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SIMULATED WIND LOAD STRENGTH TESTING OF SOFFITS

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1 Introduction

Damage investigations following cyclonic events have shown failure of soffit lining, including on contemporary buildings, as illustrated in Figure 2 to Figure 12. Failure of soffit lining can lead to further major damage to the building by allowing wind driven rain to enter the ceiling attic, causing the ceilings to collapse and further water damage. In addition to water damage to contents and internals, soffit lining failure creates increased stress to the building envelope due to the increased internal pressure caused by wind entering the roof cavity through the eaves, which can lead to further failure such as roof failure.

Small weaknesses can therefore lead to large failures.

This report uses results, and summarises parts, of the thesis “*Design of soffits and eaves to resist wind loads in cyclonic regions*” by Lalin Chhoeuk, in particular the mechanical assessment of various combinations of soffit lining to batten connections to evaluate their suitability for use in cyclonic regions.

The aim of this test programme was to perform full-scale simulated wind load strength testing of these different configurations of soffit lining to batten connections. The AS 4040.2 static simulated wind load strength test regimes was used as guides to load the test specimens.

The simulated wind load strength tests were conducted in an airbox testing facility located at the Cyclone Testing Station at James Cook University.

Figure 1 shows cross section views of typical boxed eave constructions.

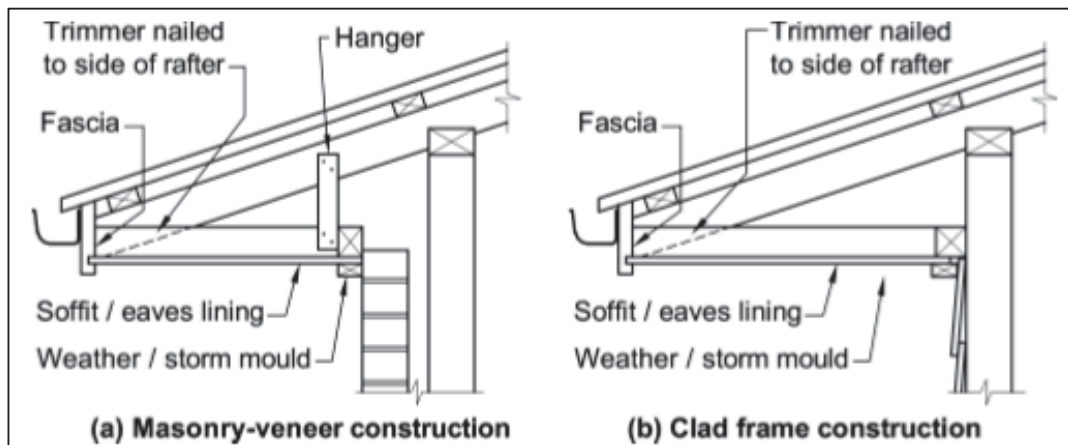


Figure 1: Eave Cross-Section, Source: Australian Building Codes Board, 2016



Figure 2: Failure of Soffit, Cyclone Larry, 2006



Figure 3: Failure of Soffit, Cyclone Larry, 2006



Figure 4: Failure of Soffit, Cyclone Larry, 2006



Figure 5: Failure of Soffit, Cyclone Yasi, 2011



Figure 6: Failure of Soffit, Cyclone Yasi, 2011



Figure 7: Failure of Soffit, Cyclone Yasi, 2011



Figure 8: Failure of Soffit, Cyclone Yasi, 2011



Figure 9: Failure of Soffit, Cyclone Yasi, 2011



Figure 10: Failure of Soffit, Cyclone Debbie, 2017



Figure 11: Failure of Soffit, Cyclone Debbie, 2017



Figure 12: Failure of Soffit, Cyclone Debbie, 2017

2 Test Programme

A programme of three (3) static simulated wind load strength testing was conducted. A summary of the test programme is provided in Table 1.

Table 1: Test Programme Summary

Trial No	Test regime	Connection Type	Soffit Dimensions	Nail (Soffit to Batten) Spacing
Test 1	Static	32 mm × 2.5 mm plain shank nails - gun driven	600 mm × 2000 mm	200 mm Centres (Edge Spacing: 20 mm)
Test 2				
Test 3		30 mm × 2.8 mm galvanised clouts - hand driven		

3 Eave Test Specimens and Installation Details

Three eave test specimens were build and installed in an airbox testing rig. Tests specimens details are as follow:

Table 2: Eave Test Specimens Details

Component	Quantity	Details
Supporting Beam*	3	970 mm lengths of 120 mm × 38 mm MGP12 Pine
Soffit Hanger	6	300 mm lengths of 42 mm × 35 mm MGP10 Pine
Soffit Trimer	3	600 mm lengths of 75 mm × 38 mm MGP10 Pine
Soffit Batten	2	2000 mm lengths of 42 mm × 35 mm MGP10 Pine
Soffit Lining	1	4.5 mm HardieFlex Sheet 600 mm × 2000 mm
Soffit/Batten Connection, Test 1 and	11 per Batten	32 mm × 2.5 mm plain shank nails - gun driven
Soffit/Batten Connection, Test 3	11 per Batten	30 mm × 2.8 mm galvanised clouts - hand driven

*Note that the strength of the supporting beams was not being evaluated in this programme.

Soffit trimer spacing was 900 mm and soffit batten spacing was 300 mm.

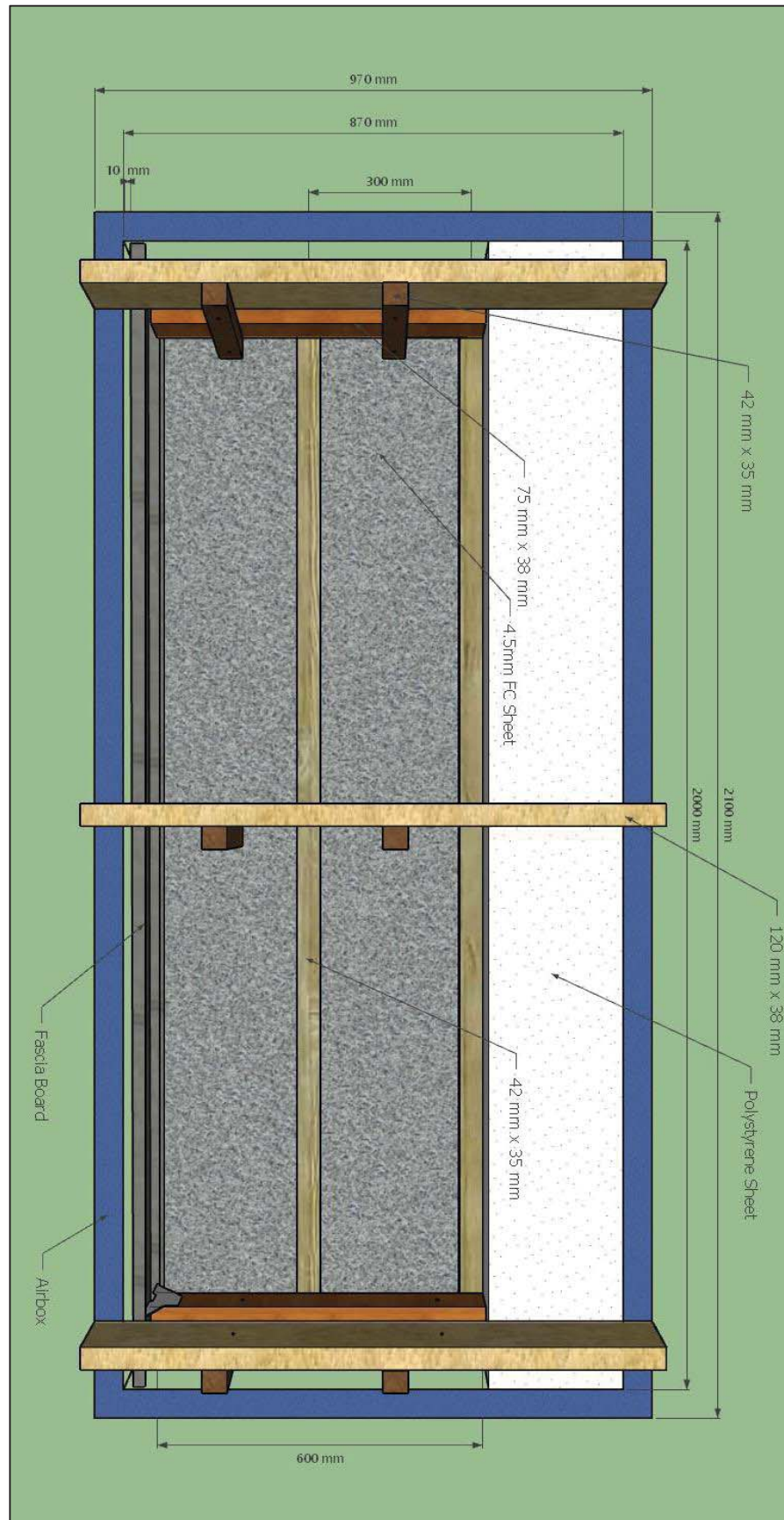


Figure 13: Test Specimen Set Up in Airbox (Top View) – Drawing by Lalin Chhoeuk

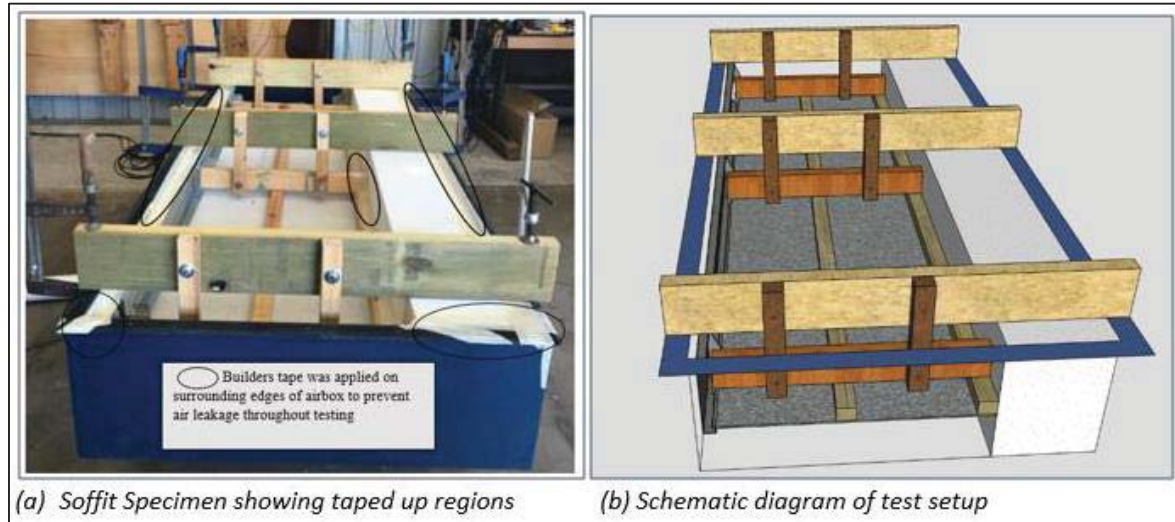


Figure 14: Test Specimen Set Up in Airbox – Photograph and Drawing by Lalin Chhoeuk

Figure 13 and Figure 14 show the eave test specimen set up in the airbox testing rig. In order to account for potential failure mode of the fascia board, a 10 mm gap was left to allow for its rotation during testing. A polystyrene sheet was placed inside the airbox, both to prevent air leakage and to permit structural movement. Prior to commencement of the experiment, builders tape was used to seal the gaps between the airbox and the specimen to ensure airtightness throughout the testing phase.

4 Test Apparatus and Procedure for Simulated Wind Load Tests

4.1 Test Set Up in Airbox Test Facility

The test specimens were installed in the Cyclone Testing Station's airbox test facility. The airbox is an open-topped pressure chamber with a maximum test width of 870 mm and a maximum test length of 2000 mm. For this testing programme, the eave test specimens were installed to become the top (horizontal) surface of the chamber. Polystyrene infills were used to seal the gaps between the test specimens and the walls of the airbox test rig.

4.2 Simulated Wind Load Strength Testing

A uniform negative pressure was applied to the external face of the soffit lining by a pressure loading actuator (PLA) extracting air from the airbox chamber, hence creating partial vacuum. This pressure simulated the combined effect of both the outward pressure and the internal pressure acting on the soffit lining. A pressure transducer measured the applied load on the test specimens.

4.3 Static Simulated Wind Load Strength Testing

A total of three experiments were conducted. The first sample test was performed in manual mode where the soffit specimen was subjected to a range of pressures running at fan speed of 50 Hz. The position of the Servo motor was moved at an increment of -0.05 and pressure was recorded until failure of the specimen occurred. The last two specimens were tested using a ramp load running at fan speed of 60 Hz, where the PLA followed a pressure trace set at negative pressure (suction)

1.0 kPa sustained for 10 seconds, and the suction pressure was then ramped to 1.0 kPa per minute until failure of specimen. The pressures at which the specimen failed were recorded and compared.

5 Results

5.1 Static Simulated Wind Load Strength Testing

Three static simulated wind load strength test were performed. A summary of the test results is provided in Table 3.

Table 3: Static Simulated Wind Load Strength Testing Results

Trial No	Soffit/Batten Connection	Failure Mode	Failure Pressure (kPa)
Test 1	32 mm × 2.5 mm plain shank nails - gun driven	Nail head pulled through the soffit lining	-2.1
Test 2	32 mm × 2.5 mm plain shank nails - gun driven	Nail head pulled through the soffit lining	-1.7
Test 3	30 mm × 2.8 mm galvanised clouts - hand driven	Fascia bracket buckled	-4.3

Failure mode of fibre-cement nail shank nail connection for Test 1 and Test 2 was the pull-through of the nail heads as shown in Figure 15.

For Test 3, failure mode of fibre-cement nail connection was not at the nails. One of the fascia brackets deformed but the clouts showed no sign of deformation. The failure of the fascia bracket can be explained as the clouts had adequate capacity to withstand the suction pressure at which the connection failed. Failure of the bracket led to deformation of fascia as shown in Figure 16.

Note: As seen on Figure 1, gutters are often fastened to the fascia board. Wind and water can create additional stress to the fascia board through the gutter. Therefore, the failure observed in Test 3 would potentially occur earlier in a 'real world' installation since the test was conducted without gutter.

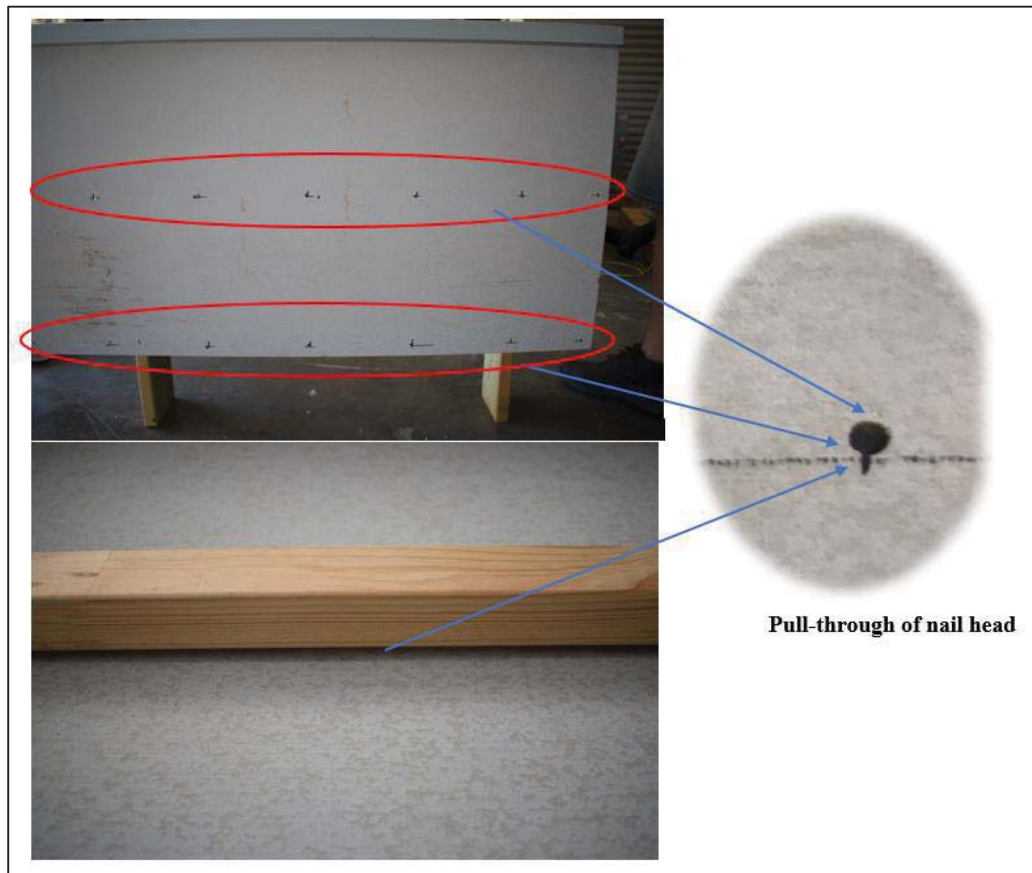


Figure 15: Failure mode of soffit-to-batten connection for Test 1 and Test 2 – Photograph by Lalin Chhoeuk



Figure 16: Failure mode for Test 3 – Photograph by Lalin Chhoeuk

6 Determination of Ultimate Limit State Design Wind Capacities

The Ultimate Limit State design wind pressure capacities can be back calculated from the static test results by dividing the lowest of the highest test pressures held by each specimen by the factor to allow for variability of structural units (k_t).

Table B1 of AS/NZS 1170:2002, “Structural design actions, Part 0: General principles” was used to determine k_t .

The tests were full-scale test of timber and timber composite doors in metal frame; therefore, a coefficient of variation of structural characteristics (V_{sc}) of 15% was chosen to determine k_t .

Two static strength wind load tests were conducted for Test 1 and Test 2 set up, in this programme, and therefore $k_t = 1.64$ for those tests.

One static strength wind load test was conducted for Test 3 set up, in this programme, and therefore $k_t = 1.79$ for this test.

Important note: The design values are indicative only as this study was conducted for informative purposes. These values should NOT be used to design buildings. The specimen may not be representative of other materials from different manufacturers.

The ultimate limit state design wind capacities are summarised in Table 4. Note that these design capacities are only applicable for the soffit lining, connections and support details, as used in this testing programme.

Table 4: Ultimate Limit State Design Wind Capacities

Soffit/Batten Connection	Ultimate Limit State Design Wind Capacities (kPa)
32 mm × 2.5 mm plain shank nails - gun driven	-1.04
30 mm × 2.8 mm galvanised clouts - hand driven	-2.40

7 Recommended Ultimate Limit State Design Wind Capacities

From *Table 3.3* of *AS 4055-2012*, “*Wind loads for housing*”, shown in Figure 17, the ultimate strength design pressure on a wall of a standard residential building is -4.02 kPa within 1200 mm of corners and -2.68 kPa elsewhere on the wall for a wind classification C2. *Note 4* of *Table 3.3* of *AS 4055-2012* states: “*The design net pressures for eaves and soffit linings are taken as equal to the net pressures applied to adjacent wall surface (e.g. the design pressure for eaves lining within 1200 mm of a corner for a C2 classification is +2.68 kPa and -4.02 kPa)*”.

Wind class	Walls			Roofs			
	Any position	Away from corners (see Note 3)	Within 1200 mm of corners (see Note 3)	Any position	General away from edges (see Note 2)	Within 1200 mm of edges (see Note 2)	At corners (within 1200 mm of both edges) (see Note 2)
	G, SC Figure 3.2	G Figure 3.2	SC Figure 3.2	G, RE, RC Figure 3.1	G Figure 3.1	RE Figure 3.1	RC Figure 3.1
$K_e C_{p,n}$	+0.9	-0.77	-1.35	+0.63	-0.99	-1.8	-2.61
N1	+0.62	-0.53	-0.94	+0.44	-0.69	-1.25	-1.81
N2	+0.86	-0.74	-1.30	+0.60	-0.95	-1.73	-2.51
N3	+1.35	-1.16	-2.03	+0.95	-1.49	-2.70	-3.92
N4	+2.01	-1.72	-3.01	+1.41	-2.21	-4.02	-5.83
N5	+2.96	-2.53	-4.44	+2.07	-3.25	-5.91	-8.58
N6	+3.99	-3.42	-5.99	+2.80	-4.39	-7.99	-11.58
$K_e C_{p,n}$	+1.2	-1.2	-1.8	+0.95	-1.44	-2.25	-3.06
C1	+1.80	-1.80	-2.7	+1.43	-2.16	-3.38	-4.59
C2	+2.68	-2.68	-4.02	+2.12	-3.21	-5.02	-6.83
C3	+3.94	-3.94	-5.91	+3.12	-4.73	-7.39	-10.05
C4	+5.33	-5.33	-7.99	+4.22	-6.39	-9.98	-13.58

Figure 17: Table 3.3 of AS 4055-2012, “Wind loads for housing”

8 Comments on Results

The ultimate limit state design wind capacities of the configurations tested and reported in Table 4 are lower than the recommended ultimate limit state design wind capacities from *Table 3.3* of *AS 4055-2012*, “*Wind loads for housing*”.

The results obtained for eave samples built using nails gun driven are significantly lower than those obtained for the samples built using hand driven nails.

Note: only one test was performed with the hand driven clouts (Test 3), therefore the factor to allow for variability of structural units (k_t) was high, resulting a low recommended ultimate limit state design wind capacity for this configuration. In addition, the failure occurred at the fascia bracket, not at the batten/soffit lining connection. Therefore, additional testing would be required to confirm the suitability of use of the clouts, with configuration of Test 3, in cyclonic area with up to C2 wind classification.

Finally, for eaves built in such a way that the internal side of the soffit lining is not linked to the rest of the roof cavity, and not subject to internal pressures, could be design with lower recommended ultimate limit state design wind capacities. Those values can be calculated using *Table 3.2 (A)* of *AS 4055-2012*, “*Wind loads for housing*” and are provided in Table 5 bellow.

Table 5: Recommended Ultimate Limit State Design Wind Capacities (External Only), calculated using Table 3.2 (A) of AS 4055-2012, “Wind loads for housing”

Wind Class	Within 1200 mm of Corners (kPa)	Away from Corners (kPa)
C1	-1.95	-0.975
C2	-2.90	-1.45

In such cases, the configuration tested in Test 3 would be suitable for all locations for wind class C1 and away from corners for wind class C2. Additional testing (repeat tests of Test 3) would decrease the factor to allow for variability of structural units (k_t) and likely show the suitability of the configuration tested in Test 3 for all locations of wind class C2.

9 Conclusions

A programme of simulated wind load strength testing was performed on two configurations of eave samples.

The methods of testing have been presented.

Table 4 outlines indicative design values for soffit lining. However, these values are obtained from static tests, which does not reflect the forces imposed to building during a cyclone as well as cyclic test.

Those results show that the use of gun driven nails as a fixing method for the soffit lining to the battens is inadequate for use in cyclonic regions.

Failure of soffit lining during a cyclone will create an opening, potentially resulting in damaging water ingress and an increase of internal pressure and subsequently increased stress on the building envelope and the likelihood of building failure.

It is recommended that:

- Hand driven nails should be used for the soffit to batten connection
- Builders should adhere to manufacturers fixing specification and the NCC
- The NCC should reviewed/update eave and soffit fixing details for cyclonic regions

Three soffit tests were not enough to justify the failure of soffits, it is recommended more testings to be conducted.