# Performance of light gauge metal roof cladding subjected to cyclonic wind loading – A review

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## Introduction

Storm damage studies have shown large external pressures combined with large internal pressures acting in the same direction to be the main cause of roof and wall failures. The roof generally experiences the highest wind loads and is the component most susceptible to failure. A dominant opening on the windward wall can generate large positive internal pressures resulting in large net uplift pressures on the roof, especially near the windward edges.

Significant damage was caused by cyclone Althea in Townsville in 1971. Although the Darwin building authorities implemented changes learnt from Althea, cyclone Tracy still caused major damage in Darwin in 1974. The major component of damage, which resulted in catastrophic loss of light gauge metal roof cladding, was caused by low cycle fatigue (Morgan and Beck [1]). Low cycle fatigue was defined by Beck [2] 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 (suction) followed by a proof load of 1.8 × design load, for evaluating roofing. This test regime was subsequently incorporated into the Darwin Area Building Manual (DABM). In 1977, Morgan and Beck [1] noted that the conservative DABM test regime was to be used as an interim acceptance criteria and commented that this should be replaced with a more realistic test, when additional data becomes available.

Research reported at a workshop organised by the Experimental Building Station by Melbourne [3] and Morgan and Beck [1] suggested loading regimes for roof systems, based on pressure measurements from wind tunnel models and simulated tests on cladding. These recommendations were simplified to produce "Guidelines for the testing and evaluation of products for cyclone prone areas", commonly referred to as TR440[4]. TR440 sets out parameters and methods for loading, assessment criteria, and testing of roofing and walls. The TR440 loading regime was subsequently rejected by the building regulators in Darwin on the basis that roofing systems, similar to the ones that failed during cyclone Tracy, were "satisfying" the test criteria. This lack of coherence of a standard test method unfortunately leaves manufacturers having the same product evaluated for two different test regimes.

## Cyclic Test Regimes

Further research has been carried out, for instance by Beck [2], Mahendran [5, 6] and Xu [7, 8], in an attempt to formulate a more realistic uniform test regime, acceptable throughout Australia. They studied the behaviour of the cladding under low cycle-high strain rate cyclic loading regimes in an attempt to understand the effects that cladding profile, material properties, and crack propagation have on fatigue life. The reviewed cyclic load test regimes are summarised in Figure 1.

Various cycle counting techniques, such as upcrossing and "rainflow" methods [9], have been used to determine the number of loading cycles during the passage of a cyclone. External pressure measurements on a model of a typical house [10] and on the Texas Tech building [11, 12] have been used to derive wind load cycles on the walls and roof of the building. Positive pressures pushing the cladding onto its supports have generally been neglected as the net uplift pressures pulling the cladding against the fastener heads cause much higher stresses in the cladding [2, 6]. Beck stated his regime was more realistic than TR440 as the load cycles about an off set mean were incorporated as opposed to the simplified zero to load approach of TR440. For corrugated cladding, TR440 was demonstrated to be un-conservative [10], but conservative for trapezoidal cladding [8].

The Random Block Loading (RBL) method suggested by Mahendran [13] is based on combining external pressure coefficients measured on a 1/50 scale wind tunnel model with approach winds (ie. speed and direction) determined from a Category 4 "design" cyclone, using the rainflow method. An extensive matrix of load cycles was formulated, where each cell of the matrix, contains the number of load cycles relating to a percentage of the range and mean of the ultimate wind load. Loading blocks are then randomly selected from the matrix over the duration of the cyclone. This method was considered too complex for routine product evaluation and standardised testing and was simplified into a low-high-low regime [14] representing the passage of a cyclone with the increasing then decreasing wind speeds.

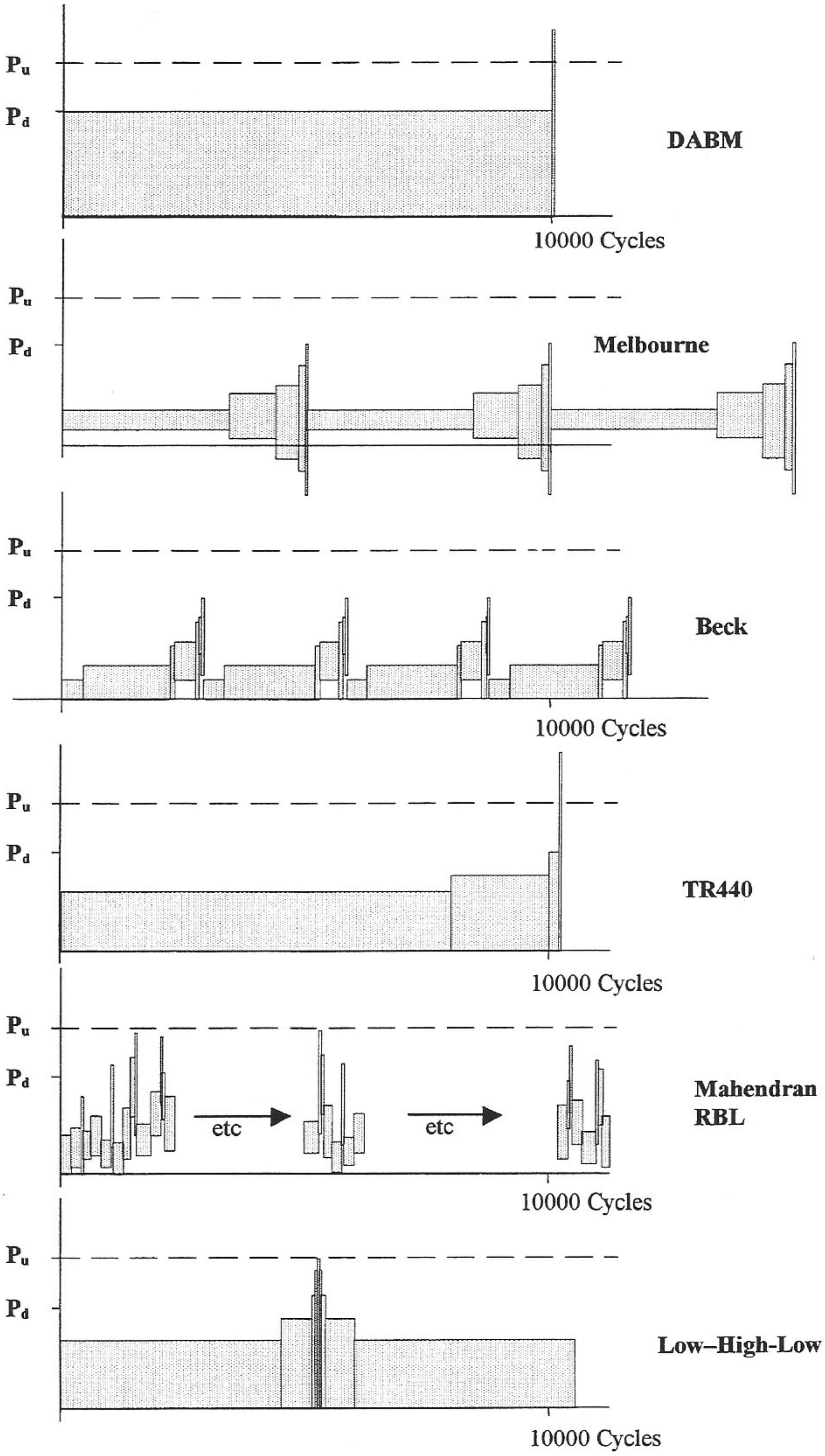

**Figure 1 : Cyclic load regimes**

### Test Configurations and Criteria for Acceptance

A range of configurations and apparatus are used to carry out tests for evaluating roofing systems. They range from individual fastener pull through test, double span systems loaded in the middle of the spans via a line load or double span systems subjected to a uniform load using airbags, to using air chambers that apply pressure to the cladding, which in the case of BRERWULF [15] is a suction to the external face and in the

BHP [16] and CSTS air boxes is a positive pressure to the inside face.

Multispan roof cladding systems are mostly evaluated by testing double span arrangements. As high suction develops close to roof edges (eaves, ridges), the central batten represents the critical, that is most heavily loaded support from the eaves or ridge [7]. The simple pull through test is used (mainly in USA), instead of the two span roofing assembly test, as the failure of the roof sheeting is dominated by the magnitude of the fastener reaction [5, 8]. This failure mechanism of the cladding has also led to the midspan loading method instead of the application of a uniformly distributed load. The midspan load method is more reasonable than the pull over test method, in that it attempts to generate the correct moment and reaction combination on the cladding, at the central support by using an equivalent span for the cladding test specimen. Xu [8] states that the behaviour of cladding from both pull through and midspan loading have not been clearly validated under either static or dynamic loading.

Although simulating uniform loading, the commonly used air bag loading method also has its drawbacks when testing profiled cladding. As the air bag does not make complete contact with the profiled (ie. corrugated, ribbed) cladding surface, local effects are not accurately replicated [17]. This shortcoming has been rectified in the airbox test set up. Recent tests using the positive pressure air chamber rig at the CSTS have also identified other modes of failure, such as cracking and tearing of cladding at laps.

TR440 defines failure as any disengagement of the cladding from the support structure. This includes failure of the cladding to fastener fixing, fastener to batten fixing, or the fracture of fastener. The CSTS extends these criteria to include the failure of the batten or purlin (especially light gauge top hat battens) and its connections to the structure, as it considers them to be part of the roofing system.

**Dynamic wind loads on roof**

The pressure variation on a part of the roof (ie. cladding fastener or batten-truss connection) can be described in terms of a pressure coefficient (referenced to the mean dynamic pressure at roof height), as $C_p(t) = C_{\bar{p}} + C_{p'}(t) = C_{\bar{p}} + g_p.C_{\sigma p}$, where $C_{\bar{p}}$ is the mean value averaged over time $t$, $C_{p'}$ is the fluctuating component, $C_{\sigma p}$ is the standard deviation, and $g_p$ a normalised pressure factor. The maximum and minimum pressures are given in terms of a pressure, peak factor, $g_{\hat{p},\breve{p}}$ as $C_{\hat{p},\breve{p}} = C_{\bar{p}} + g_{\hat{p},\breve{p}}.C_{\sigma p}$.

Model and full scale studies [12, 18, 19] have shown that the probability density function of the windward wall pressures is close to the Gaussian form, but, the pressure fluctuations under the separated flow regions on the roof are negatively skewed. The pressure spectra under the separated flow regions showed that energy is distributed towards the higher frequencies compared to the approach velocity and windward wall pressure fluctuations [18].

In domestic housing roof construction, battens are typically placed ~ 1.0 m apart on roof trusses located up to 1.2 m apart. The roof cladding is attached to the battens by fasteners at a spacing of 150 to 200mm. Each cladding fastener takes wind loads acting on an area of about 0.2 $m^2$, whilst the batten truss connection bears wind loads acting on a tributary area six times the area supported by a cladding fastener. Nevertheless, smaller tributaries are subjected to larger peak pressures, which is reflected by the larger local pressure factors stipulated for smaller areas in AS1170.2 [20].

Wind loads on the roof of the Texas Tech full-scale building shown in Figure 2 with a 2% windward wall opening, [20] are reviewed here. Peak pressure coefficients for design of cladding and fixtures on specific areas are also compared with values derived from AS1170.2. Table 1 gives the pressure coefficients and pressure peak factors obtained from the Texas Tech full-scale study, and effective peak $C_p$s derived from AS1170.2, by $C_{\hat{p},\breve{p}} = C_p \times K_l \times \left(\hat{U}_{3s}/\overline{U}\right)^2 = C_p \times K_l \times G_U^2$, where $G_U = \left(\hat{U}_{3s}/\overline{U}\right)$ is the velocity gust factor. Table 1 shows that large external suction and net uplift $C_{\breve{p}}$ s were measured on areas A and B of the Texas Tech building. The net uplift $C_{\breve{p}}$ on area A, exceeded values derived from AS1170.2 but compared favourably on area B. Studies at Texas Tech [21] have found $C_{\breve{p}}$ exceeding –12.0 at the windward roof edges on areas representative of a cladding fastener tributary. Such large peak suction pressures have not been measured in typical wind tunnel model studies, and therefore cycle counts and test pressures based on such wind model studies may not accurately represent the loads on a cladding fastener during the passage of a cyclone.

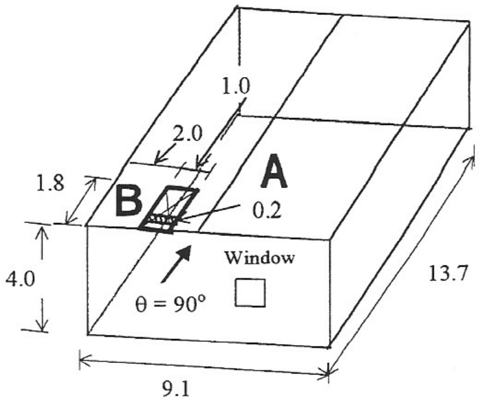

**Figure 2 : Texas Tech full-scale building**

**Table 1. Pressure coefficients and pressure peak factors on the Texas Tech full-scale building**

| Tributary | Area, m$^2$ | $C_{\bar{p}}$ | $C_{\hat{p}}$ | $C_{\breve{p}}$ | $g_{\hat{p}}$ | $g_{\breve{p}}$ | K$_1$ | $C_{\hat{p},\breve{p}}$ |
|---|---|---|---|---|---|---|---|---|
| | | Measured | | | | | | AS1170.2* |
| θ = 90° | | | | | | | | θ = 90° |
| Internal | | 0.65 | 2.80 | -0.24 | 5.37 | -2.23 | | 2.14 |
| A Ext | 0.2 (0.06a$^2$) | -1.43 | -0.28 | -7.10 | 1.93 | -9.52 | 2.0 | -5.51 |
| B Ext | 1.8 (0.54a$^2$) | -1.37 | -0.31 | -4.50 | 1.99 | -5.81 | 1.74 | -4.82 |
| A Net | 0.2 (0.06a$^2$) | -2.08 | -0.34 | -8.36 | 1.97 | -7.14 | | -7.65 |
| B Net | 1.8 (0.54a$^2$) | -2.02 | -0.35 | -6.36 | 1.97 | -5.14 | | -6.96 |

* Pressure gust factor = $(1.75)^2 = 3.063$

**Fatigue Behaviour of Materials**

The most common light gauge metal cladding is of the corrugated and rib/pan profiles and is rolled from 0.42 mm bmt G550 coil. The measured mean yield stress typically exceeds 700 MPa, satisfying the minimum yield stress for G550 of 550 MPa [7]. The mechanical properties (ie tensile strength and modulus of elasticity) vary in the longitudinal and transverse directions of the coil.

The fatigue behaviour of the cladding is dependent on the load causing local plastic deformation (LPD), seen as dimpling under the screws around the fastener holes [6]. This is typically 650 N to 700 N per fastener, for corrugated cladding. This LPD strength strongly influences the fatigue life. The longevity of corrugated cladding increases markedly if the cyclic load per fastener is kept below this LPD load. [2, 7, 22]. Beck [2] found that there is a progressive reduction in the strength of the cladding-fastener assembly under repeated loading. The number of cycles to failure increases as the load per fastener decreases. He also found that the cladding failure patterns (crack and tear orientation, size etc) observed from damage inspections conducted after cyclone Tracy, closely resembled the repeated loading failure modes in the laboratory tests.

Laboratory studies showed that a decreased block load, following crack initiation, results in a slower crack growth and a longer life [2]. Whilst the opposite occurred when loads were increased after the initiation of a crack, resulting in shorter life [6]. These studies also showed that the strength of cladding, fixed through the crests or ribs, was dependant on the shape and height of the crest or rib, and the use of cyclone washers, which delays dimpling and thereby increases the failure load. Increasing the roofing span from 900 mm to 1200 mm caused a reduction of approximately 10% in the limit values of the reaction force per fastener at the central support due to the local failure and bending at the crests or ribs[7]. However the initial cracking of the roofing sheets is mainly due to the fastener reaction force causing the local plastic deformation under the screw head.

From a review of the TR440 test regime held in 1994 the low-high-low regime was further modified. The inclusion of a proof load and material capacity reduction factors was suggested but not finalised. These factors and the location of a proof load (middle or end of the test regime) have a profound effect on the load per fastener and therefore on the cladding design load.

## Concluding Comments

A realistic test loading regime, for evaluating roof systems must be developed by:

- Including the variation of both external and internal pressure (ie. net pressure) across the roof cladding during the passage of the design cyclone.
- Accounting for the larger external suction pressures acting on cladding fastener tributary areas in flow separation regions in full scale buildings.
- Quantifying the discrepancies in the various test configurations and fatigue life estimates.

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