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Critical Review on Dynamic Analysis of R.C. Chimney

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Abstract—In order to establish a system that vents hot gases or smoke into the open air, a chimney must surround the flue. In order to ensure a smooth flow of gases and to draw air into the combustion, known as the stack effect or chimney effect, chimneys are typically vertical or almost vertical. Today's industrial chimneys are typically constructed using reinforced concrete (RC), including those in India. The purpose of the chimney is to release flue gases into the environment at a height and speed that keep the concentration of pollutants, like sulphur dioxide, below ground level within allowable limits. The gases are propelled upward after exiting the top of the chimney by their own buoyancy in relation to the surrounding air and the velocity of the flue gases released. The purpose of this paper is to review the prior literature on thorough analysis of RC chimneys subjected to static-dynamic wind load and seismic loading. We also attempted to identify any gaps in the prior literature that might affect our future work.

Indexed Terms— R.C. chimney, Wind moment, IS4998, natural frequency

I. INTRODUCTION

In order to protect the environment, chimneys must carry vertically and release gaseous byproducts of combustion, chemical waste gases, and exhaust air from industries into the atmosphere. Many chimneys are built each year as a result of the quick industrial expansion. The height of RCC chimneys has increased over the course of a few years as a result of rising pollution. As far as we are aware, no modular chimney has ever been built (configured as needed) anywhere in the world in any business, unless the chimney is too small. It is possible to build domestic chimneys with external support. In order to build self-standing structures that can withstand wind load, earthquake load, dead load, and other forces operating on them, accurate analysis of RCC chimneys is required.

Due to advancements in design codes, it is deemed essential to evaluate the design of previously constructed chimneys using current codes in order to ensure their safety. The behaviour of the RC chimney's windscreen during seismic activity and the structure's reaction to a certain wind load are the main subjects of this study.

1.1 Load effects on Concrete Chimneys

RC concrete chimneys are subjected to various loads in both the lateral and vertical axes. The principal loads that a concrete chimney normally experiences include pressure from wind loads, pressure caused by seismic activity, and pressure brought on by temperature changes, in addition to the structure's own weight and the forces exerted on the service platforms. The effects of wind on RC chimneys have a substantial impact on their structural behaviour because they are frequently relatively tall and slender structures. A significant factor for chimneys is earthquake since seismic load is a dynamic natural load. Code regulations advise using the quasi-static technique when assessing earthquake loads.

The main source of load for RC chimneys is wind, which applies significant pressure to the wall of the chimney. Additionally, wind load could be separated into three components, such as,

1. Along-wind load
2. Across-wind load
3. Torsional effect

A quasi-static load component and a dynamic load component can be combined to represent the pressure applied by the wind at a specific location on a surface of the chimney wall. The force that the wind will apply at a mean steady speed, causing a displacement in a structure, is known as the quasi-static load component.

Figure 1 depicts the schematics of the along-wind, across-wind, and torsional moment in relation to the direction of wind flow.

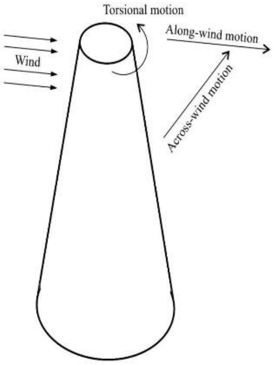

Figure 1. Schematics of wind effects with respect to its direction of flow

II. RELATED WORK

Swati Pandey et al. (2023) evaluated the induced pressure across the chimney with different shapes: sharp-edged, chamfered, and filleted-edged. The FSI analyses were carried out on chimneys made of M25 concrete. They came to the conclusion that, when compared to the generic or sharp-edged RCC chimney model, the RCC chimney model with a filleted edge and chamfered edge has the least impact on the wind load. At high wind speeds (i.e., 44 m/s), the robustness and structural stability of chimney constructions were established. It was determined that the CFD simulation tool could accurately calculate the induced pressure on the chimney construction. [1]

Gagandeep Singh et al. (2022) aimed at deriving standard curves with the help of which one can easily calculate the approximate wind load on a chimney in shell-completed condition. For chimneys with differing heights, top internal diameters, taper, and placements in various wind zones, the curves have been plotted. The finalization of the initial sizing of the chimney and its supporting structure will depend on these curves. The codes IS 4998: 2015 and IS 875 (Part 3): 2015 are used for wind analysis. They came to the conclusion that as wind zone rises, wind load also does. Although wind has a parabolic relationship with height, in very tall tapered stacks, the along wind load decreases as the diameter increases as the wind speed increases. [2]

Khaled M. Ahmida et al. (2022) investigated a chimney at the Tripoli-West power plant. The excitation forces acting on the chimney were mainly due to wind; therefore, data about wind velocities over a long period of time were collected from the National Centre of Meteorology in Tripoli. In the analysis, wind velocities' maximum and average values were used. The wind flow was modelled using the flow simulation tool, and the simulations were carried out using SolidWorks, the finite element analysis software. The deflection at the top of the chimney was estimated and compared to internationally acceptable criteria after conducting stress and deformation analyses. They discovered that the chimney might still be built taller to shield the local buildings from dangerous emissions because of the plant's expanding surrounding population. [3]

Alqama Hasan et al. (2020) analyzed the chimney of a circular section on the basis of finite element modelling using SAP2000 software. The R.C.C. chimney was subjected to a nonlinear time history study taking into account two separate earthquake ground motions. For the nonlinear time history analysis of the R.C.C. chimney, the base was assumed to be fixed and various seismic responses, such as the maximum base shear, maximum base moment, maximum top displacement, and chimney time period, were taken as input ground motion from the El Centro near field and Landers Baker far field earthquake records. Here, the laminated rubber bearing was used as an isolator as part of the base isolation strategy to control the reactions. According to the findings, base isolation significantly reduces seismic responses under strong ground motion because it decouples the superstructure from the earthquake ground motion by creating a flexible interface between the foundation and the base of the structure. The seismic responses under the El Centro near-field earthquake were found to be very high in comparison to the Landers-Baker far-field earthquake. [4]

Prathyusha Yadav et al. (2020) reviewed the findings of a 100-m reinforced cement concrete chimney's seismic and wind analyses. The lumped mass modelling technique was used to model the chimney in STAAD.Pro V8i SS6. The wind load study was carried out in accordance with IS 4998:2015, while the earthquake analysis was carried out in accordance with

IS 1893 (Part-4):2005. The design values were determined by considering the results of seismic and wind analyses. They created a 100-meter RCC chimney using the limit state method and the most recent code. [5]

Changdong Zhou et al. (2019) proposed a useful technique known as partitioned fragility analysis. The practical project was a single, 240-meter-high reinforced concrete chimney, whose analytical model was made using the ABAQUS modelling programme. The chosen high-rise chimney structure was separated into 17 components, and the fragility analysis was used to determine the damage probability of each part in various damage states while taking into account multidimensional ground motions. The peak ground acceleration was chosen as the intensity measure, and 20 ground motion records were picked as input motions from the Next Generation Attenuation database. Based on incremental dynamic analysis, the chimney structure's response to multidimensional ground motions was determined. The damage limit states of the chimney construction were established as the maximum strains of concrete and steel bars. According to the fragility curves and surfaces produced by this research, the chimney construction is most vulnerable between the heights of 0 and 20 metres, 90 and 130 metres, and 150 and 200 metres, respectively. Based on the findings of the analysis, these weak spots can be retrofitted to increase the seismic resistance of the chimney structures that are already in place. [6]

K. Shruti et al. (2019) by taking into account the presence of an identical chimney at various distances and under various wind angles, the interference factors of a typical chimney structure were assessed. They came to the conclusion that a 0 degree wind incidence angle caused about 40–50% of the shielding effect seen for all locations of interfering objects evaluated. For the chimney layouts under consideration, a 30-degree wind incidence angle provides the least interference effect of any wind angle. The areas of the main chimney structure with s/b values between 0 and 0.6 (left windward face) are vulnerable to increased wind loads for all chimney locations (1.5D, 2D, and 2.5D) and for all wind angles (0 degree, 30 degree, 60 degree, and 90 degree). [7]

Babu, B. Jose Ravindraraj, R. Ram Kumar, and R. Saranya (2016) examined the tall chimneys' dynamic behaviour. They used a 275m-tall reinforced concrete chimney in Warora, Maharashtra, for their research. Their goals were to investigate how the presence of flue holes alters the stress pattern and to test how along-wind and across-wind influences affect the height of the chimney for various wind directions and speeds. In order to analyze the chimney, a three-dimensional model made with plate parts and STADD Pro was developed. They came to the conclusion that the wind load always determines the design of reinforced concrete chimneys, and that the along wind effect regulates the design more so than the across wind effect. When compared to a flue duct with a rectangular opening, the semi-circular flue duct has the least compressive stress at the corners. For the semi-circular flue duct, the forces at the aperture are also 30% lower. [8]

Elias et al. (2016) examined the efficiency of the distributed tuned mass dampers in terms of the multi-mode control of reinforced chimneys during seismic ground motion. They displayed the geometrically regular and irregular features of the chimneys in both cracked and uncracked circumstances. By positioning the tuned mass damper where the amplitude of the mode form of the chimney was the maximum, the parametric investigation was conducted to realize the most suitable mass and damping ratios. Using tuned mass dampers, the study's findings led to a decrease in peak displacement and enhanced seismic response control. [9]

Rakshith B. D., Ranjith A., Sanjith J., and Chethan G. (2015) incorporated by finite element analysis, detailed the analysis and design principles of chimneys in accordance with Indian codal requirements. Effect of the inspection manhole on the behaviour of cantilever steel chimneys was studied using two chimney models, one with and one without the manhole. The finite element programme STAAD Pro was used to examine these models, with a focus on how geometric restrictions affected the construction of chimneys. These analyses revealed that the top-to-base diameter ratio and height-to-base diameter ratio are continuous factors of the geometry, which determine the maximum moment and the maximum bending stress caused by dynamic wind load in a cantilever steel chimney. This research does not support the IS 6533 (Part-2): 1989 requirements for the top diameter to height ratio and minimum base diameter to top diameter of the chimney. [10]

T. Saran Kumar and R. Nagavinothini (2015) presented a study on the impact of vortex shedding on steel chimneys. According to the size and shape of the body, vortex shedding occurs when air or fluid flowing by a cylindrical body at a specific speed creates an oscillating flow. When a body is stable or turbulent, the Reynolds number is utilised to forecast the patterns of fluid flow. According to IS 6533-1989 (Part 2), five models of chimneys with various top and bottom heights and diameters were created, and the wind load was computed using IS 875 (Part 3)-1987. According to research on the impact of vortex shedding on various chimney types, the height of tall chimneys affects how much vibration is caused by the wind. [11]

Jeevan T. and Sowjanya G. V. (2014) centred on quantifying how soil flexibility affects the key design parameters affecting the seismic response of chimney structures with raft footing. The behaviour of the soil beneath the structure was examined using both linear and elastic soil models, with the research taking into account RC Chimney models. The soil structure interface was modelled as surface-to-surface contact. The standard FEM programme SAP 2000 for ground motions (BHUJ) was used to analyze the soil-structure model's temporal history. In other words, it was noticed that vertical displacement is not linearly variable, showing the maximum vertical displacement below the chimney shell for all scenarios. They came to the conclusion that for the raft deflection criteria, the deflection decreases as the stiffness of the soil is increased. When compared to the usual approach, the influence of soil-structure interaction significantly reduced the radial and tangential moments of the annular raft. Peak displacement was reduced and seismic response management was improved as a result of mass damper adjustment. [12]

Dr. B K Raghu Prasad, Dr. Nitin Shepur, and Dr. Amarnath K (2014) covered the dynamic analysis of a 150-metre-high RCC chimney exposed to wind. There has been analysis done for the fixed base scenario. For the purpose of determining the overall design loads, they used a method described in the IS 4998 (Part 1): 1992 code. Their objective was to analyze chimneys with pendulum dampers for design wind loads. They arrived to the conclusion that the pendulum damper and the mass at the top of the chimney reduce the chimney's natural frequency. The corresponding logarithmic decrement curve damper that best fits the data is chosen for study. The displacement, velocity, and acceleration are decreased to the chimney with the pendulum damper. [13]

III. RESEARCH GAP

From all of the aforementioned research publications, it is clear that the majority of researchers focused on across and along wind analysis, or static and dynamic wind force, and their behaviour in relation to chimney height. At any one time, wind forces only operate in one direction. The design takes into account the structure's height as well as the wind's predominant direction. The wind force increases with the structure's height. But as long as the seismic shock waves remain flowing through the ground, they will turn around like a clock's pendulum. Seismic waves can also travel in any direction, according to a compass. As a result, the foundation level of the structure is built to withstand seismic forces from all directions. Since seismic and wind forces are not assumed to act simultaneously, we will study the dynamic behaviour of the structure using the Response Spectrum Method. From these two forces, only one force will be applied at a time, and the distribution of temperature stresses will also be determined.

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