RELIABILITY STUDY FOR PERFORMANCE OF TIMBER ROOF CONNECTIONS UNDER WIND FORCES

Geoff Boughton¹, Debbie Falck², John Ginger³, David Henderson⁴, Navaratnam Satheeskumar⁵

ABSTRACT: This paper presents some stochastic models to estimate the reliability of batten-to-rafter connections in contemporary Western Australian house roof construction under wind loads. The study used statistical load distributions from wind tunnel studies on representative housing and probability distributions of strength of connections to estimate likelihoods of first failure during wind events with various gust wind speeds. The stochastic models predicted patterns and levels of damage during recent high wind events and were used to confirm reliability of connections specified in Australian Standards.

KEYWORDS: Wind loads, wind damage, timber roof framing, probability, reliability models, connections

1 INTRODUCTION

This paper presents the development of stochastic models to predict the reliability of batten-to-rafter connections in contemporary houses in Perth, WA under wind loads.

The prevalent form of construction in Perth has aerodynamically complex roof shapes; many hips and valleys with short ridges. In the past 10 years, building practice has seen a shift from clay and concrete roof tiles to steel roof cladding. This has coincided with an apparent change in the vulnerability of housing.

2 WIND DAMAGE

Severe wind events in Perth tend to occur in thunderstorms that are often embedded in cold fronts that cross the coast in the late autumn and early winter. Figures 1 and 2 present some wind damage typical of that seen in the past 5 years.

Figure 1: Wind damage to tiled roofs

Figure 2: Wind damage to lightweight roofs

Both photos were taken after the same wind event with wind speeds estimated to be just less than the design wind speed. Figure 1 shows some damage to tiled roofs. Typically this damage was dominated by removal of individual tiles and could be repaired relatively simply.
Figure 2 shows damage to a steel clad roof where the primary cause of the damage was failure of the batten-to-rafter connections in withdrawal. Contemporary house construction typically uses bugle-head screws or gun-driven nails in direct tension, which were used as the basis for the reliability study presented in this paper.

3 RELIABILITY STUDY

Aerodynamically complex roofs produce a large range of pressures across the roof structure that are difficult to model deterministically, but can be modelled using stochastic methods. The large number of batten-to-rafter connections in a single house mean that even relatively low probabilities of failure can lead to loss of one or more fasteners and subsequent load redistribution causing substantial roof damage. Normal reliability methods were used in this study. Stochastic distributions of loads were related to statistical distributions of resistance to derive probabilities of failure. The model required the development of statistical distributions of:

• resistance (capacity) of each type of connection in direct withdrawal, and
• wind loading in uplift of each connection sourced from wind tunnel studies on representative houses.

Standard statistical methods for structural reliability were used to determine the probability of failure ($P_f$) from the log-normal distribution of the loads $F(\lambda_r, \Xi)$ and the log-normal distribution of the resistance or capacity $R(\lambda_R, \Xi_R)$.

The probability of failure of batten-to-rafter connections using 2 nails or one bugle head screw is illustrated in Figure 3 by the area of overlap between the load histograms and the resistance or capacity histograms.

Vulnerability curves for each type of batten-to-rafter connection were produced by plotting the probability of first failure of the connection against the gust wind velocity. Figure 4 was derived for a whole roof in which Corner, Edge and General zones all used the same type of batten-to-rafter connection.

4 CONCLUSIONS

The stochastic distributions for wind loads on batten-to-rafter connections were derived from the pressure distributions and the tributary area distributions. These force distributions were compared with the capacity distributions for the most common batten-to-rafter connections to derive probability of first failure and reliability index of individual connections. They were able to predict observed patterns and failure rates of batten-to-rafter connections in aerodynamically complex roofs of contemporary housing during high wind events. They were also able to demonstrate the sensitivity of performance to small changes in connection details.

Vulnerability curves indicated that Plain shank nails had higher probabilities of first failure than deformed shank nails. Bugle head screws had lowest probability of first failure. Also, using 45 mm thick battens increased the probability of first failure for all connection types.

The analysis determined that using single self-tapping bugle head screws for batten-to-rafter connections reduces the probability of first failure and delivers a satisfactory reliability index at the design wind speed. This was demonstrated for all aerodynamic zones in contemporary sheet roofs and for both of the commonly used timber batten thicknesses.

The study confirmed that stochastic analysis of load and resistance relationships can be used to effectively assess the performance of nailed and screwed connections in withdrawal that are subject to spatially and temporally variable wind loads.

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