Probabilistic Failure of Roof Elements in Wind

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1 INTRODUCTION

Over the last year BRANZ has been collecting data on the performance of various connections of roofing elements in low rise (predominantly domestic) structures with the aim of producing fragility curves that could be fed into the National Institute of Water & Atmospheric Research/Institute of Geological and Nuclear Sciences (NIWA/GNS) Riskscape project. The predicted effects and costs of wind damage cannot currently be accurately determined by emergency management agencies and territorial authorities to assist with planning for such an event because of the lack of probabilistic data. The expected outcome will be better cost predictions for damaging wind events.

2 LITERATURE REVIEW

A literature review was conducted to ascertain what other work had been undertaken in this field. While there was a wealth of research information on the behaviour of the wind itself and its effect on roofs, little was turned up on the behaviour of the roof components.

Chen et al [1] suggested from model tests undertaken on a gable end house roof that the most vulnerable region for wind induced roof damage in severe wind storms is just behind the ridge at the windward end of the roof. Xu [2] appealed for higher code wind loads for gable roofs than for hip roofs after conducting wind tunnel studies on gable and hipped roof houses and finding that local negative pressures were 50% higher for the gable roof. Kumar et al [3] used fuzzy theory to predict wind damage for domestic dwellings. Cochran et al [4] observed that small individual roof cladding components such as tiles are particularly vulnerable to the high local wind suction effects. The tiles discussed were asphaltic which are not so common in New Zealand. Mijinyawa et al [5] surveyed roof failures in Nigeria and found that all roofs could be broadly classified into two types – up to 10° slope and those greater than 10° - and the performance was affected by wind, poor workmanship, age, poor maintenance, height of building, and the use of cheap and substandard materials. Failures were also caused by rusting, open laps, tearing off, truss damage, nail withdrawal (62% of 600 roofs in the survey had this issue), and wood decay. Closer to the New Zealand and Australian experience, Boughton and Falck [6] found that tie down of all structural elements in the roof is essential and wind uplift forces are significantly higher for sheet roofs compared with tile roofs. They particularly mentioned that the areas of weakness were the batten to truss connection and the truss to wall anchorage. Van de Lindt et al [7] also reiterated that the use of straps and ties to ensure a continuous load path to the foundation were essential for satisfactory performance. Shanmugam et al [8], when testing as-built rafter to plate connections that had been in place for some years, warned that comparisons with the performance of new structures should be made with caution unless an age factor was calculated.

3 BRANZ STUDIES

3.1 Scope of investigation

The investigation was limited to a selection of roof claddings and joints between timber roof framing elements that were considered to be typical of New Zealand low rise buildings (particularly houses). Several roof cladding materials were considered and eliminated for various reasons. Concrete and clay roof tiles, while exhibiting some poor behaviour in high winds, were not considered because the main issue with such elements appears to be removal of the capping tiles due to already failed mortar joints. Asphaltic tiles were not sufficiently common in New Zealand to be worth investigating and often these are fixed on to a plywood substrate which is adequately connected to the framing. A common roofing product in the last 20-30 years is pressed metal roofing tiles. While these are lightweight, and therefore susceptible to uplift, they are generally well fixed to the supporting battens and there has been little evidence of damage. Therefore they were not considered in the study and it concentrated on the connection of corrugated steel roofing to two typical substrates – radiata pine (exotic) and rimu (NZ native) – these being commonly used species in modern and older house construction respectively. Common joints between battens or purlins and rafters or trusses were considered, along with the connections between rafters or trusses and wall top plates.

It was considered to be very desirable to conduct an experimental investigation on examples of roof component connections that had been removed from existing structures for which the age of the joints could be established from Local Territorial Authority records. However, this proved to be too difficult to arrange. Properties available for such a study are generally due for demolition and we found that the demolition company's motive was to demolish in as quick a time as possible, with little regard to our needs. We therefore resorted to creating joints to model as best we could the real situation, using timber salvaged from the demolition sites.

3.2 Investigation details

The following joints were investigated:

1. Corrugated steel to radiata pine purlins – dry timber and new lead head nails
2. Corrugated steel to rimu purlins – dry timber and new lead head nails
3. Rimu purlins to rimu rafters – dry and new nails
4. Rimu rafters to rimu top plates – dry and new nails
5. Radiata pine trusses to top plates - wet and dry framing and new nails (also one set with wire dogs included)

The reader may note that the nails used in the joints were all new. Attempts were made however, to source old stocks of unused nails that showed some signs of corrosion but the majority of nails removed from the salvaged timber were still in very good condition. Therefore, new bright steel nails were used. The radiata pine joints were fabricated with 90 mm long by 3.15 mm diameter D-head gun driven nails and the rimu joints were fabricated with 100 mm long by 4 mm diameter jolt head nails. The truss elements were built using MSG8 H1.2 framing. The radiata pine top plate elements were untreated MSG8 framing. Density and moisture content samples were taken from each specimen at the time of testing. Thirty replicates were made for the truss/plate joint variations. Lesser numbers were fabricated for the rimu specimens due to the short supply of rimu timber (13 for corrugated steel to rimu purlin joints, 20 for corrugated steel roofing to radiata pine purlin joints, 18 for rafter/plate joints, 26 purlin/rafter joints).

All of the tests were conducted in the Dartec Universal Test Machine in the BRANZ structures laboratory. The loading rate was set at the fastest speed that the machine could operate (600mm/s) to simulate the likely wind force in the field. An example of a truss/top plate test setup is given in Fig. 1.

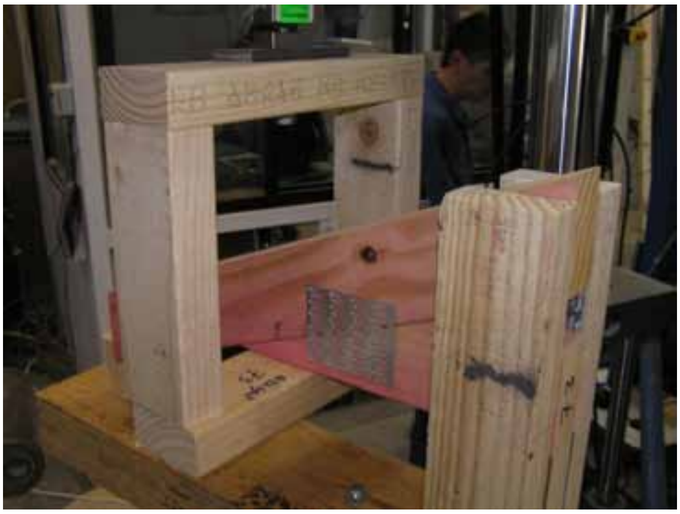

Fig. 1 Sample test setup in the test machine

3.3 Derivation of fragility curves

Various distributions were tested against the results of the tests. Generally, a normal distribution was found to provide a reasonable fit to the data and then from this a plot of the likelihood of failure (as a percentage) was made against the range of failure loads (the fragility curve). A sample plot of the fragility curve is presented in Fig. 2.

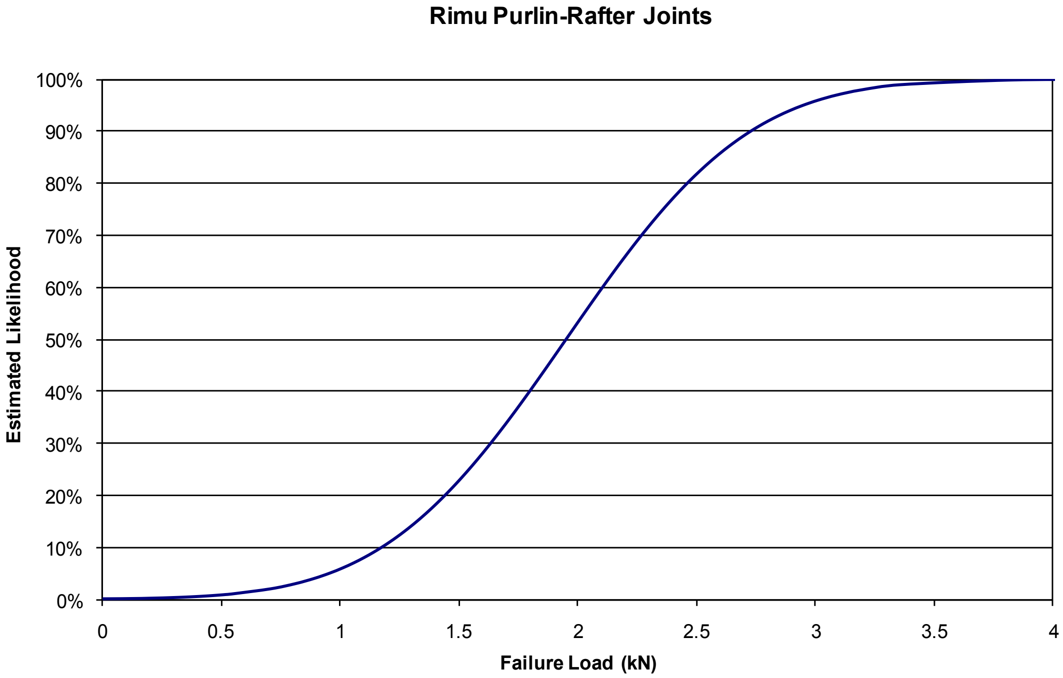

Fig. 2 Sample plot of the likelihood of failure

Still to be undertaken at the time of writing this abstract is the correlation of the failure load with an associated wind speed. This will be undertaken by a review of the prescriptive construction standards of the day for the rimu framed structures and the radiata pine framed structures. This will provide the roof areas associated with the element fixings, from which a pressure range can be derived and then the associated wind speed. This will allow the Riskscape model to be populated with probabilistic resistance information for commonly encountered roofs.

4 REFERENCES

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