Wind Loads on Long Low-rise Buildings

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1. INTRODUCTION

Long low-rise buildings with spans greater than 30m and lengths exceeding 100m are often used for bulk storage of materials such as sugar, cement and minerals. The structural systems of such large buildings generally consist of portal or pin-jointed frames, sometimes spaced evenly at the mid section and closer together at the gable-ends. Metal sheet cladding is attached to roof purlins and wall girts, which are fixed to these frames. Cross bracing between the end frames resist longitudinal (ie. in direction of ridge-line) wind loads. Steep roof pitches of 30º to 50º are most common, but other low pitched and curved roof shapes are also used. In Australia, these buildings are often located adjacent to port facilities in tropical-cyclone prone coastal regions, where wind loading is the dominant structural design consideration. Design wind loads on the cladding and structural system of these large buildings are usually determined using data given in wind load standards such as AS/NZS 1170.2 [1].

An early study by Howe [2] in smooth uniform flow identified the significant effect of aspect ratio (length, b / span, d) on wind pressures at the ends of low rise buildings. More recently, the variation of pressure distribution with varying aspect ratio on such buildings has been studied in boundary-layer flows, by Kanda and Maruta [3], Holmes [4] and Ginger *et al* [5]. Kanda and Maruta [3] found that an increase in aspect ratio resulted in a variation in the area averaged pressure on windward and leeward slopes of the roof. This effect was most noticeable for high pitch roofs, on the leeward slope, for oblique approach winds. Holmes [4] and Ginger *et al* [5] showed that design wind loads on these buildings was significantly underestimated by the previous edition of the Australian Standard AS 1170.2 [6], especially for large aspect ratio buildings with steep roofs. The revised AS/NZS 1170.2 [1] attempts to overcome this shortcoming by increasing the magnitude of pressure coefficients on the leeward slopes of steep roof buildings.

This paper summarises results from a wind tunnel study carried out on a range of large buildings with gable and curved roofs. More details of theses results are given by Ginger [7].

2. WIND TUNNEL TESTS

The wind tunnel tests were carried out in the 2.0m high × 2.5m wide × 22m long Boundary Layer Wind Tunnel at the School of Engineering at James Cook University. Tests were carried out on the four building configurations shown in Figures 1 to 4 and described in Table 1, at length scales of 1/200 and 1/300.

Building configuration Nos. 1, 2 and 3 were tested in a simulated rural boundary layer (Terrain Category 2 in [1]), while configuration No. 4 was tested in simulated urban terrain (Terrain Category 3 in AS/NZS 1170.2).

External pressures on the wall and roof panels were obtained for approach wind directions (θ) of -90º to 90º at intervals of 15º. Pressure taps were connected to Honeywell pressure transducers via Scanivalves and a calibrated tube and restrictor system. The pressure signals were low-pass filtered at a frequency of 250Hz, and sampled at 500Hz for 24secs for a single run. The pressures were analysed to give mean, standard deviation, maximum and minimum pressure coefficients as;

$$C_{\bar{p}} = \bar{p} \big/ (\tfrac{1}{2}\rho \bar{U}_h^{\,2}), \; C_{\sigma_p} = \sigma_p \big/ (\tfrac{1}{2}\rho \bar{U}_h^{\,2}),$$

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

where, $\frac{1}{2}\rho \bar{U}_h^{\,2}$ is the mean dynamic pressure at height h, the mid roof level for the planar roof buildings and maximum roof height for the curved roof building.

The results were obtained from averaging the data from five separate runs. The correlation coefficients between pressures on each pair of panels on selected frame tributaries on some building configurations were also determined.

3. PRESSURE DISTRIBUTIONS

The peak (positive on windward half and negative on leeward half) pressure coefficients for $\theta = 45^o$, on the tributary of the second frame from the gable-end (ie. Frame B) on building configurations 1, 2, 3 and 4 of varying aspect ratios are shown in Figures 5, 6, 7 and 8 respectively. Comparison of these peak values with the corresponding peak pressure coefficients C_{peak} derived from the previous AS1170.2 [6] for $\theta = 0^o$, (Ginger [7]), shows that peak suction pressures were being significantly underestimated on the leeward roof and wall on the steep pitch, planar roof buildings of aspect ratio greater than 3.

4. STRUCTURAL LOAD EFFECTS

A previous study by Holmes [4] showed that structural load effects in supporting frames of a long building with a 36 degree gable roof, were being grossly underestimated by the 1989 Australian Standard [1].

Based on a typical 3-pin frame system used in storage sheds, the knee and centre rafter bending moments (M_K and M_C) and horizontal (H) and vertical (V) reactions at the base of the second frame from the gable-end of building configuration No 1 are analysed here. The bending moments and horizontal and vertical reactions are non-dimensionalised as $C_M = M \Big/ (\frac{1}{2}\rho \overline{U}_h^2 d^2 w)$, $C_H = H \Big/ (\frac{1}{2}\rho \overline{U}_h^2 h_f w)$ and $C_V = V \Big/ (\frac{1}{2}\rho \overline{U}_h^2 d w)$ respectively, where w is the width of the tributary area and h_f is the height of the frame. Table 2 shows peak wind load effects for $\theta = 45^o$ and $\theta = 90^o$, derived from the "covariance integration" method [8] and compared with that derived from AS/NZS 1170.2-2001. Generally good agreement is seen, although some underestimation by the 2001 edition of the Standard is evident for the aspect ratio of 6.

5. CONCLUSIONS

Wind tunnel studies were carried out to determine pressure distributions and wind load effects on long low-rise buildings with a range of roof shapes and varying aspect ratios. The following conclusions were reached:

- Large mean and peak suction pressure coefficients measured on the leeward half of the roof and wall over a distance of b/3 from the windward gable-end, of the steep pitch gable roof buildings for oblique approach winds (ie. $\theta = 45^o$) increase in magnitude with increasing aspect ratio (Figures 5, 6).
- There is less variation with aspect ratio for buildings with a *low pitched* gable roofs and curved roofs (Figures 7, 8).
- The 1989 edition of the Australian Standard AS 1170.2 underestimated wind loads on steep pitch gable roof buildings of aspect ratio greater than 3 on areas near the windward gable-end, compared with wind loads derived from wind tunnel tests. This anomaly has largely been rectified in the 2001 edition.

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Table 1 Test building configurations and specifications

Config. No.	Roof Pitch (^{o})	Span (d), m	Mid roof height, m	Total height, m	Length (b), m	Aspect Ratio (b/d)
1-Fig 1	35	40	22	29	96, 160, 240	2.4, 4, 6
2-Fig 2	50	50	15	29.8	150, 200, 250, 300, 350, 400	3, 4, 5, 6, 7, 8
3-Fig 3	Curved	45	22.1	29.1	108, 225, 360	2.4, 5, 8
4-Fig 4	15	80	20.4	25.7	108, 240, 350	1.35, 3, 4.35

Table 2 Wind load effects on Building configuration No. 1 Frame B versus aspect ratio

Load Effect Coeff.	AR	Wind tunnel.	AS/NZS1170. 2-2001	Load Effect Coeff.	AR	Wind tunnel.	AS/NZS1170. 2-2001
		$\theta = 45^{o}$	$\theta = 0^{o}$			$\theta = 45^{o}$	$\theta = 0^{o}$
C_{MK}	2.4	0.094/-0.062	0.126/-0.106	C_H	2.4	-1.10	-1.55
	4	0.121/-0.073			4	-1.36	
	6	0.139/-0.081			6	-1.52	
C_{MC}	2.4	0.072/-0.089	0.111/-0.128				
	4	0.082/-0.123				$\theta = 90^{o}$	$\theta = 90^{o}$
	6	0.089/-0.146		C_V	6	-0.92	-1.23

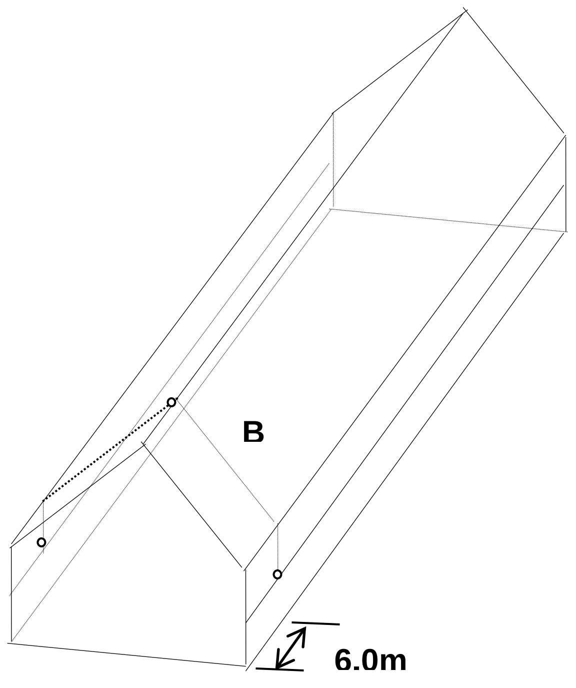
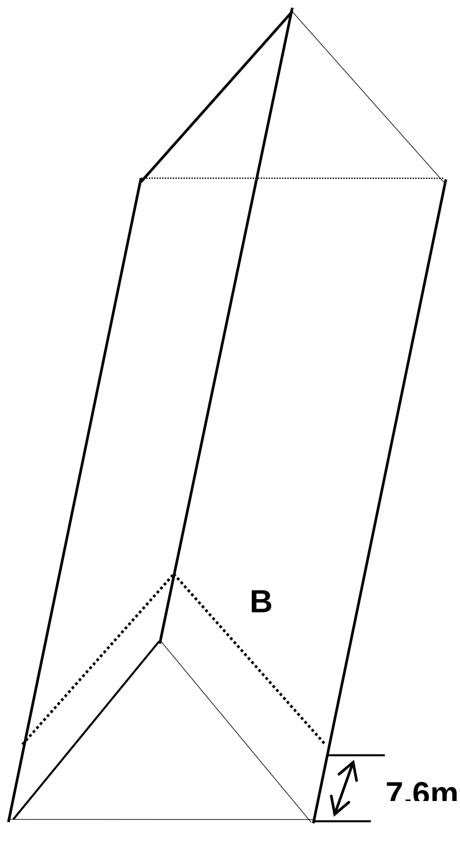


Fig 1. (left) Building Configuration No. 1, span = 40m, height = 29m, AR= 2.4, 4 and 6, $\alpha = 35^{o}$

Fig 2. (right) Building Configuration No. 2, span = 50m, height = 30m, AR= 3, 4, 5, 6, 7 and 8, $\alpha = 50^{o}$



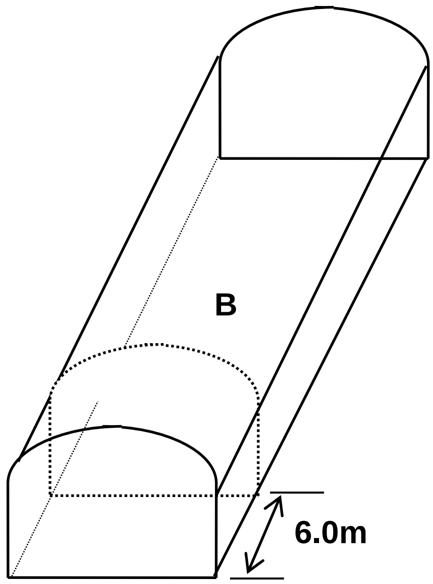


Fig 3. Building Configuration No. 3, span = 45m, height = 29m, AR= 2.4, 5 and 8, Curved roof

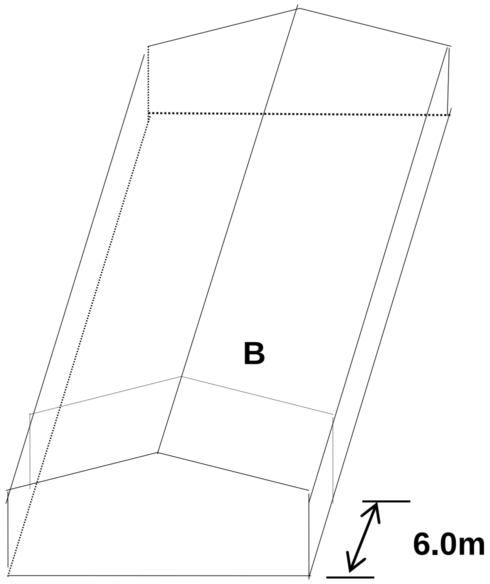


Fig 4. Building Configuration No. 4, span = 80m, height = 20m, AR= 1.35, 3 and 4.35, α = 15°

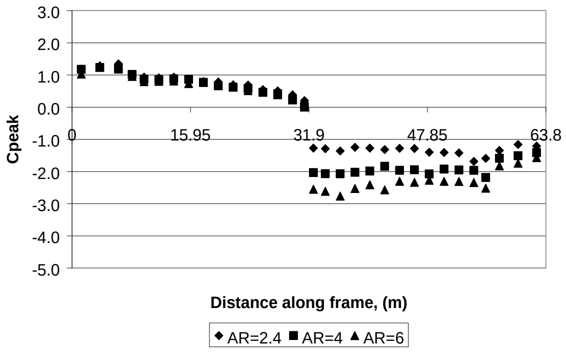


Fig 5. Peak positive and peak negative Cps on windward and leeward halves of Frame B on Building Configuration No. 1, θ = 45°

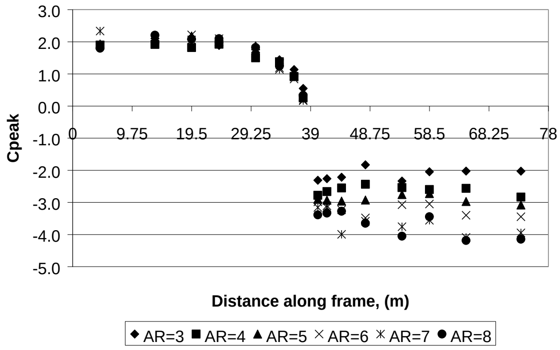


Fig 6. Peak positive and peak negative Cps on windward and leeward halves of Frame B on Building Configuration No. 2, θ = 45°

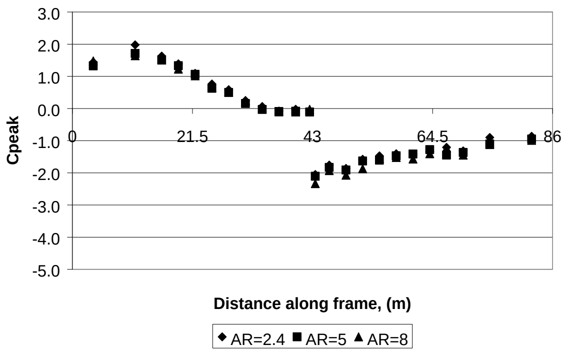


Fig 7. Peak positive and peak negative Cps on windward and leeward halves of Frame B on Building Configuration No. 3, θ = 45°

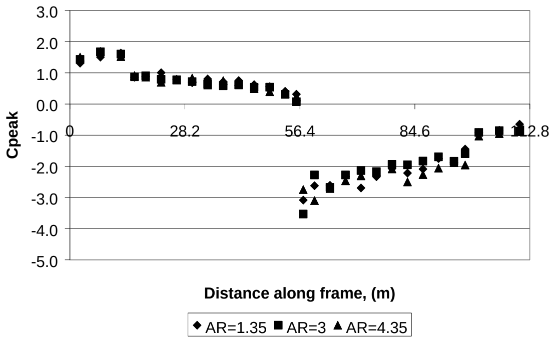


Fig 8. Peak positive and peak negative Cps on windward and leeward halves of Frame B on Building Configuration No. 4, θ = 45°