FORCES ON LOW-ASPECT RATIO RECTANGULAR PLATES, WITH THE EFFECT OF POROSITY

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Introduction

The rectangular plate of finite aspect ratio in a free stream (i.e. distant from a ground plane), is a bluff body of considerable significance in wind engineering, being representative of elevated hoardings and similar structures. The rectangular plate is also a generic shape used in studies of wind-borne debris. Aerodynamic forces on such shapes were covered by Hoerner [1], [2] and in an early ESDU Data Item [3], although the database of early measurements is quite limited. For example, there is a lot of data on drag forces on plates of various aspect ratios with zero porosity, with their planes normal to the flow, but relatively few on plates at other angles of attack, or with some porosity, at any angle to the flow.

The present paper describes some measurements in low-turbulence flow (relative to atmospheric conditions near the ground), of aerodynamic forces on solid plates of various aspect ratios between 0.5 and 2, for winds inclined at 90 and 45 degrees to the planes of the plates. Measurements were also made for perforated plates, with an aspect ratio of 1.5, for both normal and inclined winds. By comparing with the equivalent measurements on a solid plate with the same aspect ratio, porosity reduction factors for the normal forces on the plate were obtained.

These measurements were not intended to form a comprehensive research programme, but were 'ad-hoc' in nature, and 'added on' to a series of commercial tests which used the same measuring equipment. However, the presented data fills in some gaps in the standard databases [1] to [3], and an interesting conclusion on the reduction effects of porosity for an oblique wind direction is drawn.

The measurements described here were carried out in low-turbulence flow and the effect of turbulence intensity, and the proximity to the ground plane is significant for signboards and hoardings [4]. However, for windborne debris, the sizes of the bodies are very small compared to the scales of atmospheric turbulence in wind storms, and smooth flow coefficients should be more relevant than those obtained in highly turbulent flow with scales of the order of the body size or greater.

Experimental Techniques

Measurements were carried out in the 2 m by 1 m section of the 450kW wind tunnel at Monash University, using a sting balance constructed especially for the purpose of measurements on three-dimensional bodies. The wind speeds during the tests were between 20 and 42 m/s. The turbulence intensity in the flow was approximately 2%.

The sting balance had two sets of bending gauges – one set - the 'lower' gauges at the bottom of the inclined support arm - was located vertically below the model position and measured drag forces. The gauges at the end of the horizontal arm of the sting primarily measured lift forces. Thus, only two force components can be measured by the equipment – however this is adequate for many cases for which the centre of pressure can be assumed to act at the centroid of the body – this is usually the calibration point for lift and drag forces. However, for inclined plates of zero porosity, the centre of pressures are displaced from the centroid. For those cases, the resultant aerodynamic forces were assumed to act normal to the plane of the plates, and the eccentricity of loading was determined from the additional bending moments measured by the strain gauges due to this effect.

Blockage corrections were made to the measurements, but these were small – the largest correction being 4%. The correction formula used was as follows :

$$C_{N,corr} = \frac{C_{N,meas}}{1+3(A_m / A_s)} \tag{1}$$

where A_m is the projected area of the model normal to the flow, and A_s is the cross-section area of the wind tunnel.

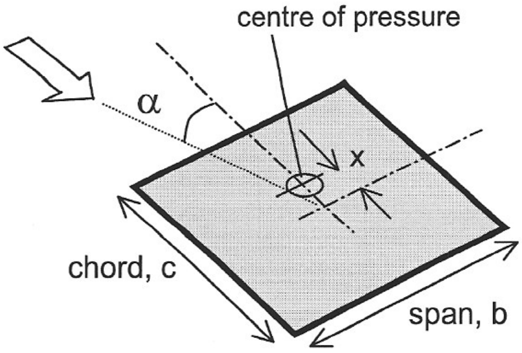

Figure 1. Definitions of dimensions

Effect of Aspect Ratio (solid plates)

Measurements of the normal force coefficients were measured for solid plates for angles of attack, α, of 90 and 45 degrees to the plane of the plates (Figure 1). For α equal to 90 degrees, the normal force is equal to the drag force, the coefficient, C_N=C_D, varies little for values of b/c between 0.5 and 2.0, and is in the range of 1.15 to 1.20. These values are similar to those obtained by Flachsbart (reported in [5]), by Fail, Lawford and Eyre [6], and by Bearman [7].

Results obtained at Monash for α equal to 45 degrees, for the normal force coefficients, are shown in Table I. Since the resultant wind force has been assumed to be normal to the plate, the lift and drag coefficients are equal to each other, and to the normal force coefficient divided by √2. The normal force coefficients do not vary greatly with aspect ratio but larger values occur for lower aspect ratios, b/c. The centre of pressure positions are also shown in Table I. These are 8 to 13% of the chord, c, from the centroid of the plate. This range is somewhat lower than the value of 20% of the chord given for hoardings and walls in AS/NZS1170.2:2002 [8] – although the effect of the ground plane, and the high turbulence intensities near the ground, are apparently significant on the centre of pressure position [4].

Table I. Normal force coefficients and centre of pressure for α = 45°

Aspect ratio b/c	C_N	x/c
0.50	1.31	0.124
0.67	1.30	0.126
1.00	1.19	0.096
1.50	1.12	0.081
2.00	1.20	0.093

Effect of Porosity (b/c = 1.5)

The effect of porosity was determined by measuring the aerodynamic forces on four different types perforated steel plates with an aspect ratio, b/c, of 1.5 - the actual values of b and c were 0.1875 and 0.125 mm respectively. The diameters of the perforated holes varied between 2.4 and 6.35 mm, and the resulting porosities from 10 to 51%. Table II shows the details of the perforations.

Table II. Perforations in porous plates

Type	Hole diameter (mm)	Hole pattern	Hole spacing (mm)	Porosity 1- δ
1	3.25	triangular	4.8	0.41
2	2.4	square	6.7	0.10
3	4.75	triangular	6.35	0.51
4	6.35	triangular	8.9	0.46

For wind normal to the plates ($\alpha = 90^o$), Figure 2 shows a porosity reduction factor, K_p, defined as the the ratio of the normal (drag) force on the porous plate, to that on the solid plate with the same overall dimensions. The expression given in [8] for K_p is as follows, where δ is the solidity of the plate:

$$K_p = [1-(1-\delta)^2] \qquad (2) \qquad \text{(Equation D1 in [8])}$$

The normal force coefficient used for the solid plate ($\delta = 1.0$) to calculate K_p in Figure 2 was 1.15. Figure 2 shows that the expression for K_p given in AS/NZS1170.2;2002 is quite a good fit (slightly conservative) to the measured data for the normal wind direction.

For the oblique wind direction ($\alpha = 45^o$), the resultant wind force is not normal to the plate for high porosities, and hence the lift force cannot be assumed to equal the drag force, as it can for a solid plate at that wind direction. Table III shows the measured lift, drag and normal force coefficients for this wind direction. The reference area for the coefficients is the total enclosed plan area ($b \times c$).

Table III. Effect of porosity on lift, drag and normal force coefficients ($b/c = 1.5$; $\alpha = 45^o$)

Porosity 1- δ	C_D	C_L	C_N
0	0.79	0.79	1.12
0.41	0.56	0.31	0.61
0.46	0.49	0.44	0.66
0.51	0.52	0.23	0.53

Figure 3 shows the porosity reduction factor, K_p, obtained from the measured data for the *normal* force component for the oblique wind direction; for the solid plate a value of C_N of 1.12 was used, as obtained from the Monash measurements and shown in Tables I and III. For this case, Equation (2) is over-conservative, and a linear variation between K_p and porosity is a better fit to the measured data, as shown in Figure 3.

Conclusions

Some 'ad-hoc' measurements of aerodynamic forces on normal and inclined rectangular plates of low aspect ratio, with varying porosity, are presented. The measurements obtained in these tests are consistent with published databases for solid plates where overlap occurs. The effect of porosity is consistent with the reductions given in AS/NZS1170.2:2002 [8] for normal winds. For winds oblique to the plane of porous plates, the measurements indicate a linear reduction in normal force with increasing porosity, and the expression given in [8] underestimates the reduction due to porosity.

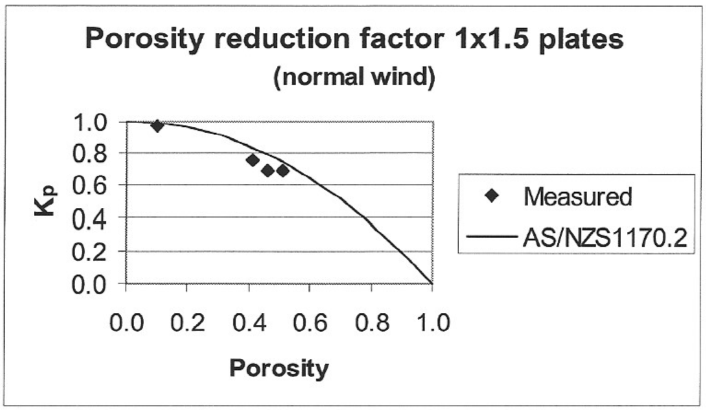

Figure 2. Porosity reduction factors for wind normal to plates

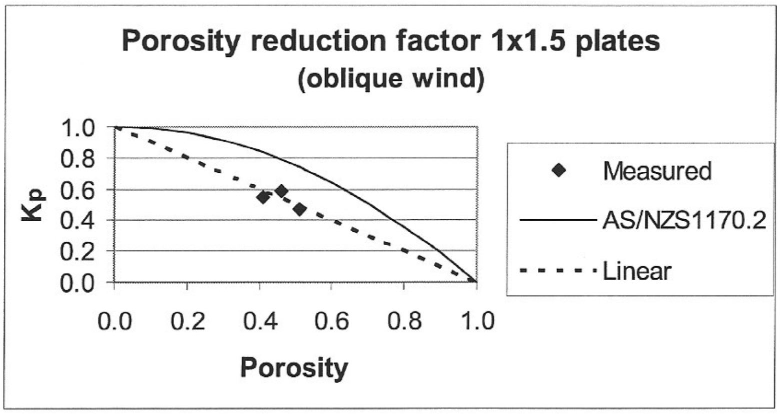

Figure 3. Porosity reduction factors for wind inclined (45°) to plates

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