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Wind loads on Queensland Cyclone Shelter Buildings

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ABSTRACT

A wind tunnel model study on the Cyclone Shelter Buildings showed that venting the corners of the overhanging roof results in a significant reductions in external design wind pressures. The inclusion of vents in the corners of the roof have reduced the peak pressure by about 25% compared to the pressures at the un-vented corners. The vents have resulted in higher negative pressures along the roof edges away from the corners, but these are considerably lower in magnitude than those at the un-vented corner.

1. Introduction

The Cyclone Testing Station was commissioned by Project Services, Queensland Department of Public Works to carry out a wind tunnel study to determine external design wind pressures on the roof and walls of Cyclone Shelter Buildings built along the Queensland coast. These buildings are of square plan-form with a 10^{o} pitch gabled roof, as shown in Figure 1. They are equipped with a number of specific features intended to mitigate and reduce wind loading: the lower walls are chamfered, and the corners of the upper walls are equipped with porous horizontal sunshades and porous wing walls, all intended to reduce the effects of flow separations and to reduce negative wind pressure peaks. The corners of the overhanging roof have been vented, also designed to reduce wind loading. A number of buildings of this design have been built in North Queensland.

These buildings are located in Region C – as defined in Figure 3.1(A) AS/NZS 1170.2 [1]. The 10,000 yr return period (i.e. ultimate limit state) gust wind speed in this Region at an elevation of 10m in terrain category 2 is 85 m/s.

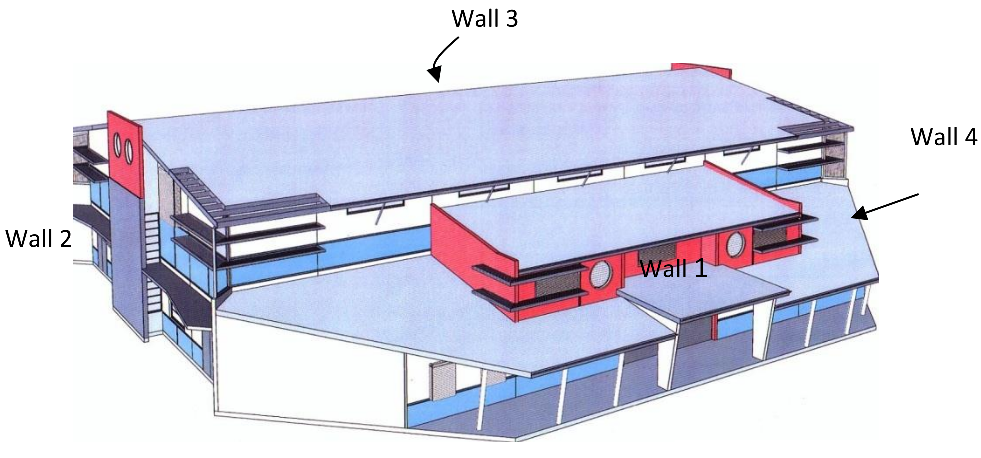


Figure 1. Cyclone Shelter Building

2. Wind-tunnel tests

Model-scale, tests were carried out by simulating the approach boundary layer flow and testing a model of the building at the same length scale in the simulated flow, in the 2.5m wide × 2m tall × 22m long Boundary Layer Wind Tunnel at James Cook University.

The approach boundary layer wind flow was modelled at a length scale of 1/100, using a 250mm fence at the upstream end followed by a layer of carpet on the wind tunnel floor. This arrangement satisfactorily simulated an approach flow representative of terrain category 2 as shown by the mean velocity and turbulent intensity profiles given in the Report TS824 [2], albeit with reduced turbulence intensities at higher elevations and smaller turbulent length scales. The actual turbulence intensity of 0.165 at building height was used when converting the pressure coefficients from the mean wind speed in the wind tunnel to a short duration gust speed as used in the Standard.

The mean approach wind velocity at 500mm height in the wind tunnel (i.e. 50m in full-scale) was about 12 m/s, leading to a velocity scale of 12/60, based on a 10-minute mean wind speed of 60 m/s . This combined with the length scale of 1/100 gives a time scale of 1/20, which means that 10min in full scale corresponds to 30 s at model scale in the wind tunnel.

3. Building model

The 11m high building covers a plan area of approximately 40m × 40m (with wall faces identified as 1, 2, 3 and 4) as shown in Figure 1. The building includes mid-level roofs on Faces 1 and 3. A model of the building was constructed from perspex, at a length scale of 1/100 and installed on the turntable in the wind tunnel are shown in Figure 2. Two corners of the roof are constructed without venting to enable the effect of venting on pressures to be assessed.

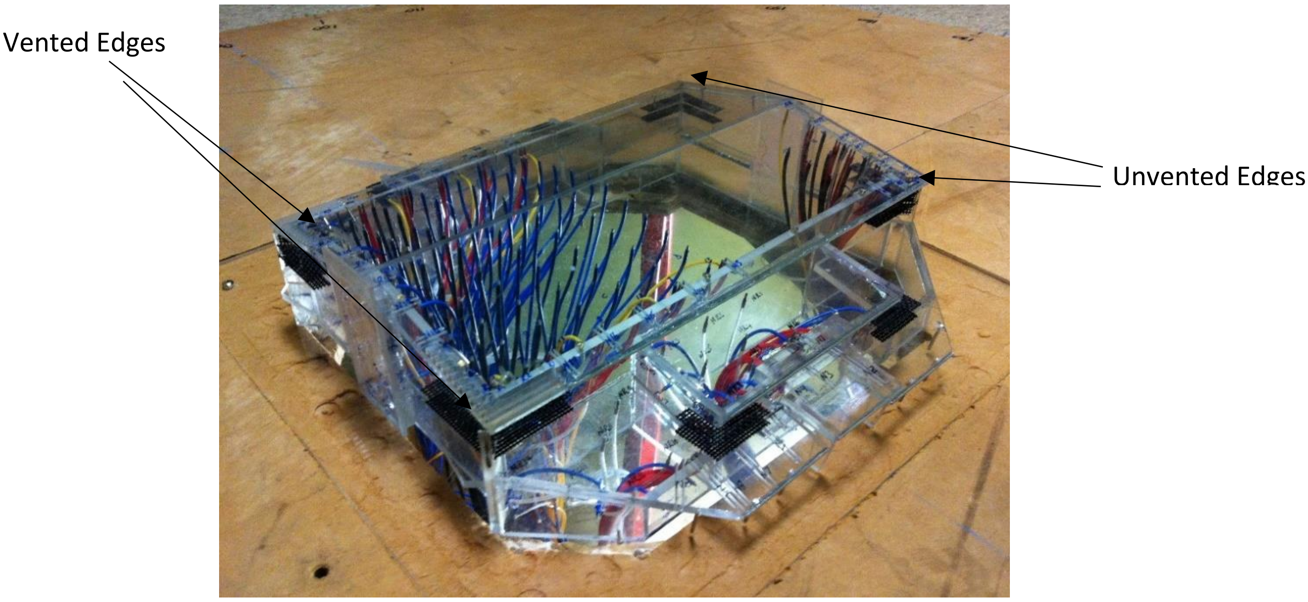


Figure 2. General View of the 1/100 scale Cyclone Shelter model in the Wind Tunnel

4. Pressure measurements

Two hundred and seventy-five pressure taps were installed on roof, including the top and bottom faces of the overhangs as shown in Figure 3, Walls 1, 2, 3 and 4. Positive and negative pressures are defined acting towards and away from a surface. The taps on the top and bottom faces of the overhangs and canopies can be used to obtain the "net" (i.e. (top-bottom)) pressures across the roof overhangs. 1.0m long, 1.5mm diameter, flexible tubing linked the taps to pressure transducers in a TFI system. The pressure signals were sampled at 1250Hz for 31 sec (about 10 minutes in full scale). Three pressure records of 31s duration each were statistically analyzed to give the mean, standard deviation and peak (i.e. maximum and minimum) pressure coefficients:

$$C_{\overline{p}} = \overline{p}\Big/\left(\tfrac{1}{2}\rho\overline{U}_h^{\,2}\right) \quad C_{\sigma_p} = \sigma_p\Big/\left(\tfrac{1}{2}\rho\overline{U}_h^{\,2}\right) \quad C_{\hat{p}} = \hat{p}\Big/\left(\tfrac{1}{2}\rho\overline{U}_h^{\,2}\right) \qquad C_{\breve{p}} = \breve{p}\Big/\left(\tfrac{1}{2}\rho\overline{U}_h^{\,2}\right) \tag{1}$$

where, ρ is the density of air and $\overline{U}_h$ is the mean velocity, averaged over ten minutes in full scale, at the reference height of h = 100mm (i.e. 10m in full-scale).

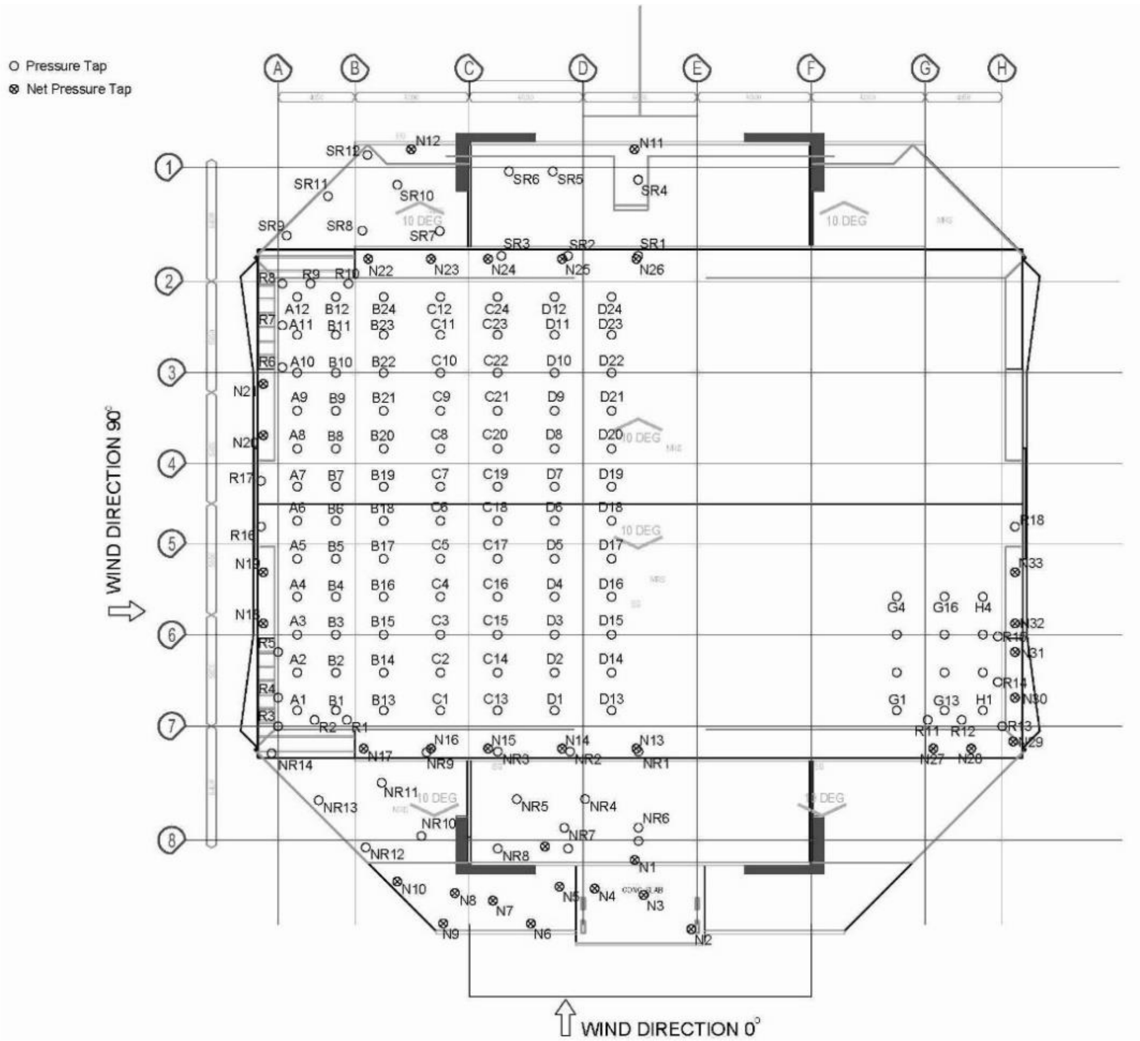


Figure 3. Pressure taps locations on Roof of Cyclone Shelter building

Pressure coefficients were obtained for approach winds at 10° intervals from θ = 0° for the full 360° circle around the compass, and used to calculate external positive and negative design pressures (on the faces) and across the roof overhangs and canopies, from Equation (2):

$$\hat{p}, \breve{p} = C_{\hat{p},\breve{p}} \times \left(\tfrac{1}{2}\rho\overline{U}_h^{\,2}\right) \qquad (2)$$

This is equivalent to the design pressure derived from AS/NZS1170.2 given by Equation (3), where $C_{fig} = C_{p,e}(K_a \times K_c \times K_l \times K_p)$ is the aerodynamic shape factor. The quasi-static external pressure coefficients, $C_{p,e}$ are obtained from *Section 5* in AS/NZS 1170.2, and K_a, K_c, K_l and K_p are factors for area-averaging, load combination, local-pressure effects, and cladding permeability. $V_{des,\theta}$ is the peak design gust wind speed at mid roof height.

$$\hat{p}, \breve{p} = 0.5\rho V_{des,\theta}^2 C_{fig} C_{dyn} \qquad (3)$$

These design external pressures derived from AS/NZS 1170.2 can be equated to the values obtained from the wind tunnel tests as shown in Equation (4).

$$\hat{p}, \breve{p} = 0.5\rho V_{des,\theta}^2 C_{fig} = 0.5\rho V_{des,\theta}^2 C_{p,e}(K_a \times K_c \times K_l \times K_p) = 0.5\rho \overline{U}_h^2 C_{\hat{p},\breve{p}} \qquad (4)$$

The peak pressure coefficients derived from the wind tunnel can be presented as effective AS/NZS 1170.2 aerodynamic shape factors, $C_{fig} = C_{peak} / G_U^2$, where the velocity gust factor $G_U = (V_{des,\theta} / \overline{U}_h)$ = 1.61 is the ratio of the gust wind velocity to the mean wind velocity at the reference mid-roof height.

5. Pressure distributions

The positive and negative external design pressures on the main roof (with vented corners) of the Cyclone Shelter building are given in Figures 4(a) and (b) respectively. These design external pressures for cladding design are obtained by combining the peak (positive and negative) pressure coefficients at each tap with the 10,000-year return period directional mean wind speed at 10m as in Equation 1.

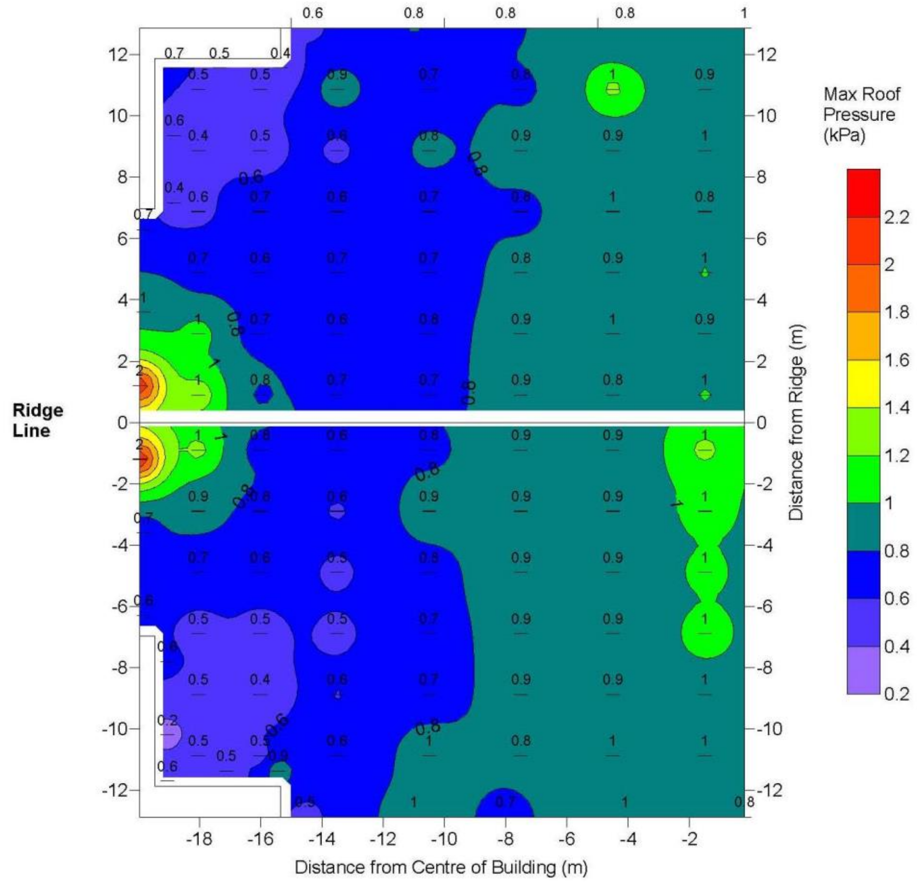
- Peak External Positive Pressure Distribution

The data in the Report TS824 [2] shows that Wall Elevations 1, 2, 3 and 4 are subjected to mean positive pressures for nominally perpendicular sector approach winds. The top roof experiences small positive pressures as shown in Figure 4a. However, the bottom surface of the overhangs, and the top and bottom surface of the canopies and the mid-level roofs are subjected to moderate positive pressures when they are on the windward side of the building. The largest positive pressures on the walls and roofs are about 3.3 kPa and 2.2 kPa respectively.

- Peak External Negative Pressure Distribution

Figure 4.1b shows that the edges of the roof experience the largest peak negative (i.e. minimum) pressures. The largest negative pressures on the main roof (with vented corners) and walls are -8.9 kPa and -3.5 kPa respectively.

(a)



(b)

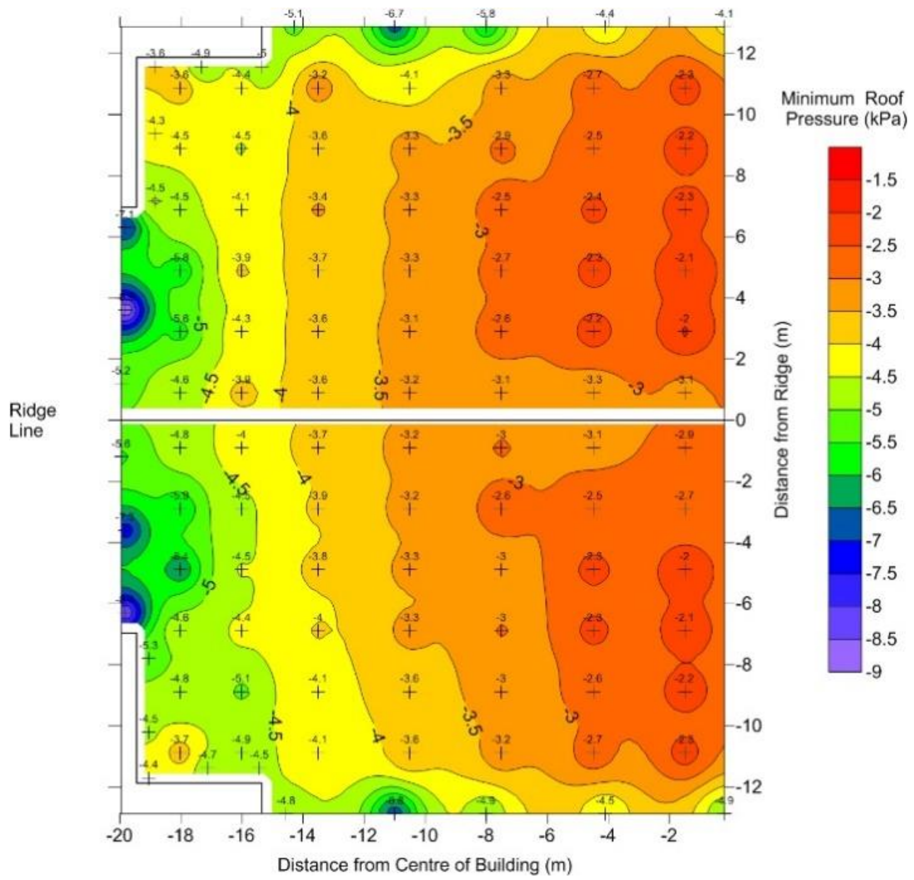


Fig 4. External a) Maximum b) Minimum Pressures on Roof with Vented Corners - (All directions)

For comparison purposes, the positive and negative external design pressures for the section of the main roof without the vented corner are provided in Table 1.

Table 1. Cladding Pressures on Main Roof Area (without vented corners)

Tap Label	Cladding Pressures (kPa) (All directions)			Tap Label	Cladding Pressures (kPa) (All directions)	
	Minimum	Maximum			Minimum	Maximum
G01	-3.78	0.65		NT27	-5.88	0.53
G02	-3.82	1.11		NT28	-6.07	0.53
G03	-4.01	0.83		NT29	-10.91	0.64
G04	-4.41	0.72		NT30	-7.29	0.58
G13	-4.30	0.59		NT31	-6.15	0.72
G14	-4.58	0.92		NT32	-5.86	0.59
G15	-5.04	0.93		NT33	-10.55	0.68
G16	-5.36	0.82		R11	-4.42	0.51
H01	-6.47	1.14		R12	-4.19	0.62
H02	-7.04	0.84		R13	-7.49	2.19
H03	-7.95	0.41		R14	-8.97	0.63
H04	-7.54	0.56		R15	-7.59	0.44
				R18	-6.66	2.07

The inclusion of vents in the corners of the roof at the edges to both sides of Wall 2 have reduced the peak pressure by about 25% compared to the pressures at the un-vented corners. The vents have resulted in higher negative pressures along the roof edges away from the corners, but these are considerably lower in magnitude than those at the unvented corner. The inclusion of porous wing walls at the corners, the chamfering of the wall edges and the inclusion of sunshades have significantly reduced the negative wall pressures compared with data given in AS/NZS 1170.2 for walls that do not have these features.

6. Conclusions

A wind tunnel model study on the roof of Cyclone Shelter Buildings showed that venting the corners of the overhanging roof results in a significant reductions in external design wind pressures. The inclusion of vents in the corners of the roof have reduced the peak pressure by 20-30% compared to the pressures at the un-vented corners. The vents have resulted in higher negative pressures along the roof edges away from the corners, but these are considerably lower in magnitude than those at the unvented corner.

References

Standards Australia, (2011), "Structural design actions. Part 2 Wind actions", Australian/New Zealand Standard, AS/NZS 1170.2:2011.

Cyclone Testing Station, James Cook University (2011), "Wind Tunnel Study- Cyclone Shelter Building", CTS Report TS824 to Project Services, Queensland Department of Public Works.