TESTING OF BOLTED COLD-FORMED STEEL CONNECTIONS IN BEARING (WITH AND WITHOUT WASHERS)

Final Report

By

James A. Wallace
Research Assistant

Professor R. M. Schuster
Project Director
Professor R. A. LaBoube
Consultant

Canadian Cold Formed Steel Research Group
Department of Civil Engineering
University of Waterloo
Waterloo, Ontario, Canada

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Abstract

Contained in this report are the test results of double and single shear cold-formed steel bolted connections failing in bearing. Connections with and without washers were studied. The test data was compared with the current S136 and AISI methods for determining the bearing strength of cold-formed steel bolted connections. In addition, comparisons were also made with the new bearing approach currently being considered by AISI and with a recommended approach resulting from this study. Calibrations in accordance with the AISI Commentary were also carried out to establish the factors of safety and respective resistance factors for AISI and the resistance factors for S136.

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1.0 Introduction

The bearing strength of bolted connections is treated differently in the two current North American Standards for the design of cold formed steel structural members (AISI-96 [1] and CSA S136-94 [3]), from hereon simply referred to as AISI [1] and S136 [3], respectively. In the case of S136 [3], only one expression is presented that applies to all bolted connections such as single and double shear, as well as, with and without washers. In AISI [1], however, a distinction is made regarding if it is a single shear or a double shear connection and whether or not washers are being used. More specifically, the following two categories are presented, with and without washers:

1) Inside sheet of double shear connection

2) Single shear and outside sheet of double shear connection

Having recently carried out calibrations using the available bolted connection data found in the published literature, it was discovered that no data exists for the case of a double shear connection without washers where the outside sheets fail in bearing. Therefore tests were carried out at the University of Waterloo to provide data for double shear connections. It was also decided to test additional single shear specimens failing in bearing to add to the pool of existing data. As well, all of these tests were duplicated with washers in order to obtain a good comparison with the specimens without washers.

AISI [1] is currently considering a new approach for bearing of bolted connections and a ballot has been issued for consideration. This approach is similar to what is currently contained in S136 [3].

Contained in this report are the test results of double and single shear cold-formed steel bolted connections failing in bearing. Connections with and without washers were studied. The test data was compared with the current S136 and AISI methods for determining the bearing strength of a cold-formed steel bolted connection. In addition, comparisons were also made with the new bearing approach currently being considered by AISI and with a recommended approach resulting from this study.

2.0 Bearing Strength Methods

2.1 Current S136 Approach (Clause 7.3.5.1)

Currently, the factored bearing resistance per bolt, B_r, is computed in accordance with Clause 7.3.5.1 of S136, which is presented in Equation 2.1 below. No differentiation is made between connections using washers or not using washers. The coefficient, C, can be considered as the bearing factor, which is a function of the ratio of the bolt diameter to the plate thickness, d/t.

$$B_r = \phi_u C\, d\, t\, F_u \tag{2.1}$$

where

C = value from Table 1
d = nominal bolt diameter
t = uncoated sheet thickness
F_u = tensile strength of sheet
ϕ_u = resistance factor (= 0.75)

Although it is recommended that a washer be used under the end of the fastener that is turned, the values of Table 1 shall be applied whether or not washers are used. The bearing resistance is independent of whether the thread or shank bears, or if any tension is in the fastener.

Table 1: Factor C, for Bearing Resistance

Ratio of fastener diameter to member thickness, d/t	C
$d/t < 10$	3
$10 \le d/t \le 15$	$30(t/d)$
$d/t > 15$	2

2.2 Current AISI Approach (Section E3.3)

Section E3.3 of AISI presents an approach similar to S136 to determine the nominal bearing strength. As in S136, AISI uses a similar formulation to Equation 2.1 to determine the nominal bearing strength. Unlike S136, AISI uses a table of nominal bearing strength expressions containing the bearing factor, which varies from 2.22 to 3.33. Shown in Tables 2 and 3 are the nominal strength expressions for the different cases of bolted connections. The AISI method recognises that the use of washers does increase the bearing strength, however, the d/t ratio, is not included in the expression. The equations in Tables 2 and 3 give the nominal bearing strength per bolt.

Table 2: Nominal Bearing Strength for Bolted Connections <u>With Washers</u> Under Both Bolt Head and Nut

<table>
<tr><th>Thickness of Connected Part, t in. (mm)</th><th>Type of Joint</th><th>F_u/F_{sy} ratio of Connected Part</th><th>Ω ASD</th><th>ϕ LRFD</th><th>Nominal Strength P_n</th></tr>
<tr><td rowspan="3">0.024 ≤ t < 0.1875
(0.61) ≤ t < (4.76)</td><td rowspan="2">Inside sheet of double shear connection</td><td>≥ 1.08</td><td>2.22</td><td>0.55</td><td>3.33 F_u d t</td></tr>
<tr><td>< 1.08</td><td>2.22</td><td>0.65</td><td>3.00 F_u d t</td></tr>
<tr><td>Single shear and outside sheets of double shear connection</td><td>No Limit</td><td>2.22</td><td>0.60</td><td>3.00 F_u d t</td></tr>
<tr><td>t ≥ 3/16
t ≥ (4.76)</td><td colspan="5">See AISC ASD or LRFD Specifications</td></tr>
</table>

Table 3: Nominal Bearing Strength for Bolted Connections <u>Without Washers</u> Under Both Bolt Head and Nut, or With Only One Washer

<table>
<tr><th>Thickness of Connected Part, t in. (mm)</th><th>Type of Joint</th><th>F_u/F_{sy} ratio of Connected Part</th><th>Ω ASD</th><th>ϕ LRFD</th><th>Nominal Strength P_n</th></tr>
<tr><td rowspan="2">0.036 ≤ t < 0.1875
(0.914) ≤ t < (4.76)</td><td>Inside sheet of double shear connection</td><td>≥ 1.08</td><td>2.22</td><td>0.65</td><td>3.00 F_u d t</td></tr>
<tr><td>Single shear and outside sheets of double shear connection</td><td>≥ 1.08</td><td>2.22</td><td>0.70</td><td>2.22 F_u d t</td></tr>
<tr><td>t ≥ 3/16
t ≥ (4.76)</td><td colspan="5">See AISC ASD or LRFD Specifications</td></tr>
</table>

2.3 Proposed AISI Method

The proposed AISI method for bearing of bolted connections with washers is based on Equation 2.1, but is using a linear function for the bearing factor, C. This is similar to the approach currently used in S136. This new formulation of the bearing factor, C, is based on the research by Rogers and Hancock [8, 9]. A distinction between connections with washers and connections without washers is now recognised, resulting in reduced values for connections without washers. Again, the equation defines the bearing capacity per bolt.
If washers are used, Table 4 presents the values for the bearing factor, C.

Table 4: Bearing Factor, C, for Bolted Connections with Washers

Ratio of fastener diameter to member thickness, d/t	C
$d/t < 10$	3.0
$10 \leq d/t \leq 22$	$4 - 0.1(d/t)$
$d/t > 22$	1.8

If washers are not used, the values for the bearing factor, C, are to be taken from the current AISI approach as shown in Table 3.

3.0 Testing

3.1 Test Equipment

All testing was performed on an Instron testing machine - Model 4206 (see Figure 1). The maximum tensile capacity of the machine is 5000 kg and it is capable of providing both digital readings and it can generate the load-elongation curve for the test specimen. This curve can then easily be converted into a stress-strain curve.

Figure 1: Instron Machine Model 4206

3.2 Specimens

Two different thicknesses of sheet steel were used to create the specimens. Standard coupon tests for the steel were performed, the results of which are summarised in Table 5. Single bolt specimens were assembled and measured as per Figure 2. Multiple bolt specimens were assembled and measured as per Figure 3. Varying the values of e, e1, and the bolt diameter, d, created a variety of different specimen configurations. It should be noted that the hole that was punched in each specimen had a diameter 1/16th of an inch (1.6 mm) larger than the bolt diameter.

Standard machine bolts and washers, supplied by the Faculty of Engineering machine shop, were used.

Six specimens of each configuration were made, three bolted together using washers and three bolted without washers. For double shear connections, the smaller steel thickness was chosen for the outer plate. The two thicknesses were chosen such that the thicker plate would be more than double the thickness of the thinner plates combined, thereby insuring that the failure would be in the outer plates.

Table 5: Mechanical Properties

	Thickness (mm)	Average Yield Stress, F_y (MPa)	Average Ultimate Stress, F_u (MPa)	Percent Elongation (%)
Plate 1	0.64	350	382	35.3
Plate 2	1.38	356	361	38

Note: Values were determined by taking the average of three 50 mm coupon tests

The Instron testing machine is equipped with non-changeable closed grips, hence, limiting the specimens to a maximum width of 54 mm, which further imposed a limit on the size of bolts that could be used. Bolts larger than ½” (12.7 mm) in diameter could result in the specimen to fail in tension instead of bearing. Using a wider specimen would introduce an eccentricity into the specimen during loading, making it impossible to have a true bearing mode of failure. Based on this, all specimens tested were 50 mm in width.

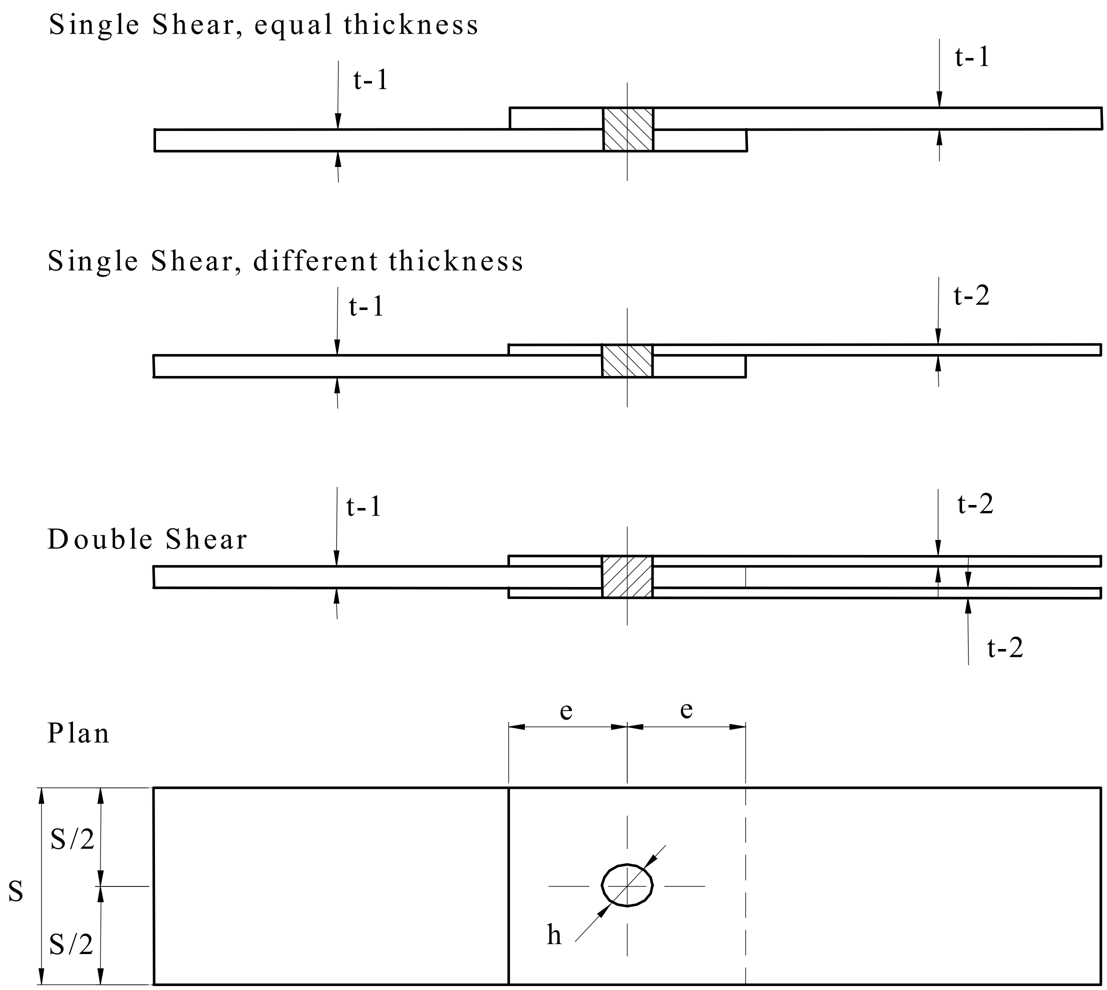

Figure 2: Schematic of Single Bolt Specimens

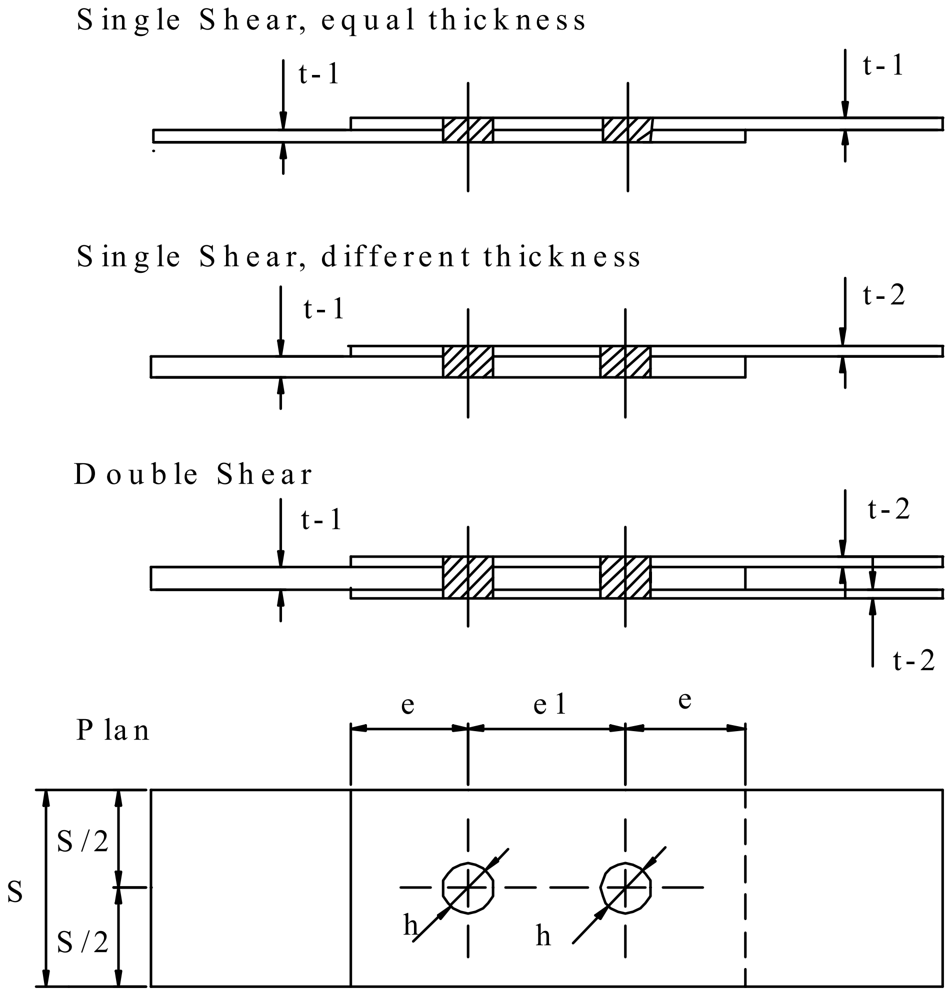

Figure 3: Schematic of Double Bolt Specimens

3.3 Testing of Specimens

Each specimen was placed in the grips of the Instron machine and a tension load was applied until failure was reached (see Figure 4). Loading of each specimen was plotted during testing - the applied load was plotted on the vertical y-axis and the elongation was plotted on the horizontal x-axis. Failure of the specimen was defined as the point at which the specimen entered into plastic deformation, which was observed as the maximum value on the load-elongation curve. Once the applied load began to drop, even as the specimen continued to elongate, the test was stopped. At this point, the bearing mode of failure could be clearly identified for each specimen.

Figure 4: Double Shear Specimen Positioned in Test Frame

4.0 Test Results

4.1 General

Geometric properties and test loads of test specimens (Tables A1 and A2) and results of specimen testing (Tables B1 and B2) can be found in the Appendices. Tables B1 and B2 include comparisons between the predicted bearing capacity and the actual bearing capacity as tested. The preferred bearing method shall be the one that produces a P_t/P_c (test/calculated) ratio closest to one. These comparisons are summarised in Tables 7 through 12 below.

4.2 Specimen Notation

The following notation was used to identify the test specimens:

For Single Bolt X-WW-SS-30-3/8-T15 For Double Bolt X-WW-SS-30-30-3/8

Where:

- X - specimen number of a particular configuration
- WW - with washers; [if WO, then without washers]
- SS - single shear using thicker plate; [if SST, then single shear using thinner plates; if MIX, then single shear with one thin and one thick plate]; if not given, specimen was double shear
- 30 - end distance in (mm) for single bolt
- 30 - centre to centre distance between bolts in (mm) of double bolt connection
- 3/8 - bolt diameter in (in.)
- T15 - torque applied to bolt in ft-lb; if not given, then a value of 10 ft-lb was used

4.3 Description of Typical Bearing Failure Mode

Shown in Figure 5 is a typical load-elongation curve of a bearing failure. As can be observed from Figure 5, at initial load application some bolt slippage was experienced. This bolt slippage was the result of the degree of bolt torque that was present in the specimen. Following this, the specimen experienced elastic deformation (linear behaviour), which then progressed into plastic deformation (non-linear behaviour). Failure of the specimen was defined as the maximum load that the specimen was able to carry, which could be observed from the load-elongation curve, as well as from the peak volt meter reading. After the maximum load was reached, the specimen continued to deform, resulting in greatly elongated bolt holes (See Figure 6). Once the applied load began to drop, even as the specimen continued to elongate, the test was stopped. More specifically, the single shear sheets curled outward, which was also the case with the outside sheets of the double shear specimens, as can be observed from Figures 7 and 8, respectively.

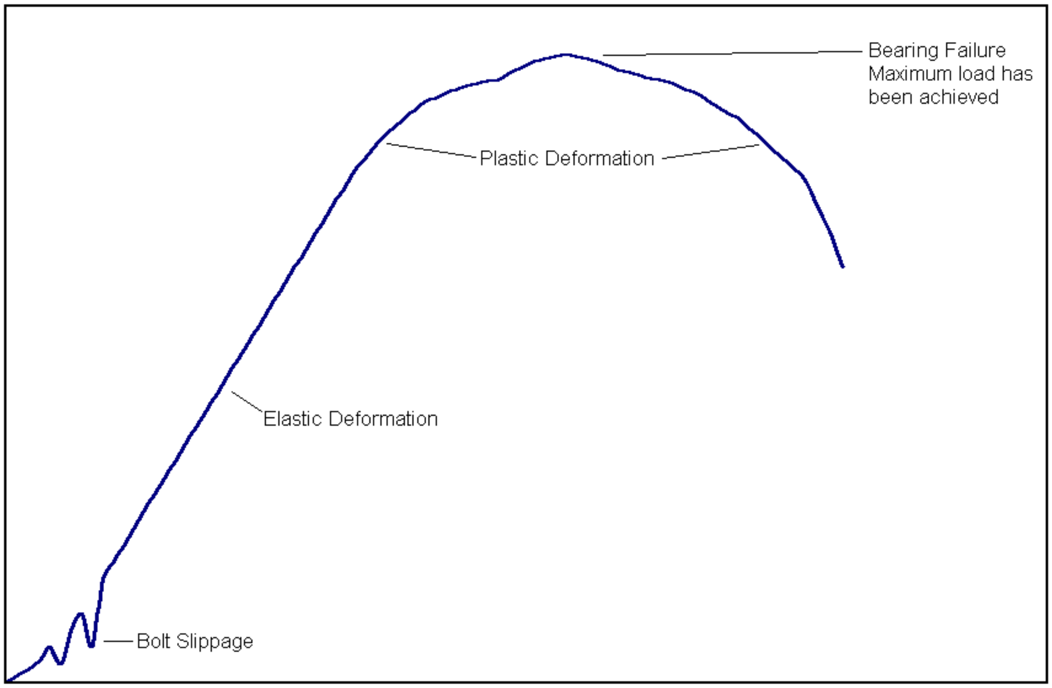

Figure 5: Typical Load-Elongation Curve of Bearing Failure

(a)

(b)

Figure 6: Typical Bearing failure of a Bolted Connection [(a) Without Washers and (b) With Washers]

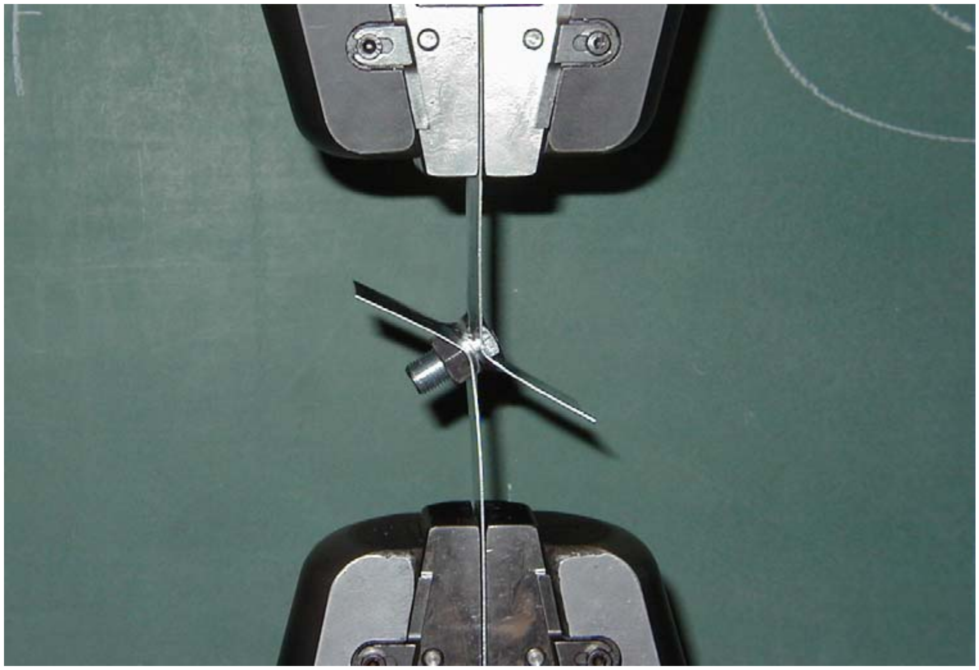

Figure 7: Typical Bearing Failure of a Bolted Connection in Single Shear [Without Washers]

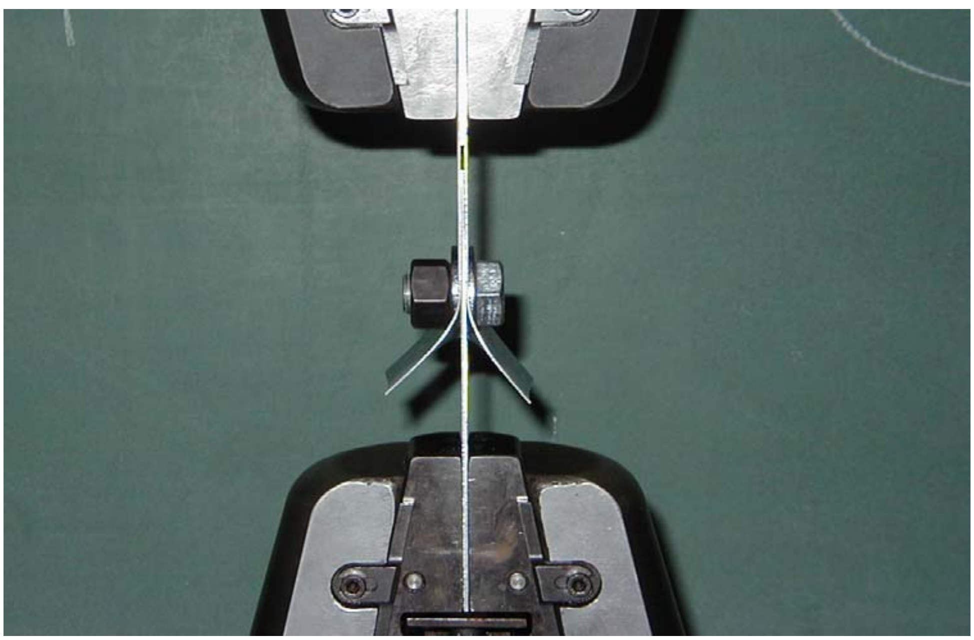

Figure 8: Typical Bearing Failure of a Bolted Connection in Double Shear [With Washers]

As can be observed from Figure 9, at failure the outside sheets of both single and double shear specimens without washers conformed to the perimeter contour of the bolt head or bolt nut. In contrast, specimens with washers conformed to the perimeter of the washers, as can be observed from Figure 10.

Figure 9: Failed Double Shear Specimens Without Washers

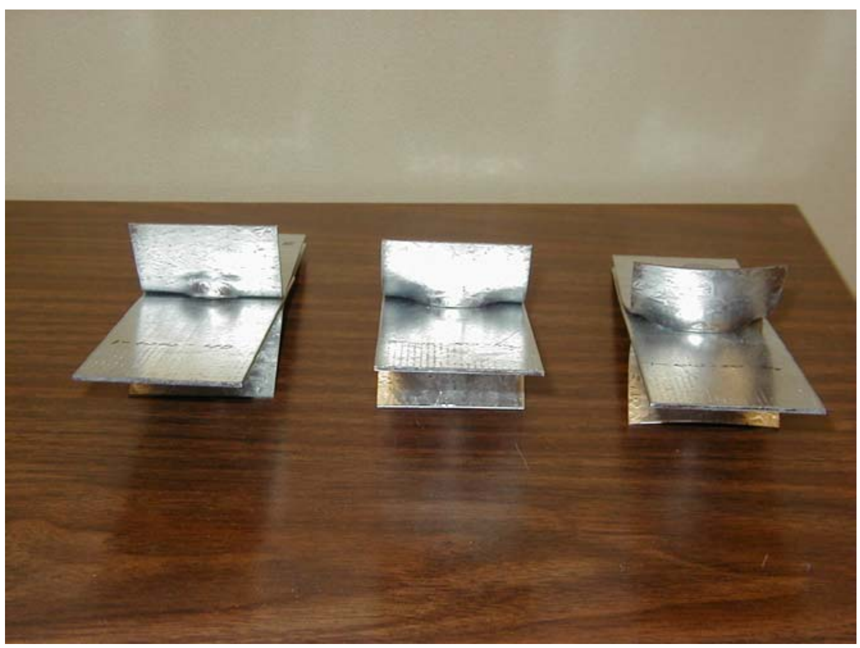

Figure 10: Failed Double Shear Specimens With Washers

4.3 Comparisons

Summarised in Tables 6 and 7 are the comparisons of the bearing method currently used by S136.

Table 6: Summary of Comparison Using Current S136 for Bolted Connections <u>With Washers</u>

	Number of Specimens	Average P_t/P_c	Standard Deviation	Coefficient of Variation
Single Shear Single Bolt	21	1.030	0.135	0.131
Double Shear Single Bolt	30	0.986	0.101	0.102
Double Shear Double Bolt	9	0.997	0.018	0.018
Total	60	1.003	0.108	0.107

Table 7: Summary of Comparison Using Current S136 for Bolted Connections <u>Without Washers</u>

	Number of Specimens	Average P_t/P_c	Standard Deviation	Coefficient of Variation
Single Shear Single Bolt	20	0.750	0.093	0.125
Double Shear Single Bolt	30	0.723	0.056	0.077
Double Shear Double Bolt	9	0.782	0.029	0.037
Total	59	0.741	0.071	0.095

Summarised in Tables 8 and 9 are the comparisons of the bearing method currently used by AISI.

Table 8: Summary of Comparisons Using Current AISI Method for Bolted Connections in Bearing <u>With Washers</u>

	Number of Specimens	Average P_t/P_c	Standard Deviation	Coefficient of Variation
Single Shear Single Bolt	21	0.911	0.233	0.256
Double Shear Single Bolt	30	0.864	0.146	0.169
Double Shear Double Bolt	9	0.997	0.018	0.018
Total	60	0.900	0.176	0.196

Table 9: Summary of Comparisons Using Current AISI Method for Bolted Connections in Bearing <u>Without Washers</u>

	Number of Specimens	Average P_t/P_c	Standard Deviation	Coefficient of Variation
Single Shear Single Bolt	20	0.893	0.236	0.265
Double Shear Single Bolt	30	0.857	0.144	0.167
Double Shear Double Bolt	9	1.057	0.039	0.037
Total	59	0.900	0.183	0.204

Summarised in Table 10 are the comparisons of the bearing method currently proposed by AISI method.

Table 10: Summary of Comparisons Using Proposed AISI and S136 Method for Bolted Connections in Bearing <u>With Washers</u>

	Number of Specimens	Average P_t/P_c	Standard Deviation	Coefficient of Variation
Single Shear Single Bolt	21	1.032	0.126	0.122
Double Shear Single Bolt	30	0.962	0.101	0.106
Double Shear Double Bolt	9	0.997	0.018	0.018
Total	60	0.991	0.107	0.108

The relationship of the bearing factor, C, versus the d/t ratio for bolted connections with washers is illustrated in Figure 11 and for bolted connections without washers in Figure 12. In accordance with Equation 2.1, the theoretical bearing factors, C, used by S136, AISI, and the proposed AISI method are highlighted on Figures 11 and 12. In addition, the Waterloo method is also included on these two Figures.

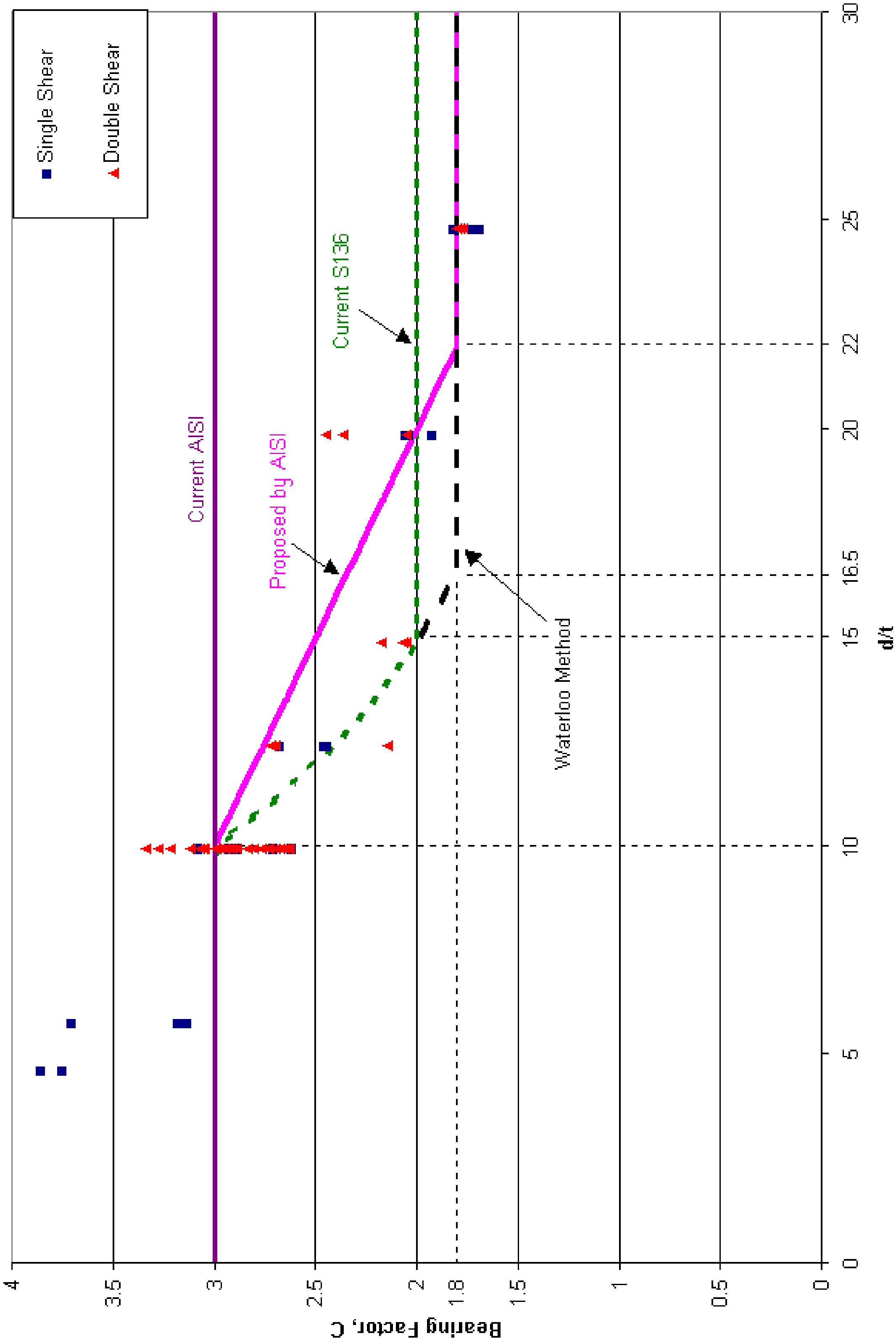

Figure 11: Bearing Factor, C, for Single Shear and Outside Sheets of Double Shear Bolted Connections <u>With Washers</u>

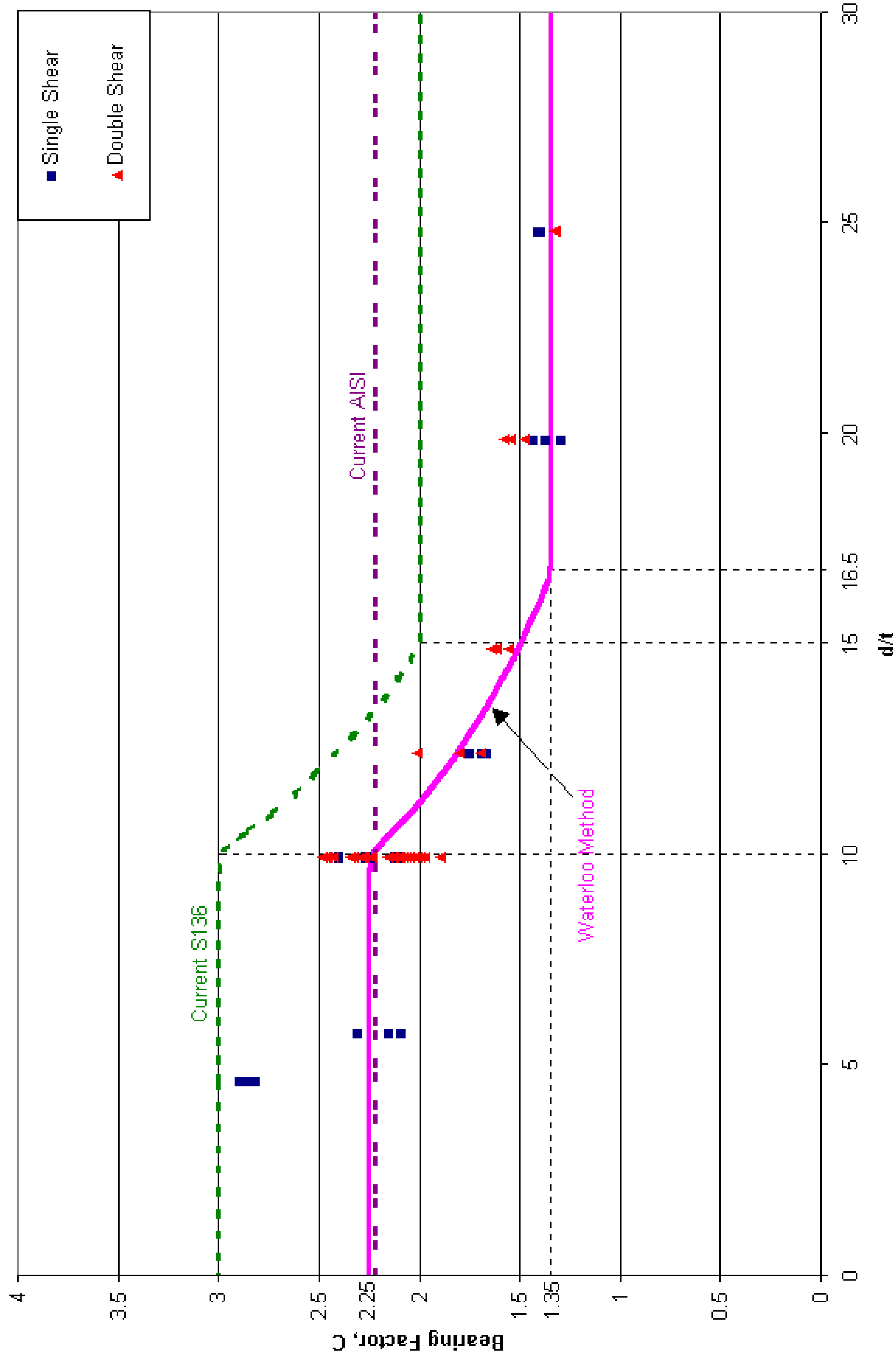

Figure 12: Bearing Factor, C, for Single Shear and Outside Sheets of Double Shear Bolted Connections <u>Without Washers</u>

4.4 Waterloo Method

Reviewing the three methods described in Section 2, one can observe that the current S136 method best fits the data documented in this report for connections with washers. For specimens tested with washers, it was determined that the current S136 method was ideal for d/t ratios less than 15. Table 11 shows an optimized expression for determining the bearing factor, C, for bolted connections with washers. The expression has been changed from the current S136 approach, resulting in slightly smaller bearing factor values for large d/t ratios.

Table 11: Bearing Factor, C, for Data With Washers

Ratio of fastener diameter to member thickness, d/t	C
$d/t < 10$	3.0
$10 \le d/t \le 16.5$	$30/(d/t)$
$d/t > 16.5$	1.80

For bolted connections without washers, the bearing factor, C, can be obtained from Table 12.

Table 12: Bearing Factor, C, for Data Without Washers

Ratio of fastener diameter to member thickness, d/t	C
$d/t < 10$	2.25
$10 \le d/t \le 16.5$	$22.5/(d/t)$
$d/t > 16.5$	1.35

It can be observed from Table 12 that the bearing factor, C, is 75% of the values of Table 11.

4.5 Results of Waterloo Method

Using the Waterloo Method, the resulting comparisons and statistical data are detailed in Tables 13 and 14, with and without washers, respectively.

Table 13: Summary of Results Using Waterloo Method for Bolted Connections <u>With Washers</u>

	Number of Specimens	Average P_t/P_c	Standard Deviation	Coefficient of Variation
Single Shear Single Bolt	21	1.024	0.130	0.127
Double Shear Single Bolt	30	0.962	0.101	0.106
Double Shear Double Bolt	9	0.997	0.018	0.018
Total	60	0.989	0.108	0.109

Table 14: Summary of Results Using Waterloo Method for Bolted Connections <u>Without Washers</u>

	Number of Specimens	Average P_t/P_c	Standard Deviation	Coefficient of Variation
Single Shear Single Bolt	20	1.031	0.113	0.110
Double Shear Single Bolt	30	0.985	0.085	0.086
Double Shear Double Bolt	9	1.043	0.038	0.037
Total	59	1.009	0.093	0.092

From Tables 13 and 14 one can observe that the Waterloo approach gives good results for bolted connections with washers and the best results for bolted connections without washers.

4.6 Calibration

Resistance factors, ϕ, are used with the LRFD design method in AISI [1] and the LSD design method in S136 [3] to reduce the nominal resistances. They are determined in conformance with load factors to provide a target reliability index, β, value of 3.5 according to the AISI [1] provisions and 4.0 for the S136 [3] provisions.

A satisfactory design can be obtained by equating the factored resistance to the factored loads:

$$\phi R_n = c(\alpha_D D_n + \alpha_L L_n) \tag{4.1}$$

Where R_n is the nominal resistance and α_D and α_L are the dead and live load factors, respectively, such that the load combinations are 1.2D + 1.6L for AISI[1] and 1.25D + 1.5L for S136[3]. The dead to live load ratios, D/L, are 1/5 in AISI[1] and 1/3 in S136[3]. Considering Equation (4.1), it can be shown that the resistance factors, ϕ, can be determined as follows.

For AISI
$$\phi = \frac{1.521(P_m M_m F_m)}{e^{\beta\sqrt{V_R^2+V_Q^2}}} \tag{4.2}$$

For S136
$$\phi = \frac{1.420(P_m M_m F_m)}{e^{\beta\sqrt{V_R^2+V_Q^2}}} \tag{4.3}$$

Where:

$$V_R = \sqrt{V_P^2 + V_M^2 + V_F^2} \tag{4.4}$$

$$V_Q = \frac{\sqrt{(D_m V_D)^2 + (L_m V_L)^2}}{D_m + L_m} \tag{4.5}$$

P_m = mean ratio of experimental to calculated results
M_m = mean ration of actual yield point to minimum specified value
F_m = mean ratio of actual to specified section modulus
D_m = mean dead load intensity (= 1.05 D_n^*)

L_m = mean live load intensity (= L_n [*])
D_n = nominal dead load intensity
L_n = nominal live load intensity
V_P = coefficient of variation of experimental to calculated results
V_M = coefficient of variation reflecting material properties' uncertainties
V_F = coefficient of variation reflecting geometric uncertainties
V_D = coefficient of variation of the dead load intensities
V_L = coefficient of variation of the live load intensities

Since the S136 Commentary [4] does not contain a detailed description and development of how to determine the resistance factors, it was decided to use the methodology outlined in the AISI Commentary [2]. Hence, the values of M_m = 1.10, V_M = 0.08, F_m = 1.00, and V_F = 0.05 were adopted in this report and were taken from Table F1 – Statistical Data for the Determination of Resistance Factor in AISI [1].

By knowing the resistance factor, ϕ, the corresponding factor of safety, Ω, can be computed as follows:

For AISI $$\Omega = \frac{1.2 D/L + 1.6}{\phi(D/L + 1)} = 1.533/\phi \qquad (4.6)$$

Summarised in Table 15 are the statistical values used and the corresponding factors of safety, Ω, and resistance factors, ϕ, calculated for the given test data. Calibrations for S136 and AISI have only been performed for the proposed Waterloo Methods, with and without washers.

[*] Values recommended by Hsiao et al. [6]

Table 15: Resistance Factors and AISI Factor of Safety for Bolted Connections Failing in Bearing using the Proposed Waterloo Methods

			With Washers	Without Washers
		# of specimens	60	59
		Mean	0.989	1.009
		Std. Dev.	0.108	0.093
		C.O.V.	0.109	0.092
		M_m	1.10	1.10
		V_M	0.08	0.08
		F_m	1.00	1.00
		P_m	0.989	1.009
		V_F	0.05	0.05
		m	59	58
		C_P	1.05	1.05
		β (S136)	4.0	4.0
		β (AISI)	3.5	3.5
		D/L (S136)	0.33	0.33
		D/L (AISI)	0.20	0.20
		V_Q (S136)	0.187	0.187
		V_Q (AISI)	0.207	0.207
AISI Commentary	S136	ϕ	**0.601**	**0.631**
	AISI	ϕ	**0.684**	**0.715**
		Ω	**2.24**	**2.14**
Chapter F of AISI Specification	S136	ϕ	**0.598**	**0.629**
	AISI	ϕ	**0.681**	**0.713**
		Ω	**2.25**	**2.15**

5.0 Conclusions and Recommendations

The use of washers is significant in bolted connections when bearing is the mode of failure. This distinction should be recognized in future editions of S136.

Based on this study, when single shear or outside sheets of double shear bolted connections with washers are considered, S136 and AISI should consider adopting Equation 2.1, using the Bearing Factor, C, method as presented in Table 11.

Outside sheet failure in double shear bolted connections behave in a similar manner as single shear connections. Based on this study, when single shear or outside sheets of double shear bolted connections without washers are considered, it is recommended that S136 and AISI use Equation 2.1 in conjunction with the reduced bearing factor, C, method as given in Table 12. Alternatively, S136 and AISI could use only the bearing factor, C, method as given in Table 11, and apply a 75% reduction factor to the values of Table 11 for bolted connections without washers.

6.0 References

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3 – Canadian Standards Association, “S136 – Cold Formed Steel Structural Members”, 1994 Edition, Toronto, ON, Canada, 1994.

4 – Canadian Standards Association, “Commentary on CSA Standard S136-94, Cold Formed Steel Structural Members”, 1995 Edition, Toronto, ON, Canada, 1995

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8 – Rogers, C.A., Hancock, G.J., “New Bolted Connection Design Formulae for G550 and G300 Steels less than 1.0 mm Thick,” Research Report No. R769, Department of Civil Engineering, Centre for Advanced Structural Engineering, The University of Sydney, Sidney, Australia, June 1998.

9 - Rogers, C.A., Hancock, G.J., “Bolted Connection Design for Sheet Steels less than 1.0 mm Thick,” Journal of Constructional Steel Research, Vol. 51. No. 2, 123-146, 1999.

Appendix A – Geometric Properties and Test Loads

Table A1: Geometric Properties and Test Loads of Double Shear Specimens WITH WASHERS

Specimen Notation	Number of Bolts Used	t-1 (mm)	t-2 (mm)	d (mm)	d/t	h (mm)	s (mm)	e (mm)	e1 (mm)	F_u (MPa)	P_t (kN)
1-ww-50	1	1.38	0.640	6.35	9.92	7.94	50	50	-	382	8.72
2-ww-50	1	1.38	0.640	6.35	9.92	7.94	50	50	-	382	8.38
3-ww-50	1	1.38	0.640	6.35	9.92	7.94	50	50	-	382	8.20
1-ww-40	1	1.38	0.640	6.35	9.92	7.94	50	40	-	382	8.16
2-ww-40	1	1.38	0.640	6.35	9.92	7.94	50	40	-	382	9.99
3-ww-40	1	1.38	0.640	6.35	9.92	7.94	50	40	-	382	9.68
1-ww-30	1	1.38	0.640	6.35	9.92	7.94	50	30	-	382	8.24
2-ww-30	1	1.38	0.640	6.35	9.92	7.94	50	30	-	382	8.32
3-ww-30	1	1.38	0.640	6.35	9.92	7.94	50	30	-	382	10.4
1-ww-20	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	8.49
2-ww-20	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	8.97
3-ww-20	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	8.60
1-ww-20-t5	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	9.09
2-ww-20-t5	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	8.50
3-ww-20-t5	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	8.38
1-ww-20-t15	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	8.81
2-ww-20-t15	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	10.2
3-ww-20-t15	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	9.27
1-ww-30-50	2	1.38	0.640	6.35	9.92	7.94	50	30	50	382	18.3
2-ww-30-50	2	1.38	0.640	6.35	9.92	7.94	50	30	50	382	18.4
3-ww-30-50	2	1.38	0.640	6.35	9.92	7.94	50	30	50	382	18.6
1-ww-30-40	2	1.38	0.640	6.35	9.92	7.94	50	30	40	382	18.5
2-ww-30-40	2	1.38	0.640	6.35	9.92	7.94	50	30	40	382	19.0
3-ww-30-40	2	1.38	0.640	6.35	9.92	7.94	50	30	40	382	18.3
1-ww-30-30	2	1.38	0.640	6.35	9.92	7.94	50	30	30	382	18.1
2-ww-30-30	2	1.38	0.640	6.35	9.92	7.94	50	30	30	382	19.1
3-ww-30-30	2	1.38	0.640	6.35	9.92	7.94	50	30	30	382	18.9
1-ww-40-3/8	1	1.38	0.640	9.53	14.9	11.1	50	40	-	382	9.64
2-ww-40-3/8	1	1.38	0.640	9.53	14.9	11.1	50	40	-	382	9.55
3-ww-40-3/8	1	1.38	0.640	9.53	14.9	11.1	50	40	-	382	10.1
1-ww-30-5/16	1	1.38	0.640	7.94	12.4	9.53	50	30	-	382	8.32
2-ww-30-5/16	1	1.38	0.640	7.94	12.4	9.53	50	30	-	382	10.5
3-ww-30-5/16	1	1.38	0.640	7.94	12.4	9.53	50	30	-	382	10.6
1-ww-50-1/2	1	1.38	0.640	12.7	12.4	14.3	50	50	-	382	14.7
2-ww-50-1/2	1	1.38	0.640	12.7	12.4	14.3	50	50	-	382	15.2
3-ww-50-1/2	1	1.38	0.640	12.7	12.4	14.3	50	50	-	382	12.8
1-ww-50-5/8	1	1.38	0.640	15.9	5.75	17.5	50	50	-	382	13.9
2-ww-50-5/8	1	1.38	0.640	15.9	5.75	17.5	50	50	-	382	14.0
3-ww-50-5/8	1	1.38	0.640	15.9	5.75	17.5	50	50	-	382	13.7

Table A2: Geometric Properties and Test Loads of Single Shear Specimens
<u>WITH WASHERS</u>

Specimen Notation	Number of Bolts Used	t-1 (mm)	t-2 (mm)	d (mm)	d/t	h (mm)	s (mm)	e (mm)	e1 (mm)	F_u (MPa)	P_t (kN)
1-ww-ss-5/16	1	0.640	0.640	7.94	12.4	9.53	50	30	-	382	4.77
2-ww-ss-5/16	1	0.640	0.640	7.94	12.4	9.53	50	30	-	382	5.20
3-ww-ss-5/16	1	0.640	0.640	7.94	12.4	9.53	50	30	-	382	4.74
1-ww-sst-5/16	1	1.38	1.38	7.94	5.75	9.53	50	30	-	361	14.7
2-ww-sst-5/16	1	1.38	1.38	7.94	5.75	9.53	50	30	-	361	12.6
3-ww-sst-5/16	1	1.38	1.38	7.94	5.75	9.53	50	30	-	361	12.4
1-ww-sst-1/4	1	1.38	1.38	6.35	4.60	7.94	50	30	-	361	12.2
2-ww-sst-1/4	1	1.38	1.38	6.35	4.60	7.94	50	30	-	361	12.2
3-ww-sst-1/4	1	1.38	1.38	6.35	4.60	7.94	50	30	-	361	11.9
1-ww-mix-1/4	1	1.38	0.640	6.35	9.92	7.94	50	30	-	382	4.78
2-ww-mix-1/4	1	1.38	0.640	6.35	9.92	7.94	50	30	-	382	4.52
3-ww-mix-1/4	1	1.38	0.640	6.35	9.92	7.94	50	30	-	382	4.21
1-ww-ss-1/4	1	0.640	0.640	6.35	9.92	7.94	50	30	-	382	4.48
2-ww-ss-1/4	1	0.640	0.640	6.35	9.92	7.94	50	30	-	382	4.06
3-ww-ss-1/4	1	0.640	0.640	6.35	9.92	7.94	50	30	-	382	4.53
1-ww-ss-1/2	1	0.640	0.640	12.7	19.8	14.3	50	50	-	382	6.32
2-ww-ss-1/2	1	0.640	0.640	12.7	19.8	14.3	50	50	-	382	6.37
3-ww-ss-1/2	1	0.640	0.640	12.7	19.8	14.3	50	50	-	382	5.98
1-ww-ss-5/8	1	0.640	0.640	15.9	24.8	17.5	50	50	-	382	6.69
2-ww-ss-5/8	1	0.640	0.640	15.9	24.8	17.5	50	50	-	382	7.05
3-ww-ss-5/8	1	0.640	0.640	15.9	24.8	17.5	50	50	-	382	6.55

Table A3: Geometric Properties and Test Loads of Double Shear Specimens <u>WITHOUT WASHERS</u>

Specimen Notation	Number of Bolts Used	t-1 (mm)	t-2 (mm)	d (mm)	d/t	h (mm)	s (mm)	e (mm)	e1 (mm)	F_u (MPa)	P_t (kN)
1-wo-50	1	1.38	0.640	6.35	9.92	7.94	50	50	-	382	6.29
2-wo-50	1	1.38	0.640	6.35	9.92	7.94	50	50	-	382	6.95
3-wo-50	1	1.38	0.640	6.35	9.92	7.94	50	50	-	382	6.53
1-wo-40	1	1.38	0.640	6.35	9.92	7.94	50	40	-	382	6.64
2-wo-40	1	1.38	0.640	6.35	9.92	7.94	50	40	-	382	6.12
3-wo-40	1	1.38	0.640	6.35	9.92	7.94	50	40	-	382	6.70
1-wo-30	1	1.38	0.640	6.35	9.92	7.94	50	30	-	382	6.38
2-wo-30	1	1.38	0.640	6.35	9.92	7.94	50	30	-	382	6.41
3-wo-50	1	1.38	0.640	6.35	9.92	7.94	50	30	-	382	6.24
1-wo-20	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	5.89
2-wo-20	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	6.20
3-wo-20	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	6.60
1-wo-20-t5	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	7.24
2-wo-20-t5	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	6.63
3-wo-20-t5	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	6.45
1-wo-20-t15	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	7.11
2-wo-20-t15	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	6.50
3-wo-20-t15	1	1.38	0.640	6.35	9.92	7.94	50	20	-	382	7.71
1-wo-30-50	2	1.38	0.640	6.35	9.92	7.94	50	30	50	382	14.5
2-wo-30-50	2	1.38	0.640	6.35	9.92	7.94	50	30	50	382	15.3
3-wo-30-50	2	1.38	0.640	6.35	9.92	7.94	50	30	50	382	14.2
1-wo-30-40	2	1.38	0.640	6.35	9.92	7.94	50	30	40	382	14.1
2-wo-30-40	2	1.38	0.640	6.35	9.92	7.94	50	30	40	382	14.6
3-wo-30-40	2	1.38	0.640	6.35	9.92	7.94	50	30	40	382	14.2
1-wo-30-30	2	1.38	0.640	6.35	9.92	7.94	50	30	30	382	15.1
2-wo-30-30	2	1.38	0.640	6.35	9.92	7.94	50	30	30	382	15.4
3-wo-30-30	2	1.38	0.640	6.35	9.92	7.94	50	30	30	382	14.0
1-wo-40-3/8	1	1.38	0.640	9.53	14.9	11.1	50	40	-	382	7.26
2-wo-40-3/8	1	1.38	0.640	9.53	14.9	11.1	50	40	-	382	7.52
3-wo-40-3/8	1	1.38	0.640	9.53	14.9	11.1	50	40	-	382	7.65
1-wo-30-5/16	1	1.38	0.640	7.94	12.4	9.53	50	30	-	382	7.82
2-wo-30-5/16	1	1.38	0.640	7.94	12.4	9.53	50	30	-	382	6.58
3-wo-30-5/16	1	1.38	0.640	7.94	12.4	9.53	50	30	-	382	6.98
1-wo-50-1/2	1	1.38	0.640	12.7	19.8	14.3	50	50	-	382	9.80
2-wo-50-1/2	1	1.38	0.640	12.7	19.8	14.3	50	50	-	382	9.62
3-wo-50-1/2	1	1.38	0.640	12.7	19.8	14.3	50	50	-	382	9.16
1-wo-50-5/8	1	1.38	0.640	15.9	24.8	17.5	50	50	-	382	10.3
2-wo-50-5/8	1	1.38	0.640	15.9	24.8	17.5	50	50	-	382	10.3
3-wo-50-5/8	1	1.38	0.640	15.9	24.8	17.5	50	50	-	382	10.3

Table A4: Geometric Properties and Test Loads of Single Shear Specimens WITHOUT WASHERS

Specimen Notation	Number of Bolts Used	t-1 (mm)	t-2 (mm)	d (mm)	d/t	h (mm)	s (mm)	e (mm)	e1 (mm)	F_u (MPa)	P_t (kN)
1-wo-ss-5/16	1	0.640	0.640	7.94	12.4	9.53	50	30	-	382	3.23
2-wo-ss-5/16	1	0.640	0.640	7.94	12.4	9.53	50	30	-	382	3.27
3-wo-ss-5/16	1	0.640	0.640	7.94	12.4	9.53	50	30	-	382	3.39
1-wo-sst-5/16	1	1.38	1.38	7.94	5.75	9.53	50	30	-	361	9.12
2-wo-sst-5/16	1	1.38	1.38	7.94	5.75	9.53	50	30	-	361	8.51
3-wo-sst-5/16	1	1.38	1.38	7.94	5.75	9.53	50	30	-	361	8.26
1-wo-sst-1/4	1	1.38	1.38	6.35	4.60	7.94	50	30	-	361	9.16
2-wo-sst-1/4	1	1.38	1.38	6.35	4.60	7.94	50	30	-	361	8.92
3-wo-sst-1/4	1	1.38	1.38	6.35	4.60	7.94	50	30	-	361	9.03
1-wo-mix-1/4	1	1.38	0.640	6.35	9.92	7.94	50	30	-	382	3.52
2-wo-mix-1/4	1	1.38	0.640	6.35	9.92	7.94	50	30	-	382	3.47
3-wo-mix-1/4	1	1.38	0.640	6.35	9.92	7.94	50	30	-	382	3.73
1-wo-ss-1/4	1	0.640	0.640	6.35	9.92	7.94	50	30	-	382	3.27
2-wo-ss-1/4	1	0.640	0.640	6.35	9.92	7.94	50	30	-	382	3.30
1-wo-ss-1/2	1	0.640	0.640	12.7	19.8	14.3	50	50	-	382	4.25
2-wo-ss-1/2	1	0.640	0.640	12.7	19.8	14.3	50	50	-	382	4.43
3-wo-ss-1/2	1	0.640	0.640	12.7	19.8	14.3	50	50	-	382	4.00
1-wo-ss-5/8	1	0.640	0.640	15.9	24.8	17.5	50	50	-	382	5.45
2-wo-ss-5/8	1	0.640	0.640	15.9	24.8	17.5	50	50	-	382	5.43
3-wo-ss-5/8	1	0.640	0.640	15.9	24.8	17.5	50	50	-	382	5.41

Appendix B – Calculations and Comparisons

Table B1: Calculated Bearing Strengths of Specimens WITH WASHERS, Using the Current S136 Method, the Current AISI Method, the Proposed AISI Method and the Proposed Waterloo Method

Specimen Notation	P_t (kN)	P_c (S136) (kN)	P_t / P_c	P_c (AISI) (kN)	P_t / P_c	P_c (Proposed AISI) (kN)	P_t / P_c	P_c (Waterloo) (kN)	P_t / P_c
1-ww-50	8.72	9.32	0.936	9.32	0.936	9.32	0.936	9.32	0.936
2-ww-50	8.38	9.32	0.899	9.32	0.899	9.32	0.899	9.32	0.899
3-ww-50	8.20	9.32	0.880	9.32	0.880	9.32	0.880	9.32	0.880
1-ww-40	8.16	9.32	0.876	9.32	0.876	9.32	0.876	9.32	0.876
2-ww-40	9.99	9.32	1.07	9.32	1.07	9.32	1.07	9.32	1.07
3-ww-40	9.68	9.32	1.04	9.32	1.04	9.32	1.04	9.32	1.04
1-ww-30	8.24	9.32	0.885	9.32	0.885	9.32	0.885	9.32	0.885
2-ww-30	8.32	9.32	0.893	9.32	0.893	9.32	0.893	9.32	0.893
3-ww-30	10.4	9.32	1.11	9.32	1.12	9.32	1.11	9.32	1.11
1-ww-20	8.49	9.32	0.911	9.32	0.911	9.32	0.911	9.32	0.911
2-ww-20	8.97	9.32	0.963	9.32	0.963	9.32	0.963	9.32	0.963
3-ww-20	8.60	9.32	0.924	9.32	0.924	9.32	0.924	9.32	0.924
1-ww-20-t5	9.09	9.32	0.976	9.32	0.976	9.32	0.976	9.32	0.976
2-ww-20-t5	8.50	9.32	0.912	9.32	0.912	9.32	0.912	9.32	0.912
3-ww-20-t5	8.38	9.32	0.899	9.32	0.899	9.32	0.899	9.32	0.899
1-ww-20-t15	8.81	9.32	0.946	9.32	0.946	9.32	0.946	9.32	0.946
2-ww-20-t15	10.2	9.32	1.09	9.32	1.09	9.32	1.09	9.32	1.09
3-ww-20-t15	9.27	9.32	0.995	9.32	0.995	9.32	0.995	9.32	0.995
1-ww-30-50	18.3	18.6	0.985	18.6	0.985	18.6	0.985	18.6	0.985
2-ww-30-50	18.4	18.6	0.991	18.6	0.991	18.6	0.991	18.6	0.991
3-ww-30-50	18.6	18.6	0.999	18.6	0.999	18.6	0.999	18.6	0.999
1-ww-30-40	18.5	18.6	0.991	18.6	0.991	18.6	0.991	18.6	0.991
2-ww-30-40	19.0	18.6	1.02	18.6	1.02	18.6	1.02	18.6	1.02
3-ww-30-40	18.3	18.6	0.981	18.6	0.981	18.6	0.981	18.6	0.981
1-ww-30-30	18.1	18.6	0.971	18.6	0.971	18.6	0.971	18.6	0.971
2-ww-30-30	19.1	18.6	1.02	18.6	1.02	18.6	1.02	18.6	1.02
3-ww-30-30	18.9	18.6	1.02	18.6	1.02	18.6	1.02	18.6	1.02
1-ww-40-3/8	9.64	9.39	1.03	14.0	0.690	11.7	0.824	11.7	0.824
2-ww-40-3/8	9.55	9.39	1.02	14.0	0.684	11.7	0.817	11.7	0.817
3-ww-40-3/8	10.1	9.39	1.080	14.0	0.726	11.7	0.867	11.7	0.867
1-ww-30-5/16	8.32	9.39	0.886	11.6	0.714	10.7	0.777	10.7	0.777
2-ww-30-5/16	10.5	9.39	1.12	11.6	0.901	10.7	0.979	10.7	0.979
3-ww-30-5/16	10.6	9.39	1.12	11.6	0.907	10.7	0.986	10.7	0.986
1-ww-50-1/2	14.7	12.4	1.18	18.6	0.789	12.5	1.17	12.5	1.17
2-ww-50-1/2	15.2	12.4	1.22	18.6	0.816	12.5	1.21	12.5	1.21
3-ww-50-1/2	12.8	12.4	1.03	18.6	0.686	12.5	1.02	12.5	1.02
1-ww-50-5/8	13.9	15.5	0.894	23.3	0.596	14.0	0.993	14.0	0.993
2-ww-50-5/8	14.0	15.5	0.902	23.3	0.601	14.0	1.00	14.0	1.00
3-ww-50-5/8	13.7	15.5	0.885	23.3	0.590	14.0	0.984	14.0	0.984
1-ww-ss-5/16	4.77	4.69	1.02	5.82	0.819	5.36	0.890	5.36	0.890
2-ww-ss-5/16	5.20	4.69	1.11	5.82	0.893	5.36	0.971	5.36	0.971
3-ww-ss-5/16	4.74	4.69	1.01	5.82	0.814	5.36	0.885	5.36	0.885

Table B1: Continued

Specimen Notation	P_t (kN)	P_c (S136) (kN)	P_t / P_c	P_c (AISI) (kN)	P_t / P_c	P_c (Proposed AISI) (kN)	P_t / P_c	P_c (Waterloo) (kN)	P_t / P_c
1-ww-sst-5/16	14.7	11.9	1.24	11.9	1.24	11.9	1.24	11.9	1.24
2-ww-sst-5/16	12.6	11.9	1.06	11.9	1.06	11.9	1.06	11.9	1.06
3-ww-sst-5/16	12.4	11.9	1.04	11.9	1.04	11.9	1.04	11.9	1.04
1-ww-sst-1/4	12.2	9.49	1.29	9.49	1.29	9.49	1.29	9.49	1.29
2-ww-sst-1/4	12.2	9.49	1.29	9.49	1.29	9.49	1.29	9.49	1.28
3-ww-sst-1/4	11.9	9.49	1.25	9.49	1.25	9.49	1.25	9.49	1.25
1-ww-mix-1/4	4.78	4.66	1.03	4.66	1.03	4.66	1.03	4.66	1.03
2-ww-mix-1/4	4.52	4.66	0.971	4.66	0.971	4.66	0.971	4.66	0.971
3-ww-mix-1/4	4.21	4.66	0.904	4.66	0.904	4.66	0.904	4.66	0.904
1-ww-ss-1/4	4.48	4.66	0.963	4.66	0.963	4.66	1.02	4.66	0.963
2-ww-ss-1/4	4.06	4.66	0.872	4.66	0.872	4.66	0.923	4.66	0.872
3-ww-ss-1/4	4.53	4.66	0.973	4.66	0.973	4.66	1.03	4.66	0.973
1-ww-ss-1/2	6.32	6.21	1.02	9.32	0.678	6.26	1.01	6.26	1.01
2-ww-ss-1/2	6.37	6.21	1.02	9.32	0.684	6.26	1.02	6.26	1.02
3-ww-ss-1/2	5.98	6.21	0.964	9.32	0.642	6.26	0.956	6.26	0.956
1-ww-ss-5/8	6.69	7.76	0.862	11.6	0.575	6.99	0.958	6.99	0.958
2-ww-ss-5/8	7.05	7.76	0.909	11.6	0.606	6.99	1.01	6.99	1.01
3-ww-ss-5/8	6.55	7.76	0.844	11.6	0.563	6.99	0.938	6.99	0.938

Number:	**60**	**60**	**60**	**60**
Mean:	**1.003**	**0.900**	**0.991**	**0.989**
S.D.:	**0.108**	**0.176**	**0.107**	**0.108**
C.O.V.:	**0.107**	**0.196**	**0.108**	**0.109**

Table B2: Calculated Bearing Strengths of Specimens WITHOUT WASHERS, Using the Current S136 Method, the Current AISI Method, and the Proposed Waterloo Method

Specimen Notation	P_t (kN)	P_c (S136) (kN)	P_t / P_c	P_c (AISI) (kN)	P_t / P_c	P_c (Waterloo) (kN)	P_t / P_c
1-wo-50	6.29	9.32	0.675	6.89	0.912	6.99	0.900
2-wo-50	6.95	9.32	0.746	6.89	1.01	6.99	0.994
3-wo-50	6.53	9.32	0.701	6.89	0.948	6.99	0.935
1-wo-40	6.64	9.32	0.713	6.89	0.964	6.99	0.951
2-wo-40	6.12	9.32	0.657	6.89	0.888	6.99	0.876
3-wo-40	6.70	9.32	0.719	6.89	0.972	6.99	0.959
1-wo-30	6.38	9.32	0.685	6.89	0.925	6.99	0.913
2-wo-30	6.41	9.32	0.688	6.89	0.929	6.99	0.917
3-wo-50	6.24	9.32	0.670	6.89	0.905	6.99	0.893
1-wo-20	5.89	9.32	0.632	6.89	0.854	6.99	0.843
2-wo-20	6.20	9.32	0.666	6.89	0.899	6.99	0.887
3-wo-20	6.60	9.32	0.709	6.89	0.958	6.99	0.945
1-wo-20-t5	7.24	9.32	0.777	6.89	1.05	6.99	1.036
2-wo-20-t5	6.63	9.32	0.712	6.89	0.962	6.99	0.949
3-wo-20-t5	6.45	9.32	0.693	6.89	0.936	6.99	0.924
1-wo-20-t15	7.11	9.32	0.764	6.89	1.03	6.99	1.02
2-wo-20-t15	6.50	9.32	0.698	6.89	0.944	6.99	0.931
3-wo-20-t15	7.71	9.32	0.828	6.89	1.12	6.99	1.10
1-wo-30-50	14.5	18.6	0.776	13.8	1.05	14.0	1.04
2-wo-30-50	15.3	18.6	0.820	13.8	1.11	14.0	1.09
3-wo-30-50	14.2	18.6	0.760	13.8	1.03	14.0	1.01
1-wo-30-40	14.1	18.6	0.759	13.8	1.02	14.0	1.01
2-wo-30-40	14.6	18.6	0.781	13.8	1.06	14.0	1.04
3-wo-30-40	14.2	18.6	0.761	13.8	1.03	14.0	1.02
1-wo-30-30	15.1	18.6	0.811	13.8	1.10	14.0	1.08
2-wo-30-30	15.3	18.6	0.824	13.8	1.11	14.0	1.10
3-wo-30-30	14.0	18.6	0.749	13.8	1.01	14.0	0.998
1-wo-40-3/8	7.26	9.39	0.773	10.3	0.702	7.04	1.03
2-wo-40-3/8	7.52	9.39	0.801	10.3	0.728	7.04	1.07
3-wo-40-3/8	7.65	9.39	0.815	10.3	0.740	7.04	1.09
1-wo-30-5/16	7.82	9.39	0.833	8.6	0.907	7.04	1.110
2-wo-30-5/16	6.58	9.39	0.701	8.6	0.764	7.04	0.935
3-wo-30-5/16	6.98	9.39	0.744	8.6	0.811	7.04	0.992
1-wo-50-1/2	9.80	12.4	0.789	13.8	0.711	8.38	1.17
2-wo-50-1/2	9.62	12.4	0.775	13.8	0.698	8.38	1.15
3-wo-50-1/2	9.16	12.4	0.738	13.8	0.665	8.38	1.09
1-wo-50-5/8	10.3	15.5	0.664	17.2	0.598	10.5	0.984
2-wo-50-5/8	10.3	15.5	0.665	17.2	0.599	10.5	0.986
3-wo-50-5/8	10.3	15.5	0.661	17.2	0.595	10.5	0.979
1-wo-ss-5/16	3.23	4.69	0.688	4.31	0.749	3.52	0.917
2-wo-ss-5/16	3.27	4.69	0.696	4.31	0.758	3.52	0.928
3-wo-ss-5/16	3.39	4.69	0.723	4.31	0.788	3.52	0.964
1-wo-sst-5/16	9.12	11.9	0.769	8.78	1.04	8.91	1.02

Table B2: Continued

Specimen Notation	P_t (kN)	P_c (S136) (kN)	P_t / P_c	P_c (AISI) (kN)	P_t / P_c	P_c (Proposed) (kN)	P_t / P_c
2-wo-sst-5/16	8.51	11.9	0.717	8.78	0.969	8.90	0.956
3-wo-sst-5/16	8.26	11.9	0.696	8.78	0.941	8.90	0.928
1-wo-sst-1/4	9.16	9.49	0.965	7.02	1.30	7.12	1.29
2-wo-sst-1/4	8.92	9.49	0.940	7.02	1.27	7.12	1.25
3-wo-sst-1/4	9.03	9.49	0.951	7.02	1.28	7.12	1.27
1-wo-mix-1/4	3.52	4.66	0.756	3.45	1.02	3.49	1.01
2-wo-mix-1/4	3.47	4.66	0.746	3.45	1.01	3.49	0.994
3-wo-mix-1/4	3.73	4.66	0.800	3.45	1.08	3.49	1.07
1-wo-ss-1/4	3.27	4.66	0.701	3.45	0.948	3.49	0.935
2-wo-ss-1/4	3.30	4.66	0.708	3.45	0.956	3.49	0.944
1-wo-ss-1/2	4.25	6.21	0.684	6.89	0.616	4.19	1.01
2-wo-ss-1/2	4.43	6.21	0.714	6.89	0.643	4.19	1.06
3-wo-ss-1/2	4.00	6.21	0.645	6.89	0.581	4.19	0.955
1-wo-ss-5/8	5.45	7.76	0.703	8.62	0.633	5.24	1.04
2-wo-ss-5/8	5.43	7.76	0.700	8.62	0.631	5.24	1.04
3-wo-ss-5/8	5.41	7.76	0.696	8.62	0.627	5.24	1.03

Number:	**59**	**59**	**59**
Mean:	**0.741**	**0.900**	**1.009**
S.D.:	**0.071**	**0.183**	**0.093**
C.O.V.:	**0.095**	**0.204**	**0.092**