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Characteristic Wind Pressures on Net Protection Canopies

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Abstract

The application of large net protection canopies has extended from the traditional protection of agricultural and horticultural crops to the protection of assets such as high value imported vehicles, water reservoirs and ore stockpiles. With the damage risk increasing, insurance companies and Local Government Authorities are frequently requesting structural certification for these structures. Practice has shown that if the structures are well detailed and anchored, they generally have strong capacity to withstand loads from high winds.

Currently there is very little relevant research and information on which structural engineers can base their analysis of wind actions on the structures. The magnitude of pressure coefficients and their distribution across these large structures are the main factors influencing the design of the cables, posts and foundations.

This project investigates the magnitude and distribution of wind pressure coefficients across the roof and walls of a typical net canopy structure using wind tunnel scale model testing.

A solid non-porous model and a porous model of the same size are being tested in the Cyclone Testing Station's wind tunnel. Further models covering varying porosity, dominant wall openings and physical design are also proposed to be tested.

Introduction

The safe and economic structural design of large porous clad protection canopies is essential as applications for these kinds of structures increase. Common applications currently being constructed include protection canopies for:

Protection of crops from birds, bats, insects, wind, sun and hail with added benefits of reduction in evaporation of water and the positive management of the microclimate for the plants

Protection of water storage facilities with dam and channel covers providing evaporation control, improvement of water quality, reduced chemical treatment, reduced bank erosion and allowing rain to run through the porous material

Protection of vehicles from hail, sun and wind

Examples of these structures are shown in Figures 1a-1c.

Figure 1a. Canopy over Large Orchard

Figure 1b. Dam Cover Construction

Figure 1c. Car Protection Canopy

Current Practice

A large amount of practical experience has been accumulated with regard to structure economy, efficiency and also failures, but most of these structures in the past were not structurally designed by professional engineers and the emphasis was on economy, constructability and simplicity. Cable, post and anchor sizes and construction techniques were developed from experience to provide a well tensioned and fastened anchored structure.

The consequences of failure of agricultural protection canopies were relatively low with regard to human safety and repair was able to be performed effectively and quickly. Typically failures came from inadequate fastening of the net to the wire and cable structure, inadequate tensioning of the cloth and/or the cables, failure of tie back anchors due to poor drainage and saturation of soil and build up of snow or hail. However with the canopy applications extending to vehicle protection or high value horticultural crops, the consequences of failure became more significant and canopy contractors began to look for engineering support. One example of this was the failure of a canopy protecting orchid tissue being grown for export to Asia. The canopy's construction was inadequate and failure in a severe storm led to a claim by the grower against the canopy contractor (Floraculture v Plant 1988) that ended up in the Supreme Court of Queensland. At this time it became very evident that more knowledge was required regarding wind loads on the canopies and also more development work was required in the connecting of cloths to structural members.

Structural engineers are now frequently asked to certify these structures by local government bodies, particularly when they are erected close to occupied buildings and work areas. Vehicle importers who store a large number of cars before distribution to dealers particularly now request structural certification of hail protection canopies and insurers are demanding this engineering design.

Porous protection canopies are typically constructed with flat roofs and sloping sides. Construction employs timber or steel posts on a regular grid, pre-tensioned high strength multi-strand roof cables in a two way rectangular pattern and the porous netting tensioned and clipped to the cables. Cable tension loads are taken to the ground using guy cables which are typically at 45 degrees and constructed with two cables of the same size as the roof cables. Foundations vary but are now frequently constructed using steel screw anchors. Concrete bored piers and also buried timber logs in back filled earth trenches are also used.

Net porosities can vary from around 88% to 10%, depending on the prescribed protection requirements. The low porosity nets are used where bird and hail protection are predominantly required. High shade and low porosity nets are used for sun and heat protection and also dust reduction in stock piles.

The analysis of a large cable supported canopy is able to be carried out using finite element analysis with a non-linear solver. The various load cases are applied in increments to allow for the incremental deflection of the cables and resulting change in geometry. Tension only beam elements are used to model the cables and beam elements to model the posts. The designer has the option of including the net as part of the structural system, providing additional tensile strength and membrane action. However the net load-displacement characteristics vary enormously with the weft, weave and porosity and are typically influenced by the tightening of the threads at the net nodal points. Specific material load-deformation testing is possible for each net, but currently is not usually carried out by the manufacturer. Currently work is being carried out to gauge the influence of the net on the structural capacity of the overall structure. A more simplistic approach is to ignore the net and analyse the structure as a cable and post structure with net cladding.

The load cases that need to be considered are:

Dead load: this is usually negligible as most nets are of the order of 60 to 240g/m^2 and cables are also relatively light compared to the load carrying widths. The self weight of the cables can be allowed for in the FEA.

Live load: live load is usually neglected as the canopy roofs are considered to be non trafficable. In particular circumstances, the canopies can be made trafficable, but to avoid large deflections and damage to the net, cable spacing is reduced.

Pre-tension: this load is applied during erection and is typically around 15 to 20% of the ultimate break load of the cable. This is the first load case applied incrementally by the non linear solver.

Wind load: these loads have proved to be the hardest loads to predict and model due to the lack of reliable data for wind loads on large porous structures. The high sensitivity of the structure to small changes in the pressure coefficients becomes apparent during analysis. Typically, lift coefficients of between 0.04 and 0.3 have been used based on previous research. The variation of these coefficients with distance from the windward edge in a manner similar to the AS/NZS 1170.2 (2011) recommendations for flat roofs, has also been used. This appears to have produced conservative design with a number of these structures withstanding cyclonic wind conditions.

Recent testing indicates that the negative internal pressures balance external suction, leading to virtually no net load on the roof. The external pressure and internal pressures balance at the net surface due to the porosity.

The magnitude of positive pressures on the nets appears from previous testing, to be of higher magnitude than the suction pressures, particularly with regard to pressures on canopy walls and wind fences. Local failures have been observed where the structure has failed at the corners indicating that peak effects are likely to occur at the definite changes in structural geometry.

Porosity

Porosity has been derived by the measurement of pressure loss through a porous material subjected to a steady air flow.

This is represented by Equation 1.

$$\Delta P = \tfrac{1}{2}\rho V^2 \, k \qquad (1)$$

where ΔP = the static pressure difference across the porous material, k = the pressure loss coefficient, V = the velocity of the fluid, ρ = the fluid density

Richards and Robinson (1999) developed this approach, identifying that the solidity, type of construction and Reynolds number of the net were the main contributing factors. For round wire rectangular mesh they developed the relationship of the pressure loss coefficient to the porosity β of the material by Equation 2.

$$k = C_d(1-\beta)/(1-0.75(1-\beta))^2 \qquad (2)$$

where β is the estimated porosity.

Wind Tunnel Testing

Wind tunnel model tests were carried out at the Cyclone Testing Station Wind Tunnel. 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 models tested in the Tunnel are both 1:250 scale models of a 200 metre square × 6 metre high protection canopy. Walls have been constructed at 45 degrees slope.

The first model shown in Figure 2, is made from solid sheeting. It is to be used as a reference for same size and scale models with porous cladding of varying porosity.

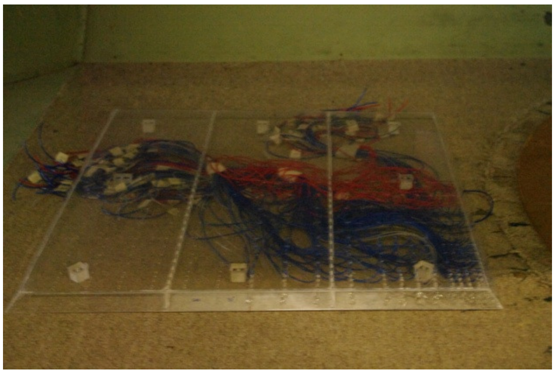

Figure 2. Non-porous model with pressure taps and tubes

The second model shown in Figure 3, is clad with a fine brass gauze. The brass gauze has allowed the brazing of tapping points to which tubes can be fixed and connection made to the transducer measuring the pressure readings. The pressure loss of the mesh was measured in the 600mm diameter circular wind tunnel at the James Cook University. The porosity was estimated to average 58%.

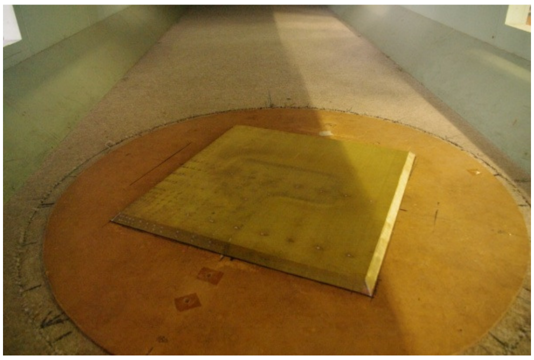

Figure 3. Porous model on wind tunnel turntable

Non-Porous model testing

The model is tapped at 62 locations on a quarter of the model and connected to the transducer. The pressures experienced at each tap are then monitored and recorded 1250 times over a 30 to 31 second period. The minimum, mean, maximum and standard deviation at each tap is then calculated by the recording software. This was repeated four times to give data for 225 tap locations.

The model is placed on a turntable which is rotated through increments of 15 degrees. Data is recorded at each of these intervals providing data for the whole model under wind loads from directions through 360 degrees.

The tap locations are shown in Figure 4.

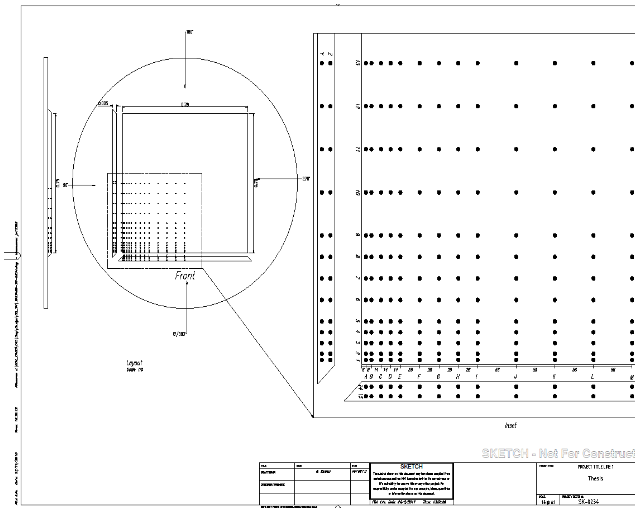

Figure 4. Tapping layout

The measured results are 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 (taken as 25mm).

$$Cp_h = Cp_{500} \text{x} (\frac{1}{x})^2$$

The normalising factor $x = 0.605$

To compare the results with the pressure coefficients given in AS/NZS 1170.2 (2011) the results are also adjusted using a gust factor.

$$C_{fig} = Cp_h / G_u^2$$

G_u = gust factor = 1.76

Porous Model

The testing of the porous model has proved more difficult to date with initial results being wrongly influenced by an opening in the base turntable on which the model is placed. This caused a flow of air through the porous material and through the opening in the base. Positive pressures resulted across the roof rather than the expected uplift values.

Recent testing with the base of the model sealed indicates low net negative and positive values across the roof when the external and internal pressure measurements are combined. The following tables in Figures 5 and 6 shows preliminary results for $\theta = 0^{\circ}$ and $\theta = 180^{\circ}$ degree wind directions. The sample is taken down the central axis of the model and the distance across the roof is shown in increments of the structures height (H). Results are compared with the non-porous model test results and the recommendations of AS/NZ 1170.2 for flat roof external pressure coefficients.

The porous model results show no significant increase in pressures at the upwind edge of the roof and generally fluctuate minimally around 0.0 across the roof. Wall pressures on the upwind side are similar to the AS/NZ 1170.2 coefficients for a pitched 45 degree roof. On the downward side the negative coefficients are significantly lower for the porous model, consistent with the roof results.

Distance across roof	Porous	Porous	Non Porous	Non Porous	AS1170.2
H= height	C_{fig} min	C_{fig}max	C_{fig}min	C_{fig}max	$C_{p.e} \times K_l$
.25H	-.04	.05	-2.8	1.0	-1.8
.5H	-.01	.08	-2.5	.8	-1.8
1H	0	.05	-2.3	.6	-1.35
1.5H	-01	.07	-1.4	.35	.5
2H	-.01	.02	-1.2	.35	.5
3H	-.07	0	-.9	.35	.3
4H	-.03	.06	-.8	.35	.2
5H	0	.04	-.7	.35	.2
6H	-0.03	.01	-.6	.35	.2
7H	-03	0	-.6	.35	.2
12H	0	.02	-.6	.35	.2
14H	0	.05	-.6	.35	.2

Figure 5. Wind Direction θ = 0°

Distance across roof	Porous	Porous	Non Porous	Non Porous	AS1170.2
H= height	C_{fig} min	C_{fig}max	C_{fig}min	C_{fig}max	$C_{p.e} \times K_l$
.25H	-.01	.01	-.6	.35	.2
.5H	-.03	.01	-.6	.35	.2
1H	-.04	.02	-.6	.35	.2
1.5H	0	.04	-.6	.35	.2
2H	-.03	.03	-.6	.35	.2
3H	-.02	.04	-.6	.35	.2
4H	-.04	.06	-.6	.35	.2
5H	-.07	.06	-.6	.35	.2
6H	-0.01	.01	-.6	.35	.2
7H	-01	.01	-.6	.35	.2
12H	-.04	.04	-.6	.35	.2
14H	0	.02	-.6	.35	.2

Figure 6. Roof Pressures Wind Direction θ = 180°

The preliminary wall pressure results for the 45 degree slopes wall are shown in Figures 7 and 8.

Distance	Porous	Porous	Non Porous	Non Porous	AS1170.2
H= height	C_{fig} min	C_{fig}max	C_{fig}min	C_{fig}max	$C_{p.e}$
.33H	.23	.52	-.46	1.85	.56
.66H	.21	.59	-.20	2.04	.56

Figure 7. Wall Pressures Wind Direction θ = 0°

Distance	Porous	Porous	Non Porous	Non Porous	AS1170.2
H= height	C_{fig} min	C_{fig}max	C_{fig}min	C_{fig}max	$C_{p.e}$
.33H	-.16	.09	-.83	.12	-.6
.66H	-.16	.10	-.84	.11	-.6

Figure 8. Wall Pressures Wind Direction θ = 180°

Discussion

The measurement of relatively small negative and positive pressures on a scale model is sensitive to the materials used and method of tapping the porous material. In practice the cables and net system form an elastic structural system capable of large displacements and also dissipation of peak loads across the structure. With displacement the fabric stretches and porosity will increase. Pressure coefficients in practice may be reduced with the increase in wind speed.

The relative displacements of the cables and the net fabric under wind loads require investigation into the deflected roof shape formed, possibly leading to greater frictional drag. The failure mechanisms of the integrated net and cable structure require further investigation. Frequently the tie back anchors fail first. Load prediction for clipping of the net to the cables is also required as this has shown to be a common point of failure.

The amount of pre-tension in the structure will determine the success of the canopy to withstand wind loads. Inadequate pre-tension will cause large displacements and repetitive flapping under low winds leading to tearing and fatigue type failures.

In scale models the roughness and surface friction are likely to play a larger part than in practice in influencing the way the structure responds. The use of fine brass mesh has been adopted to reduce this affect. AS/NZ1170.2 provides values for frictional drag across a roof in the range of 0.01 to 0.04. This would lead to a significant horizontal force on a large canopy due to the large roof area. It is likely that this value varies across a large porous roof and investigation into the influence of this force on a large structure presents an interesting challenge. The use of force balance measurements can be used to assess the total horizontal reaction on a particular fabric.

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