Static Testing of Batten Connections at University of Western Australia

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TECHNICAL REPORT NO. 62

Static Testing of Batten Connections
at University of Western Australia

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LIMITATIONS OF THE REPORT

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Static Testing of Batten Connections

Executive Summary

The project aimed to determine the uplift capacity and critical failure modes of four batten to MGP10 timber rafter connections now commonly used for sheet metal roofs in Perth houses:

a) One 75 mm long bugle head screw through 35 mm thick timber battens;
b) One 75 mm long bugle head screw through 45 mm thick timber battens;
c) Two 40 mm long M5.5 Batten Zip® screws through 40 mm steel top-hat battens;
d) Two 57 mm long hot-dipped galvanised nails through 40 mm steel top-hat battens.

AS 1684.2 only provides capacities for connection a). Some manufacturers and suppliers specify connections b) and c). Connections b) to d) have been increasingly used as batten to rafter or batten to truss connections in Perth in the past decade as materials and fixing techniques have changed.

The results of static tests on these connections were analysed using AS/NZS 4063 and ISO 12122.5. The capacities of the fasteners and connections were compared with values in AS 1720.1 and AS 1684.2. AS 1684.2 presents capacities for connection (a), but not for connections (b), (c) or (d). The results for the capacity of connection (a) were consistent with the values in Table 9.25 in AS 1684.2.

The characteristic capacities of correctly driven connections into JD5 timber rafters were as follows.

a) One 75 mm long bugle head screw through 35 mm thick timber battens – 3.5 kN;
b) One 75 mm long bugle head screw through 45 mm thick timber battens – 2.7 kN;
c) Two 40 mm long M5.5 Batten Zip® screws through 40 mm deep 0.55 mm BMT top-hat battens – 3.5 kN;
d) Two 57 mm long hot-dipped galvanised nails through 40 mm deep 0.55 mm BMT top-hat battens – 0.74 kN.

Notes: 1. The results on timber battens are valid for batten widths of 70 mm or greater.
2. Where fasteners are not correctly installed, capacities of some of the connections can be significantly lower than the above values.

Tests also showed that:

• There is no significant difference in connection capacity for 57 mm galvanised nails through four commonly available 40 mm deep 0.55 mm BMT top-hat battens; and
• 75 mm smooth shank nails are inappropriate for fixing 40 mm deep 0.55 mm BMT top-hat battens in general and edge zones in all wind classifications.

The tests confirmed that top-hat and timber battens should only be fixed in accordance with either Standards, manufacturers' recommendations or joint capacities justified by appropriate test programs. The test program and investigations of damage following wind events has reinforced that nails should not be used to fasten either timber or steel battens in all parts of the roof in any wind region.

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Acknowledgements

1. INTRODUCTION

1.1. Batten to rafter connections in practice

Failure of batten to rafter or batten to truss connections have been identified in investigations of wind damage in Australia: Reardon et al (1999), Boughton (1999), Henderson and Leitch (2005), Henderson et al (2006), Boughton (2007), Boughton (2008), Leitch et al (2009), Boughton et al (2011), Henderson et al (2012), Boughton (2015) and Parackal (2015).

These reports include damage to buildings in the cyclone prone wind regions (Wind regions C and D) and the non-cyclone prone wind regions (Wind regions A and B). Design capacities of batten to rafter connections have been derived from product specific tests and generic test programs on fasteners. However, construction practices are changing and some commonly used connections are not supported by design values in AS 1684.2 (Standards Australia 2010a) or manufacturers' information. Figure 1.1 shows a roof in wind region A that has metal top-hat battens fastened to softwood rafters with gun-driven nails, which are not included in manufacturers' recommendations for these connections.

Figure 1.1 – Gun-driven nails used in metal battens (inset shows top view of connection).

Failure of gun-driven nail connections between metal battens and softwood trusses were observed by Boughton and Falck (2008) and are illustrated in Figure 1.2. In this case, some of the nails withdrew from the trusses and in other cases, the battens

pulled over the nail heads near the edge of the roof, and progression of the failure tore roofing fasteners out of the battens near the ridge.

Figure 1.2 – Failure of gun-driven nails connections between metal battens and trusses. (Shading shows area of batten to truss failure.)

Other roofs are constructed with timber battens. The 90 x 35 battens shown in Figure 1.3 can use connections selected directly from AS 1684.2 (Standards Australia 2010a), as the assumed batten depth in the Standard is 38 mm. However, the battens in Figure 1.4 are 45 mm deep so the connectors do not have the same depth of penetration into the rafter assumed in AS 1684.2. Hence the capacity of these connections cannot be directly obtained from AS 1684.2.

Figure 1.3 – connections between 35 mm thick battens and rafters.

Figure 1.4 – connections between 45 mm thick battens and rafters. (Inset shows connection detail.)

Batten connections to trusses or to rafters have the same loads, the same load transfer mechanism and the same capacity. In this report, batten to rafter and batten to truss connections are both referred to as batten to rafter connections.

Section 2 details three undergraduate research projects (Duong 2015), (Nguyen 2015) and (Pham 2015) to investigate the capacity of batten to rafter/truss connections observed in contemporary construction in Perth WA. Some of these connections also have relevance for other parts of Australia. The investigation focused on:
- Nailed connections between steel battens and MGP10 rafters. 0.55 mm steel is usually used for the steel battens, and a number of different profiles are available. Two different types of gun-driven nails are commonly used for these connections.

- Screwed connections between top-hat battens and MGP10 rafters. These connections are recommended by a batten manufacturer (Lysaght 2014).
- Screwed connections between 35 mm and 45 mm thick timber battens and MGP10 rafters. In many cases, 75 mm bugle head screws are used on both 35 mm and 45 mm thick battens.

1.2.   Selecting batten to rafter fasteners from AS 1684

Table 9.14 in AS 1684.2 (Standards Australia 2010a) provides the net uplift force (kN) on roof battens and is used to determine the loads fasteners must resist depending on the following parameters:
- Wind Region A or B (use AS 1684.2), Wind Region C or D (use AS 1684.3);
- Wind classification; N1 to N4 for Wind Regions A and B; and C1 to C4 for Wind Regions C and D, calculated using AS 4055 (Standards Australia 2012);
- Roof cladding material – tiles (including concrete or terracotta tiles) or metal sheet (or other lightweight cladding);
- Rafter spacing (mm)
- Batten spacing (mm)
- Roof zone – Edge (within 1200 mm of the perimeter of the roof, hips, ridges, fascias and barges) or General (all areas that are not edges).

TABLE 9.14
NET UPLIFT FORCE ON ROOF BATTENS

Rafter or truss spacing	Batten spacing	Uplift force, kN							
		Wind classification							
		N1		N2		N3		N4	
mm	mm	General area	Edges	General area	Edges	General area	Edges	General area	Edges
Tile roof									
450	330	0.04	0.14	0.09	0.21	0.17	0.37	0.29	0.59
600	330	0.06	0.18	0.11	0.29	0.23	0.50	0.39	0.79
900	330	0.08	0.27	0.17	0.43	0.35	0.75	0.59	1.1
1200	330	0.12	0.36	0.22	0.58	0.46	1.0	0.78	1.6
Sheet roof									
600	370	0.15	0.29	0.22	0.41	0.35	0.65	0.53	0.97
	450	0.18	0.35	0.26	0.50	0.42	0.79	0.64	1.1
	600	0.24	0.47	0.35	0.66	0.57	1.0	0.86	1.5
	750	0.31	0.59	0.44	0.83	0.71	1.3	1.0	1.9
	900	0.37	0.71	0.53	1.0	0.85	1.5	1.2	2.3
	1200	0.49	0.94	0.71	1.3	1.1	2.1	1.7	3.1
900	370	0.23	0.44	0.33	0.61	0.52	0.97	0.79	1.4
	450	0.28	0.53	0.40	0.75	0.64	1.1	0.96	1.7
	600	0.37	0.71	0.53	1.0	0.85	1.5	1.2	2.3
	750	0.46	0.88	0.66	1.2	1.0	1.9	1.6	2.9
	900	0.55	1.0	0.79	1.5	1.2	2.3	1.9	3.5
	1200	0.73	1.4	1.0	2.0	1.7	3.1	2.5	4.7

Figure 1.5 – Evaluation of connection load from AS 1684.2 Table 9.14
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Figure 1.5 shows the uplift force on a batten to rafter connection for the following example:
- Wind Region A;
- Wind classification N2;
- Sheet roof;
- Rafter spacing 900 mm;
- Batten spacing 900 mm;
- Edge zone

The uplift force for this example is 1.5 kN.

The uplift force from Table 9.14 can be compared with the capacities of different types of fasteners in Table 9.25. Table 9.25 shows uplift capacities of smooth shank nails, deformed shank nails, screws and framing anchors into unseasoned and seasoned timber battens of different cross-sections. In each case, the capacity is for connections that have been correctly installed.

Figure 1.6 shows that only Type 17 screws have sufficient capacity to resist the 1.5 kN force on the fastener in the above example when fastened into JD5 timber rafters. Nails should not be used for JD5 batten to rafter/truss connections in edge zones.

Position of tie-down connection		Uplift capacity, kN					
		Unseasoned timber			Seasoned timber		
Roof battens to rafters/trusses		J2	J3	J4	JD4	JD5	JD6
(b) 38 × 75 or 38 × 50 mm batten — Nailed as per table. Two screws shall be used only with 75 mm wide batten	Plain shank						
	1/75 × 3.05	0.61	0.52	0.45	0.32	0.21	0.15
	2/75 × 3.05	1.2	1.0	0.90	0.64	0.42	0.30
	Deformed shank						
	1/75 × 3.05	1.2	1.0	0.90	0.65	0.43	0.30
	2/75 × 3.05	2.5	2.1	1.8	1.3	0.86	0.60
	2/75 × 3.75	2.8	2.5	2.2	1.7	1.0	0.72
(d) 38 × 75 or 38 × 50 mm batten — No. 14 Type 17 screws as per table. Two screws shall be used only with 75 mm wide batten	Screws (length)						
	1/75 mm long	5.7	4.2	2.4	4.5	3.6	2.7
	1/90 mm long	7.4	5.5	3.2	6.0	4.7	3.6
	2/75 mm long	11	8.4	4.8	9.0	7.2	5.4
	2/90 mm long	15	11	6.4	12	9.4	7.2
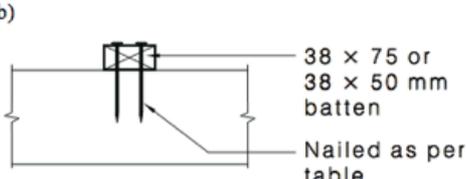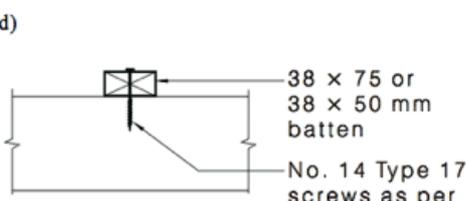
Figure 1.6 – Connection capacity for 35–38 mm thick battens from AS 1684.2 Table 9.25 (Reproduced with permission from SAI Global Ltd under Licence 1505-c035.)

AS 1684.2 (Standards Australia 2010a) provides deemed-to-satisfy solutions referenced by Volume 2 of the National Construction Code for many connections in domestic construction. However, it does not provide connection capacities for the following connections observed in practice in WA:

- Nails into the flanges of steel battens;
- Screws into the flanges of steel battens; and
- Screws into 45 mm thick softwood battens

Specifications for structural work in domestic roofs often refer to AS 1684. The connections that are not included in AS 1684, or cannot be evaluated by calculations from a referenced structural design manual such as AS 1720.1, must be regarded as alternative solutions. (Manufacturers have provided guidance that can be used for some of these connections, but otherwise, the alternative solution must be supported by documentation that the solution complies with the performance requirements of the National Construction Code – most commonly by analysis or test data.) The test program presented in this report was designed to determine the characteristic capacities for these connections.

1.3.   Over- and under-driven fasteners

The capacity of connections in AS 1684.2 (Standards Australia 2010a) assumes that the fasteners are correctly driven/installed and doesn't consider variations in installation practices. However, observations of fasteners in roofs under construction have highlighted a range of installation practices:

- Under-driven fasteners – there is some space between the underside of the fastener head and the surface of the batten. Figure 1.7(a) shows an under-driven nail into a top-hat batten and Figure 1.7(b) shows an under-driven screw into a top-hat batten.
- Correctly-driven fasteners – the underside of the fastener is just in contact with the surface of the batten.
- Over-driven fasteners – the fastener is driven further into the batten as shown in Figures 1.8(a), and Figure 1.8(b).

(a) Nail into top hat batten   *(b) screw into top-hat batten*
Figure 1.7 –Under-driven fasteners on building sites– (Photo (a) Greg Flowers, Building Commission of WA and (b) Lex Sommerville)

(a) deformed surface of batten   *(b) punched through a batten*
Figure 1.8 – Over-driven fasteners – (Photos Greg Flowers, Building Commission of WA)

1.4. Previous studies

This section summarises some of the relevant test programs on batten to rafter/truss connections.

1.4.1. Batten to rafter/truss capacities in AS 1684

Testing by Reardon (1979a) and Reardon (1979b) provided the basis of many of the capacities of batten to rafter connections given in AS 1684.2 (Standards Australia 2010a). These tests and other tests on connections in Australia have been conducted to various versions of AS 1649 (Standards Australia 2001), and were originally reported as basic working strengths. The limit state version of AS 1684 presents reanalysed data as true characteristic values.

1.4.2. Pull-through failures in batten to rafter/truss connections

Studies by Prevatt et al. (2014) in the USA have shown that most failures in batten to rafter connections have occurred due to poor nail installation; roof battens pulling over the nail heads (pull-through failures) or by nails withdrawing from their wood support (pull-out failures).

Research conducted by Mahaarachchi and Mahendran (2002) suggest that premature pull-through failures of light-gauge metal battens are associated with splitting around fastener holes, which may exacerbate roof structure damage during wind events. However, their study has yet to determine the criterion for the splitting of the fastener hole.

In timber to timber screwed connections, three possible failure modes are: withdrawal of the screw threads from the timber, pull-through of the screw head and steel failure of the screw shank (AS 1720.1 Standards Australia 2010b). AS 1720.1 recommends that designers consider pull-through failure for screws, although it does not explicitly provide an appropriate calculation method.

1.4.3. Withdrawal failures in batten to rafter/truss connections

In practice, timber design codes such as the Australian Standards for residential timber-framed construction, AS1684.2 (Standards Australia 2010a) contains provisions for the withdrawal strength of screws and nails from timber as indicated in Section 1.2.

1.5. Aims of the project

The project aimed to determine the uplift capacity and critical failure modes of four batten to MGP10 timber rafter connections commonly used for sheet metal roofs in Perth houses and their suitability in different wind classifications:

a) One 75 mm long bugle head screw through 35 mm thick timber battens;
b) One 75 mm long bugle head screw through 45 mm thick timber battens;
c) Two 40 mm long M5.5 Batten Zip® screws through 40 mm top-hat battens;
d) Two 57 mm long hot-dipped galvanised nails through 40 mm top-hat battens.

The project also aimed to investigate the effects of:

• Rafter density;
• Over- and under-driving of fasteners;
• Profile of top-hat battens;
• Type of nail used with top-hat battens.

The project did not investigate the capacity of nails through timber battens as AS 1684.2 tables show that two smooth shank nails do not have the capacity to resist the uplift forces on edge or general zones of roofs in any wind region in Australia. Smooth shank nails are nails with a smooth surface and include plain shank nails as referred to in AS 1684.2 and any plain shank nails with a smooth coating, for example; electroplating. (Two deformed shank nails have capacity to carry uplift forces in general areas of roofs in N1 wind classifications through 35 mm thick battens only.)

2. LABORATORY TESTS

2.1. Sampling

2.1.1. Rafters for main test program

The rafters were commercially available 120 x 35 MGP10 timber selected to give a wide range of densities. The densities of the supplied timber were between 438 and 618 kg/m^3. The rafters were cut into 900 mm length specimens. The specimens were divided into groups to give similar average density and standard deviations in each test group. Figure 2.1 shows:

- The range of density in each group given by the thin lines;
- One standard deviation either side of the mean, indicated by the boxes on the graph;
- Test groups 1 to 3 were for screws through top-hat battens;
- Groups 4 to 6 were for nails through top-hat battens;
- Groups 7 to 9 were for bugle head screws through 35 mm thick timber battens;
- Groups 10 to 12 were for bugle head screws through 45 mm thick timber battens.
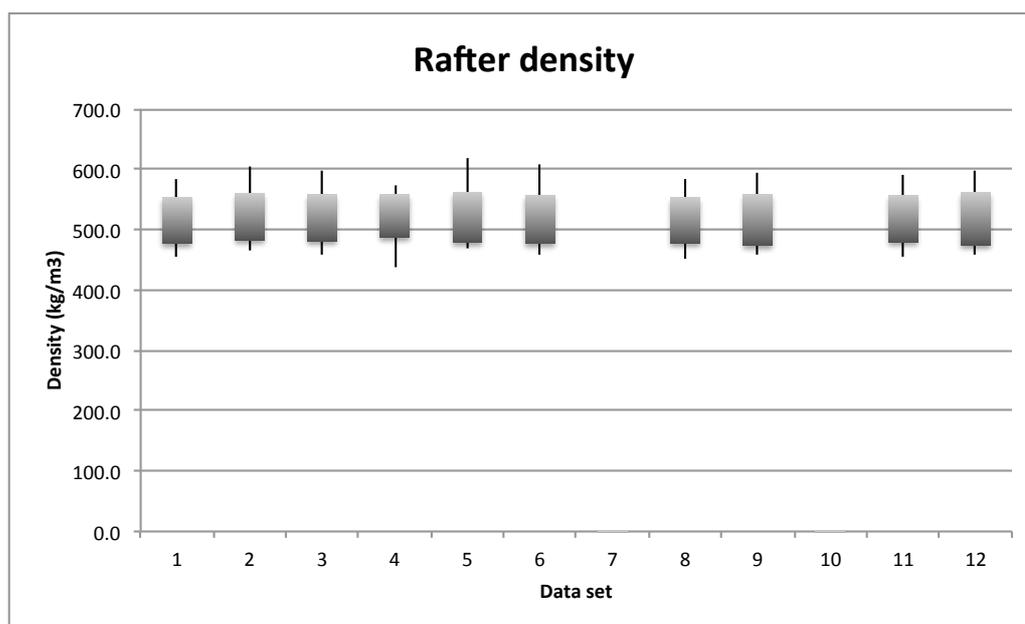
Figure 2.1 Density of rafters
Note: Groups 7 and 10 were not required.

Table 2.1 shows the density of rafters for each group. There was no statistically significant difference in the mean density of any of the groups.

Table 2.1 Density of rafters

Group	1	2	3	4	5	6	7	8	9	10	11	12
No	10	20	20	10	20	21	0	9	10	0	9	10
Avg	515	521	519	522	520	517		515	516		518	518
Std dev	38.2	38.6	38.3	35.2	41.7	40.2		37.5	42.5		38.4	43.7

2.1.2.　　Top-hat battens

A local building inspector supplied samples of a number of different top-hat batten products for the preliminary tests (see Section 2.4). The preliminary tests were used to select a specific top-hat batten profile for testing from a number that are commonly used on housing projects in Perth WA. The TS4055 battens, Lysaght Topspan 40 0.55 mm BMT, selected for the main test program were purchased from local suppliers. All top-hat battens were manufactured from G550 feedstock.

2.1.3.　　Timber battens

The battens were commercially available and commonly used 45 x 90 Batten900 (Wespine Industries) timber product. This product is a locally produced softwood product marked 'For batten use only' and has properties that enable 900 mm batten spans at 900 mm spacings for wind classes N1 to N3.

As a comparison, superseded 35 x 90 battens from the same manufacturer were also tested to give a baseline for comparison with connection capacities tabulated in AS 1684.2. (Standards Australia 2010a) All of the timber battens were cut into lengths of 750 mm.

2.2.　Fabrication of specimens

A fabrication jig (Figure 2.2) was used to ensure all the test specimens were precisely and consistently nailed and screwed so that loads would be applied concentrically and connections would be free of moments or prising forces. The nails were installed using a compressed air nail gun tailored to the nails selected. The screws were installed using a battery powered electric drill.

Figure 2.2 Connection assembly jig

2.3. Testing equipment

The equipment used in the test program included:

- A Universal test machine set to a loading rate estimated to produce time to failure between one and five minutes;
- A loading frame consisting of two U-shaped bearing elements that provided tension between the rafter and the batten as the UTM platens were moved closer together.
- A loading plate that distributed tension loads to five roofing screws that were used to apply the load to the batten in a realistic manner (see Figure 2.3).
- Load cell attached to the test machine to provide accurate force measurements;
- A laser displacement transducer was used to measure relative deflection between the batten and rafter. This provided a measurement of deflection of the connection.

These features are shown in Figures 2.3(a) and 2.4 for timber battens, but the top-hat battens were fastened in the same fashion.
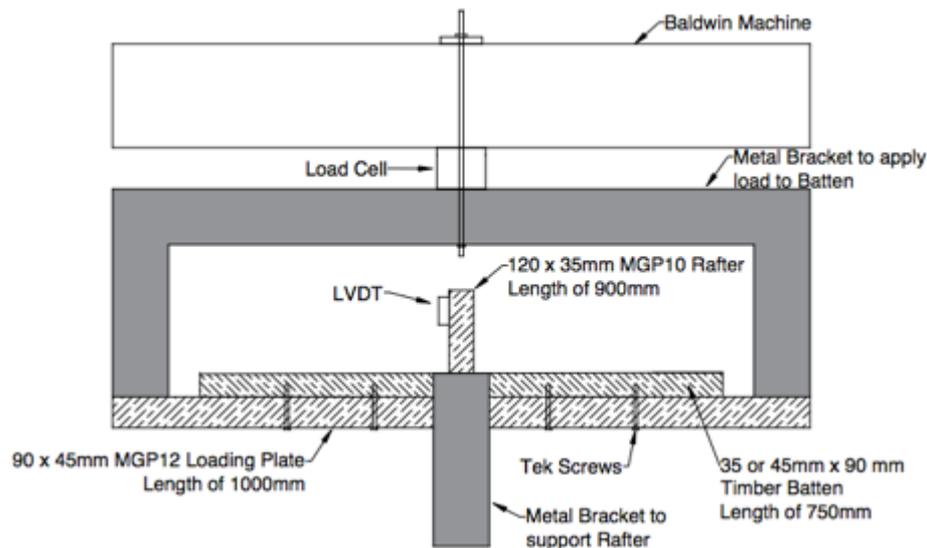
(a) Schematic diagram of test setup

(b) Connection to steel battens from roofing (Photo by Lex Sommerville)
Figure 2.3 Load transfer to battens
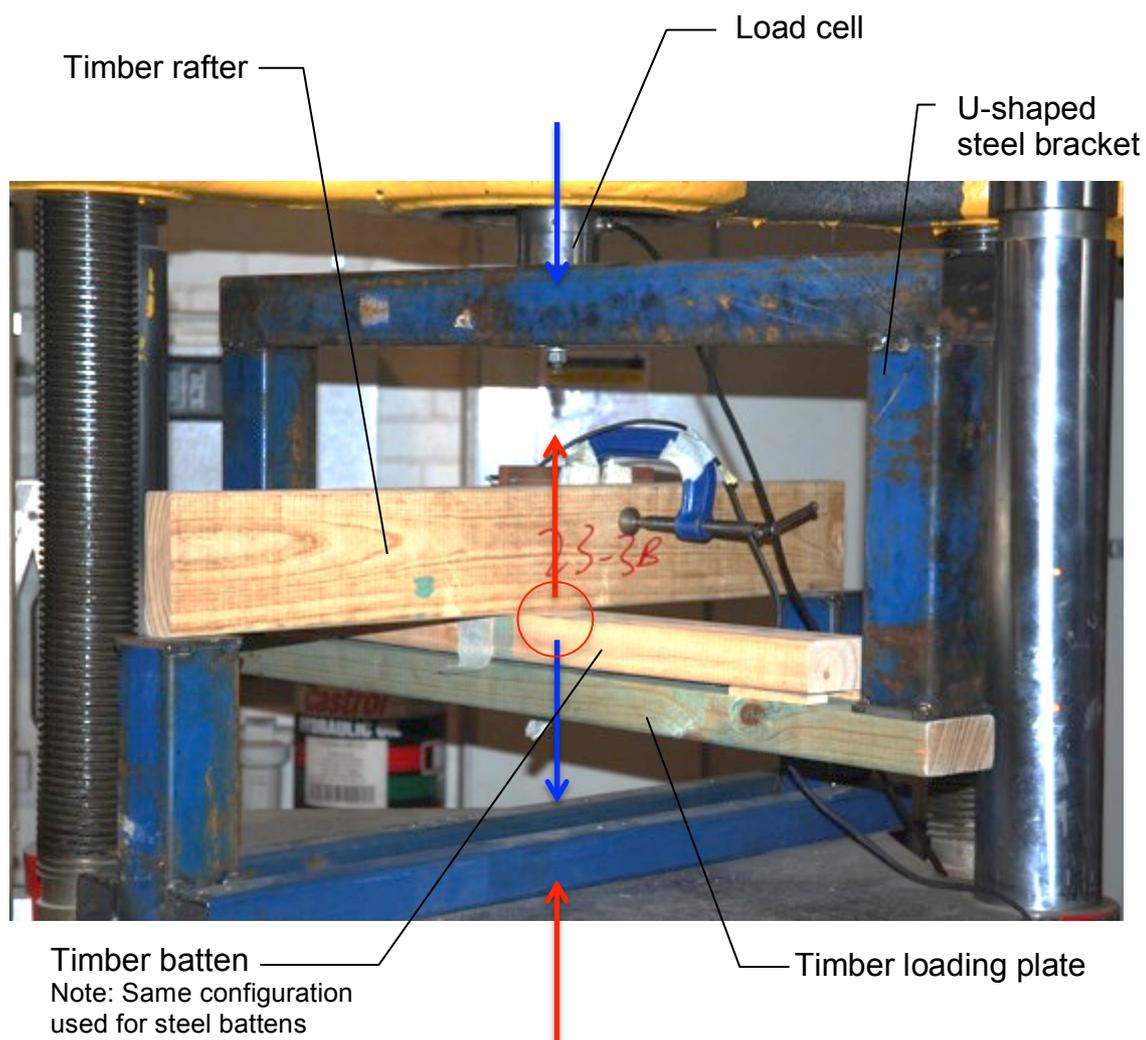
Figure 2.4 Photo of UWA Universal test machine (Note that the orientation of the batten and rafter is inverted compared with orientation in service.)

2.4.   Preliminary testing

A series of 20 preliminary tests were undertaken to select the top-hat battens and the nail type for the main test program detailed in Section 2.5.

Tests were conducted on a range of 40 mm deep top-hat steel battens, with a base metal thickness (BMT) of 0.55mm, from different batten manufacturers to examine the influence of batten type on the uplift capacity of connections between steel battens and timber rafters.

The following nails were tested to determine the nail that would be used in the test program:
- 57mm length Ortons hot-dipped galvanised smooth shank nails with a round 5.5mm head and 2.56 mm diameter shank;
- 75 mm length Paslode smooth shank nails with a D-shaped 5.5 mm x 7 mm head and 3.06 mm diameter shank.

Each of the nails were driven with a nail gun that had been carefully set to ensure that the nails were neither under-driven nor over-driven in order to remove the effect of differences in installation that may affect the preliminary test results. All nails were inspected prior to testing to confirm that they were correctly driven.

The rafters for the preliminary tests only were cut from matched MGP12 120 x 45 so that all specimens had high densities, to increase the likelihood that failure occurred by tearing or pull-through in the battens. This test strategy aimed to determine whether there was any difference between the capacities of the different batten brands.

A factorial analysis was used to differentiate between the nail strengths.

2.4.1.   Results

Table 2.2 presents the results of the 20 preliminary tests.

Table 2.2 Results of preliminary tests on nails through top-hat battens

Batten Type	Nail Type	Failure Load (kN)	Failure Mode
Lysaght	75mm D	2.5	Withdrawal
Lysaght	57mm R	3.38	Pull-Through
Lysaght	57mm R	3.4	Pull-Through
Lysaght	57mm R	2.8	Pull-Through
Roof Mart	75mm D	1.9	Withdrawal
Lysaght	75mm D	1.8	Withdrawal
Roof Mart	57mm R	2.81	Pull-Through
Lysaght	75mm D	1.93	Withdrawal
Stramit	57mm R	3.2	Pull-Through
Stramit	75mm D	2.9	Withdrawal
Lysaght	57mm R	3.7	Pull-Through
Lysaght	75mm D	2.28	Withdrawal
Roof Mart	57mm R	3.09	Pull-Through
Roof Mart	57mm R	3.16	Pull-Through
BGC	57mm R	3.17	Pull-Through
Roof Mart	57mm R	3.18	Pull-Through
BGC	57mm R	3.11	Pull-Through
Stramit	57mm R	3.07	Pull-Through
Stramit	57mm R	3.23	Pull-Through
x2 Lysaght	57mm R	3.71	Withdrawal

Table 2.3 summarises the analysis of the preliminary test data and shows:
- The average strengths of 57 mm nails into the different top-hat battens ranged between 3.06 kN (RoofMart) and 3.32 kN (Lysaght). Each of the tests using the 57 mm nails failed by pull-though of the nail through the batten, so all had the same failure mechanism and could be compared directly.
- A student t-test was conducted to see if the difference in strengths of the battens was significant. There was no statistically significant difference between the connection strengths for any of the battens.
- A single test using 57 mm nails was performed on two top-hat battens together to simulate increased steel thickness in an effort to obtain a withdrawal failure. The failure of this test was by withdrawal at a slightly higher load than the best of the pull-through failures using the same length nail.

- As there was no significant difference between the capacity of the connections through any of the batten products, the results were pooled to compare the capacity of the nails.
- The capacity of the 57mm length Ortons hot-dipped galvanised smooth shank nails was significantly greater than the capacity of the 75 mm Paslode nails. The student t-test on the difference gave significance at the 1%ile level.

Table 2.3 Results of preliminary tests on nails through steel battens

Batten	Lysaght	Roof Mart	Stramit	BGC	x2 Lysaght	Any	Any
Nail	57mm R	57mm R	57mm R	57mm R	57mm R	57mm R	75 mm D
# Pull-through	4	4	3	2	0	13	0
# Withdrawal	0	0	0	0	1	1	6
Avg	3.32	3.06	3.17	3.14	3.71	3.22	2.22
T-test signif'ce		35%	56%	50%	20%		1%

It was concluded that the batten type does not affect the uplift capacity of the nailed connection. Lysaght Topspan 40 0.55 mm BMT steel roof battens were used for the main experimental investigation. Because there was no difference between the connection capacities of the nailed steel battens, the results are applicable to other 40mm high top hat steel battens with a BMT of 0.55mm.

The 57mm length Ortons hot-dipped galvanised smooth shank nails failed by tearing through the top-hat battens at an average load of 3.22 kN. Withdrawal failure for these nails only occurred when two battens were tested together, at a load of 3.71 kN.

The average withdrawal capacity of the longer, thicker 75 mm Paslode nails was 2.22 kN and was significantly less than the capacity of the 57 mm nails. Longer nails usually have higher withdrawal capacity and larger diameter nails have higher withdrawal capacity. However, the 57 mm Ortons nails had a rough galvanised finish, which may have provided more friction in withdrawal than the smooth 75 mm Paslode smooth shank nails.

The 57 mm Ortons nails were selected for testing with top-hat battens in the final testing program; if the higher capacity nail could not achieve the strength for particular roof configurations, then the lower strength nail would also be unsuitable for the same connections.

Because the capacity of the 75 mm nail was only limited by withdrawal, the strength of a 75 mm nail can be estimated by scaling from the withdrawal strength of the 57 mm nails in the main test program using the ratio of strengths found in the preliminary test program.

2.5. Main test program

Four configurations of batten to rafter connections were tested:

- One Buildex® No.14 Type 17, 75 mm length bugle head screws into 35 mm thick timber battens;
- One Buildex® No.14 Type 17, 75 mm length bugle head screws into 45 mm thick timber battens;
- Two 57 mm Ortons hot-dipped galvanised smooth shank nails into Lysaght Topspan 40 0.55 mm BMT steel roof battens;
- Two 40 mm M5.5–11x40 Batten Zip® screws* into Lysaght Topspan 40 0.55 mm BMT steel roof battens ;

*Note: Batten Zip® screws are recommended by Lysaght (2014) for use with Lysaght TS4055 Topspan steel roof battens into timber rafters.

A settling-in period of at least one week was allowed between the installation of the fasteners and the tests. This allowed wood fibres to redistribute localised residual stresses caused by the installation of the fasteners.

2.5.1. Rafter density

The density of the 120 x 35 MGP10 rafters used for each of the groups in the main test program was distributed as described in Section 2.1.1. The average density of each group was between 515 and 522 kg/m^3. AS 1649 (2001) gives the mean density requirements for Joint Strength Groups (reproduced as Table 2.4).

Table 2.4 Mean density for Joint Strength groups from AS 1649

Joint Group	Group mean density range (kg/m^3)
JD1	>940
JD2	750 to 935
JD3	600 to 745
JD4	480 to 495
JD5	380 to 475
JD6	300 to 375

The mean density of each test group corresponded to JD4. Each test group had between one and three pieces with a density lower than 480 kg/m^3, which would be classified as JD5. However, the test groups as a whole were classified as JD4. The timber design standard AS 1720.1 (Standards Australia 2010b) –requires that MGP10 timber is considered to be JD5 unless heart-in material is specifically excluded.

Therefore, the test results were regarded as applicable for JD4 timber rafters. In order to make the results applicable to JD5 (the joint strength group of MGP10 timber), the capacity of the connections into JD5 was estimated using established relationships between receiving member density and connection withdrawal capacity.

2.5.2. Bugle head screws into 35 mm thick timber battens

30 pieces of 35 x 90 radiata pine battens were cut into 750 mm lengths and connected to the rafters using one Buildex® # 14 Type 17 bugle head screw with nominal length 75 mm. The battens had an average density of 540 kg/m^3 and a CoV of 9%.

Table 4.8 in AS 1720.1 (Standards Australia 2010(b)) specifies the minimum edge distance (centre-line distance) for screws in timber connections; 5D (5 times the diameter of the screw). The diameter of the #14 screws used in the tests is 5.10 mm, so the distance from the edge of the rafter should be greater than 25.5 mm, but the largest achievable distance is 35/2 = 17.5 mm if the screw is in the centre of the rafter. The batten to rafter connections cannot meet the rafter edge distance requirements of the standard.

To investigate the variations in screw installation practices:
- 10 specimens were correctly driven (the head of the screw was flush with the surface of the batten) – Figure 2.5(a);
- 10 specimens were over-driven (the head of the screw was below the surface of the batten) – Figure 2.5(b);
- 10 specimens had correctly driven screws installed close to the edge of the batten, and therefore, not in the centre of the rafter underneath – Figure 2.5(c).

(a)Correctly driven   (b)Over-driven   (c) Close to rafter edge
Figure 2.5 Screws driven into timber battens

No screws were under-driven, as under-driven screws have not been seen in practice, and under-driven screws would sit proud of the upper surface of the batten and affect installation of the roof sheeting.

2.5.3. Bugle head screws into 45 mm thick timber battens

30 pieces of 45 x 90 radiata pine battens were cut into 750 mm lengths and connected to the rafters using one Buildex® # 14 Type 17 bugle head screw with nominal length 75 mm. The battens had an average density of 518 kg/m^3 and a CoV of 9%. The screws were installed as for the 35 mm battens: 10 specimens correctly driven, 10 specimens over-driven and 10 used to explore the effect of edge distances in the rafter.

2.5.4.   Screws into steel top-hat battens

The materials used were:
- Lysaght Topspan 40 BMT 0.55mm steel battens; and
- 2 x M5.5–11x40 Batten Zip® screws, with a length of 40mm, as recommended by Lysaght for fixing to timber rafters (Lysaght 2014)

To investigate the variations in screw installation practices:
- 10 specimens were under-driven screws (there was a gap between the head of the screw and the batten flange) – Figure 2.6(a);
- 20 specimens were correctly driven (the head of the screw was flush with the surface of the batten, but did not indent it) – Figure 2.6(b);
- 20 specimens were over-driven (the head of the screw had indented and deformed the surface of the batten flange) – Figure 2.6(c).

All the screws were installed so they were centrally located in the rafter and the flange of the screw was a snug fit with the upstand of the batten in accordance with recommended Lysaght fixing details (Lysaght 2014), as shown in Figure 2.6(b).

(a) Under-driven   *(b) Correctly driven*   *(c) Over-driven*
Figure 2.6 Screws driven into top-hat battens

2.5.5.   Nails into steel battens

The materials used were:
- Lysaght Topspan 40 BMT 0.55mm steel battens; and
- 57mm length Ortons hot-dipped galvanised smooth shank nails with a round 5.5mm head and 2.56mm diameter shank.

The nails were installed as for the screw-fixed battens: 11 specimens under-driven, 18 specimens correctly driven, 21 specimens over-driven and as shown in Figure 2.7.

(a) Under-driven   *(b) Correctly driven*   *(c) Over-driven*
Figure 2.7 Nails driven into top-hat battens

2.6.   Analysis Methods

The data for each connection was divided into analysis groups.

2.6.1.   Analysis Groups

The experimental design enabled direct comparison between a number of different groupings of test specimens. The rafters in each group had similar characteristics. The following groups were analysed:

- All tests on the fasteners;
- All fasteners that were under-driven;
- All fasteners that were under-driven and had a withdrawal failure
- All fasteners that were under-driven and had a pull-through failure
- All fasteners that were correctly driven;
- All fasteners that were correctly driven and had a withdrawal failure
- All fasteners that were correctly driven and had a pull-through failure
- All fasteners that were over-driven;
- All fasteners that were over-driven and had a withdrawal failure
- All fasteners that were over-driven and had a pull-through failure

In addition, some variations were analysed to determine characteristic values for design. These included:

- All fasteners that were not over-driven (total of under-driven and correctly driven fasteners); and
- All correctly driven fasteners where the capacity of any withdrawal failures was de-rated to give equivalent characteristic capacities for JD5 timber.

2.6.2.   Characteristic values

Log-normal distributions were fitted through the data to estimate the 5%ile values of capacity. This method is used by both AS/NZS 4063 (Standards Australia 2010c) and ISO 12122.5 (International Standards Organisation 2015) to estimate the 5%ile of test values and is calculated using *equations 2.1 to 2.3*.

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} ln(R_i) \qquad\qquad\qquad\qquad \textit{equation 2.1}$$

$$S_y = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(ln(R_i) - \bar{y})^2} \qquad\qquad \textit{equation 2.2}$$

$$R_{0.05} = exp(\bar{y} - 1.645 S_y) \qquad\qquad\qquad \textit{equation 2.3}$$

with

$\bar{y}$	=	Mean of natural logarithms of capacity
R_i	=	Value of connection capacity
n	=	number of test specimens in the analysis group
S_y	=	Standard deviation of natural logarithms of capacity
$R_{0.05}$	=	5%ile capacity from log-normal fit to the data

Characteristic values were evaluated from the 5%ile capacity using *equations 2.4 and 2.5*. The characteristic value is a conservative estimate of the 5%ile capacity of the whole population of connections. It is calculated as the lower 75%ile confidence limit of the 5%ile based on the sample.

$$V_R = \sqrt{exp(S_y^2) - 1} \qquad \qquad \textit{equation 2.4}$$

$$R_k = R_{0.05} \left(1 - k_s \frac{V_R}{\sqrt{n}}\right) \qquad \qquad \textit{equation 2.5}$$

with

V_R =   Coefficient of Variation of capacity from log-normal fit to the data

R_k =   Characteristic value of capacity data

The characteristic values were calculated using three different methods:

- AS/NZS 4063.2– the Australian and New Zealand Standard for characteristic values of timber products (Standards Australia 2010(c)). The scope of this document includes stress-graded timber and other timber products. It does not include connections, but the philosophy is the same.

  The characteristic value is found as the 5%ile with a single sided 75%ile confidence limit using *equation 2.5*. The sampling factor (k_s = 1.15) is an approximation that is close to the statistically rigorous value for a sample size of 25 to 30. Some of the data sets used in this project were around 20 specimens, so this is a reasonable approximation.

- AS 1649 – the Australian Standard for testing connections (Standards Australia 2001). This document was designed for the testing of any configuration of timber connection, and was based on a working stress design method.

  The basic working strength (BWS) is found by dividing the 5%ile of the test values by a safety factor. For withdrawal tests, this factor is 2.2. The soft conversion to a conservative estimate of the characteristic values multiplies the BWS by 1.7. (Similar soft conversions of timber products in the past have used a factor of 1.95.) This indicates that it will be conservative for most test programs.

- ISO 12122.5 (International Standards Organisation 2015) is a draft International Standard that focuses on the derivation of characteristic values from tests on structural timber connections. While at present the standard is a draft, it uses the statistical analysis methods in ISO 12122.1, which is a published International Standard.

  The analysis method outlined in ISO 12122.1 is similar to that in AS/NZS 4063.2 (Standards Australia 2010(c)) but uses slightly different sampling factors that are a function of the number of specimens in the analysis.

3. TESTS ON TIMBER BATTENS

Two series of tests were conducted on timber battens. The fasteners for each were one Buildex® #14 Type 17, 75 mm long bugle head screw. Section 3.1 presents the results and discussion of the tests on 35 mm thick timber battens (a configuration for which design values are given in AS 1684.2) and Section 3.2 presents the results and discussion of the tests on 45 mm thick timber battens.

In the 35 mm batten test program, some fasteners failed by pull through in the batten as shown in Figure 3.1(a) and others failed by withdrawal from the rafter as shown in Figure 3.1(b). In the 45 mm batten test program, all fasteners failed by withdrawal.

(a) Pull-through failure *(b) Withdrawal failure*
Figure 3.1 Failure modes for screws through timber battens

3.1. 35 mm thick battens

Centrally located screws were installed either correctly driven (Data set 8) or overdriven (Data set 9), as shown in Figure 2.5. For this series, there were no under-driven screws (Data set 7). The centrally located screws are presented in Section 3.1.1.

A small number of screws were correctly driven, and non-central to the rafter, as shown in Figure 2.5(c). These connections were used to examine the sensitivity of the capacity of the connection to edge distances. The results are presented in Section 3.1.2.

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3.1.1. Centrally located screws

Table 3.1 shows data for centrally located bugle head screws through 35 mm timber battens.

Table 3.1 Joint capacity (kN) – centrally located batten screws through 35 mm thick timber battens

Data set	8 & 9	8			9		
Driven	All	Correctly driven			Over-driven		
Failure	All	All	With-drawal	Pull-through	All	With-drawal	Pull-through
Number	20	10	9	1	10	7	3
Average	7.03	6.71	6.67	7.12	7.34	7.42	7.16
Std dev	0.95	0.99	1.04		0.84	0.99	
CoV	14%	15%	16%		11%	13%	
Max	8.85	7.52	7.52	7.12	8.85	8.85	7.66
Min	4.85	4.85	4.85	7.12	6.58	6.58	6.9
LN 5%ile	5.49	5.07			6.09		
AS 4063 CV*	5.29	4.77	4.64		5.85	5.62	
AS 1649 BWS#	2.50	2.31	2.26		2.77	2.71	
AS 1649 CV	4.24	3.92	3.84		4.71	4.60	
ISO 12122 CV	5.27	4.74	4.60		5.82	5.57	

*CV = Characteristic Value
= Basic Working Strength

Table 3.1 shows that for the batten to rafter connections where the screws were centrally located in the rafter:

- More connections failed in withdrawal than by pull-through;
- No standard deviations or characteristic values were calculated for the specimens that failed by pull-through as there were less than four specimens in the analysis groups;
- The CoVs for capacity were around 15%, which is expected for connections into timber;
- The capacity of the over-driven screws was more than that of the correctly driven screws;
- A slightly higher percentage of over-driven fasteners failed by pull through compared with correctly driven fasteners.
- There was a small difference in characteristic values between the columns in Table 3.1. All connections, correctly driven and over-driven connections had values within 20%; batten to rafter connections using bugle head screws into 35 mm thick timber battens are not especially sensitive to differences in driving.

It was observed that over-driving pulls the head of the screw into the batten as shown in Figure 2.5(b). This reduced the depth of the batten under the flange of the fastener,

which makes a pull-through failure more likely. However, the failure strength was higher for over-driven screws. These trends can be seen in Figure 3.2.
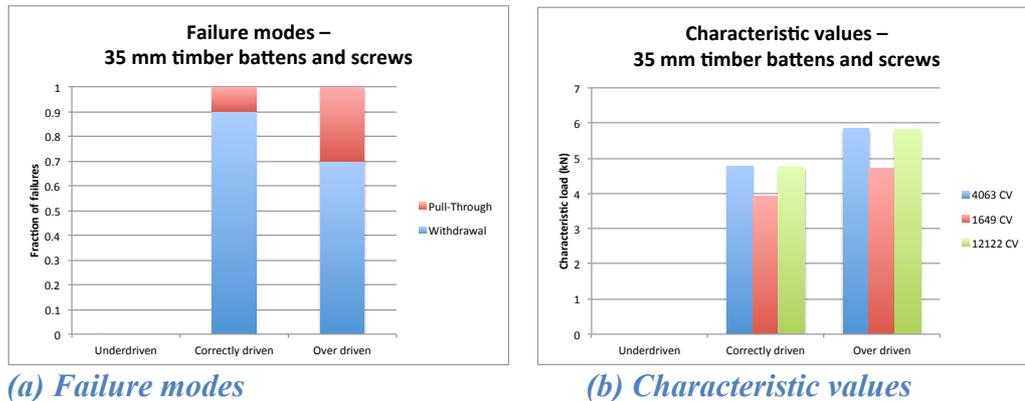
(a) Failure modes   *(b) Characteristic values*
Figure 3.2 Results for screws through 35 mm thick timber battens

Figure 3.2 (b) shows that the characteristic values determined by AS/NZS 4063.2 (Australian Standards 2010c) and ISO 12122.5 (International Standards Organisation 2015) were almost identical and the value determined using AS 1649 (Standards Australia 2001) was conservative. An average of the AS/NZS 4063.2 and the ISO 12122.5 values was used as a representative characteristic value. The correctly driven fasteners had a representative characteristic strength of 4.75 kN, while the over-driven fasteners had a characteristic strength of 5.83 kN.

The correctly driven screw strength will be taken as the benchmark for this study as previous tests in JD4 material had produced the design values for this connection tabulated in AS 1648.2 (Australian Standard 2010a).
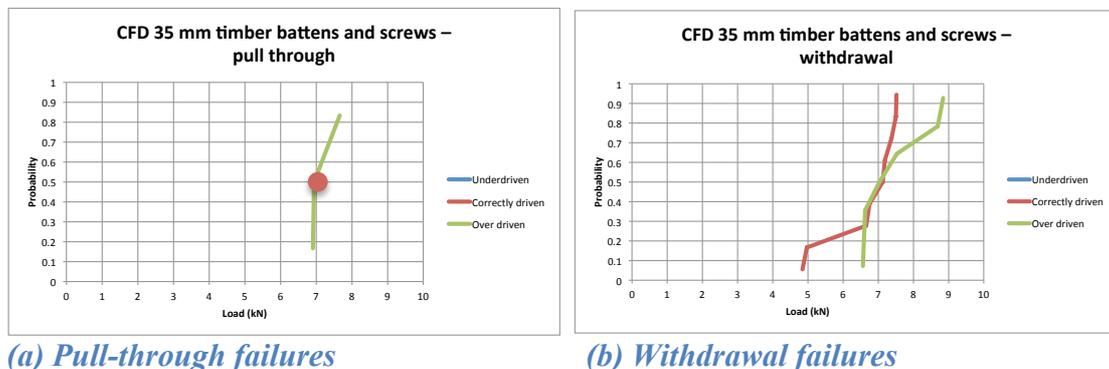
(a) Pull-through failures   *(b) Withdrawal failures*
Figure 3.3 Cumulative frequency distribution for screws through 35 mm thick timber battens

Most of the failures were by withdrawal of the screws from the rafters; the withdrawal load could be related to the rafter density. Figure 3.4 shows that the two low values of two correctly driven specimens were significantly lower than the capacities of all others, and independent of the rafter density. Aside from those two points, the capacities of most other correctly driven and over-driven specimens are clustered together.

Section 2.1.1 showed that the average density of the rafters was within the range for JD4 timbers. Therefore the results of the tests applied to JD4 timber rafters.
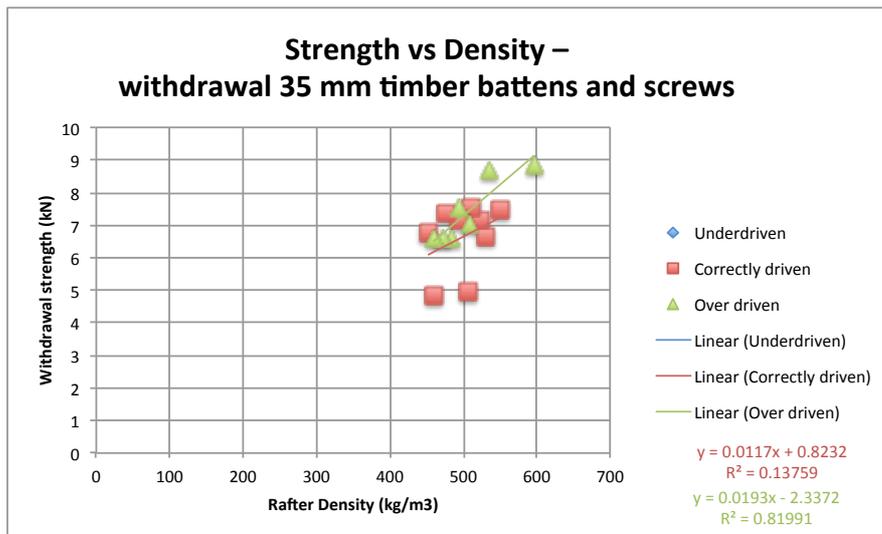
Figure 3.4 Strength vs rafter density for screws through 35 mm thick timber battens

An estimate of the strength of the same connections into JD5 timber rafters was calculated by scaling withdrawal loads by 0.8 (the ratio of JD5 withdrawal strength to JD4 withdrawal strength for screws in AS1720.1 (Standards Australia 2010b). The strength for any connections that failed by pull-through were not scaled as the mode of failure was independent of the density of the rafter; it was only affected by the properties of the batten. From the scaled individual test values, the JD5 characteristic values could be found using the analysis techniques outlined in section 2.6.2.

JD5 capacities were evaluated for correctly driven screws only and for all screws (whether correctly driven or over-driven). The cumulative frequency diagrams are shown in Figure 3.5 and the characteristic values in Table 3.2. The correctly driven screws had known depth of penetration that enabled the calculation of the resistance to withdrawal in N/mm total depth of embedment. This is shown in the last line of Table 3.2
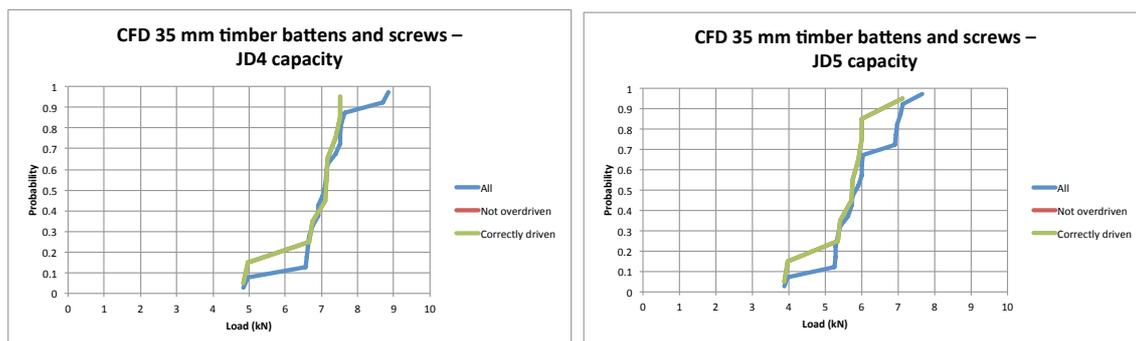
(a) JD4 timber rafters   *(b) JD5 timber rafters*

Figure 3.5 Cumulative frequency distribution for screws through 35 mm thick timber battens

The characteristic strength of correctly driven fasteners can also be compared with the characteristic strength for this fastener and batten combination in AS 1684.2 (Standards Australia 2010a).

Table 3.2 JD4 and JD5 test characteristic values (kN) – centrally located batten screws through 35 mm thick timber battens

Driven	JD4		JD5	
	All	Correctly driven	All	Correctly driven
Failure	All	All	All	All
Number	20	10	20	10
Average	7.03	6.71	5.91	5.51
Std dev	0.95	0.99	0.99	0.97
CoV	14%	16%	18%	19%
Maximum	8.85	7.52	7.66	7.12
Minimum	4.85	4.85	3.88	3.88
LN 5%ile	5.49	5.07	4.35	3.99
4063 CV	5.29	4.77	4.15	3.71
1649 BWS	2.50	2.31	1.98	1.81
1649 CV	4.24	3.92	3.36	3.08
12122 CV	5.27	4.74	4.13	3.68
N/mm		118.8		92.5

For JD4, the ratio of test CV and AS 1684 value is $\frac{4.75}{4.5} = 1.05$

For JD5, the ratio of test CV and AS 1684 value is $\frac{3.69}{3.6} = 1.03$

The data from the test program compares well with the tabulated design values for the same screws into JD4 rafters. The AS 1684 values were originally obtained from tests on batten to rafter connections (Reardon 1979a). The calculated values for JD5 also compare well with the capacities in AS 1684.2 (Standards Australia 2010a).

The test results from this test program appear to be slightly conservative compared with tabulated values with a ratio of only 1.05. Equivalent AS 1684 values from the lab test results can be found by dividing the test characteristic values by 1.05 for this connection. As the rafters for all other tests in this report were matched with the rafters for this connection, the same factor can be applied to all of the test results.

The test results for the bugle head screws from Table 3.2 was factored to give equivalent results to AS 1684.2, presented in Table 3.3.

Table 3.3 JD4 and JD5 design characteristic values (kN) – centrally located screws through 35 mm thick timber battens

	JD4	JD5
Driven	Correctly driven	Correctly driven
Failure	All	JD5
Design value (kN)	4.5	3.5
N/mm per fastener	113	88

The capacities presented in Table 3.3 did not appear to be adversely affected by over-driving. (Under driving was not likely or practical for these fasteners.) The characteristic strength of over-driven fasteners was higher than that for normal fasteners, so this connection is not sensitive to installation technique.

3.1.2. Effect of edge distances

As indicated in Section 2.5.2, correctly installed batten to rafter connections cannot satisfy the rafter edge distance requirements in Table 4.8 in AS1720.1 (Standards Australia 2010b). 10 connections were prepared with correctly driven fasteners installed non-centrally in rafters as shown in Figure 3.6. A range of rafter edge distances was selected.

Figure 3.6 Splitting of rafter with inadequate edge distance

Failure modes were all by withdrawal from the rafter. In some cases, the withdrawal was accompanied by splitting of the rafter as shown in Figure 3.6.
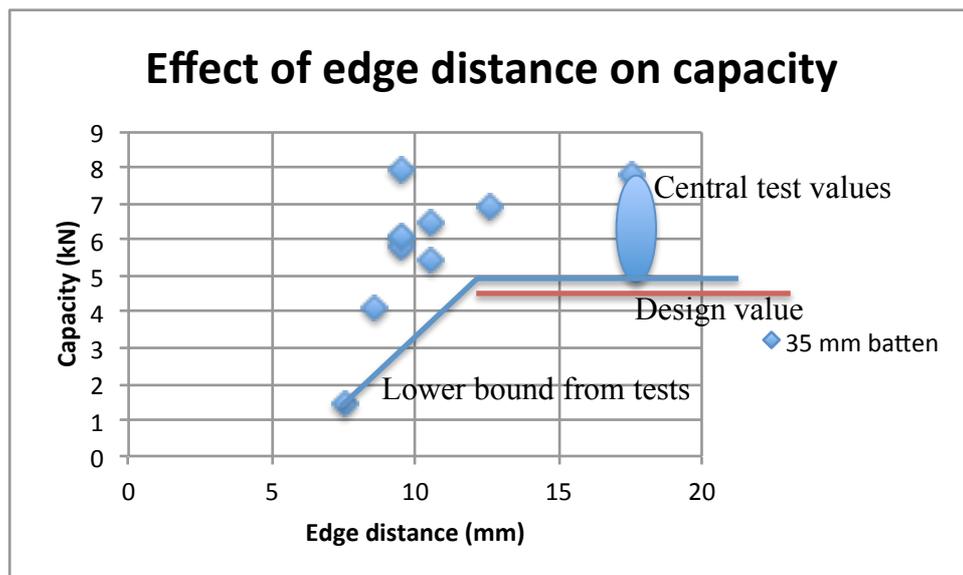
Figure 3.7 Effect of rafter edge distance on capacity of connections through 35 mm thick timber battens

Figure 3.7 shows the 10 test results from the edge distance study as blue diamonds and the results from the correctly driven central test values as a blue ellipse. The design value from Table 3.3 is shown as a red line, and the blue line reflects the lower bound of the combined data sets for correctly driven screws through 35 mm battens. For most edge distances, the test data reflected a similar range to the central test data. However, at edge distances less than 12.5 mm, the connection capacity was lower. 12.5 mm is 5 mm less than the edge distance for a centrally installed connection. i.e. for this connection, the fastener placed centrally in the rafter with a tolerance of +/− 5 mm gave the characteristic capacity.

3.2. 45 mm thick battens

Each timber batten was connected to a MGP10 rafter by a single 75 mm long bugle head screw. Centrally located screws were installed either correctly driven (Data set 11) or overdriven (Data set 12). (Refer to Figure 2.5.) There were no under-driven screws (Data set 10). The centrally located screws are presented in Section 3.2.1.

A small number of screws were correctly driven, and non-central to the rafter. These connections were used to examine the sensitivity of the capacity of the connection to edge distances. The results are presented in Section 3.2.2.

3.2.1. Centrally located screws

Table 3.4 shows data for centrally located bugle head screws through 45 mm thick timber battens.

Table 3.4 Joint capacity (kN) – centrally located batten screws through 45 mm thick timber battens

Data set	11 & 12	11			12		
Driven	All	Correctly driven			Over-driven		
Failure	All	All	With-drawal	Pull-through	All	With-drawal	Pull-through
Number	20	10	10	0	10	10	0
Average	5.27	5.01	5.01		5.52	5.52	
Std dev	0.88	0.78	0.78		0.94	0.94	
CoV	17%	16%	16%		17%	17%	
Max	6.85	6.45	6.45		6.85	6.85	
Min	3.67	3.67	3.67		4.24	4.24	
LN 5%ile	3.93	3.80	3.80		4.10	4.10	
AS 4063 CV*	3.76	3.58	3.58		3.85	3.85	
AS 1649 BWS#	1.79	1.73	1.73		1.87	1.87	
AS 1649 CV	3.04	2.94	2.94		3.17	3.17	
ISO 12122 CV	3.75	3.55	3.55		3.82	3.82	

*CV = Characteristic Value
= Basic Working Strength

Table 3.4 shows that for the batten to rafter connections where the screws were centrally located in the rafter:
- All connections failed in withdrawal and none failed by pull-through;
- The CoVs for capacity were around 17%, similar to the CoV for 35 mm battens;
- The capacity of the over-driven screws was only slightly more than that of the correctly driven screws;
- There was little difference in characteristic values of capacity between any of the columns in Table 3.4. All connections, correctly driven and over-driven connections had similar values; batten to rafter connections using bugle head

screws into 45 mm thick timber battens are not sensitive to differences in installation.

These trends can be seen in Figure 3.8.
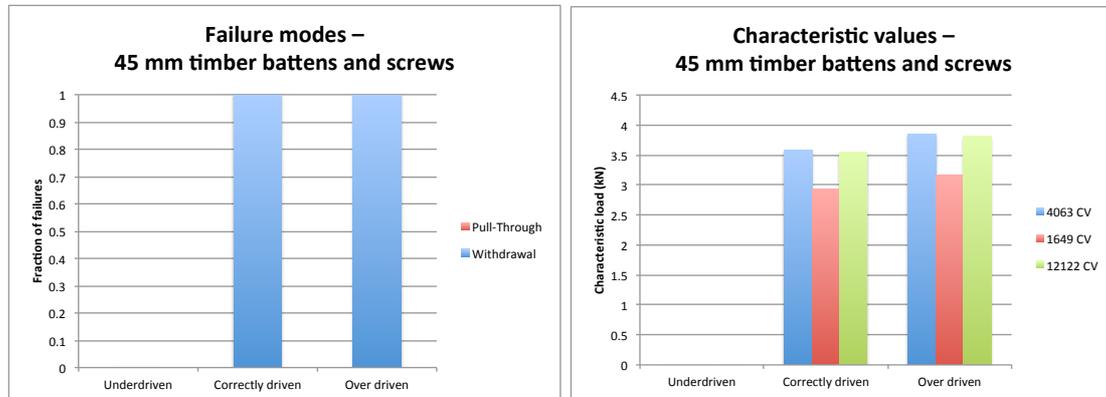
(a) Failure modes   *(b) Characteristic values*
Figure 3.8 Results for screws through 45 mm thick timber battens

Figure 3.9 shows that the capacity of screws through 45 mm thick battens at the 50%ile level is the same for all specimens at around 5.2 kN, regardless of how they were driven. This value divided by the depth of embedment gives 173 N/mm – almost identical to the 50%ile capacity of screws into 35 mm thick battens divided by its depth of embedment – 175 N/mm. The average of the characteristic values calculated using AS/NZS 4063.2 (Standards Australia 2010c) and ISO 12122.5 (International Standards Organisation 2015) was 3.56 kN for correctly driven fasteners, and 3.83 kN for the over-driven fasteners.
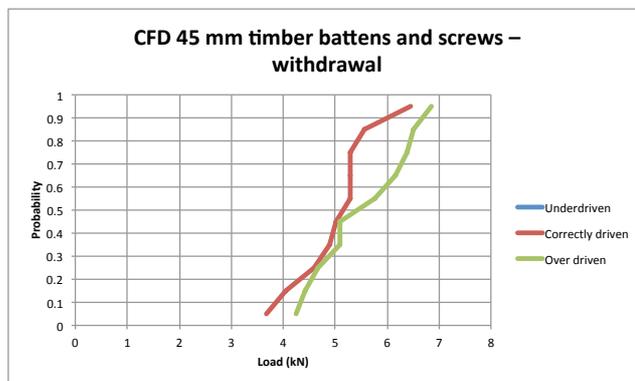
Figure 3.9 Cumulative frequency distribution of withdrawal failures for screws through 45 mm thick timber battens

All of the failures were by withdrawal of the screws from the rafters; the withdrawal load could be related to the rafter density. The capacities of correctly driven and over-driven specimens are clustered together, as shown in Figure 3.10.
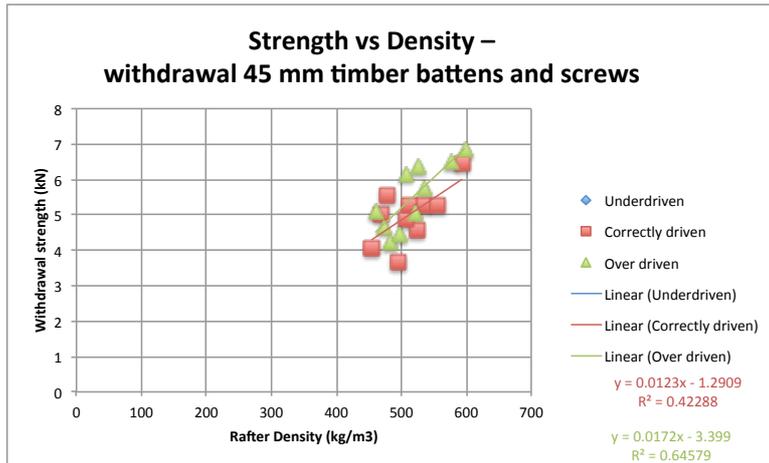
Figure 3.10 Strength vs rafter density for screws through 45 mm thick timber battens

Section 2.1.1 showed that the average density of the rafters was within the range for JD4 timber. Therefore the results of the tests applied to JD4 timber rafters.

An estimate of the strength of the same connections into JD5 timber rafters was calculated by scaling withdrawal loads by 0.8 (the ratio of JD5 withdrawal strength to JD4 withdrawal strength for screws using AS1720.1 (Standards Australia 2010b). From the scaled individual test values, the JD5 characteristic values could be found using the analysis techniques outlined in section 2.6.2.

JD5 capacities were evaluated for correctly driven screws only and for all screws (whether correctly driven or over-driven). The cumulative frequency diagrams are shown in Figure 3.11 and the characteristic values in Table 3.5. The correctly driven screws had known depth of penetration that enabled the calculation of the resistance to withdrawal in N/mm depth of embedment. This is shown in the last line of Table 3.5. These values are nearly identical to the values in Table 3.2 for screws into 35 mm battens.

The characteristic strength of correctly driven fasteners can also be compared with the characteristic strength for this fastener and batten combination in AS 1684.
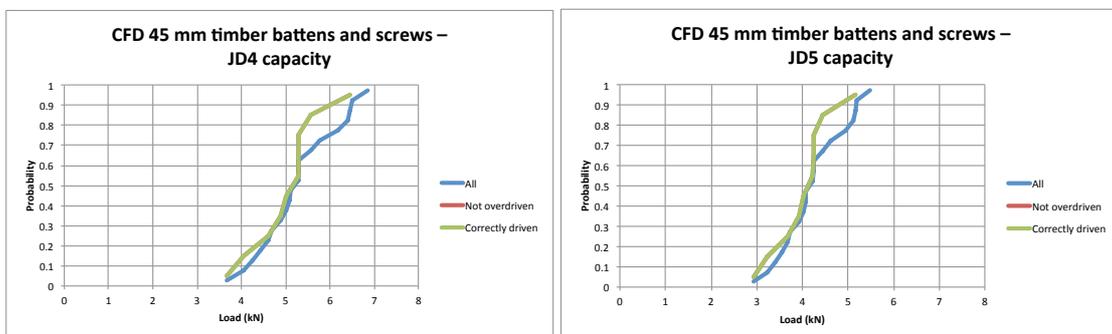
(a) JD4 timber rafters   *(b) JD5 timber rafters*
Figure 3.11 Cumulative frequency distribution for screws through 45 mm thick timber battens

Table 3.5 JD4 and JD5 test characteristic values (kN) – centrally located batten screws through 45 mm thick timber battens

	JD4		JD5	
Driven	All	Correctly driven	All	Correctly driven
Failure	All	All	All	All
Number	20	10	20	10
Average	5.27	5.01	4.21	4.01
Std dev	0.88	0.78	0.70	0.63
CoV	17%	16%	17%	16%
Maximum	6.85	6.45	5.48	5.16
Minimum	3.67	3.67	2.94	2.94
LN 5%ile	3.93	3.80	3.15	3.04
4063 CV	3.76	3.58	3.01	2.86
1649 BWS	1.79	1.73	1.43	1.38
1649 CV	3.04	2.94	2.43	2.35
12122 CV	3.75	3.55	3.00	2.84
N/mm	125.1	118.8	100.1	95.0

A ratio of 1.05 between the design values and test values from this series of experiments was evaluated in section 3.1.1. The test results for the bugle head screws from Table 3.5 was factored to give equivalent results to AS 1684.2 (Standards Australia 2010a), presented in Table 3.6.

Table 3.6 JD4 and JD5 design characteristic values (kN) – centrally located screws through 45 mm thick timber battens

	JD4	JD5
Driven	Correctly driven	Correctly driven
Failure	All	JD5
Design value (kN)	3.4	2.7
N/mm per fastener	113	90

The capacities presented in Table 3.6 were not adversely affected by over-driving. (Under-driving was not likely or practical for these fasteners.) The characteristic strength of over-driven fasteners was slightly higher than that for normal fasteners, so this connection is not sensitive to installation technique.

3.2.2.   Effect of edge distances

Tests on the variation in rafter edge distance experiments detailed in section 3.1.2 on the connections through the 35 mm thick batten were also performed on connections through the 45 mm thick battens. Figure 3.12 showed that similar trends were obtained with in general, the test data reflecting the range of capacities from the centrally placed fasteners. However, at rafter edge distances less than 12.5 mm, the connection capacity was lower. 12.5 mm is 5 mm less than the edge distance for a centrally installed connection. i.e. for this connection, the fastener placed centrally in the rafter with a tolerance of +/– 5 mm gave the characteristic capacity.

Figure 3.12 shows the 10 test results from the rafter edge distance study as red squares and the results from the central test values as a red ellipse. The design value from Table 3.6 is shown as a red line, and the blue line reflects the lower lower bound of the combined data sets for correctly driven screws through 45 mm thick battens.
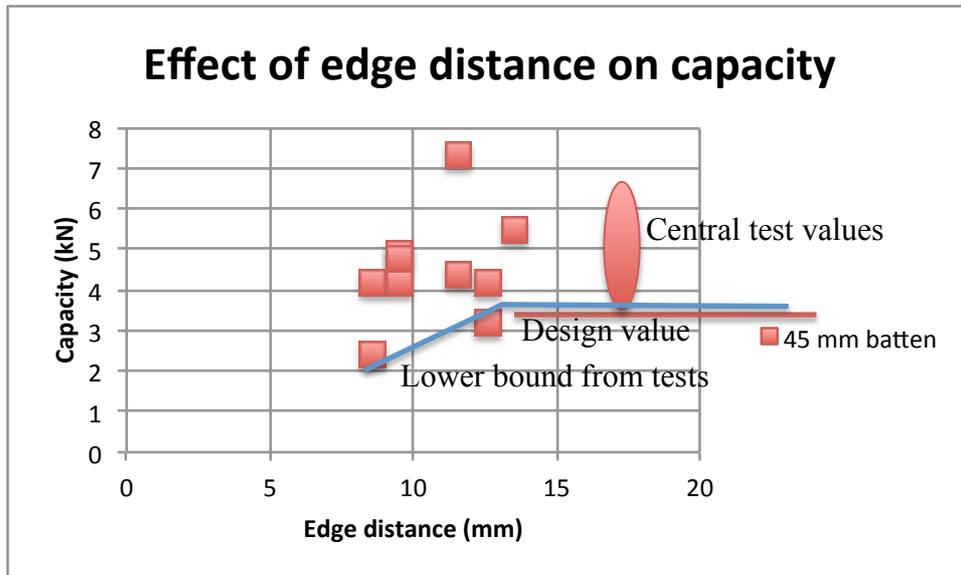
Figure 3.12 Effect of edge distance on strength of connections with 45 mm thick timber battens

Tables 3.3 and 3.6 gave very similar results for the unit withdrawal capacity per mm depth of embedment for the tests in 35 mm thick battens (penetration 40 mm) and the tests in 45 mm thick battens (penetration 30 mm). These unit strengths were 119 N/mm and 113 N/mm respectively. Edge distance studies on the two battens were combined and shown in Figure 3.13.
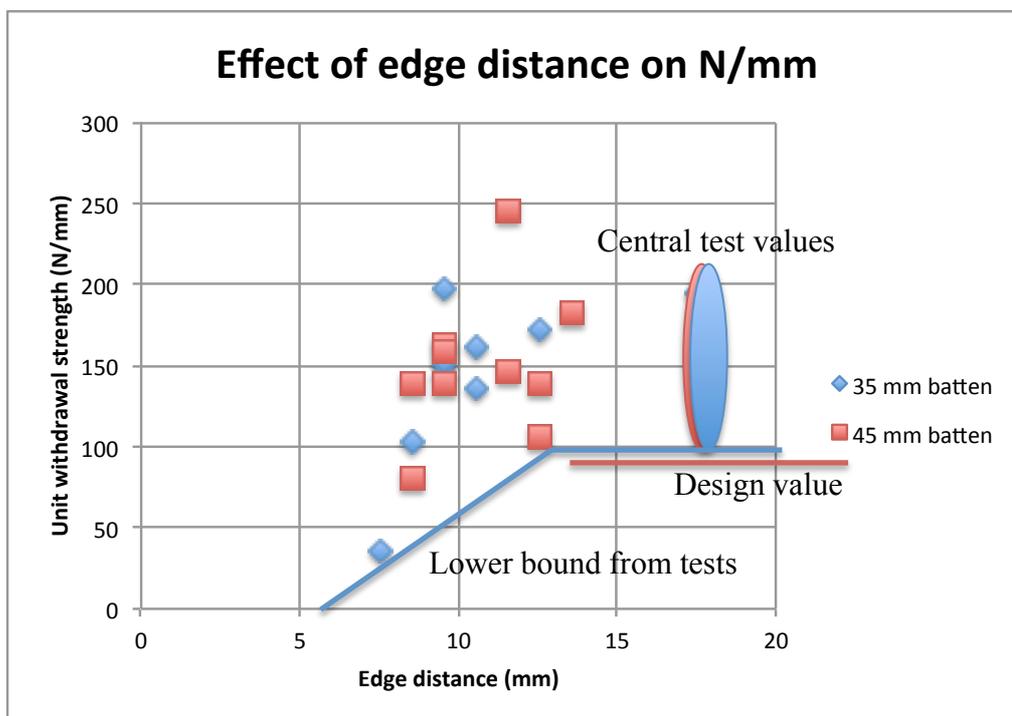
Figure 3.13 Effect of edge distance on unit withdrawal strength of connections with both 35 mm and 45 mm thick timber battens

Figure 3.13 shows that the two different test programs gave very similar results and indicates +/- 5mm in tolerance for the positioning of the batten screw in the width of the batten.

4. TESTS ON METAL TOP-HAT BATTENS

Two series of tests were conducted on steel top-hat battens:

- Two M5.5–11x40 Batten Zip® screws, with a length of 40mm, as recommended by Lysaght for fixing steel battens to timber rafters (Lysaght 2014)
- Two 57mm length Ortons hot-dipped galvanised smooth shank nails with a round 5.5mm head and 2.56 mm diameter shank

4.1. Screws through top-hat battens

Each top-hat batten was connected to the MGP10 rafter by a pair of Batten Zip® screws – one on each side of the batten. The screws were installed either under-driven (Data set 1), correctly driven (Data set 2) or over-driven (Data set 3). Refer to Figure 2.6.

4.1.1. Test results

Some fasteners failed by pull through in the batten as shown in Figure 4.1(a) and others failed by withdrawal from the rafter as shown in Figure 4.1(b).
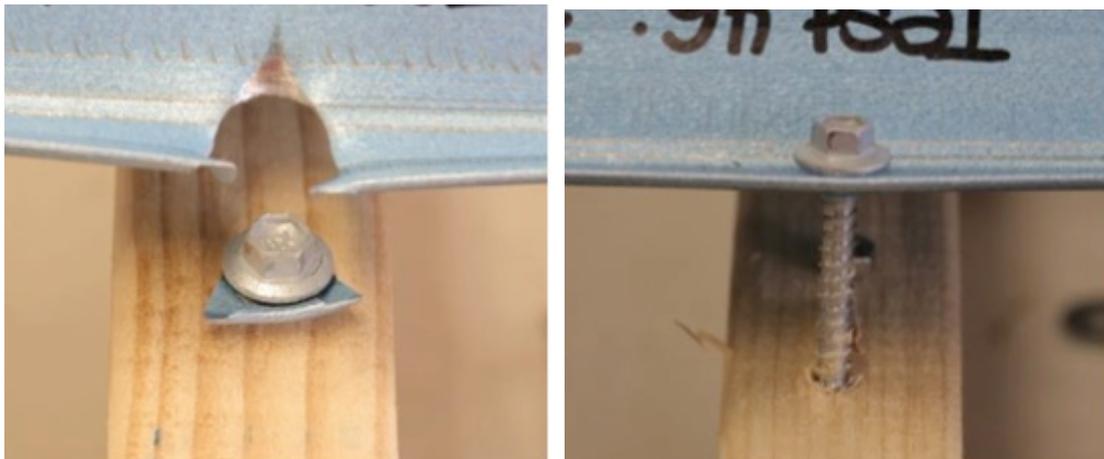
(a) Pull-through failure   *(b) Withdrawal failure*
Figure 4.1 Failure modes in screwed top-hat battens

Table 4.1 shows data for two Batten Zip® screws through top-hat battens and is illustrated in Figure 4.2.

Table 4.1 shows that for the batten to rafter connections:

- Most connections failed by pull-through rather than withdrawal;
- Over-driven connections had a significantly higher percentage of withdrawal failures and the characteristic capacity was around half that of the correctly driven fasteners;
- The CoVs for capacity were around 15% for the under- and correctly driven fasteners, but over 30% for the over-driven fasteners;
- There is little difference in capacity between the correctly driven and over-driven connections that failed by pull-through. The capacity of under-driven fasteners was significantly higher (see Figure 4.3(a));

- For all failure modes, the capacity of the correctly driven and under-driven screws was more than that of the over-driven screws;
- There was a significant difference in characteristic values of capacity between the columns in Table 4.1. Batten to rafter connections using Batten Zip® screws through top-hat battens are sensitive to differences in installation.

Table 4.1 Joint capacity (kN) – two Batten Zip® screws through top-hat battens

Data set		1			2			3		
Driven	**All**	**Under-driven**			**Correctly driven**			**Over-driven**		
Failure	All	All	With-drawal	Pull-thru'	All	With-drawal	Pull-thru'	All	With-drawal	Pull-thru'
No.	50	10	1	9	20	0	20	20	9	11
Avg	4.36	5.98	6.31	5.94	4.38		4.38	3.53	2.66	4.24
Std dev	1.18	0.86		0.90	0.42		0.42	0.98	0.68	0.48
CoV	30%	15%		16%	9%		9%	32%	25%	11%
Max	7.30	7.30	6.31	7.30	5.64		5.64	4.92	3.83	4.92
Min	1.86	4.69	6.31	4.69	3.91		3.91	1.86	1.86	3.59
LN 5%ile	2.57	4.64		4.56	3.77		3.77	2.04	1.72	3.49
4063 CV*	2.45	4.39		4.28	3.68		3.68	1.87	1.56	3.36
1649 BWS#	1.17	2.11		2.07	1.71		1.71	0.93	0.78	1.59
1649 CV	1.99	3.59		3.52	2.91		2.91	1.58	1.33	2.70
ISO CV	2.45	4.36		4.25	3.67		3.67	1.86	1.54	3.34

*CV = Characteristic Value
= Basic Working Strength

The characteristic strengths of two Batten Zip® screws through top-hat battens using the average of the characteristic values determined by AS/NZS 4063.2 (Standards Australia 2010c) and ISO 12122.5 (International Standards Organisation 2015) are:
- 4.37 kN for under-driven fasteners;
- 3.67 kN for correctly driven fasteners; and
- 1.86 kN for over-driven fasteners.

These differences are illustrated in Figure 4.2(b).

Wood fibre was embedded in the flutes of the over-driven Batten Zip® screws that failed in withdrawal, as shown in Figure 4.1(b). Over-driving the screws had the following effects:
- Before the head of the screw hit the flange of the batten rotation of the screw drew the screw into the timber. Each rotation pulled the screw downwards by one screw pitch.
- However, once the head of the screw contacted the flange of the batten, the large surface area of the flange acted as a large washer and prevented any further downward movement of the screw head.
- If the screw continued to rotate, but didn't move downwards relative to the rafter, each rotation pulled wood fibre upwards by one screw pitch. The screw effectively behaved like a drill in these circumstances.
- The damage to the wood fibre between the flutes reduced the withdrawal capacity of the screw.
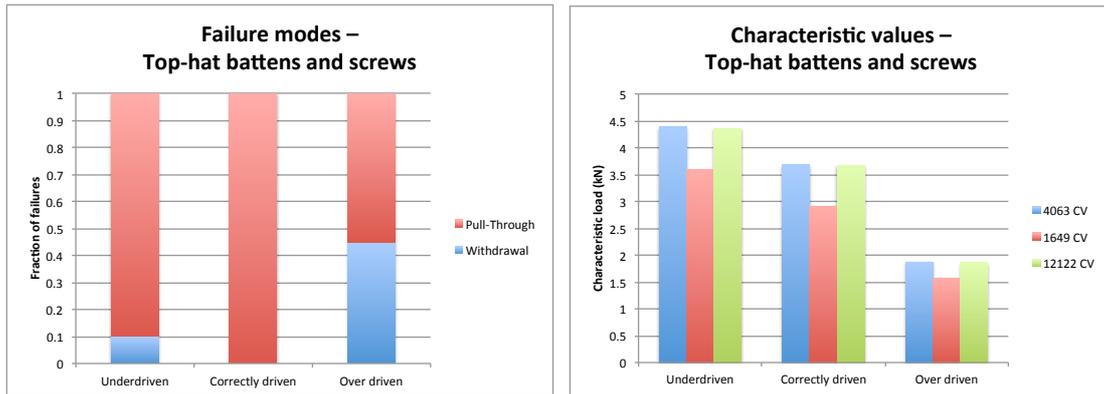
(a) Failure modes   *(b) Characteristic values*

Figure 4.2 Results for two Batten Zip® screws through top-hat battens

Figure 4.3 shows that:

- Most Batten Zip® screws that failed in withdrawal were over-driven;
- The strongest over-driven screws that failed in withdrawal had around the same capacity as the weakest of the over-driven screws that failed by pull-through;
- There was a significant difference between the capacity of the only under-driven screw that failed in withdrawal and the capacities of the over-driven screws that failed in withdrawal;
- The CFDs for the correctly driven and over-driven screws that failed by pull-through were similar. However, the CoV for the capacity of over-driven screws was much higher than the capacity of correctly driven screws because it was obtained from the total over-driven data shown in Figure 4.3(a) and (b).
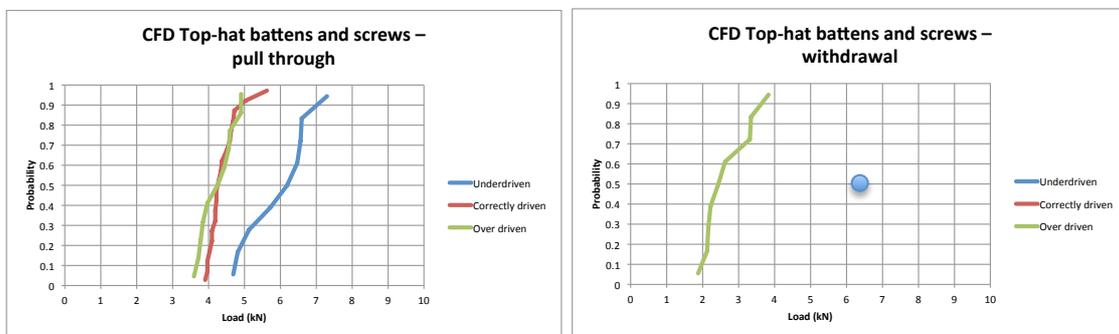
(a) Pull-through failures   *(b) Withdrawal failures*

Figure 4.3 Cumulative frequency distribution for two Batten Zip® screws through top-hat battens

Figure 4.4 indicates that there is almost no relationship between rafter density and strength of the fasteners that failed in withdrawal. Most of the withdrawal failures were for over-driven screws where over-driving damaged the fibres. The low capacity probably reflects the extent of the fibre damage rather than the inherent strength of the rafter material.
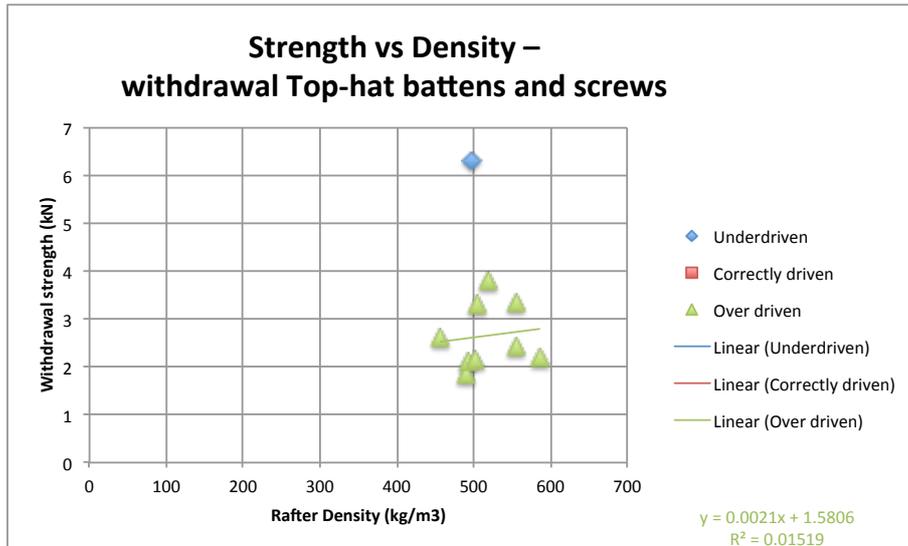
Figure 4.4 Strength vs rafter density for two Batten Zip® screws through top-hat battens

Section 2.1.1 showed that the average density of the rafters was within the range for JD4 timbers. Therefore the results of the tests applied to JD4 timber rafters.

An estimate of the strength of the same connections into JD5 timber rafters was calculated by scaling withdrawal loads by 0.8 (the ratio of JD5 withdrawal strength to JD4 withdrawal strength for screws in AS1720.1 (Standards Australia 2010b). The strength for any connections that failed by pull-through were not scaled as the mode of failure was independent of the density of the rafter; it was only affected by the properties of the batten. From the scaled individual test values, the JD5 characteristic values could be found using the analysis techniques outlined in section 2.6.2.

The cumulative frequency diagrams for capacity of screws through top-hat battens into JD4 and JD5 rafters are shown in Figure 4.5 and the characteristic values in Table 4.2. The correctly driven screws had known depth of penetration that enabled the calculation of the resistance to withdrawal in N/mm depth of embedment. This is shown in the last line of Table 4.2.

The capacity of the screws in JD4 timber rafters was limited by pull-through of the metal batten flange so was identical to the capacity in JD5 rafters.
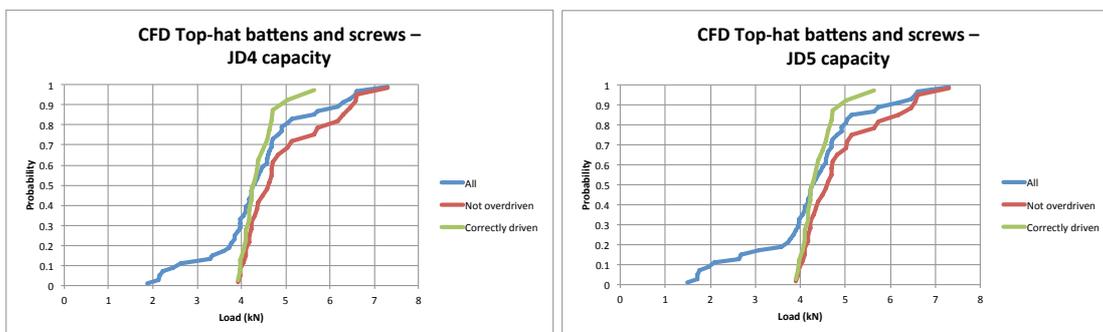
(a) JD4 timber rafters *(b) JD5 timber rafters*
Figure 4.5 Cumulative frequency distribution for two Batten Zip® screws through top-hat battens

The significant difference at the 5%ile level between data for all connections and correctly driven connections highlights the sensitivity of the Batten Zip® screws to over-driving.

Table 4.2 JD4 and JD5 test characteristic values (kN) – two Batten Zip® screws through top-hat battens

	JD4		JD5	
Driven	All	Correctly driven	All	Correctly driven
Failure	All	All	All	All
Number	50	20	50	20
Average	4.36	4.38	4.24	4.38
Std dev	1.18	0.42	1.29	0.42
CoV	30%	9%	38%	9%
Maximum	7.30	5.64	7.30	5.64
Minimum	1.86	3.91	1.49	3.91
LN 5%ile	2.57	3.77	2.21	3.77
4063 CV	2.45	3.68	2.07	3.68
1649 BWS	1.17	1.71	1.00	1.71
1649 CV	1.99	2.91	1.70	2.91
12122 CV	2.45	3.67	2.07	3.67
N/mm	31.5	47.3	26.6	47.3

A ratio of 1.05 between the design values and test values from this series of experiments was evaluated in section 3.1.1. The test results for the Batten Zip® screws from Table 4.2 were factored to give equivalent results to AS 1684.2 (Standards Australia 2010a), and are presented in Table 4.3.

Table 4.3 JD4 and JD5 design characteristic values (kN) – two Batten Zip® screws through top-hat battens

	JD4	JD5
Driven	Correctly driven	Correctly driven
Failure	All	JD5
Design value (kN)	3.5	3.5
N/mm per fastener	45.0	45.0

The capacities presented in Table 4.3 are for correctly driven fasteners, but Table 4.2 indicates that the capacity is adversely affected by over-driving. This connection is sensitive to installation technique.

4.1.2.   Significance of results

Under-driven screws had similar (but slightly better) capacity to the correctly driven screws. The characteristic capacity of over-driven screws was 50% of the capacity of correctly driven screws. However, it is quite unlikely that Batten Zip®s will be over-driven on site:

- The kick of the battery powered drill as the screws hit the flange of the batten, caused pain in the wrist.
- It is easy to remove the socket from the head of the screw once it is correctly driven to avoid over-driving the screw, even if the trigger was released too

late. In most cases screws will be installed with drivers that include a clutch to limit over-driving.

4.2.   Nails through top-hat battens

Each top-hat batten was connected to the MGP10 rafter by a pair of 57 mm hot-dipped galvanised nails – one on each side of the batten. The nails were installed as under-driven (Data set 4), correctly driven (Data set 5) or overdriven (Data set 6). Refer to Figure 2.7.

It was difficult to consistently install the nails as required because the nail-gun needed to be set at the right pressure to leave the head in the required position – clear of the flange (under-driven), in contact with the flange (correctly driven) or having crushed the flange (overdriven). Refer Figure 2.6. Differences in density of the timber caused some difference in resistance to driving the nails:

- Under-driven nails were generally installed as required;
- Some correctly driven nails may have been slightly over- or under-driven;
- Some of the over-driven nails may have been more over-driven than others, and caused more damage to the batten flange.

Some fasteners failed by pull through in the batten as shown in Figure 4.6(a) and others failed by withdrawal from the rafter as shown in Figure 4.6(b).

(a) Pull-through failure   *(b) Withdrawal failure*
Figure 4.6 Failure modes for nailed top-hat batten connections

Table 4.4 shows data for two 57 mm nails through top-hat battens and is illustrated in Figure 4.7. Table 4.4 shows that for the nailed top-hat batten to rafter connections:

- Slightly more connections failed in withdrawal regardless of how they were installed;
- Over-driven connections had a significantly lower capacity – the characteristic strength was around half that of the under driven fasteners and around 80% of the correctly driven nails;
- The CoVs for capacity were around 30% for over- and correctly driven nails, and around half that value for the under-driven nails;
- The capacity of the over-driven connections that failed by pull-through the top-hat battens was around half the capacity of the under-driven and correctly driven connections that failed by pull-through. (See Figure 4.8(a));

- There was a significant difference in characteristic values of capacity between the columns in Table 4.4. Batten to rafter connections using 57 mm nails into top-hat battens are sensitive to differences in installation.

Table 4.4 Joint capacity (kN) – two 57 mm nails through top-hat battens

Data set		4			5			6		
Driven	All	Under-driven			Correctly driven			Over-driven		
Failure	All	All	With-drawal	Pull-thru'	All	With-drawal	Pull-thru'	All	With-drawal	Pull-thru'
No.	50	11	6	5	18	11	7	21	12	9
Avg	2.50	2.82	2.60	3.09	2.72	2.44	3.17	2.15	1.99	2.36
Std dev	0.68	0.45	0.40	0.38	0.68	0.69	0.36	0.64	0.53	0.75
CoV	33%	16%	16%	12%	35%	39%	12%	32%	30%	34%
Max	3.75	3.50	3.17	3.50	3.75	3.06	3.75	3.44	2.66	3.44
Min	0.85	2.10	2.10	2.74	0.85	0.85	2.65	1.02	1.02	1.46
LN 5%ile	1.41	2.14	2.00	2.51	1.50	1.24	2.61	1.23	1.19	1.30
4063 CV*	1.34	2.02	1.85	2.36	1.36	1.07	2.48	1.13	1.07	1.13
1649 BWS#	0.64	0.97	0.91	1.14	0.68	0.56	1.19	0.56	0.54	0.59
1649 CV	1.09	1.65	1.55	1.94	1.16	0.96	2.02	0.95	0.92	1.01
ISO CV	1.34	2.01	1.83	2.33	1.35	1.05	2.46	1.12	1.06	1.11

*CV = Characteristic Value
= Basic Working Strength

The characteristic strengths of nails through top-hat battens using the average of the characteristic values determined by AS/NZS 4063.2 (Standards Australia 2010c) and ISO 12122.5 (International Standards Organisation 2015) are:
- 2.01 kN for under-driven fasteners;
- 1.35 kN for correctly driven fasteners; and
- 1.12 kN for over-driven fasteners.

These differences are illustrated in Figure 4.7(b).
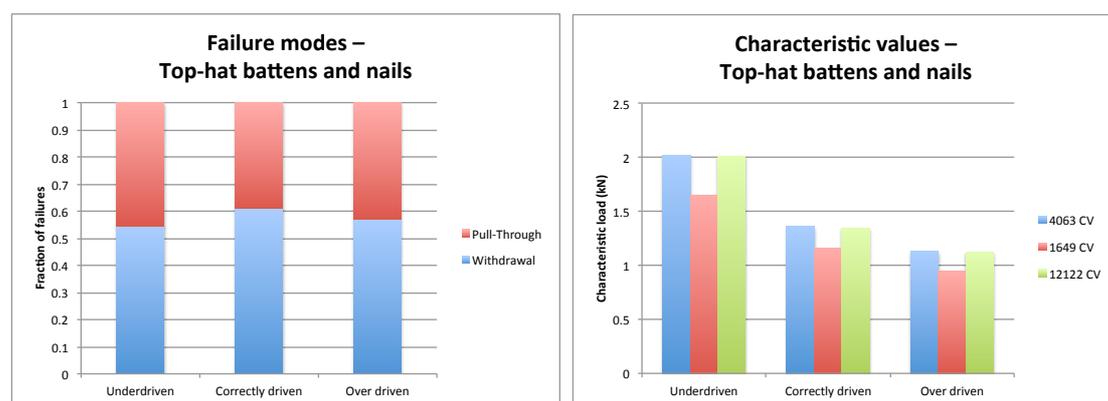
(a) Failure modes   *(b) Characteristic values*
Figure 4.7 Results for two 57 mm nails through top-hat battens

Figure 4.8 shows that:
- In general, the capacity of connections that failed in withdrawal were lower than those that failed by pull-through;

- There was a significant difference between the capacity of the over-driven nails that failed by pull-through and the capacities of the correctly and under-driven nails that failed by pull-through;
- The CFDs for the correctly driven and under-driven nails that failed in withdrawal were similar, except at the lower tail of the distribution;
- In general, over-driven nails had the lowest capacity for both withdrawal and pull-through failures – CFDs for over-driven nails are to the left of the correctly and under-driven nails in Figure 4.8(a) and (b).
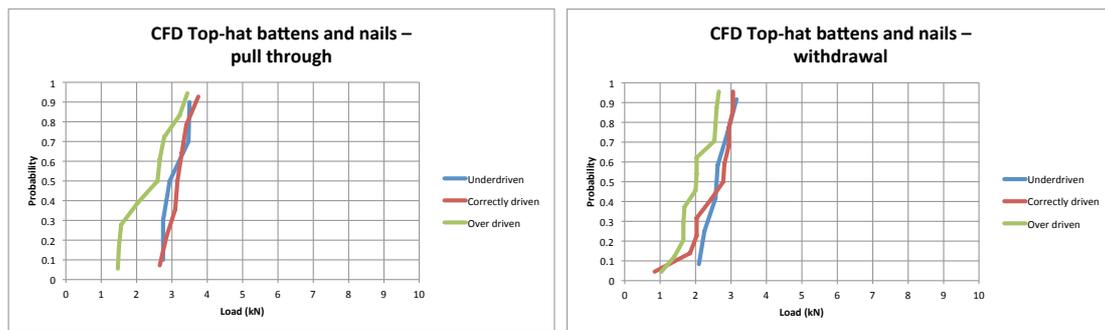
(a) Pull-through failures   *(b) Withdrawal failures*

Figure 4.8 Cumulative frequency distribution for two 57 mm nails through top-hat battens

Figure 4.9 shows the CFD for correctly driven fasteners that failed by pull-through in the main test program overlaid on the CFD for correctly driven 57 mm nails that failed by pull-through in the preliminary test program. The results are similar for both, which indicates that the preliminary tests were a valid representation of correctly driven nails in the main test program.
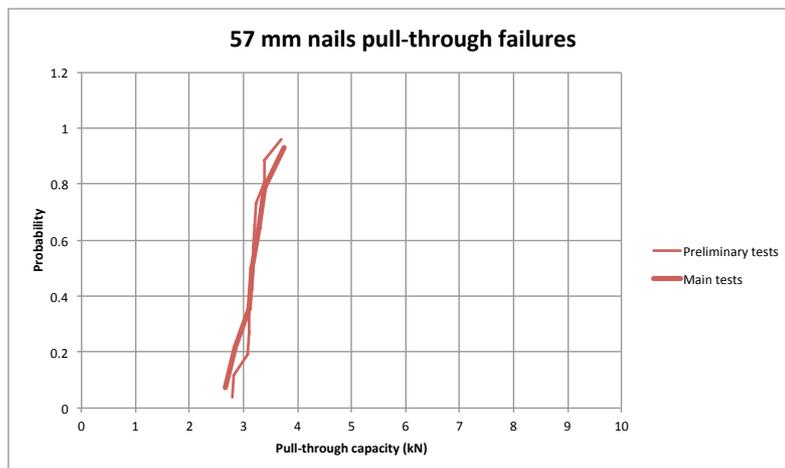
Figure 4.9 Comparison between preliminary and main test data for two correctly driven 57 mm nails through top-hat battens

Figure 4.10 indicates that there is almost no relationship between rafter density and strength of the nails that failed in withdrawal. Some nails had a rougher galvanised surface than other nails, which may have contributed more to the differences in withdrawal capacity than the density of the timber.

Section 2.1.1 showed that the average density of the rafters was within the range for JD4 timbers. Therefore the results of the tests applied to JD4 timber rafters.

An estimate of the strength of the same connections into JD5 timber rafters was calculated by scaling withdrawal loads by 0.65 (the ratio of JD5 withdrawal strength to JD4 withdrawal strength for nails in AS1720.1 (Standards Australia 2010b). The strength for any connections that failed by pull-through were not scaled as the mode of failure was independent of the density of the rafter; it was only affected by the properties of the top-hat batten. From the scaled individual test values, the JD5 characteristic values were found using the analysis techniques outlined in Section 2.6.2.
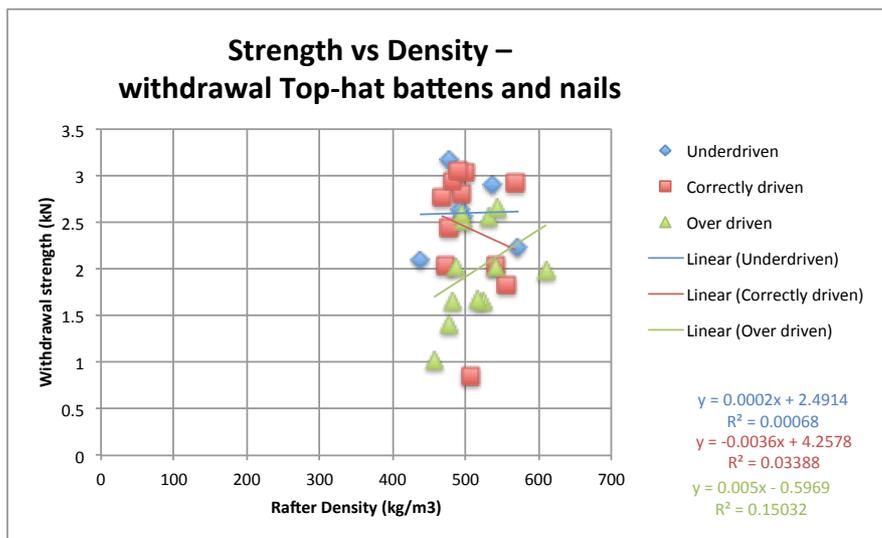
Figure 4.10 Strength vs rafter density for two 57 mm nails through top-hat battens

The cumulative frequency diagrams for the capacity of two nails through top-hat battens into JD4 and JD5 rafters are shown in Figure 4.11 and the characteristic values in Table 4.5. The correctly driven nails had known depth of penetration that enabled the calculation of the resistance to withdrawal in N/mm depth of embedment. This is shown in the last line of Table 4.5. The value for JD5 timber rafters (7.0 N/mm) is significantly less than the values in Table 4.2 for Batten Zip® screws through top-hat battens (47.3 N/mm).
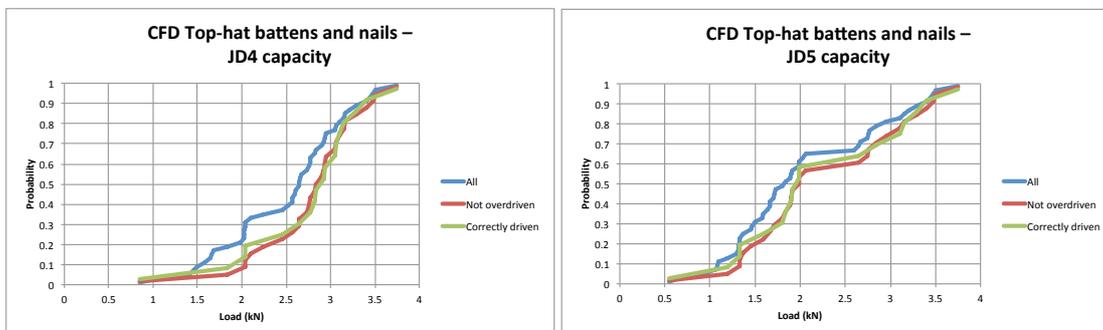
(a) JD4 timber rafters   *(b) JD5 timber rafters*

Figure 4.11 Cumulative frequency distribution for two 57 mm nails through top-hat battens

Table 4.5 JD4 and JD5 test characteristic values (kN) – two 57 mm nails through top-hat battens

	JD4		JD5	
Driven	All	Correctly driven	All	Correctly driven
Failure	All	All	All	All
Number	50	18	50	18
Average	2.50	2.72	2.04	2.20
Std dev	0.68	0.68	0.84	0.89
CoV	33%	35%	46%	50%
Maximum	3.75	3.75	3.75	3.75
Minimum	0.85	0.85	0.55	0.55
LN 5%ile	1.41	1.50	0.90	0.92
4063 CV	1.34	1.36	0.83	0.79
1649 BWS	0.64	0.68	0.41	0.42
1649 CV	1.09	1.16	0.70	0.71
12122 CV	1.34	1.35	0.84	0.78
N/mm	12.0	12.1	7.5	7.0

A ratio of 1.05 between the design values and test values from this series of experiments was evaluated in Section 3.1.1. Factoring the test results for the two 57 mm nails from Table 4.5 to give equivalent results to AS 1684 (Standards Australia 2010a) gives the information in Table 4.6.

Table 4.6 JD4 and JD5 design characteristic values (kN) – two 57 mm nails through top-hat battens

	JD4	JD5
Driven	Correctly driven	Correctly driven
Failure	All	JD5
Design value (kN)	1.29	0.74
N/mm per fastener	11.5	6.7

The characteristic capacities presented in Table 4.6 were significantly lower than the values for top-hat battens with Batten Zip® screws presented in Table 4.3.

4.2.1. Significance of results

The characteristic strength per mm of embedment of the nailed connections was around 16% of the value of the Batten Zip® screws. However, as the depth of embedment of the nails was greater than the depth of embedment of the Batten Zip® screws, the capacity of the nailed connection was between 20% and 25% the capacity of the Batten Zip® connection. The nailed connection cannot be regarded as being equivalent to the recommended connection.

The test data indicated that it is better to slightly under-drive these nails rather than over-drive them. The overdriven nails had the lowest capacities for both withdrawal and pull through failure modes. While the over-driven nails in this test program were controlled so that they did not punch through the batten flange, some nails in top-hat battens on building sites have punched through the flange and the connection would have no uplift capacity. As indicated in 4.1.1, it is difficult to control the depth to which the nail gun fasteners are installed into rafters of varying densities.

4.2.2. 75mm smooth shank nails

Table 2.3 showed that during the preliminary study, it was found that two 57 mm hot-dipped galvanised coil nails were significantly stronger than two 75 smooth shank gun-driven nails in batten to rafter connections using top-hat battens.

The average capacity of two 57 mm hot-dipped galvanised nails was 1.45 times the average capacity of two 75 mm smooth shank nails. With similar Coefficient of Variation, the characteristic capacity of two smooth shank 75 mm nails anchoring top-hat battens to JD5 rafters was estimated at 0.50 kN.

4.3. Other connection configurations for top-hat battens

Testing was necessary to determine the characteristic capacity of the correctly driven fasteners limited by both withdrawal and pull through. Section 5 compares the test results with analytical withdrawal strength models in AS 1720.1 (Standards Australia 2010b). However, there are no analytical models to predict pull through capacity in metal batten flanges.

Other configurations of connections between top-hat battens and timber rafters will also need to be evaluated by rigorous testing programs. This is even more necessary if the connection is not symmetrical (e.g. a screw in only one flange, or a screw in one flange and a nail in the other). The lack of symmetry causes:

- moments on the whole connection;
- torsion in the batten; and
- prying forces

all of which may reduce pull through capacity of a single fastener.

These differences in behaviour mean that it will not be possible to extrapolate from the results published in this report for symmetrical connections to predict capacities for the same fasteners used in asymmetrical connections. However, the capacity of asymmetric connections using a screw in one flange of the batten is very likely to be less than half of the capacity of a connection using screws in each flange as determined in Section 4.1.

5. COMPARISON OF TEST CHARACTERISTIC VALUES WITH DESIGN VALUES

5.1. Comparison with values in AS 1684

Figure 1.5 shows the batten to rafter connection loads for a number of different batten and rafter configurations and wind classifications (Standards Australia 2012). Table 5.1 shows the performance of the batten to rafter connections presented in this report for the common configuration of batten spacing of 900 mm and rafter spacing of 900 mm.

Table 5.1 Performance of batten to rafter connections in JD5 rafters – 900 mm batten and rafter spacing

Batten			35 mm thick timber	45 mm thick timber	0.55 mm BMT Top-hat battens	0.55 mm BMT Top-hat battens
Fastener	(two per connection	batten	75 mm bugle head screw	75 mm bugle head screw	Batten Zip® M5.5	57 mm galv nail
JD5 Design value (kN)			3.5	2.7	3.5	0.74
Wind class	Roof zone	load (kN)	Satisfies batten connection uplift loads			
N1	General	0.55	OK	OK	OK	OK
N1	Edge	1.0	OK	OK	OK	NA
N2	General	0.79	OK	OK	OK	NA
N2	Edge	1.5	OK	OK	OK	NA
N3	General	1.2	OK	OK	OK	NA
N3	Edge	2.3	OK	OK	OK	NA
N4	General	1.9	OK	OK	OK	NA
N4	Edge	3.5	OK	NA	OK	NA

The JD5 design values for the connections presented in this document were taken from:
- 35 mm thick timber batten with 75 mm bugle head screw (Table 3.3);
- 45 mm thick timber batten with 75 mm bugle head screw (Table 3.6);
- Top-hat metal batten with M5.5 Batten Zip® screw (Table 4.3); and
- Top-hat metal batten with 57 mm hot-dipped galvanised nail (Table 4.6).

The wind load requirements in the 3rd column in Table 5.1 were obtained from AS 1684.2 (Standards Australia 2010a) for 900 mm batten and rafter spacings.

Table 5.1 shows that:
- The 75 mm bugle head screw is satisfactory for general and edge roof zones in N1 to N4 inclusive in 35 mm thick battens.
- For 45 mm thick battens, the lower design capacity of the 75 mm bugle head screw is still satisfactory for both roof zones in N1 to N3 inclusive, but for N4, a longer screw will be required.

- The recommended Batten Zip® screws for top-hat battens have sufficient capacity for general and edge roof zones in N1 to N4 inclusive.
- Two 57 mm gun-driven hot-dipped galvanised nails through top-hat battens only have capacity to resist loads in general zones of N1 roofs.
- Section 4.2.2 estimated the characteristic capacity of 75 mm smooth shank nails through top-hat battens as 0.50 kN, so those nails would not have enough capacity for general zones in N1.

The test program has showed that the recommended use of 75 mm bugle head screws for 35 mm thick timber battens and M5.5 Batten Zip®s for top-hat battens (Lysaght 2014) is appropriate. While the tests showed that 75 mm bugle head screws are satisfactory in 45 mm thick battens for wind classifications N1 to N3, currently some builders are using 100 mm long bugle head screws with the 45 mm thick battens for all wind classifications.

The tests have demonstrated that:
- smooth shank 75 mm nails should NOT be used for top-hat battens in any wind classification; and
- 57 mm hot-dipped galvanised nails should NOT be used to fix steel top-hat battens in edge regions (within 1200 mm of eaves, ridges, hips or gables) of N1 roofs OR to fix metal battens on any part of the roof in other wind classifications

5.2. Comparison with values in AS 1720.1

5.2.1. Screws

This study found that the unit withdrawal capacity of the #14 Type 17, 75 mm long bugle head screws in JD5 timber was 88 N/mm for 35 mm thick battens and 90 N/mm for 45 mm thick battens. This capacity was compatible with the design value tabulated in AS 1684.2 (Standards Australia 2010a). However, AS 1720.1 (Standards Australia 2010b) indicates that the characteristic capacity for #14 screws in JD5 timber is based on 68 N/mm, around 75% of the test characteristic value in spite of the fact that edge distances in the test program were less than the minimum required in AS1720.1.

Because the failure of the M5.5 Batten Zip® screws was only by pull-through, it was not possible to compare test results the characteristic withdrawal capacity interpolated from AS 1720.1.

5.2.2. Nails

The unit withdrawal capacity of the 2.56 mm diameter 57 mm long galvanised nails from testing was 6.7 N/mm total depth of penetration. This is higher than an interpolated value in AS 1720.1 of 5.4 N/mm depth of penetration. The AS 1720.1 design value is around 80% of the test characteristic value. In this case, the rough surface of the galvanising may have given it a higher strength than the smooth shank nails that are the basis of the data in AS 1720.1.

6. Conclusions

The testing and analysis program investigated four batten to MGP10 rafter connections that are commonly used under sheet metal roofing in Perth WA. AS 1684.2 (Standards Australia 2010a) includes connection capacities for one 75 mm long bugle head screw through 35 mm thick timber battens, but does not provide capacities for the other three connections tested in this study.

MGP10 timber can be either JD4 or JD5. The timber for the rafters used in this test program was JD4, but because some pieces of MGP10 supplied to the industry can be JD5, JD5 capacities are used in design. The models for connection capacity in AS 1720.1 (Standards Australia 2010b) were used to derive capacities in JD5 timber. The results of tests on 75 mm bugle head screws through 35 mm thick timber battens were used to confirm the models by comparing derived capacities with the values for these connections into JD5 timber presented in AS 1684.2.

6.1. 75 mm long bugle head screws through 35 mm thick timber battens

The characteristic capacity derived from tests on 75 mm long bugle head screws through 35 mm thick timber battens into JD5 rafters is 3.5 kN where the screw is driven within 5 mm of the centre of the 35 mm rafter. This connection is suitable for:
- Edge zones in sheet roofs for wind classifications N1 to N4; and
- General zones in sheet roofs for wind classifications N1 to N4.

Note: The results on timber battens are valid for batten widths of 70 mm or greater.

The characteristic capacities were derived for correctly driven screws. However, the tests showed that this connection capacity was not sensitive to over-driving. The tests showed that the characteristic capacity can be achieved for screws within 5 mm of the centre of the rafter.

The test data was compared with the values in Table 9.25 in AS 1684.2:
- The test characteristic value in JD4 rafters was 4.5 kN compared with 4.5 kN in AS 1684.2 ;
- The test characteristic value in JD5 rafters was 3.5 kN compared with 3.6 kN in AS 1684.2.

6.2. 75 mm long bugle head screws through 45 mm thick timber battens

The characteristic capacity derived from tests on 75 mm long bugle head screws through 45 mm thick timber battens into JD5 rafters is 2.7 kN where the screw is driven within 5 mm of the centre of the 35 mm thick rafter. This connection is suitable for:
- Edge zones in sheet roofs for wind classifications N1 to N3; and
- General zones in sheet roofs for wind classifications N1 to N4.

Note: The results on timber battens are valid for batten widths of 70 mm or greater.

The characteristic capacities were derived for correctly driven screws. The tests showed that this connection capacity was not sensitive to over-driving of the screw.

The lower capacity of this connection compared with the same screw through 35 mm battens was due to the reduced depth of embedment in the rafters. The 75 mm long bugle head screws had the same capacity per mm depth of embedment in the rafter through both 35 mm and 45 mm thick battens.

The tests showed that the characteristic capacity can be achieved for screws within 5 mm of the centre of the rafter.

6.3. 40 mm long M5.5 Batten Zip® screws through 40 mm top-hat battens

The characteristic capacity derived from tests on 40 mm long Batten Zip® screws through 40 mm top-hat battens into JD5 rafters is 3.5 kN. Preliminary tests indicated that the capacity of the connection can apply to all 40 mm top-hat batten profiles made from 0.55 mm steel. This connection is suitable for:
- Edge zones in sheet roofs for wind classifications N1 to N4; and
- General zones in sheet roofs for wind classifications N1 to N4.

The characteristic capacities were derived for correctly driven screws. However, the tests showed that over-driving the screws decreased the capacity of this connection by 50%. Appropriate settings on installation tools should limit the number of connections with reduced capacity. The findings of this test program are consistent with the manufacturers' recommendations; 40 mm long M5.5 Batten Zip® screws should be used to connect top-hat battens to timber rafters.

6.4. 57 mm long hot-dipped galvanised nails through 40 mm top-hat battens

The characteristic capacity derived from tests on 57 mm long hot-dipped galvanised nails through 40 mm top-hat battens into JD5 rafters is 0.74 kN. Preliminary tests indicated that the capacity of the connection can apply to all 40 mm top-hat batten profiles made from 0.55 mm steel.

Manufacturers do not recommend fixing steel top-hat batten with nails. This test program has confirmed that 57 mm long hot-dipped galvanised nails into JD5 rafters are not suitable to fix 40 mm top-hat battens in edge regions of roofs in N1 classifications, or for any part of the roof in higher wind classifications.

The characteristic capacities were derived for correctly driven nails. However, significantly over-driving the nails has the potential to punch through the top-hat batten flange and give zero capacity for this connection. The tests showed that over-driven nails that failed by pull-through or withdrawal had generally lower capacity than correctly driven nails.

The preliminary tests on 75 mm smooth shank nails gave significantly lower capacities than the 57 mm hot-dipped galvanised nails. 75 mm smooth shank nails are NOT appropriate for general and edge zones in ALL wind classifications.

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