WIND LOAD EFFECTS AND EFFECTIVE STATIC WIND LOADS ON CANOPY ROOFS

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INTRODUCTION

Open, canopy roof structures (ie. free roof structures which do not have walls) are frequently used in many parts of the world, especially to provide shade. Examples of such canopy roof, shade structures, are found in car parks, schoolyards, and on pontoons on the Barrier Reef. These roofs generally are up to 30 m × 30 m and are 5 to 10m high. Such canopy roofs are planar or curvilinear in form, sheet or fabric (porous or non-porous) clad and supported either by a truss-column system or frames, or of tension membrane type. Larger spans and lighter weight materials are becoming more commonplace and roofs more wind sensitive. There is a need for wind loading data on such roofs for use in structural design and for inclusion in codes.

The variations of pressure distribution on a range of canopy roofs have been studied by Ginger and Letchford (1991) and Pun and Letchford (1993). Ginger and Letchford (1991) showed that wind load effects on planar, canopy roof structures are significantly overestimated by using data given in AS 1170.2 (1989). Additional data on curved, free roof shapes are included and data on planar shapes have been revised in the draft AS/NZS 1170.2 (2001). In this paper, data obtained from wind tunnel studies on a range of planar canopy roofs are used to calculate selected wind load effects and associated effective static pressure distributions. These results are compared with calculations from data in AS/NZS 1170.2 (2001).

WIND TUNNEL TEST

Wind tunnel tests were carried out on a range of canopy roofs, at a length scale of 1/100, in the 2.0m high × 3.0m wide × 12m long Boundary Layer Wind Tunnel at Queensland University. Area averaged, net (ie. (top-bottom)) pressures were obtained on Panels A, B C, D, E, and F, of the 30m × 30m planar canopy roof, shown in Fig 1. Tests were conducted for pitch angles (α) 0° to 30°, in simulated terrain category 3 approach for wind directions (θ) = 0° to 90°. Details of the study are given in Ginger and Letchford (1991).

The pressure signals were low-pass filtered at a frequency of 100Hz, and sampled at 250Hz for 60secs for a single run. The pressures were analysed to give mean, standard deviation, maximum and minimum, net (top-bottom)) pressure coefficients as;

$$C_{\bar{p}} = \bar{p}/(\tfrac{1}{2}\rho\bar{U}_h^{\,2}), \quad C_{\sigma_p} = \sigma_p/(\tfrac{1}{2}\rho\bar{U}_h^{\,2}), \quad C_{\hat{p}} = \hat{p}/(\tfrac{1}{2}\rho\bar{U}_h^{\,2}) \text{ and } C_{\breve{p}} = \breve{p}/(\tfrac{1}{2}\rho\bar{U}_h^{\,2})$$

where, $\frac{1}{2}\rho\bar{U}_h^{\,2}$ is the mean dynamic pressure at a reference height h = 10m.

The results were derived from analysing the coefficients obtained from five separate runs. The correlation coefficients between pressures on each pair of panels on the canopy roof of $\alpha = 22.5^\circ$ were also determined.

PRESSURE DISTRIBUTIONS

Some results from the comprehensive set of wind load data on planar canopy roofs with a range of pitch angles, given in the report by Ginger and Letchford (1991), are presented in this paper. The distribution of mean, standard deviation, maximum and minimum pressure coefficients, for $\theta = 0^\circ, 30^\circ, 60^\circ$ and 90° on Panels A, B, C, D, E and F, for roof pitch $\alpha = 22.5^\circ$, are given in Tables 1 to 4. Combing the minimum pressures on both the windward and leeward halves to get the peak lift force, or the maximums on the windward half with the minimums on the leeward half to get peak drag force will however be conservative. This is because the peak pressures do not have to coincide with the peak (ie. design) load effects. An area reduction factor K_a is used in AS/NZS1170.2 (2001) to reduce this conservatism.

AS/NZS1170.2 (2001) gives net pressure coefficient $C_{p,n}$ of –0.3 and 0.6 on the windward and –0.6, 0.0 on the leeward slopes for θ = 0°, and -0.3 and 0.4 upto h, -0.4 and 0.0, from h to $2h$, and –0.2 and 0.2, from $2h$ to $3h$, on the roof for θ = 90°. Equivalent AS/NZS1170.2 (2001) peak pressure coefficients C_{peak} may be derived by multiplying these values with K_a and the square of the velocity gust factor $G_U^2 = (1.88)^2$.

The load effect $x(t)$ resulting from wind loads acting on a tributary area divided into N panels is given by Eqn 1, where and β_i and P_i are the influence coefficient and load on panel i of area A_i. $\overline{x}$ and x' are the mean and fluctuating components of x. The covariance integration method developed by Holmes and Best (1981), which accounts for the lack of correlation of pressures over the roof can be used to determine the peak (ie. design) load effect, $\hat{x}, \breve{x} = \overline{x} \pm g_x \sigma_x$, where σ_x is the standard deviation obtained from Eqn 2, g_x is the peak factor of x is ~ 4.0, and r_{pipj} is the correlation coefficient between the pressures on panels i and j.

$$x(t) = \sum_{i=1}^{N} \beta_i p_i(t) A_i = \sum_{i=1}^{N} \beta_i P_i(t) = \sum_{i=1}^{N} \beta_i (\overline{P_i} + P_i'(t)) = \overline{x} + x'(t) \qquad (1)$$

$$\sigma_x = \left[\sum_{i=1}^{N} \sum_{j=1}^{N} \beta_i \beta_j r_{p_i p_j} \sigma_{p_i} \sigma_{p_j} A_i A_j \right]^{1/2} \qquad (2)$$

The Load-Response-Correlation (LRC) method developed by Kasperski (1992) is applied in Eqn 3, to obtain the effective static pressure on each panel of the canopy roof associated with the selected load effect.

$$(P_j)_{\hat{x}} = \overline{P_j} + g_x r_{P_j x} \sigma_{P_j} \qquad (3)$$

The correlation coefficients of area averaged pressures on Panels A, B, C, D, E and F, on the α = 22.5° canopy roof for winds approaching from θ = 0°, 30°, 60° and 90° are given in Tables 5 and 6.

PEAK LIFT AND DRAG AND EFFECTIVE STATIC LOADS

Lift (L) and drag (D) forces, and effective static pressures for a). Whole Roof and b). End Panels A and F are presented in this section. The influence coefficients for lift on all panels A, B, C, D, E and F, are – 0.924, and for drag on Panels A, B, and C are -0.383 and Panels D, E and F, are 0.383. The lift and drag are determined in coefficient form $C_L, C_D = L, D / (\frac{1}{2} \rho \overline{U}_h^2 A_T)$, where A_T is the total tributary area. The mean, standard deviation and peak, lift and drag force coefficients are calculated from Eqns 1 and 2, and are given in Table 7. The effective pressure coefficients associated with peak lift and peak drag are determined from Eqn 3, and given in Table 8. These values can be directly compared with AS/NZS1170.2 (2001) data.

Calculations for Case b) End Panels A and F for θ = 30°, are summarised here. The pressure coefficients measured in the wind tunnel are divided by the square of the mean velocity ratios = $(1.05)^2$, at AS/NZS1170.2 (2001) reference, average roof height of 11.72m to height of 10m. Details of this procedure can be found in Holmes (2001).

Mean lift $C_{\overline{L}}$ = ([-0.924 × 150 × (0.241 – 0.685))] / 300) ÷ $(1.05)^2$ = 0.186

Standard deviation lift $C_{\sigma L}$ = 0.159, Maximum lift $C_{\hat{L}}$ = 0.821, and Minimum lift $C_{\breve{L}}$ = –0.449

Mean drag $C_{\overline{D}}$ = ([0.383 × 150 × (0.241 – (- 0.685))] / 300) ÷ $(1.05)^2$ = 0.161

Standard deviation drag $C_{\sigma D}$ = 0.071, Maximum drag $C_{\hat{D}}$ = 0.443, and Minimum drag $C_{\breve{D}}$ = -0.121

The design lift and drag coefficients derived from AS/NZS 1170.2 (2001) are:

Max. lift $C_{\hat{L}}$ = 1.176, Min. lift $C_{\breve{L}}$ = -0.784, Max. drag $C_{\hat{D}}$ = 0.649 and Min. drag $C_{\breve{D}}$ = -0.162

Effective, net static pressure coefficients on Panels A and F, for maximum and minimum lift forces are: (C_{pA} = -1.179, C_{pF} = -0.598) and (C_{pA} = -0.064, C_{pF} = 1.036) respectively.

Effective, net static pressure coefficients on Panels A and F, for maximum and minimum drag forces are (C_{pA} = -1.236, C_{pF} = 1.076) and (C_{pA} = -0.006, C_{pF} = -0.639) respectively.

CONCLUSIONS

Peak lift and drag forces on a planar canopy roof structure were calculated from data obtained from a wind tunnel study carried out at a length scale of 1/100. The effective static pressures causing these peak lift and drag forces were also determined. These were compared with results derived from data given in the revised wind load standard AS/NZS1170.2 (2001). The following conclusions were reached;

- Unlike AS1170.2 (1989), the revised net pressure coefficient data given in AS/NZS1170.2 (2001) provide satisfactory estimates of design lift and drag coefficients, when compared with those obtained from applying the covariance integration method to the wind tunnel data.
- The effective static pressure coefficients derived from the LRC method, were satisfactorily enveloped by the $C_{peak}s$ derived from AS/NZS1170.2, for the cases studied.

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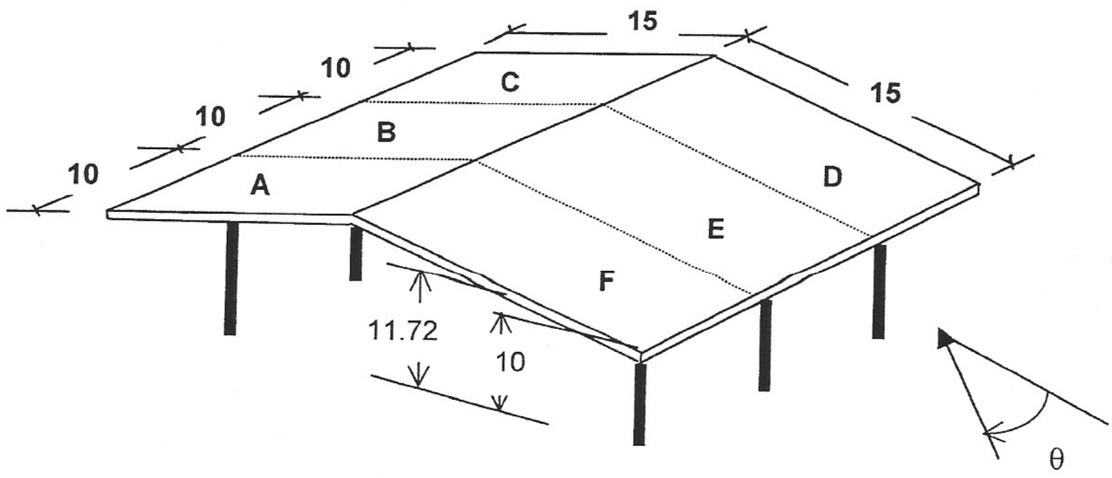

Fig 1 30m × 30m × h =10m, planar canopy roof with 10m × 15m Panels A, B, C, D, E and F

Table 1. Mean, standard deviation, maximum and minimum pressure coefficients on panels A, B, C, D, E and F on canopy roof $\alpha = 22.5^o$, $\theta = 0^o$.

Panel	$C_{\bar{p}}$	$C_{\sigma p}$	$C_{\hat{p}}$	$C_{\breve{p}}$
A	-0.597	0.223	-0.051	-1.714
B	-0.596	0.198	0.034	-1.898
C	-0.575	0.216	-0.039	-1.824
D	0.427	0.313	1.978	-0.418
E	0.462	0.348	2.529	-0.651
F	0.434	0.322	1.844	-0.510

Table 2. Mean, standard deviation, maximum and minimum pressure coefficients on panels A, B, C, D, E and F on canopy roof $\alpha = 22.5^o$, $\theta = 30^o$.

Panel	$C_{\bar{p}}$	$C_{\sigma p}$	$C_{\hat{p}}$	$C_{\breve{p}}$
A	-0.685	0.252	0.169	-1.776
B	-0.644	0.246	0.022	-1.739
C	-0.466	0.178	0.059	-1.433
D	0.200	0.208	1.196	-0.418
E	0.213	0.246	1.636	-0.736
F	0.241	0.301	2.009	-0.842

Table 3. Mean, standard deviation, maximum and minimum pressure coefficients on panels A, B, C, D, E and F on canopy roof $\alpha = 22.5^o$, $\theta = 60^o$.

Panel	$C_{\bar{p}}$	$C_{\sigma p}$	$C_{\hat{p}}$	$C_{\breve{p}}$
A	-0.408	0.256	0.878	-1.714
B	-0.214	0.139	0.169	-1.066
C	-0.126	0.098	0.254	-0.822
D	0.062	0.119	0.927	-0.663
E	0.058	0.141	1.074	-0.479
F	0.231	0.270	1.242	-0.600

Table 4. Mean, standard deviation, maximum and minimum pressure coefficients on panels A, B, C, D, E and F on canopy roof $\alpha = 22.5^o$, $\theta = 90^o$.

Panel	$C_{\bar{p}}$	$C_{\sigma p}$	$C_{\hat{p}}$	$C_{\breve{p}}$
A	0.018	0.291	1.624	-1.384
B	-0.004	0.086	0.584	-0.406
C	0.006	0.064	0.328	-0.382
D	0.000	0.064	0.315	-0.602
E	0.007	0.089	0.523	-0.577
F	0.013	0.300	1.712	-1.187

Table 5. Correlation coefficients between pressures on Panels A..F on canopy roof $\alpha = 22.5^o$, $\theta = 0^o$ and 30^o.

$\theta = 0^o$

	A	B	C	D	E	F
A	1.00	0.47	0.07	-0.07	-0.18	-0.29
B	0.60	1.00	0.47	-0.15	-0.17	-0.15
C	0.41	0.70	1.00	-0.30	-0.19	-0.08
D	-0.02	-0.29	-0.32	1.00	0.71	0.35
E	-0.02	-0.35	-0.24	0.72	1.00	0.71
F	-0.07	-0.28	-0.18	0.28	0.63	1.00

$\theta = 30^o$

Table 6. Correlation coefficients between pressures on Panels A..F on canopy roof $\alpha = 22.5^o$, $\theta = 60^o$ and 90^o.

$\theta = 60^o$

	A	B	C	D	E	F
A	1.00	0.63	0.46	0.09	0.23	0.25
B	0.68	1.00	0.70	-0.11	-0.08	-0.04
C	0.41	0.44	1.00	-0.18	-0.10	-0.05
D	0.18	0.22	0.22	1.00	0.66	0.27
E	0.38	0.44	0.26	0.50	1.00	0.57
F	0.35	0.39	0.12	0.40	0.66	1.00

$\theta = 90^o$

Table 7. Lift and drag coefficients obtained from wind tunnel data and AS/NZS1170.2 (2001)

Load Effect	Covariance Integration.			AS/NZS1170.2
	$\bar{x}$	σ_x	$\hat{x}$, $\breve{x}$	$\hat{x}$, $\breve{x}$
	Whole Roof – Panels A..F, $\theta = 0°$			
C_L	0.062	0.118	0.533, -0.409	1.176, -0.784
C_D	0.179	0.062	0.427, -0.070	0.649, -0.162
	End Roof – Panels A & F, $\theta = 30°$			
C_L	0.186	0.159	0.821, -0.449	1.176, -0.784
C_D	0.161	0.071	0.443, -0.121	0.649, -0.162

Table 8. Effective static pressures on the whole roof for peak lift and peak drag, $\theta = 0^o$

Load Effect	$C_{\hat{L}}$	$C_{\breve{L}}$	$C_{\hat{D}}$	$C_{\breve{D}}$
Panel A	-0.689	-0.394	-0.925	-0.158
Panel B	-0.754	-0.328	-0.915	-0.167
Panel C	-0.651	-0.392	-0.894	-0.149
Panel D	-0.371	1.145	1.216	-0.441
Panel E	-0.605	1.444	1.494	-0.656
Panel F	-0.392	1.180	1.254	-0.467