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Wind Tunnel Testing for the Design of Large Porous Canopies

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Abstract

Wind tunnel testing of scale models of a large porous protection canopy has been carried out at the James Cook University Cyclone Testing Station Wind Tunnel in Townsville. Four models of 0%, 19%, 38% and 58% porosity have been tested and the results of the analysed data are presented. Various features are indicated strongly from this research to date. These include drag pressures on the windward walls similar to or greater than for solid walls and low fluctuating pressures across the roof.

Introduction

The rate of construction of large protection canopies in Australia and New Zealand continues to grow with an increased number of water storage covers for water quality and evaporation control, protection canopies for cars at importer and exporter storage facilities, shade canopies for feedlot pens and traditional horticultural structures. The use of non porous plastic covers supported on cable structures over large areas has also seen an increase in application. At the same time reports have been made of several recent failures of these kinds of structures – each time during high wind events. While these large canopy structures provide an economical and efficient way to provide protection to assets, a greater understanding of how these structures respond under wind is required for safe and serviceable design.

Figure 1. Flat vehicle cover

Scale Model Testing

A program of testing scale models of varying porosity of a large protection canopy has been undertaken at the Cyclone Testing Station Wind Tunnel, James Cook University, Townsville. The models tested in the Tunnel are 1:250 scale models of a 200 metre square × 6 metre high protection canopy. Walls have been constructed at 45 degrees slope and the porosities tested are 0%, 19% 38% and 58% based on percentage of open area. The 22m long tunnel has a cross section of 2.1m x2.5m. The floor is of suitable roughness to represent a terrain category 2 at a length scale of 1:250.

The porous models were tapped in a one eighth sector and symmetry, together with results from the four normal side directions, was used to compile a full distribution across the surface. The model was rotated through 360 degrees in the tunnel in increments of 15 degrees and tested three times at each location.

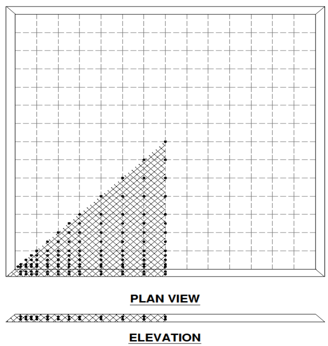

Figure 2. Model plan and elevation with tap locations

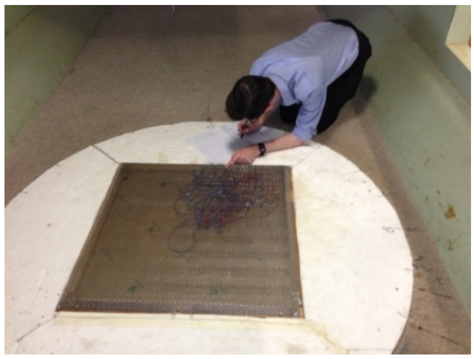

Figure 3. Model on turntable in wind tunnel

Solid or Zero Porosity Model

The solid model was tested for comparison with the porous models and also with the design standard AS/NZS 1170.2:2011 Structural design actions - Wind actions, pressure coefficients for large impermeable flat roofs. It is constructed from clear plastic and has a tapping distribution consistent with other models. One eighth of the model was tapped, allowing measurement of the pressure at each tap location. The porosity, being a ratio, is applicable to both model and full size canopy.

The measured results were first normalised using a normalizing velocity factor for converting between velocity at 500mm above the floor of tunnel and velocity at roof height of model (25mm).

$$Cp_h = Cp_{500} \times \left(\frac{1}{x}\right)^2 \qquad (1)$$

The normalising factor $x = 0.605$

To compare the results with the pressure coefficient distribution for large flat roofs in AS/NZS 1170.2 (2011), the results were also adjusted using a gust factor. The gust factor is defined as the ratio of the maximum gust speed within a specified period to the mean wind speed. AS/NZS 1170.2 uses a peak 3-second gust wind speed for design purposes.

$$C_{fig} = Cp_h / G_u^2 \qquad (2)$$

G_u = gust factor = 1.76

The following pressure contours were obtained from the wind tunnel measured results.

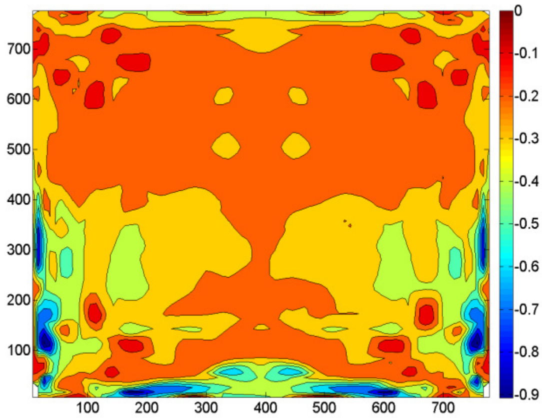

Figure 4a. Contour plot of maximum upward (suction) roof pressure coefficients C_{fig}, zero porosity

The wind direction is from the bottom for this plot and all subsequent contour plots in this paper. The wall values are not shown. The plot shows a variation from -0.9 to -0.1 which are in reasonable agreement with the external pressure coefficient distribution for flat roofs in AS/NZS 1170.2.

The results for downward pressures were measured between 0.2 at the leading edge to 0.05 over the majority of the surface. AS/NZS 1170.2 specifies values up to 0.2.

The following plot shows sample readings of the variation of uplift pressure with percentage distance across the model taken at the centreline of the model (blue). Values along a line a distance 7% across the roof width of the model are also shown (red). For comparison, the AS/NZS 1170.2 values for a large flat roof are also shown (green).

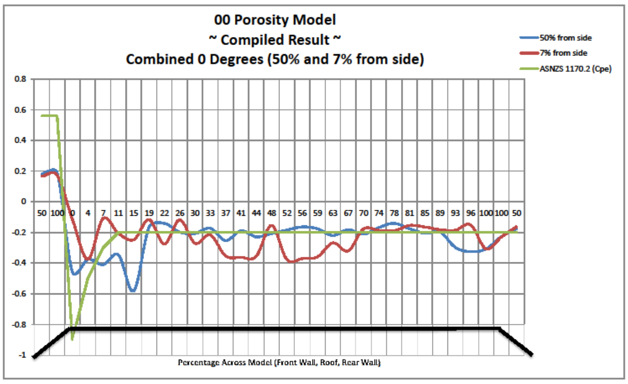

Figure 4b. Sample measured pressure coefficients and ASNZ1170.2 values for a large flat roof

These graphs demonstrate the positive upwind wall pressure, then the peak roof suction at the roof and wall intersection, followed by a reduction in uplift pressure across the roof and at the downwind wall. The windward wall value shown for ASNZS 1170.2 is based on a 45 degree roof value. The flat roof values from ASNZS 1170.2 shown assume vertical walls.

38 percent Porous Model

The first porous model tested was constructed using a brass mesh which allows even wind flow through the model. The porosity by open area was measured as 38%. Tapping tubes were brazed onto the mesh. This was slow and during testing several of the tubes were pushed through the mesh when the tapping tubes were connected.

Figure 5. Underside of 38% porous model

The maximum resultant value of combined external uplift pressure and internal pressure measurements at each tap was found at any one instant to obtain a contour plot of maximum uplift values acting on the canopy. Similarly the maximum resultant downward pressure on the particular roof tap was found to obtain peak downward coefficients. The plot presents a combination of peak resultants at different instances measured as the model was rotated on the eighth sector and then combined using symmetry.

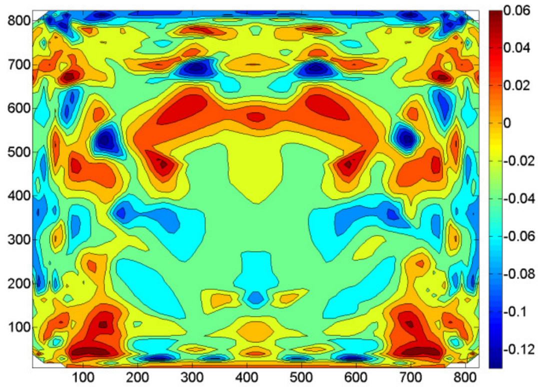

Figure 6a. Contour plot of maximum uplift roof pressure coefficients, 38% porosity, C_{fig}

The uplift values range from -0.12 to 0. There are areas where small positive or only uplift pressures occur.

The resulting downward pressure coefficients vary from 0 to 0.16 with some areas showing minor uplift.

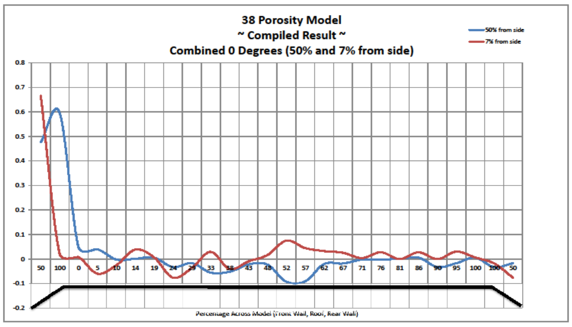

Figure 6b. Combined external and internal measured pressure coefficients C_{fig}, 38% Porosity

These graphs show sample readings of the variation of combined internal and external pressure coefficients across the model along the centreline and also along a line 7% of the model width from one side. They are a compilation of several sample readings and show the trend of the models behaviour with the larger wall positive pressures initially followed by the roof pressures fluctuating around zero. The wall pressure coefficient $\boldsymbol{C}_{fig}$ peaks at 0.4 and the roof pressure coefficients $\boldsymbol{C}_{fig}$ vary between $\pm$ 0.1 with the average around -0.05

19% porous model

The next model tested was constructed from a perforated steel sheet. This proved to be easier to tap and more robust. The open area porosity was calculated as 19% with 6.3mm diameter holes at 13.8mm centres.

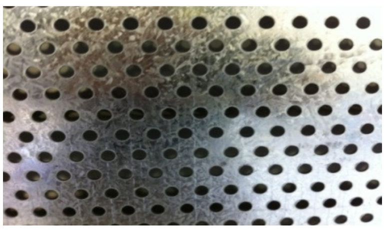

Figure 7. 19% Porous Perforated Sheet

In this model, there is a solid section at the wall to roof intersection which influences pressure readings in this area, differing from the 38% porous mesh model which allows air flow through and around this intersection. The following results were obtained.

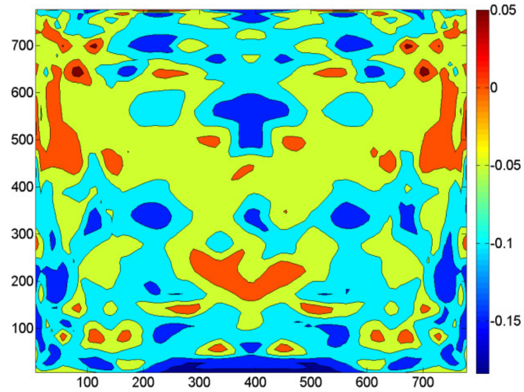

Figure 8a. Contour plot of maximum uplift roof pressure coefficients C_{fig}

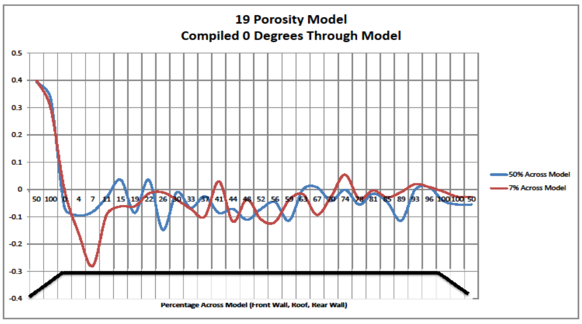

Figure 8b. Internal and external pressure coefficients acting on the walls and roof of the Canopy, C_{fig}

58% porous model

A second model made with perforated steel sheet was tested. This model has a greater open area percentage equal to 58%. The hole diameters are 8mm at 10mm centres.

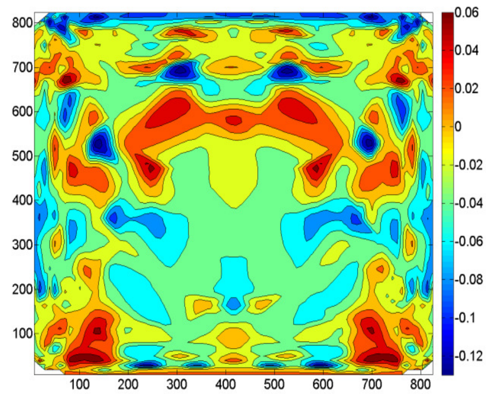

Figure 9a. Contour plot of maximum uplift roof pressure coefficients C_{fig}, 58% porosity

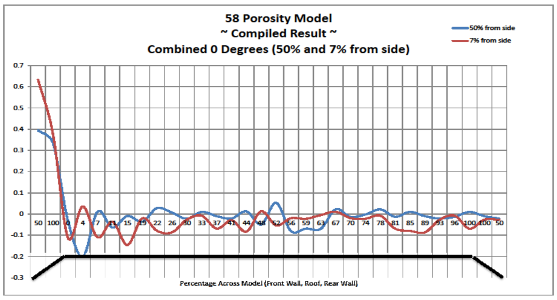

Figure 9b. Internal and external pressure coefficients acting on the walls and roof of the Canopy, C_{fig} 58% Porosity

Combined results

The following figures show the combined results of the various models together with the ASNZS 1170.2 values.

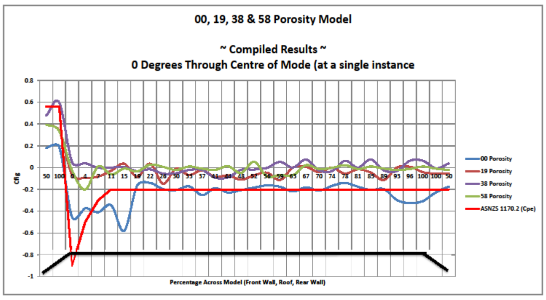

Figure 10a. Combined compiled results for all models and ASNZS 1170.2 reference – centre line of model

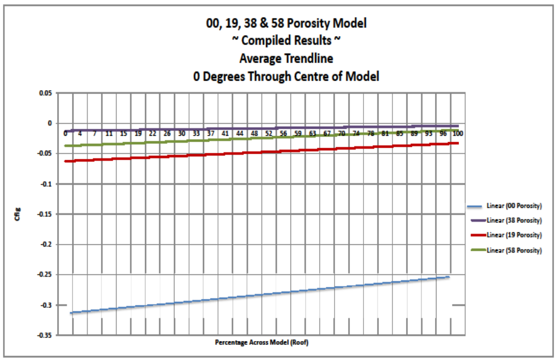

Figure 10b. Combined trendline results for all models

The trendline values are very similar for the three porous models. The 38% porous model shows the lowest average and this is most likely due to the more even flow through the mesh compared to the perforated sheets.

Conclusion

The results presented provide good indication of the pressure distribution behaviour.

The following has been strongly indicated:

(i)The upwind wall pressures on the porous canopy models are significantly higher than the roof pressures and are equal or greater than those measured on the solid model.

(ii) The combined roof pressure (external and internal) on the porous model roof surfaces oscillates between low magnitude positive and negative values and are lower in magnitude than the solid roof results. This low oscillation has been observed on constructed canopies with a rippling effect being observed.

(iii) The average values of pressure across the roof are similar for the three porosities tested, with the average being slightly lower for the 38% porosity mesh model. These averages for $\boldsymbol{C}_{fig}$ are between 0.02 and 0.05. The peak values for $\boldsymbol{C}_{fig}$ are approximately ± - 0.16.

These results show reasonable correlation with the research by Robertson et al who tested the pressure distribution across the flat roof of a scale model of a greenhouse structure with porous cladding. Although the structure modelled by Robertson is significantly smaller that the canopy for this current testing, the same pressure distribution trends are observed.

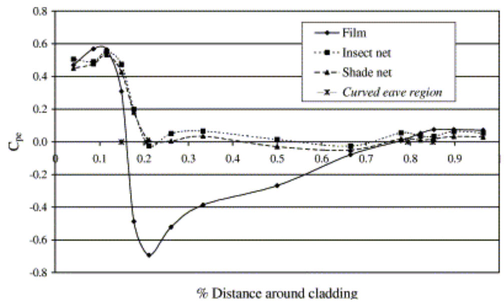

Figure 11. Pressure coefficients around the walls and roof of a flat roofed greenhouse structure, Robertson et al

The design of the canopy roof for uplift and/or downward wind loads needs to be assessed in terms of the structural element being designed. Local connections between the net and cables and posts will need to be designed for peak values. Local pressures also will need to be considered when assessing the biaxial tensile strength of a net in a particular canopy bay of the orthogonal cable support structure. Using peak roof pressure values across the roof for the design of the cables and also the design of the external tie back foundations will lead to over conservative designs. The use of an average value can be considered for design. A roof surface friction needs also to be included in the analysis model.

Acknowledgments

Thank you to Associate Professor John Ginger and the staff at the Cyclone Testing Station, Don Braddick and Dennis Smith and to Michael Barbagallo for his model testing work. Thank you also to Dr John Holmes and to Netpro Protection Canopies - Claude Grayling, Michael Thompson and Adrian Pradella who built the models.

References

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