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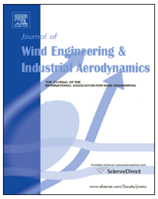

A model of probability density function of non-Gaussian wind pressure with multiple samples

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ABSTRACT

The extreme value of non-Gaussian wind pressure coefficients is usually estimated by fitting the probability density function (PDF) of maximum or minimum values while a large number of observations except the peak values in the measured samples are discarded. The implicit or explicit translation between non-Gaussian and Gaussian histories can also be utilized to estimate the extreme value of non-Gaussian wind pressure coefficients while the randomness of aerodynamic effect is not taken into account. The Hermite moment models are summarized and applied to formulate the PDF of non-Gaussian peak factors which is expressed as the joint PDF (JPDF) of the shape parameters of the Hermite moment model and the PDF of the translated Gaussian peak factors. After the variations of mean, standard deviation and non-Gaussian peak factor are considered, an innovative and analytical PDF formula of extreme wind pressure coefficients for multiple samples, which is expressed as a function of the JPDF of mean, standard deviation and the PDF of non-Gaussian peak factor, is presented in this paper. The theoretical developments are applied to establish the PDF and cumulative density function (CDF) of the negative peak wind pressure coefficients with multiple samples. It is verified that the analytical probability distribution model is a reasonable model to estimate the peak pressure coefficients.

1. Introduction

The extreme value of the wind pressure on buildings is an important factor for the cladding design, which may be determined on the basis of its probability distribution function (PDF). It is observed that the wind pressure acting on the windward claddings follows the Gaussian distribution. The method to obtain the extreme value of the windward pressure has been developed by Davenport (1964), based on the first-crossing probability of Gaussian processes, and applied in many wind codes and specifications, named as the peak factor method. However, the wind pressure acting on the side, the leeward and the roof does not follow the Gaussian distribution.

The method to obtain the extreme value of non-Gaussian wind pressure has not been fully developed yet, even though a lot of research has been done. The extreme value theory has been adopted (Kasperski, 2009, 2003; Tieleman et al., 2007; Harris, 2005; Holmes and Cochran, 2003; Simiu et al., 2001; Cook and Mayne, 1980), in which a considerable larger number of independent samples with enough length to identify the tail in PDF curve of the extreme values (Kasperski, 2003) are needed, and the peak value of each sample is taken into account, while the left information in the sample is discarded.

Translating a non-Gaussian sample into a Gaussian sample is another possible way. Based on an implicit model (Grigoriu, 1995), a point-to-point procedure for estimating the peak value of non-Gaussian sample was presented by Sadek and Simiu (2002), in which the three-parameter Gamma distribution is adopted to fit the PDF of non-Gaussian pressure samples. However, there are some theoretical deviations in the fitted PDF if the combination of the skewness and kurtosis cannot satisfy the inherent relationship in the Gamma distribution; and the Gamma distribution cannot be applied to describe the distribution of samples with kurtosis less than three. The explicit translation model, called the moment-based Hermite model in which the shape parameters of the first three-degree Hermite polynomials are determined by the skewness and kurtosis (Winterstein, 1985, 1987, 1988), was adopted to estimate the extreme values of the non-Gaussian wind pressure samples (Balderrama et al., 2012; Binh et al., 2008; Kareem and Zhao, 1994; Kareem et al., 1998; Winterstein, 1988). After the non-Gaussian sample is expressed as the monotonic function of a standard Gaussian sample, the extreme value of non-Gaussian sample is mapped onto the Gaussian peak factor. As it is observed that the lower order models may overestimate the non-Gaussian peak factor (Chen and Huang, 2009), the exact translation model, the 4th-order Hermite model, was

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recommended (Chen and Huang, 2009; Kwon and Kareem, 2011). Yang et al. (2013) proposed an approximate solution for the shape parameters of 4th-order model in the form of the skewness and kurtosis to make the Hermit model easy to be applied. The improvement was applied to the estimation of peak negative pressure coefficients in Peng et al. (2014) for the non-Gaussian softening histories. However, it cannot be applied to the translation of hardening histories. Both the Hermite model and the Sadek–Simiu method are the sample-by-sample translations and cannot take account of the randomness of the extreme values caused by the aerodynamic effects (Kasperski, 2003) and cannot be utilized directly to determine the statistically-derived extreme wind loads.

It is desired to establish the probability distribution of extreme values of non-Gaussian wind pressure in which the randomness of aerodynamic effect as well as more information in samples is taken into account, by combining the characteristics of the extreme value theory and the translation models. The objective of this paper is to formulate the PDF of extreme values in terms of the first four moments and to apply the developments to the estimation of extreme wind pressure coefficients. The wind pressure on a flat roof will be analyzed as case study to validate the developments.

Section 2 introduces the non-Gaussian wind pressure histories measured in wind tunnel tests. Section 3 summarizes the Hermite moment models and their monotonic limits. All forms of Hermite models, including softening, hardening and skewed models, are introduced and their applicable scopes are clarified in the form of skewness and kurtosis. The PDF of non-Gaussian peak factor for multiple samples is presented in Section 4, in terms of the PDF of Gaussian peak factor and the JPDF of the shape parameters of Hermite models, which are related directly to the skewness and kurtosis. Section 5 focuses on the derivation of the PDF of extreme values for multiple samples, in which the mean pressure, the standard deviation and the non-Gaussian peak factor are considered as three random variables. The correlations and independence between any two of the variables on a flat roof are investigated to simplify the PDF expression of extreme values. Some examples are given to demonstrate the application of developments to the gentle, strong softening histories and hardening histories and its advantages comparing to the original Hermite models in Section 6. Finally, some conclusions are drawn in Section 7.

2. Non-Gaussian characteristics of wind pressures on a flat roof

To investigate the non-Gaussian characteristics of wind pressure, a building model with flat roof was made and tested in wind tunnel. The first four moments of measured pressure histories on the roof are summarized. The non-Gaussian pressure histories are classified into three types as the softening, hardening and skewed histories.

The wind pressure histories on a rigid and 1/200 scaled model of flat-roof structure (Fig. 1) with dimensions of 600 mm × 600 mm × 200 mm were measured in the Laboratory of Structural Wind Engineering and Urban Wind Environment in Beijing Jiaotong University, China. The wind field of terrain Category B in the Load Code for the Design of Building Structures (GB50009-2012) in China was simulated. Both the wind speed and the turbulence intensity profiles are plotted in Fig. 2, where the mean wind speed at the height of roof is 6.15 m/s and the turbulence intensity is 13.5%. A pitot-static tube was mounted at a height of twice of the roof to monitor the approach wind speed and the static pressure inside the wind tunnel.

The velocity scale was set to be 1/6, and the time scale is 3/100 for a 1/200 length scaled model. In this test, the sampling frequency was set to be 312.5 Hz and the sampling period was 18 s corresponding to 9.375 Hz and 10 min in full scale. Each test case was recorded 175 times for 210 taps on the roof surface, shown in Fig. 3. As a case study, more attention will be paid to the records at Tap A to demonstrate the developments in this paper; and the discussion of the proposed model will be also applied to Taps B, C and other taps.

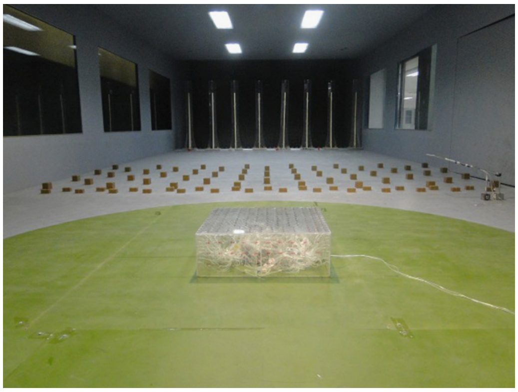

Fig. 1. Photo of flat-roof model in wind tunnel.

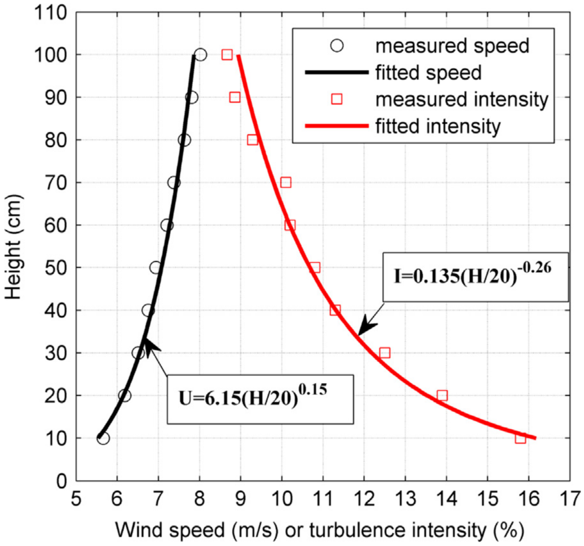

Fig. 2. Wind speed and turbulence intensity profiles.

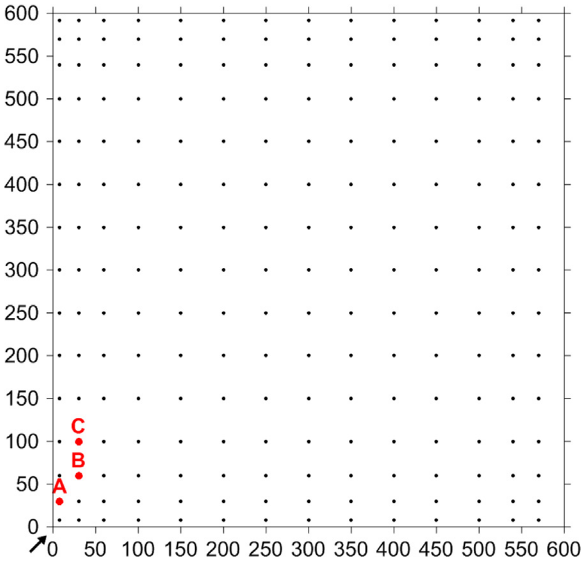

Fig. 3. Configuration of taps.