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Wind load fluctuations on roof batten to rafter/truss connections

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A R T I C L E I N F O

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A B S T R A C T

Batten to rafter connections in light framed housing can be vulnerable to progressive or cascading failures where a localised failure can cause the loss of a large section of the roof envelope. The synchrony of loads at neighbouring connections may affect the initiation of such failures. A 1/50 length scale wind tunnel model study was performed on a gable roof house to record spatial and temporal pressure fluctuations on the roof surface and data were studied to determine the flow separation mechanisms causing different loading patterns on batten to rafter connections. The cross correlation between load time histories was used to give a measure of synchrony between loads experienced at neighbouring connections and indicate the direction that fluctuations move across the roof. Orthogonal wind directions result in 2-dimensional flow separation that produce more synchronous loads at batten to rafter connections than cornering wind directions, where conical vortices produce high uplift forces on connections. The patterns of loading and their correlations give a means of identifying which parts of the roof and which approach wind directions may result in the initiation of a progressive failure of batten to rafter connections.

1. Introduction

Batten to rafter connections in light framed residential structures are vulnerable to failure in wind storms. Recent damage surveys have shown that the failure of batten to truss/rafter connections are one of the more likely causes of roof damage during high wind events (Boughton et al. 2011, 2017; Ginger et al., 2007; Henderson et al., 2010; Parackal et al., 2015). An example of such a failure is shown in Fig. 1, with further details of the structural system provided in Section 2.

Batten to rafter connections are arranged in a grid pattern under roof cladding. Despite the redundancy from the repeated connections, batten to rafter connections can be vulnerable to progressive or cascading failures where the failure of one or more connections can trigger the failure of a large section of the building envelope. Such progressive failures are dependent on the pressure distributions on the roof surface, the response of the connections to these rapidly fluctuating loads and the behaviour of the structural system as loads are redistributed.

Wind loads on roof surfaces are highly fluctuating spatially as well as through time. These fluctuations can result in high loads occurring at different batten to rafter connections and at different times. The level of synchrony between time histories of load at neighbouring connections may influence the likelihood of a progressive failure occurring. If neighbouring connections experience high loads at the same time or near the same time, then a progressive failure is more likely to initiate as neighbouring connections will also be subject to high uplift loads when loads are redistributed from neighbouring connections that have failed. Determining how these high loads across the roof surface are correlated is necessary to identify when and where cascading failures begin and the associated approach wind directions. Previous work has studied high pressures in the flow separation regions and the correlation of pressures under 2-dimensional separation bubbles and 3-dimensional conical vortices on bluff bodies, but not for assessing the initiation of failure in a light framed structure.

Wind loads on low-rise buildings have been studied extensively. Holmes (1982), Ahmad and Kumar (2002) and Gavanski et al. (2013), amongst others, have examined the external pressure distributions across roof surfaces to determine the effects of roof pitch, upstream terrain, and wind direction. Saathoff and Melbourne (1989) studied the formation and correlation of high negative pressures on the leading edge of rectangular bluff bodies for flow perpendicular to the edge of the body. Ginger and Letchford (1993) studied the correlation of wind pressure on a flat-roofed rectangular shaped building for two flow separation mechanisms: 2-dimensional flow separation when the wind is perpendicular to a leading edge and the 3-dimensional conical vortex formed for cornering wind directions.

More recently, Boughton et al. (2014) presents a reliability study of batten to truss connections for a contemporary Australian house. Fragility curves for various connection fasteners are developed for

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Fig. 1. Typical batten-rafter connection failure: large section of the roof envelope removed (right) with cladding still attached to battens and rafters left intact (left).
Adapted from Boughton et al. (2017).

different roof areas (corner, edge and general). This study analysed the probabilities of ‘first failure’ of connections but did not examine what may be occurring to neighbouring connections at the time of failure.

In this paper, a 1/50 scale wind tunnel test was used to determine fluctuating wind loads on batten to rafter connections. The movement of eddies and vortices across the roof surface are studied and the timing and correlations of loads among neighbouring connections are examined. The results identify which parts of the roof and which wind directions are vulnerable to progressive failures.

2. Roof structure and wind loading

Light framed construction is described as the use of small cross section members to create structural elements such as floors, walls and roof framing with mechanical fasteners such as nails, plates or straps. Light framed structures are complex structural systems due to the large number of members, and connections and fasteners. This leads to behaviour such as load sharing, partial composite action and, during extreme loading: the nonlinear behaviour of connections and load redistribution. Wolfe and LaBissoniere (1991), Morrison et al. (2012) and more recently Satheeskumar et al. (2016) have quantified the load sharing mechanisms in these types of structures.

Traditional light framed housing in Australia with metal cladding consists of timber rafters that support timber or metal battens that in turn support roof cladding, shown in Fig. 2. Modern Australian roof framing now often consists of prefabricated softwood trusses instead of rafters that are craned into place on site. The roof structure can be described as a set of parallel primary beams (the rafters or the top chords of the trusses) that support a perpendicular set of secondary beams, the battens. Thus a grid pattern of batten to rafter/connections is formed. The battens support corrugated metal cladding that acts as a structural membrane with its primary span direction along the corrugations, from batten to batten. Timber batten to truss/rafter connections are traditionally single or double nailed to the rafters with newer cold formed ‘top hat’ battens using self-drilling batten screws.

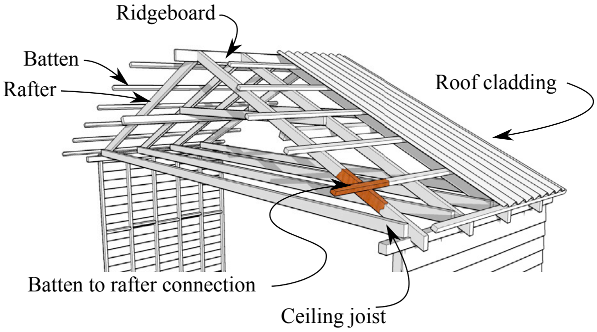

Fig. 2. Light framed timber roof structure with corrugated metal roof cladding.

Damage surveys have noted that such batten to rafter connection failures are some of the most common structural failures in housing during severe wind events. It is also noted that such failures occur in isolation, that is, when batten to rafter connections are weaker than other connections the corrugated roof cladding with the battens attached is removed with little effect on other connections such as the cladding fasteners and roof to wall connections, as shown previously in Fig. 1. Similarly, If the cladding fasteners are the weak link in the vertical load path, the corrugated roof cladding is removed leaving the battens and rafters behind. After the cladding has been removed the batten to rafter connections are then unlikely to fail as they are no longer supporting uplift loads from the building envelope.

The movement of wind over bluff bodies, such as a low rise building results in highly fluctuating negative pressures on the building envelope due to the turbulence from the approach wind flow as well as flow separation at roof edges and discontinuities such as ridge lines, hips and valleys.

Building induced turbulence results in high negative pressures in certain parts of the roof for different wind directions. These high load areas are transient and move across the roof rapidly due to the formation of eddies and vortices. The size, location and duration of these high load areas, as well as the level of synchrony of loads among neighbouring connections affects the likelihood of a progressive failure initiating.

Two-dimensional flow separation regions form when flow is perpendicular or near perpendicular to the roof edge or discontinuity. In these cases, flow separation results in the formation of vortices that periodically roll up and are convected along the roof surface - creating a moving zone of high suction pressure, as described by Saathoff and Melbourne (1997).

Cornering winds generate three-dimensional flow separation that can create especially high suction pressures at roof corners. Conical vortices can form in these cases, similar to those formed over an aircraft delta wing. Such vortices are less stable than for 2 dimensional flow separation and thus high loads occur intermittently as these vortices form and dissipate.

3. Wind tunnel tests

A wind tunnel study to determine simultaneous loads at batten to rafter/truss connections of a typical roof system was conducted. Tests were carried out in the 2.0 m high × 2.5 m wide × 22 m long boundary layer wind tunnel at the James Cook University Cyclone Testing Station, Australia.

The approach wind flow simulated at a length scale (L_r) of 1/50 was that of a suburban environment using an array of 50 mm tall blocks on the upstream fetch of the wind tunnel. A Turbulent Flow Instruments (TFI) ‘Cobra Probe’ was used to measure the approach wind velocity and turbulence intensity at various heights (z) above the floor of the tunnel. The measured profiles and those specified in the Australian wind loading