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LOOPED STRAP CONNECTIONS

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ABSTRACT: The uplift forces on roofs can be quite severe, particularly in cyclonic regions. Roof-to-wall connections (RWCs) must be robust enough to safely resist expected loads from high wind events. Several RWC details in the Australian Standard for residential timber-framed construction AS 1684.2 describe a steel strap wrapped over a rafter, looped under the top plate, and nailed into the back of the top plate. Supporting data could not be found for these details. We tested 21 different configurations of looped strap RWCs and found that the design load of 13 kN in AS 1684.2 is appropriate if quality steel strap is used.

KEYWORDS: steel strap, looped strap, roof to wall connections, tie-down

1 – INTRODUCTION

Timber-framed roofs must be designed for uplift forces from wind loads. In cyclonic regions, uplift forces can be extremely high. The Australian Standard for residential timber-framed construction AS 1684.2 [1] provides several tie-down options for roof-to-wall connections (RWCs). Some details in AS 1684.2 [1] show a 30 × 0.8 mm steel strap wrapped over the top of the rafter, looped under the top plate of the wall, and nailed into the back of the top plate (e.g., details 9.17(c) (Fig. 1), 9.21(e), and 9.25(g), AS 1684.2 [1]). The WoodSolutions website, in 2018, noted that original test data could not be found for this detail and invited research on the topic [2].

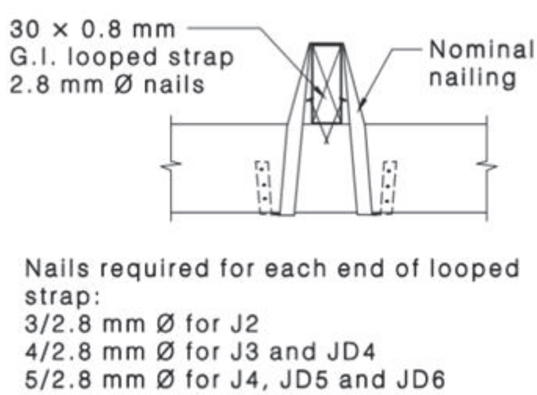

Figure 1. Detail 9.17(c), AS 1684.2 [1].

The rated design capacity for looped strap RWCs, as per AS 1684.2 [1], is 13 kN for one strap and 25 kN for two straps. Similar proprietary products are available to the Australian market from nailplate manufacturers with rated capacities varying depending on the joint group of the timber and how the products are installed. Joint group is a classification assigned to a timber species or species group for the purposes of calculating joint capacity. We note the rated capacities of proprietary products is, in most cases, lower than the rated capacity in AS 1684.2 [1].

Here, we report on our experimental test plan to determine appropriate design capacities for looped strap connections as described in AS 1684.2 [1].

2 – LITERATURE REVIEW

The looped strap RWC of interest in this study is shown in Fig. 1. The $30 \times 0.8mm$ steel strap is wrapped over the rafter, looped under the top plate or beam, and fixed with nails into the back of the top plate or beam. The number of nails depends on the joint group of the timber.

A search strategy was developed to identify any literature on the looped strap RWC detail in AS1684 [1]. Search terms included variations of the following: timber, roof, wall, connect*, strap, metal, steel, tie, hold, and down. In addition to commonly used databases and search engines, such as Google Scholar, searches were also conducted in specialist repositories including the CSIRO, Forest & Wood Products Australia, the Cyclone Testing Station, the Forest Products Journal, and CIB/W18 Proceedings. We were unable to find any literature on experimental studies of looped strap RWCs.

A review article on RWCs was published in the Journal of Wind Engineering & Industrial Aerodynamics in 2023 by Alawode et al. [3]. Their review identified nine different RWC types in the literature. The looped strap detail was not included in their review.

Two papers deserve some commentary.

Satheeskumar et al. [4] conducted testing on triple grip connections between roof trusses and walls. They

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mention the fact that tiedown straps are amongst "the most popular roof-to-wall connection types currently used in timber-framed buildings in Australia;" however, their literature review did not include any papers where the looped strap connection was tested.

Reardon and Henderson [5] tested high-capacity hold down systems with 2 mm thick steel overstrap, a through-bolt, and tiedown rods for connections between roof trusses and walls. Although this detail does not match the looped strap detail in AS 1684.2 [1], this is the only paper found with a steel strap over the top of a rafter.

Several proprietary products are available on the Australian market that are similar to the looped strap detail. MiTek's Cyclone Tie (CT) [6], when fixed in accordance with the "Wrap Under" detail, is rated between 6.1 kN for joint group J6 and 12.7 kN for joint groups J3/JD5 or better. There are several different sizes among MiTek's Cyclone Ties. The CT1200 is 30 mm wide × 0.8 mm thick and has a maximum rating of 11.2 kN. Pryda's Cyclone Straps [7] are 32 mm wide and, when they are "wrapped around," they are rated at 12.4 kN for the 1 mm thick strap or 15 kN for the 1.2 mm thick strap. Multinail's Cyclone Tie [8] is made from 1 mm thick steel and, when "wrapped under" the top plate, it is rated between 9.8 kN for joint group JD5 and 11.4 kN for joint group JD4 or better. We note the rated capacities of proprietary products of similar cross-sectional area is lower than the rated capacity in AS 1684.2 [1]. Only the 1.2 mm thick QHS9/2 product by Pryda has a higher rated capacity than that in the standard.

3 –DESCRIPTION OF TEST SPECIMEN

For this study, we were primarily interested in checking the validity of the details in AS 1684.2 [1]. We conducted monotonic tensile testing on 10 specimens in each of 21 different configurations of the looped strap RWC for a total of 210 specimens. Test specimens comprise two lengths of timber connected with 30 × 0.8 mm galvanised steel strap looped and nailed off with

Figure 2. Typical Test Setup (left) and Test Setup for Group R51 (right).

Table 1. Test Matrix.

Group	Strap	Top Timber Species	Joint Group	Bottom Timber Species	Timber Dimensions (mm)	Number of Nails per Leg of Strap	Number of Straps
K31	A	Kwila	J2	Kwila	100×38×300	3	
G11						1	
G21		Spotted Gum	JD1			2	1
G31						3	
G22						2	2
B31		Blackbutt	JD2			3	
A11	I			MGP10 Radiata Pine		1	
A21		Victorian Ash	JD3			2	1
A31							
A32					90×35×300		2
O31		Oregon				3	
P31		MGP10 Southern Queensland Pine					
P51			JD4	MGP10 Southern Queensland Pine		5	1
I41	A	MGP12 Imported Spruce/Pine/Fir		MGP12 Imported Spruce/Pine/Fir		4	
I42							2
R21						2	
R31		MGP10 Radiata Pine				3	1
R51	I		JD5	MGP10 Radiata Pine	90×45×1200	5	
R32							2
M31		Meranti			90×35×300	3	
C31		Western Red Cedar	JD6				1

2.8 (ϕ) × 30 mm galvanised clouts. Groups were designated a letter to represent the timber species (K = kwila, G = spotted gum, B = blackbutt, A = Victorian ash, O = Oregon, P = Southern Queensland pine, R = radiata pine, I = imported spruce/pine/fir, M = meranti, and C = western red cedar), then a number to represent the number of nails per leg (1 to 5), followed by a number to represent the number of straps (1 or 2). Two different brands of steel strapping were used in this study (A = Australian made and I = Imported). Specimens were stored in a climate-controlled room for at least two weeks after fabrication. Twenty groups were tested using the test setup shown in Fig. 2 (left). Group R51 was tested using the setup shown in Fig. 2 (right). No special care was taken during fabrication, ensuring that specimens were representative of high-volume trade work.

Testing of groups K31, P51, I41, and I42 occurred during October 2020. Group R51 was tested in November 2023. The remaining groups were tested in October 2021. Construction materials were scarce in 2021 due to a building boom and Australian made steel strap was unavailable. Consequently, the decision was made to use an imported brand of steel strap.

4 – TEST METHOD

A custom steel jig was manufactured for testing the majority of specimens (Fig. 2 left and Fig. 3). The jig was secured to a 50 kN Instron universal testing machine. Each specimen was placed into the jig and covers were locked into position with steel pins. The specimen was then subject to a monotonically increasing load at a displacement-controlled rate of 10 mm/min until failure occurred. Measurements were recorded by the Instron machine. Observations were recorded for each specimen. The moisture content of the timber was recorded afterwards using a Trotec T510 moisture meter.

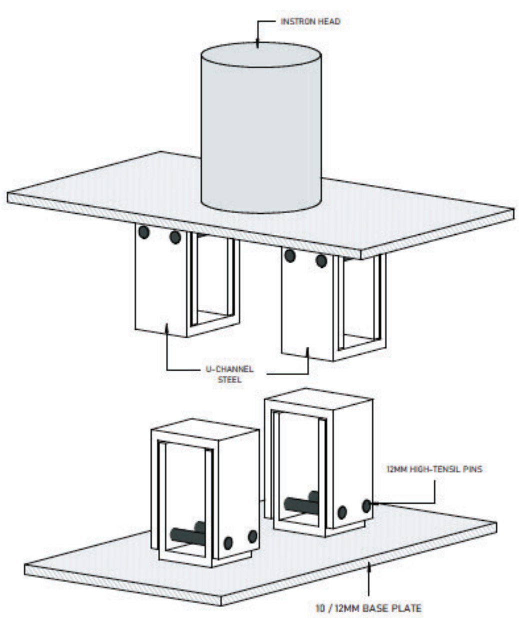

Figure 3. Custom Steel Jig.

A custom steel jig was manufactured for testing of group R51 (Fig. 2 right). The jig was secured to a 250 kN Hylec actuator. Each specimen was fixed to the jig with six evenly spaced Type 17, 14 gauge (6.3 mm (ϕ)) × 75 mm self-drilling batten screws. The bottom stick of timber was clamped firmly to the strongfloor at each end. The specimen was then subject to a monotonically increasing load at a displacement-controlled rate of 10 mm/min until failure occurred. Measurements were recorded by the Hylec machine. Observations were recorded for each specimen. The MC of the timber was not recorded.

5 – RESULTS

Results for mean peak load ($\boldsymbol{P_{ULT}}$) and mean moisture content ($\boldsymbol{MC}$) of the top piece of timber (i.e., the piece of timber which the strap was nailed to) are presented in Table 2 along with standard deviations.

Table 2. Results.

Test Group	P_{ULT} (kN)	σ	MC (%)	σ
K31	17.07	0.29	12.28	0.30
G11	8.43	1.29	11.99	0.88
G21	12.25	0.20	13.14	1.29
G31	13.06	0.24	11.94	0.72
G22	22.22	0.58	13.76	0.62
B31	12.83	0.65	12.39	1.56
A11	11.29	1.33	11.07	0.91
A21	12.42	0.18	11.41	0.80
A31	13.09	0.21	11.63	0.84
A32	25.17	5.80	12.47	0.85
O31	12.83	0.13	8.43	0.72
P31	13.45	0.12	10.81	0.76
P51	16.98	0.16	10.64	0.29
I41	15.31	1.86	11.06	0.13
I42	25.37	2.93	10.45	0.18
R21	12.53	1.36	9.00	1.11
R31	12.28	0.23	9.13	0.79
R51	11.44	0.72	n/a	n/a
R32	29.46	3.79	10.23	1.12
M31	12.71	0.15	9.28	0.34
C31	12.85	0.25	11.90	0.67

Load-deflection plots are not included in this paper due to the large number of specimens.

Moisture content was mostly between 8% and 12%. The minimum recorded MC was 7.0% and the maximum recorded MC was 14.5%.

The influence of species and joint group can be studied directly by selecting the groups using the imported brand of strap, with three nails in each leg, and having only one strap (Fig. 6). The mean peak load for hardwood specimens is 12.99 kN compared to 12.82 kN for softwood specimens. However, this minor difference in performance is heavily influenced by the surprisingly strong performance of the P31 test group. The test group with the highest mean peak load was P31, made with Southern Queensland pine (13.45 kN), and the test group with the lowest mean peak load was R31, made with radiata pine (12.28 kN). A one-sided Wilcoxon rank-sum test was used to evaluate the statistical significance of these results. Both the strong performance of test group P31 and the weak performance of test group R31 are

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statistically significant with respect to all other groups with $p \leq 0.001$. If groups P31 and R31 are removed from the analysis and outlier specimen B31-4 is also removed, the mean peak load is 12.92 kN for specimens with one looped imported strap having three nails into each leg. A normal distribution was fitted to this reduced dataset (n=59) to find the 5th percentile with 75% confidence which is 12.48 kN. If the full dataset is used (n=80), the 5th percentile with 75% confidence is 12.11 kN. This value applies to specimens using the imported strap. Characteristic values apply to the 5th percentile values estimated with 75% confidence [9].

To isolate and study the influence of a variable on the peak load of these RWCs, the data are normalised and centred on the mean:

$$x_{i_{rescaled}} = (x_i - \mu_k) \cdot \frac{\mu_A}{\mu_k} + \mu_A \tag{1}$$

$$x_{j_{rescaled}} = \left(x_j - \mu_l\right) \cdot \frac{\mu_B}{\mu_l} + \mu_B \tag{2}$$

where μ_A and μ_B are the means for all specimens in category A and B respectively, μ_k and μ_l are the means of test groups k and l, and i and j are indices for individual specimens within groups k and l. So, x_i is the peak load of the ith specimen from group k in category A. The normalised (i.e., rescaled) data are then used to study the influence of different categories of variable on the peak load of RWCs. This method is used here to study how the peak load is affected by 1) the number of nails in each leg of the strap, 2) doubling the number of straps, and 3) the brand of strap.

To study the influence of the number of nails on peak load, test groups were clustered into three categories based on the number of nails used per leg of strap. Category 1 includes test groups G11 and A11. Category 2 includes test groups G21, A21, and R21. Category 3 includes test groups G31, B31, A31, O31, P31, R31, M31, and C31. The data from all the test groups were normalised as described above and plotted in Fig. 7. As the number of nails increases, the mean peak load increases; however, the difference in performance of specimens with 2 nails per leg and 3 nails per leg is only 4%. The difference between all three groups is statistically significant with $p \ll 0.001$. It is worth noting that the spotted gum specimens with one nail per leg (G11) failed at much lower loads than the Victorian ash specimens (A11) (i.e., mean of 8.43 kN compared to 11.29 kN). This difference in performance is due to different failure modes. Most of the G11 specimens (90%) failed because the strap popped off the nails whereas the A11 specimens failed by fracture of the strap (60%) and nail pullout (40%).

To study the influence of the number of straps on peak load, test groups were clustered into two categories based on the number of straps used. Category 1 represents specimens with one strap and includes test groups G21, A31, I41, and R31. Category 2 represents specimens with 2 straps and includes test groups G22, A32, I42, and R32. The data from all the test groups were normalised as described above and plotted in Fig. 8. The mean peak load for specimens with one strap was 13.23 kN compared to 25.56 kN for specimens with two straps. The most notable difference between these two categories is the large variance in Category 2 by comparison with Category 1. The large variance in Category 2 could be due to the fact that one of the straps invariably has more slack than the other. This leads to one strap being fully engaged in resisting the load up to failure while the other strap is only partially engaged. The difference between the two groups is statistically significant with $p \ll 0.001$. A normal distribution was fitted to the original data (i.e., not the normalised data) for test groups G22, A22, and R32 (n=30) to find the 5th percentile with 75% confidence which is 15.91 kN. This value applies to specimens using the imported strap and is only 31% higher than the value for specimens with only one strap reported above. Failure modes of specimens with two straps were interesting. Specimens in the hardwood test groups G22 and A32 all failed by fracture of the strap. More than 50% of the specimens in the softwood test groups I42 and R32 failed due to crushing of the timber. Curiously, 90% of specimens in test group R32 achieved peak loads higher than all the specimens in test group G22 and 60% of the specimens in test group A32. It was noted during testing that softwood specimens crushed at the corners (Fig. 4 right and Fig. 5) whereas there was very little crushing at the corners on hardwood specimens (Fig. 4 left). Strap

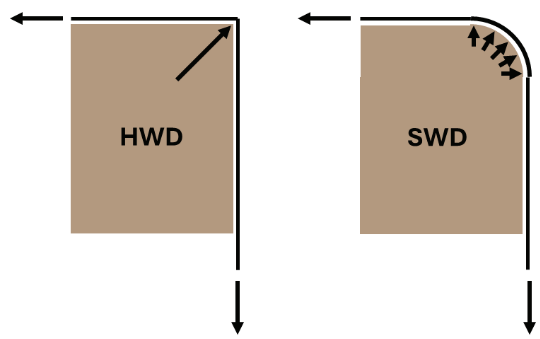

Figure 4. Strap on Hardwood (L) and Softwood (R).

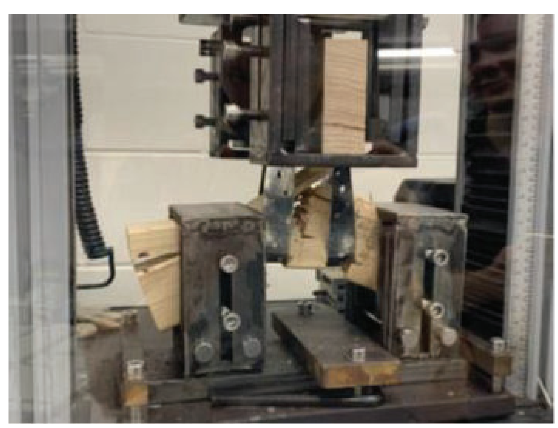

Figure 5. R32 Specimen during Testing.

failures among hardwood specimens tended to occur near the corner of the timber. This could explain why the R32 test group outperformed both the G22 and A32 test groups.

To study the influence of the brand of strap on peak load, test groups were clustered into two categories based on the brand of strapping. The imported brand of strapping includes test groups B31, P31, and R31. The Australian brand of strapping includes K31, P51, and I41. The data from these test groups were normalised as described above and plotted in Fig. 9. The mean peak load for specimens using the imported brand of strapping was 12.85 kN compared to 16.45 kN for specimens using the Australian brand of strapping. The difference between the two groups is statistically significant with $p \ll 0.001$. A normal distribution was fitted to the original data (i.e., not the normalised data) for the Australian brand of strapping (n=30) to find the 5th percentile with 75% confidence which is 13.81 kN. This result is higher than the rated design load of 13k N in AS 1684.2 [1].

The test method for test group R51 was developed to better simulate a roof-to-wall connection where the members are imperfectly constrained. This test method allows more movement in the specimen during testing. The mean peak load for test group R51 of 11.44 kN was 0.84 kN lower than the mean peak load for test group R31 of 12.28 kN. There was some overlap in results between these two groups with five specimens in test group R31 having peak loads below the highest peak load from test group R51 and three specimens in test group R51 having peak loads above the lowest peak load from R31. The difference between the two groups approaches statistical significance with $p = 0.0016$ on a one-sided Wilcoxon rank-sum test.

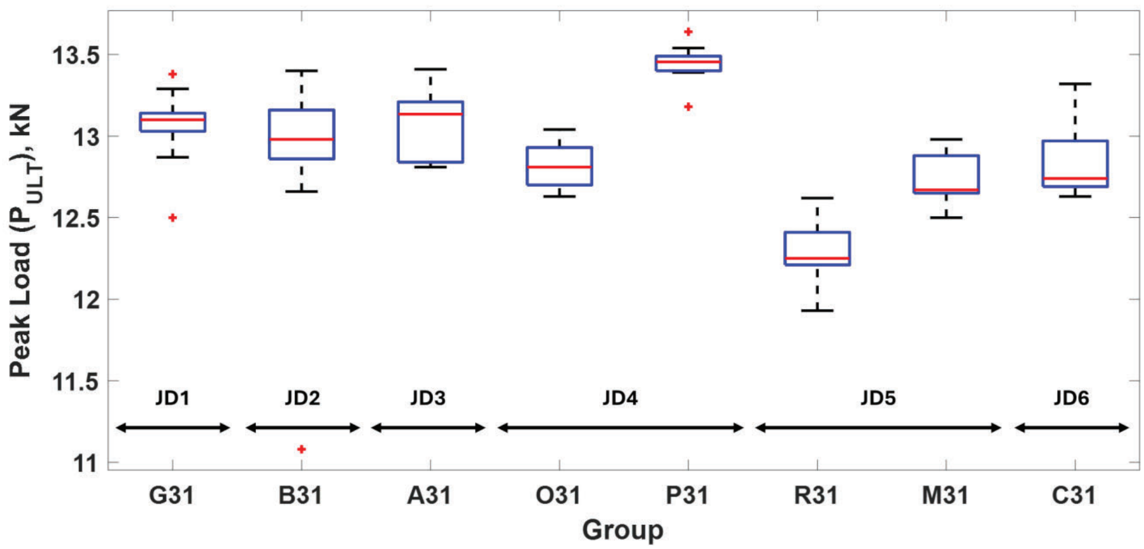

Figure 6. Peak Load (kN/m) by Species and Joint Group – Imported Brand, Single Strap, 3 Nails Each Leg.

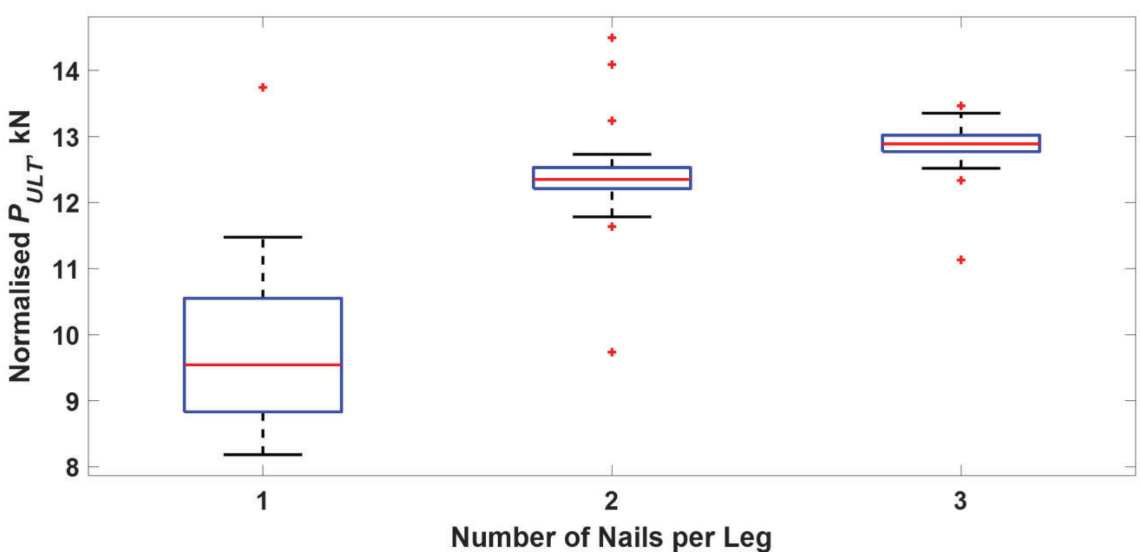

Figure 7. Normalised Peak Load (kN) by Number of Nails per Leg of Strap.

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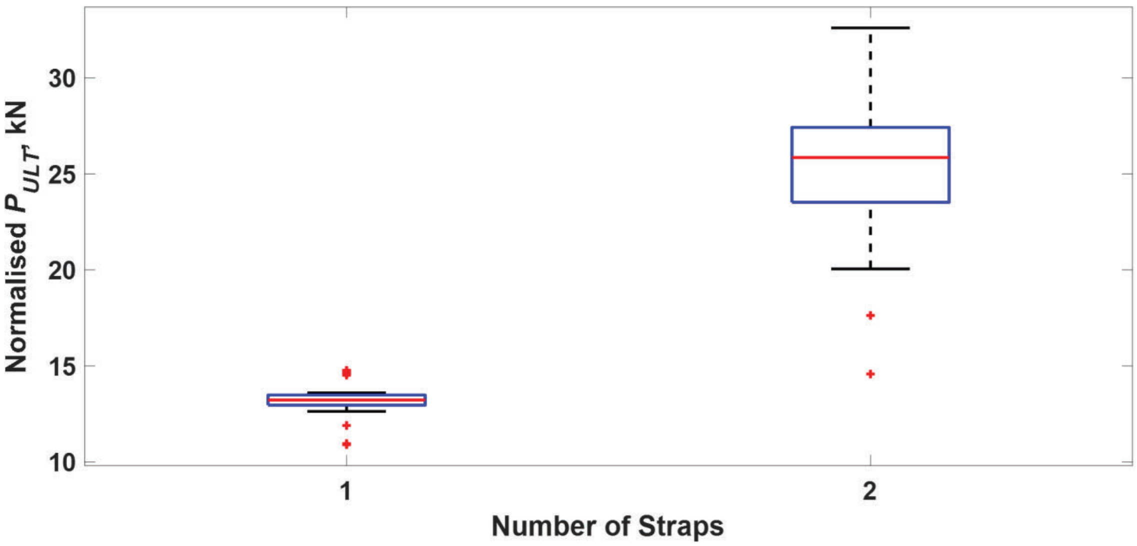

Figure 8. Normalised Peak Load (kN) by Number of Straps.

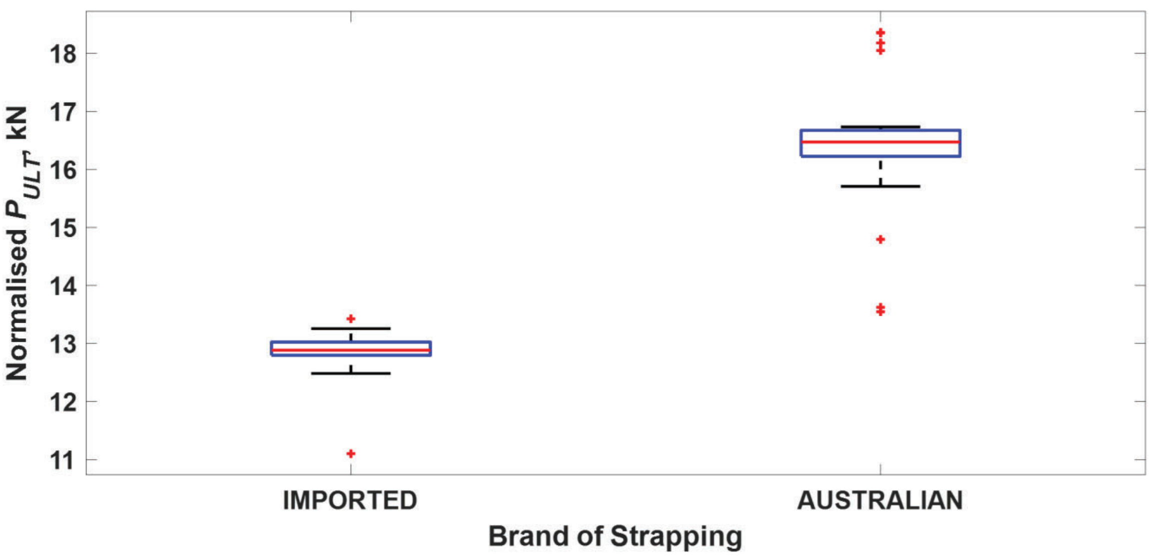

Figure 9. Normalised Peak Load (kN) by Brand of Strapping.

6 – DISCUSSION

There was no consistent relationship between peak load in these RWCs and timber species or joint group (Fig. 6). There is, therefore, no rationale for using a different number of nails based on joint group. The characteristic strength of a looped strap connection using the imported strap and having three nails per leg is 12.1 kN.

Three nails are better than two nails, but not by much. If the Australian brand of strap had been used on all the "31" specimens, it is likely that the peak load for Category 3 in Fig. 7 (i.e., specimens with three nails per leg) would have been closer to the results obtained for test groups K31, P51, and I41. As such, the looped strap details in AS 1684.2 [1] can be revised to show three nails per leg for all joint groups.

Doubling the strap does not double the capacity of these RWCs (Fig. 8). This finding is due to two reasons. Firstly, one strap is fully engaged in resisting the load whereas the second strap is only partially engaged. Secondly, when low density timber is used, timber failures occur, and the full capacity of the strap is not realised. Consequently, there is a much higher variance in peak load for double strap specimens, which penalises the characteristic value more heavily. The characteristic strength of a doubled looped strap connection using the imported strap and having three nails per leg is 15.9 kN.

The decision to use an imported brand of strap during the construction boom of 2021 has led to an unfortunate limitation of this study. However, it has highlighted the importance of product certification to ensure quality in building products. The mean peak load for specimens using the Australian brand of strapping was 28% higher than the mean peak load for specimens using the imported brand of strapping. The characteristic strength of a looped strap connection using the Australian brand of strap and having three nails per leg is 13.8 kN.

Results show that when a more realistic test setup is used (see Fig. 2 right) the peak load is reduced by 0.8 kN. This result can be used to infer an appropriate design load of 13 kN for a looped strap connection using quality steel strap (i.e., $13.8 - 0.8 = 13.0$). In other words, the design load of 13 kN in AS1684.2 for single looped strap connections is confirmed.

7 – CONCLUSION

We have presented here the findings of our study into the looped strap detail described in AS 1684.2 [1] and rated at 13 kN (e.g., details 9.17(c) (Fig. 1), 9.21(e), and 9.25(g), AS1684). A total of 210 specimens were fabricated and tested to determine peak load. Variables in the study include timber species (kwila, spotted gum, blackbutt, Victorian ash, Oregon, Southern Queensland pine, an imported spruce/pine/fir, radiata pine, meranti, and western red cedar), number of nails per leg of strap (1 to 5), number of straps (1 or 2), brand of strap (an Australian brand vs. an imported brand), and test method (small-scale vs. medium-scale).

Results confirm that the design load of 13 kN for one looped strap is appropriate if quality strap is used. If quality strap is not used, the design load should be reduced to 12 kN. The current requirement to use four nails per leg in JD4 timber and five nails per leg in JD5/JD6 timber is unnecessary. Three nails per leg is sufficient regardless of the joint group. Doubling the strap does not double the strength of the connection. Results from this study support an increase of 31% which translates to 17 kN if quality strap is used. Doubling the strap is not recommended for softwood.

Further study is recommended to compare the performance of specific brands of steel strap in the Australian market, to improve our understanding of the performance of specimens with two straps, and to confirm that three nails per leg is sufficient.

ACKNOWLEDGEMENTS

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