Performance of roof cladding and battens subjected to wind loads

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Introduction

Typical low-rise house roof systems in Australia have battens placed at about 1.0 m intervals attached to roof trusses placed up to 1.2 m apart, as shown in Figure 1. The roof cladding is screwed to the battens by fasteners at a spacing of 150 to 200 mm. In these systems, a 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 roof tributary area of 1.0 m $\times$ 1.2 m, six times the area supported by a cladding fastener. Thin-gauge steel (~ 0.6 mm), "top-hat" battens are increasingly replacing the traditional 40 mm deep timber battens.

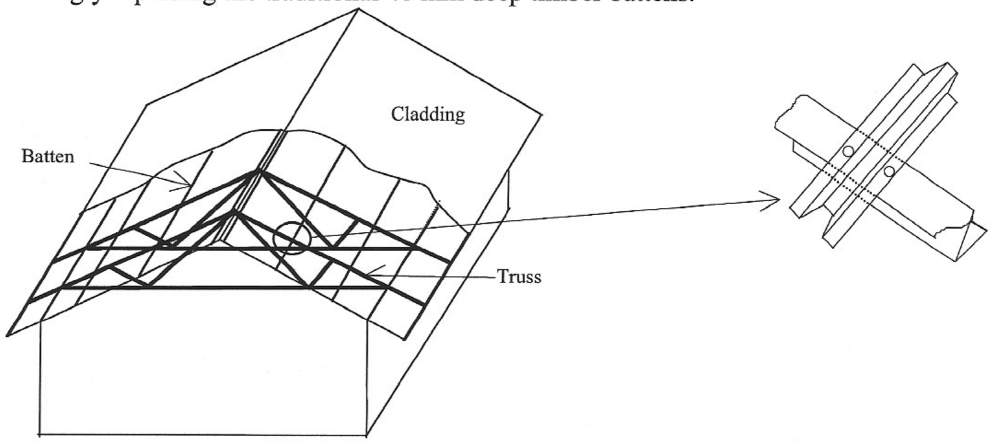


Figure 1 Typical truss batten layout on house and a top-hat batten connection detail

Wind damage investigations following cyclones which hit northern Australia in the 1970s, found that most sheet metal roof failures were initiated by fatigue cracking at the cladding fastener and the subsequent disengagement of cladding, in the edge regions subjected to large net suction pressures. Ginger [1] and Ginger and Henderson [2] showed that batten-truss connections are also subjected to fluctuating pressures with similar characteristics to cladding fasteners within the same parts of the roof. Using full-scale data Ginger [1] also showed that AS/NZS 1170.2 [3] underestimates design loads on cladding fasteners in the edge regions of the roof. Batten-truss connections near roof edges can experience large wind loads and are also susceptible to fatigue failure at loads smaller than the ultimate limit state design load. Furthermore, AS/NZS 1170.2 [3] specifies that cladding, its connections and immediate supporting members (i.e. battens) shall demonstrate performance in resisting fatigue loading. The fatigue-test loading regime is that given in TR440 [4] and AS 4040.3 [5], and presently being revised to a more realistic Low-High-Low method [6].

Wind loads on cladding, battens and fixings

The design wind loads on a 2.7m tall low-rise house located in Cyclone Region C (as per AS/NZS 1170.2) are presented in this section. The design loads are derived on cladding fasteners and batten-truss connections in the edge and inner parts of the roof. Battens spaced at 900mm are attached to trusses spaced 900mm apart, and the cladding fasteners are spaced 200 mm apart. This gives cladding-fastener and batten truss tributaries of 0.18 m^2 and 0.81 m^2 respectively. Internal pressure generated due to a dominant opening is applied, as is generally the case in cyclone regions.

Design loads on cladding fastener(s) and batten-truss connection(s)
Using AS/NZS 1170.2, ultimate limit state design wind loads on cladding-fastener and batten-truss tributary areas are calculated for a 500yr return period, regional wind speed of 69.3 m/s, and a terrain height multiplier $M_{z,cat} = 0.85$. This results in a design wind speed $V_{des,\theta} = 58.9$ m/s. The external pressure coefficient ($C_{p,e}$) is –0.9 and –0.5, and the local pressure factors(K_l) are 2.0 and 1.0, for the edge and inner parts respectively. An internal pressure coefficient ($C_{p,i}$) of +0.7 representing a dominant windward wall opening is applied. This gives external $C_{fig,ext}$ of –1.8 and –0.5 respectively, and an internal $C_{fig,int} = +0.7$.

Design wind load (in N), $W = p_{ext} \times A - p_{int} \times A$
where: External design pressure (in Pa), $p_{ext} = (0.5\rho_{air}) \times V_{des,\theta}{}^2 \times C_{fig,ext}$
Internal design pressure (in Pa), $p_{int} = (0.5\rho_{air}) \times V_{des,\theta}{}^2 \times C_{fig,int}$, and
A is the area of tributary (in m^2) and the density of air $\rho_{air} = 1.2$ kg/m^3

AS/NZS 1170.2, design load in edge and inner parts of roof:
Cladding fastener $W_{ed,cla}$= -674.5 – 262.3 = -0.94kN, $W_{in,cla}$= -187.4 – 262.3 = -0.45kN
Batten-truss $W_{ed,bat}$= -3035.4 – 1180.4 = -4.22kN, $W_{in,bat}$= -843.2 – 1180.4 = -2.02kN

Metal sheet fatigue
Metal roof cladding and top-hat battens are manufactured from roll formed G550 steel which nominally has a minimum yield strength of 550MPa. Tensile tests on test samples have indicated that the yield stress generally exceeds 650MPa, and has less ductility compared to structural steel of lower yield stress grades. Metal cladding (typically 0.42mm bmt) profiles are identified as corrugated, trapezoidal and rib/pan. Top-hat batten profiles, for the support of sheet roofing, typically have a thickness ranging between 0.55mm to 0.75mm. The fatigue performance and fatigue failure mechanisms of cladding and battens are dependent on the method of fastening, cross sectional profile, sheet fastener interaction, load range and sequence of loading. Tests on a range of roof cladding configurations by Mahendran [7] and Xu [8], and on top hat battens by the CTS and Fowler [9] have provided an understating of fatigue performance of these elements, represented by the S-N curve and the limitations of Miners rule, and the process of crack initiation and propagation.

Performance of cladding
From extensive constant amplitude repeated load tests for cladding profiles, different crack propagation modes were observed for cycling at different load levels by Mahendran [7], and Xu [10]. They also showed that failure mechanisms were dependent on the variation in material properties across the coil, variation in profile, screw tightness, alignment and position of the screw on the crest or rib, and the method of test.

For the constant amplitude load tests, when the load per cycle was well below the local plastic deformation (LPD) load, cracks propagated from the screw hole along the crest (Type B in Fig 2 and segment 1 in Fig 3). Xu [10] noted that this maybe attributed to local transverse bending moments and the more brittle properties in the transverse direction. When the load per cycle was around 500 N per fastener (i.e. approaching LPD) cracks propagated in both the longitudinal and transverse directions (Type A-B in Fig 2 and approaching segment 2 from segment 1 in Fig 3). For load cycling through the LPD, cracks initiate at the edges of the flattened crests where the cladding creases, and then progress towards the screw hole causing failure within 1000 cycles (Type A in Fig 2 and segment 2 in Fig 3). The Type C failure is from a few cycles at high loads, not unlike a straight static pull through failure. Similar studies were conducted on rib/pan profiled cladding [11].

These various modes of crack initiation and propagation indicate a different fatigue response depending on the load level. Miner's rule relies on constant material properties and hence cannot be applied in this situation of changing profile shape, strength and stiffness [12, 13, 14]. A modified Miner's rule was suggested, however the method did not adequately predict fatigue damage, for the cladding subjected to varying cycle histories especially when higher load level cycles preceded lower load cycle blocks.

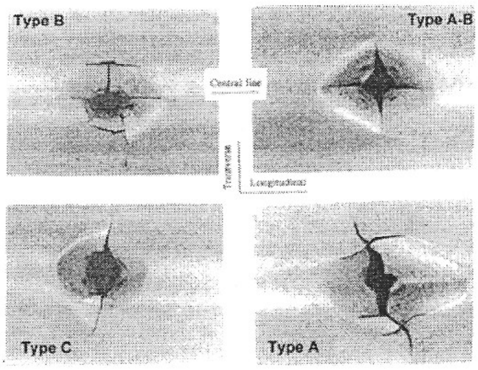


Figure 2 Crack patterns [10]

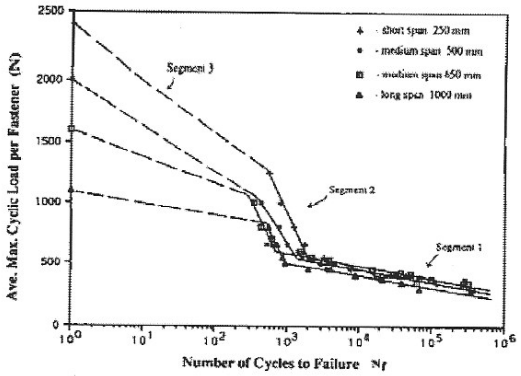


Figure 3 S-N curve [7]

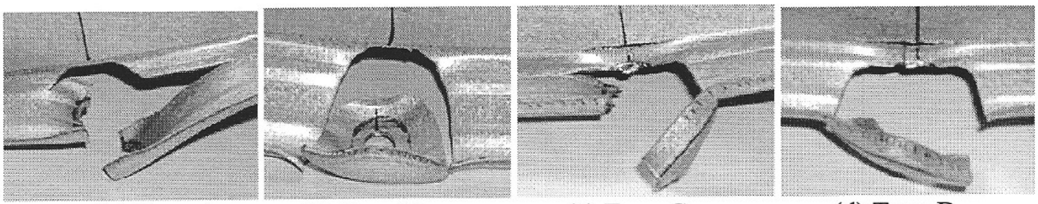
Neither of the current cyclic load test methods employed; TR440 as described in AS4040.3 or the DABM test as specified in the NT appendix of the Building Code of Australia, represents the changing approach wind conditions during a cyclone. Henderson [6] notes the Low-High-Low (LHL) test regime is a more realistic representation of the increasing then decreasing dynamic wind loading on the building envelope that occurs during the passage of a cyclone than the current test methods. The importance of representing this wind loading can be seen by the range of crack initiation and propagation rates during different load levels.

Boughton [15] noted that fatigue testing is an ultimate strength type test and should be designed to simulate the design ultimate wind conditions, whereas the TR440 test requirement is a curious mix of fatigue tests based on design working loads followed by an ultimate static test. The LHL regime tests for an extreme event, where the consequences of failure of the roof system pose a threat to the occupants through loss of structural integrity and to neighbouring properties through flying debris.

Performance of light gauge "top-hat" battens

Tests on light gauge metal, top-hat battens have indicated that the battens are also susceptible to fatigue failure at loads smaller that their static failure load. Tests for industry and studies by Fowler [9] have shown that the fatigue performance of the battens was sensitive to several parameters such as the batten fixing condition such as initial screw tightness, location, screw head not touching web, the cross sectional shape of the batten, grade, and thickness. These tests showed that fatigue failure could take place within a few thousand cycles at loads less than 50% of the batten-truss connections static strength.

Constant amplitude cyclic tests for one manufacturer's batten have indicated that the load vs. number of cycles to failure (S-N curve) was approximately a straight line. However, these trials showed that the battens exhibited different failure crack modes for different cyclic load levels, similar to the failure modes observed in cladding. The range of crack patterns for the constant amplitude cyclic tests are shown in Figures 4 a, b, c, and d. The crack Type A and B were consistent with the higher loading (i.e. greater than about 60% of the average static failure load), whereas Type C and D crack patterns were associated with the load ranges lower than 60% of the average static failure load. The occurrence of different crack failure modes highlights the importance of satisfactorily representing the increasing then decreasing wind loads that occur during a cyclonic event.



(a) Type A (b) Type B (c) Type C (d) Type D

Figure 4 Fatigue failure of top hat battens for constant amplitude cyclic tests [9]

Roof systems used in low-rise buildings

Manufacturers, designers, certifiers and builders need to be aware when specifying the use of a roofing system (which includes the cladding, the cladding fixings, the battens and the batten fixings) that it has been designed and tested to appropriate cyclic load criterion. Figure 5 shows the allowable capacities for cladding and battens, derived from a manufacturer's published data. For the example of trusses at 900 mm centres, the top hat roof batten controls the cladding system design. This contradicts the 'in-grained' construction practice of the cladding profile governing the system when fixed to hardwood battens, such as the common, "W50C has battens at 900 centres for corrugated". There is therefore a responsibility to ensure that the roof batten system is tested by the manufacturer, and then installed in accordance with the manufacturer's specifications.

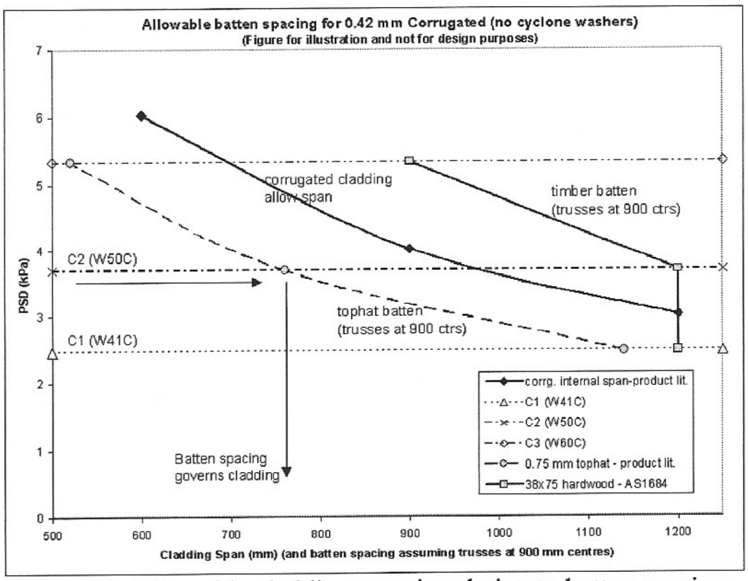


Figure 5: Allowable cladding span in relation to batten spacing

Conclusions

Findings from damage surveys conducted after cyclones and severe storms, and full-scale house testing results demonstrate that the predominant mode of wind-induced failure is associated with the wind load exceeding the load capacity of the joints. Therefore the load at the joints and the performance of the connections needs to be understood. Wind load studies, data in codes and tests on a range of cladding types and top hat battens show that these elements are subjected to a concentration of forces and are susceptible to low cycle fatigue.

The fatigue failures of metal battens show similar characteristics to metal claddings. Claddings and battens exhibited different failure crack modes for different cyclic load levels. Work at the CTS is attempting to understand the fundamental fracture mechanics characteristics of thin gauge metals subjected to fluctuating wind loads.

References

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