-elastic response of scale models of full-scale chimneys. Tests were conducted primarily on smooth surface models, which were replicated with artificially abraded surface.

G. Piccardo, G. Solari discussed the Study of along and across wind effects on a 275m tall RCC lined chimneys for Ist & VIth wind zones of India and the results show that in shell completed condition, for zone I (i.e. basic wind speed 33m/s) across winds are governing and for highest wind zone of VI (i.e. basic wind speed 55m/s), along wind loads are leading rather than the across wind loads. The analysis is passed out using STAAD PRO &MS excel spread sheets.

K. Anil Pradeep, C.V. Siva Rama Prasad analysed the 60m reinforced concrete chimney. Assessment has been made for wind and seismic analysis. Seismic analysis is done as per IS 1893(part 4): 2005 and wind analysis as per Draft Code CED38 (7892):2013 (Third revision of IS 4998(part 1):1992). On studying the results given in the paper, it shows that as the zone factor rises the values of shear force and bending moment rises. The effect of wind force for 55m/s wind speed is quite significant as compared with the earth quake forces in Zone II and Zone III. Moment due to earthquake in Zone III is almost equal to the Combined Moment due to wind speed of 55m/s.

A. Objective of Work

- To carry out computerized analysis on different types of models using stad-pro software.
- To study various primary load cases and their combination consideration
- To identify and use of load combination
- To identify geometry variation parameter
- To study the effect of variation in geometry of cantilever reinforced concrete chimney
- To compare the reliability of cantilever structures in different geometry.
- To determine the bending stress, lateral displacement and lateral forces for the cantilever concrete chimney by analyzing the models for static forces.

B. Problem Statement

Cantilever or self-supported reinforced concrete chimney is hollow cylindrical type of reinforced concrete structure generally use for emission of hazardous and poisonous gases to a higher elevation from ground level so that these gases do not contaminate surrounding atmosphere. This type of structure subjected to wind load. The Height, Diameter of top and bottom as well thickness of shell of reinforced concrete chimney plays an important role to withstand for the effect of wind and seismic action. The wind load consider as a static as well as dynamic. Analysis for such type of action or effect of loading on various models of reinforced concrete chimney by considering geometry variation (Height, Diameter, Thickness) and it is need to be evaluate correctly.

C. Methodology

- Development of loading configuration for wind
- Modeling of cantilever reinforced concrete chimney using stad-pro
- Development of load cases
- Development of load combination
- Static analysis of reinforced concrete chimney for wind load
- Identify critical load combination for model of chimney
- Calculate moment ,force and bending stresses for the chimney models
- Discussion on detailing of analysis and graphs
- Results.

III. LOAD EFFECTS ON REINFORCED CONCRETE CHIMNEY

Cantilever concrete chimneys experience various loads in vertical and lateral directions. Important loads that a concrete 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 concrete 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 concrete design of chimney. This chapter describes the wind load and seismic load effects on cantilever concrete chimney.

A. Wind Engineering

For cantilever concrete 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:
Gusts Vortex shedding and Buffeting

B. Estimation of Wind Loads

Two methods of estimating of wind loads are given in IS 4998 (Part 1): 1992. The first is a simplified method and is likely to yield slightly conservative results as far as across wind loads are concerned. The reason for this, as explained earlier, is the paucity of basic fluid-elastic interaction information, sufficiently acceptable data on atmospheric turbulence in several parts of our country and absence of any systematic full scale investigation on tail structures in our country. The second method is based on random response method

- Simplified Method
- Along-Wind Load or Drag Force

The along-wind load or drag force per unit height of the chimney at any level shall be calculated from the equation:

$$F_z = p_z . C_D . d_z \quad (1)$$

Where p_z = design wind pressure obtained in IS 875 (Part 3): 1987

Z = height of any section of the chimney in m measured from the top of foundation

C_D = drag coefficient of the chimney to be taken as 0.8

d_z = diameter of chimney at height z in m

The design wind pressure (p_z), for the along- wind response, shall be obtained in accordance with IS 875 (Part 3); 1987, taking the appropriate factor depending upon the class of the structure as defined in that standard.

The chimney shall be divided into ten or more sections along its height and the load at any section shall be calculated by suitably averaging the loads above and below it. The moments are calculated from the sectional forces treating the chimney as a free standing structure.

C. Across-Wind Loads

The amplitude of vortex excited oscillation perpendicular to direction of wind for any mode of oscillation shall be calculated by the formula:

$$\eta_{oi} = \left\{ \frac{\int_0^H d_z \phi_{zi} \, d_z}{\int_0^H \phi^2_{zi} \, d_z} \right\} \times \frac{C_L}{4 \pi S_n^2 K_{si}}$$

Where
= peak tip deflection due to vortex shedding in the i^{th} mode of vibration in m
= peak oscillatory lift coefficient to be taken as 0.16
= height of chimney in m
= mass damping parameter for the i^{th} mode of vibration
= Strouhal number to be taken as 0.2
= mode shape function normalized with respect to the dynamic amplitude at top of the chimney in the i^{th} mode of vibrations.

- Random Response Method
- Along-Wind Response

The along-wind response of a chimney shall also be calculated by the Gust Factor method as described below. The use of the Gust Factor method requires knowledge of Hourly Mean Wind Speed (HMW). Hourly mean wind speed at any height (z), shall be obtained as per IS 875 (Part 3): 1987. Along-Wind Load on a Chimney

The along-wind load per unit height at any height z on a chimney shall be calculated from the equation:

$$F_z=F_{zm}+F_{zf} \quad (3)$$

Where

F_{zm} is the wind load in N/m height due to HMW at height z and is given by:

$$F_{zm}=p_z.C_D.d_z \quad (4)$$

Where

F_{zf} is the wind load in N/m height due to the fluctuating component of wind at height z and is given by:

$$F_{zf} = 3 \cdot (G-1)/H^2 \cdot (Z/H) \int_0^H F_{zm} \cdot z \cdot d_z \quad (5)$$

p_z = design pressure at height z, due to HMW is obtained as 0.6 v^2 z (N/m^2)

G is the gust factor which shall be calculated from the equation:

$$G=1+g_f.r.\sqrt{(SE/\beta)} \quad (6)$$

Where

g_f = peak factor defined as the ratio of the expected Desk value to RMS value of the fluctuating load

r = twice the turbulence intensity

= 0.662-0.178 $\log_{10}$ H

E = a measure of the available energy in the wind at the natural frequency of chimney

B = background factor indicating the slowly varying component of wind load fluctuation = $[1 + (H/265)^{0.63}]^{-0.88}$

V_{10} = hourly mean wind speed in m/set at 10 m above ground level = V_b. k_2,

Where, v_b and k_2 are as defined in IS 875 (Part 3): 1987

f_i = natural frequency of chimney in the first mode of vibration in Hz

S = size reduction factor =

$$[1+ 5.78\,(\frac{f1}{v10}) \times 1.14 \times H^{0.98}]^{-0.88}$$

D. *Seismic Effect*

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. For designing earthquake resistant structures, it is necessary to evaluate the structural response to ground motion and calculate respective shear force, bending moments. Hence ground motion is the important factor for seismic evaluation. To estimate exact future ground motion and its corresponding response of the structure, it depends on soil-structure interaction, structural stiffness, damping etc. For analysis purpose, chimney is behaved like a cantilever beam with flexural deformations. Analysis is carried out by following one of the methods according to the IS codal provision,

- Response-spectrum method

This method consists of three steps such as, Fundamental period, Horizontal seismic force and Determine design shears and moments

The fundamental period of the free vibration is calculated as,

$$T = C_T \sqrt{\frac{W_t \cdot h}{E_s \cdot A \cdot g}} \quad (7)$$

Where

= coefficient depending on slenderness ratio of the structure

= 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

= modulus of elasticity of material of the structural shell

g = acceleration due to gravity

Stiffness of the flared chimney is approximately two times the prismatic chimney. Therefore the conservative estimate of natural time period for this self-supported steel chimney will be:

$$T_{empirical} = \frac{T}{2} \quad (8)$$

D. Horizontal seismic force

The horizontal seismic force (Ah) is to be calculated according to IS 1893 (Part 1): 2002 as Follows:

$$A_h = \frac{\left[\frac{Z}{2}\right]\left[\frac{S_a}{g}\right]}{\left(\frac{R}{I}\right)} \quad (9)$$

Where

Z= zone factor

I= importance factor

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

$\frac{S_a}{g}$ = spectral acceleration coefficient for rock and soil sites

E. *Design Shear Force and Moment*

Either simplified method (that is, equivalent static lateral force method) or the dynamic response spectrum modal analysis method is recommended for calculating the seismic forces developed in such structures.

1) Simplified Method (Equivalent Static Lateral Force Method)

The simplified method can be used for ordinary stack like structures. The design shear force, V and design bending moment M for such structures at a distance X from the top, shall be calculated by the following formulae:

$$V = C_v \cdot A_h \cdot W_t \cdot D_v \quad (10)$$

$$M = A_h \cdot W_t \cdot \bar{h} \cdot D_m \quad (11)$$

Where

= coefficient of shear force depending on slenderness ratio k

= design horizontal seismic coefficient

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

= height of centre of gravity of structure above base, and

= distribution factors for shear and moment respectively at a distance X from the top

IV. CONCLUDING REMARK

From the above study the following conclusions were noted:

- Cantilever reinforced concrete chimney is affected due to its various parameters like height, base diameter, top diameter as well as thickness of shell.
- Also the geometry of cantilever reinforced concrete chimney will be affected to strength, stability to withstand in steady
- Tapering angle is also one of the important parameter for designing the cantilever reinforced concrete chimney.
- Thus tapering angle plays an important role in the analyzing cantilever reinforced concrete chimney.

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