Analysis of tall chimney with piled raft foundation under wind load using ANSYS

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Abstract. Chimneys are the principal structures in any industry that emits pollutants to higher parts of the atmosphere. The geometrical traits of the chimney are so unique that it has slender dimensions and tapering geometry and therefore the analysis and design of chimney and other forms of tower structures should be carried out individually. Nowadays chimney heights have gone up from 100 m to more than 400 m according to the purpose that it serves. These tall chimneys are very sensitive to wind loads. Wind load is one of the most important parameters that affect the response of tall building’s chimneys. When tall chimneys are subjected to wind load, it may undergo lateral deflection. It also leads to the development of radial and tangential moments along with base moments. The dynamic wind effects on chimneys by analytical procedures are intricate and take a great amount of time. To analyze and further improve the response of chimneys, analysis using commercial finite element (FE) software ANSYS is carried out. Chimney with and without providing stiffeners is analyzed using ANSYS and the lateral deflection and bending moment found from the chimney models are compared. This method is more economical and time-saving.

1. Introduction
Chimneys are the principal structures in any industry that emits pollutants to higher parts of the atmosphere. Nowadays chimney heights have gone up from 100 m to more than 400 m according to the purpose that it serves. An increase in the number of power plants and other manufacturing industries gave rise to taller chimneys [1]. The geometrical traits of the chimney are so unique that it has slender dimensions and tapering geometry and therefore the analysis and design of chimney and other forms of tower structures should be carried out individually [2]. The wind is the most destructive natural phenomenon, whose action is crucial for the safety and cost of construction [3]. For structures with extreme heights and dynamic performance, the effect of wind load will have an important role in the design [4]. For instance, the wind effect over a solar chimney is important even at low velocities of 1-2m/s [5]. Slender structures like RC chimneys are also severely damaged or collapsed during severe wind storms [6]. The damage in chimneys is mainly caused by wind load, temperature stress, and construction defect. The dynamic wind effects on chimneys by analytical procedures are intricate and take a great amount of time and require specialized software like ANSYS for its analysis [7].

In this paper, an annular raft foundation is used for the chimney under consideration as they are more sensible and inexpensive compared to a full circular raft for commercial chimneys. Piled foundations can be used when the geotechnical circumstances are not commendatory for raft
foundations. Skin friction piles are more acceptable for chimney foundations compared to end bearing piles [7].

Most of the chimneys are damaged and suffering from deficient maintenance and conservation. These types of damages are classified according to their origin [8]. When chimneys are subjected to wind load, it may undergo deflection. So, to reduce or prevent the deflection in tall chimneys due to wind load, stiffeners are provided to it as an additional fitting. This paper focuses on analyzing the deflection and bending moment of tall chimneys subjected to wind load using ANSYS software and also to compare the deflection under conditions with and without stiffeners using ANSYS.

2. Methodology
The methodology of the study includes preparing a model of the chimney with piled raft foundation, generating meshed structure, data validation, and analysis. Analysis of chimney subjected to wind load is carried out with and without providing stiffeners and the results of deformation produced are compared.

2.1. Modelling
The model of a tall chimney is prepared using ANSYS software with a height 100m, height to base diameter ratio 7, base diameter 14.5m, top diameter 4m, base thickness 0.5m, and top thickness 0.2m. Young’s modulus of the chimney is 30 GPa as per IS: 4998(Part 1)-1992. Poisson’s ratio and density of concrete are taken as 0.18 and 23 kN/m³ respectively. Soil is assumed to be having young’s modulus of 108000 kN/m² and Poisson’s ratio of 0.4. The chimney is kept up over the piled raft foundation with an annular raft of uniform thickness. The raft is piled with 79 RC friction piles of 1m diameter and 20m length. Bedrock is considered at a depth of 30m. Piled raft foundation is used for conveying high vertical and horizontal loads efficiently to the subsoil[9]. The pliability of the soil and the raft thickness are the two main factors upon which responses in chimney and raft depends. [10].

A concrete model that represents a tall chimney is formulated by drawing areas at plan (x-y) in the first step. The model of a 100m tall chimney prepared is shown in Figure 1. After preparing the model, a meshed structure is generated for the model using the available options. The meshing of the chimney is done directly as cubic elements by the element SOLID65. The meshed structure of the chimney is shown in Figure 2 and the model of chimney provided with a piled raft foundation is shown in Figure 3.

Figure 1. Model of 100m chimney. Figure 2. Meshed structure of 100m chimney.
2.2 Data Validation
The prepared model of the chimney with piled raft foundation is analyzed and total deformation in the structure is found out as shown in Figure 4.

![Figure 3](image1.png)  ![Figure 4](image2.png)

**Figure 3.** Chimney model with piled raft foundation.  **Figure 4.** Variation in chimney deformation.

The natural frequency obtained from the analysis of a 100m tall chimney model using ANSYS is 1.3333Hz, which is in accordance with previous studies [7]. The error percentage was found to be 0.004%. Hence the data is validated.

3. Analysis of Chimney Subjected to Wind load

3.1 Chimney without Stiffeners
Using ANSYS software, a model and meshed structure of a tall chimney are prepared with height 200m, height to base diameter ratio 7, base diameter 29m, top diameter 17.4m, base thickness 0.82m, and top thickness 0.35m. After creating the model and meshed structure of the chimney, the boundary conditions, the turbulent intensity of 5%, and wind velocity of 39m/s are defined in fluid flow. The analysis of chimney subjected to wind load without providing stiffener to resist the deformation caused by wind load is carried out and is shown in Figure 5.

![Figure 5](image3.png)

**Figure 5.** Chimney subjected to wind load.
When the chimney is subjected to wind loads, imported pressures get developed on the chimney which causes deformation. Imported pressure development is shown in Figure 6.

![Figure 6. Imported pressure in the chimney.](image)

As a result of applied wind load and developed pressure in the chimney, deformation will occur in the chimney which is analyzed using the static structural tool and is shown in Figure 7.

![Figure 7. Deformation in chimney without stiffeners.](image)

3.2 Chimney with Stiffeners

Analysis of chimney of 200 m height with stiffeners subjected to wind load is carried out and results are compared. The cross-section of stiffener provided is 0.60m x 0.60m. A combination of horizontal and vertical stiffeners is provided to a 200m tall chimney. Vertical stiffeners are provided for 200m length and the length of horizontal stiffeners are varied according to the chimney’s diameter. The link
element used is Link 180. The model and meshed structure of the chimney with stiffeners are shown in Figure 8 and Figure 9.

One of the main factors to be considered while providing stiffeners to the chimney is contact. Here bonded contact is provided for chimney and stiffeners. Bonded contact will provide a welding effect between the chimney and the stiffeners. The bonded contact between chimney and stiffener is as shown in Figure 10. After modeling the chimney, it is subjected to wind load with velocity and boundary conditions in the fluid flow system. Once wind load is applied on the chimney, the pressure gets imported and is shown in Figure 11. The deformation generated due to windload in chimneys provided with stiffeners is shown in Figure 12.

Figure 8. Model of chimney with stiffeners
Figure 9. Meshed structure of chimney

Figure 10. Bonded contact between chimney & stiffeners
Figure 11. Imported pressure in chimney
4. Results and Discussion
A 200m chimney with and without stiffener is analyzed by applying wind load of same velocity 39m/s using fluid flow in ANSYS. The deformation generated in the chimney with the application of windload when with and without stiffeners is found out using a static structural analytical tool.

It is found that in chimney without stiffener, the maximum deflection occurred at the topmost part is 17.951mm and for chimney with stiffeners, maximum deflection is reduced to 7.881mm. Hence with the increase in elevation of the chimney, deformation due to wind load also increases. The difference in maximum deflection in the chimney with and without providing stiffeners is 10.07mm. Hence stiffeners are found to be useful in reducing deflection in chimneys caused due to wind load.

5. Conclusion
In this study concrete chimneys subjected to wind, loads are analyzed using ANSYS software. The deformation that occurred in the chimney is evaluated and validation of the model with data from the base journal is also done. The chimney is then provided with vertical and horizontal stiffeners to reduce the deformation. The deformations that occurred in chimneys with and without stiffeners are then compared.

Conclusions made from the study are as follows:
- When the chimney without and with stiffener was analysed by applying wind load, the maximum deflection occurred at the topmost part of the chimney.
- With the provision of horizontal and vertical stiffeners, the maximum deflection in the chimney due to wind load reduced considerably.
- Hence stiffeners are found to be useful in chimneys for reducing deflection due to wind loads.

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