Simulation of Cyclonic Wind Loads on Roof Cladding

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1. Introduction

The roofs of low-rise buildings are subjected to large pressures during windstorms. The creation of a dominant opening by debris impact, door failure, etc, in the windward wall can generate large positive internal pressures, which, in combination with large suctions at the edges of the roof, will generate large net pressures. Cyclone Tracy caused catastrophic damage to housing in Darwin in 1974 (Walker, 1975). A major component of damage was caused by low cycle fatigue cracking of the cladding under the fixings, which resulted in extensive loss of light gauge metal roof cladding.

Australian pierced fixed metal roof cladding is roll formed from G550 (specified minimum yield strength 550MPa) steel into typical corrugated or rib-pan profiles. The most common thickness of cladding is 0.42 mm base metal thickness. G550 is characterised by its high strength and low ductility. Over the last decade, G550 material is being used in more and more building components. The cladding is pierced fixed through a crest or rib, with typically a 50 mm long 14 gauge self tapping screw, into the supporting structure (batten). Thin-gauge steel G550 "top-hat" battens have all but replaced the traditional 40 mm deep hardwood battens in these domestic roof systems.

Low cycle fatigue was defined by Beck and Stevens (1979) as failure typically within 10000 load cycles. The Darwin Reconstruction Committee expediently stipulated a test method of 10000 cycles from zero to the permissible stress design load followed by a proof load of 1.8 x design load, for evaluating roofing. In the following years other test methods were introduced into other Australian cyclonic wind regions leading to manufacturers evaluating products against different test criteria which were meant to represent the same loading but could result in different outcomes (Henderson, et al 2001).

This paper looks at the variation of pressure near the windward edge of a gable roof building with and without a dominant opening, during the passage of a "design" cyclone. The analysis uses pressures wind tunnel measurements from a 1/100 model-scale building at the University of Western Ontario (UWO). An advanced pressure loading actuator (PLA) developed by UWO, is used to apply the fluctuating pressures of the "design" cyclone to sections of roof cladding (Kopp, et al 2008). The cladding response and accumulated damage is compared to similar test specimens subjected to current test methods.

2. Wind loading

The wind load acting on a part of the roof of a building during a cyclone event will depend on the parameters of the cyclone such as the peak and mean wind speeds, size and translational speed of the cyclone, and also building geometry, and internal pressures. Buildings located in the path of a cyclone near the radius of maximum winds just outside the eye of the cyclone (where the highest wind speeds are usually found), are generally subjected to the largest wind loads. The variation of external pressure (i.e. magnitude and cycles) will depend on the characteristics of the cyclone, and building shape and orientation with respect to the passage of the cyclone. For instance, a cyclone travelling slowly is expected to generate a larger number of pressure cycles of the same intensity than a cyclone with the same intensity but moving faster, whilst an increase in the wind speed is expected to increase the pressure and also number of cycles in a given time span.

Mahendran (1995) and Jancauskas et al (1994) proposed a "design" cyclone with the variation of 10 min mean wind speed and direction similar to that shown in Figure 1, for evaluating the range of loading cycles over a four to five hour period. The curves represent a cyclone with radius to maximum winds of 25 km and a translational speed of 15 kph. Jancauskas et al (1994) used a 3 second peak to mean gust factor of approximately 1.7 giving a peak gust of approximately 70 m/s.

These studies, using external pressures measured on a single storey gable ended building model and extensive sinusoidal loading tests, formed the basis of the Low-High-Low (L-H-L) test, specified in the BCA (2007). They did not incorporate the effects of internal pressure resulting from dominant openings in the building envelope.

For this paper, time series pressures on a cladding fastener (0.15 x 0.9 m tributary area) were scaled from the UWO model study of a 6 m eaves height industrial style gable end building with a low pitch roof. The simulated cyclone pressure trace was assembled from 15 minute increments over the five hour period, as shown in Figure 2. Each 15 minute period was for an advancing wind direction. The maximum mean velocity of 42 m/s was set to coincide with the wind angle of 25° which gave the largest peak suctions at the corner region of the building. A dominant opening (failed roller door, window, etc) on the windward wall was assumed to have occurred at the 2.5 hour mark. The internal pressure is assumed to be "equal" to the external pressure at the dominant opening. This is considered to be a satisfactory representation of the actual internal pressure, notwithstanding that the internal pressure fluctuations will be dependent on the size of the opening, volume of the building, and the approach wind speed etc (Ginger et al, 2008).

The peak net pressure on this corner cladding fastener is -6.8 kPa. Figure 2 shows the increasing and then decreasing wind loads on this area, in a form similar to that specified by the L-H-L test. However, these fluctuating pressures have various means, peaks, ranges and load ratios as opposed to each pressure cycles of the L-H-L always returning to zero.

3. Loading the cladding

The PLA loading system has been developed for the "Three Little Pigs" (3LP) full scale house testing facility at UWO (Kopp et al., 2008). The PLAs permit the application of actual temporally varying wind pressures to a representative test section of the building envelope, and can adapt to changes in geometry and leakage of the test section. In collaboration with UWO, a PLA, housed at CTS, is used to apply the simulated "design" cyclone pressure to a double 900 mm span of corrugated cladding (Figure 3). The test sample can be installed to allow a "positive" pressure to be applied to its inside face or a "negative" pressure applied to its external face to give the required net suction pressure on the cladding element. A three axis load cell (JR3) is used to measure the response of a central cladding fastener during the test.

There are many parameters affecting the performance of roof cladding (such as fixing alignment, tightness, supporting structure, age) so any current findings should be taken as preliminary. The simulated cyclonic wind trace with an assumed dominant opening, caused creasing and cracking of the cladding adjacent to the screwed crests at approximately 90 minutes into the trace. Crack growth increased, with cracks reaching lengths in the order of 20 mm. However, there was minimal crack growth during the last quarter (~70 minutes) of the trace, during which the pressure progressively dropped. The cladding resisted the applied loads, that is, did not disengage from its supporting structure, which is defined as a successful outcome according to Australian cladding test standards. A similar cladding specimen that was subjected to a L-H-L test in the CTS large airbox, was not able to resist a test with a peak load of 4.8 kPa.

Standard laboratory tests (e.g. L-H-L) apply nominal sinusoidal loads at frequency of typically 1 Hz. However, the simultaneous measurements from the JR3 show that the reaction at the screw is not just dependant on the tributary area but also influenced by the rate of loading (peaks of trace) and the state of the cladding (deformation and cracking) thereby influencing the resilience of the cladding.

4. Conclusion

The results show that wind loads on roof cladding and its response leading to low cycle fatigue cracking is significantly influenced by the peak load, load range and the sequence of loading. The L-H-L test is by necessity a simplification of the actual loading of the cladding and fixings during the passage of a cyclone. In the formulation of the L-H-L fatigue loading sequence, assumptions such as material properties, test configuration, cycle counts, load range and geometry have been made. The PLA is used to evaluate these inherent simplifications of the L-H-L with the potential for increasing design values. Further work will investigate this in greater detail.

5. References

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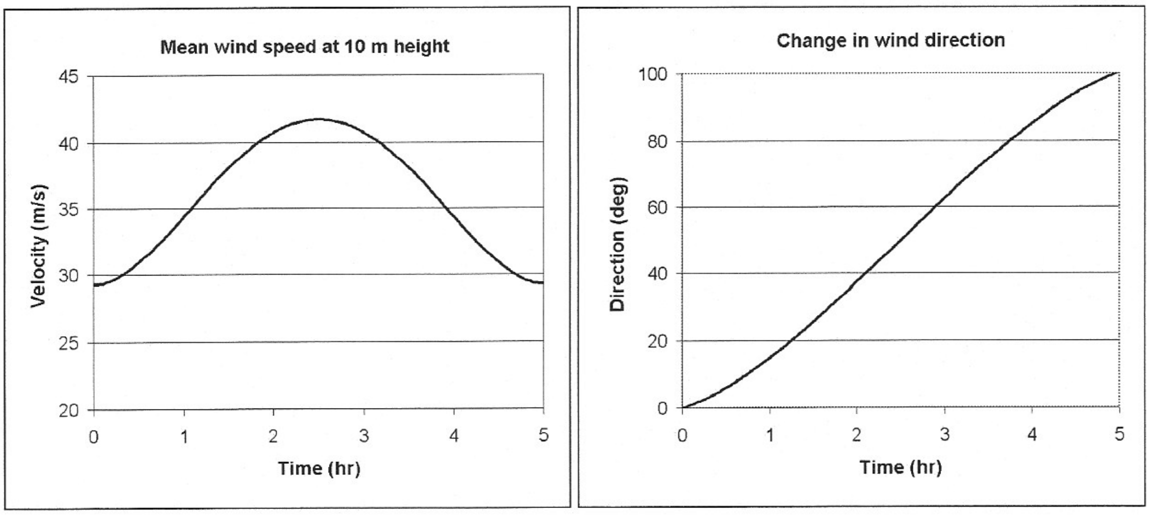

Figure 1: Variation of mean wind speed and direction over time

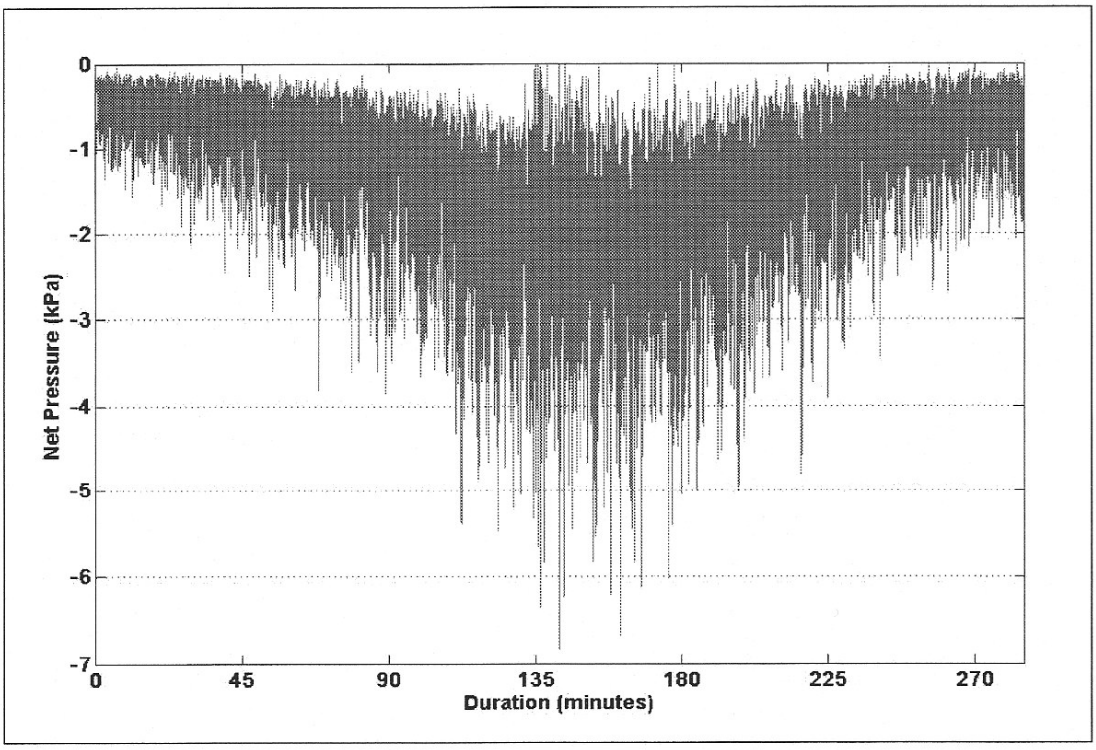

Figure 2: Change in peak pressures with changing direction and mean wind speed

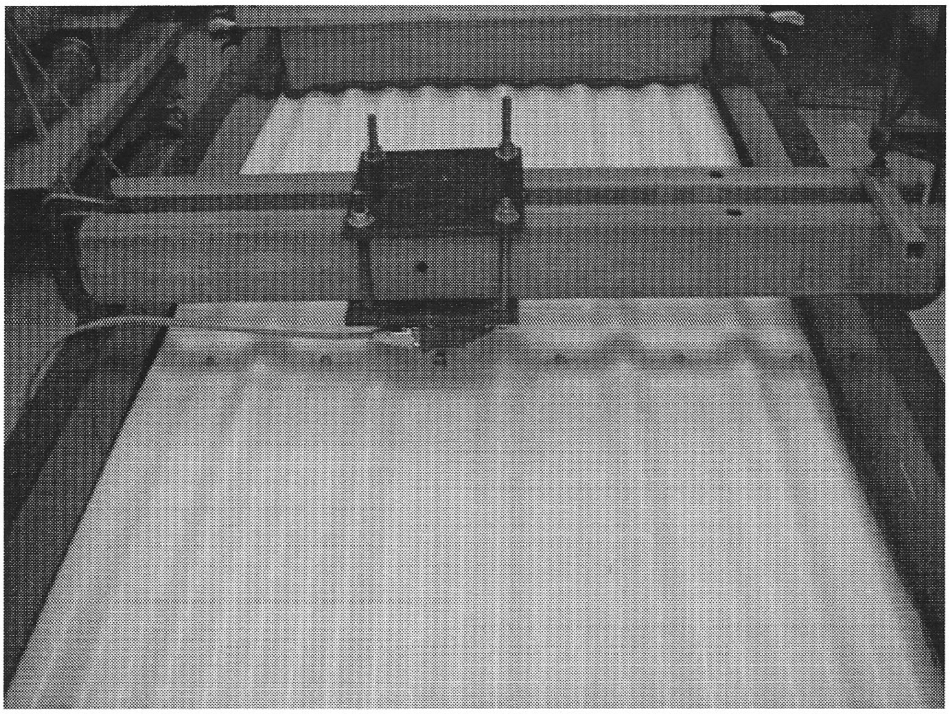

Figure 3: Corrugated cladding under load with JR3 measuring load at screw