

# Aerodynamic Load Reduction Using Shape Optimization Of Tall Buildings

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## Abstract.

Wind-driven consequences are critical in the design and study of towering and slim buildings. Among these, directional winds are a dynamical element of wind loads that can have a substantial impact on structural response. The Gust Factor Method, which is used in ETABS, provides a simple yet efficient way to account for the variability of wind by adjusting the mean wind load with a gust factor that is determined based on building height, exposure category, and wind terrain features. ETABS allows for the immediate incorporation of gust factor estimates into structural evaluations, assisting engineers in modelling realistic wind load conditions for compliance with codes. Shapes refinement is growing more popular as a means to enhance aerodynamics and structural performance. The method alters building design to reduce wind drag and vortex shedding, therefore minimizing dynamic wind impacts and structure demands. Shape refinement and wind simulation methods may now be strongly combined because to developments in computational tools. The firm's RWIND digital wind tunnel software complements ETABS by allowing for extremely accurate computational fluid dynamics (CFD) simulations. It allows engineers to see and measure wind flow around complex building shapes, as well as generate precise pressure distribution. RWIND interfaces with ETABS modelling tools, allowing for more precise windy load calculation and structure response prediction.

**Keywords:** Aerodynamic Loads; ETABS; RWIND; Shape Modification; CFD

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## 1. INTRODUCTION

The nature of wind is unpredictable; wind doesn't flow in a straight steady pattern rather it flows irregularly causing generation of various aerodynamic loads on towering structures which can lead to collapse if the structure is not designed properly. Tanagawade T and T.S. (2022) analyzed fourteen towering buildings with the help of ETABS. Comparing static, dynamic wind, and earthquake loads, finding that dynamic wind responses showed nonlinear parabolic patterns, contrasting with the linear behavior of static wind loads. Wind flow creates zones of positive and negative pressures on the structure, where positive pressure is generated when wind flows directly on the face of the structure and negative pressure is generated at the back of the structure. These pressure differences give rise to wind loads which can cause the structure to the displace in a particular direction based on the wind impact. The obstruction around a structure is also a main factor affecting the generation of wind load. (Maied & S Rao, 2023) examines 100-meter buildings for all four terrain categories, showing that absence and presence of obstruction height around the structure also is responsible for the wind load generation. Gust Factor Method and Wind Tunnel examination is used on towering structures for accurate load calculation for design and safety purposes; however, the dynamic wind calculation requires accurate knowledge of the standard codes for calculation and involves lengthy calculations. Whereas wind tunnel examination is a costly method. Virtual Wind Tunnel examination is a cost-effective new concept for dynamic analysis and load calculation. (P. Me 2024) examines wind behaviour using a virtual wind tunnel, story-to-story load calculations respectively.

## 2. Aerodynamic Loads: Digital Wind Tunnel

Fig. 1 displays the vortex shedding which gives rise to aerodynamic loads like drag and lift forces. Where drag loads tends to pull away the structure from its resting position and lift forces tend to lift the structure from its resting position, pressure differences also develop which are due to the shape of the structure. Shah et al. (2022) studied performance of RCC buildings with various degree twist in the model height confirmed that digital wind tunnel examination helped to know the behaviour of wind with respect to the structural shape and can help suggest even more better geometrical shape and angle of twist for shape optimisation. Li (2024) used wind tunnel tests to study wind loads on cable-suspended structures strong negative

pressures affected the first windward rows. DKran, TK Aurlien (2019) shows that the wind gust follows a chaotic pattern which needs dynamic load calculation for the safety and serviceability of the structure. JGinger, Holmes, Harper (2021) studies and calculates the wind load with the help of mechanical sensors on tall structures.

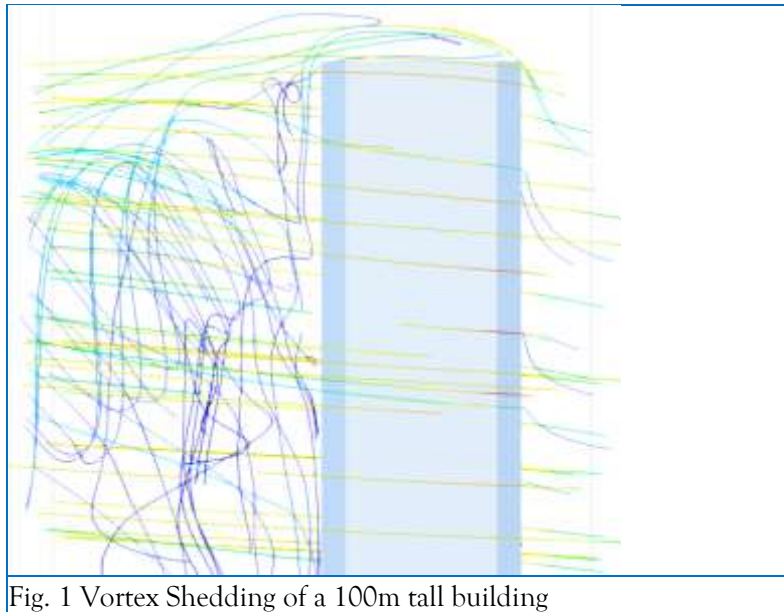


Fig. 1 Vortex Shedding of a 100m tall building

### 2.1 Dynamic Effects of Wind

Wind impact causes dynamic displacement which gives rise to bending moment, shear, torsion in the structural members which affects the stability of the structure. That's why engineers check the maximum story displacement and story drifts of the structure. In most of the cases height of the structure divided by 500 check is done to check the safety and stability of the structure. Das Gupta et al. (2023) analysed a 10-story structure with wind speeds of 150–260 km/h. Results showed increases in displacement and drift with wind speed. Davari et al. (2019) developed tall framed-tube buildings using a revised shape factor enhancing design stages. Patel (2024) studied tall buildings and towers wind loads using various design principles showed reduced displacements and drifts for taller buildings. Khan and Jeelani (2019) analysed seven stories building using various advanced designs combination for stability analysis of the structure. Soni et al. (2021) evaluated 18 stories RC building comparing shear walls, bracing, dampers, for effecting wind load mitigation. Mudassir et al. (2020) reviews wind-induced displacements, drifts, and forces for regular and irregular structural shape.

(Badami et al., 2020, p. 6) evaluates lateral systems for tall buildings, concluding deflection and moments increase with stature. XFuWen (2020) reveals that dynamic air response for towers during storms checking the turbulence and wind speed impacts with GRF calculations for stability. This study uses ANSYS Fluent CFD with  $k-\epsilon$  and LES models to analyse wind effects on a 200m building, validated by experiments. Pressures applied in ETABS show CFD aligns with codes, highlighting the Indian code's conservatism and CFD's reliability for wind analysis. (W. S., 2020, pp. 18–20). Ahsank and Ming study wind-gust to improve structural integrity which will resist the high wind load generations. DaeKKwon, AhsanK (2019) study various design standards for improvement in the strength and stability of the structure comparing the structural response.

Liu, GrA. Kopp (2022) studies gust factor importance in wind load analysis refining wind pressure design, enhancing building safety and resilience. LiuY, S.-F. (2019) examines various building models with the different plan ratios, analysing wind pressures. showing how building shape influences airflow and wind forces. (GLiang, 2022) uses CFD simulations on actual places with and without trees to study arising the wind forces. Thun (2020) analyses tall buildings with the Static and dynamic methods which affects the generating wind forces calculations. RA.C and AJ. (2022) analyses tall building models in design and analysis softwares, according to codal provisions.

## 3. METHODOLOGY: DESIGN OF STRUCTURES

Tall structures are designed according to the wind load calculation by a countries codal provisions by which the amount of force generation on each story and structure is calculated and these loads are inputted in design and

analysis software's where the actual behaviour of the structure can be observed. The observation of the structural model shows the highest story displacement and story drifts respectively. If any structural member fails then the structural member needs an optimised design to withstand these generating forces."XFu,WLong; HNan Li,and LRen(2021) monitors increase in air response factor with increase in wind speed which required an optimised structural design. (Rathikindi et al., 2018) uses design and analysis software to analyse towers which showed that towering structures required a stability optimised design. Fig. 2 shows a tall building modelled in a design and analysis software for dynamic wind analysis

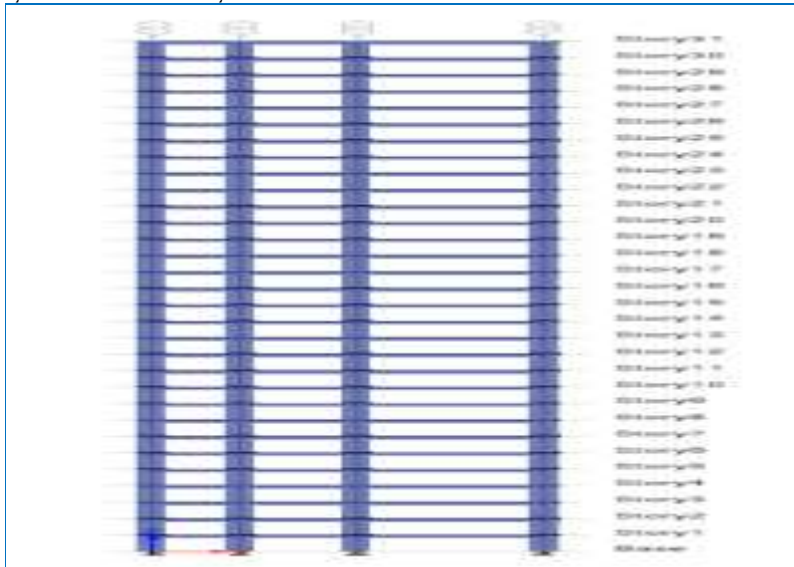


Fig. 2 Model of a 100m tall building for wind load analysis

Similarly, the wind load calculation can be done by using Wind Tunnel Examination which requires to develop the model of the structure which is tested in the tunnel and the load values are found out with the help of sensors and digital recording devices. These load outputs are then inputted in the design and analysis software's and the structural response and integrity is checked respectively. (Pj vicekry2018) study storm factors on all of the structure models and target to get a neutral steady flow on the model with the help of geometry optimisation in the research A.Agarwal,JSingh(2018) analyse shaking of the structure due to the wind loads for towering structure in wind tunnel examination noting the speed of wind and its impact with respect to terrain category. Fig. 3 shows a tall structure model in a wind tunnel facing wind load generation according to the wind speed input.

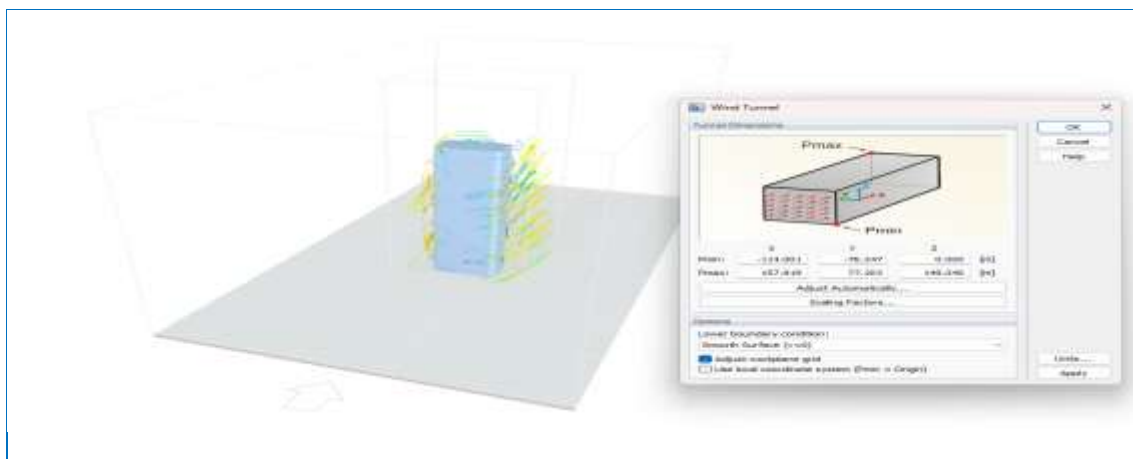


Fig. 3 Model of a tall building for wind load analysis in wind tunnel

(Shaikh et al., 2017) observes the displacement, for various advanced structural design elements to reduce the structural vibrations. (K. R R, M.I. S, R Iyer, Gopal, 2018) Analyse a tall structure in a design and analysis software for wind and seismic loads. The structural design needed to be revised for strength and stability purposes. (SRaza,2019) analyses regular and irregular structure in design and analysis software, showing the

importance of symmetry in design of structures. (Q.S.Li,2020) studies the reports of various tower during high storms and wind tunnel load values focusing on the design procedures. (Kwon et al., 2016, p. 1) presents an artificial intelligence for aerodynamic load calculation, and the dynamic displacements of the structures. (Utkin 2018) studies a tall building in the design and analysis software, captures structural performance beyond the allowable safety limits.(Zhao et al., n.d., p. 3) introduces the aerodynamic loads as deforming loads for the wind load calculation to know the safety and structural integrity. Sukumar et al. (2019) investigates design wind loads on a regular structural shape using wind tunnel examination and the codal provisions. Maziar; M Emes; J Yu (2022) analyses the air factor giving importance to the various terrain categories for the aerodynamic load's calculation. Sébastien Légeronb, Kaabiaa,Langloisa (2018) predicts dynamic responses of wind gust with dragging and lift forces. (Alaghmandan et al., 2019, p. 4) present optimised design method with computational fluid dynamics and design and analysis software's which help to strengthen the structure. Jani and Patel (2021) analysed wind loads using tunnel-based reports and also the codal based calculations for the process. Khan and Subhan (2018) analyse a tall building for wind as well seismic calculations concluding that stiffness of the structure is the main factor to control these loads. Pavai, Kumar, and Spingale (2019) structural design for high statured building using design and analysis software to improve the structural stability. Chandran (2018) develops the tall building design and optimization and emphasizes the safety, serviceability, stability, and comfort, discussing advanced structural systems. (Kwon et al., 2018) compares wind codes for tall buildings, which helps to conclude the difference of forces in each of the code-based calculations.

#### 4. Reduction of Aerodynamic Loads: Shape Modification

Shape Optimization involves modifying a structures geometry and shape to reduce the amount of wind loads generating by allowing the wind to pass around a structure in such a way that the vortex shedding is minimal which will help to reduce the wind loads generation. Fig. 3 shows a 200 meters steel tower experiencing high wind load generation due to its sharp edges, which gives high generation of vortex shedding which is also known as vortex tail. The longer the vortex tail the higher will be the wind load generation.

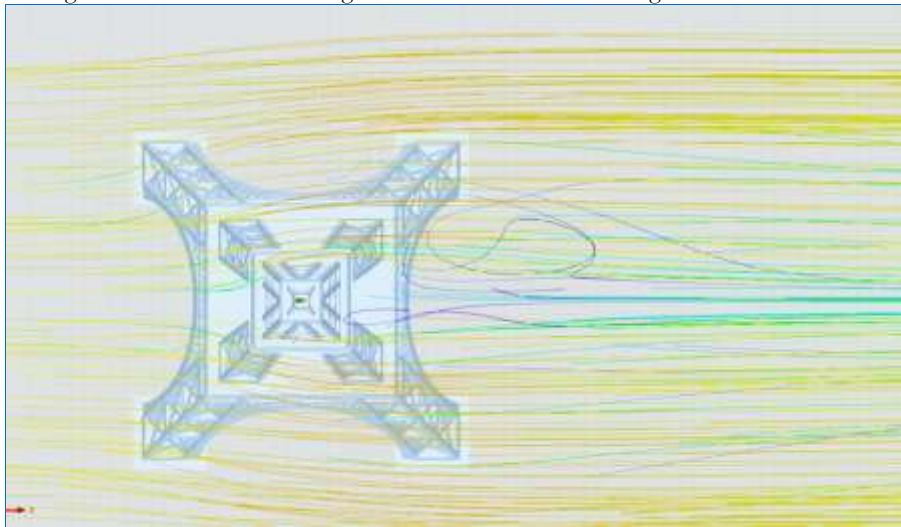


Fig. 3 Top view of a 200m steel tower

Fig. 4 shows how wind acts to a curved surface RCC steel tower, compared to Fig. 3 the wind load is reduced due to curves at the edges of the structure and also a reduced vortex shedding tail is observed in the figure. Which shows that how just modification in the edges and centre of the structure can help reduce wind loads.

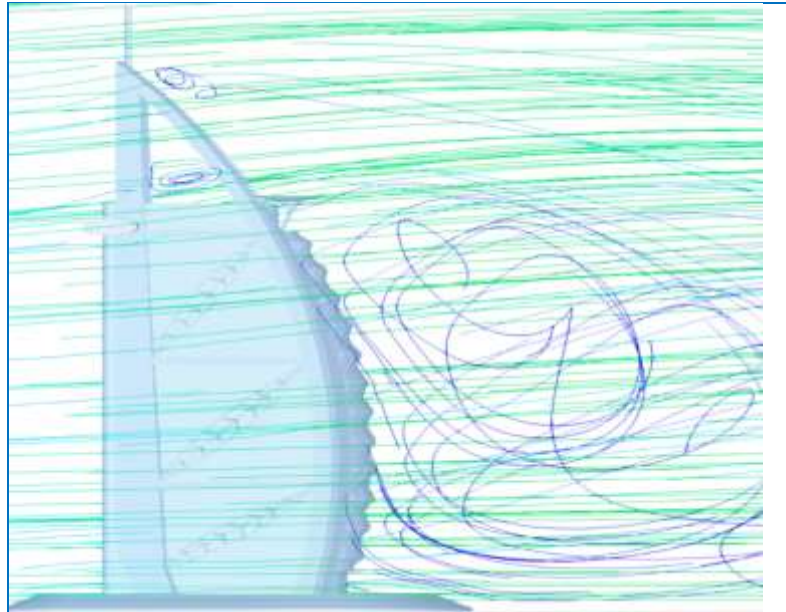


Fig. 4 Model of a 200m RCC+ steel tower

## 5. CONCLUSIONS

A shape optimizing procedure and digital wind tunnel examination is used for reducing the generation of wind forces which has been proposed in this study.

- Shape optimization is a good strategy to reduce the wind loads.
- Lower the length of vortex shedding tail lower the wind load generation.
- Higher the length of vortex shedding tail higher the wind load generation.
- Digital wind tunnel examination is an effective and cheaper method which mimics the actual wind tunnel testing.
- Design and analysis software's combined with computational fluid dynamics software helps to know the behavior of wind on the structure which helps in shape modification strategy

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