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Analysis of wind action on unique structures with application to Seville Fair Gateways

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ABSTRACT

The implementation of temporary large structures for different events such as large stages for concerts, advertising posters or symbolic accesses to public festival areas is threatened by the danger of collapse due to wind action. An analysis of the European code is necessary, using comparisons with other analysis tools such as wind tunnels, to establish whether such standards are secure for specific unconventional geometries.

For the purposes of this comparison, a model corresponding to a particular structure is analyzed, the Gateway to the Seville Fair in Spain. This paper first establishes a comparison between the national and the European code for wind action: the Spanish Technical Building Code (CTE DB SE-AE 2006) and Eurocode 1 (EN 1991-1-4 2007), taking into account that the national code has been developed using the European one as a model. Both standards are analyzed to demonstrate that the national code is not fully adapted to the European one. Subsequently, the results obtained from the European code are compared with those derived from the development of an experimental test of the same model in a wind tunnel.

The final objective of this paper is to demonstrate that neither national nor international codes are valid for structures with unique geometries, and therefore in this case it is necessary to perform an experimental test to determine wind action accurately.

1. Introduction

Wind action plays a fundamental role in the design of structures, especially in structures with complicated geometries. The complexity of determining the wind pressure coefficient for this type of structure has traditionally been a major obstacle in successive updates to wind codes.

The process for the development of the Eurocode program began in 1975, aiming to develop an extensive regulatory package for the design and analysis of structures. The main objective of the Eurocode project is to homogenize the European regulatory framework. Wind action is included in the "Eurocode 1: Actions on structures. Part 1–4: General actions. Wind actions" or EC-1 [1].

Internationally, the Eurocode regarding wind load is positioned as one of the most advanced codes compared to others such as the American ASCE 7, the Canadian NBCC or the Japanese JIA. Different studies relating to quantification of the wind load in these codes can be found in the literature [2–5].

In keeping with the final stage of the Eurocode project where all conflicting national standards were to be phased out before the end of March 2010, the Spanish Technical Building Code or CTE [6] was published in 2006 and last updated in 2009.

This paper presents a comparative study of both codes, from a practical point of view, discussing the differences detected in the CTE with respect to EC-1, as related to the calculation of the wind action [7–9]. The study decomposed the formulation of wind load according to both codes, identifying the various terms and comparing them. Finally, and in order to validate the results obtained, we applied these to a particular structure, the Seville Fair Gateway, comparing the results previously obtained to those derived from the performance of a wind tunnel test.

2. The regulatory framework for wind action

In this section a regulatory analysis for the wind action compares Eurocode 1, EN 1991-1-4, 2007 [1], with the Spanish code, CTE DB SE-AE: Technical Building Code, 2006 [6]. This is a comparative study of the different terms involved in the formulation to obtain global wind action.

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The formulation contained in the Spanish Technical Building Code (Section 3.3, in conjunction with Annex D) is developed from that of Eurocode 1 (Section 5.3), although it appears transposed into the national code in a more simplified manner.

Both EC1-2007 (1) and CTE-2006 (2) define the equivalent force of the wind as a perpendicular force to the exposed surface at each point, obtained in each case from more or less direct formulations, but with an almost identical final formulation:

$$F_w = 0.5 \cdot \rho \cdot v_b^2 \cdot \left\{ k_r^2 \cdot \left[\ln^2\left(\frac{z}{z_0}\right) + 7 \cdot \ln\left(\frac{z}{z_0}\right) \right] \right\} \cdot c_f \cdot c_{prob}^2 \cdot A_{ref} \cdot c_s \cdot c_d \quad (1)$$

$$F = 0.5 \cdot \delta \cdot v_b^2 \cdot \left\{ k^2 \cdot \left[\ln^2\left(\frac{Z}{L}\right) + 7 \cdot \ln\left(\frac{Z}{L}\right) \right] \right\} \cdot c_p \cdot c_{prob}^2 \cdot A \quad (2)$$

In simple terms, we can say that in both cases the equivalent wind force acting on a structure is obtained by the product of the terms listed in Table 1 below: (a) the basic velocity pressure, (b) the exposure factor, (c) the pressure coefficient, (d) the probability factor, and (e) the wind area. However, although the overall formulation is nearly identical in both codes analyzed, there are some differences in the calculation of some of the factors listed in Table 2.

2.1. Wind action according to EC1-2007

According to EC1-2007, wind load F_w is determined from the expression (1) by multiplying the following factors:

(a) *Basic velocity pressure:*

$$q_b = 0.5 \cdot \rho \cdot v_b^2 \quad (3)$$

where ρ is the air density and v_b is the basic wind velocity:

$$v_b = c_{dir}(z) \cdot c_{season}(z) \cdot v_{b.0} \quad (4)$$

where c_{dir} is the directional factor and c_{season} is the seasonal factor (their recommended value is 1), and $v_{b,0}$ is the fundamental value of the basic wind velocity. All these values are included in the National Annex.

(b) *Probability factor:* The value of the basic wind velocity with a probability p of being exceeded, vb(p), is defined as:

$$v_b(p) = v_b \cdot c_{prob} = v_b \cdot \left(\frac{1 - K \cdot \ln[-\ln(1-p)]}{1 - K \cdot \ln[-\ln(0.98)]} \right)^n \quad (5)$$

where K is the shape parameter depending on the coefficient of variation of the extreme-value distribution (recommended value 0.20) and n is usually 0.50.

Fig. 1. Seville Fair Gateway, 2011.

Fig. 2. Construction process of the Seville Fair Gateway, 2011.

(c) *Exposure factor:*

$$c_e(z) = \frac{q_p(z)}{q_b} = \frac{[1 + 7 \cdot I_v(z)] \cdot [\frac{1}{2} \cdot \rho \cdot v_m^2(z)]}{(\frac{1}{2} \cdot \rho \cdot v_b^2)} = \left\{ k_r^2 \cdot \left[\ln^2\left(\frac{z}{z_0}\right) + 7 \cdot \ln\left(\frac{z}{z_0}\right) \right] \right\} \quad (6)$$

where $I_v(z)$ is the turbulence intensity at height z and $v_m(z)$ is the mean wind velocity at height z:

$$I_v(z) = \frac{k_z}{\ln\left(\frac{z}{z_0}\right) \cdot c_0(z)} \quad (7)$$

where k_z is the turbulence factor (recommended value 1) and z_0 is the roughness length.

$$v_m(z) = c_r(z) \cdot c_0(z) \cdot v_b \quad (8)$$

Table 1
Equivalence between code factors.

	(a) Basic velocity pressure	(b) Probability factor	(c) Exposure factor	(d) Pressure coefficient	(e) Wind area	(f) Structural factor
EC1-2007	$q_b = 0.5 \cdot \rho \cdot v_b^2$	c_{prob}	$c_e(z) = \left\{k_r^2 \cdot \left[\ln^2\left(\frac{z}{z_0}\right) + 7 \cdot \ln\left(\frac{z}{z_0}\right)\right]\right\}$	c_f	A_{ref}	$c_s \cdot c_d$
CTE-2006	$q_b = 0.5 \cdot \rho \cdot v_b^2$	c_{prob}	$c_e = \left\{k^2 \cdot \left[\ln^2\left(\frac{z}{L}\right) + 7 \cdot \ln\left(\frac{z}{L}\right)\right]\right\}$	c_p	A	–

Table 2
Equivalence of factors between codes.

	Basic wind velocity	Exposure factor	Parameters that depend on the terrain	Pressure coefficient	Orography coefficient	Roughness coefficient	Probability factor
EC1-2007	$v_{b,0}$	$c_e(z)$	k_r, z_0, z_{min}	c_f	$c_0(z)$	$c_r(z)$	c_{prob}
CTE-2006	v_b	c_e	k, L, Z	c_p	–	F	c_{prob}