Vulnerability of metal-clad, hot rolled sheds subjected to wind loads

J. D. Ginger[1], C. J. Leitch[1], P. Y. Kim1, N. C Jayasinghe[1] and D. J. Henderson[1]
[1]Cyclone Testing Station, School of Engineering & Physical Sciences, James Cook University, Australia.
john.ginger@jcu.edu.au

1 INTRODUCTION

Low-rise metal-clad, metal framed industrial sheds can be categorized by the type of framing member as; hot-rolled or cold-formed. The resilience of these sheds to wind loads is dependent on the strength of their components. This paper provides a general vulnerability assessment of typical hot-rolled low-pitch roof gable-end shed components in cyclone Region C of Australia, to wind-induced failures when subjected to increasing wind speeds.

Low roof pitch (<10^o), gable-ended metal-clad sheds of height (*h*), width (*d*), and length (*b*) shown in Fig. 1, typically have a series of portal frames placed at regular intervals of between 4m and 10m along its length to which purlins are attached up to about 1.2 m apart. The roof cladding is screwed to the purlins by fasteners at a spacing of 150 to 200 mm. Often thicker gauge purlins are used in the end bays to account for the higher wind loads, and the z-purlins are usually lapped at the frame supports. The vulnerability of cladding and purlins on edge and mid parts of the roof (RCE, RPE), and the Frames B, and Mullion M, shown in Fig. 1, are assessed by analysing their response to increasing wind loads.

2 DESIGN APPROACH

Structural design standards used in Australia adopt criteria related to a specific limit state, such as the ultimate limit state of component or structural failure. AS/NZS 1170.0 [1] provides calibrated combinations of factored, dead, live and wind loads to be applied on structural components and connections and checked against their factored resistances. The basic framework for probability based, limit state design is provided by reliability theory, where the loads and resistances are random variables. Using this approach, probabilistic models for loads and component strengths are derived using methods developed by Pham et al [2], Holmes [3], Pham [4] Pham and Bridge [5] and Henderson and Ginger [6], to determine the vulnerability of components of these sheds in windstorms. Statistical parameters are used to account for the uncertainty and variability associated with loads and component strengths.

In this study, the critical design action is wind load, with component failure taking place when its strength, *R* is exceeded by the combined load effect *S*. Data on loading and component strength are required in order to calculate the risk of component failure or reliability. The information required is the probability distributions of load and strength variables, and estimates of their mean and standard deviation or coefficient of variation (COV).

Wind load effects for the design of cladding and primary structure on these sheds are usually calculated from pressures derived from nominal pressure coefficients, provided in AS/NZS 1170.2 [7]. The design pressures are calculated from Eq. 1, where ρ is the density of air, V_h is the 3s-peak design gust wind speed at mid-roof height and C_{fig} is the aerodynamic shape factor. Quasi-steady internal pressure coefficients $C_{p,i}$ and external, pressure coefficients $C_{p,e}$ combined with factors for area-averaging K_a, loads on multiple surfaces K_c, and local-pressure effects, K_l are used to determine C_{fig} values for internal and external pressures. External and internal design pressures acting over the tributary area are combined to get the nominal, net design wind load, W_N from which the wind load effect is calculated.

$$p_{design} = 0.5\rho V_h^2 C_{fig} \quad (1)$$

The nominal, gust wind speed at 10m elevation in terrain category 2 approach, V_N is modified by multipliers M_d, $M_{z,cat}$, M_s and M_t respectively in Eq. 2, to calculate V_h.

$$V_h = V_N M_d (M_{z,cat} M_s M_t) \quad (2)$$

Edge regions are located within a distance '*a*' from the roof edges, where according to AS/NZS 1170.2 [7], '*a*' is the minimum of (0.2*b*, 0.2*d*, *h*). Local pressure factor K_l of 2.0 and 1.5 are generally applicable to cladding, fixings and purlin on tributary areas less than $0.25a^2$ and $0.25a^2$ to a^2 within distances of $a/2$ and a respectively from the windward edge. The internal pressure coefficient, $C_{p,i}$ for a nominally sealed building is 0.0 and for a building with a dominant windward wall opening is + 0.7.

3 WIND LOADS – PROBABILISTIC MODEL

Wind load, *W* acting on roof components are given by the probabilistic model in Eq. 3, where *V* is the maximum gust velocity at 10m height in terrain category 2 in 50 yrs (lifetime) and the parameter *B* includes all the other components of the wind load. Pham et al [2] and Holmes [3] used a similar model to describe the wind load component in the limit state design approach used in AS/NZS 1170.2.

$$W = B\,V^2 \qquad \text{where, } B = \lambda .\ A\ (C.\ E^2.\ D^2.\ G.\ \rho/2) \quad (3)$$

The variables within the bracket can be directly related to the nominal values given in AS/NZS 1170.2 [7], where, *C* is the quasi-steady pressure coefficient, *E* is a velocity height multiplier that accounts for the exposure and height, *D* is a factor for wind directionality effects, *G* is a factor that accounts for gusting effects and is related to K_a, K_c and K_l, and ρ is the density of air. The variable, λ is a factor to account for inaccuracies and uncertainties in analysis, and *A* is the tributary area. The nominal values of these parameters are combined to give B_N which is used to deduce the nominal design wind load, W_N from Eq. 4, where V_N is the ultimate limit state design wind speed typically with a mean return period of 500 to 1000yrs.

$$W_N = B_N\,V_N^2 \qquad \text{where, } B_N = \lambda_N\,A_N\ (C_N\ .\ E_N^2.\ D_N^2.G_N\ .\ \rho_N/2) \quad (4)$$

Giving $[W/W_N] = [B/B_N]\ [V/V_N]^2 = ([\lambda/\lambda_N]\ [A/A_N]\ [C/C_N]\ [E/E_N]^2\ [D/D_N]^2[G/G_N]\ [\rho/\rho_N])\ [V/V_N]^2$ (5)

Each of the variables contained in *B* are assumed to have a log-normal probability distribution with assumed mean and coefficient of variation (COV), deduced from testing, surveys and other studies [2, 3,6]. Statistical data of these variables is used to estimate the mean and COV of the random variable *B*, which also has a log-normal probability distribution. In these assumptions, values in AS/NZS 1170.2 [7] are generally considered conservative, on average, especially when calculating design wind load effects on the primary structure. Scarcity of such data means that a considerable amount of knowledge and experience is needed when estimating these values.

4 STRENGTH OF COMPONENTS - PROBABILISTIC MODEL

The components of the shed are designed for two cases; with the application of internal pressures based on the building being nominally sealed and the existence of a dominant opening. Manufacturer specifications were used to select cladding, purlins and frame components (with capacity ΦR_N). Roof cladding is fixed to the purlins at the "rib", and cyclone washers are used within the "*a*" wide strip along the roof perimeter. The vulnerability of cladding and purlins on edge and mid parts of the roof, and the frames are assessed by analyzing their failures under increasing wind speeds. The probabilistic distribution of capacity for each of these components in typical modes of failures, based on available and assumed data is log-normal and is given in terms of ($R/\ \Phi R_N$).

Leitch et al [8] analysed survey data of sheds in cyclonic regions, to determine the structural form of roofs and cladding, and ascertained load parameters and design capacities used by a range of engineers. They found that a range of small internal pressures (i.e. $C_{p,i}$ = 0 to 0.3) had been used in the design of more than 25% of the sheds, that could potentially have a dominant opening. Determination of the external pressure coefficients on such sheds is straightforward, but the internal pressure coefficients are based on a judgment of the size and locations of openings in the envelope. For instance, if the shed is considered to be nominally sealed or if all its walls are equally permeable, then $C_{p,i}$ = 0 is appropriate. However, the internal pressure will be significantly higher if a dominant opening is created in a wall, say by the impact of flying debris or failure of a roller door or window. Damage investigations of sheds have shown engineered cold formed sheds to have a significantly higher proportion of structural damage to similar age domestic construction typically due to a dominant opening (such as roller door failure).

5 RELIABILTY OF COMPONENTS

The estimated probability of failures of cladding and purlins on edge parts of the roof, with varying wind speed, V for sheds designed with $C_{p,i}$ of +0.7 and 0 are given in Fig. 2a-b. The estimated probability of failures of Frame B and Mullion, with varying wind speed, V for sheds designed with $C_{p,i}$ of +0.7 and 0 are given in Fig. 3a-b. The analysis assumes progressively increasing wind speeds responsible for an increasing percentage of sheds with a dominant windward wall opening causing large positive internal pressures. In this analysis, failure of each component is considered independently.

6 DISCUSSION AND CONCLUSIONS

Fig. 2a-b and 3a-b show that when the shed is designed for a dominant opening ($C_{p,i}$ = +0.7), the edge roof cladding is more vulnerable than the purlins to wind damage at the ultimate limit state wind speed of 70 m/s. The probability of failure of frames is significantly lower. According to loading standards (i.e. AS/NZS 1170.0 [1]) the failure probability of typical primary structural components at ultimate limit state is calibrated to about 10^{-3}. Fig. 2a-b and 3a-b show significantly increased vulnerability of all these components if the shed is designed as a nominally sealed building ($C_{p,i}$ = 0), with significantly increased roof and wall cladding failures at a wind speed of 70 m/s. In practice, the failure of a component could significantly alter the wind load acting on another component thus influencing its probability of failure. This aspect can be modelled using methods, such as in WindSim being developed by GeoScience Australia, by applying a set of rules based test data and damage investigations.

7 REFERENCES

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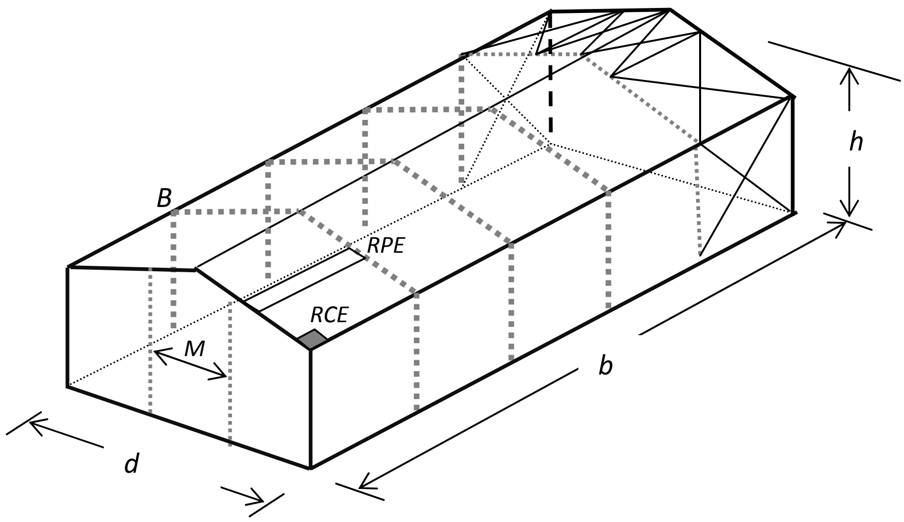
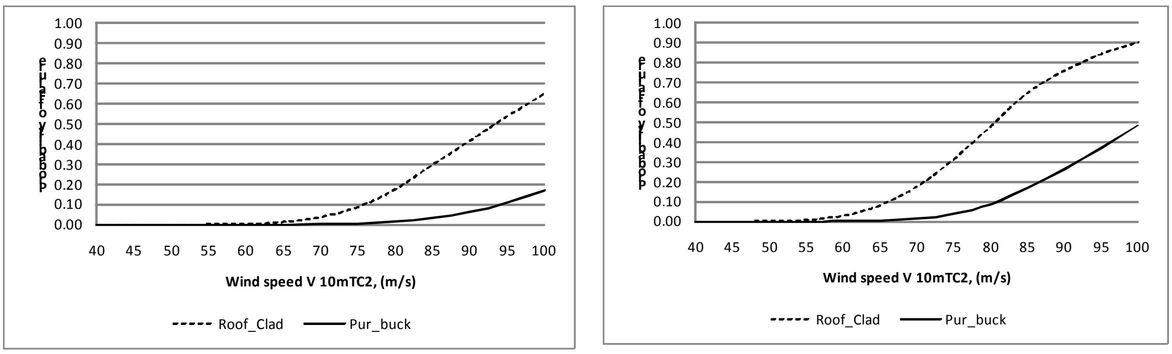
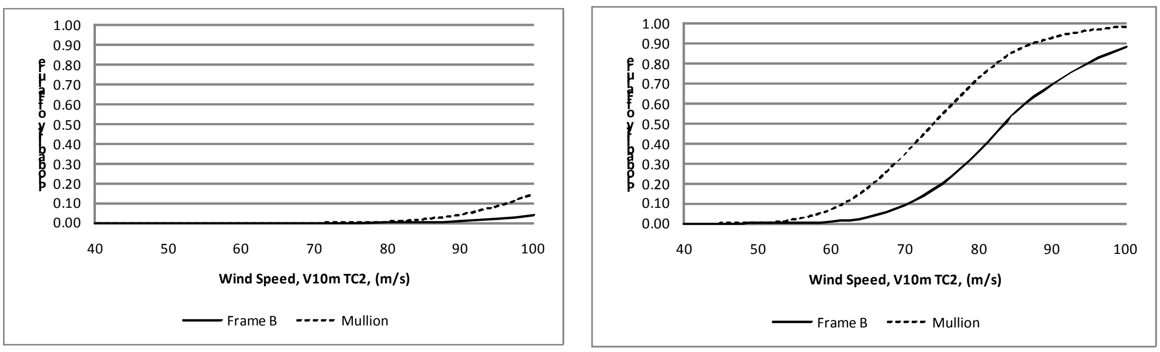


Figure 1. Typical low roof pitch shed showing roof cladding, and purlin, regions, and frames



a) Design $C_{p,i} = +0.7$ *b) Design $C_{p,i} = 0$*

Figure 2. Probability of failure of roof edge cladding (RCE) and purlins (RPE) vs wind speed



a) Design $C_{p,i} = +0.7$ *b) Design $C_{p,i} = 0$*

Figure 3. Probability of failure of Frame B and Mullion M vs wind speed