Journal of Wind Engineering & Industrial Aerodynamics 174 (2018) 252–259

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia

Assessment of downburst wind loading on tall structures

Letícia Fleck Fadel Miguel [a,*], Jorge Daniel Riera [b], Leandro Fleck Fadel Miguel [c]

[a] Federal University of Rio Grande do Sul, Department of Mechanical Engineering, Av. Sarmento Leite, 425, 2° andar, CEP 90050-170, Porto Alegre, RS, Brazil
[b] Federal University of Rio Grande do Sul, Department of Civil Engineering, Av. Osvaldo Aranha, 99, 3° andar, CEP 90035-190, Porto Alegre, RS, Brazil
[c] Federal University of Santa Catarina, Department of Civil Engineering, Rua João Pio Duarte da Silva, CEP 88040-970, Florianópolis, SC, Brazil

ARTICLE INFO

Keywords:
Wind action
Dynamic and size effects
Structural design
Non-synoptic wind
Downburst
Velocity field

ABSTRACT

Wind features for purposes of structural analysis and design, implicit in wind codes worldwide until the end of last century, were based on the behavior of synoptic winds in the vicinity of the ground surface. Afterwards it was finally recognized that synoptic storms are not the only cause of wind damage to buildings and structures, not even its main cause. In spite of this evidence, non-synoptic winds are still far from being considered as standard loading in structural design. A simplified approach recently proposed by one of the authors to describe the wind velocity field in this type of meteorological phenomenon, more specifically, in downbursts within instability lines, is herein examined, including an assessment of dynamic and size effects not previously addressed. The predictions of the proposed method in applications to tall and slender structures are determined in the paper, assuming that available aerodynamic coefficients, obtained assuming synoptic wind, may be still applied with negligible error.

1. Introduction

Wind loads play a significant role in structural design, especially for tall or light constructions. Most technical standards assume that above plane, horizontal ground, the mean velocity vector is constant and parallel to the ground surface. This hypothesis is valid in case of synoptic winds, caused by extra-tropical storms or Extended Pressure Systems (EPS) and in tropical storms or hurricanes. On the other hand, wind effects caused by downdrafts or downbursts, typical of thunderstorms (TS), or of combinations of the latter with an EPS event, in so-called instability or squall lines, have not yet been considered in wind codes in South America, although the latter seems to be the most important type of wind excitation for structural design in temperate regions. As an evident consequence, procedures recommended in wind standards for evaluating the response of structures subjected to EPS winds cannot be directly applied to excitation due to TS winds. In temperate regions, not affected by tropical storms, roughly one out of every ten observations of the maximum annual horizontal component of the wind velocity at the standard 10 m height occur during a TS event, but it is typically the largest value. In consequence, extreme velocities for return periods that exceed 10 years are typically due to TS events, which should then govern structural design, at least for low buildings heights (Riera and Nanni, 1989). Additional evidence on the relevance of winds caused by TS events is found in CIGRÉ SC22 WG16 (2002), which reports that in temperate climates more than 83% of informed failures of transmission towers or lines were caused by downbursts. Letchford and Lombardo (2015) discuss the possibility of adding in wind standards guidelines for designing structures subjected to downbursts. The issue had already been raised by Gomes and Vickery (1978), who recognized the need to separate wind velocity records according to the causative meteorological phenomenon. Furthermore, recent studies confirm that the wind loads that control structural design in most areas of the continental USA and Europe are due to TS event (Lombardo, 2012; De Gaetano et al., 2014). These researches led to the consideration of TS winds in the revised map of wind velocities of ASCE Code 7 (2016), following previous developments of the Australia/New Zealand Standard AS/NZS 1170.2 (2011).

In this context, Riera (2016) recently suggested a simplified procedure to account for the effects of TS events in structural design, based on the observation that the horizontal component of the maximum wind velocities at reference 10 m height during TS events (downbursts) caused by stationary causative clouds very rarely exceeds 30 m/s. This velocity is below the minimum wind design velocity in most regions of the entire South American continent and since the dimensions of the area affected by any stationary TS event is, more often than not, of the same order of magnitude or smaller than the dimensions of the structures under consideration, the resulting TS wind forces should rarely exceed current code prescriptions for synoptic winds. In consequence, except in special

* Corresponding author.
E-mail addresses: letffm@ufrgs.br (L.F.F. Miguel), jorge.riera@ufrgs.br (J.D. Riera), leandro.miguel@ufsc.br (L.F. Fadel Miguel).

https://doi.org/10.1016/j.jweia.2018.01.015
Received 15 September 2017; Received in revised form 8 January 2018; Accepted 12 January 2018

situations, the action of TS events (downbursts) caused by stationary causative clouds should not have any influence on structural design. However, in so-called instability lines, also known as squall lines, in which the wind velocities caused by the downdraft from the causative cumulonimbus cloud sums up with the velocity of the (usually synoptic) wind that carries the cloud, the horizontal velocity component at 10 m height for usual recurrence periods may exceed 60 m/s, and hence *should certainly be considered in design*. The approach differs from the scheme developed by Solari et al. (2015), Solari (2016) and Solari et al. (2017), in which a response spectrum approach, similar to the spectrum used in seismic engineering is adopted, without restricting the analysis to the most damaging meteorological events. Moreover, in those references the fluctuations responsible for dynamics effects are not separated in their synoptic and downdraft contributions, but accounted for jointly.

In the present paper, the method proposed by Riera (2016), briefly described in Section 3, is examined further, in order to take into account both dynamic and size effects of downbursts on the structural response. Similarly to the applications described by Solari et al. (2017), attention is focused on free standing slender structures. Thus, the paper is organized as follows: Section 2 discusses basic characteristics of the wind fields in TS and EPS events, Section 3 describes the simplified model of a squall line, Section 4 examines the influence of size and dynamic effects of TS winds occurring in squall lines and Section 5 presents a comparison of the response of tall and slender buildings to synoptic (EPS) and non-synoptic (TS) wind action.

2. Basic features of the wind field in EPS and TS events

The objective of this section is to demonstrate that wind action on any construction cannot be completely defined by specifying only the horizontal component of the wind velocity at a 10 m height without indicating, at the same time, which is the meteorological phenomenon responsible for the wind. Of paramount interest is the vertical profile of the mean velocity. In case of synoptic winds (EPS events), as implicit for instance in Brazilian Code ABNT NBR 6123 (1988), the profile may be represented by a parabolic function with the exponent defined by the upwind terrain roughness, corresponding to a velocity that increases indefinitely with height. The model coincides with recommendations of most standards, some of which resort to a logarithmic law, differing marginally in the coefficients adopted for various degrees of roughness of the surrounding terrain. Note that the mean wind velocity is a function of the vertical coordinate only, *i.e.*, it is a one-dimensional field. On the other hand, the wind velocity field in a downdraft is a complex 3D function, characterized by axial symmetry only when the axis of the downdraft is vertical, case that occurs when the translational velocity of the causative cloud is zero. This implies that the causative cumulonimbus cloud is stationary, case that has less interest for engineering design. Note that the vertical profile of the wind velocity in TS events is not unique, depending on the position of the downdraft axis in relation to the location of interest.

Chen and Lectchford (2004) presented a critical assessment of models for TS wind profiles available at the time in the technical literature. Oseguera and Bowles (1988) suggest an empirical equation to determine the mean horizontal velocity in downdrafts. Afterwards, Vicroy (1992) and Wood and Kwok (1998), updated by Wood et al. (2001), proposed alternative equations to define the vertical profile. These equations provide results similar to the predictions of the model employed by Ponte (2005), as may be seen in Fig. 1. All the models presented in Fig. 1 describe well known features of TS wind fields, such as the fact that the maximum horizontal wind velocity component is reached at heights below 100 m, decreasing more or less rapidly at higher elevations.

The prediction of TS wind fields requires, in addition, consideration of the fact that the cloud causing the downdraft is typically in motion, which introduces the need of determining the ratio between the translation velocity of the cloud and the downdraft velocity. A second difference between EPS and TS winds, mentioned already in the Introduction, is that in the former the incident wind may be modeled as a stationary random process, which is susceptible to analytical formulations. The assumption was introduced in Wind Engineering by A. G. Davenport, who established the basis of procedures extensively adopted in technical standards for determining the dynamic response of structures subjected to the action of EPS turbulent winds. Chapter 9 of NBR 6123 (1988), for instance, belongs to this group of codes.

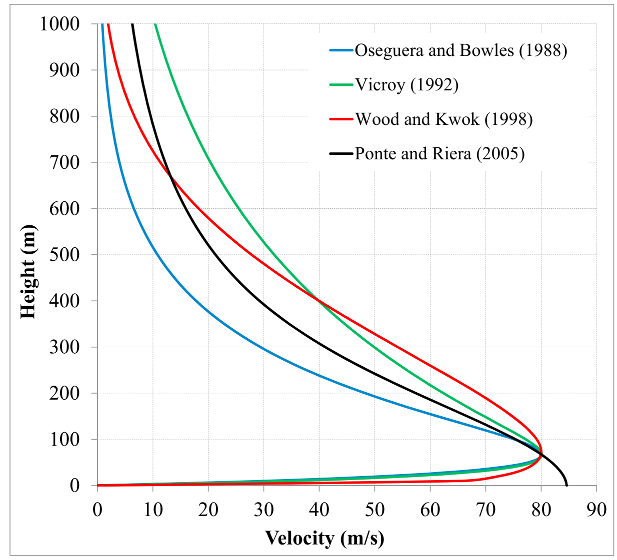

Fig. 1. TS wind vertical profile.

Riera (2016) analyzed TS records available in the literature estimating the relation between the mean translation velocity (V_{EPS}) of the storm and the peak TS velocity (V_{TS}). The ratio V_{EPS}/V_{TS} for these records, shown in Table 1, range from 0.3 to 0.4. Both the mean and the median of the available records are close to 0.35.

3. Simplified model of a squall line

In case of downdrafts caused *by stationary clouds, or by clouds that displace very slowly*, as discussed previously, the horizontal wind velocity component at the 10 m reference height does not exceed around 30 m/s (Ponte and Riera, 2007, 2010). Thus, such typical upper bound of the velocity would be below the design wind velocity for extra-tropical storms (EPS winds) and hence *horizontal loadings* induced by downdrafts caused by stationary or quasi-stationary clouds do not require specific consideration (Fadel Miguel and Riera, 2013).

Additionally, the frequency of occurrence of downdrafts caused by stationary or quasi-stationary causative clouds on an isolated standard construction is negligibly small. This argument is clarified by Fig. 2, which illustrates the traces of simulated TS events, in a one year period, in the vicinity of a weather station located at the center of a circular 40 km diameter region.

Table 1
Relation between mean translation velocity of the storm and peak TS velocity.

Case	V_{EPS} (m/s)	V_{TS} (m/s)	V_{EPS}/V_{TS}
1	12	35	0.34
2	14	41	0.34
3	15	39	0.38
4	13	35	0.37
5	14	35	0.40
6	14	46	0.30
7	13	40	0.33
Mean	13.6	38.7	0.35
CV (%)	7.2	10.6	9.6