WIND LOADS ON LARGE BUILDINGS WITH STEEP ROOFS

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INTRODUCTION

Large sheds which have spans greater than 30m and lengths of 100 to 300m are used for bulk storage of materials such as sugar, grain and mineral ore. The structural system of such large sheds generally consist of frames with a steep roof pitch of 30^o to 50^o spaced at regular intervals along the length of the shed. Metal sheet cladding is attached to roof purlins and wall girts, which are fixed to the frames. Cross bracing between the end frames resist longitudinal (ie. in direction of ridge-line) wind loads. These sheds are often located adjacent to port facilities in cyclone prone coastal regions where wind loading is the dominant structural design consideration. The variation of pressure distribution with varying aspect ratio (length/span) on such buildings have been studied by Kanda and Maruta (1993) and Holmes (1998).

Design wind loads on the cladding and structural system of these large sheds are usually determined using data given in wind load standards such as AS 1170.2 (1989). However, Holmes (1998) showed that some wind load effects on the frames of these sheds are significantly underestimated by AS 1170.2, especially for large aspect ratios. An attempt has been made to overcome this shortcoming in the draft AS/NZS 1170.2 by referencing pressure coefficients to the average roof height and incorporating an extended building factor, $K_e = 1.5$ for buildings of aspect ratio greater than 3.

This wind tunnel study was carried out to obtain reliable wind load data for a range of large buildings with a steep roof pitch. The pressure distributions on cladding and fixings and resulting wind load effects on selected frames are determined. These results are also compared with those obtained from using data in AS/NZS 1170.2. The results of this study provides more accurate design data and enables optimal design of cladding and structural components (ie. purlins, frames) of such buildings.

WIND TUNNEL TEST

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. The approach wind flow was satisfactorily simulated to terrain category 2 (as per AS/NZS 1170.2) at a length scale of 1/200. Three rectangular plan buildings of 40m span (d) and lengths (b) of 96m, 160m and 240m (ie. aspect ratio (b/d) of 2.4, 4 and 6 respectively) shown in Figure 1, were constructed at a length scale of 1/200 and tested in this simulated flow. Based on the design of bulk sugar storage sheds, 3-pin frames with a roof pitch of 35^o are attached to 7.5m high, rigid concrete walls to give an eaves height 15m and a ridge height of 29m. The second frame is located at a distance of 6.0m from the end frame A, and the other frames are spaced 7.5m apart. Pressure taps were installed on twenty six roof purlin-frame panel areas and six wall girt-frame panel areas on tributaries of Frames A, B C, D, E, F, G and H, as identified by the nomenclature specified in Figure 1. Frames A, B C, D, E, F, G and H are located at the end-wall and 6.0, 13.5, 21.0, 28.5, 36.0, 51.0 and 81.0m respectively from the end-wall as shown in Figure 1

External pressures on these panels were obtained for approach wind directions (θ) of -90^o to 90^o at intervals of 15^o. 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;

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

where, $\frac{1}{2}\rho\bar{U}_h^{\,2}$ is the mean dynamic pressure at average roof height h = 22m.

The results were obtained from averaging the data from five separate runs. The mean and peak pressure distributions were used to identify the parts of the shed subjected to large wind loads. The pressure distributions were used for comparisons with data prescribed in AS/NZS1170.2. The correlation coefficients between pressures on each pair of panels on selected frame tributaries were determined using a DATA6000 Signal Analyser.

PRESSURE DISTRIBUTIONS

A comprehensive report on the wind loads on the buildings of aspect ratio 2.4, 4 and 6, are given in the report by Ginger (2000). A summary of these results are given in this paper. The distribution of mean, standard deviation, maximum and minimum pressure coefficients for $\theta = 45^o$, on the tributary of Frame B for sheds of aspect ratio 2.4, 4 and 6, and corresponding peak pressure coefficients C_{peak} derived from AS/NZS1170.2 for $\theta = 0^o$ are given in Figures 2, 3 and 4. The pressure coefficients for $\theta = 45^o$, on the tributaries of Frames G and H on sheds of aspect ratio 4 and 6 (ie. ~ b/3 from the windward end) are given in Figures 5 and 6 respectively. The pressure coefficients for $\theta = 90^o$, on the tributary of Frame B on the shed of aspect ratio 6 are given in Figure 7. The AS/NZS1170.2 C_{peak}s have been derived by multiplying the Cp values with the local pressure factor K_l to be applied when designing cladding and fixtures, the extended building factor K_e and the square of the velocity gust factor $G_U{}^2 = (1.648)^2$.

Figures 2 to 4 show that the measured mean and peak suction pressure coefficients on the downwind half of the roof and leeward wall of the shed, for $\theta = 45^o$, progressively increase in magnitude as the aspect ratio is increased from 2.4 to 4 to 6 by about 50% and 80% respectively. Increases albeit of smaller magnitude were measured on the tributary at distances b/3 away from the windward end. The draft AS/NZS1170.2 accounts for these increasing loads with aspect ratio, by including an extended building factor K_e for $\theta = 0^o$. This study however indicates that a step increase in K_e from 1 to 1.5 for aspect ratios exceeding 3 results in large overestimations of design peak pressures. More satisfactory outcomes are obtained as shown by the proposed CSTS values in Figures 2 to 6, by applying a K_e that varies linearly from 1.0 to 1.3 for aspect ratios of 3 to 6, to the suction pressure coefficients on the leeward half of roof and wall on the end 1/3 of the shed (ie. distance of b/3 from the windward end).

DESIGN LOAD EFFECTS

The bending moments (M) at B, C, E and F and horizontal (H) and vertical (V) reactions at A on Frame B are analysed here. The bending moments and horizontal and vertical reactions are non-dimensionalised as $C_M = M/(\frac{1}{2}\rho\bar{U}_h{}^2 d^2 w)$, $C_H = H/(\frac{1}{2}\rho\bar{U}_h{}^2 h_f w)$ and $C_V = V/(\frac{1}{2}\rho\bar{U}_h{}^2 dw)$ respectively, where w is the width of the tributary area and h_f is the height of the frame. Table 1 shows peak wind load effects for $\theta = 45^o$ and $\theta = 90^o$, derived from the "covariance integration" method of Holmes and Best (1981) and compared with load effects derived from AS/NZS1170.2 and with the changes suggested by the CSTS in this paper.

CONCLUSIONS

A wind tunnel study was carried out at a length scale of 1/200 to determine pressure distributions and wind load effects on 35^o roof pitch, storage sheds of aspect ratios 2.4, 4 and 6, and compared with results obtained from data given in the draft AS/NZS1170.2. The following conclusions were reached;

- Large mean and peak suction pressure coefficients measured on the downwind half of the roof and leeward wall over a distance of b/3 from the windward end, for oblique approach winds (ie. $\theta = 30^o$ to 45^o) increase in magnitude with increasing aspect ratio.

- The inclusion of K_e = 1.5 for θ = 0°, for aspect ratios greater than 3 in the draft AS/NZS1170.2 overestimates design peak pressures. A more satisfactory outcome could be obtained by applying a K_e that varies linearly from 1.0 to 1.3 for aspect ratios of 3 to 6, to the suction pressure coefficients on the leeward half of roof and wall on the end 1/3 of the shed (ie. distance of b/3 from the windward end).
- The application of data given in AS/NZS1170.2 with these suggested K_e values provide more satisfactory estimates of selected load effects when compared with those obtained from applying the covariance integration method to the wind tunnel data.
- The peak pressure coefficients obtained in the wind tunnel study for θ = 90°, were satisfactorily enveloped by the C_{peak}s derived from AS/NZS1170.2 in areas near the windward gable end.

REFERENCES

Australian Standard SAA Loading Code Part 2 Wind Loads AS1170.2 (1989). Revised Draft Structural design – General requirements and design actions, Wind actions AS/NZS 1170.2

J. D. Ginger, "Wind loads on large storage buildings", CSTS Research Report, In Press, (2000)

J. D. Holmes and R. J. Best, "An Approach to the determination of Wind Load Effects on Low-Rise Buildings", Jour. of Wind Engg. & Indus. Aerodyn., Vol. 7, 273-287, (1981)

J. D. Holmes, "Wind loads on the frames of large bulk-storage sheds", 7th AWES workshop Auckland NZ, (1998)

M. Kanda and E Maruta, " Characteristics of fluctuating wind pressure on long low-rise buildings with gable roofs", Jour. of Wind Engg. & Indus. Aerodyn., Vol. 50, 173-182, (1993)

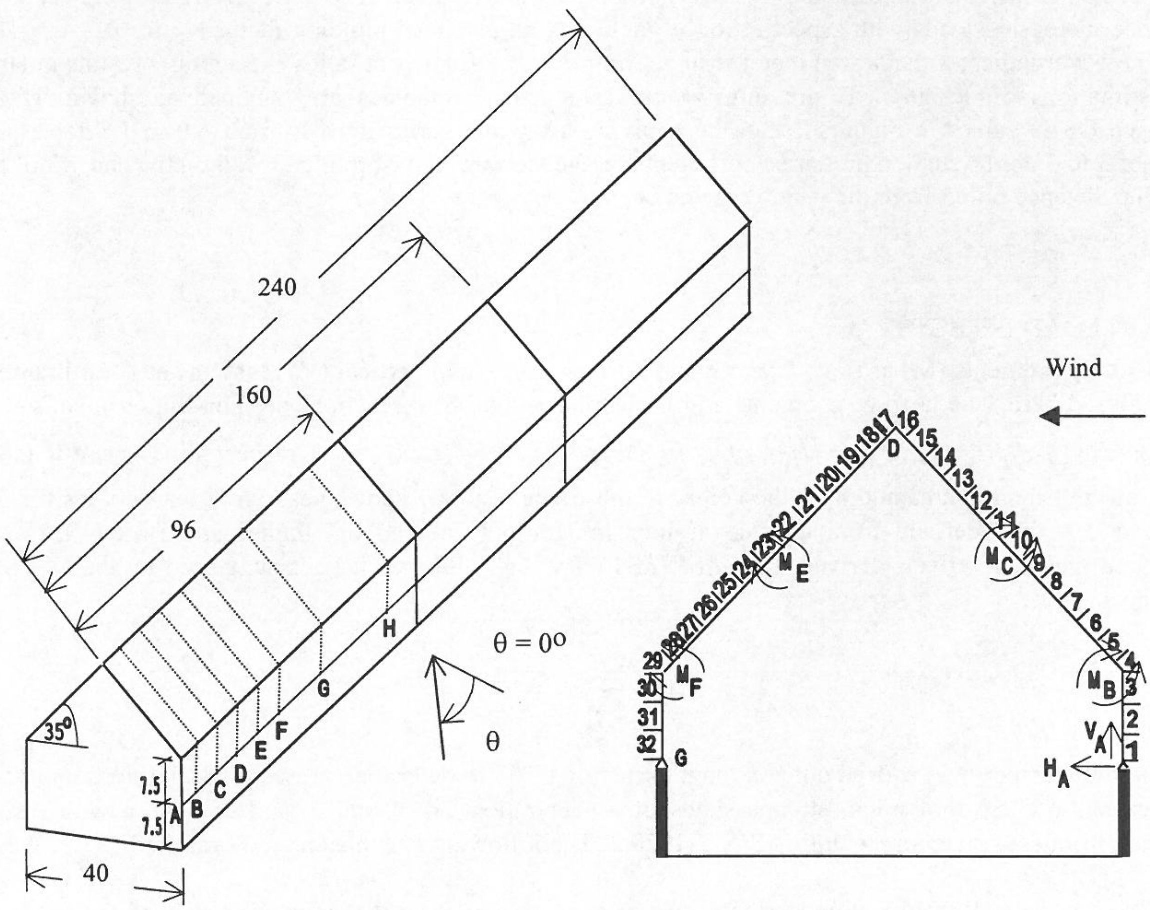

Figure 1 Positions of frames and wall and roof panels on building All dimensions in m

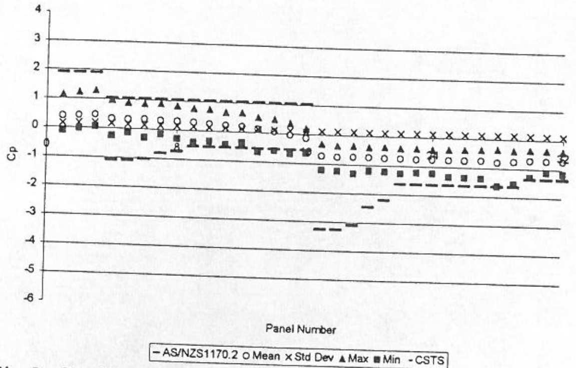

Fig 2. Cp distribution, frame B, aspect ratio = 2.4, θ = 45°

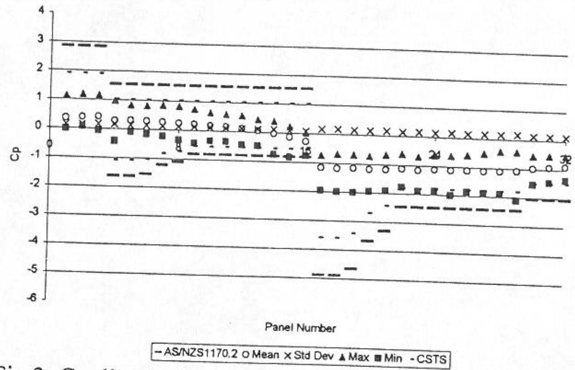

Fig 3. Cp distribution, frame B, aspect ratio = 4, θ = 45°

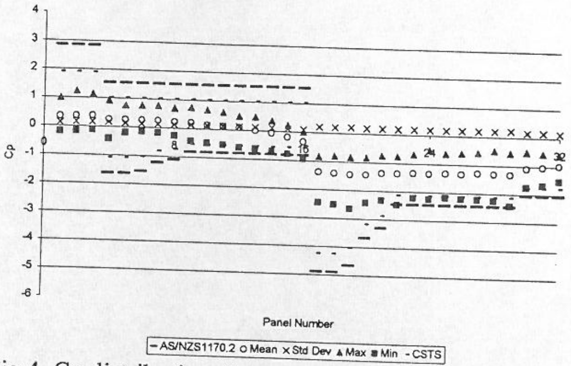

Fig 4. Cp distribution, frame B, aspect ratio = 6, θ = 45°

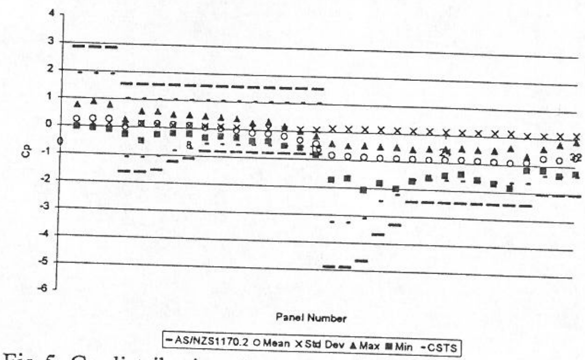

Fig 5. Cp distribution, frame G, aspect ratio = 4, θ = 45°

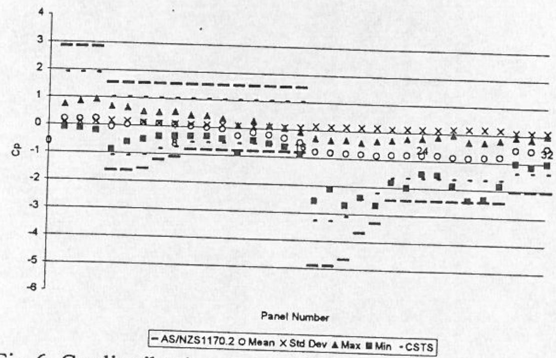

Fig 6. Cp distribution, frame H, aspect ratio = 6, θ = 45°

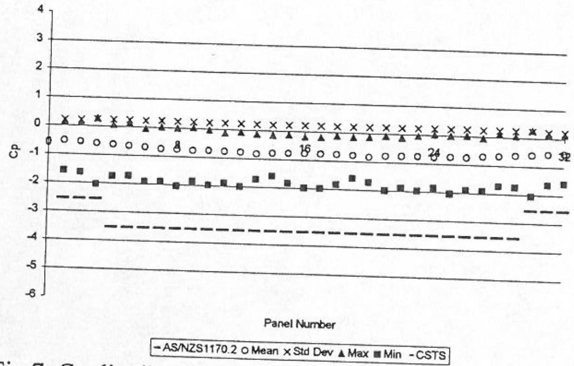

Fig 7. Cp distribution, frame B, aspect ratio = 6, θ = 90°

Table 1 Variation of wind load effects on Frame B with aspect ratio (AR)

Load Effect Coeff.	AR	Cov. Int.	AS/NZS 1170.2	CSTS Proposal
		θ = 45°	θ = 0°	θ = 0°
C_{MB}/C_{MF}	2.4	0.094/-0.062	0.126/-0.106	0.126/-0.106
	4	0.121/-0.073	0.189/-0.159	0.133/-0.112
	6	0.139/-0.081	0.189/-0.159	0.149/-0.123
C_{MC}/C_{ME}	2.4	0.072/-0.089	0.111/-0.128	0.111/-0.128
	4	0.082/-0.123	0.166/-0.193	0.114/-0.139
	6	0.089/-0.146	0.166/-0.193	0.122/-0.159

Load Effect Coeff.	AR	Cov. Int.	AS/NZS 1170.2	CSTS Proposal
		θ = 45°	θ = 0°	θ = 0°
C_{HA}	2.4	-1.10	-1.55	-1.55
	4	-1.36	-2.32	-1.62
	6	-1.52	-2.32	-1.77
		θ = 90°	θ = 90°	θ = 90°
C_{VA}	6	-0.92	-1.23	-1.23