MEAN WIND LOADS ON POROUS CANOPY ROOFS

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Introduction

The provision of sun protection has become a significant economic and health issue for humans, animals and plants. The incidence of skin cancers in people, heat stress in feedlot animals and microclimate control in intensive horticulture has accelerated the provision of shade structures, particularly in Australia where the problem appears more acute. Typically of large span suspended porous roof form, these shade structures are wind sensitive and the aim of this research project is to develop a model of the response of this class of structure to fluctuating wind loads and impliment this model as a rational design method. This design approach and newly obtained wind loading information will replace the current, largely ad-hoc approach which has the possibility of allowing unsafe structures to be constructed.

This paper deals specifically with wind tunnel measurements on rigid models to obtain loading coefficients on porous canopy or open roof forms. Further stages of the project will examine the influence of flexibility of shade cloth structures before producing the full design method.

Experimental procedure

Porosity was deemed the dominant dimensionless parameter for the first stage of this research project. The porosity (p) or solidity (ϕ) of the materials studied was calculated from;

$$p = 1 - \phi = \frac{open\_area}{total\_enclosed\_area} \quad (1)$$

For shade cloth fabrics, however, porosity is difficult to define and indeed these fabrics are classified in a number of ways; by weight, weaving type, or UV reduction rating, but not by porosity. Therefore, similarity of porous material was achieved by measuring the pressure loss characteristics for a range of shade cloth fabrics and matching, as far as possible, those measured for various metal meshes; woven, perforated and expanded. The pressure loss characteristic is defined as;

$$K = \frac{P_u - P_d}{\rho \overline{U}^2 / 2} \quad (2)$$

where P_u and P_d are the upstream and downstream static pressures either side of the mesh and $\overline{U}$ is the average approach velocity. These measurements were performed in a small wind tunnel, approximately 300mm square, in which the entire cross section was covered by the various materials being tested. Figure 1 shows the experimental results plotted as

K vs mean wind speed $\overline{U}$. Ideally a Reynolds Number should have been evaluated but there was a difficulty in determining a characteristic length dimension (gap size, thread diameter ?) for the fabrics. As the perforated metal pates of porosity 11% and 23% encompassed most of shade cloth results, these were chosen for the wind tunnel study.

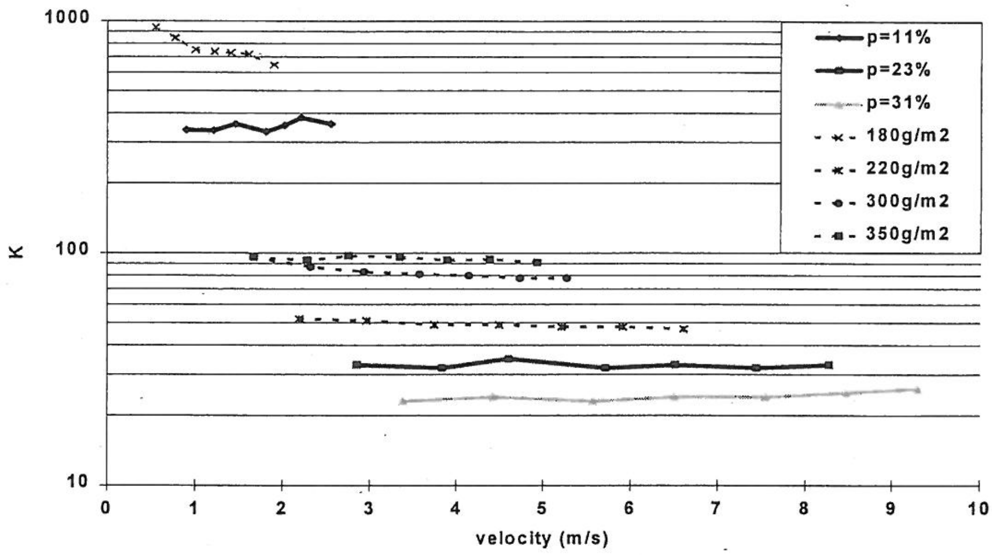

Figure 1. Pressure loss characteristic K for various porous materials. Perforated metal plates specified by porosity, p(%), and shade cloth fabrics specified by weight, g/m^2.

Generic canopy roof forms of hip, gable and monopitch were selected for the study. Two roof pitch angles were selected as being typical of current construction; namely 15^{o} and 27^{o}. The full scale structures being modelled were nominally 15m by 15m in plan area with an eaves height of approximately 5m. The models were constructed at a scale of 1:50 which matched the wind tunnel simulation of a rural terrain category 2 [1].

The tests were conducted in the Department of Civil Engineering's Boundary Layer Wind Tunnel which is 3m wide by 2m high and has some 12m of upstream fetch for boundary layer simulation. A 300mm fence and uniform carpet roughness were employed in the simulation. The turbulence intensity at eaves height 100mm was approximately 20%.

A simple one component force balance was constructed [2] to measure the very small loads. This force balance could be mounted in several ways to obtain separately, measures of the overall drag and lift forces on the models for various angles of attack. A paddle in a container of a viscous fluid was used to dampen the fluctuating loads. Only mean values are presented here which represent the average of five repeated runs of 30s duration at a sampling frequency of 100Hz. The forces were reduced to coefficient form by dividing by the mean dynamic pressure at eaves height (the lower height for the monopitch roof) and the projected plan area. Lift is defined as positive downwards.

Results

The drag and lift coefficients for the 15° pitch gable roof at an azimuth of 0° (normal to the ridge line) are plotted against porosity in Figure 2. The overall drag coefficient increases slightly whereas the lift coefficient reduces as porosity increases. In AS1170.2 [1] the values for a solid roof, after resolving the windward and leeward pressure coefficients into drag and lift coefficients, are: C_d, 0.06 to 0.17 and C_l, -0.16 to -0.56 which compare favourably with those obtained here for a solid roof. A K_A of 0.8 has been employed for the code values.

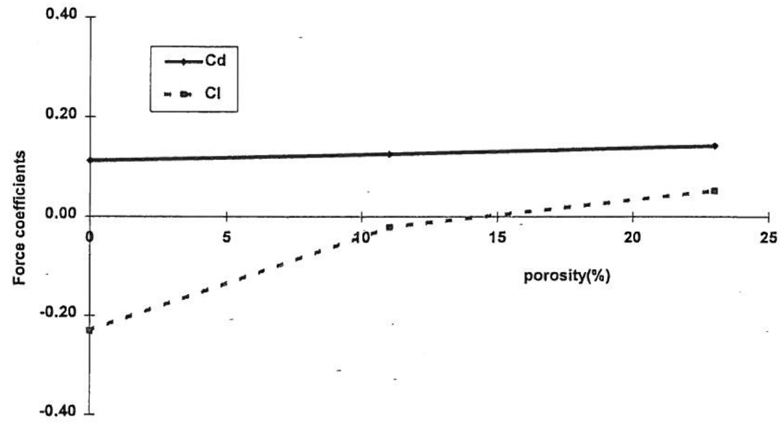

Figure 2. Drag and lift coefficients for 15° pitch gable roof at 0° azimuth.

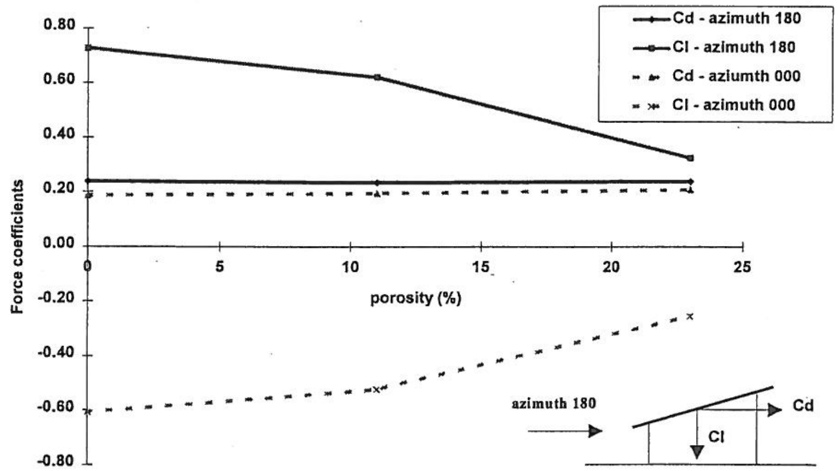

Figure 3. Drag and lift coefficients for 15° monopitch roof at 0° and 180° azimuth.

The drag and lift coefficients for the 15° monopitch roof at aziumths of 0° and 180° are presented in Figure 3. Once again, the drag remains practically unchanged while the lift reduces with porosity. Table 1 compares the present study results with the AS1170.2[1] values for a solid roof at the two azimuths. Again a K_A of 0.8 has been employed for the code values. Whereas there is good agreement between the present results and the code at 0°, for the 180° case, the code[1] significantly underestimates the current mean pressure measurements.

The drag and lift coefficients for a 15° pitch hip roof, in effect a pyramid, for an azimuth of 0° are presented in Figure 4. As with the other roof forms the drag increases slightly, while the lift decreases and changes sign as porosity increases.

souce - azimuth	C_d	C_l
AS1170.2 - 0°	0.11 to 0.17	-0.4 to -0.64
present study - 0°	0.19	-0.61
AS1170.2 - 180°	0.13	0.48
present study - 180°	0.24	0.73

Table 1. Comparison between present study and AS1170.2 [1] for the lift and drag on a solid monopitch roof at 0° and 180°.

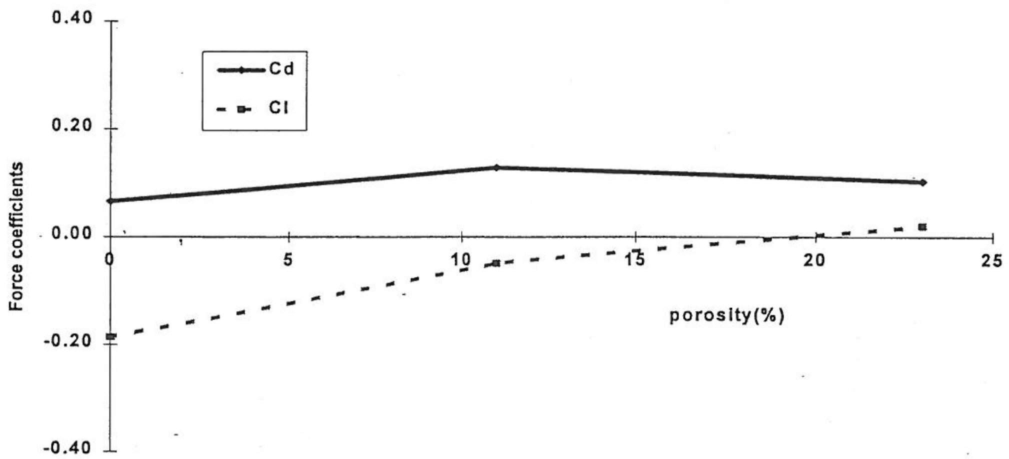

Figure 4. Drag and lift coefficients for 15° pitch hip roof (pyramid) at 0° azimuth.

Conclusions

Overall wind loading coefficients, both lift and drag, have been determined for a range of porous canopy roof forms. Similarity of the pressure loss characteristic was used to match the range of shade cloth materials used in the construction of these structures to a range of perforated metal plates used to construct the wind tunnel models. Hip, gable and monopitch roof forms were studied for two pitch angles, 15° and 27°, for porosities ranging from 0 (solid) to 23% and for several wind directions.

In general windward loads increase and leeward loads reduce with increasing porosity. Flow visualisation on a gable roof model revealed that the porosity induces flow through the windward roof preventing reattachment beneath this section of the roof and thereby increasing both the upper surface load through increased stagnation area and lower surface load through preventing pressure recovery after reattachment. The leeward roof experiences reduced loading because the separation bubble formed on the upper surface at ridge lines is vented somewhat while the lower surfaces experience a much more significant wake effect from the flow through the windward roof section.

References

[1] Standards Australia, AS-1170.2, SAA loading code Part 2: Wind Loads, 1989.
[2] A. Row & J. Wolbers, Wind loads on shade cloth structures, BE Thesis, Department of Civil Engineering, The University of Queensland, 1996.