The contribution of vorticity to wind loads

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Abstract

'Tornadoes hit Rugby and Essex' – BBC News 26th April 2012. Vortices are inherent in all turbulent shear flows including the atmospheric boundary layer (ABL). In the ABL there is also likely to be a significant contribution to vorticity from thermal effects and the reference to 'tornadoes' is likely to be applied to strong vortex structures of moderate extent, O(10 m), which are more intense and larger than the average vortex in the ABL. However, no direct allowance is made in existing wind loading codes for the contribution arising from the pressure within vortices to the load on a structure. The reason for this is that the pressure within these vortices is not generally measured and the mode in which this pressure is transferred to static pressure on the surface of a structure is unknown. To illustrate this, the pressure within the ABL at low height has been measured using a 'static' pressure probe. The term 'static' in Bernoullian flow refers to the contribution to total pressure less the dynamic pressure, and in steady, irrotational flow, this is constant at a point. However, the unsteadiness associated with rotational elements within the flow results in the 'static' pressure not being steady. This may be stating what is well known, but it is ignored when taking measurements in boundary layer flows where surface pressures on structures are solely related to the local dynamic pressure. An example of the dynamic and 'static' pressure measured at full scale in the ABL at a height of 3 m is shown in figure 1. (Note: the 'true' zero for static pressure is not known; the static pressure data shown are with reference to a long-term static pressure average at ground level)

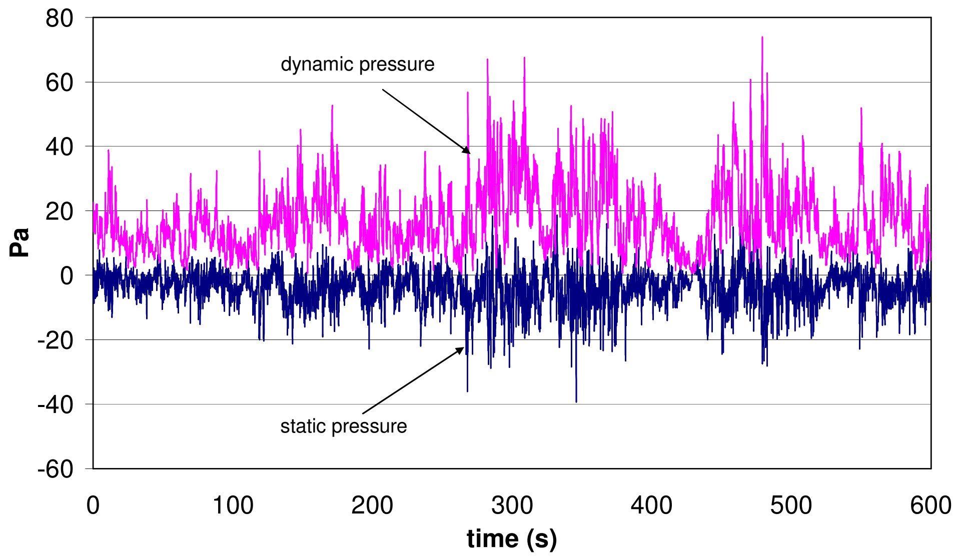

Figure 1. Example of the wind dynamic and static pressure in the ABL at a height of 3 m.

The contribution to the pressure on the surface of a building from static pressure variations has not been investigated, but there is considerable evidence of small-scale damage that can translate into additional load that exceeds the expected wind load related to wind speed (squared) alone. A further complicating factor is that simulation of the variability of static pressure in boundary-layer wind-tunnel flows has the likelihood of a significant Reynolds Number (Re) effect. This expectation follows from work at Southampton [1] where the flow over a cube showed significant Re dependency in regions of the flow where there were well developed vorticies. This is illustrated in figure 2 for the case of a cube at 45 degrees to the stream, and where the tapping point is under the 'delta wing' type vortex. This Reynolds Number effect is likely to reduce the vorticity and hence account for the frequently reported turbulence intensity in boundary-layer wind tunnels. (from typically 20% at full scale to 9 to 12% at model scale). The wind tunnel is therefore likely to moderate the static pressure in the centre of vorticies and hence underpredict extreme negative surface pressure.

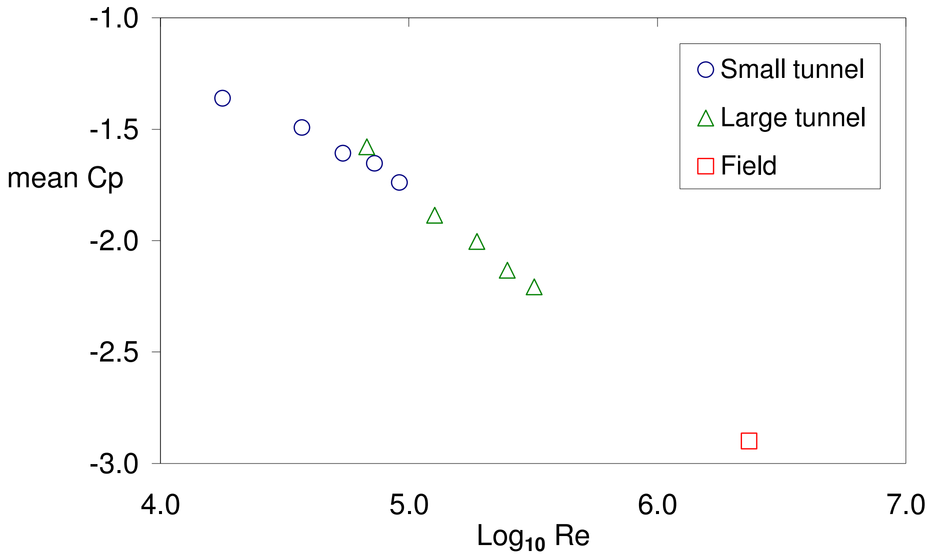

Figure 2. Mean surface pressure coefficients along a line parallel to the 45^0 leading edge and at a distance 0.069h from it, where h is the height of the cube.

The full abstract and presentation will develop the concept outlined above using full-scale data to explore the implication to wind loading.

Reference

[1] Lim, H. C., Castro, I. P. & Hoxey, R. P. 2007. Bluff bodies in deep turbulent boundary layers: Reynolds-number issues. Journal of Fluid Mechanics, 571, 97-118.