A Study of Pyramidal Roof Structures: Wind Effects

Anoop Bahuguna
Department of Civil Engineering, Graphic Era Hill University, Dehradun, Uttarakhand, India 248002

Article Info
Page Number: 1171-1183
Publication Issue:
Vol. 70 No. 2 (2021)

Article History
Article Received: 18 October 2021
Revised: 20 November 2021
Accepted: 22 December 2021

Abstract: Human life isn't the only thing that can be lost in a cyclone; other animals and property can be impacted as well. A number of hurricanes or cyclones have occurred at various times in the past. Among all the parts of a building, the roof is the one that is directly subjected to the effects of climate change. Roofing structures are common in India's coastal regions and elsewhere around the globe. The roofs of these exposed buildings must withstand considerable wind loads due to the high wind speeds in the atmosphere. The purpose of this research is to examine how wind pressure coefficients vary across a variety of pyramidal roofs and to monitor wind behavior in the vicinity of the building.

Keywords: Roof Structures, Climate, Cyclones, Building, Wind.

1. Introduction

Human life isn't the only thing that may be lost in a cyclone; other animals and property might be impacted as well. A number of hurricanes or cyclones have happened at various periods in the history. Of all the parts of a building, the roof is the one that is directly subjected to the impacts of climate change. Roofing structures are common in India's coastal regions and elsewhere throughout the globe. The roofs of these exposed buildings must withstand considerable wind loads due to the high wind speeds in the atmosphere. There is a wide variety of roof styles, and each has its unique characteristics. Roofing materials make up less than 3% of the total cost of constructing a home, yet they do so much more. Not only the materials used, but the layout of the roof's ridges and valleys also contribute to its unique character. Figure depicts 20 of the most common roof types to illustrate the variety of options available to homeowners.[1]

While thinking about roof types, design, and architecture, it's important to weigh the benefits and drawbacks of each option. Furthermore, the distribution of wind loads on roof surfaces is influenced by factors such as roof type, design, and architecture. There was excellent agreement between computational and experimental results more specifically, the hemispherical roof model exhibited the highest critical pressure field compared to the other two.[2-3]

The wind's behavior is altered when a pyramidal roof is present, making for some fascinating aerodynamics. Nevertheless, not enough investigation has been done in this area Previous research found that between the hip roof and the gable roof, the pyramidal roof had the least amount of uplift . Further research on roof pitch, wind direction, and base design is necessary for a pyramidal roof with all these features and high wind resistance. By

ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2186

doing such a study, we may learn more about the characteristics of wind flow across pyramidal roofs.[4-5]

But we need a method to estimate the wind pressure, and there are undoubtedly other ways to accomplish the same, regardless of the form of the roof or the structure. Some typical approaches to estimating wind load include wind tunnel analysis, the wall of wind technique, analytical investigation, and numerical methods, such as computational fluid dynamics (CFD) simulation. Wind tunnel testing is among the most precise procedures, but it is also time-consuming, costly, and takes a lot of work. The wall of wind technique is similarly labor intensive and needs substantial scale models and apparatus. Wind standards must be consulted for data in an analytical research, although the standards cover only a small range of roof types and wind directions.[6-7]

Wind regulations also lack information on typical wind loads for pyramidal structures. Thus, it is crucial to keep an eye on the direction and strength of the wind around pyramid-shaped roofs. The dispersal of wind force on the roof and walls of a building is significantly influenced by its size and form. Nonetheless, many previous wind-related projects have been analyzed utilizing CFD technique's building simulation. The velocity streamline, magnitude of pressure coefficients, velocity vectors, and a number of related constraint variables may all be calculated by doing a CFD analysis on the model's exterior. The separation of the boundary layer and the creation of the wake zone are two more applications of CFD modeling that have been studied. Several studies, however, are being conducted without a wind tunnel, with the help of CFD modeling, and the findings obtained are sufficiently consistent with the experimental data.[8-9]

As compared to traditional approaches to wind load analysis, CFD simulation is both more functional and more efficient. Nowadays, computational fluid dynamics (CFD) modeling is used instead of wind tunnel testing to measure the effect of wind on buildings . Computational fluid dynamics (CFD) makes use of numerical analysis to obtain answers to questions about fluid motion. Hence, Computational Fluid Dynamics (CFD) may be described as the assessment of fluid flow behavior via the application of applied mathematics, physics, and computer software.[10]

2. Material and Methods

The purpose of this research is to examine how wind pressure coefficients change over a range of pyramidal roofs and how wind behaves in the vicinity of the structure. Previous research has shown that pyramidal roofs are more resistant to wind than gable and hip roofs. The wind behavior of pyramidal roofed structures is not well understood, hence additional study is required into factors like roof slope or wind direction. The primary purpose of this research is to analyze the wind pressure distribution on roof surfaces as a function of plan form, roof slope, and wind direction.

For this purpose, we have been making use of ANSYS, a CFD program. Results are gathered from ANSYS Fluent and CFD-Post, whereas ANSYS ICEM and Fluent are utilized

ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2186

for simulation and modeling, respectively. A mesh sensitivity study has been completed to guarantee a high-quality grid.

The current research takes into account two typical polygonal plan forms, the pentagon and the hexagon. Five different roof angles, including 200, 250, and 300 degrees, have been modeled for each plan form.

3. Results

In the present investigation, many ANSYS Fluent simulations of buildings with pyramidal roofs are shown. Each model varies in terms of its regular polygonal floor design, roof pitch, and prevailing wind direction. The primary goal of this research is to determine how varying roof slopes affect the distribution of wind pressure on the roof surface.

- **Pentagonal Pyramidal Model**

In this research, seven different plan forms were tested for their susceptibility to wind. Wind load analysis was performed on all seven forms by tracing the contours of the pressure coefficient, graphing the maximum negative Cp on various sides of the same roof, and tracing velocity streamlines all around model.

Pressure Coefficients

Face A, face B, face C, face D, and face E are all shown on the model of the building's pentagonal pyramidal roof.

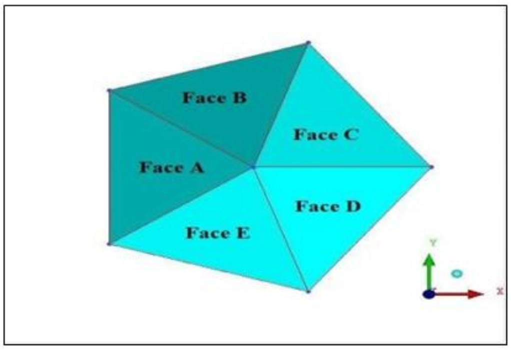


Figure 1: The pentagonal roof's five sides form a pyramid. Maximum Pressure Negative

Coefficient Coefficient of Pressure on Average

ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2186

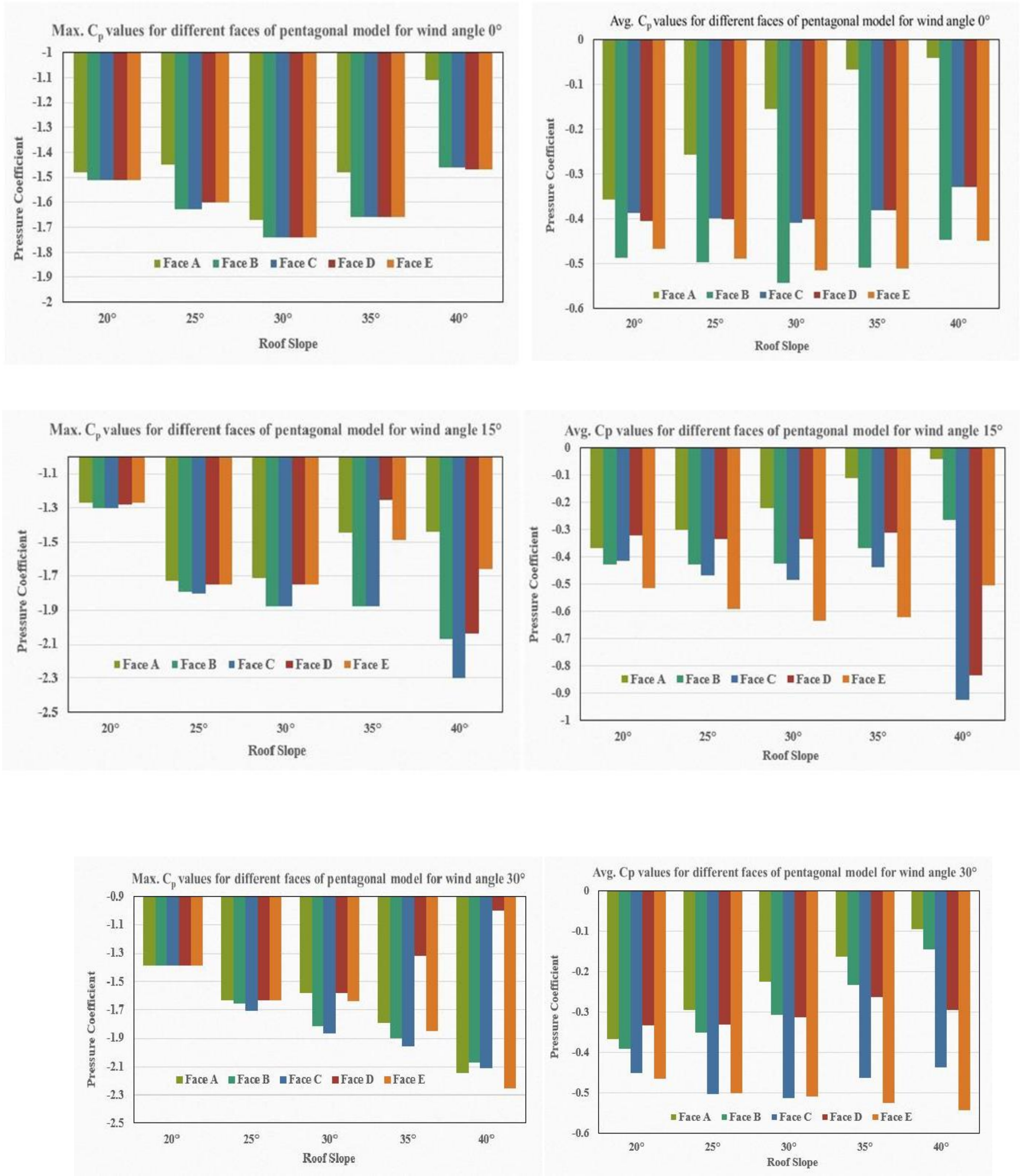


Figure 2: The highest and lowest Cp values on each of the five sides of the pentagonal pyramid's cap

As can be seen in Figure, there is considerable variation in the maximum negative Cp values across all five pentagonal roof faces, roof angles, and wind directions. Maximum negative Cp values for all five sides are about the same magnitude for each wind direction for roof pitches of 20 and 25 degrees.

Maximum Cp values for all roof pitches are the same for face B/C and face D/E if the wind angle is 0 degrees, demonstrating symmetry over the wind direction. The pressure is lowest

Mathematical Statistician and Engineering Applications
ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2186

on side A for any given roof pitch. The minimum Cp value varies across faces A, D, & E at a wind angle of 15 degrees. The minimum maximum Cp value for various roof pitches is located on face D for wind directions of 30 degrees.

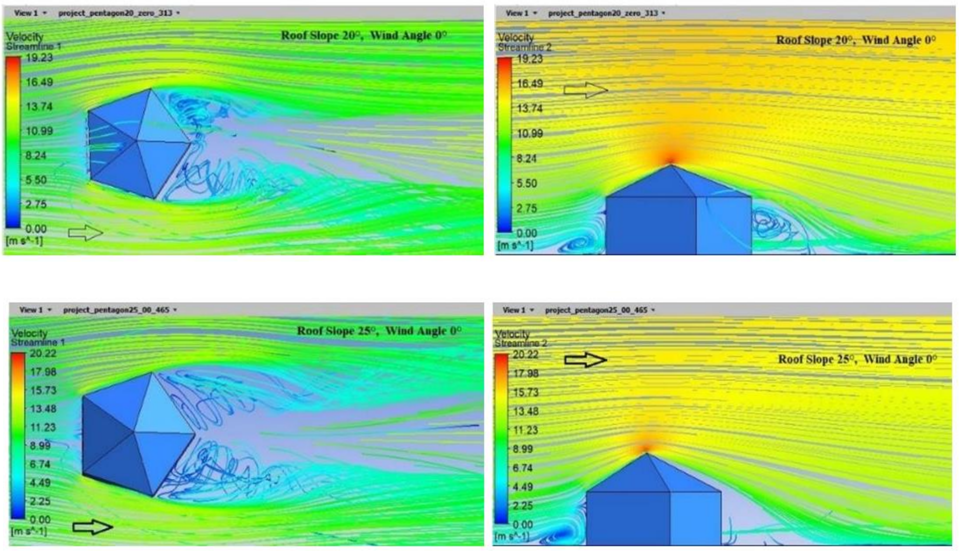
Yet, there is no discernible relationship between changes in roof slope or wind direction and shifts in the average Cp value (area-weighted). In the absence of wind, at 15 degrees and 30 degrees, the average Cp is lowest on face A. In addition, a steeper roof pitch reduces the minimum average Cp value. Cp values often hover around -1.95. Negative pressure rises with roof pitch, as seen by the contours of pressure coefficients in Figure.

Although there is no discernible trend when the wind direction changes, the greatest maximum pressure coefficient is obtained at 15 degrees for all roof slopes except the 20 degree roof slope. In the case of a 40 degree roof pitch and a wind direction of 15 degrees, the maximum pressure coefficient is -2.3. Maximum pressure coefficients of -1.3 are obtained at 20 degrees of roof slope and 15 degrees and 60 degrees of wind direction. Moreover, the windward roof has a small but statistically significant positive pressure coefficient.

Velocity Streamlines

By showing the velocity streamlines in two dimensions, we can get a better look at how the wind behaves around the building model. Figure depicts the velocity streamlines for the same for all planes, wind directions, and roof pitches. In the XY plane, the velocity streamlines have been drawn at a height of 0.0475 m, and on the ZX plane, at the center of the building models. Colored streamlines indicate wind speed, whereas streamline shapes reveal how the wind behaves in the vicinity of the model.

TopView Elevation



ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2186

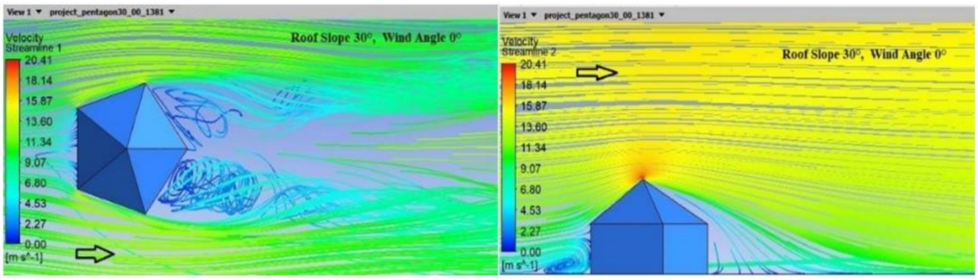


Figure 3: The zero-degree wind streamline model is based on a pentagonal pyramid.

As the wind hits the model's front wall, the variations in airflow are shown graphically. Wake zones form on the downstream side of the model when the whole front wall blocks the prevailing wind at an angle of 0 degrees. This is because the two additional cornices of the model divide the flow from the surface of the model.

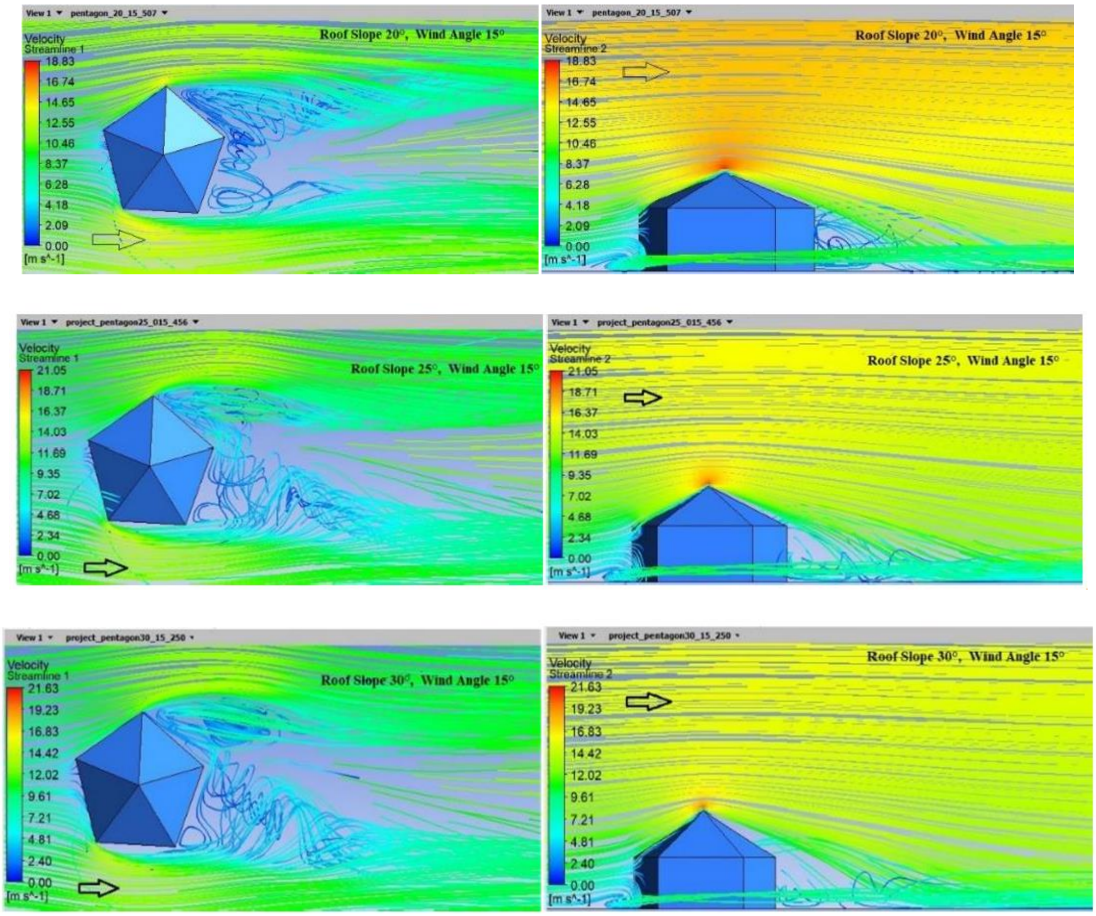


Figure 4: At a wind direction of 15 degrees, a pentagonal pyramidal model of velocity streamlines is shown.

Figure displays top views and elevations of streamline flow, revealing that the wake zone on the leeward side expands with increasing roof slope.

ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2186

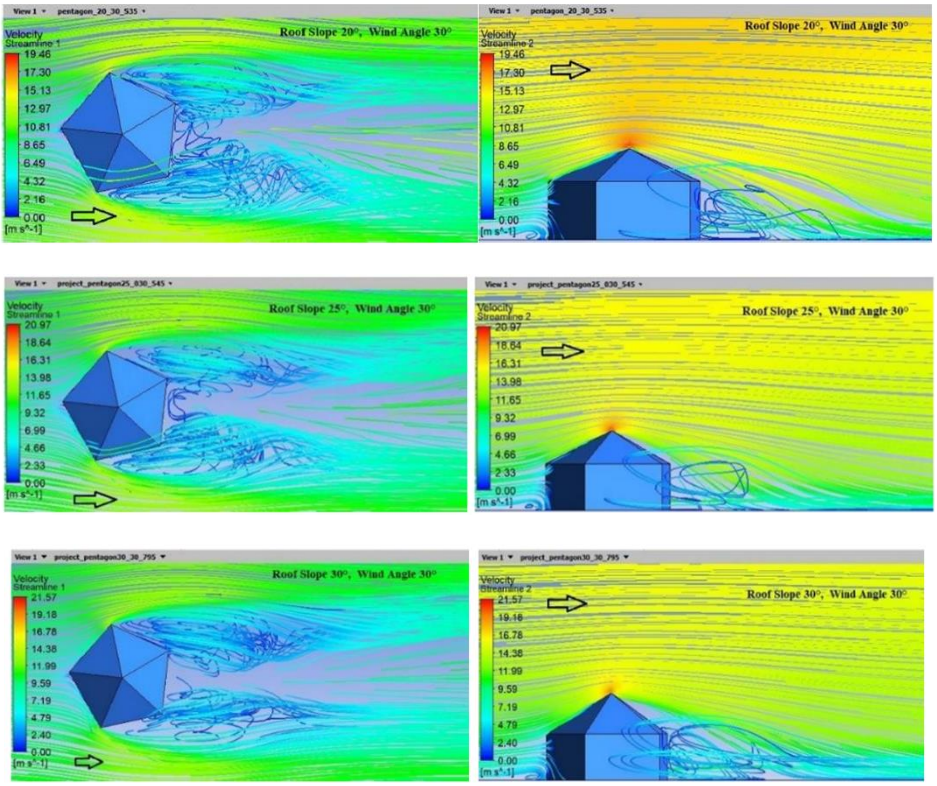


Figure 5: If the wind direction is 30 degrees, the velocity streamlines will be shaped like a pentagonal pyramid.

For wind directions of 0 and 15 degrees, As can be seen in Figure the horizontal flow patterns surrounding the building model alter very little as the wind direction changes. If the whole roof is sloping, the streamlines, or the smooth flow downstream, will be a chaotic mess. The flow separation or the sucked zone on the leeward are much more obvious in the vertical plane. As a result, the downstream end of the model experiences a decrease in pressure. On the windward side, close to the base of the model, the horseshoe vortex is visible for all roof pitches and wind directions.

- **Hexagonal Pyramidal Model**

Seven different plan designs, including a model with a hexagonal pyramidal roof, were examined for their potential to withstand wind speeds. The figure depicts the six possible roof surfaces of the hexagonal pyramid model: faces A, B, C, D, E, and F. Figure displays, for hexagonal models, a comparison between the greatest negative Cp value and the average Cp value on faces of various forms. Figure depicts the pressure coefficient (Cp) contours for varying roof pitches and wind directions.

Mathematical Statistician and Engineering Applications
ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2186

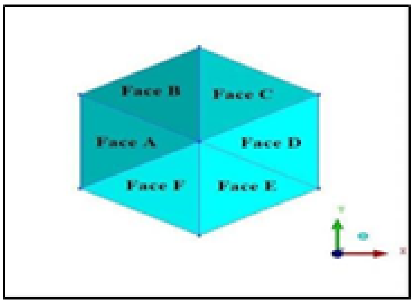


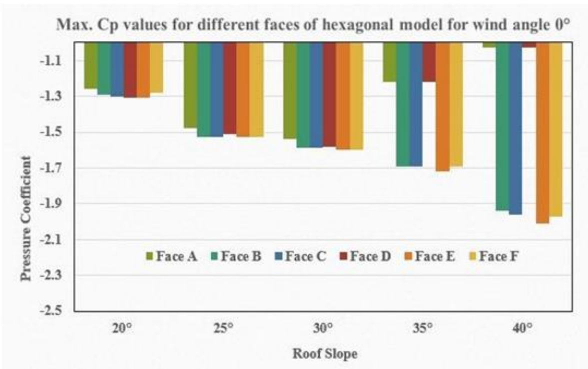
Figure 6: The roof is a hexagonal pyramid with several facets.

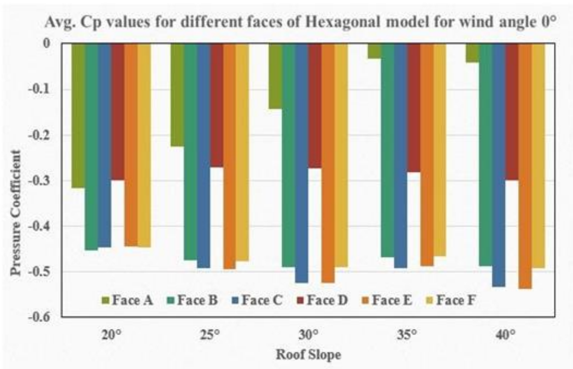
Pressure Coefficients

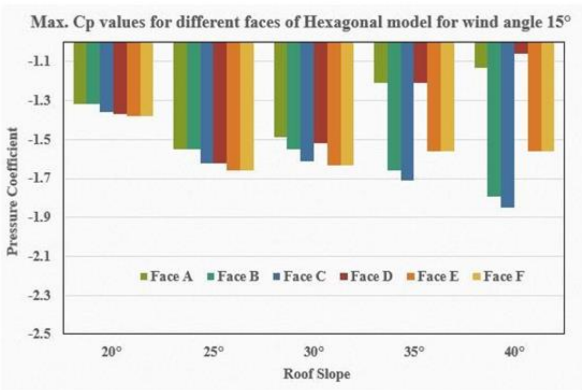
The maximum pressure coefficient (Cp) for all wind directions is obtained at a roof pitch, as shown by the Cp value on the various roof faces in Figure. Faces B and F, which are symmetrical along the wind direction or X-axis, have equal Cp values when the wind direction is 0 degrees.

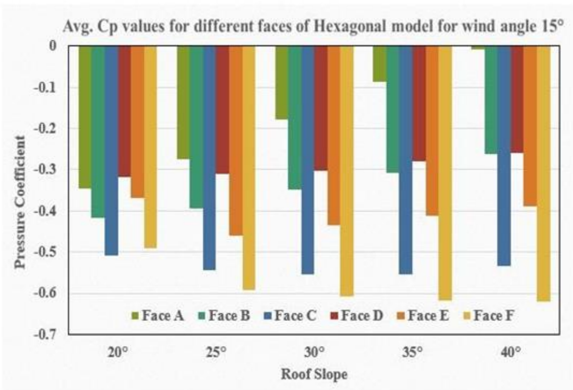
The maximal pressure coefficient is greatest on face E with a roof pitch of 40 degrees and a wind direction of 0 degrees. In contrast, face D has the lowest maximum Cp in the 0°, 15°, and 30° wind cases.

Maximum Coefficient of Decay in PressureCoefficient of Pressure on Average.









ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2186

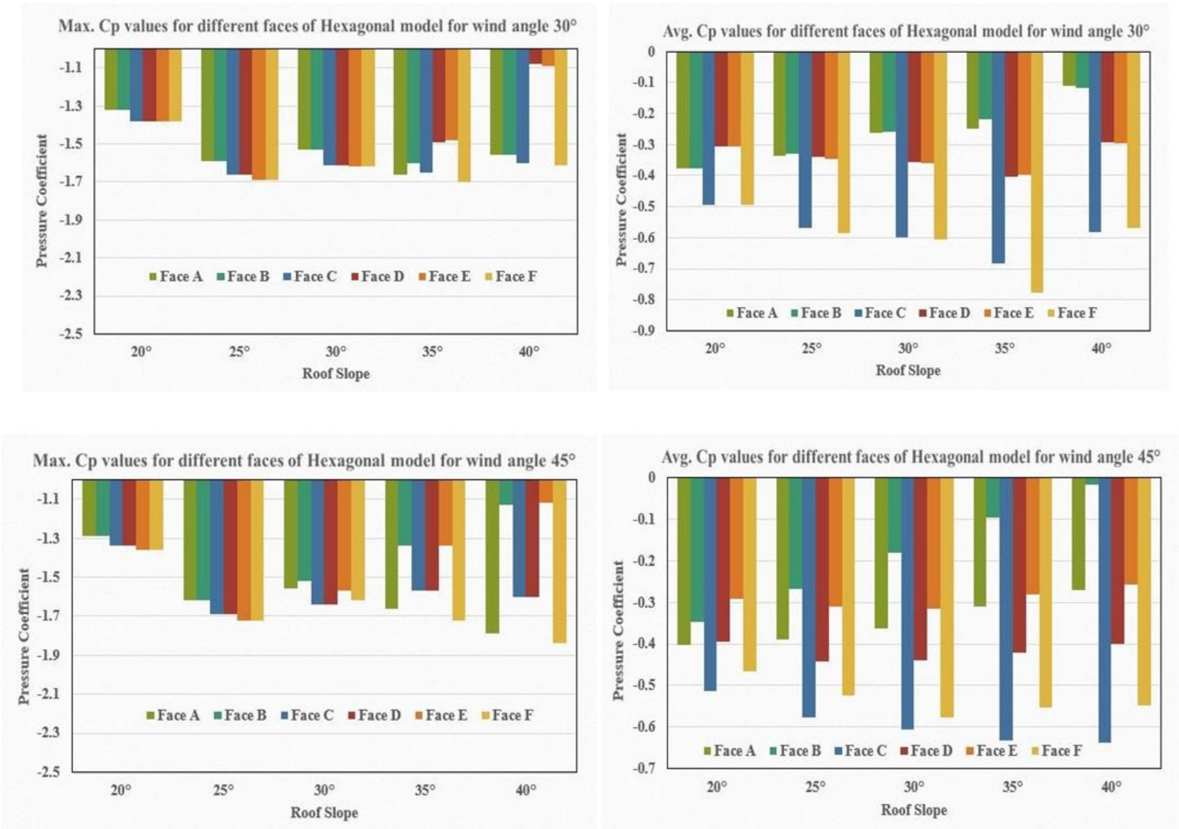


Figure 7: Variable pressure coefficients at each of the six peaks of the pyramidal base

The average pressure coefficient, Cp, varies across all sides due to the wind blowing at 0 degrees, with the exception of side A. The negative pressure coefficient on side A (at 0 and 15 degrees) and side B decreases with increasing roof pitch. In all models, the average Cp values for all six faces are below zero , with values ranging from -0.8 to 0.0.

Figure displays the Cp contours on the hexagonal model roof for a variety of roof pitches and wind directions. It is clear that the area and amplitude of negative Cp values grow as the roof slope increases from flat to steep for all wind directions. The pressure distribution pattern changes as the wind direction or angles of attack shifts from 0 degrees to 15 degrees, and so on.

Hexagonal models have symmetry along the X-axis, leading to a symmetrical pressure distribution for two wind directions (0 degrees and 30 degrees). Since positive Cp levels are uncommon and seldom have much of an impact. Maximum Cp values are greatest when the ridgeline, which connects the windward and leeward sides of the roof, is perpendicular to the wind.

Velocity Streamlines

CFD-Post has generated velocity streamlines for varied roof angles and wind directions, much as it does for pentagonal models. All the velocity streamline charts show how the flow behavior changes in response to variations in roof pitch and wind direction.

ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2186

Similar to the pressure coefficient contours, velocity streamlines have been created for four wind incidence angle to account for rotational symmetry . Figure shows a top view and an elevation showing how the velocity streamlines translate when the wind angle is zero on any of the five roof pitches.

TopView Elevation

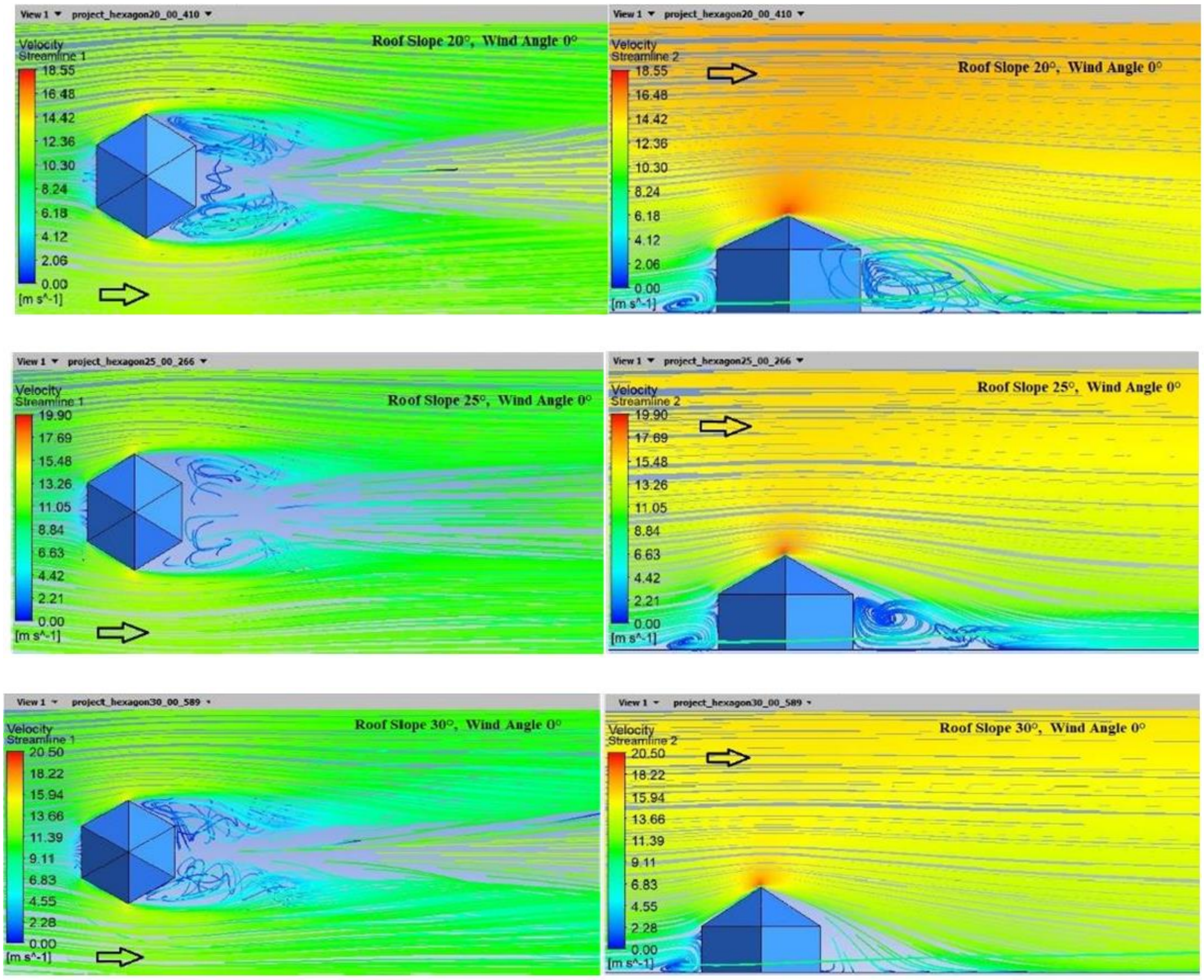


Figure 8: For a wind direction of zero degrees, velocities trace out a hexagonal pyramid

Figure Shows that when the wind knocks on the wall at a 0 degree angle, there is divergence of flow along two cornices of the model, just as there is in pentagonal models. This is shown by the symmetry of the wind flow in a plan view, which is perpendicular to the direction of the wind. In the case of all five roof pitches, turbulence or wake zones on the leeward side are clearly evident in both the top view and the elevation.

The wake zone expands with increasing roof pitch even for a hexagonal floor design. Figure shows that compared to the situation of a wind angle of 0 degrees, the size of the wake areas and the separation of the boundary layer are both smaller when the wind is blowing at an angle of 15 degrees. Furthermore, the suction on the roof's leeward side is reduced. In the 15° wind scenario, there is less space blocking the wind direction directly than in the 0°

ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2186

wind instance, and this has an effect on the wind flow and pressure patterns.

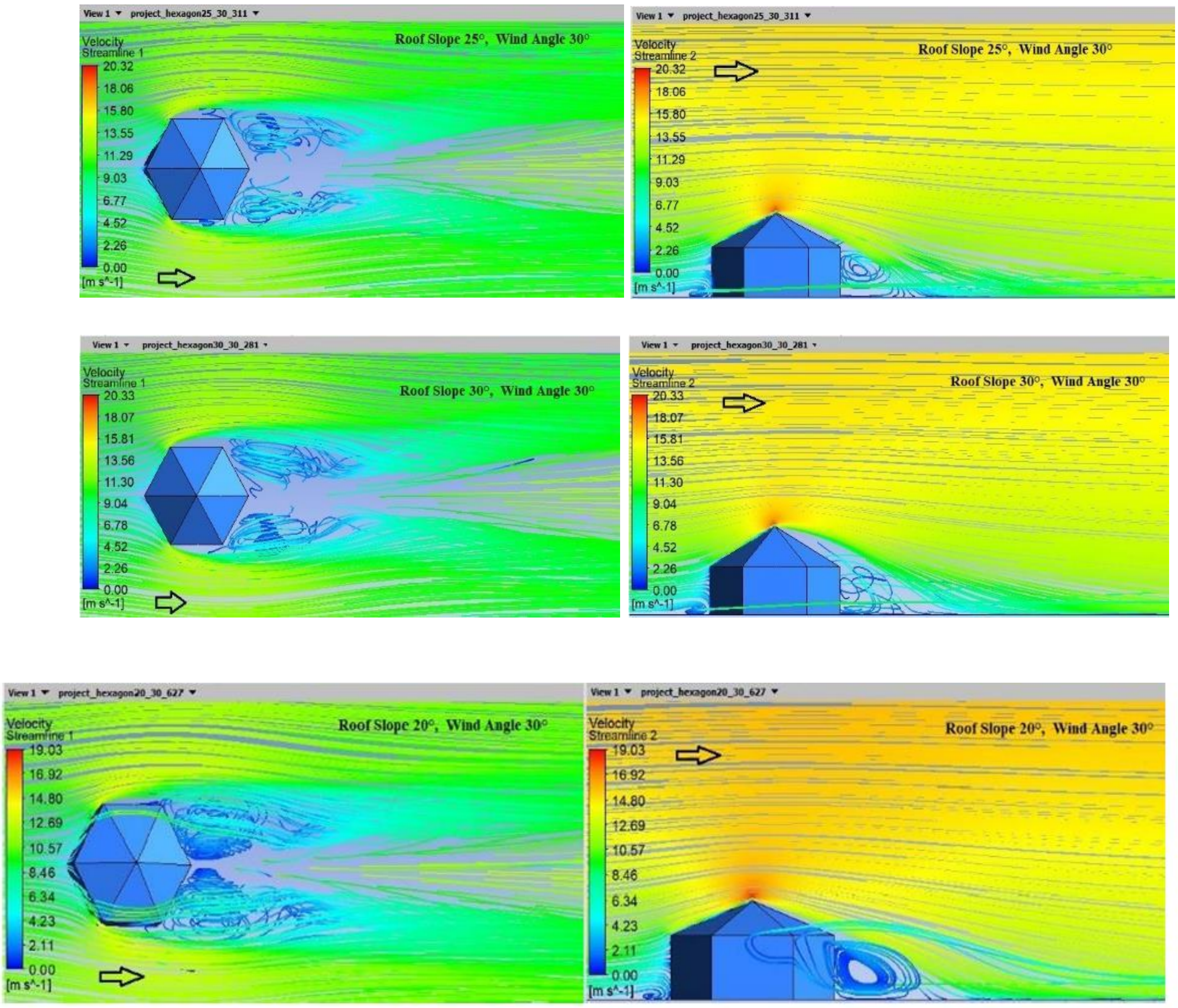


Figure 9: Streamlines of velocities around a hexagonal pyramidal shape at a wind direction of 30 degrees

Several hexagonal models' velocity streamlines at 30 wind angles are shown in Figure. In the same way that wind at an angle of 0 degrees flows symmetrically around the model, so does wind at an angle of 30 degrees. Hexagonal models, like pentagonal ones, exhibit downwind turbulence and vortex flow.

Validation of CFD Study

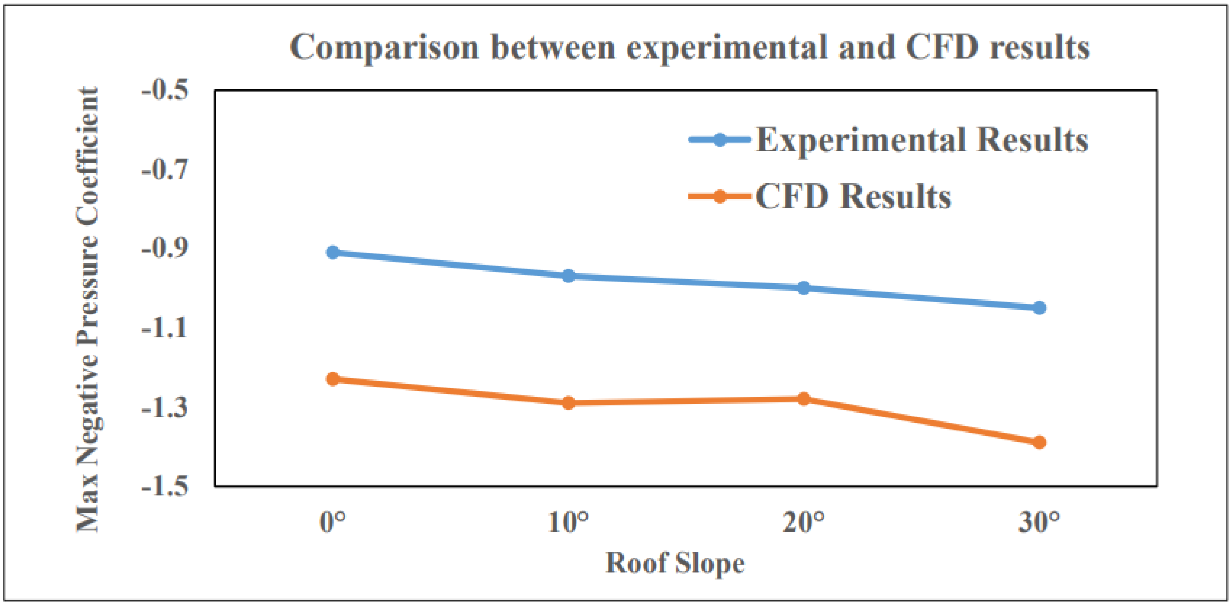


Figure 10: Evaluation of Experimental and Computational Fluid Dynamics

The highest negative pressure coefficient calculated using CFD is compared to experimental data in Figure For roofs with a pitch of 0 degrees, 10 degrees, 20 degrees, and 30 degrees, the CFD values were determined to be 35%, 33%, 28%, and 32% bigger than the experimental values, respectively. Also, this discrepancy between CFD with experimental values seems to be acceptable. So, the CFD findings are reliable.

4. Conclusion

Both the pressure coefficient and the velocity streamlines have been shown and discussed for all the models with TWO distinct floor plans. While the magnitude changes, the pattern of pressure coefficient distribution across all form models with various roof slopes is the same. With the exception of a cone, the pressure coefficients increase with increasing roof pitch. The pressure coefficients are affected differently depending on the form and the wind direction. The maximum force coefficient is sometimes found to be greater for 0° than it is for other wind directions, whereas in other circumstances the opposite is seen.

References

[1] K.C. Asthana and M.P. Roy, "Wind loads on pyramidal roofs with reference to the surrounding parapets," Journal of Wind Engineering and Industrial Aerodynamics, vol. 83, no. 1-2, pp. 129-137, 2019.

[2] S. Banerjee and S. Bhattacharya, "Wind-induced response of pyramidal roof structures," Journal of Structural Engineering, vol. 133, no. 10, pp. 1398-1409, 2017.

[3] K. Fujimoto and K. Tamura, "Aerodynamic characteristics of pyramidal roofs," Journal of Wind Engineering and Industrial Aerodynamics, vol. 93, no. 1, pp. 63-75, 2015.

[4] Larsson and J. Holmberg, "Experimental study of wind-induced loads on a low-rise pyramidal roof structure," Journal of Wind Engineering and Industrial Aerodynamics, vol. 92, no. 2, pp. 159-170, 2020.

[5] Larsson and J. Holmberg, "Numerical and experimental study of wind loads on a low-rise pyramidal roof structure," Journal of Wind Engineering and Industrial Aerodynamics, vol. 94, no. 12, pp. 861-876, 2016.

[6] Mashaly and A. Aly, "Wind loads on pyramidal roofs," Alexandria Engineering Journal, vol. 53, no. 4, pp. 573-579, 2017.

[7] Pandey, "Wind-induced response of tall buildings with pyramidal roof structures," Journal of Wind Engineering and Industrial Aerodynamics, vol. 98, no. 12, pp. 641-651, 2018.

[8] M. Pour-Ghaz and M.H. Bagheripour, "Investigation of wind-induced vibration of a pyramidal roof structure using wind tunnel tests," Journal of Wind Engineering and Industrial Aerodynamics, vol. 146, pp. 1-10, 2016.

[9] H. Rezaei, A. Noorzad, and S. Vahdani-Nejad, "Experimental and numerical study of wind loads on a pyramidal roof," Engineering Structures, vol. 33, no. 5, pp. 1601-1609, 2020.

[10] R. Yavuzturk, "Wind loads on low-rise pyramidal roofs," Journal of Wind Engineering and Industrial Aerodynamics, vol. 87, no. 1, pp. 21-34, 2020.