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Analysis and Design of Self-Supporting RCC Chimney Considering Wind, Seismic, and Geometrical Effects

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ABSTRACT

Industrial RCC chimneys are tall and slender structures that play a vital role in dispersing flue gases at higher elevations to reduce environmental pollution at ground level. Due to their height and geometry, these structures are highly susceptible to lateral loads such as wind and seismic forces. The present project focuses on the analysis and design of a self-supporting reinforced cement concrete (RCC) chimney by considering wind load, seismic load, self-weight, and geometrical parameters in accordance with Indian Standard codes.The study investigates the influence of chimney geometry, particularly the height-to-diameter ratio and top-to-base diameter ratio, on the structural behavior of RCC chimneys. Manual calculations and finite element analysis are carried out using software tools such as STAAD.Pro and ANSYS to evaluate stresses, bending moments, and lateral displacements. Dynamic wind effects, vortex shedding, and seismic behavior are also examined as per IS 6533 and IS 1893 provisions. The results highlight the critical role of geometry in governing the structural response of RCC chimneys. It is observed that wind load is the dominant factor influencing the design, and increased height and slenderness significantly amplify bending moments and displacements. The study also emphasizes the importance of considering inspection manholes and dynamic effects in chimney design for ensuring safety and durability.

*Keywords:*RCC Chimney, Wind Load, Seismic Load, Slender Structures, Finite Element Analysis, Height-to-Diameter Ratio, Vortex Shedding, Lateral Displacement, STAAD.Pro, ANSYS, IS 6533, IS 1893, Structural Stability, Dynamic Analysis**.**

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, rcc or masonry, are used to build chimneys. Rcc chimneys are ideally suited for process work where a short heat-up period and low thermal capacity are required. Also, rcc chimneys are economical for height upto 45m. Fig. 1 shows a photograph of self-supporting rcc chimneys located in an industrial plant.

Fig. 1: Self-supporting Rcc Chimney

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There are many standards available for designing self supporting industrial rcc chimneys:Indian Standard IS 6533: 1989 (Part-1 and Part-2), Standards of International Committee on Industrial Chimneys CICIND 1999 (rev 1), etc.Geometry of a self supporting rcc 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 basic geometrical parameters of the rcc chimney (*e.g.*, overall height, diameter at exit, etc.) are associated with the corresponding environmental conditions. On top of that design code (IS-6533: 1989 Part 2) imposes several criteria on the geometry of rcc chimneys to ensure a desired failure mode. Two important IS 6533: 1989 recommended geometry limitations for designing self supporting rcc chimneys are asfollows:

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 rcc chimneys with various geometrical configurations.

Chimneys or stacks are important industrial structures for the emission of toxic gases to a better elevation such the gases don't contaminate the close atmosphere. These structures are tall, slender and customarily with circular cross-sections. Different construction materials, like concrete, rcc or masonry, are accustomed build chimneys. Rcc chimneys are ideally fitted to method work wherever a brief heat- up amount and low thermal capability area unit needed. Also, rcc chimneys considerable & economical for height up to 45m

“Chimneys are the tall vertical structures used to disperse the hot flue gases from the industriesto the higher altitudes to reduce the effect of pollutants at the ground level.” By dispersing the pollutants at higher altitudes, the pollutants get dissolved and the effect of the pollutants will getreduced. Generally, chimneys are constructed with different type of materials such as masonry,concrete, rcc, RCC.Bricks chimneys are become more outdated due to heavier cross sections, high expensive foundations and highlimitations. In between 45 to 65m height, RCC chimneys arevery competitive with rcc chimneys. Whenever the height of the chimney is greater than 65mat that time RCC chimneys are preferable. “The draft is defined as the pressure available for producing a flue burnt gases.” The draft of the chimney depends on the following factors,

a) Height of the chimney above mean sea level.

b) Type of the fuel to be burnt

c) Type of furnace installed in the chimney.

d) Temperature of the burnt-out gases.

The process in the chimney is given below:

When the chimney is heated to a particular temperature, the gases within the chimney are gets heatedup. These hot gases will expand. Normally these gases will occupy larger volume space inchimney than the before. Thus, weight of hot gases per cubic meter becomes less. Asa result of this, pressure at the bottom of chimney will be less than the pressure due to weight of cold air outside the chimney. The difference between two pressures will be the reason for the flow of flue burnt gases outside the chimney. While competent design engineers generally address the primary factors in designing industrial chimneys, there are certain aspects that might sometimes be overlooked or underestimated. These aspects, while may not seem critical at first glance, can significantly impact the performance and lifespan of the chimney. Here are some key technical parameters that may occasionally be ignored:

- Corrosion Resistance: Although material selection is a primary consideration, the specific resistance to corrosion may not be thoroughly evaluated. The flue gases may contain acidic or caustic compounds, and selecting materials or applying coatings that are highly resistant to corrosion can extend the life of the chimney.
- Fatigue Analysis: Repeated thermal cycling, wind loads, and vibrations can lead to material fatigue over time. Fatigue analysis, which considers the cumulative effect of these cyclic loads, is sometimes overlooked but is essential to prevent premature failure.
- Condensate Management: When flue gases cool down, condensation may occur inside the chimney.

The handling of this condensate is often not given adequate attention. Thiscan be particularly problematic if the condensate is acidic, as it can cause corrosion or environmental issues if not properly managed.

II.LITERATURE REVIEW

1. Menon and Rao (1997)

Menon and Rao conducted a detailed study on the across-wind response of reinforced concrete chimneys by reviewing various international code procedures. Their research examined discrepancies in codal estimates of across-wind bending moments and load factors using a reliability-based approach. The study emphasized that across-wind effects caused by vortex shedding can produce significant stresses in tall chimneys and, in certain cases, may even govern the design. The authors recommended incorporating reliability analysis in chimney design to reduce uncertainties in wind load estimations and improve structural safety.

2. Kareem and Hseih (1986)

Kareem and Hseih performed a reliability analysis of concrete chimneys under wind loading conditions. The study considered both along-wind and across-wind load effects using probabilistic structural dynamics. Parameters such as wind environment, structural properties, and wind–structure interaction were treated as random variables. Failure criteria were defined based on excessive top deflection and exceedance of ultimate bending moment capacity. Their findings highlighted that wind-induced dynamic effects significantly influence chimney reliability and should not be neglected in structural design.

3. Flaga and Lipecki (2010)

Flaga and Lipecki analyzed the lateral response of circular RCC chimneys due to vortex shedding. A mathematical model was proposed to estimate the maximum top displacement resulting from vortex excitation. The study showed that cross-wind vibrations are strongly dependent on the Strouhal frequency and the natural frequency of the structure. The authors compared codal approaches and suggested improvements for better prediction of stress and displacement responses. Their work underlined the importance of considering dynamic wind effects in slender chimney structures.

4. Chmielewski et al. (2005)

Chmielewski and co-researchers investigated the natural frequencies and vibration modes of a 250 m high multi-flue industrial RCC chimney considering soil flexibility. Finite element analysis was used along with experimental validation through geophone sensors. The results demonstrated that soil–structure interaction significantly affects the dynamic characteristics of tall chimneys. The study concluded that ignoring foundation flexibility may lead to inaccurate estimation of natural periods and seismic response.

5. Wilson (2003)

Wilson conducted experimental and analytical studies on the earthquake response of tall reinforced concrete chimneys. A nonlinear dynamic analysis procedure was developed to evaluate inelastic behavior under seismic excitation. The research showed that ductility plays a crucial role in preventing brittle failure during strong ground motion. The findings emphasized that seismic design of chimneys must consider nonlinear behavior and energy dissipation capacity to ensure structural resilience.

III.WORKING METHODOLOGY

The analysis and design of the self-supporting RCC chimney were carried out using a systematic approach combining literature review, codal provisions, manual calculations, and finite element analysis. Initially, relevant Indian Standard codes such as IS 6533 (Part 1 & Part 2): 1989, IS 875 (Part 3): 1987, and IS 1893 (Part 4): 2005 were studied to understand loading criteria, geometric limitations, and structural design requirements. Based on these provisions, different chimney geometries were selected by varying parameters such as height-to-base diameter ratio, top-to-base diameter ratio, flare height, and shell thickness. Both codal-compliant and non-compliant configurations were considered to evaluate the influence of geometry on structural behavior.

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The chimney was modeled as a cantilever cylindrical shell structure with fixed base support. Loads considered in the analysis included dead load (self-weight), wind load (along-wind and across-wind effects), seismic load using response spectrum method, and temperature load due to thermal gradients between inner lining and outer shell. Wind loads were calculated as per IS 875 and amplified for dynamic effects as specified in IS 6533. Finite element modeling was performed using STAAD.Pro and ANSYS software by discretizing the shell into plate elements to obtain accurate stress and displacement results. Eigenvalue analysis was carried out to determine natural frequencies and mode shapes for evaluating resonance effects.

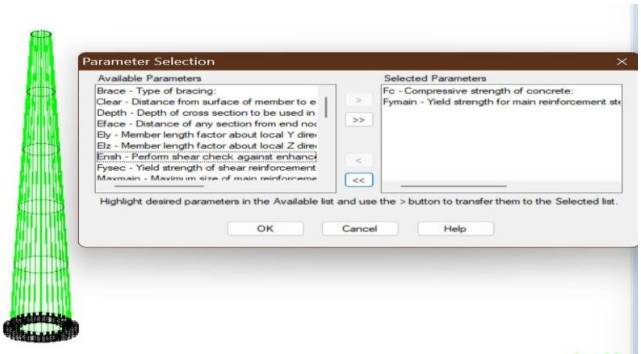

Fig. 1 – Parameter Selection Window in STAAD.Pro

Fig. 1 shows the **Parameter Selection dialog box** used during the concrete design stage of the RCC chimney in STAAD.Pro. This window allows the designer to define essential material and design parameters such as compressive strength of concrete (Fc) and yield strength of reinforcement steel (Fy main). Other available parameters include effective depth, clear cover, shear reinforcement strength, and member length factors. By selecting these parameters, the software performs design checks according to codal provisions. Proper selection of these values ensures accurate calculation of bending capacity, shear resistance, and overall structural safety of the chimney shell.

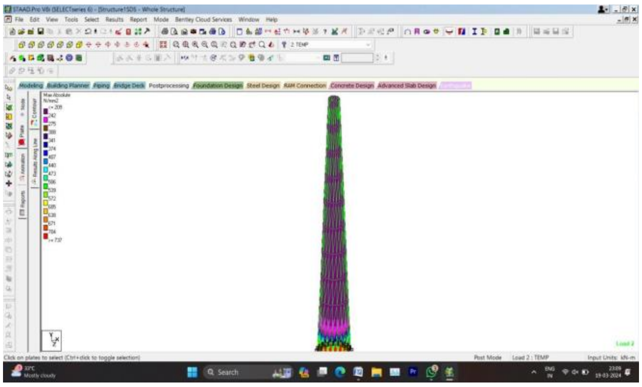

Fig. 2 – Stress Contour under Temperature Load (Post-Processing Mode)

Fig. 2 illustrates the stress distribution of the RCC chimney under a **temperature load case** in STAAD.Pro post-processing mode. The color contour (ranging from blue to red) represents variation in stress intensity along the height of the chimney. Higher stress concentrations are visible near the base region, indicating maximum bending and restraint effects due to fixed support conditions. The upper portion shows comparatively lower stress values. This analysis helps evaluate thermal stress effects caused by internal flue gas temperature variation and ensures that temperature-induced stresses remain within permissible limits.

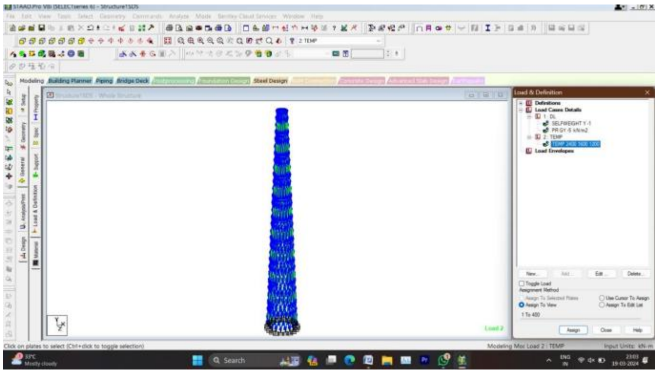

Fig. 3 – Load Definition Panel with Temperature Load Assignment

Fig. 3 displays the **Load & Definition window** where different load cases are defined and assigned to the chimney model. The listed loads include dead load (self-weight), platform load, and temperature load (TEMP). The temperature gradient values are applied to simulate thermal expansion and contraction of the chimney shell. Assigning loads correctly is crucial because load combinations determine the critical design forces. This figure demonstrates how temperature loading is incorporated into the structural model for realistic analysis.

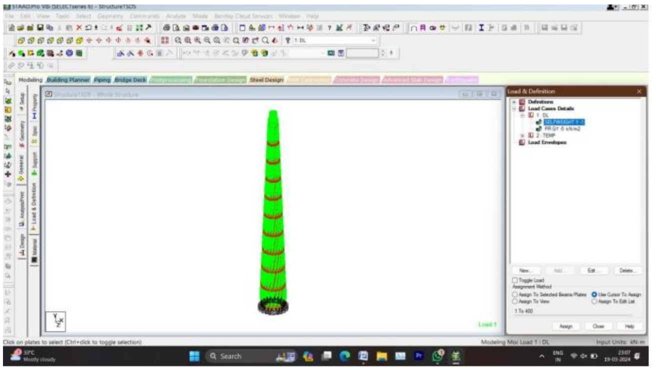

Fig. 4 – Dead Load Analysis

Fig. 4 represents the RCC chimney model subjected to **dead load (self-weight)** analysis. The structure is shown in green color, indicating uniform stress distribution due to gravity loading. Since chimneys act as cantilever structures fixed at the base, maximum compressive stresses occur near the bottom region. This analysis verifies the effect of self-weight on axial compression and ensures that base stresses remain within allowable concrete limits. It also confirms structural stability before applying lateral wind and seismic loads.

IV.CONCLUSIONS

It is found from these analyses that maximum moment and the maximum bending stress due to dynamic wind load in a self supporting rcc 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. Last part of this chapter presents the effect of inspection manhole on a self supporting rcchimney. This results show that manhole increases the von-mises stress resultant and top displacement in a chimney. This is because manhole reduces the effective stiffness of a chimney as evident from the modal analysis results. Inspection manhole increases the von-mises stress resultant and top displacement in a self supporting rcc chimney. This is because manhole reducesthe 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 self supporting rcc chimney.The main goal of this thesis was to compare the geometrical constraints of self-supporting RC and rcc chimneys in terms of analysis. Here, we examine and evaluate rcc and concrete chimneys, taking into account lateral forces and the results produced in terms of Node Displacement.The analysis concluded that as the H/D ratio increases, node displacement increases, and RC rcchimneys are more exact than rcc chimneys when the peak of the stack is increased. An increase in the structure's weight increases wind moments, whereas an increase in the structure's height and the height to bottom diameter ratio increases both static and dynamic wind moments

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