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Experimental study of topographic effects on gust wind speed

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ABSTRACT

This paper presents a follow-up study to our earlier work on comparing approaches to determine topographic effects in four major wind load codes. These codes are further evaluated and compared with earlier studies as well as new tests undertaken in the Texas Tech University boundary layer wind tunnel. Wind tunnel experiments with a model scale of 1:1000 were carried out to evaluate the wind speed-up effects of two main types of topography: escarpments and symmetrical ridges. Of particular interest were effects of ground surface roughness and the upwind slope of the two topographic features on wind speed-up and the space limits for speed-up applications around the crest of topography. Experimental results show that the surface roughness has significant speed-up effects for ridges rather than for escarpments. The results also indicate that wind load codes tend to be unconservative in specifying the minimum and maximum upwind slope as well as the spatial extent around the crest for application of speed-up factors.

1. Introduction

Over topographic features such as escarpments, ridges, embankments, and hills, airflow can both accelerate and decelerate. It is usually conservative for building codes to consider only regions where wind speed increases so that greater wind pressure on parts of structures in the regions is taken into account. Topographic effects on wind speed are even more important in exploiting wind energy since wind turbines should be located in regions where optimum wind power is obtained. Thus, it is necessary to investigate the effects of topographic features on wind flows to address these issues.

Holmes et al. (2005) presented comparison of topographic effects on wind speed between various major codes and standards and showed that using different approaches and parameters to account for the effects produced large difference in calculated wind loads. Differences of up to 80% arose between values of wind pressure when topographic factors from different codes were used. Meanwhile, Li et al. (2005) identified considerably different procedures between many current wind codes and concluded that the vertical and horizontal spatial extents around the crest of topographic features were noticeably different and that the speed-up ratio near the crest of an escarpment was generally smaller than that of a ridge under similar approach flow boundary conditions.

Among major wind load codes investigated in this study, the American Standard ASCE/SEI 7-05 (ASCE, 2005) is the only code that explicitly considers the influence of surface roughness on the speed-up ratio. Wind tunnel experiments by Cao and Tamura (2006) confirmed that surface roughness had a significant influence on topographic effects. They observed that where the topography and the upstream surface had the same roughness, a rougher surface produced higher speed-up effects. If the upstream surface is of a smooth type, a topographic feature with smooth surface was found to produce higher effects than the corresponding feature with rougher surface. However, the study of Cao and Tamura was limited to ridges while evaluating the effects of escarpments is of the same importance and is addressed in most wind load codes.

Despite studies by Jackson and Hunt (1975) and Taylor and Lee (1984) through more recent investigations, a detailed study of wind speed-up effects of topography specified in wind codes is still lacking. Major concerns about these effects are the influence of ground surface roughness and different effects between ridges and escarpments. Limiting upwind slope and spatial extents for application of speed-up factors and mathematical formulations to describe speed-up effects also require consideration.

This paper follows the previous study on topographic effects of Ngo and Letchford (2008), which presented detailed analysis and comparison of four major wind codes: ASCE/SEI 7-05, AS/NZS 1170.2: 2002, EN 1991-1-4: 2005 (CEN TC 250 was used in Ngo and Letchford, 2008), and AIJ: 2004. In this study, our recent Wind Tunnel experiments in the Texas Tech University boundary layer

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wind tunnel are presented, and experimental results are introduced in order to evaluate the codes accurately and to address the aforementioned matters of topographic effects thoroughly. Experiments with a length scale of 1:1000 were undertaken to examine speed-up effects of two main types of topography: escarpments and symmetrical ridges. Section 2 describes the Wind Tunnel experiments. Mathematical models and discrepancies between the four wind codes are summarized in Section 3. Wind Tunnel test results are discussed in Section 4. Conclusions and recommendations are presented in Section 5.

2. Experimental setup

The boundary layer Wind Tunnel where test samples were set up is 1.8 m wide, 1.2 m high and 17 m long as shown in Fig. 1. The Wind Tunnel was typically operated at a speed of 15 m/s. Modeling topographic effects in a wind tunnel is a compromise between being able to neglect Reynolds number effects due to too small a model and minimizing blockage effects for models that are too large. Glanville and Kwok (1997) carried out 1:1000 scale wind-tunnel measurements of topographic multipliers and suggested that Reynolds number effects could be neglected at this scale and so a model scale of 1:1000 was selected here. The maximum blockage ratio for these experiments was thus limited to 4.2%. Furthermore, the roof of the test section expands at 0.38% with respect to its floor and so no blockage corrections were undertaken. A combination of a barrier at the start of the test section, followed by uniform surface roughness, was used to simulate neutral atmospheric boundary layer at the appropriate scale. A smooth wood surface was used for a turbulent boundary layer over smooth terrain while deep carpet (10 mm thick) was employed to simulate rougher terrain. The experimental models were also covered with the carpet for these rough terrain simulations.

In order to address the major concerns in study of topographic effects, seven wooden models were designed and manufactured. The experimental models represent 50-m-high topographic features with different upwind slopes as shown in Fig. 2. Two symmetrical ridges with slope of 10% and 30% and five different escarpment models with upwind slopes of: 4.1%, 10%, 30%, 100% and a cliff were tested in the Wind Tunnel.

Wind speeds were measured along the centerline of the Wind Tunnel at specified distances from the crest of the topographic feature. Series 100 Cobra probes were used to measure wind speed at each specified point over the models. The measuring tool is a 4-hole pressure probe capable of providing real-time 3-component velocity and local static pressure of approach flows within a ±45° cone. The frequency response of the probe is better than 2000 Hz. The probe and its data acquisition system provide accurate wind speed estimates in the range 2–100 m/swith an accuracy of ±0.3 m/s. Wind gust speed was obtained from the longitudinal mean speed, $\overline{V_z}$, longitudinal turbulence intensity, I_u, and a peak factor $g = 3.7$ as shown in Eq. (1). This facilitated comparisons with the four wind load codes.

$$\hat{V}_z = \overline{V_z}(1 + g \times I_u) \tag{1}$$

3. Calculation methods

Both mean wind speed and gust speed are used in wind load codes while ultimately a peak wind pressure is required. In addition, Bowen and Lindley (1974) concluded, "the mean wind speed profiles may not accurately predict the maximum gust speeds that will occur (over topographic features)" because the turbulent intensity may not remain constant over all sections of a topographic feature. In this study, gust speed was therefore selected for comparison. The mean speed used in EN 1991-1-4 (EC, 2005) and AIJ: 2004 (AIJ, 2004) was converted to 3-s gust speed. The conversion was executed by its own internal procedures for EN 1991-1-4, and by the gust factor proposed by Ishizaki (1983) for AIJ:2004. A topographic effect multiplier on gust speed can be

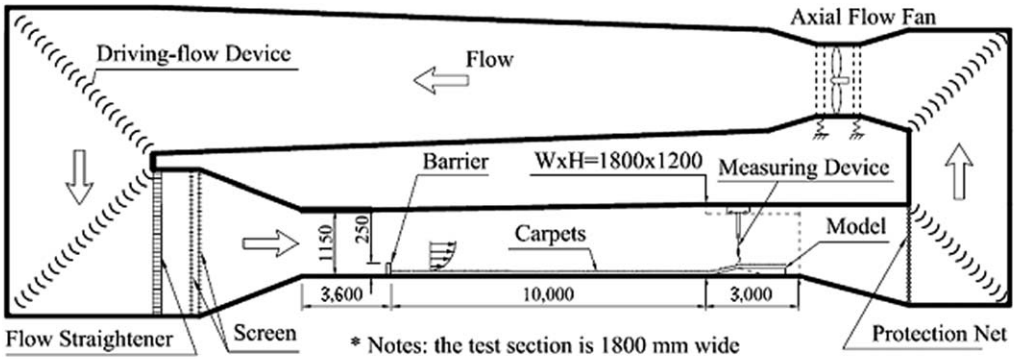

Fig. 1. Description of experiments in Texas Tech University boundary layer wind tunnel.

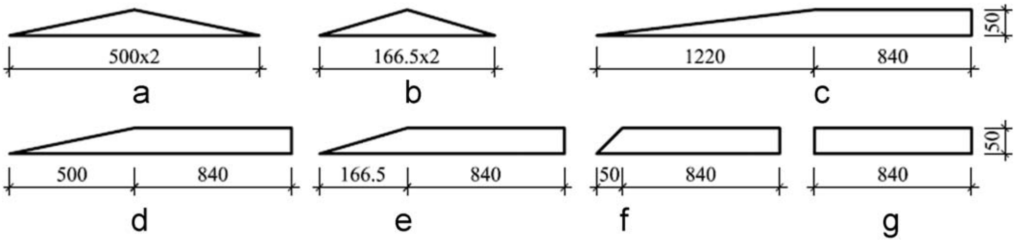

Fig. 2. Design of experimental models (unit in mm): (a) 10%-slope ridge, (b) 30%-slope ridge, (c) 4.1%-slope escarpment, (d) 10%-slope escarpment, (e) 30%-slope escarpment, (f) 100%-slope escarpment, and (g) cliff.