Probabilistic model of wind load on the roof of low rise houses

Chana Jayasinghe[1], John Ginger[1]

[1]School of Engineering and Physical sciences, James Cook University, Townsville, Australia,
nandana.jayasinghe@jcu.edu.au , john.ginger@jcu.edu.au

1 INTRODUCTION

Contemporary houses typically have either gable or hip roofs or a combination of these. Design wind pressures acting on these roofs are dependent on its geometry, as shown in AS/NZS 1170.2[1]. These pressures are obtained from wind tunnel studies such as those by Holmes [3], Xu and Reardon [4] who have presented wind pressures on low rise houses with hip and gable roofs with a range of slopes. In addition, there is large variability associated with the pressures near roof corners, where normally the most severe wind loading occurs. Several studies have been carried out to assess the variation of wind loads on roof corners [6] and the influence of roof eaves (over hang) on the characteristics of pressures. The variability of wind loads on different parts of gable roof houses is determined in this study as a part of assessing variation in loading.

Previous studies have investigated the probability distributions of extreme local pressures on buildings. Holmes and Cochran [2] used several thousand extreme pressure coefficients from repeated time history samples from a wall tap and a roof tap on a model of the Texas Tech University Building to determine the appropriate probability distributions for the data. Both the Type I (Gumbel) Extreme Value Distribution, and the Generalized Extreme Value Distribution were used to fit the data. Li and Hu [5] studied a similar type of full scale building and found that the Type III Extreme Value Distribution matched the data measured on a roof corner. Kasperski and Hoxey [7] also found that Type III distribution can be fitted to the full scale data from the 6m Silsoe cube.

This paper presents the probabilistic descriptions of external pressures on the roof of typical contemporary gable end houses. The wind loads are obtained from a wind tunnel model study on a house with dimensions based on survey data. The objective of this study is to obtain appropriate probability distribution functions of external pressures on tributary areas representing roof cladding elements. This study also analyses structural wind load effects on roof trusses and compares these with load effects obtained using AS/NZS 1170.2[1]. These outcomes can be used for optimizing the design of houses and assessing their vulnerability to windstorms.

2 WIND TUNNEL MODEL TESTS

Wind tunnel model studies were carried out in the 2.0m high 2.5m wide 22.0m long boundary layer wind tunnel at the School of Engineering & Physical Sciences, James Cook University. The approach atmospheric boundary layer was simulated at a length scale of 1/50 over a fetch by using a 250mm high trip board at the upstream end followed by an array of blocks on the tunnel floor. A gable end 10m x 19.8m x 2.7m low rise house with 0.6m roof overhang and 22.5° pitch as shown in Fig 1 was constructed at a length scale of 1/50. This house is typical of the contemporary houses being built in cyclonic regions of Australia. The wind loads were measured on tributary areas representing cladding fixing in regions; P,Q,R,S,T and on roof trusses spaced 900mm apart identified as A,B,C,D,F and L shown in Fig 1. The trusses are connected to the wall and the vertical reactions at each wall are defined as V_1 and V_2 as shown in Fig 1. Each roof truss tributary was divided in to sixteen panels identified as 1...16.These panels are the batten-truss connection tributary areas. External pressures were obtained for approach wind directions 0° to 360° in steps of 15°. Pressure taps on each panel were connected to a transducer using a tubing system via a dynamic pressure measurement system. The fluctuating pressures were sampled at 1250 Hz for

30 secs and statistically analysed to get mean ($C_{\bar{p}}$), standard deviation (C_{σ_p}), maximum ($C_{\hat{p}}$) and minimum ($C_{\check{p}}$) pressure coefficients in a single run;

$$C_{\bar{p}} = \frac{\bar{p}}{\frac{1}{2}\rho\,\bar{U}_h^2} \qquad C_{\check{p}} = \frac{\check{p}}{\frac{1}{2}\rho\,\bar{U}_h^2} \qquad C_{\hat{p}} = \frac{\hat{p}}{\frac{1}{2}\rho\,\bar{U}_h^2} \qquad C_{\sigma_p} = \frac{\sigma_p}{\frac{1}{2}\rho\,\bar{U}_h^2}$$

Where $\frac{1}{2}\rho\bar{U}_h^2$ is the mean dynamic pressure at mid roof height h. Five runs were conducted for each angle to obtain repeat sets of pressure coefficients.

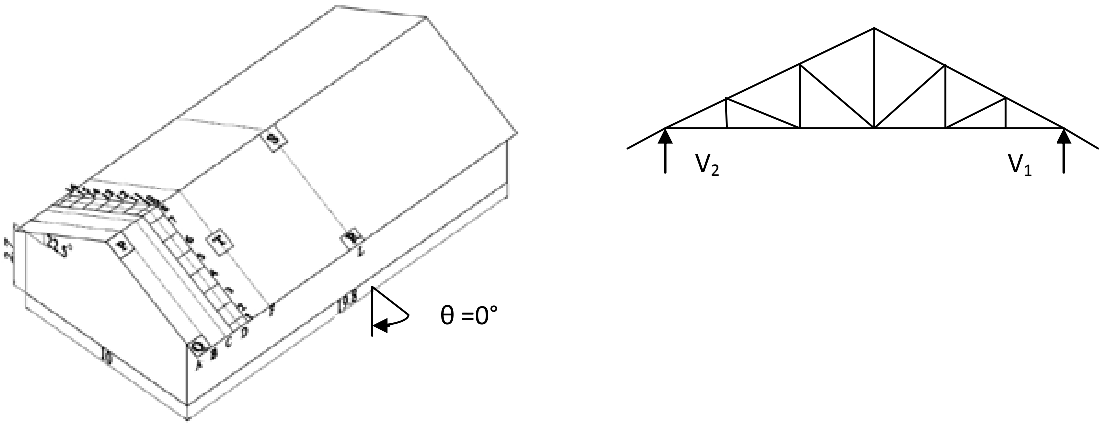

Figure 1: 10m x 19.8m x 2.7m gable end low rise house with 22.5°roof pitch

3 PRESSURE DISTRIBUTION

Fig 2a and 2b show the variation of pressure coefficients $C_{\bar{p}}$, $C_{\hat{p}}$ and $C_{\check{p}}$ with the wind approach direction (θ), for regions P and Q of the roof. Figures 2a and 2b show that the largest peak suction pressures in regions P and Q are for wind approach directions 135° and 150° and at 75°and 90°, respectively.

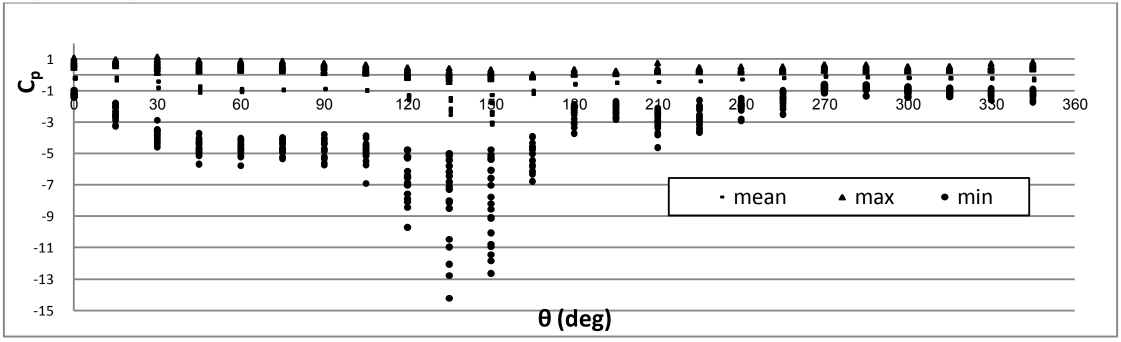

Figure 2a: Pressure coefficients vs wind direction – P (cladding)

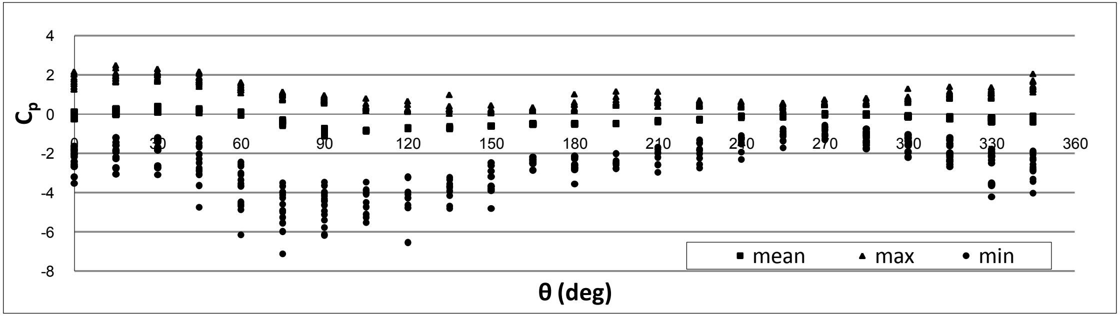

Figure 2b: Pressure coefficients vs wind direction - Q (cladding)

Wind loading standards typically provide design pressure coefficients for approach winds across and along the ridge. The corresponding nominal peak pressure coefficients (C_{pN}) derived from AS/NZS1170.2 [1] for regions; P and Q for θ= 0°, 90°, 180° & 270 are -1.05, -6.3, -4.22, -0.7 and -2.11, -6.3, -2.11, -0.7 respectively.

3.1 Probabilistic distributions

The variation of normalized peak pressure coefficients ($C_{\breve{p}}/\mathrm{C}_{\mathrm{pN}}$) is described with statistical parameters to represent the loading on the overall roof for each wind approach direction. The appropriate probability distribution function (PDF) for each region is determined by fitting the data to several standard PDFs including normal, lognormal, Rayleigh, Gamma, extreme value and Weibull. The assumed distribution is statistically verified by goodness of fit tests. Table 1 gives the statistical parameters of regions P and Q for selected θ.

Table 1. The statistical descriptions of peak pressure coefficients for P and Q regions

Approach angle(θ°)	Location P			Location Q		
	Mean ($C_{\breve{p}}/\mathrm{C}_{\mathrm{pN}}$)	COV	PDF	Mean ($C_{\breve{p}}/\mathrm{C}_{\mathrm{pN}}$)	COV	PDF
0	1.16	0.11	Gamma	1.10	0.25	Gen. Extreme value
45	0.73	0.10	Gen. Extreme value	0.40	0.36	Gen. Extreme value
90	0.74	0.12	Gen. Extreme value	0.75	0.18	Gen. Extreme value
135	1.25	0.35	Gen. Extreme value	0.66	0.13	Weibull
180	0.60	0.21	Gen. Extreme value	1.23	0.17	Lognormal

4 STRUCTURAL LOAD EFFECT ON TRUSSES

Eq 1 is used to calculate the fluctuating vertical reaction forces (X (t)) for trusses B and F for each approach wind direction. The influence coefficients for truss reaction forces V_1 and V_2 shown in Fig 1 were found by placing an inward unit load at each batten to truss connection, and calculating reactions using SPACEGASS. As described previously each truss has been divided to sixteen panels according to the batten to truss connection tributary areas.

$$X(t) = \sum_{i=1}^{N} \beta_i \, p_i(t) A_i \qquad \text{Eq. (1)}$$

Where β_i - the influence coefficient, p_i-wind pressure and A_i- tributary area, of panel i, N-is the total number of panels on the tributary

The vertical reaction forces and be presented in coefficient form, $C_X(t)$, as shown in Eq 2 , where, C_{p_i}-pressure coefficient at panel i, and A_T -Total tributary area of the truss

$$C_x(t) = \frac{X(t)}{\frac{1}{2}\rho \bar{U}_h^2 . A_T} = \frac{\sum_{i=1}^{N} \beta_i A_i \, C_{P_i}(t)}{A_T} \qquad \text{Eq. (2)}$$

Fig 3a and 3b show the variation of the peak values C_{V1} and C_{V2} with the wind approach angles for Trusses B and F, respectively. Figures 3a and 3b show that, for truss B the larger peak reaction occurred at V_1 for wind approach direction 90° whereas for truss F it occurred at reaction force V_2 for 30°.

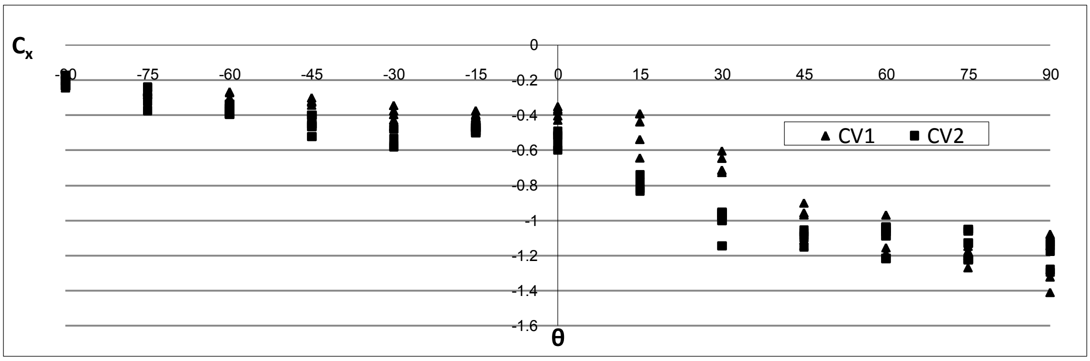

Figure 3a: Peak C_{V1} and C_{V2} vs wind approach angles -Truss B

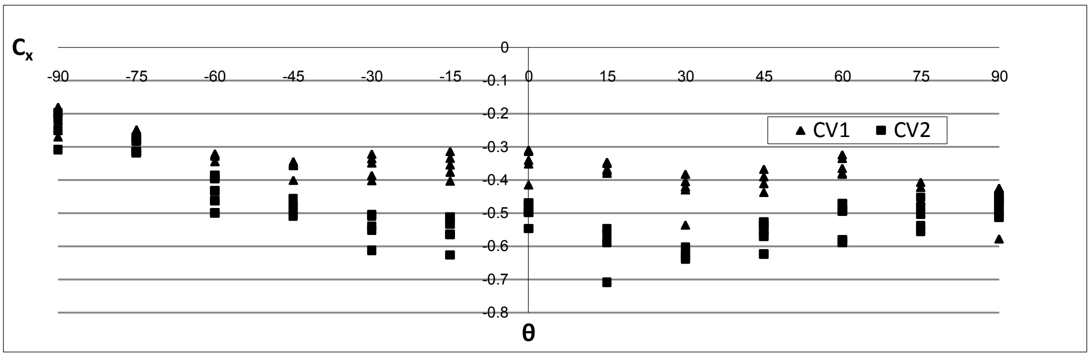

Figure 4b: Peak C_{V1} and C_{V2} vs wind approach angles for -Truss F

Probabilistic descriptions for truss reaction forces also can be found by using the method used in Section 3.1. The corresponding nominal (X_N) values are obtained from AS/NZS 1170.2[1].

5 CONCLUSIONS

This study presented the variation of external pressures for different wind approach directions on roof of typical contemporary gable end house. The probabilistic descriptions of the peak pressure acting on the overall roof for each wind approaching direction were obtained. The structural load effects on roof truss hold down connections were also obtained with the probabilistic descriptions for each wind approaching direction and compared with the load effects obtained using AS/NZS 1170.2. These outcomes can be used for optimizing the design of houses, assessing their vulnerability to wind events.

6 REFERENCES

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