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Evaluation of extreme value estimation methods based on statistical inference of wind pressure coefficient behavior for low-rise buildings under stationary winds

Mohamed Eissa [1], Amal Elawady [1,2], Ioannis Zisis [1,2]

[1]Civil and Environmental Engineering, Florida International University, Miami, FL, USA
[2]Extreme Events Institute, Florida International University, Miami, FL, USA
Email addresses: meissa@fiu.edu (M. Eissa), aelawady@fiu.edu (A. Elawady), izisis@fiu.edu (I. Zisis).

SUMMARY:
Wind hazards cause losses in human lives and have inevitable damage to buildings, consequently, the importance of studying and defining wind pressure coefficients on structures has substantially increased. Defining the most appropriate method to estimate extreme value for wind pressure coefficients according to inconsistent behavior of wind pressure coefficients on the building surface, is a substantial issue to settle. Many studies tacitly predict wind pressure coefficient peaks using the same methodology throughout the entire building surface. However, non-Gaussian characteristics are likely to be pronounced on the building surfaces, therefore, employing the conventional Davenport method to estimate the peak distribution may not always be as accurate. Many researchers developed more reliable and accurate methods to better evaluate the peak distribution with the translation from Gaussian to non-Gaussian processes. To this end, this study presents a zoning classification for the gable-roofed building to distinguish Gaussian and non-Gaussian areas concerning certain angles. This paper will demonstrate most of the peak pressure coefficient estimation methods, e.g., moment-based Hermite model, Revised and Modified Hermite model, Sadek-Simiu method, and Generalized Extreme Value distribution, followed by a discussion of their accuracy level.

Keywords: Extreme value analysis, Gaussian, Non-Gaussian, Peak factor, Wind pressure, Low-rise building

1. BACKGROUND AND MOTIVATION

Local peak wind pressures on the building surface instantaneously result in large forces which induce significant failures in building and non-structural components. Wind pressure on building surfaces is considered a random process, which may be stationary or non-stationary (e.g., downburst) and its statistical characteristics are critical in the process of interpreting wind effect on buildings. The stationary wind model has been adopted to deal with the characteristics of atmospheric boundary-layer (ABL) winds (Davenport 1961, 1967), assuming that the fluctuation component of ABL winds can be handled as a zero-mean stationary Gaussian random process by subtracting a constant mean from the time history wind data. Peterka and Cermak (1974) proposed that probability densities are skewed and far from Gaussian shape when the mean pressure coefficient is lower than -0.25 (flow separation region). Davenport (1964) assumed explicitly that fluctuating wind pressures are stationary random processes, and the extreme value of wind pressures can be determined by summing the mean values of the data and their standard deviation multiplied by a peak factor. On the contrary, other studies (Dalgliesh 1971; Peterka and Cermak

1975) show inevitable non-Gaussian characteristics in the separated-flow region and on leeward walls. Holmes (1981) deduced that those non-gaussian characteristics are more likely to be pronounced on the windward-wall pressures of low-rise buildings with high turbulence intensity, as well as on the leeward and separated-flow regions. Furthermore, Gioffrè and Gusella (2002) stated that the conventional gaussian assumption employed to model wind pressure is unsafe, and Holmes (1985) indicated that the intensity and skewness of the probability distribution have a notable contribution to the damage accumulation rate. The extreme peaks that eventuate rarely during a wind event, have a major contribution to the failure which necessitates finding a new methodology to deal with non-Gaussian behaviors. Consequently, many researchers tried to address this issue. Kareem and Zhao (1994) formulated the extreme value distribution of non-gaussian wind by utilizing the moment-based Hermite transformation approach by considering skewness and kurtosis coefficients. S. N. Pillai and Y. Tamura (2009) introduced their proposed method for attaining the peak factor for any stationary random process whether it has Gaussian or non-Gaussian characteristics; they found that Davenport (1964) and D. E. Cartwright and M. S. Longuet-Higgins (1956) methods underestimate the peak factor, and on the other hand, the peak factor calculated according to the method by Kareem and Zhao (1994), is overestimated. Kwon and Kareem (2009) revisited their previous method and implemented some improvements for the peak factor estimation and extreme values. In addition, it can be deduced that the extreme peak estimates attained from data analysis have less reliability unlike those estimates obtained from data-driven models (Asghari Mooneghi et al., 2014; Ding and Chen, 2014). Quan et al. (2014) alluded to a novel approach to estimating extreme values by fractionating a sample of wind pressure time history into a number of epochs. In this study, they concluded that the Kareem and Zhao method shows a notably large deviation on both tails of the PDF; thereby, they stated that wind pressure distributions on the several locations are not conformed to a sole probability distribution, owing to inconsistency in the wind pressure behavior. Cope et al. (2005) had the same inference about using different appropriate PDFs for different regions on structure surfaces.

To the extent of which, we could employ one method to estimate the peak pressure coefficient whether it has Gaussian or non-Gaussian characteristics on the building surface (e.g., low-rise building? And how does that affect the estimated peaks which consequently influence the building design?

To discuss this previous statement, Ke and Ge (2015) depicted the zoning map for the Gaussian and non-Gaussian areas in the hyperbolic cooling tower surface, however, this method may be adopted for other types of buildings. In this study, it has been shown that using a single value as a corresponding peak factor of different areas during the extreme value analysis, leads to substantial misinterpretation of the expected peak values. Yet, the zoning map for the classification of Gaussian and non-Gaussian areas has not been proposed for the entire surface of low-rise buildings. Therefore, in this study, the main contribution is to propose a classification map for all surfaces of a gable low-rise building based on certain criteria to obtain the most reliable and accurate peaks of wind pressure coefficients. In addition, this work will discuss the current misleading norm that using a single value for peak factor through the extreme value analysis of all building surfaces regardless of the wind pressure coefficient behavior, which results in a less-resilient design against wind extremes.

2. GAUSSIAN AND NON-GAUSSIAN: CLASSIFICATION & CONCLUSION

The reliable design process necessitates the extreme value analysis of peak pressures to be accurate, therefore knowing that pressure fluctuations classification has an influential contribution in opting the convenient extreme value analysis method. The tap location, wind direction, and surface geometry influence the pressure fluctuations behavior (Ke and Ge, 2015; Kumar and Stathopoulos, 2000). The judgment and classification of stationary stochastic processes based on kurtosis and skewness value are appropriate parameters to describe Gaussian and non-Gaussian characteristics. As it is commonly known that kurtosis and skewness illustrate the weight of a distribution tail and the asymmetry of a distribution, respectively. The mapping classification technique herein, considering the tap exhibits non-gaussian characteristics when the absolute skewness and kurtosis value is more than 0.5 and 3.5, respectively. In this study, Pressure data from Tokyo Polytechnic University (TPU) database are analyzed for different wind directions to determine the kurtosis and the skewness values, and the results are shown in Figure 1 for 0^o wind direction. A considerable skewness amplitude is observed through all surfaces; the windward sides are slightly skewed near building edges, however, skewness magnitudes above 0.5 have been recorded and negative skewness at the separation region is noticed. The roof surfaces have significant negative skewness values near windward roof corners, up to more -2, and the skewness attenuates gradually toward the leeward side. On the contrary, the leeward and side walls show a comparatively low tendency to exhibit high skewness values. Moreover, most kurtosis values are tremendously high, they can be reached up to 10, see Figure 1 (a). the highest values are more likely to be pronounced at corners of windward roof sides and downside wall sides, owing that to flow separation. These results prove that most of the building surfaces attain notably non-Gaussian behavior.

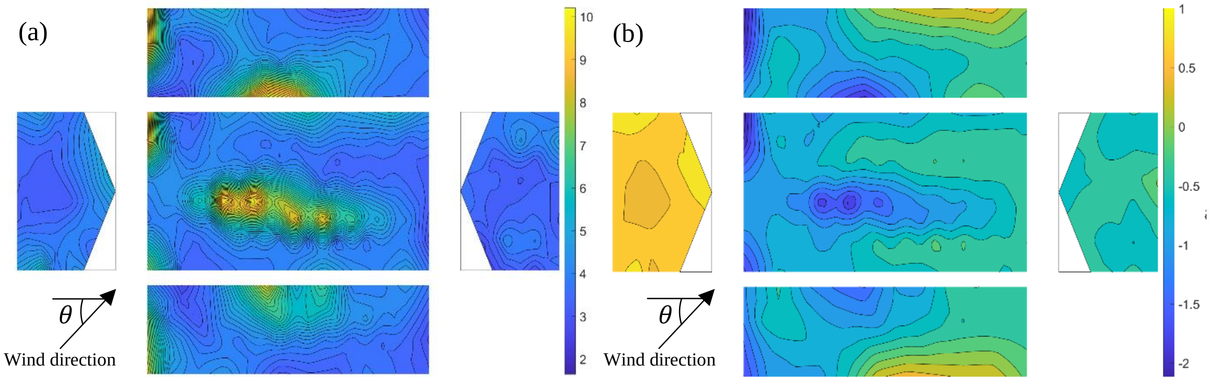

Figure 1. Contours plots of the building with 0^o wind direction; (a) Kurtosis and (b) Skewness.

Based on the aforementioned results, the Gaussian and non-Gaussian map for pressure taps has been developed for only the case of a gable roof and for certain wind directions, see Figure 2. These results do not match with its counterpart in the study by Kumar and Stathopoulos (2000) which states that the length of 10% only of the least horizontal dimension from the windward side of the roof, shows non-Gaussian characteristics, nevertheless, the current map reveals approximately 50% of the roof are subjected to non-Gaussian fluctuations. On the contrary, the leeward side of the roof and side walls are prone to Gaussian characteristics. To that end, it should not be deliberately assumed that the pressure fluctuation across the building has the same behavior whether Gaussian or non-Gaussian, that consequently leads to erroneous peak estimations.

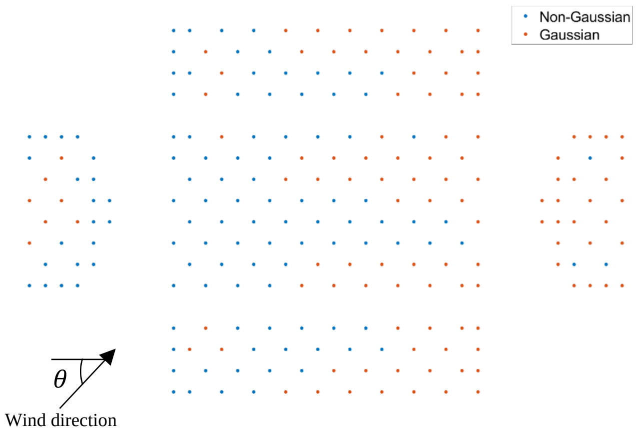

Figure 2. The Gaussian and non-Gaussian mapping for pressure taps for $\boldsymbol{\theta} = 0^{\mathrm{o}}$

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