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Abstract:

The Limit States Australian/New Zealand Standard AS/NZS 4600:2005 and the North American Specification for the Design of Cold-Formed Steel Structural Members 2001 (2004 Supplement) include the newly developed Direct Strength Method of Design (DSM). In both Standards, the method presented (Chapter 7 of AS/NZS 4600:2005, Appendix 1 of NAS) is limited to pure compression and pure bending. The situation of combined bending and shear as occurs in a continuous purlin system is not considered.

In order to extend the DSM to purlin systems, it is necessary to prescribe and calibrate a method for combined bending and shear. Eight different test series on purlin sheeting systems with single, double and triple spans and both uplift and downwards load cases as well as screw and concealed sheeting have been performed at the University of Sydney over a 10 year period. As many of these tests consisted of continuous lapped purlins where combined bending and shear occurred at the purlin section just outside the end of the lap, it is possible to use this test data to propose an extension to the DSM. Furthermore, calibration of the proposals using the limit states design methodology is included in the report

This report makes two proposals for combined bending and shear, and calibrates them both for the full sets of vacuum rig test data.

Keywords:
Cold-formed; High strength steel; Direct strength method; Effective width method; Vacuum test; Combined bending and shear; Reliability

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1. INTRODUCTION

The Direct Strength Method (DSM) (Schafer and Peköz, 1998) was formally adopted in the North American Design Specification in 2004 (AISI, 2004) and in AS/NZS 4600:2005 (Standards Australia, 2005) as an alternative to the traditional Effective Width Method (EWM). It uses elastic buckling solutions for the entire member cross section to give the direct strength rather than for elements in isolation. The first advantage of the DSM is that it allows direct computation of the capacity of cold-formed thin walled members of complex section shape (eg. with intermediate stiffeners). Secondly, the interaction between local and overall modes and distortional and overall modes is taken into account. The DSM uses numerical solutions for elastic buckling and requires computer software such as THIN-WALL (CASE, 2006a) or CUFSM (Cornell University, 2001) to evaluate elastic buckling stresses. There is no need to calculate cumbersome effective sections especially with intermediate stiffeners.

In roof systems, high strength steel profiled sheeting fastened to high strength steel cold-formed purlins of lipped C or Z-section are commonly used throughout the world. The design of such systems in Australia is performed according to the provisions of the limit states Australia/ New Zealand Standard AS/NZS 4600:2005. The design procedures using the effective width method in the standard have been developed and verified (Clarke and Hancock, 1999, 2000) using an extensive database of test data obtained from more than 10 years of testing in the vacuum testing rig at the University of Sydney. These tests have covered a wide range of parameters including: single, double and triple spans; inwards and outwards loading; zero, one and two rows of bridging per span; screw fastened and concealed fixed sheeting systems; and cleat and flange bolting of purlins to rafters (Hancock et al., 1990, 1992, 1994, 1996)

The purpose of this report is to describe the basis of purlin design using an extension to the DSM in Section 7 of AS/NZS 4600:2005, and to evaluate the effectiveness of the design provisions against tests performed at the University of Sydney since the late 1980s. The comparisons between the DSM and the EWM are also included in this report. Moreover, two approaches for combined bending and shear are proposed and the calibration of the full set of vacuum rig test data as well as combined bending and shear controlling the design are made to determine the limit states safety index. A recommendation for combined bending and shear in the DSM is given in the report.

2. SUMMARY OF TEST DATA ON PURLIN-SHEETING SYSTEMS

In 1988, a large vacuum test rig was commissioned in the Centre for Advanced Structural Engineering (CASE) at the University of Sydney using funds provided by the Metal Building Products Manufacturers Association (MBPMA) for the purpose of provided test data on metal roofing systems. The test rig uses a conventional vacuum box to simulate wind uplift or inwards load. While the early series of tests were "generic" by virtue of their funding through the MBPMA, later test programs have been performed specifically for individual companies who have nevertheless made their results available in the public domain. All test series included cleats. The bridging provides a lateral and torsional restraint at the point of attachment to the purlin. The test programs which have been conducted are summarized in Table 1.

Table 1. Purlin-Sheeting Test Programs Performed at the University of Sydney

Series	Loading	Spans*	Bridging †	Sheeting Type	Rafter Fixing
S1	Uplift	3-span lapped	0, 1, 2	Screw fastened	Cleats
S2	Uplift	2-span lapped	0, 1, 2	Screw fastened	Cleats
S3	Uplift	Simply supported	0, 1, 2	Screw fastened	Cleats
S4	Downwards	3-span lapped	0, 1	Screw fastened	Cleats
S5	Uplift	Simply supported	0, 1, 2	Concealed fixed	Cleats
S6	Uplift	3-span lapped	1	Concealed fixed	Cleats
S7	Uplift	Simply supported	0, 1, 2	Screw fastened	Cleats
S8	Uplift	Simply supported 3-span lapped	1, 2	Screw fastened	Cleats

* 3x7.0 m spans with 900 mm laps between bolt centres for 3-span lapped configuration
2x10.5 m spans with 1500 mm laps between bolt centres for 2-span lapped configuration
1x7.0 m span for simply supported configuration.

† 0: Zero rows of bridging in each span
1: One row of bridging in each span
2: Single and double spans: Two rows of bridging in each span
Triple spans: Two rows of bridging in the end spans, one row in the central span

The bending moment distribution (BMD) and shear force distribution (SFD) for uplift loading are shown in Figures 1,2 and 3 for the single, double and triple spans at a uniform distributed load of w = 1 kN/m

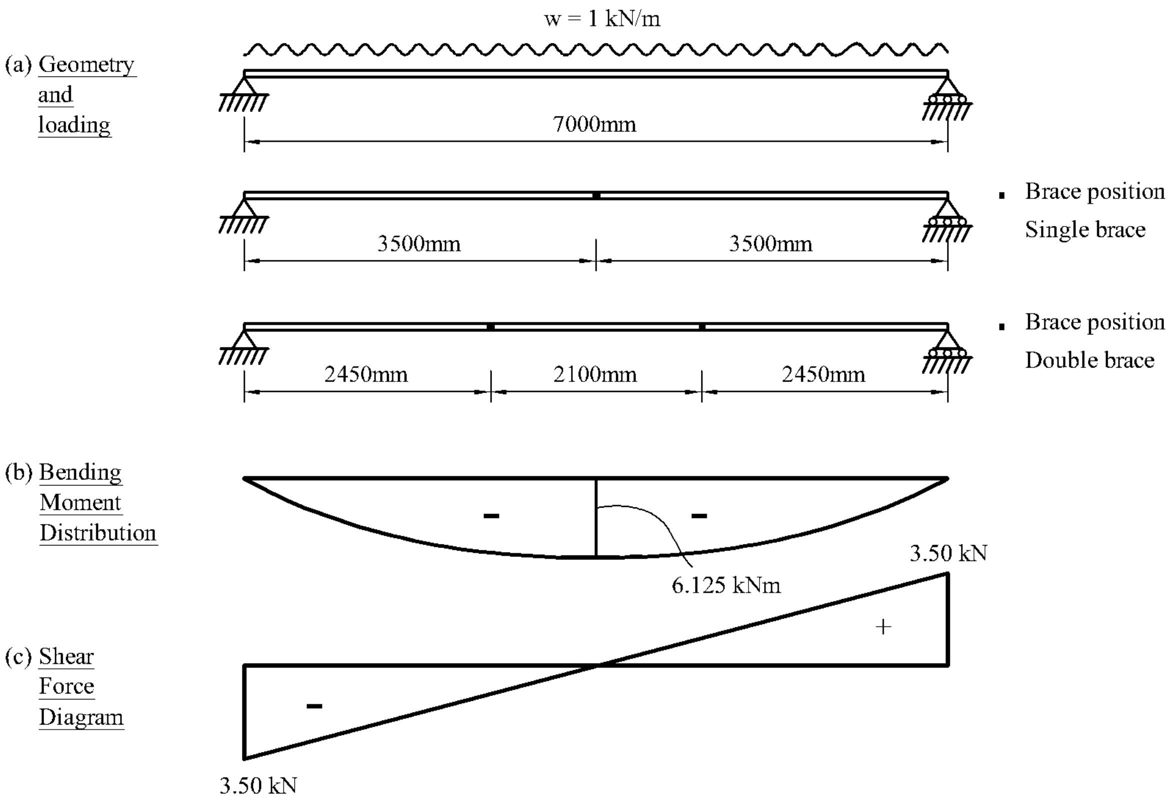

Figure 1. Single Span Z and C Section Purlin

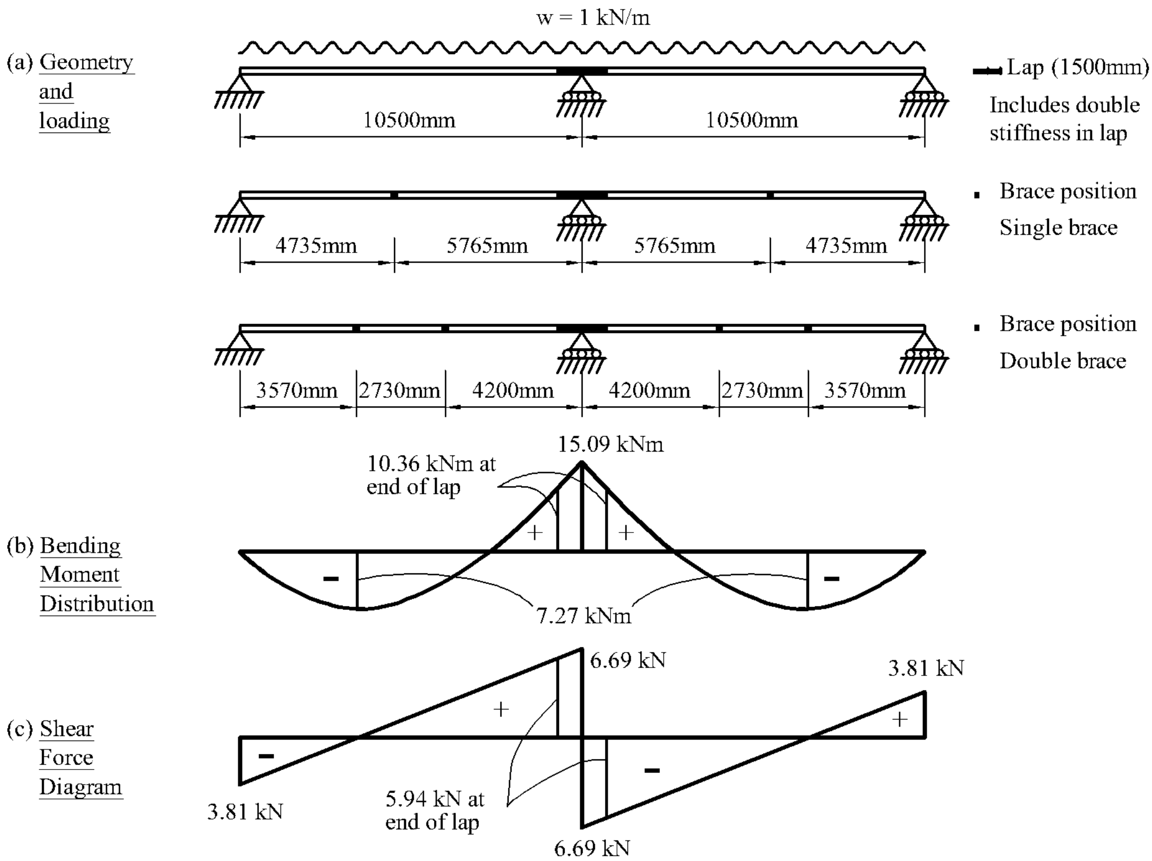

Figure 2. Double Span Lapped Z and C Section Purlin

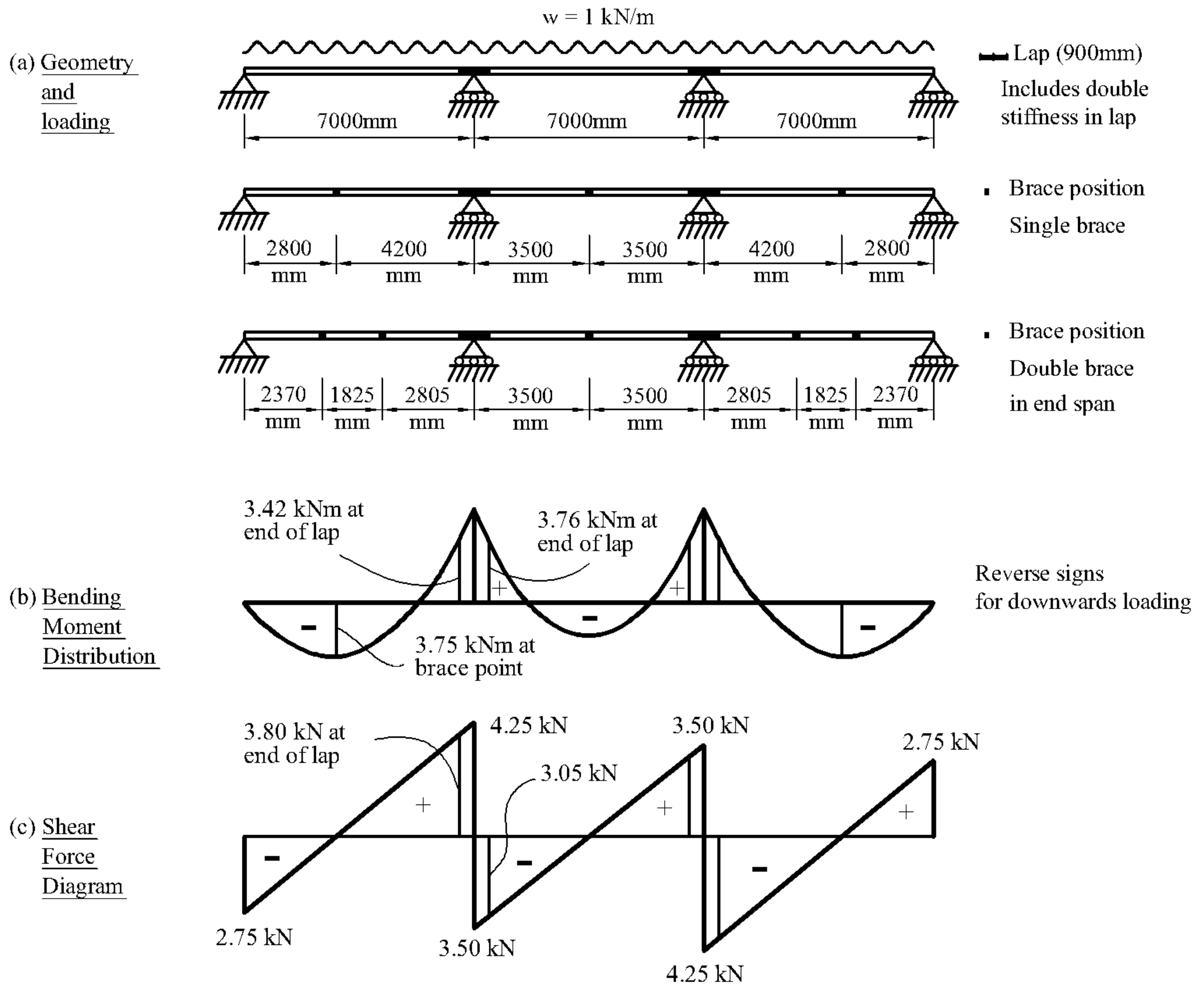

Figure 3. Triple Span Lapped Z and C Section Purlin

3. DSM DESIGN CRITERIA FOR PURLINS SYSTEMS

3.1 Lateral-Torsional Buckling Moment Capacity

3.1.1. C-factor approach for elastic buckling moment.

The so-called C-factor approach is outlined in Clause 3.3.3.2 of AS/NZS 4600:2005. For each segment of the purlin system between brace positions, a C_b factor based on the shape of the bending moment diagram is determined. This C_b factor is then used in conjunction with beam effective lengths (l_{ez}, l_{ey}) to determine the elastic buckling moment (M_o) of the segment. The advantage of the C-factor approach is that it is universally applicable to all purlin systems, including all section shapes, loading types, sheeting types and bridging layouts. It does not, however, consider the effect of load height or the lateral and torsional restraint provided by sheeting on the buckling moment. This latter aspect can be a source of considerable conservatism when it is applied to purlin systems as demonstrated later for purlins without bridging.

3.1.2. FELB approach for elastic buckling moment.

In the so called FELB approach, a Finite Element Lateral Buckling (FELB) analysis (CASE, 2006b) of the purlin system is performed to obtain the elastic buckling moment *(M_o)*. The advantages of the FELB approach are that the load height and sheeting restraint effects can be accounted for in the buckling analysis, and the whole purlin system is analyzed at the same time accounting for interaction between the segments.

3.1.3. Nominal member moment capacity.

The nominal member moment capacity *(M_{be})* for lateral-torsional buckling of the full section is calculated from Section 7.2.2.2 of AS/NZS 4600:2005 (Appendix 1, Section 1.2.2.1 of NAS (2004)) as follows:

For $M_o < 0.56M_y$: $$M_{be} = M_o \quad (1)$$

For $2.78M_y \geq M_o \geq 0.56M_y$: $$M_{be} = \frac{10}{9}M_y\left(1 - \frac{10M_y}{36M_o}\right) \quad (2)$$

For $M_o > 2.78M_y$: $$M_{be} = M_y \quad (3)$$

where

M_o = elastic lateral-torsional buckling moment as defined above

$M_y = Z_f f_y$

Z_f = section modulus about a horizontal axis of the full section

3.2 Local Buckling Moment Capacity (M_{bl})

The Direct Strength accounting for the interaction of Local with Lateral-Torsional buckling is computed using the appropriate Direct Strength equation.

The nominal member moment capacity *(M_{bl})* for local buckling is calculated from Section 7.2.2.3 of AS/NZS 4600:2005 (Appendix 1, Section 1.2.2.2 of NAS (2004)) as follows:

For $\lambda_l \leq 0.776$: $$M_{bl} = M_{be} \quad (4)$$

For $\lambda_l > 0.776$: $$M_{bl} = \left[1 - 0.15\left(\frac{M_{ol}}{M_{be}}\right)^{0.4}\right]\left(\frac{M_{ol}}{M_{be}}\right)^{0.4} M_{be} \quad (5)$$

where

λ_l = non-dimensional slenderness used to determine M_{bl}
$= \sqrt{M_{be} / M_{ol}}$
M_{ol} = elastic local buckling moment of the section
$= Z_f f_{ol}$
Z_f = section modulus about a horizontal axis of the full section
f_{ol} = elastic local buckling stress of the section in bending

3.3 Distortional Buckling Moment Capacity (M_{bd})

The Direct Strength accounting for the interaction of distortional buckling with yielding is computed using the appropriate Direct Strength equation.

The nominal member moment capacity *(M_{bd})* for distortional buckling is calculated from Section 7.2.2.4 of AS/NZS 4600:2005 (Appendix 1, Section 1.2.2.3 of NAS (2004)) as follows:

For $\lambda_d \leq 0.673$: $$M_{bd} = M_y \quad (6)$$

For $\lambda_d > 0.673$: $$M_{bd} = \left[1 - 0.22\left(\frac{M_{od}}{M_y}\right)^{0.5}\right]\left(\frac{M_{od}}{M_y}\right)^{0.5} M_y \quad (7)$$

where

λ_d = non-dimensional slenderness used to determine M_{bd}
$= \sqrt{M_y / M_{od}}$
M_{od} = elastic distortional buckling moment of the section
$= Z_f f_{od}$
Z_f = section modulus about a horizontal axis of the full section
f_{od} = elastic distortional buckling stress of the section in bending

From the above limiting strengths the nominal member capacity (M_b) is determined as:

M_b = the lesser of (M_{bl}, M_{bd}) (8)

3.4 Combined Bending and Shear

3.4.1 Nominal Shear Capacity

The nominal shear capacity *(V_v)* of a web is calculated from Section 3.3.4.1 of AS/NZS 4600:2005 in DSM format as follows:

$$\text{For } \lambda_v \leq 0.841: \quad V_v = V_y \tag{9}$$

$$\text{For } 0.841 < \lambda_v \leq 1.191: \quad V_v = 0.841\sqrt{V_{cr}V_y} \tag{10}$$

$$\text{For } \lambda_v > 1.191: \quad V_v = V_{cr} \tag{11}$$

where

$\lambda_v = \sqrt{V_y / V_{cr}}$

V_y = yield load of web $= 0.64 A_w f_y$

V_{cr} = elastic shear buckling force of web = $\dfrac{k_v \pi^2 E A_w}{12(1-\nu^2)\left(\dfrac{d_1}{t_w}\right)^2}$

d_1 = depth of the flat portion of the web measured along the plane of the web

t_w = thickness of web

A_w = area of web = $d_1 \times t_w$

k_v = shear buckling coefficient: $k_v = 5.34$ for unstiffened webs

3.4.2 Nominal Section Moment Capacity

3.4.2.1 __Proposal 1:__ ***(Local Buckling and Distortional Buckling for Bending)***

The nominal section moment capacity at local buckling *(M_{sl})* is determined by

$$M_{sl} = M_y \quad \text{for } \lambda_l \leq 0.776 \tag{12}$$

$$M_{sl} = \left[1 - 0.15\left(\frac{M_{ol}}{M_y}\right)^{0.4}\right]\left(\frac{M_{ol}}{M_y}\right)^{0.4} M_y \quad \text{for } \lambda_l > 0.776 \tag{13}$$

where $\lambda_l = \sqrt{\dfrac{M_y}{M_{ol}}}$

The nominal section moment capacity at distortional buckling *(M_{sd})* equals M_{bd} in Equation (6) and (7)

From the above limiting strengths the nominal section moment capacity *(M_s)* is determined as:

$$M_s = \text{the lesser of } \left(M_{sl}, M_{sd}\right) \tag{14}$$

3.4.2.2 **Proposal 2:** ***(Local Buckling alone for Bending)***

The nominal moment section moment capacity *(M_s)* equals M_{sl} in Equation (12) and (13) and distortional buckling is ignored

3.4.3 Combined Bending and Shear

The combined bending and shear limit state interaction equation is given in 3.3.5 of AS/NZS 4600:2005 as follows:

$$\left(\frac{M^*}{\phi_b M_s}\right)^2 + \left(\frac{V^*}{\phi_v V_v}\right)^2 \le 1.0 \tag{15}$$

When the term on the left hand side of this equation is greater than one for a purlin design controlled previously by lateral buckling, local buckling and/or distortional buckling, then combined bending and shear controls the design. In order to obtain the reduced design load, the interaction equation is divided by a factor that will bring the left hand side of this equation to one, and a reduced design load us computed.

4. COMPARISONS OF DESIGN LOADS WITH TESTS

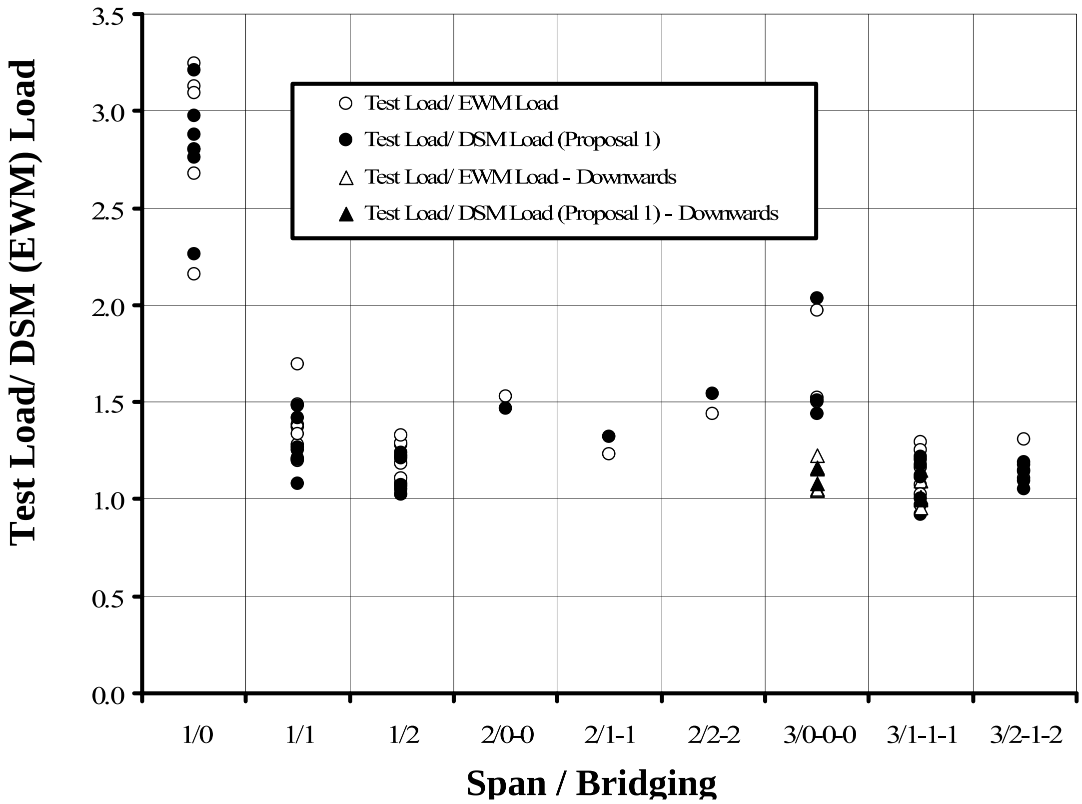

Figure 4. Comparison of DSM (Proposal 1) and EWM – FELB Approach

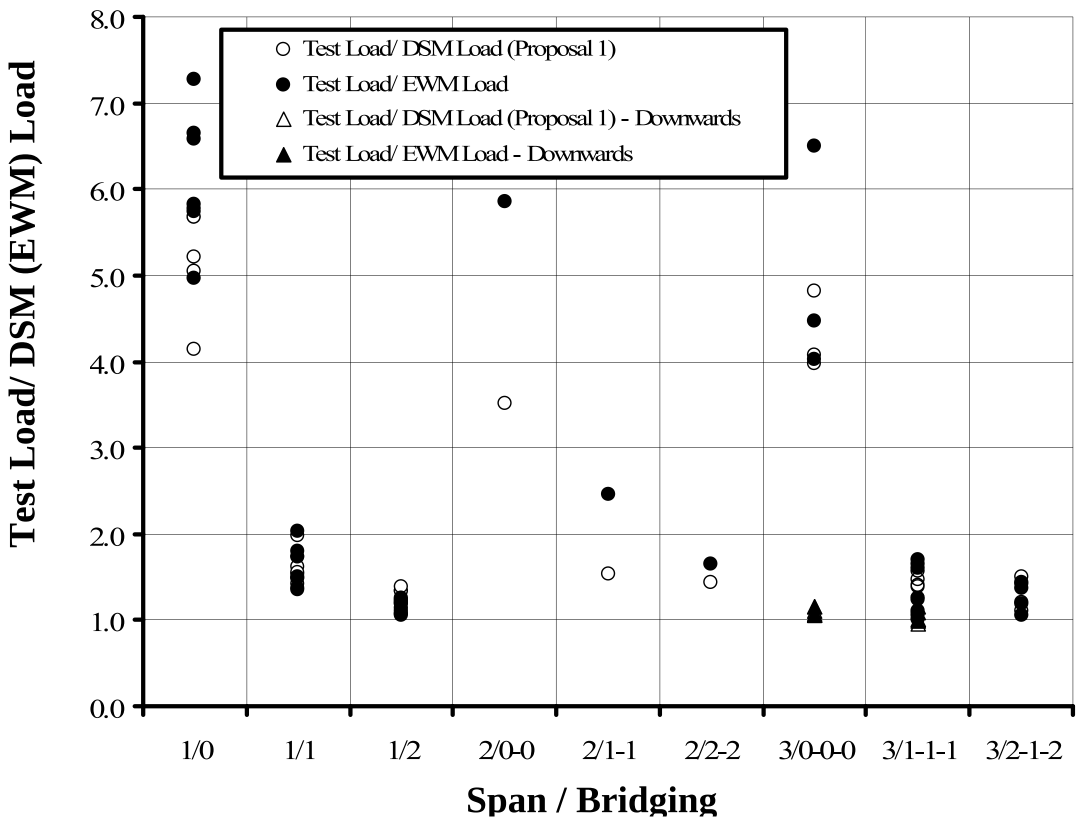

Figure 5. Comparison of DSM (Proposal 1) and EWM – C-Factor Approach

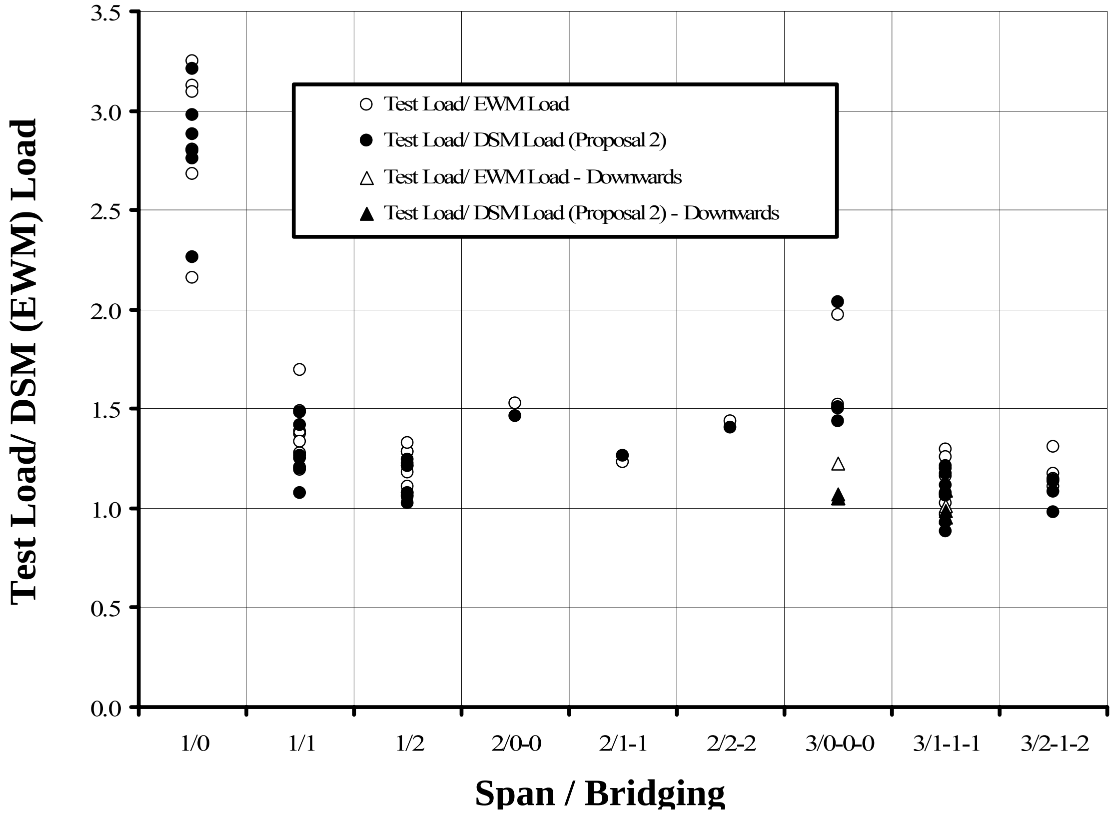

Figure 6. Comparison of DSM (Proposal 2) and EWM – FELB Approach

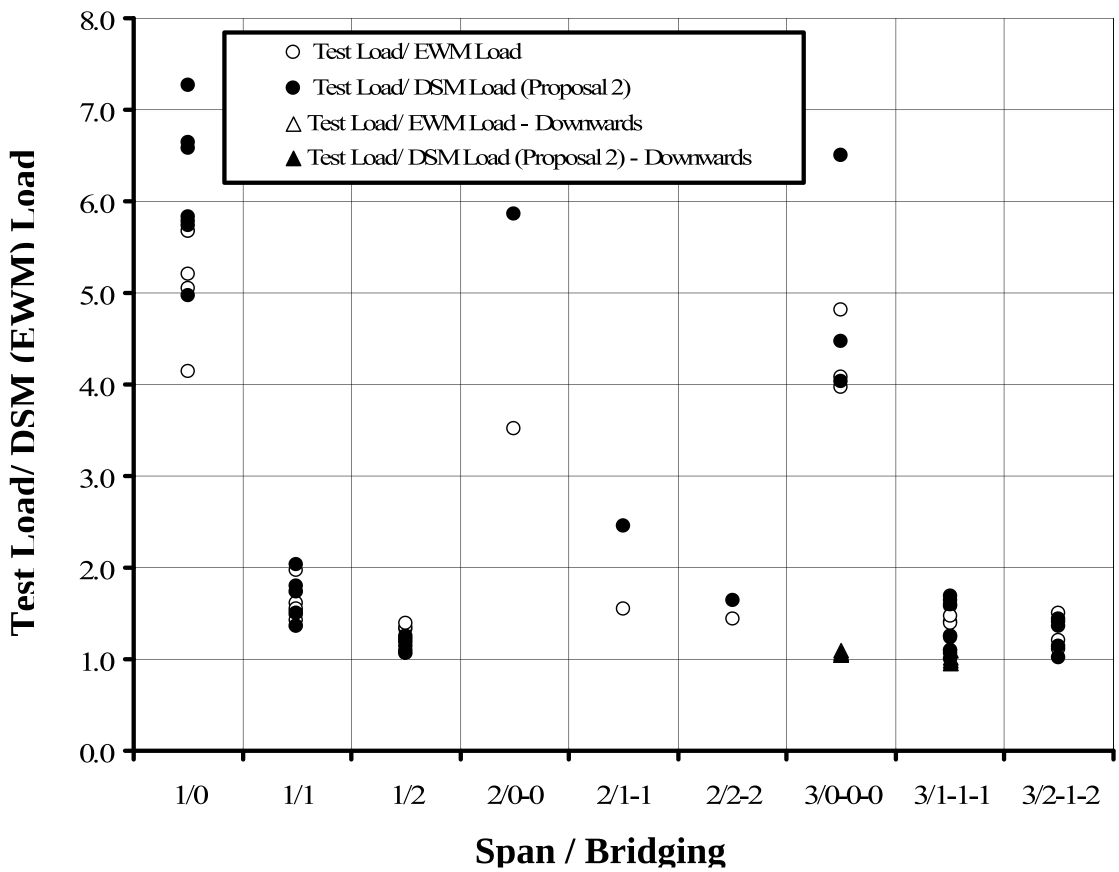

Figure 7. Comparison of DSM (Proposal 2) and EWM – C-Factor Approach

The results of the tests for all cleat-fastened systems compared with both the EWM and DSM are shown in Tables 2 and 3 respectively. The FELB approach is outlined in Table 2a and 2b and the C-factor approach in Table 3a and 3b. With respect to determination of the nominal section bending capacity *(M_s)* for use in Equation *(15)*, the results of the two proposals are summarized in Tables 2 and 3 for each approach. Proposal 1 uses the lesser of the local buckling and distortional buckling moments (See 3.4.2.1), whereas Proposal 2 uses the local buckling moments alone (See 3.4.2.2). Tables have been partitioned into single span, double span and triple span tests, and further subdivided in the case of single spans to 0, 1 and 2 rows of bridging. All calculations have been based on the test values of yield stress *(f_y)* and the measured dimensions to provide a true measure of design model accuracy. The EWM values are taken from the papers by Clarke and Hancock (1999, 2000). The comparisons of DSM (Proposal 1& Proposal 2) and EWM with both C-factor and FELB approaches are graphically reproduced in Figs 4 to 7 where they are plotted against the span and bridging cases.

The DSM strengths *(q_{DSM})* are the minimum of the combined bending and shear strengths *(q_{MV})* based on Equation *(15)* and the direct strengths *(q_b)* based on Equation (8). The elastic lateral-torsional buckling moments *(M_o)*, elastic local buckling stresses *(f_{ol})* and distortional buckling stresses *(f_{od})* are given in Appendices 1-4 along with the calculation for M_{be}, M_{bl}, and M_{bd}. With EWM, the EWM strengths *(q_{EWM})* are the minimum of the distortional buckling strengths *(q_D)*, the combined bending and shear strengths *(q_{MV})* and the effective width strengths *(q_C or q_{Felb})*.

In the FELB approach, the laps over internal supports and the load height were modelled, and a minor axis rotational restraint *(k_{ry})* of 1000 kN (representing the elastic restraint provided by the sheeting to the purlins as diaphragm shear stiffness) was employed.

As can be seen in Fig 4 which compares the EWM with the DSM for Proposal 1 using the FELB approach as summarised in Tables 2a, 2b, the DSM values *(q_T/q_{DSM})* are comparable with the EWM values *(q_T/q_{EWM})* over the full range of test configurations. It is interesting to note that on average, the DSM values are slightly lower and slightly less scattered. However, the DSM values are slightly above the EWM values for the double span with one and two rows of bridging. Only in the case of the triple span with single bridging, some values of q_T/q_{DSM} *or* q_T/q_{EWM} lie below 1.0. The tests without bridging are also predicted very conservatively for both methods due mainly to the effects of the sheeting which restrains twisting of the purlins and is not adequately accounted for in the FELB approach. However, when one or two rows of bridging are included, the predictions are much more accurate especially for the DSM single span with two rows of bridging and the DSM triple span with both one and two rows of bridging. It is also interesting to note that the downwards loading cases marked with the triangles (Δ) are more accurate than the uplift loading cases by either the EWM or DSM especially for the triple span without bridging.

Figure 5 shows similar comparisons to Figure 4 except that it applies to the C-factor approach as summarised in Tables 3a, 3b. The C-factor is generally less accurate and more variable than the FELB approach except for the downwards loading cases marked with the triangles (Δ). For the single and triple spans with one and two rows of bridging, the EWM and DSM are quite similar. However, for the double spans, the DSM is a lot more conservative than the EWM mainly because the elastic buckling moments predicted by the C-factor approach are so much lower than those predicted by the FELB approach, and possible differences in assumption between the EWM paper (Clarke & Hancock) and this paper.

By comparison of the values in Figure 6 and Figure 4, Figure 6 shows the same values as Figure 4 except that they apply to Proposal 2 for Tables 2a, 2b. The DSM values for Proposal 1 and Proposal 2 with the FELB approach are identical over the full range of test configurations except the double spans and triple spans with one and two rows of bridging and the downwards loading cases marked with the triangles (Δ). The explanation for this fact is that in Proposal 1, the majority of cases in double and triple span series are controlled by combined bending and shear. The nominal section bending capacity *(M_s)* is then governed by the distortional buckling moment *(Msd)* only. However, when the Local Buckling is only used for the nominal section capacity *(M_s)* in Proposal 2, the failure mode is controlled by the other effects such as distortional buckling or interaction of local buckling and lateral-torsional buckling. By comparison of the values in Figure 7 and Figure 5, Figure 7 shows the same values as Figure 5 except they apply to Proposal 2 for Tables 3a, 3b. The DSM values for Proposal 1 and Proposal 2 with the C-factor approach are only different in the triple spans with two row of bridging and the downwards loading cases marked with the triangles (Δ).

5. CALIBRATION

5.1 Reliability Analysis

The reliability or safety index, β, is a relative measure of the reliability or safety of a structure or structural element. When two designs are compared, the one with the larger β is the more reliable. The reliability index accounts for the uncertainties and variabilities inherent in the design parameters, such as the material properties, geometry, and applied load.

In order to calculate the reliability index, a First Order Second Moment (FOSM) method, described by Ellingwood *et al* (1980), can be used. This method is outlined in the AISI Commentary (2004) and AS/NZS 4600:1996 Commentary (1998). Because of the uncertainties and variabilities in the applied load, Q, and resistance, R, the exact probability distributions of Q and R (both assumed to have lognormal distributions) are not known. However, the mean applied load, Q_m, and the mean resistance, R_m, and the corresponding variances V_Q and V_R, can be used to calculate the reliability index, β:

$$\beta = \frac{\ln(R_m / Q_m)}{\sqrt{V_R^2 + V_Q^2}} \tag{16}$$

The mean resistance, R_m, is given by the equation

$$R_m = R_n.(P_m.M_m.F_m) \tag{17}$$

Where R_n is the nominal resistance, and

P_m = mean ratio of the experimentally determined failure load to the predicted failure load for the actual material and cross-sectional properties
M_n = mean ratio of the actual yield stress to the minimum specified (nominal) yield stress
F_m = mean ratio of the actual specimen thickness to the nominal thickness

The variance V_R is given by the equation

$$V_R = \sqrt{V_P^2 + V_M^2 + V_F^2} \tag{18}$$

where V_P, V_M and V_F are the variances of P, M and F respectively

The nominal resistance, R_n, for a screw-fastened purlin under wind uplift loading must satisfy the equation

$$Q \le \phi.R_n \tag{19}$$

where ϕ is the capacity reduction (resistance) factor

5.1.1 For the wind uplift tests

$$Q = W_u - 0.9G \tag{20}$$

W_u and G are the applied wind uplift and dead loads respectively. The load combination $Q = W_u - 0.9G$ is given in the Australian loading code, AS 1170.0 (Standards Association of Australia, 2002).

The exact probability distributions of Q, and hence of W_u and G, are not known. However, the mean load, Q_m, can be expressed as

$$Q_m = W_{u_m} - G_m \tag{21}$$

where W_{u_m} and G_m are the mean wind uplift and dead loads respectively. The corresponding variance, V_Q is given by the equation (AISI Commentary, 1991b)

$$V_Q = \frac{\sqrt{\left(W_{u_m} V_W\right)^2 + \left(G_m V_G\right)^2}}{W_{u_m} - G_m} \tag{22}$$

where V_W and V_G are the variances of W_u and G respectively. Ellingwood *et al* analyzed load statistics to show that G_m = 1.05G and V_G = 0.1. The value of 1.05 indicates that dead loads are, on average, underestimated. Holmes (1995) derived the W_{u_m} = 0.42W_u and V_W = 0.37 by application of the Australian wind loading code, AS 1170.2 (1989)

By assuming that G_m = 1.05G, W_{u_m} = 0.42W_u, and G/W_u = 0.1

$$Q_m \le 0.346.\phi.R_n \tag{23}$$

By substituting V_G=0.1 and V_W = 0.37 into Eq , V_Q =0.494

$$\beta = \frac{\ln((P_m.M_m.F_m)/(0.346.\phi))}{\sqrt{V_P^2 + V_M^2 + V_F^2 + 0.494^2}} \tag{24}$$

5.1.2 For the downwards loading tests

$$Q = 1.2G + W_u \tag{25}$$

W_u and G are the applied wind uplift and dead loads respectively. The load combination $Q = 1.2G + W_u$ is given in the Australian loading code, AS 1170.0 (Standards Association of Australia, 2002)

The exact probability distributions of Q, and hence of W_u and G, are not known. However, the mean load, Q_m, can be expressed as

$$Q_m = G_m + W_{u_m} \tag{26}$$

where W_{u_m} and G_m are the mean downwards wind and dead loads respectively. The corresponding variance, V_Q is given by the equation (AISI Commentary, 1991)

$$V_Q = \frac{\sqrt{\left(W_{u_m} V_W\right)^2 + \left(G_m V_G\right)^2}}{W_{u_m} + G_m} \tag{27}$$

where V_W and V_G are the variances of W_u and G respectively. G_m = 1.05G, W_{u_m} = 0.42W_u, and G/W_u=0.1

$$Q_m \le 0.468.\phi.R_n \tag{28}$$

By substituting V_G=0.1 and V_W = 0.37 into Eq , V_Q =0.297

$$\beta = \frac{\ln((P_m.M_m.F_m)/(0.468.\phi))}{\sqrt{V_P^2 + V_M^2 + V_F^2 + 0.297^2}} \tag{29}$$

The reliability index, β, can be calculated for a fixed value of the resistance factor ϕ = 0.9.

5.2 Results of Reliability Analyses

The results of the reliability analyses performed according to Section 5.1 are given using the FELB approach in Table 4 and the C-factor approach in Table 5. Both tables included the DSM by Proposals 1 and 2, and the EWM. The reliability analyses have been grouped according to the number of spans (1, 2 or 3), uplift or downwards loading, and number of rows of bridging (0, 1 or 2). All of the parameters used for each case are shown in Tables 4 and 5 and the resulting safety indices β are also shown.

The safety indices β in Table 4 for the FELB approach vary from 2.844 to 4.684 for DSM Proposal 1 and 2.764 to 4.684 for DSM Proposal 2. By comparison, the EWM values vary from 2.906 to 4.645. The lowest values correspond to Triple Span Uplift tests with one row of bridging where combined bending and shear controlled in some cases. All of the cases with no bridging have high safety indices and those with one or two rows of bridging have lower safety indices as expected. On the basis that a target safety index of 2.5 is required (AISI Commentary 2004 and AS/NZS 4600:1996 Commentary 1998), then both the DSM by either Proposals 1 and 2 and the EWM give acceptable values when the FELB approach is used.

The safety indices β in Table 5 for the C-factor approach vary from 2.967 to 6.169 for DSM Proposal 1 and 2.967 to 6.169 for DSM Proposal 2. By comparison, the EWM values vary from 2.883 to 5.899. The lowest values correspond to Double Span Uplift tests where the high variability of predictions leads to lower safety indices. Excluding the double span cases, then the Triple Spans with 1 and 2 rows of bridging and the Single Spans with two rows of bridging give the lowest safety indices. As for the FELB approach, all of the cases with no bridging have high safety indices and those with one or two rows of bridging have lower safety indices as expected. On the basis that a target safety index of 2.5 is required (AISI Commentary 2004 and AS/NZS 4600:1996 Commentary 1998), then both the DSM by either Proposals 1 and 2 and the EWM give acceptable values when the C-factor approach is used.

6. CONCLUSION

This paper has outlined two current approaches to the design of purlin systems using an extension to the Direct Strength Method (DSM) in Section 7 of AS/NZS 4600:2005 which are referred to herein as C_b-factor and FELB approaches. The results are compared with the Effective Width Method (EWM) as well as the ones from purlins test results which was implemented at the University of Sydney by using the vacuum testing rig more than 10 years.

This report has also made two proposals for the bending and shear failure mode for use in the Direct Strength Method. Proposal 1 uses the lesser of the local buckling and distortional buckling section strengths in the combined bending and shear interaction equation, and Proposal 2 uses only the local buckling section strength in the interaction equation. All methods produce acceptable safety indices including those test cases where combined bending and shear dominated such as the triple spans under uplift loading with one and two rows of bridging. It therefore appears that Proposal 2 is an acceptable method for safe design even though it ignores the distortional buckling strength.

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APPENDICES

Table 2a. Purlin Test Results and Comparison with DSM (Proposal 1 & Proposal 2) and EWM with FELB Approach

Test	Section	Bridging	q_T (kN/m)	DSM								EWM				
				Proposal 1				Proposal 2								
				Bending/Shear q_{MV1} (kN/m)	DSM q_b (kN/m)	q_{DSM1} (kN/m)	q_T/q_{DSM1}	Bending/Shear q_{MV2} (kN/m)	DSM q_b (kN/m)	q_{DSM2} (kN/m)	q_T/q_{DSM2}	Distort. q_D (kN/m)	Bending/Shear q_{MV} (kN/m)	EWM q_{FELB} (kN/m)	q_{EWM} (kN/m)	q_T/q_{EWM}
S3S1	Z200-24	0	3.28	3.84	1.14	1.14	2.88	4.83	1.14	1.14	2.88	3.84	4.25	1.17	1.17	2.80
S3T4	C200-24	0	3.63	3.89	1.13	1.13	3.21	4.78	1.13	1.13	3.21	3.89	4.23	1.16	1.16	3.13
S5L1	Z200-25/1L	0	2.57	3.95	1.14	1.14	2.26	4.95	1.14	1.14	2.26	3.95	4.35	1.19	1.19	2.16
S5S1	Z200-19/S1	0	2.17	2.57	0.78	0.78	2.80	3.10	0.78	0.78	2.80	2.57	3.05	0.81	0.81	2.68
S7T1	Z20015/1	0	1.85	1.97	0.62	0.62	2.98	2.16	0.62	0.62	2.98	1.97	2.06	0.57	0.57	3.25
S7T2	C20015/2	0	1.70	2.00	0.62	0.62	2.76	2.23	0.62	0.62	2.76	2.00	1.99	0.55	0.55	3.09
						Mean	2.81			Mean	2.81				Mean	2.85
						SD	0.32			SD	0.32				SD	0.40
S3T2	Z200-24	1	3.69	3.84	2.92	2.92	1.27	4.83	2.92	2.92	1.27	3.84	4.25	2.69	2.69	1.37
S3T5	C200-24	1	3.63	3.89	2.90	2.90	1.25	4.78	2.90	2.90	1.25	3.89	4.23	2.84	2.84	1.28
S5L2	Z200-25/2L	1	4.19	4.03	2.95	2.95	1.42	5.06	2.95	2.95	1.42	4.03	4.35	2.82	2.82	1.49
S5S2	Z200-19/S2R	1	2.28	2.60	2.12	2.12	1.08	3.15	2.12	2.12	1.08	2.60	3.05	1.91	1.91	1.19
S7T3	C20015/3	1	1.77	1.92	1.47	1.47	1.20	2.13	1.47	1.47	1.20	1.92	1.91	1.28	1.28	1.38
S8T2	C200-15/2	1	1.71	1.82	1.42	1.42	1.21	2.03	1.42	1.42	1.21	1.82	1.84	1.28	1.28	1.34
S8T3	C150-12/3	1	0.83	1.00	0.56	0.56	1.48	1.12	0.56	0.56	1.48	1.00	1.05	0.49	0.49	1.69
						Mean	1.27			Mean	1.27				Mean	1.39
						SD	0.14			SD	0.14				SD	0.16
S3T3	Z200-24	2	4.76	3.84	3.84	3.84	1.24	4.83	3.84	3.84	1.24	3.84	4.25	3.72	3.72	1.28
S3T6	C200-24	2	4.71	3.89	3.89	3.89	1.21	4.78	3.89	3.89	1.21	3.89	4.23	3.67	3.67	1.28
S5L3	Z200-25/2L	2	4.90	4.01	4.01	4.01	1.22	5.00	4.01	4.01	1.22	4.01	4.35	3.69	3.69	1.33
S5S3	Z200-19/S3	2	2.74	2.60	2.60	2.60	1.05	3.13	2.60	2.60	1.05	2.60	3.05	2.54	2.54	1.08
S7T5	C20015/5	2	1.95	1.91	1.90	1.90	1.02	2.12	1.90	1.90	1.02	1.91	1.91	1.65	1.65	1.18
S8T1	C200-15/1	2	1.98	1.87	1.86	1.86	1.06	2.09	1.86	1.86	1.06	1.87	1.88	1.63	1.63	1.21
S8T4	C150-12/4	2	0.93	0.99	0.87	0.87	1.07	1.11	0.87	0.87	1.07	0.99	1.05	0.84	0.84	1.11
						Mean	1.13			Mean	1.13				Mean	1.21
						SD	0.09			SD	0.09				SD	0.09
S2T1	Z300-25*	0_0	4.33	3.73	2.95	2.95	1.47	4.07	2.95	2.95	1.47	4.08	4.07	2.83	2.83	1.53
S2T2	Z300-25*	1_1	4.93	3.73	3.90	3.73	1.32	4.07	3.90	3.90	1.26	4.08	4.07	4.01	4.01	1.23
S2T3	Z300-25**	2_2	5.77	3.74	4.10	3.74	1.54	4.10	4.10	4.10	1.41	4.10	4.07	4.01	4.01	1.44
						Mean	1.44			Mean	1.38				Mean	1.40
						SD	0.11			SD	0.10				SD	0.15

Table 2b. Purlin Test Results and Comparison with DSM (Proposal 1 & Proposal 2) and EWM with FELB Approach

Test	Section	Bridging	q_T (kN/m)	DSM								EWM				
				Proposal 1				Proposal 2								
				Bending/Shear q_{MV1} (kN/m)	DSM q_b (kN/m)	q_{DSM1} (kN/m)	q_T/q_{DSM1}	Bending/Shear q_{MV2} (kN/m)	DSM q_b (kN/m)	q_{DSM2} (kN/m)	q_T/q_{DSM2}	Distort. q_D (kN/m)	Bending/Shear q_{MV} (kN/m)	EWM q_{FELB} (kN/m)	q_{EWM} (kN/m)	q_T/q_{EWM}
S1T1	Z150-19	0_0_0	2.31	2.73	1.14	1.14	2.03	3.37	1.14	1.14	2.03	2.76	2.91	1.17	1.17	1.97
S1T4	Z200-15	0_0_0	2.58	2.63	1.79	1.79	1.44	2.92	1.79	1.79	1.44	2.95	2.85	1.72	1.72	1.50
S1T7	Z200-19	0_0_0	3.51	3.81	2.32	2.32	1.51	4.54	2.32	2.32	1.51	4.00	4.36	2.31	2.31	1.52
						Mean	1.66			Mean	1.66				Mean	1.66
						SD	0.33			SD	0.33				SD	0.27
S1T2	Z150-19	1_1_1	2.63	2.73	2.17	2.17	1.21	3.37	2.17	2.17	1.21	2.75	2.91	2.03	2.03	1.30
S1T5	Z200-15	1_1_1	2.94	2.63	2.77	2.63	1.12	2.92	2.77	2.77	1.06	2.94	2.85	2.75	2.75	1.07
S1T8	Z200-19	1_1_1	4.28	3.81	3.99	3.81	1.12	4.54	3.99	3.99	1.07	3.99	4.36	3.69	3.69	1.16
S6L1	Z150-19/L1	1_1_1	2.56	3.18	2.30	2.30	1.11	3.94	2.30	2.30	1.11	3.22	3.52	2.13	2.13	1.20
S6L2	Z200-19/L2	1_1_1	3.81	4.15	4.33	4.15	0.92	4.77	4.33	4.33	0.88	4.40	4.57	3.94	3.94	0.97
S6S1	Z200-15/S1	1_1_1	2.64	2.64	2.84	2.64	1.00	3.02	2.84	2.84	0.93	2.93	2.74	2.58	2.58	1.02
S6S2	Z150-19/S2	1_1_1	2.71	2.93	2.31	2.31	1.17	3.61	2.31	2.31	1.17	2.96	3.14	2.16	2.16	1.25
						Mean	1.09			Mean	1.06				Mean	1.14
						SD	0.10			SD	0.12				SD	0.12
S1T3	Z150-19	2_1_2	2.98	2.73	2.75	2.73	1.09	3.37	2.75	2.75	1.09	2.75	2.84	2.54	2.54	1.17
S1T9	Z200-19	2_1_2	4.55	3.81	3.99	3.81	1.19	4.54	3.99	3.99	1.14	3.99	4.36	3.96	3.96	1.15
S8T5	Z200-15/5	2_1_2	2.93	2.78	3.14	2.78	1.05	3.00	3.14	3.00	0.98	3.14	2.74	2.65	2.65	1.11
S8T6	Z150-19/6	2_1_2	3.37	2.94	2.97	2.94	1.14	3.68	2.97	2.97	1.14	2.97	3.15	2.58	2.58	1.31
						Mean	1.12			Mean	1.09				Mean	1.18
						SD	0.06			SD	0.08				SD	0.09
S4T3	Z200-15/3	0_0_0	2.90	2.50	2.76	2.50	1.16	2.83	2.76	2.76	1.05	2.76	2.90	2.90	2.76	1.05
S4T4	Z200-15/4	0_0_0	2.94	2.54	2.81	2.54	1.16	2.88	2.81	2.81	1.05	2.81	2.90	2.90	2.81	1.05
S4T5	Z150-19/5	0_0_0	2.92	2.70	2.73	2.70	1.08	3.31	2.73	2.73	1.07	2.73	2.88	2.38	2.38	1.23
						Mean	1.13			Mean	1.06				Mean	1.11
						SD	0.05			SD	0.01				SD	0.10
S4T1	Z200-19/1	1_1_1	3.97	3.95	4.15	3.95	1.01	4.60	4.15	4.15	0.96	4.15	4.49	4.22	4.15	0.96
S4T2	Z200-19/2	1_1_1	4.42	3.85	4.05	3.85	1.15	4.52	4.05	4.05	1.09	4.05	4.49	4.22	4.05	1.09
S4T6	Z150-19/6	1_1_1	2.69	2.70	2.72	2.70	1.00	3.32	2.72	2.72	0.99	2.72	2.88	2.66	2.66	1.01
						Mean	1.05			Mean	1.01				Mean	1.02
						SD	0.09			SD	0.07				SD	0.07

Table 3a. Purlin Test Results and Comparison with DSM (Proposal 1 & Proposal 2) and EWM with C-factor Approach

Test	Section	Bridging	q_T (kN/m)	DSM								EWM				
				Proposal 1				Proposal 2								
				Bending/Shear q_{MV1} (kN/m)	DSM q_b (kN/m)	q_{DSM1} (kN/m)	q_T/q_{DSM1}	Bending/Shear q_{MV2} (kN/m)	DSM q_b (kN/m)	q_{DSM2} (kN/m)	q_T/q_{DSM2}	Distort. q_D (kN/m)	Bending/Shear q_{MV} (kN/m)	EWM q_C (kN/m)	q_{EWM} (kN/m)	q_T/q_{EWM}
S3S1	Z200-24	0	3.28	3.84	0.45	0.45	7.27	4.83	0.45	0.45	7.27	3.84	4.25	0.63	0.63	5.21
S3T4	C200-24	0	3.63	3.89	0.63	0.63	5.73	4.78	0.63	0.63	5.73	3.89	4.23	0.64	0.64	5.67
S5L1	Z200-25/1L	0	2.57	3.95	0.44	0.44	5.83	4.95	0.44	0.44	5.83	3.95	4.35	0.62	0.62	4.15
S5S1	Z200-19/S1	0	2.17	2.57	0.33	0.33	6.58	3.10	0.33	0.33	6.58	2.57	3.05	0.43	0.43	5.05
S7T1	Z20015/1	0	1.85	1.97	0.28	0.28	6.64	2.16	0.28	0.28	6.64	1.97	2.06	0.32	0.32	5.78
S7T2	C20015/2	0	1.70	2.00	0.34	0.34	4.96	2.23	0.34	0.34	4.96	2.00	1.99	0.30	0.30	5.67
						Mean	6.17			Mean	6.17				Mean	5.25
						SD	0.82			SD	0.82				SD	0.62
S3T2	Z200-24	1	3.69	3.84	2.05	2.05	1.80	4.83	2.05	2.05	1.80	3.84	4.25	2.41	2.41	1.53
S3T5	C200-24	1	3.63	3.89	2.43	2.43	1.49	4.78	2.43	2.43	1.49	3.89	4.23	2.44	2.44	1.49
S5L2	Z200-25/2L	1	4.19	4.03	2.06	2.06	2.04	5.06	2.06	2.06	2.04	4.03	4.35	2.42	2.42	1.73
S5S2	Z200-19/S2R	1	2.28	2.60	1.52	1.52	1.50	3.15	1.52	1.52	1.50	2.60	3.05	1.61	1.61	1.42
S7T3	C20015/3	1	1.77	1.92	1.30	1.30	1.36	2.13	1.30	1.30	1.36	1.92	1.91	1.10	1.10	1.61
S8T2	C200-15/2	1	1.71	1.82	1.25	1.25	1.36	2.03	1.25	1.25	1.36	1.82	1.84	1.10	1.10	1.55
S8T3	C150-12/3	1	0.83	1.00	0.48	0.48	1.74	1.12	0.48	0.48	1.74	1.00	1.05	0.42	0.42	1.98
						Mean	1.61			Mean	1.61				Mean	1.62
						SD	0.25			SD	0.25				SD	0.19
S3T3	Z200-24	2	4.76	3.84	3.84	3.84	1.24	4.83	3.84	3.84	1.24	3.84	4.25	3.58	3.58	1.33
S3T6	C200-24	2	4.71	3.89	3.89	3.89	1.21	4.78	3.89	3.89	1.21	3.89	4.23	3.52	3.52	1.34
S5L3	Z200-25/2L	2	4.90	4.01	3.91	3.91	1.25	5.00	3.91	3.91	1.25	4.01	4.35	3.54	3.54	1.38
S5S3	Z200-19/S3	2	2.74	2.60	2.57	2.57	1.06	3.13	2.57	2.57	1.06	2.60	3.05	2.54	2.54	1.08
S7T5	C20015/5	2	1.95	1.91	1.85	1.85	1.06	2.12	1.85	1.85	1.06	1.91	1.91	1.65	1.65	1.18
S8T1	C200-15/1	2	1.98	1.87	1.80	1.80	1.10	2.09	1.80	1.80	1.10	1.87	1.88	1.63	1.63	1.21
S8T4	C150-12/4	2	0.93	0.99	0.81	0.81	1.14	1.11	0.81	0.81	1.14	0.99	1.05	0.78	0.78	1.19
						Mean	1.15			Mean	1.15				Mean	1.25
						SD	0.08			SD	0.08				SD	0.11
S2T1	Z300-25*	0_0	4.33	3.73	0.74	0.74	5.85	4.07	0.74	0.74	5.85	4.08	4.07	1.23	1.23	3.52
S2T2	Z300-25*	1_1	4.93	3.73	2.01	2.01	2.45	4.07	2.01	2.01	2.45	4.08	4.07	3.20	3.20	1.54
S2T3	Z300-25**	2_2	5.77	3.74	3.50	3.50	1.65	4.10	3.50	3.50	1.65	4.10	4.07	4.01	4.01	1.44
						Mean	3.32			Mean	3.32				Mean	2.17
						SD	2.23			SD	2.23				SD	1.17

Table 3b. Purlin Test Results and Comparison with DSM (Proposal 1 & Proposal 2) and EWM with C_b-factor Approach

Test	Section	Bridging	q_T (kN/m)	DSM								EWM				
				Proposal 1				Proposal 2								
				Bending/Shear q_{MV1} (kN/m)	DSM q_b (kN/m)	q_{DSM1} (kN/m)	q_T/q_{DSM1}	Bending/Shear q_{MV2} (kN/m)	DSM q_b (kN/m)	q_{DSM2} (kN/m)	q_T/q_{DSM2}	Distort. q_D (kN/m)	Bending/Shear q_{MV} (kN/m)	EWM q_C (kN/m)	q_{EWM} (kN/m)	q_T/q_{EWM}
S1T1	Z150-19	0_0_0	2.31	2.73	0.36	0.36	6.50	3.37	0.36	0.36	6.50	2.76	2.91	0.48	0.48	4.81
S1T4	Z200-15	0_0_0	2.58	2.63	0.64	0.64	4.03	2.92	0.64	0.64	4.03	2.95	2.85	0.65	0.65	3.97
S1T7	Z200-19	0_0_0	3.51	3.81	0.79	0.79	4.47	4.54	0.79	0.79	4.47	4.00	4.36	0.86	0.86	4.08
						Mean	5.00			Mean	5.00				Mean	4.29
						SD	1.32			SD	1.32				SD	0.46
S1T2	Z150-19	1_1_1	2.63	2.73	1.55	1.55	1.69	3.37	1.55	1.55	1.69	2.75	2.91	1.67	1.67	1.57
S1T5	Z200-15	1_1_1	2.94	2.63	2.37	2.37	1.24	2.92	2.37	2.37	1.24	2.94	2.85	2.36	2.36	1.25
S1T8	Z200-19	1_1_1	4.28	3.81	3.41	3.41	1.26	4.54	3.41	3.41	1.26	3.99	4.36	3.05	3.05	1.40
S6L1	Z150-19/L1	1_1_1	2.56	3.18	1.60	1.60	1.60	3.94	1.60	1.60	1.60	3.22	3.52	1.84	1.84	1.39
S6L2	Z200-19/L2	1_1_1	3.81	4.15	3.78	3.78	1.01	4.77	3.78	3.78	1.01	4.40	4.57	3.60	3.60	1.06
S6S1	Z200-15/S1	1_1_1	2.64	2.64	2.43	2.43	1.09	3.02	2.43	2.43	1.09	2.93	2.74	2.40	2.40	1.10
S6S2	Z150-19/S2	1_1_1	2.71	2.93	1.65	1.65	1.64	3.61	1.65	1.65	1.64	2.96	3.14	1.85	1.85	1.46
						Mean	1.36			Mean	1.36				Mean	1.32
						SD	0.28			SD	0.28				SD	0.19
S1T3	Z150-19	2_1_2	2.98	2.73	2.18	2.18	1.36	3.37	2.18	2.18	1.36	2.75	2.84	2.11	2.11	1.41
S1T9	Z200-19	2_1_2	4.55	3.81	3.99	3.81	1.19	4.54	3.99	3.99	1.14	3.99	4.36	3.77	3.77	1.21
S8T5	Z200-15/5	2_1_2	2.93	2.78	2.89	2.78	1.05	3.00	2.89	2.89	1.02	3.14	2.74	2.65	2.65	1.11
S8T6	Z150-19/6	2_1_2	3.37	2.94	2.35	2.35	1.43	3.68	2.35	2.35	1.43	2.97	3.15	2.25	2.25	1.50
						Mean	1.26			Mean	1.24				Mean	1.31
						SD	0.17			SD	0.19				SD	0.18
S4T3	Z200-15/3	0_0_0	2.90	2.50	2.76	2.50	1.16	2.83	2.76	2.76	1.05	2.76	2.90	2.90	2.76	1.05
S4T4	Z200-15/4	0_0_0	2.94	2.54	2.81	2.54	1.16	2.88	2.81	2.81	1.05	2.81	2.90	2.90	2.81	1.05
S4T5	Z150-19/5	0_0_0	2.92	2.70	2.73	2.70	1.08	3.31	2.73	2.73	1.07	2.73	2.88	2.66	2.66	1.10
						Mean	1.13			Mean	1.06				Mean	1.06
						SD	0.05			SD	0.01				SD	0.03
S4T1	Z200-19/1	1_1_1	3.97	3.95	4.15	3.95	1.01	4.60	4.15	4.15	0.96	4.15	4.49	4.22	4.15	0.96
S4T2	Z200-19/2	1_1_1	4.42	3.85	4.05	3.85	1.15	4.52	4.05	4.05	1.09	4.05	4.49	4.22	4.05	1.09
S4T6	Z150-19/6	1_1_1	2.69	2.70	2.72	2.70	1.00	3.32	2.72	2.72	0.99	2.72	2.88	2.66	2.66	1.01
						Mean	1.05			Mean	1.01				Mean	1.02
						SD	0.09			SD	0.07				SD	0.07

Table 4. Reliability Index-FELB Approach

Test Section Bridging	DSM														EWM						
	Proposal 1							Proposal 2													
	M_m	V_M	F_m	V_F	P_m	V_P	β	M_m	V_M	F_m	V_F	P_m	V_P	β	M_m	V_M	F_m	V_F	P_m	V_P	β
Single Span/ Uplift No bridging	1.192	0.031	1.000	0.010	2.815	0.112	4.684	1.192	0.031	1.000	0.010	2.815	0.112	4.684	1.192	0.031	1.000	0.010	2.851	0.140	4.645
Single Span/ Uplift One row bridging	1.192	0.031	1.000	0.010	1.272	0.108	3.124	1.192	0.031	1.000	0.010	1.272	0.108	3.124	1.192	0.031	1.000	0.010	1.392	0.116	3.290
Single Span/ Uplift Two row bridging	1.192	0.031	1.000	0.010	1.128	0.082	2.914	1.192	0.031	1.000	0.010	1.128	0.082	2.914	1.192	0.031	1.000	0.010	1.210	0.077	3.060
Double Span/ Uplift	1.192	0.031	1.000	0.010	1.444	0.078	3.411	1.192	0.031	1.000	0.010	1.379	0.075	3.323	1.192	0.031	1.000	0.010	1.399	0.110	3.309
Triple Span/ Uplift No row bridging	1.192	0.031	1.000	0.010	1.661	0.196	3.474	1.192	0.031	1.000	0.010	1.661	0.196	3.474	1.192	0.031	1.000	0.010	1.665	0.161	3.557
Triple Span/ Uplift One row bridging	1.192	0.031	1.000	0.010	1.094	0.093	2.844	1.192	0.031	1.000	0.010	1.064	0.114	2.764	1.192	0.031	1.000	0.010	1.139	0.108	2.906
Triple Span/ Uplift One row bridging (end span) Two row bridging (internal span)	1.192	0.031	1.000	0.010	1.121	0.055	2.924	1.192	0.031	1.000	0.010	1.085	0.070	2.848	1.192	0.031	1.000	0.010	1.184	0.073	3.019
Triple Span/ Downwards No row bridging	1.192	0.031	1.000	0.010	1.133	0.040	3.865	1.192	0.031	1.000	0.010	1.055	0.011	3.658	1.192	0.031	1.000	0.010	1.108	0.093	3.651
Triple Span/ Downwards One row bridging	1.192	0.031	1.000	0.010	1.050	0.082	3.517	1.192	0.031	1.000	0.010	1.011	0.070	3.428	1.192	0.031	1.000	0.010	1.019	0.066	3.461

Table 5. Reliability Index- C-factor Approach

Test Section Bridging	DSM														EWM						
	Proposal 1							Proposal 2													
	M_m	V_M	F_m	V_F	P_m	V_P	β	M_m	V_M	F_m	V_F	P_m	V_P	β	M_m	V_M	F_m	V_F	P_m	V_P	β
Single Span/ Uplift No bridging	1.192	0.031	1.000	0.010	6.169	0.133	6.169	1.192	0.031	1.000	0.010	6.169	0.133	6.169	1.192	0.031	1.000	0.010	5.253	0.117	5.899
Single Span/ Uplift One row bridging	1.192	0.031	1.000	0.010	1.613	0.157	3.505	1.192	0.031	1.000	0.010	1.613	0.157	3.505	1.192	0.031	1.000	0.010	1.615	0.116	3.583
Single Span/ Uplift Two row bridging	1.192	0.031	1.000	0.010	1.153	0.072	2.967	1.192	0.031	1.000	0.010	1.153	0.072	2.967	1.192	0.031	1.000	0.010	1.246	0.087	3.107
Double Span/ Uplift	1.192	0.031	1.000	0.010	3.317	0.673	3.041	1.192	0.031	1.000	0.010	3.317	0.673	3.041	1.192	0.031	1.000	0.010	2.167	0.542	2.883
Triple Span/ Uplift No row bridging	1.192	0.031	1.000	0.010	5.001	0.264	5.262	1.192	0.031	1.000	0.010	5.001	0.264	5.262	1.192	0.031	1.000	0.010	4.288	0.107	5.525
Triple Span/ Uplift One row bridging	1.192	0.031	1.000	0.010	1.360	0.206	3.077	1.192	0.031	1.000	0.010	1.360	0.206	3.077	1.192	0.031	1.000	0.010	1.320	0.145	3.140
Triple Span/ Uplift One row bridging (end span) Two row bridging (internal span)	1.192	0.031	1.000	0.010	1.261	0.137	3.065	1.192	0.031	1.000	0.010	1.239	0.157	2.997	1.192	0.031	1.000	0.010	1.306	0.138	3.130
Triple Span/ Downwards No row bridging	1.192	0.031	1.000	0.010	1.133	0.040	3.865	1.192	0.031	1.000	0.010	1.055	0.011	3.658	1.192	0.031	1.000	0.010	1.065	0.027	3.677
Triple Span/ Downwards One row bridging	1.192	0.031	1.000	0.010	1.050	0.082	3.517	1.192	0.031	1.000	0.010	1.011	0.070	3.428	1.192	0.031	1.000	0.010	1.019	0.066	3.461

Appendix 1: Purlins Test Results and Comparison with DSM - FELB Approach – Proposal 1

									DSM										EWM				
Test	Section	Bridging	f_y (MPa)	q_T (kN/m)	f_{ol} (MPa)	f_{od} (MPa)	M_o (kNm)	V_v (kN)	M_{be} (kNm)	λ_l	λ_d	M_{bl} (kNm)	M_{bd} (kNm)	M_b (kNm)	q_b (kN/m)	q_{MV1} (kN/m)	q_{DSM1} (kN/m)	q_T/q_{DSM1}	q_D (kN/m)	q_{MV} (kN/m)	q_C (kN/m)	q_{EMW} (kN/m)	q_T/q_{EWM}
S3S1	Z200-24	0	529	3.28	752	486.4	6.98	74.77	6.98	0.398	1.043	6.98	23.49	6.98	1.14	3.84	1.14	2.88	3.84	4.25	1.17	1.17	2.80
S3T4	C200-24	0	518	3.63	757	521.1	6.92	74.38	6.92	0.394	0.997	6.92	23.82	6.92	1.13	3.89	1.13	3.21	3.89	4.23	1.16	1.16	3.13
S5L1	Z200-25/1L	0	525	2.57	815.6	526.3	6.96	82.20	6.96	0.380	0.999	6.96	24.18	6.96	1.14	3.95	1.14	2.26	3.95	4.35	1.19	1.19	2.16
S5S1	Z200-19/S1	0	517	2.17	465.2	357.3	4.75	35.00	4.75	0.477	1.203	4.75	15.73	4.75	0.78	2.57	0.78	2.80	2.57	3.05	0.81	0.81	2.68
S7T1	Z20015/1	0	527	1.85	292.5	306.6	3.81	17.19	3.81	0.601	1.311	3.81	12.06	3.81	0.62	1.97	0.62	2.98	1.97	2.06	0.57	0.57	3.25
S7T2	C20015/2	0	548	1.70	297.9	301	3.77	17.61	3.77	0.593	1.349	3.77	12.23	3.77	0.62	2.00	0.62	2.76	2.00	1.99	0.55	0.55	3.09
S3T2	Z200-24	1	529	3.69	752	486.4	17.88	74.77	17.86	0.636	1.043	17.86	23.49	17.86	2.92	3.84	2.92	1.27	3.84	4.25	2.69	2.69	1.37
S3T5	C200-24	1	518	3.63	757	521.1	17.79	74.38	17.75	0.631	0.997	17.75	23.82	17.75	2.90	3.89	2.90	1.25	3.89	4.23	2.84	2.84	1.28
S5L2	Z200-25/2L	1	525	4.19	831.8	534.4	18.11	85.11	18.09	0.602	0.991	18.09	24.71	18.09	2.95	4.03	2.95	1.42	4.03	4.35	2.82	2.82	1.49
S5S2	Z200-19/S2R	1	517	2.28	475	359.1	12.99	36.18	12.99	0.778	1.200	12.97	15.91	12.97	2.12	2.60	2.12	1.08	2.60	3.05	1.91	1.91	1.19
S7T3	C20015/3	1	512	1.77	297.9	301	10.59	17.61	10.58	0.993	1.304	9.03	11.74	9.03	1.47	1.92	1.47	1.20	1.92	1.91	1.28	1.28	1.38
S8T2	C200-15/2	1	480	1.71	306.1	302.4	9.92	17.96	9.90	0.954	1.260	8.68	11.18	8.68	1.42	1.82	1.42	1.21	1.82	1.84	1.28	1.28	1.34
S8T3	C150-12/3	1	582	0.83	324.9	323.6	3.50	12.14	3.50	0.799	1.341	3.43	6.12	3.43	0.56	1.00	0.56	1.48	1.00	1.05	0.49	0.49	1.69
S3T3	Z200-24	2	529	4.76	752	486.4	37.27	74.77	26.52	0.775	1.043	26.52	23.49	23.49	3.84	3.84	3.84	1.24	3.84	4.25	3.72	3.72	1.28
S3T6	C200-24	2	518	4.71	757	521.1	37.09	74.38	26.13	0.766	0.997	26.13	23.82	23.82	3.89	3.89	3.89	1.21	3.89	4.23	3.67	3.67	1.28
S5L3	Z200-25/2L	2	525	4.90	807.8	528.9	38.27	82.07	26.92	0.747	0.996	26.92	24.54	24.54	4.01	4.01	4.01	1.22	4.01	4.35	3.69	3.69	1.33
S5S3	Z200-19/S3	2	517	2.74	471.5	365.2	27.03	35.43	19.66	0.963	1.190	17.13	15.92	15.92	2.60	2.60	2.60	1.05	2.60	3.05	2.54	2.54	1.08
S7T5	C20015/5	2	510	1.95	297.9	301	21.42	17.61	15.54	1.204	1.302	11.66	11.71	11.66	1.90	1.91	1.90	1.02	1.91	1.91	1.65	1.65	1.18
S8T1	C200-15/1	2	500	1.98	306.1	302.4	20.04	17.96	14.88	1.170	1.286	11.39	11.46	11.39	1.86	1.87	1.86	1.06	1.87	1.88	1.63	1.63	1.21
S8T4	C150-12/4	2	578	0.93	324.9	323.6	7.02	12.14	6.65	1.102	1.336	5.30	6.09	5.30	0.87	0.99	0.87	1.07	0.99	1.05	0.84	0.84	1.11
S2T1	Z300-25*	0_0	485	4.33	398.5	385.4	31.27	54.93	31.27	0.804	1.122	30.59	42.23	30.59	2.95	3.73	2.95	1.47	4.08	4.07	2.83	2.83	1.53
S2T2	Z300-25*	1_1	485	4.93	398.5	385.4	58.27	54.93	47.08	0.986	1.122	40.39	42.23	40.39	3.90	3.73	3.73	1.32	4.08	4.07	4.01	4.01	1.23
S2T3	Z300-25**	2_2	485	5.77	385.2	366.4	108.2	53.89	56.77	1.087	1.151	45.65	42.52	42.52	4.10	3.74	3.74	1.54	4.10	4.07	4.01	4.01	1.44

Appendix 1: Purlins Test Results and Comparison with DSM - FELB Approach – Proposal 1

									DSM										EWM				
Test	Section	Bridging	f_y (MPa)	q_T (kN/m)	f_{ol} (MPa)	f_{od} (MPa)	M_o (kNm)	V_v (kN)	M_{be} (kNm)	λ_l	λ_d	M_{bl} (kNm)	M_{bd} (kNm)	M_b (kNm)	q_b (kN/m)	q_{MV1} (kN/m)	q_{DSM1} (kN/m)	q_T/q_{DSM1}	q_D (kN/m)	q_{MV} (kN/m)	q_C (kN/m)	q_{EMW} (kN/m)	q_T/q_{EWM}
S1T1	Z150-19	0_0_0	487	2.31	809.6	527.7	4.29	49.34	4.29	0.446	0.961	4.29	10.40	4.29	1.14	2.73	1.14	2.03	2.76	2.91	1.17	1.17	1.97
S1T4	Z200-15	0_0_0	520	2.58	301.7	275.6	6.97	17.61	6.97	0.813	1.374	6.77	11.12	6.77	1.79	2.63	1.79	1.44	2.95	2.85	1.72	1.72	1.50
S1T7	Z200-19	0_0_0	495	3.51	499.4	370.2	8.77	37.33	8.77	0.635	1.156	8.77	15.10	8.77	2.32	3.81	2.32	1.51	4.00	4.36	2.31	2.31	1.52
S1T2	Z150-19	1_1_1	487	2.63	809.6	527.7	8.34	49.34	8.19	0.616	0.961	8.19	10.40	8.19	2.17	2.73	2.17	1.21	2.75	2.91	2.03	2.03	1.30
S1T5	Z200-15	1_1_1	520	2.94	301.7	275.6	14.81	17.61	13.32	1.123	1.374	10.48	11.12	10.48	2.77	2.63	2.63	1.12	2.94	2.85	2.75	2.75	1.07
S1T8	Z200-19	1_1_1	495	4.28	499.4	370.2	18.31	37.33	16.12	0.861	1.156	15.10	15.10	15.10	3.99	3.81	3.81	1.12	3.99	4.36	3.69	3.69	1.16
S6L1	Z150-19/L1	1_1_1	615	2.56	805.6	534.3	8.69	49.48	8.69	0.635	1.073	8.69	12.19	8.69	2.30	3.18	2.30	1.11	3.22	3.52	2.13	2.13	1.20
S6L2	Z200-19/L2	1_1_1	517	3.81	474.2	390.6	21.31	36.13	18.20	0.915	1.150	16.39	16.66	16.39	4.33	4.15	4.15	0.92	4.40	4.57	3.94	3.94	0.97
S6S1	Z200-15/S1	1_1_1	529	2.64	303.9	251.9	14.88	18.21	13.59	1.119	1.449	10.72	11.07	10.72	2.84	2.64	2.64	1.00	2.93	2.74	2.58	2.58	1.02
S6S2	Z150-19/S2	1_1_1	527	2.71	808.1	537.5	8.82	50.26	8.73	0.632	0.990	8.73	11.19	8.73	2.31	2.93	2.31	1.17	2.96	3.14	2.16	2.16	1.25
S1T3	Z150-19	2_1_2	487	2.98	809.6	527.7	14.46	49.34	10.81	0.709	0.961	10.81	10.40	10.40	2.75	2.73	2.73	1.09	2.75	2.84	2.54	2.54	1.17
S1T9	Z200-19	2_1_2	495	4.55	499.4	370.2	31.97	37.33	19.47	0.946	1.156	17.16	15.10	15.10	3.99	3.81	3.81	1.19	3.99	4.36	3.96	3.96	1.15
S8T5	Z200-15/5	2_1_2	529	2.93	305	304.1	26.99	17.87	16.88	1.246	1.319	12.37	11.90	11.90	3.14	2.78	2.78	1.05	3.14	2.74	2.65	2.65	1.11
S8T6	Z150-19/6	2_1_2	546	3.37	784.1	503.5	15.24	51.90	12.03	0.751	1.041	12.03	11.24	11.24	2.97	2.94	2.94	1.14	2.97	3.15	2.58	2.58	1.31
S4T3	Z200-15/3	0_0_0	480	2.90	297.1	258.3	21.08	17.52	14.63	1.181	1.363	11.13	10.44	10.44	2.76	2.50	2.50	1.16	2.76	2.90	2.90	2.76	1.05
S4T4	Z200-15/4	0_0_0	480	2.94	299	258.9	21.71	17.87	14.91	1.179	1.362	11.35	10.60	10.60	2.81	2.54	2.54	1.16	2.81	2.90	2.90	2.81	1.05
S4T5	Z150-19/5	0_0_0	480	2.92	780.5	524.5	13.05	47.97	10.36	0.705	0.957	10.36	10.32	10.32	2.73	2.70	2.70	1.08	2.73	2.88	2.38	2.38	1.23
S4T1	Z200-19/1	1_1_1	480	3.97	464.4	364.7	85.55	36.36	22.32	1.017	1.147	18.76	15.72	15.72	4.15	3.95	3.95	1.01	4.15	4.49	4.22	4.15	0.96
S4T2	Z200-19/2	1_1_1	480	4.42	452.6	348.6	84.40	35.04	22.16	1.030	1.173	18.48	15.35	15.35	4.05	3.85	3.85	1.15	4.05	4.49	4.22	4.05	1.09
S4T6	Z150-19/6	1_1_1	480	2.69	769.3	513.1	36.58	47.97	12.91	0.790	0.967	12.77	10.31	10.31	2.72	2.70	2.70	1.00	2.72	2.88	2.66	2.66	1.01

Appendix 2: Purlins Test Results and Comparison with DSM - C-factor Approach – Proposal 1

Test	Section	Bridging	f_y (MPa)	q_T (kN/m)	f_{ol} (MPa)	f_{od} (MPa)	M_o (kNm)	V_v (kN)	DSM										EWM				
									M_{be} (kNm)	λ_l	λ_d	M_{bl} (kNm)	M_{bd} (kNm)	M_b (kNm)	q_b (kN/m)	q_{MV1} (kN/m)	q_{DSM1} (kN/m)	q_T/q_{DSM1}	q_D (kN/m)	q_{MV} (kN/m)	q_C (kN/m)	q_{EMW} (kN/m)	q_T/q_{EWM}
S3S1	Z200-24	0	529	3.28	752	486.4	2.76	74.77	2.76	0.250	1.043	2.76	23.49	2.76	0.45	3.84	0.45	7.27	3.84	4.25	0.63	0.63	5.21
S3T4	C200-24	0	518	3.63	757	521.1	3.88	74.38	3.88	0.295	0.997	3.88	23.82	3.88	0.63	3.89	0.63	5.73	3.89	4.23	0.64	0.64	5.67
S5L1	Z200-25/1L	0	525	2.57	815.6	526.3	2.70	82.20	2.70	0.237	0.999	2.70	24.18	2.70	0.44	3.95	0.44	5.83	3.95	4.35	0.62	0.62	4.15
S5S1	Z200-19/S1	0	517	2.17	465.2	357.3	2.02	35.00	2.02	0.311	1.203	2.02	15.73	2.02	0.33	2.57	0.33	6.58	2.57	3.05	0.43	0.43	5.05
S7T1	Z20015/1	0	527	1.85	292.5	306.6	1.71	17.19	1.71	0.402	1.311	1.71	12.06	1.71	0.28	1.97	0.28	6.64	1.97	2.06	0.32	0.32	5.78
S7T2	C20015/2	0	548	1.70	297.9	301	2.10	17.61	2.10	0.442	1.349	2.10	12.23	2.10	0.34	2.00	0.34	4.96	2.00	1.99	0.30	0.30	5.67
S3T2	Z200-24	1	529	3.69	752	486.4	12.56	74.77	12.56	0.533	1.043	12.56	23.49	12.56	2.05	3.84	2.05	1.80	3.84	4.25	2.41	2.41	1.53
S3T5	C200-24	1	518	3.63	757	521.1	14.90	74.38	14.90	0.578	0.997	14.90	23.82	14.90	2.43	3.89	2.43	1.49	3.89	4.23	2.44	2.44	1.49
S5L2	Z200-25/2L	1	525	4.19	831.8	534.4	12.60	85.11	12.60	0.503	0.991	12.60	24.71	12.60	2.06	4.03	2.06	2.04	4.03	4.35	2.42	2.42	1.73
S5S2	Z200-19/S2R	1	517	2.28	475	359.1	9.30	36.18	9.30	0.658	1.200	9.30	15.91	9.30	1.52	2.60	1.52	1.50	2.60	3.05	1.61	1.61	1.42
S7T3	C20015/3	1	512	1.77	297.9	301	8.83	17.61	8.83	0.907	1.304	7.99	11.74	7.99	1.30	1.92	1.30	1.36	1.92	1.91	1.10	1.10	1.61
S8T2	C200-15/2	1	480	1.71	306.1	302.4	8.26	17.96	8.26	0.872	1.260	7.68	11.18	7.68	1.25	1.82	1.25	1.36	1.82	1.84	1.10	1.10	1.55
S8T3	C150-12/3	1	582	0.83	324.9	323.6	2.92	12.14	2.92	0.730	1.341	2.92	6.12	2.92	0.48	1.00	0.48	1.74	1.00	1.05	0.42	0.42	1.98
S3T3	Z200-24	2	529	4.76	752	486.4	27.16	74.77	23.54	0.730	1.043	23.54	23.49	23.49	3.84	3.84	3.84	1.24	3.84	4.25	3.58	3.58	1.33
S3T6	C200-24	2	518	4.71	757	521.1	30.82	74.38	24.56	0.743	0.997	24.56	23.82	23.82	3.89	3.89	3.89	1.21	3.89	4.23	3.52	3.52	1.34
S5L3	Z200-25/2L	2	525	4.90	807.8	528.9	27.81	82.07	23.94	0.704	0.996	23.94	24.54	23.94	3.91	4.01	3.91	1.25	4.01	4.35	3.54	3.54	1.38
S5S3	Z200-19/S3	2	517	2.74	471.5	365.2	19.78	35.43	17.39	0.906	1.190	15.77	15.92	15.77	2.57	2.60	2.57	1.06	2.60	3.05	2.54	2.54	1.08
S7T5	C20015/5	2	510	1.95	297.9	301	18.74	17.61	14.84	1.177	1.302	11.32	11.71	11.32	1.85	1.91	1.85	1.06	1.91	1.91	1.65	1.65	1.18
S8T1	C200-15/1	2	500	1.98	306.1	302.4	17.53	17.96	14.18	1.142	1.286	11.03	11.46	11.03	1.80	1.87	1.80	1.10	1.87	1.88	1.63	1.63	1.21
S8T4	C150-12/4	2	578	0.93	324.9	323.6	6.14	12.14	6.06	1.052	1.336	4.98	6.09	4.98	0.81	0.99	0.81	1.14	0.99	1.05	0.78	0.78	1.19
S2T1	Z300-25*	0_0	485	4.33	398.5	385.4	7.66	54.93	7.66	0.398	1.122	7.66	42.23	7.66	0.74	3.73	0.74	5.85	4.08	4.07	1.23	1.23	3.52
S2T2	Z300-25*	1_1	485	4.93	398.5	385.4	20.85	54.93	20.85	0.656	1.122	20.85	42.23	20.85	2.01	3.73	2.01	2.45	4.08	4.07	3.20	3.20	1.54
S2T3	Z300-25**	2_2	485	5.77	385.2	366.4	42.03	53.89	40.34	0.916	1.151	36.30	42.52	36.30	3.50	3.74	3.50	1.65	4.10	4.07	4.01	4.01	1.44

Appendix 2: Purlins Test Results and Comparison with DSM - C-factor Approach – Proposal 1

Test	Section	Bridging	f_y (MPa)	q_T (kN/m)	f_{ol} (MPa)	f_{od} (MPa)	M_o (kNm)	V_v (kN)	DSM										EWM				
									M_{be} (kNm)	λ_l	λ_d	M_{bl} (kNm)	M_{bd} (kNm)	M_b (kNm)	q_b (kN/m)	q_{MV1} (kN/m)	q_{DSM1} (kN/m)	q_T/q_{DSM1}	q_D (kN/m)	q_{MV} (kN/m)	q_C (kN/m)	q_{EMW} (kN/m)	q_T/q_{EWM}
S1T1	Z150-19	0_0_0	487	2.31	809.6	527.7	1.34	49.34	1.34	0.250	0.961	1.34	10.40	1.34	0.36	2.73	0.36	6.50	2.76	2.91	0.48	0.48	4.81
S1T4	Z200-15	0_0_0	520	2.58	301.7	275.6	2.42	17.61	2.42	0.478	1.374	2.42	11.12	2.42	0.64	2.63	0.64	4.03	2.95	2.85	0.65	0.65	3.97
S1T7	Z200-19	0_0_0	495	3.51	499.4	370.2	2.96	37.33	2.96	0.369	1.156	2.96	15.10	2.96	0.79	3.81	0.79	4.47	4.00	4.36	0.86	0.86	4.08
S1T2	Z150-19	1_1_1	487	2.63	809.6	527.7	5.87	49.34	5.87	0.522	0.961	5.87	10.40	5.87	1.55	2.73	1.55	1.69	2.75	2.91	1.67	1.67	1.57
S1T5	Z200-15	1_1_1	520	2.94	301.7	275.6	10.58	17.61	10.56	1.000	1.374	8.97	11.12	8.97	2.37	2.63	2.37	1.24	2.94	2.85	2.36	2.36	1.25
S1T8	Z200-19	1_1_1	495	4.28	499.4	370.2	12.98	37.33	12.90	0.770	1.156	12.90	15.10	12.90	3.41	3.81	3.41	1.26	3.99	4.36	3.05	3.05	1.40
S6L1	Z150-19/L1	1_1_1	615	2.56	805.6	534.3	6.07	49.48	6.07	0.531	1.073	6.07	12.19	6.07	1.60	3.18	1.60	1.60	3.22	3.52	1.84	1.84	1.39
S6L2	Z200-19/L2	1_1_1	517	3.81	474.2	390.6	15.21	36.13	14.94	0.829	1.150	14.33	16.66	14.33	3.78	4.15	3.78	1.01	4.40	4.57	3.60	3.60	1.06
S6S1	Z200-15/S1	1_1_1	529	2.64	303.9	251.9	10.79	18.21	10.78	0.996	1.449	9.19	11.07	9.19	2.43	2.64	2.43	1.09	2.93	2.74	2.40	2.40	1.10
S6S2	Z150-19/S2	1_1_1	527	2.71	808.1	537.5	6.24	50.26	6.24	0.534	0.990	6.24	11.19	6.24	1.65	2.93	1.65	1.64	2.96	3.14	1.85	1.85	1.46
S1T3	Z150-19	2_1_2	487	2.98	809.6	527.7	8.46	49.34	8.27	0.620	0.961	8.27	10.40	8.27	2.18	2.73	2.18	1.36	2.75	2.84	2.11	2.11	1.41
S1T9	Z200-19	2_1_2	495	4.55	499.4	370.2	18.71	37.33	16.28	0.865	1.156	15.20	15.10	15.10	3.99	3.81	3.81	1.19	3.99	4.36	3.77	3.77	1.21
S8T5	Z200-15/5	2_1_2	529	2.93	305	304.1	15.77	17.87	13.99	1.135	1.319	10.93	11.90	10.93	2.89	2.78	2.78	1.05	3.14	2.74	2.65	2.65	1.11
S8T6	Z150-19/6	2_1_2	546	3.37	784.1	503.5	8.95	51.90	8.90	0.646	1.041	8.90	11.24	8.90	2.35	2.94	2.35	1.43	2.97	3.15	2.25	2.25	1.50
S4T3	Z200-15/3	0_0_0	480	2.90	297.1	258.3	99.06	17.52	16.96	1.271	1.363	12.27	10.44	10.44	2.76	2.50	2.50	1.16	2.76	2.90	2.90	2.76	1.05
S4T4	Z200-15/4	0_0_0	480	2.94	299	258.9	103.0	17.87	17.21	1.267	1.362	12.47	10.60	10.60	2.81	2.54	2.54	1.16	2.81	2.90	2.90	2.81	1.05
S4T5	Z150-19/5	0_0_0	480	2.92	780.5	524.5	57.30	47.97	12.82	0.784	0.957	12.73	10.32	10.32	2.73	2.70	2.70	1.08	2.73	2.88	2.66	2.66	1.10
S4T1	Z200-19/1	1_1_1	480	3.97	464.4	364.7	152.2	36.36	22.32	1.017	1.147	18.76	15.72	15.72	4.15	3.95	3.95	1.01	4.15	4.49	4.22	4.15	0.96
S4T2	Z200-19/2	1_1_1	480	4.42	452.6	348.6	149.3	35.04	22.16	1.030	1.173	18.48	15.35	15.35	4.05	3.85	3.85	1.15	4.05	4.49	4.22	4.05	1.09
S4T6	Z150-19/6	1_1_1	480	2.69	769.3	513.1	59.07	47.97	12.91	0.790	0.967	12.77	10.31	10.31	2.72	2.70	2.70	1.00	2.72	2.88	2.66	2.66	1.01

Appendix 3: Purlins Test Results and Comparison with DSM - FELB Approach – Proposal 2

Test	Section	Bridging	f_y (MPa)	q_T (kN/m)	f_{ol} (MPa)	f_{od} (MPa)	M_o (kNm)	V_v (kN)	DSM										EWM				
									M_{be} (kNm)	λ_l	λ_d	M_{bl} (kNm)	M_{bd} (kNm)	M_b (kNm)	q_b (kN/m)	q_{MV1} (kN/m)	q_{DSM1} (kN/m)	q_T/q_{DSM1}	q_D (kN/m)	q_{MV} (kN/m)	q_C (kN/m)	q_{EMW} (kN/m)	q_T/q_{EWM}
S3S1	Z200-24	0	529	3.28	752	486.4	6.98	74.77	6.98	0.398	1.043	6.98	23.49	6.98	1.14	4.83	1.14	2.88	3.84	4.25	1.17	1.17	2.80
S3T4	C200-24	0	518	3.63	757	521.1	6.92	74.38	6.92	0.394	0.997	6.92	23.82	6.92	1.13	4.78	1.13	3.21	3.89	4.23	1.16	1.16	3.13
S5L1	Z200-25/1L	0	525	2.57	815.6	526.3	6.96	82.20	6.96	0.380	0.999	6.96	24.18	6.96	1.14	4.95	1.14	2.26	3.95	4.35	1.19	1.19	2.16
S5S1	Z200-19/S1	0	517	2.17	465.2	357.3	4.75	35.00	4.75	0.477	1.203	4.75	15.73	4.75	0.78	3.10	0.78	2.80	2.57	3.05	0.81	0.81	2.68
S7T1	Z20015/1	0	527	1.85	292.5	306.6	3.81	17.19	3.81	0.601	1.311	3.81	12.06	3.81	0.62	2.16	0.62	2.98	1.97	2.06	0.57	0.57	3.25
S7T2	C20015/2	0	548	1.70	297.9	301	3.77	17.61	3.77	0.593	1.349	3.77	12.23	3.77	0.62	2.23	0.62	2.76	2.00	1.99	0.55	0.55	3.09
S3T2	Z200-24	1	529	3.69	752	486.4	17.88	74.77	17.86	0.636	1.043	17.86	23.49	17.86	2.92	4.83	2.92	1.27	3.84	4.25	2.69	2.69	1.37
S3T5	C200-24	1	518	3.63	757	521.1	17.79	74.38	17.75	0.631	0.997	17.75	23.82	17.75	2.90	4.78	2.90	1.25	3.89	4.23	2.84	2.84	1.28
S5L2	Z200-25/2L	1	525	4.19	831.8	534.4	18.11	85.11	18.09	0.602	0.991	18.09	24.71	18.09	2.95	5.06	2.95	1.42	4.03	4.35	2.82	2.82	1.49
S5S2	Z200-19/S2R	1	517	2.28	475	359.1	12.99	36.18	12.99	0.778	1.200	12.97	15.91	12.97	2.12	3.15	2.12	1.08	2.60	3.05	1.91	1.91	1.19
S7T3	C20015/3	1	512	1.77	297.9	301	10.59	17.61	10.58	0.993	1.304	9.03	11.74	9.03	1.47	2.13	1.47	1.20	1.92	1.91	1.28	1.28	1.38
S8T2	C200-15/2	1	480	1.71	306.1	302.4	9.92	17.96	9.90	0.954	1.260	8.68	11.18	8.68	1.42	2.03	1.42	1.21	1.82	1.84	1.28	1.28	1.34
S8T3	C150-12/3	1	582	0.83	324.9	323.6	3.50	12.14	3.50	0.799	1.341	3.43	6.12	3.43	0.56	1.12	0.56	1.48	1.00	1.05	0.49	0.49	1.69
S3T3	Z200-24	2	529	4.76	752	486.4	37.27	74.77	26.52	0.775	1.043	26.52	23.49	23.49	3.84	4.83	3.84	1.24	3.84	4.25	3.72	3.72	1.28
S3T6	C200-24	2	518	4.71	757	521.1	37.09	74.38	26.13	0.766	0.997	26.13	23.82	23.82	3.89	4.78	3.89	1.21	3.89	4.23	3.67	3.67	1.28
S5L3	Z200-25/2L	2	525	4.90	807.8	528.9	38.27	82.07	26.92	0.747	0.996	26.92	24.54	24.54	4.01	5.00	4.01	1.22	4.01	4.35	3.69	3.69	1.33
S5S3	Z200-19/S3	2	517	2.74	471.5	365.2	27.03	35.43	19.66	0.963	1.190	17.13	15.92	15.92	2.60	3.13	2.60	1.05	2.60	3.05	2.54	2.54	1.08
S7T5	C20015/5	2	510	1.95	297.9	301	21.42	17.61	15.54	1.204	1.302	11.66	11.71	11.66	1.90	2.12	1.90	1.02	1.91	1.91	1.65	1.65	1.18
S8T1	C200-15/1	2	500	1.98	306.1	302.4	20.04	17.96	14.88	1.170	1.286	11.39	11.46	11.39	1.86	2.09	1.86	1.06	1.87	1.88	1.63	1.63	1.21
S8T4	C150-12/4	2	578	0.93	324.9	323.6	7.02	12.14	6.65	1.102	1.336	5.30	6.09	5.30	0.87	1.11	0.87	1.07	0.99	1.05	0.84	0.84	1.11
S2T1	Z300-25*	0_0	485	4.33	398.5	385.4	31.27	54.93	31.27	0.804	1.122	30.59	42.23	30.59	2.95	4.07	2.95	1.47	4.08	4.07	2.83	2.83	1.53
S2T2	Z300-25*	1_1	485	4.93	398.5	385.4	58.27	54.93	47.08	0.986	1.122	40.39	42.23	40.39	3.90	4.07	3.90	1.26	4.08	4.07	4.01	4.01	1.23
S2T3	Z300-25**	2_2	485	5.77	385.2	366.4	108.2	53.89	56.77	1.087	1.151	45.65	42.52	42.52	4.10	4.10	4.10	1.41	4.10	4.07	4.01	4.01	1.44

Appendix 3: Purlins Test Results and Comparison with DSM - FELB Approach – Proposal 2

Test	Section	Bridging	f_y (MPa)	q_T (kN/m)	f_{ol} (MPa)	f_{od} (MPa)	M_o (kNm)	V_v (kN)	DSM										EWM				
									M_{be} (kNm)	λ_l	λ_d	M_{bl} (kNm)	M_{bd} (kNm)	M_b (kNm)	q_b (kN/m)	q_{MV1} (kN/m)	q_{DSM1} (kN/m)	q_T/q_{DSM1}	q_D (kN/m)	q_{MV} (kN/m)	q_C (kN/m)	q_{EMW} (kN/m)	q_T/q_{EWM}
S1T1	Z150-19	0_0_0	487	2.31	809.6	527.7	4.29	49.34	4.29	0.446	0.961	4.29	10.40	4.29	1.14	3.37	1.14	2.03	2.76	2.91	1.17	1.17	1.97
S1T4	Z200-15	0_0_0	520	2.58	301.7	275.6	6.97	17.61	6.97	0.813	1.374	6.77	11.12	6.77	1.79	2.92	1.79	1.44	2.95	2.85	1.72	1.72	1.50
S1T7	Z200-19	0_0_0	495	3.51	499.4	370.2	8.77	37.33	8.77	0.635	1.156	8.77	15.10	8.77	2.32	4.54	2.32	1.51	4.00	4.36	2.31	2.31	1.52
S1T2	Z150-19	1_1_1	487	2.63	809.6	527.7	8.34	49.34	8.19	0.616	0.961	8.19	10.40	8.19	2.17	3.37	2.17	1.21	2.75	2.91	2.03	2.03	1.30
S1T5	Z200-15	1_1_1	520	2.94	301.7	275.6	14.81	17.61	13.32	1.123	1.374	10.48	11.12	10.48	2.77	2.92	2.77	1.06	2.94	2.85	2.75	2.75	1.07
S1T8	Z200-19	1_1_1	495	4.28	499.4	370.2	18.31	37.33	16.12	0.861	1.156	15.10	15.10	15.10	3.99	4.54	3.99	1.07	3.99	4.36	3.69	3.69	1.16
S6L1	Z150-19/L1	1_1_1	615	2.56	805.6	534.3	8.69	49.48	8.69	0.635	1.073	8.69	12.19	8.69	2.30	3.94	2.30	1.11	3.22	3.52	2.13	2.13	1.20
S6L2	Z200-19/L2	1_1_1	517	3.81	474.2	390.6	21.31	36.13	18.20	0.915	1.150	16.39	16.66	16.39	4.33	4.77	4.33	0.88	4.40	4.57	3.94	3.94	0.97
S6S1	Z200-15/S1	1_1_1	529	2.64	303.9	251.9	14.88	18.21	13.59	1.119	1.449	10.72	11.07	10.72	2.84	3.02	2.84	0.93	2.93	2.74	2.58	2.58	1.02
S6S2	Z150-19/S2	1_1_1	527	2.71	808.1	537.5	8.82	50.26	8.73	0.632	0.990	8.73	11.19	8.73	2.31	3.61	2.31	1.17	2.96	3.14	2.16	2.16	1.25
S1T3	Z150-19	2_1_2	487	2.98	809.6	527.7	14.46	49.34	10.81	0.709	0.961	10.81	10.40	10.40	2.75	3.37	2.75	1.09	2.75	2.84	2.54	2.54	1.17
S1T9	Z200-19	2_1_2	495	4.55	499.4	370.2	31.97	37.33	19.47	0.946	1.156	17.16	15.10	15.10	3.99	4.54	3.99	1.14	3.99	4.36	3.96	3.96	1.15
S8T5	Z200-15/5	2_1_2	529	2.93	305	304.1	26.99	17.87	16.88	1.246	1.319	12.37	11.90	11.90	3.14	3.00	3.00	0.98	3.14	2.74	2.65	2.65	1.11
S8T6	Z150-19/6	2_1_2	546	3.37	784.1	503.5	15.24	51.90	12.03	0.751	1.041	12.03	11.24	11.24	2.97	3.68	2.97	1.14	2.97	3.15	2.58	2.58	1.31
S4T3	Z200-15/3	0_0_0	480	2.90	297.1	258.3	21.08	17.52	14.63	1.181	1.363	11.13	10.44	10.44	2.76	2.83	2.76	1.05	2.76	2.90	2.90	2.76	1.05
S4T4	Z200-15/4	0_0_0	480	2.94	299	258.9	21.71	17.87	14.91	1.179	1.362	11.35	10.60	10.60	2.81	2.88	2.81	1.05	2.81	2.90	2.90	2.81	1.05
S4T5	Z150-19/5	0_0_0	480	2.92	780.5	524.5	13.05	47.97	10.36	0.705	0.957	10.36	10.32	10.32	2.73	3.31	2.73	1.07	2.73	2.88	2.38	2.38	1.23
S4T1	Z200-19/1	1_1_1	480	3.97	464.4	364.7	85.55	36.36	22.32	1.017	1.147	18.76	15.72	15.72	4.15	4.60	4.15	0.96	4.15	4.49	4.22	4.15	0.96
S4T2	Z200-19/2	1_1_1	480	4.42	452.6	348.6	84.40	35.04	22.16	1.030	1.173	18.48	15.35	15.35	4.05	4.52	4.05	1.09	4.05	4.49	4.22	4.05	1.09
S4T6	Z150-19/6	1_1_1	480	2.69	769.3	513.1	36.58	47.97	12.91	0.790	0.967	12.77	10.31	10.31	2.72	3.32	2.72	0.99	2.72	2.88	2.66	2.66	1.01

Appendix 4: Purlins Test Results and Comparison with DSM - C-factor Approach – Proposal 2

Test	Section	Bridging	f_y (MPa)	q_T (kN/m)	f_{ol} (MPa)	f_{od} (MPa)	M_o (kNm)	V_v (kN)	DSM M_{be} (kNm)	λ_l	λ_d	M_{bl} (kNm)	M_{bd} (kNm)	M_b (kNm)	q_b (kN/m)	q_{MV1} (kN/m)	q_{DSM1} (kN/m)	q_T/q_{DSM1}	EWM q_D (kN/m)	q_{MV} (kN/m)	q_C (kN/m)	q_{EMW} (kN/m)	q_T/q_{EWM}
S3S1	Z200-24	0	529	3.28	752	486.4	2.76	74.77	2.76	0.250	1.043	2.76	23.49	2.76	0.45	4.83	0.45	7.27	3.84	4.25	0.63	0.63	5.21
S3T4	C200-24	0	518	3.63	757	521.1	3.88	74.38	3.88	0.295	0.997	3.88	23.82	3.88	0.63	4.78	0.63	5.73	3.89	4.23	0.64	0.64	5.67
S5L1	Z200-25/1L	0	525	2.57	815.6	526.3	2.70	82.20	2.70	0.237	0.999	2.70	24.18	2.70	0.44	4.95	0.44	5.83	3.95	4.35	0.62	0.62	4.15
S5S1	Z200-19/S1	0	517	2.17	465.2	357.3	2.02	35.00	2.02	0.311	1.203	2.02	15.73	2.02	0.33	3.10	0.33	6.58	2.57	3.05	0.43	0.43	5.05
S7T1	Z20015/1	0	527	1.85	292.5	306.6	1.71	17.19	1.71	0.402	1.311	1.71	12.06	1.71	0.28	2.16	0.28	6.64	1.97	2.06	0.32	0.32	5.78
S7T2	C20015/2	0	548	1.70	297.9	301	2.10	17.61	2.10	0.442	1.349	2.10	12.23	2.10	0.34	2.23	0.34	4.96	2.00	1.99	0.30	0.30	5.67
S3T2	Z200-24	1	529	3.69	752	486.4	12.56	74.77	12.56	0.533	1.043	12.56	23.49	12.56	2.05	4.83	2.05	1.80	3.84	4.25	2.41	2.41	1.53
S3T5	C200-24	1	518	3.63	757	521.1	14.90	74.38	14.90	0.578	0.997	14.90	23.82	14.90	2.43	4.78	2.43	1.49	3.89	4.23	2.44	2.44	1.49
S5L2	Z200-25/2L	1	525	4.19	831.8	534.4	12.60	85.11	12.60	0.503	0.991	12.60	24.71	12.60	2.06	5.06	2.06	2.04	4.03	4.35	2.42	2.42	1.73
S5S2	Z200-19/S2R	1	517	2.28	475	359.1	9.30	36.18	9.30	0.658	1.200	9.30	15.91	9.30	1.52	3.15	1.52	1.50	2.60	3.05	1.61	1.61	1.42
S7T3	C20015/3	1	512	1.77	297.9	301	8.83	17.61	8.83	0.907	1.304	7.99	11.74	7.99	1.30	2.13	1.30	1.36	1.92	1.91	1.10	1.10	1.61
S8T2	C200-15/2	1	480	1.71	306.1	302.4	8.26	17.96	8.26	0.872	1.260	7.68	11.18	7.68	1.25	2.03	1.25	1.36	1.82	1.84	1.10	1.10	1.55
S8T3	C150-12/3	1	582	0.83	324.9	323.6	2.92	12.14	2.92	0.730	1.341	2.92	6.12	2.92	0.48	1.12	0.48	1.74	1.00	1.05	0.42	0.42	1.98
S3T3	Z200-24	2	529	4.76	752	486.4	27.16	74.77	23.54	0.730	1.043	23.54	23.49	23.49	3.84	4.83	3.84	1.24	3.84	4.25	3.58	3.58	1.33
S3T6	C200-24	2	518	4.71	757	521.1	30.82	74.38	24.56	0.743	0.997	24.56	23.82	23.82	3.89	4.78	3.89	1.21	3.89	4.23	3.52	3.52	1.34
S5L3	Z200-25/2L	2	525	4.90	807.8	528.9	27.81	82.07	23.94	0.704	0.996	23.94	24.54	23.94	3.91	5.00	3.91	1.25	4.01	4.35	3.54	3.54	1.38
S5S3	Z200-19/S3	2	517	2.74	471.5	365.2	19.78	35.43	17.39	0.906	1.190	15.77	15.92	15.77	2.57	3.13	2.57	1.06	2.60	3.05	2.54	2.54	1.08
S7T5	C20015/5	2	510	1.95	297.9	301	18.74	17.61	14.84	1.177	1.302	11.32	11.71	11.32	1.85	2.12	1.85	1.06	1.91	1.91	1.65	1.65	1.18
S8T1	C200-15/1	2	500	1.98	306.1	302.4	17.53	17.96	14.18	1.142	1.286	11.03	11.46	11.03	1.80	2.09	1.80	1.10	1.87	1.88	1.63	1.63	1.21
S8T4	C150-12/4	2	578	0.93	324.9	323.6	6.14	12.14	6.06	1.052	1.336	4.98	6.09	4.98	0.81	1.11	0.81	1.14	0.99	1.05	0.78	0.78	1.19
S2T1	Z300-25*	0_0	485	4.33	398.5	385.4	7.66	54.93	7.66	0.398	1.122	7.66	42.23	7.66	0.74	4.07	0.74	5.85	4.08	4.07	1.23	1.23	3.52
S2T2	Z300-25*	1_1	485	4.93	398.5	385.4	20.85	54.93	20.85	0.656	1.122	20.85	42.23	20.85	2.01	4.07	2.01	2.45	4.08	4.07	3.20	3.20	1.54
S2T3	Z300-25**	2_2	485	5.77	385.2	366.4	42.03	53.89	40.34	0.916	1.151	36.30	42.52	36.30	3.50	4.10	3.50	1.65	4.10	4.07	4.01	4.01	1.44

Appendix 4: Purlins Test Results and Comparison with DSM - C-factor Approach – Proposal 2

Test	Section	Bridging	f_y (MPa)	q_T (kN/m)	f_{ol} (MPa)	f_{od} (MPa)	M_o (kNm)	V_v (kN)	DSM										EWM				
									M_{be} (kNm)	λ_l	λ_d	M_{bl} (kNm)	M_{bd} (kNm)	M_b (kNm)	q_b (kN/m)	q_{MV1} (kN/m)	q_{DSM1} (kN/m)	q_T/q_{DSM1}	q_D (kN/m)	q_{MV} (kN/m)	q_C (kN/m)	q_{EMW} (kN/m)	q_T/q_{EWM}
S1T1	Z150-19	0_0_0	487	2.31	809.6	527.7	1.34	49.34	1.34	0.250	0.961	1.34	10.40	1.34	0.36	3.37	0.36	6.50	2.76	2.91	0.48	0.48	4.81
S1T4	Z200-15	0_0_0	520	2.58	301.7	275.6	2.42	17.61	2.42	0.478	1.374	2.42	11.12	2.42	0.64	2.92	0.64	4.03	2.95	2.85	0.65	0.65	3.97
S1T7	Z200-19	0_0_0	495	3.51	499.4	370.2	2.96	37.33	2.96	0.369	1.156	2.96	15.10	2.96	0.79	4.54	0.79	4.47	4.00	4.36	0.86	0.86	4.08
S1T2	Z150-19	1_1_1	487	2.63	809.6	527.7	5.87	49.34	5.87	0.522	0.961	5.87	10.40	5.87	1.55	3.37	1.55	1.69	2.75	2.91	1.67	1.67	1.57
S1T5	Z200-15	1_1_1	520	2.94	301.7	275.6	10.58	17.61	10.56	1.000	1.374	8.97	11.12	8.97	2.37	2.92	2.37	1.24	2.94	2.85	2.36	2.36	1.25
S1T8	Z200-19	1_1_1	495	4.28	499.4	370.2	12.98	37.33	12.90	0.770	1.156	12.90	15.10	12.90	3.41	4.54	3.41	1.26	3.99	4.36	3.05	3.05	1.40
S6L1	Z150-19/L1	1_1_1	615	2.56	805.6	534.3	6.07	49.48	6.07	0.531	1.073	6.07	12.19	6.07	1.60	3.94	1.60	1.60	3.22	3.52	1.84	1.84	1.39
S6L2	Z200-19/L2	1_1_1	517	3.81	474.2	390.6	15.21	36.13	14.94	0.829	1.150	14.33	16.66	14.33	3.78	4.77	3.78	1.01	4.40	4.57	3.60	3.60	1.06
S6S1	Z200-15/S1	1_1_1	529	2.64	303.9	251.9	10.79	18.21	10.78	0.996	1.449	9.19	11.07	9.19	2.43	3.02	2.43	1.09	2.93	2.74	2.40	2.40	1.10
S6S2	Z150-19/S2	1_1_1	527	2.71	808.1	537.5	6.24	50.26	6.24	0.534	0.990	6.24	11.19	6.24	1.65	3.61	1.65	1.64	2.96	3.14	1.85	1.85	1.46
S1T3	Z150-19	2_1_2	487	2.98	809.6	527.7	8.46	49.34	8.27	0.620	0.961	8.27	10.40	8.27	2.18	3.37	2.18	1.36	2.75	2.84	2.11	2.11	1.41
S1T9	Z200-19	2_1_2	495	4.55	499.4	370.2	18.71	37.33	16.28	0.865	1.156	15.20	15.10	15.10	3.99	4.54	3.99	1.14	3.99	4.36	3.77	3.77	1.21
S8T5	Z200-15/5	2_1_2	529	2.93	305	304.1	15.77	17.87	13.99	1.135	1.319	10.93	11.90	10.93	2.89	3.00	2.89	1.02	3.14	2.74	2.65	2.65	1.11
S8T6	Z150-19/6	2_1_2	546	3.37	784.1	503.5	8.95	51.90	8.90	0.646	1.041	8.90	11.24	8.90	2.35	3.68	2.35	1.43	2.97	3.15	2.25	2.25	1.50
S4T3	Z200-15/3	0_0_0	480	2.90	297.1	258.3	99.06	17.52	16.96	1.271	1.363	12.27	10.44	10.44	2.76	2.83	2.76	1.05	2.76	2.90	2.90	2.76	1.05
S4T4	Z200-15/4	0_0_0	480	2.94	299	258.9	103.0	17.87	17.21	1.267	1.362	12.47	10.60	10.60	2.81	2.88	2.81	1.05	2.81	2.90	2.90	2.81	1.05
S4T5	Z150-19/5	0_0_0	480	2.92	780.5	524.5	57.30	47.97	12.82	0.784	0.957	12.73	10.32	10.32	2.73	3.31	2.73	1.07	2.73	2.88	2.66	2.66	1.10
S4T1	Z200-19/1	1_1_1	480	3.97	464.4	364.7	152.2	36.36	22.32	1.017	1.147	18.76	15.72	15.72	4.15	4.60	4.15	0.96	4.15	4.49	4.22	4.15	0.96
S4T2	Z200-19/2	1_1_1	480	4.42	452.6	348.6	149.3	35.04	22.16	1.030	1.173	18.48	15.35	15.35	4.05	4.52	4.05	1.09	4.05	4.49	4.22	4.05	1.09
S4T6	Z150-19/6	1_1_1	480	2.69	769.3	513.1	59.07	47.97	12.91	0.790	0.967	12.77	10.31	10.31	2.72	3.32	2.72	0.99	2.72	2.88	2.66	2.66	1.01