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Exploring Wind-Induced Responses in Buildings with Non-uniform Plans

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Abstract:

This study aims to investigate the wind effects on the structures with vertical irregularities. The project employs ANSYS numerical simulation to investigate the wind effects with different plan shape. The primary objective of this research is to evaluate the wind effects in terms of wind generated effects in the high-rise structure. The building dimensions are scaled down according to the ASCE wind tunnel test manual, maintaining a length scale of 1:100 for CFD investigation. This method provides essential insights into wind pattern circulation and pressure distribution across various wind incidence angles. The wind flow pattern surrounding the structure reveals characteristics of flow separation and the creation of vortices in wake regions. The study indicates that the plan layout and sizes of the model directly influence the distribution of wind pressure on its different faces. In both cases, there is positive pressure on the windward side.

1. Introduction

Due to the continuous rise in population, urban expansion in the horizontal direction has reached a saturation point. Consequently, skyscrapers are emerging globally to accommodate the growing populace. The construction of tall buildings presents a unique challenge, especially in terms of their vulnerability to wind loads. As these structures proliferate, it becomes imperative to implement efficient and meticulous wind load design measures to ensure their structural integrity and safety. This plan-shaped building is very common for residential as well as corporate buildings [1]–[4]. Effects of wind load for common plan shape are available in various international standards [5]–[9]. The design of tall buildings faces a significant challenge, as most international standards do not provide clear guidance on modifying the shape of plan cross-sectional areas. Various researchers, such as Tavakoli et al. [10]. Dadkhah et al. [11], and Kamgar and Rahgozar [12] , have explored different aspects of high-rise building design, seismic performance, and lateral resisting systems. Additionally, studies by Kamgar et al. [13] have delved into soil-structure interaction, and Dadkhah et al. [14] employed non-linear seismic analyses through incremental dynamic analysis. Furthermore, Dadkhah et al. [15] presented optimization techniques for a tuned mass damper to enhance the seismic performance of a six-story steel structure. In a separate study, Kamgar et al. [16] conducted a numerical investigation on the impact of length-to-height ratio on the behaviour of a concrete frame retrofitted with steel infill plates. Nagar et al.[17] have studied interference effects on "H" and square model, Pal and Raj [18] evaluated the full blockage condition for various plan shape tall building models, Pal et al. [19] studied

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interference effect of twin building models on square plan shape and remodelled triangle shape model, Nagar et al. [20] studied interference effect on two '+" shape models. While numerous studies in wind engineering have primarily focused on modifying the shape or height of structures, the current study distinguishes itself by concentrating on structures with equal plan areas, examining both regular and irregular shapes.

The selection of the length-scale ratio for the building model is done with careful consideration, following the guidelines outlined in various international standards and the wind tunnel manual provided by ASCE report no. 67. This study contributes to existing literature by offering a thorough analysis through multiple graphical representations. The building showcasing pressure distribution across 0-degree wind incidence angles. These graphical presentations serve as valuable tools, unveiling the intricate dynamics of wind effects on the various plan shape of the tall buildings. They enhance understanding of the structural response to varying wind conditions in the context of the high-rise building model.

2. METHODOLGY

A numerical investigation was conducted utilizing computational fluid dynamics. Previous studies predominantly employed the k-ε model, known for its well-established predictive capability, stability, and numerical reliability.

- **Basic Equations**

The basic equation used to study the fluid flow problems use Navier-Stokes and continuity equation.

- **Navier stokes equation:**

$$\frac{\partial(\rho u_i)}{\partial t} = -\frac{\partial(\rho u_i u_j)}{\partial x_j} - \frac{\partial P}{\partial x_j} + \frac{\partial}{\partial_{x_j}}\left[\mu\left(\frac{\partial_{u_i}}{\partial_{x_j}} + \frac{\partial_{u_j}}{\partial_{x_i}}\right)\right] + F \qquad (1)$$

- **Continuity equation:**

$$\frac{\partial_\rho}{\partial_t} + \frac{\partial_{\rho_i}}{\partial_{x_i}} = 0 \qquad (2)$$

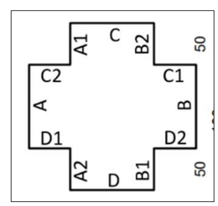
The standard k-ε model uses the following transport equations for the turbulence kinetic energy and turbulence dissipation

$$\rho\frac{\partial k}{\partial t} + \rho\overline{u_i}\frac{\partial k}{\partial x_j} = \tau_{ij}\frac{\partial\overline{u_i}}{\partial x_j} - \rho\varepsilon + \frac{\partial}{\partial_{x_j}}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right] \qquad (3)$$

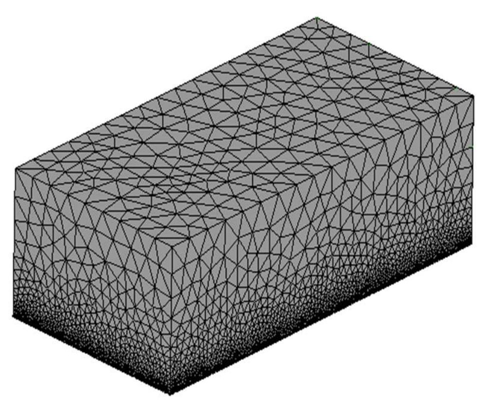
Momentum equation

$$\frac{\partial(\rho U_i)}{\partial t} = -\frac{\partial(\rho U_i U_j)}{\partial x_j} - \frac{\partial P}{\partial x_i} + \frac{\partial}{\partial_{x_j}}\left[\mu_{eff}\left(\frac{\partial_{U_i}}{\partial_{x_j}} + \frac{\partial_{U_j}}{\partial_{x_i}}\right)\right] + S_M \qquad (4)$$

Meshing is a crucial step in enhancing the accuracy of simulations. In our study, meshing is achieved through both manual and automatic methods using ANSYS CFX. In the manual approach, meshing is applied to various components, with the mesh size selected based on the nature of the problem. Additionally, the inflation process is implemented across all models in the CFD simulation. This inflation aims to minimize irregular flow patterns and optimize the overall simulation accuracy. The building and domain meshing are depicted in figure 1.



Plan Shape of Building



Domain Meshing

Figure:1 Building and Domain

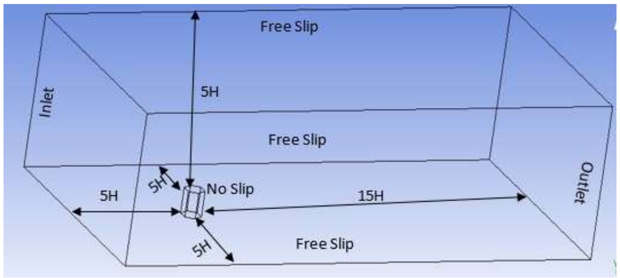


Figure:2 Domain with dimension

In numerical simulations aimed at investigating the effects of wind, the term "domain" refers to the computational space or region where the simulation takes place. This domain encompasses the entire area of interest where wind interactions with structures or geographical features are being studied. The choice and definition of the simulation domain are critical in ensuring accurate and meaningful results. The domain should be carefully selected to include all relevant features, such as buildings, terrain, or other structures, that may influence the wind flow patterns under investigation.

The dimensions and boundaries of the domain play a crucial role in capturing the complex dynamics of wind behaviour. It is essential to extend the domain far enough to account for the interactions that may affect the wind flow, while also considering computational efficiency. The accuracy of the simulation results depends on how well the chosen domain represents the real-world scenario. Researchers often use computational fluid dynamics (CFD) methods to model and simulate wind effects within the defined domain. This approach involves discretizing the domain into a mesh, solving the governing equations for fluid flow, and analysing the resulting wind patterns and their impact on structures. In summary, the domain in numerical simulations for investigating wind effects is the computational space where researchers model and analyse wind interactions with various elements. The proper definition and consideration of this domain are crucial for obtaining reliable insights into the complex dynamics of wind behaviour. Domain with the dimension is represented in figure 2.

3. RESULTS AND DISCUSSIONS

Velocity Profile and Turbulent Profile

The vertical profile of wind speed is determined by the extent of surface roughness and the drag resulting from local projections that impede the wind flow. This profile is characterized by the gradient height, which represents the height at which the drag effects diminish, and the corresponding gradient velocity. Figure 3 is denoting the velocity profile and turbulent intensity profile. The atmospheric boundary layer denotes the altitude at which the topography starts exerting an influence on wind speed. In simpler terms, the features on the surface, such as buildings or vegetation, impact the wind's behaviour, and these effects gradually diminish as we ascend, reaching a point where the terrain no longer significantly affects the wind dynamics.

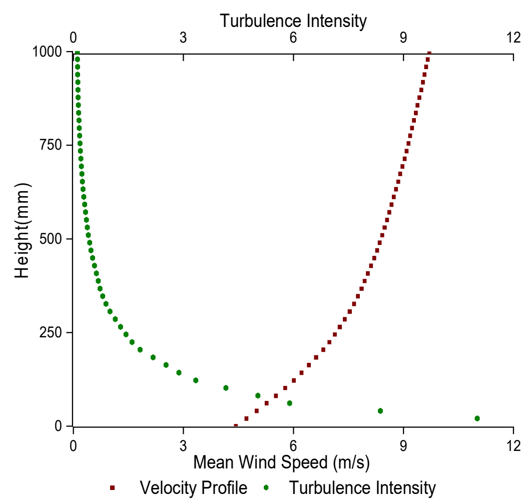
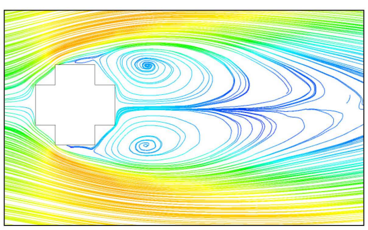


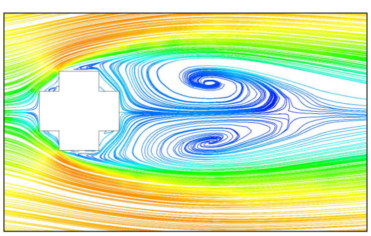
Figure:3 Velocity and Turbulent Intensity Profile

Velocity Stream Lines in Plan and Elevation

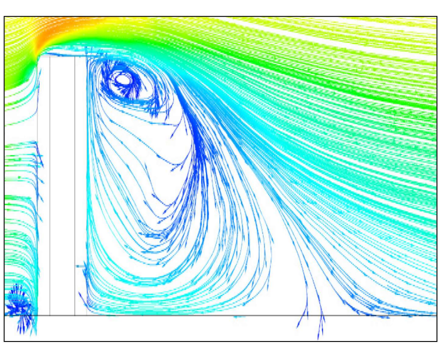
In the realm of architectural and structural engineering, the examination of wind streamlines around building models is a critical aspect of assessing their aerodynamic performance and structural response. Utilizing computational tools such as ANSYS, researchers can simulate and analyse wind flow patterns in both the plan and elevation views of building models. ANSYS provides a sophisticated platform for conducting Computational Fluid Dynamics (CFD) simulations, allowing for the visualization and understanding of how wind interacts with the structural geometry. By employing ANSYS, researchers can generate accurate representations of wind streamlines around the building, identifying areas of turbulence, pressure variations, and potential aerodynamic loads. Figure 5 is presenting the velocity stream line in plan and elevation of the building model. This comprehensive analysis aids in optimizing the building's design to enhance structural stability and minimize potential wind-induced effects. Such simulations contribute significantly to the field of architectural engineering, providing valuable insights that can inform the development of structures with enhanced resilience and efficiency against varying wind conditions.



Velocity Stream line at one third height



Velocity Stream line at one third height

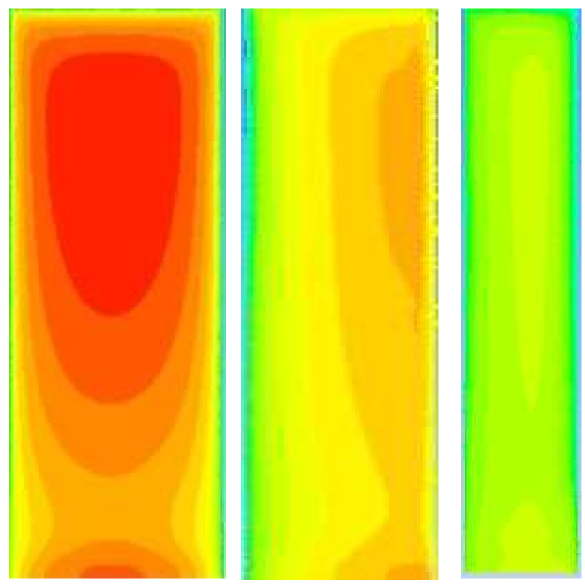


Velocity Stream line in Elevation

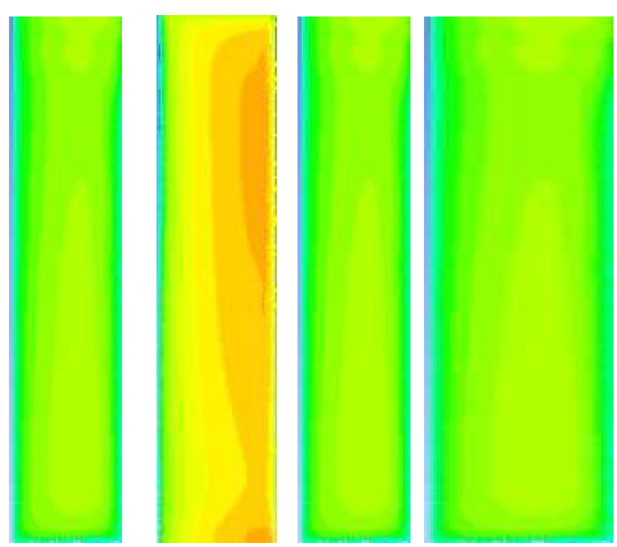
Figure:5 Velocity Stream Line in plan and elevation for the building model

Pressure Contours

In the domain of structural analysis and fluid dynamics, the exploration of pressure contours using ANSYS CFX offers a nuanced understanding of the aerodynamic behaviour of building models. Employing ANSYS CFX, a robust computational fluid dynamics (CFD) tool, researchers can conduct detailed simulations to visualize and analyse pressure distribution across various faces of a building model.



Face A Face D Face D1



Face A2 Face B1 Face D2 Face B

Figure:6 Pressure Contours of the Building Model

This process involves creating a mesh to discretize the computational domain, solving the Navier-Stokes equations governing fluid flow, and generating pressure contours to represent the varying pressures on different surfaces of the building. By scrutinizing these contours, researchers can identify regions of high and low pressure, gaining insights into the aerodynamic loads exerted on the structure. Figure 6 is representing the wind pressure in terms of the contours in various face of the building model for zero-degree wind incidence angle. This comprehensive analysis is invaluable for optimizing building designs to withstand and efficiently manage varying pressure conditions. ANSYS CFX, through its advanced capabilities, provides a sophisticated platform for engineers and researchers to delve into the intricate details of pressure distributions, contributing to the development of structurally sound and aerodynamically optimized building designs.

4. CONCLUSION

This numerical investigation aims to explore the impact of wind on a tall building with diverse corner shape. ANSYS CFX, employing the k-ε turbulence model, facilitates this study. The results encompass pressure distribution and velocity stream lines in plan and elevation. This research contributes to a deeper understanding of wind behaviour on tall buildings.

- Wind pressure distribution on the leeward face of this study shows the development of vorticity, which offers high turbulence
- The work's precision depends upon meshing the geometry model and defining the flow physics as in boundary layer wind tunnel.
- The shape of the building is having the significant effect in determining the wind load on the tall building, wind forces are varying with wind incidence angle.
- The information related to the plus-shaped configuration is valuable for structural designers tasked with planning tall building models of this specific type.

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