Gust Factors: From Theoretical Considerations to Field Measurements

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Gust factors (GFs), typically defined as the ratio between the mean value of the maxima of a quantity related to the buffeting action of wind to its mean value, have historically played a pivotal role in the design of structures under winds. While the GFs may be related to velocity, pressure, or structural response, this paper is limited to a discussion on those related to wind fluctuations only as the pressure and response related factors have been extensively addressed in the literature. The wind fluctuations are random; therefore, ideally the GFs could be derived from theoretical considerations concerning the statistics of the attendant random processes.

The theoretical treatment of GFs relies on the assumptions of stationarity and Gaussianity. Any departure from these assumptions, as often is the case in the field, results in inconsistencies between the measured and theoretical estimates. Another important variable is the averaging period, as the ratio of the peak in different averaging periods to the mean hourly average would obviously differ. Nonstationary features rooted not only in the variations in the mean values, but also in the fluctuations, both related to amplitude (variance) and frequency (spectral description) play an important role in defining the GF. These characteristics come into play more decisively near the eye wall of hurricanes and in thunderstorms and downbursts. This is further complicated by the very nature of turbulence whose genesis may differ from conventional mechanical turbulence and it may also contain principal contributions from convective turbulence. These features may have an overriding impact on the quantification of GFs. The other implied assumption in the formulation of GFs concerns the Gaussianity of the fluctuations in wind. This feature, characterized by the potential non-Gaussian aspects, may have a direct bearing on the GFs.

GFs historically based on field measurements have served as the basis of codes and standards [1]. However, these measurements being based on extratropical wind events have raised concerns regarding their applicability for hurricane winds, which led to the revised estimates based on the analysis of extremely limited data from past hurricanes [2]. These GFs indeed reflected the higher level of gustiness in wind fluctuations thus suggesting an upward adjustment of the GFs based on Durst's data [1] for the estimation of hurricane winds. The efficacy of these GFs and their implementation in hurricane wind simulations and recommendations in codes and standards is a subject of current debate. ASCE7 in its 02 version has scaled back the GFs derived from Krayer and Marshall [2] to Durst [1]. However, more recent data in the U.S. [3] and overseas utilizing digital instrumentation deployed in the path of several hurricanes has reaffirmed the higher level of gustiness in hurricane wind field, but the level of this boost may not be as marked as noted in [2]. This may potentially render recommendations implied in ASCE7 02 relatively unconservative. It is also worth pointing out that the probability distribution of GFs in hurricanes is non-Gaussian, which has its own implications in terms of the respective percentiles.

In this paper, an improved theoretical framework to model the non-Gaussian and non-stationary features in the wind field is presented. The inclusion of non-Gaussian aspects in the formulation of the GF is presented in terms of the non-Gaussian peak factor, which is expressed in terms of the Gaussian peak factor and higher moments of fluctuations, i.e., skewness and kurtosis [4]. The non-stationary nature of the wind flow is characterized by a summation of time-varying mean and fluctuating components [5]. These variations in the mean wind speed are reflected in the time-varying mean extracted by utilizing the multi-resolution filter-bank feature of the wavelet transform or an empirical mode decomposition scheme. This format redefines various kinematic and spectral properties of the time histories, which leads to a more robust description of GFs for hurricane and thunderstorm winds. This format may be very attractive for analyzing most of the collected data sets in the field as a sizeable portion of the data currently has to be discarded due to nonstationarity and in the case of thunderstorms, it precludes any conventional analysis. Example data from hurricane winds and measurements in a downdraft are used to underscore the attractiveness of the proposed scheme.

Utilizing the developed theoretical analysis framework, the role of various wind field characteristics in the quantification of GFs is delineated. These features include the averaging time, sampling time, turbulence intensity, spectral description of the wind field, spectral bandwidth, spectral moments, and skewness and kurtosis. Based on theoretical considerations, plausible scenarios have been drawn that predict GFs comparable to the measured values. A further refinement of this theoretical framework with improved assessment of input wind characteristics would lead to a reliable means of predicting GFs and would also offer a robust theoretical basis to corroborate field measured data.

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