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INVESTIGATING WIND EFFECTS AND STRUCTURAL BEHAVIOR IN LOW-ELEVATED BUILDINGS WITH MONO-SLOPE ROOFS

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ABSTRACT

Cyclones pose a significant threat to coastal regions, leading to devastating consequences such as fatalities and extensive property damage. This study delves into the dynamics of wind and structural response in low-elevated buildings with mono-slope roofs, which are particularly vulnerable to cyclonic winds. It examines various types of structures, load considerations, and factors influencing wind loads, emphasizing the importance of enhancing wind resistance and cyclone-proof building designs. Through an analysis of wind flow patterns, pressure distributions, and structural vulnerabilities, this research aims to contribute to the development of effective mitigation strategies. The study employs methodologies such as computational fluid dynamics (CFD) simulations and experimental investigations to explore wind effects and structural behaviors. Insights gained from this research can inform the design, construction, and evaluation of low-elevated buildings with mono-slope roofs, ensuring their resilience against wind hazards.

Keywords: Cyclones, Wind Dynamics, Structural Response, Low-Elevated Buildings, Mono-Slope Roofs.

1. INTRODUCTION

1. 1. Understanding the Impact of Cyclones

Cyclones, among nature's most devastating phenomena, have inflicted considerable damage and loss of life over recent years, standing as one of the most hazardous calamities. These disasters not only lead in terms of fatalities but also account for nearly half of all losses incurred due to natural disasters. The repercussions of cyclones extend beyond immediate casualties, often resulting in widespread homelessness and economic devastation, particularly in vulnerable regions where cyclone-resistant infrastructure remains inaccessible. Consequently, there is a pressing need for further research and development to enhance the resilience of structures to wind loads and fortify them against cyclonic forces.

1.2. Classification of Structures by Height

The classification of buildings based on their height distinguishes between low-elevated and high-elevated structures, each subject to distinct wind dynamics. Low-elevated structures typically have heights below 20 meters, while high-elevated structures soar 50 meters or more above ground level. Intermediate classifications, such as mid-elevated buildings, also exist, filling the height gap between these two categories. The variation in height profoundly influences load calculations and design criteria, with high-elevated structures facing amplified lateral wind pressures compared to their low-elevated counterparts. However, low-elevated structures are typically enveloped within the lower atmospheric boundary layer, where quantifying wind flow presents unique challenges.

1.3. Load Types and Their Impacts

Structures are subjected to diverse loads, including dead loads, imposed loads, wind loads, snow loads, and earthquake loads. Each type of load exerts specific forces on the structure, necessitating meticulous consideration during the design phase. Wind loads, for instance, primarily consist of lateral pressures exerted by airflow on the structure's surfaces, especially roofs and walls. Understanding these loads and their ramifications is crucial for developing robust structural designs capable of withstanding environmental forces. Additionally, factors such as roof angle, shape, building height, interference effects, and wind direction further influence wind load distribution, necessitating comprehensive analysis to ensure structural integrity.

2. LITRATURE REVIEW

2.1. Early Investigations on Wind Dynamics

Early studies in the literature focused on understanding the fundamental principles of wind dynamics and their impact on low-elevated buildings with mono-slope roofs. Holmes (1988) conducted pioneering research on uniform pressures at the final berth of manufacturing facilities, laying the groundwork for subsequent investigations. Hoxey et al. (1993) identified the significant role of construction form in stress redistribution caused by wind, emphasizing the importance of structural shape criteria such as elevation duration and roof slope. Nakayama et al. (1998) and Poitevin et al. (2013) utilized computer models and wind tunnel experiments to validate atmospheric behavior and stress ratios, contributing

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to a deeper understanding of wind flow patterns and pressure distributions. These early studies provided crucial insights into the fundamental principles governing wind dynamics and structural response, serving as the basis for further research in the field.

2.2. Recent Advances and Emerging Trends

Recent advancements in wind dynamics research have focused on addressing specific challenges and exploring emerging trends in the field. Studies by Yousef (2017) highlighted differences in tornado pressure indices, shedding light on the unique challenges posed by extreme weather events. Sanyal et al. (2020) and Liu et al. (2019) investigated the impact of roof design, aspect ratio, and building side ratio on wind load variability and structural response, providing valuable insights for design optimization. Furthermore, research by Singh et al. (2018, 2019) delved into survivability and stress ratios, offering practical implications for enhancing the resilience of low-elevated buildings with mono-slope roofs. These recent studies underscore the importance of ongoing research and innovation in addressing evolving challenges and informing design practices to ensure the structural integrity and safety of buildings in the face of changing environmental conditions.

3. METHODOLOGY

3.1. Design of Geometry of the Building

The initial step involves designing the geometry of the building to be analyzed. A rectangular plan of the structure with specific dimensions and a varying roof angle is created. A scale of 1:100 is adopted for this analysis.

3.2. Selection of Validation Model from IS Code 875 Part 3

Before proceeding with computational fluid dynamics (CFD) simulations, a validation model is chosen from IS Code 875 Part 3 to ensure the accuracy and reliability of the simulation setup.

3.3. Importing the Geometry of Building and Domain Consideration

The geometry of the building and the domain for CFD simulations are imported into the Ansys CFX software. The size of the domain is determined based on guidelines provided by Franke et al. (2004). Domain considerations are set according to established standards.

3.4. Validation Through IS Code 875 Part 3

The computational fluid dynamics (CFD) setup is validated against the wind standards specified in IS Code 875 Part 3. Wind pressure coefficients are calculated and compared to the values prescribed in the code to ensure the accuracy of the simulation results.

3.5. Meshing and Inflation for Simulation

Meshing and inflation are crucial steps in preparing the model for simulation. The meshing of the domain and the model is conducted, with appropriate sizing determined for grid connections and model surfaces.

3.6. Boundary Layer Condition and Flow Physics

Boundary layer conditions and flow physics are defined to accurately simulate the wind flow around the building. The domain sides and top are set as free-slip walls, while the model surfaces and the ground are defined as no-slip walls. Inlet and outlet conditions are specified to simulate a uniform wind flow with a velocity of 10 m/s at the inlet.

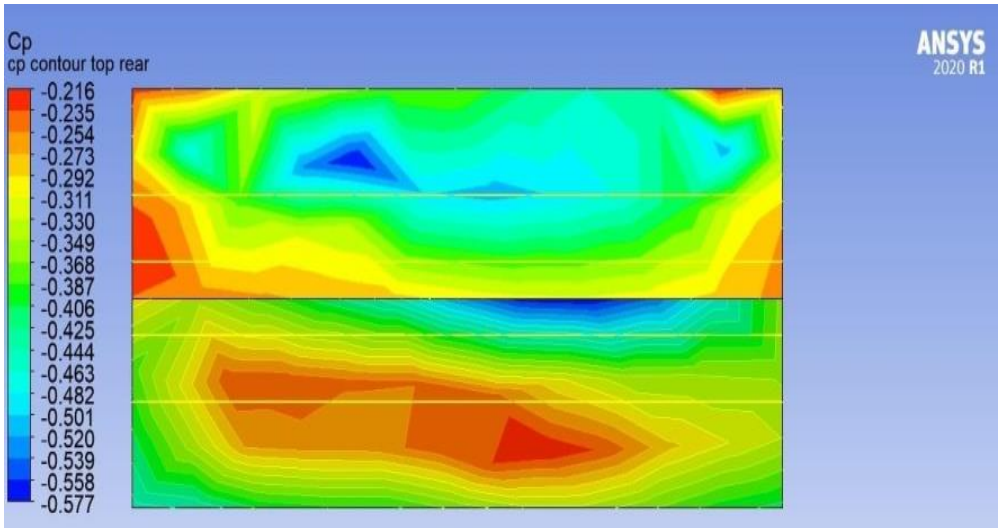

Figure 1: Coefficient of Pressure Contour

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Table 1: Coefficient of Pressure (C_{pext}) at Slope Angle 10 , Spacing 0

Cp_{ext}	Θ = 0°	Θ =30°	Θ = 45°	Θ =60 °	Θ =90°	Θ =120°	Θ =135°	Θ =150°	Θ =180 °
Expression A	-0.0406527	-0.0627486	-0.110534	-0.155597	-0.197928	-0.360115	-0.392668	-0.386884	-0.194457
Expression B	-0.0658035	-0.0979344	-0.150365	-0.20999	-0.238643	-0.334544	-0.311759	-0.254735	-0.0837728
Expression C	-0.0553772	-0.0960077	-0.150045	-0.219762	-0.23525	-0.311067	-0.285808	-0.195796	-0.101008
Expression D	-0.0807649	-0.102174	-0.14518	-0.193305	-0.189833	-0.313402	-0.386189	-0.427012	-0.333214

4. RESULT AND DISCUSSION

4.1. Effect of Roof Slope Angle on Coefficient of Pressure (Cp)

The results indicate a significant increase in the coefficient of pressure (Cp) with varying roof slope angles. As the roof slope angle increases from 100 to 200 and then from 200 to 300, there is a noticeable rise in Cp. This observation suggests that steeper roof slopes experience higher wind-induced pressures compared to shallower slopes. This finding aligns with the intuitive understanding that wind flow is more likely to be obstructed and diverted by steeper roof surfaces, leading to increased pressure coefficients.

4.2. Impact of Wind Direction on Interference Effect

The coefficient of pressure due to interference effect shows variations depending on the wind direction. Higher Cp values are observed for wind directions ranging from 900 to 1800 compared to those from 00 to 900. This discrepancy can be attributed to the shielding effect, where the presence of nearby structures mitigates the impact of wind on the building's surfaces. Consequently, the interference effect is more pronounced when the wind approaches the building from certain directions, resulting in elevated Cp values.

4.3. Relationship between Roof Slope Angle and Cp

The data demonstrate a positive correlation between roof slope angle and Cp. As the roof slope angle increases, the Cp values also tend to increase. This relationship indicates that buildings with steeper roof pitches are more susceptible to higher wind pressures. Design considerations for structures in windy environments should account for this relationship to ensure structural integrity and safety.

4.4. Variation of Internal Pressure Coefficient (Cp) with Wind Direction

The coefficient of internal pressure (Cp) exhibits variations depending on the wind direction and the location of the building. The front-facing building experiences the highest internal Cp values, indicating increased suction pressures on its internal surfaces. Moreover, Cp values are highest for wind directions of 00 and gradually increase thereafter, suggesting asymmetrical wind loading effects on the building's internal spaces.

5. CONCLUSION

1. Roof slope angle significantly influences the coefficient of pressure, indicating its crucial role in structural response to wind loads.

2. Wind direction has a notable impact on the interference effect, with shielding effects observed from 900 to 1800 wind directions.

3. Increasing roof slope angle leads to higher coefficient of pressure values, suggesting the need for careful consideration in design.

4. Internal pressure coefficients vary with building orientation and wind direction, emphasizing the importance of comprehensive analysis in structural design and resilience planning.

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