research report

Strength of Screw Connections Subject to Shear Force

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Final Report

STRENGTH OF SCREW CONNECTIONS SUBJECT TO SHEAR FORCE

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PREFACE

The report summarizes a study related to the design of cold-formed steel screw connections. The study included a review of available literature and a compilation of the available test data pertaining to the strength of a screw connection subject to a shear force.

Currently, there are equations for predicting the nominal shear strength of a screw connection given in the American Iron and Steel Institute's *North American Specification for the Design of Cold-Formed Steel Structural Members*. In an effort to increase the scope of application of the nominal shear strength equations, studies by Rogers and Hancock at the Department of Civil Engineering at the University of Sydney in Australia led to the development of a varied form of screw strength equations. A significant aspect of the University of Sydney study was the testing of screw connections using low ductility steels.

The research reported herein analyzed screw connection test data from six different research programs. The test data was evaluated by comparison to both the AISI equations and the equations developed at the University of Sydney. The intent of this research was to determine the applicability and accuracy of the equations. Both normal and low ductility screw connections were included in the analysis.

For applications in which $t_2/t_1 > 1.0$, normal ductility steel, and connections with less than seven screws, the Rogers and Hancock equation provides a slightly more accurate prediction of the connection strength.

For more than seven screws in a connection, the Rogers and Hancock equation was found to over estimate the tested connection capacity and thus a reduction factor of

0.85 has been proposed in order to provide satisfactory prediction of the connection strength.

This report is based on a thesis submitted to the Faculty of the Graduate School of the University of Missouri-Rolla in partial fulfillment of the requirements for the degree of Masters of Science in Civil Engineering.

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1. INTRODUCTION

1.1 GENERAL

Screws can provide a rapid and effective means to fasten steel metal siding and roofing to framing members. Screws can also be used for connections in steel framing systems and roof trusses.

Tapping screws are externally threaded fasteners with the ability to tap their own internal mating threads when driven into metallic materials. Cold-formed steel construction utilizes several types of tapping screws. The self-drilling screws are externally threaded fasteners with the ability to drill their own hole and form, or tap, their own internal threads without deforming their own thread. These screws are high-strength, one-piece installation fasteners. Self-piercing screws are high-strength, one-piece one-side installation fasteners with sharp point angles of 20 to 26 degrees and are used to attach rigid materials to 33mils (one thickness) or thinner. The self-piercing screws are externally threaded fasteners with the ability to self-pierce metallic material, form a sleeve by extruding metallic material and tap their own mating threads when driven.

When choosing the proper fastener for cold-formed steel construction two fundamental questions must be answered: What materials are being joined? and what is the total thickness of the material in the connection? When the application has been defined, it is then possible to choose fasteners with the appropriate point design, body diameter, length, head style, drive, thread type and plating.

Point types include self-piercing or self-drilling. Several types of tapping screws are available, including thread cutting, thread rolling and thread forming which all require a pre-drilled hole. The body diameter is specified by the nominal screw size. The length of the fastener is measured from the bearing surface of the fastener to the end of the point. The length of self-drilling screws may require special consideration since some designs have an unthreaded pilot section or reamer wings between the threads and the drill point. Common head styles include flat, oval, wafer, truss, modified truss, hex washer head, pan, round washer and pancake.

1.2 STANDARD TEST

There exists a standard for testing screw strength. The American Iron and Steel Institute's Cold-Formed Steel Design Manual (AISI, 2002) gives test methods for determining the strength of a screw connection. In the AISI TS-4-02 and AISI TS-5-02, the standard test methods for determining the tensile and shear strength of screws connections and mechanically fastened cold-formed steel connections are defined.

1.3 CONNECTION STRENGTH

Screw connection strength equations in the current American Iron and Steel Institute's Cold-Formed Steel Design Manual (AISI 2001) are based on worldwide tests.

Screw connection tests used to formulate the provisions included single fastener specimens as well as multiple fastener specimens. However, it is recommended that at least two screws should be used to connect individual elements.

2. REVIEW OF LITERATURE

2.1 GENERAL

The following summarizes literature considered important for this study.

2.2 STANDARD TEST

The following are the various sources that outline testing methods in use for determining the mechanical properties of screws and screw connections.

2.2.1. Society of Automotive Engineers J78 (SAE REV 1998). SAE J78 Self Drilling Tapping Screws (SAE, REV 1998) addresses mechanical requirements for self-drilling screws, as well as dimensional, material, process, performance, selection and installation.

The tests in SAE J78 specification focus on torsional strength, rather than the tensile or shear strengths of the screws.

2.2.2. American Society for Testing and Materials C1513-01. The standard specification for steel tapping screws for cold-formed steel framing connections covers steel self-drilling and self- piercing tapping. This standard also covers test methods for determining performance (hardness, ductility, torsional strength, drill drive, self-drilling tapping screw drill capacity) requirements and physical properties.

The test standard does not cover tensile or shear strength.

2.2.3. American Iron and Steel Institute. The American Iron and Steel Institute’s document, Test Method for Mechanically Fastened Cold-Formed Steel Connections (AISI, 1996b) outlines a lap-joint shear test. The shear test involves lapping two sheets together and connecting them with a self-drilling screw. The assembly is put into a tension testing machine and a uniaxial tension force is applied. Tension tests are also specified for determining pull-over and pull-out of a screw.

2.2.4. Manufacturers Test Methods. The test procedure, results, and installation information was provided by several manufacturers. The previously mentioned documents SAE J78 (SAE, 1979), ASTM C1513-01 or the AISI Test Methods for Mechanically Fastened Cold-Formed Steel Connections were often cited as references by manufacturers.

ITW Buildex's standard is titled, Work Instruction QWI 10.6- Lab Instructions for Mechanical Properties Testing of Buildex Fasteners" (ITW Buildex, 1995). Buildex specifies its fixtures and testing rate. The tests consist of pull-out, pull-over, torsion, tension and shear.

Another manufacturer's standard considered in this project is by Vicwest (Sommerstein, 1996). This test standard includes a fixture for testing pull-over, pull-out and shear strength of screw connections.

2.3 CONNECTION STRENGTH

The references listed below present information on available data regarding the shear strength of a screw connection. The nominal strength of the screw P_{ns} shall be determined by test according to section F1 (a) of 2001 edition of the AISI Specification.

2.3.1. Buildex Division Illinois (1979). The Buildex Division-Illinois Tool Works, inc. carried out a total of 141 tests on some of the more common types and sizes of screws and sheet materials.

In the shear test series, screw-fastened connections between two steel sheets in a single lap configuration were evaluated. The connections were subjected to forces parallel to the plane of interconnection. The ultimate shear value load of single lap connection was noted.

Seven different types of screws were tested: Teks 1 to 5, mini-point (M-P) and Teks2-MBHT (Teks2-M) screws. The steel sheets had thicknesses ranging between Gauges 26 (0.018in) and 1/8 in, and had F_u/F_y ratios consistent with normal ductile steels. Shown in Appendix A are the sheet properties and the types of screws used.

2.3.2. Eastman (1976). DOFASCO in Hamilton, Canada sponsored a total of 160 screw connection tests to determine the ultimate shear load for the connection. Various types of screws ranging in sizes between No.8 and No.14 were used in the test program. The types of screws tested were screw Types A and AB, Teks 2F, Teks 1- Stitch and Teks 2-MBHT. The thickness of the steel sheets ranged from Gauge 24 (0.0239 in.) to Gauge 18 (0.0485 in.) and had F_u/F_y ratios appropriate for normal ductile steels.

2.3.3. Sokol (1999). Sokol' s work is summarized in Civil Engineering Study 98-3 (Cold-Formed Steel Series of UMR), titled, “Determination of the tensile and shear strengths of screws and the effect of screw patterns on Cold-Formed steel connections.”

Sokol' s research established a standard test method for determining the screw strength. The study involved defining a test procedure and validating the test method concepts for practicality and reliability.

The connection strength was also studied and involved the testing of 200 single lap connections of normal ductility steel sheets. Three sheet thicknesses (0.053 in., 0.040 in., 0.030 in) were considered. Three self-drilling screw sizes, No. 8, No. 10 and No. 12 with the spacing of 2d and 3d (d is the diameter of the screw threads) were studied.

2.3.4. Daudet (1996). Daudet' s work is summarized in his Master's Thesis, titled, "Self-Drilling Screw connections in Low Ductility Light Gage Steel". Daudet investigated double-lap and single-lap shear connections that used self-drilling screws. The steel used in the study included both normal and low ductility sheets with thickness of 0.029 in., 0.037 in., 0.040in., 0.043 in., 0.050 in. and 0.054 in.

The studies include both single- screw and two- screw connections with screw sizes of No. 10, No. 12 and 0.25 in. screws.

2.3.5. Vicwest (1998). The fasteners considered by Vicwest included self-tapping and self-drilling screws with sizes between nominal 0.168 in. outside thread diameter (No. 8) and 0.348 in. The connection failures covered include fastener pull-out from base material, pull-over of fastened material over head of fastener, and shear failure.

The connection tested in a shear test may fail in four possible ways including: bearing failure of material, material tearing due to tension failure of net section, shearing of the fastener and tilting of fastener.

2.3.6. Rogers and Hancock (1997). Rogers and Hancock carried out 88 different tests using six different types of screws. The types of sheets used were 042/042-G550, 060/060-G550, 042/060-G550, 0042/100-G550, 055/055-G300 and 055/080-G300. The screw diameters ranged from 0.165 in. to 0.252 in. and the sheet thickness was between 0.0161 in. to 0.0390 in. G550 steel sheet is a low ductility material where as G300 is normal ductility steel. Single-lap connections were investigated for the different thicknesses of steel sheet stated above with two or four screw patterns. The failure modes investigated included bearing, tilting and bearing/tilting.

Rogers and Hancock developed the following connection strength equations:

For $t_2/t_1 \leq 1.0$

$P_{ns} = 4.2*(t_2^3*d)^{1/2}*F_{u2}$ Eq. 2.3.6-1

$P_{ns} = C*t_1*d*F_{u1}$ Eq. 2.3.6-2

$P_{ns} = C*t_2*d*F_{u2}$ Eq. 2.3.6-3

For $t_2/t_1 < 2.5$

$P_{ns} = C*t_1*d*F_{u1}$ Eq. 2.3.6-4

$P_{ns} = C*t_2*d*F_{u2}$ Eq. 2.3.6-5

Where **C** is

d/t	**C**
d/t< 6	2.7
6<d/t<13	3.3-0.1d/t
d/t>13	2.0

Where:

d = nominal screw diameter.

t_1 = thickness of member in contact with the screw head.

t_2 = thickness of member not in contact with the screw head.

F_{u1} = tensile strength of member in contact with screw head.

F_{u2} = tensile strength of member not in contact with screw head.

P_{ns} = nominal shear strength per screw.

t = the thickness of the smaller member.

C = Varying coefficient determine by the value of d/t.

2.3.7. American Iron and Steel Institute (AISI 2001). Based on a study by Pekoz (1990), in the AISI Specification section E4.3 (2001) there are five equations to determine the nominal shear strength per screw, P_{ns}:

For $t_2/t_1 < 1.0$ the smallest of the three equations controls.

$$P_{ns} = 4.2*(t_2^3*d)^{1/2}*F_{u2} \qquad \text{Eq. 2.3.7-1}$$

$$P_{ns} = 2.7*t_1*d*F_{u1} \qquad \text{Eq. 2.3.7-2}$$

$$P_{ns} = 2.7*t_2*d*F_{u2} \qquad \text{Eq. 2.3.7-3}$$

For $t_2/t_1 > 2.5$, P_{ns} shall be taken as the smaller of the two equations controls.

$$P_{ns} = 2.7*t_1*d*F_{u1} \qquad \text{Eq. 2.3.7-4}$$

$$P_{ns} = 2.7*t_2*d*F_{u2} \qquad \text{Eq. 2.3.7-5}$$

For $1.0 < t_2/t_1 < 2.5$, P_{ns} shall be determined by linear interpolation between the above two cases.

Where:

d = nominal screw diameter.

t_1 = thickness of member in contact with the screw head.

t_2 = thickness of member not in contact with the screw head.

F_{u1} = tensile strength of member in contact with screw head.

F_{u2} = tensile strength of member not in contact with screw head.

P_{ns} = nominal shear strength (resistance) per screw.

t = the thickness of the smaller member.

3. DATA ANALYSIS

3.1 INTRODUCTION

Tests were compiled from a variety of sources for the shear strength of screw single-lap connections. These test data were used to compare with AISI equations, Eq.2.3.7-1 to Eq.2.3.7-5 and the equation from Rogers and Hancock, Equations 2.3.6-1 to 2.3.6-5.

3.2 BUILDEX DATA COMPARED WITH AISI METHOD

The Buildex Division-Illinois Tools Works, inc. carried out a total of 141 tests on the more common types and sizes of screws and sheets materials.

In comparing test data with the AISI equations, the governing principal parameter is t_2/t_1; the nominal shear strength per screw is the smallest of the five computed values (Eqs 2.3.7-1 to 2.3.7-5). The ratio of failure shear strength for test to computed results (P_t/P_{ns}) was recorded for the 141 samples tested. The Mean **(**1.054**)**, Standard Deviation **(**0.240**)** and Coefficient of Variation **(**0.228**)** for (Pt/P_{ns}) of the 141 samples were also computed.

3.3 BUILDEX DATA COMPARED WITH ROGERS AND HANCOCK METHOD

In comparing analysis between Buildex test results and that of the Rogers and Hancock method (Eqs 2.3.6-1 to 2.3.6-5), the governing principals parameters are t_2/t_1, d/t and the varying coefficient (C); the nominal shear strength per screw was the smallest of the computed values. The ratio of failure shear strength for test to computed results

(P_t/P_{ns}) was recorded for the 141samples tested. The Mean (1.109), Standard Deviation **(**0.232) and Coefficient of Variation (0.209**)** for (P_t/P_{ns}) of the 141 samples were also computed.

3.4 DOFASCO DATA COMPARED WITH AISI METHOD

DOFASCO carried out a total of 160 tests. For comparison analysis with AISI equations, the governing principal parameter is t_2/t_1; the nominal shear strength per screw is the smallest of the five computed values. The ratio of failure shear strength for the test to computed results (P_t/P_{ns}) was recorded for the 160 samples tested. The Mean (0.984), Standard Deviation (0.182) and Coefficient of Variation (0.185) for ratio P_t/P_{ns} of the 160 samples were also computed.

3.5 DOFASCO DATA COMPARED WITH ROGERS AND HANCOCK METHOD

For the comparison analysis between the DOFASCO test results and the Rogers and Hancock method, the governing principal parameters are t_2/t_1, d/t and the varying coefficient (C**)**, the nominal shear strength per screw was the smallest of the computed values. The ratio of failure shear strength for test to computed results (P_t/P_{ns}) was recorded for the 160 samples tested. The Mean (0.996), Standard Deviation (0.181) and Coefficient of Variation (0.182) for (P_t/P_{ns}) of the 160 samples were also computed.

3.6 TEST DATA FROM ROGERS AND HANCOCK COMPARED WITH AISI METHOD

Rogers and Hancock developed their data from 150 different tests using six different types of screws.

For the comparison analysis between Rogers and Hancock and AISI equation, the governing principal parameter is t_2/t_1**,** the nominal shear strength per screw was the smallest of the computed values. The ratio of failure shear strength for test to computed results (P_t/P_{ns}) was recorded for the 180 samples tested. The Mean (0.997), Standard Deviation (0.204) and Coefficient of Variation (0.206) for (P_t/P_{ns}) of the 150 samples were also computed and recorded.

3.7 TEST DATA FROM ROGERS AND HANCOCK COMPARED WITH ROGERS AND HANCOCK METHOD

In comparing the analysis between University of Sydney test and the equations developed by Rogers and Hancock, the governing principal parameters are t_2/t_1, d/t and the varying coefficient (C); the nominal shear strength per screw was the smallest of the computed values. The ratio of failure shear strength for test to computed results (P_t/P_{ns}) was recorded for the 88 samples tested. The Mean (1.019), Standard Deviation (0.194) and Coefficient of Variation (0.190) for (P_t/P_{ns}) of the 150 samples were computed.

3.8 VICWEST DATA COMPARED WITH AISI METHOD

Vicwest carried out tests using two types of screws, the self-tapping and self-drilling. A total of 520 tests were carried out on self- tapping screw and 680 tests on self –drilling screw.

In the comparing analysis with AISI equations, the governing principal parameter is t_2/t_1; the nominal shear strength per screw was the smallest of the five computed values. The ratio of failure shear strength for test to computed results (P_t/P_{ns}) was recorded for the 520 self- tapping samples and 680 self-drilling samples. The Mean for Self-tapping screw (1.111) and for Self-drilling screw (1.035), Standard Deviation for Self-tapping screw (0.261) and for Self-drilling screw (0.199) and Coefficient of Variation for Self-tapping screw (0.235) and Self-drilling (0.193) (P_t/P_{ns}) of the total 1250 samples were computed.

3.9 VICWEST DATA COMPARED WITH ROGERS AND HANCOCK METHOD

Vicwest carried out tests using two types of screws, the self tapping and self - drilling. A total of 520 tests were carried out on self tapping screw and 680 tests on self – drilling screw.

In the comparing analysis, the governing principal parameters are t_2/t_1, d/t and the varying coefficient (C); the nominal shear strength per screw was the smallest of the computed values. The ratio of failure shear strength for test to computed results P_t/P_{ns}) was recorded for the 1250 samples tested. The Mean, Standard Deviation and Coefficient of Variation for (P_t/P_{ns}) of the 1250 samples were computed as 1.035, 0.199, and 0.199.

3.10 SOKOL DATA COMPARED WITH AISI METHOD

Sokol carried out tests on self-drilling screws with spacing of two times and three times the screw diameter under different patterns of screw arrangements. In this comparison, the connections with three times the screw diameter are used.

For the comparison analysis between the Sokol test results and the AISI Method, the governing principal parameter is t_2/t_1; the nominal shear strength per screw was the smallest of the five computed values. The ratios of failure shear strength for the test to computed results (P_t/P_{ns}) were recorded for the samples.

The Mean (0.855), Standard Deviation (0.126) and Coefficient of Variation (0.147) for the ratio P_t/P_{ns} of all the samples were computed.

3.11 SOKOL DATA COMPARED WITH ROGERS AND HANCOCK METHOD

For the comparison analysis between Sokol's test results and the Rogers and Hancock Method, the governing principal parameters are t_2/t_1, d/t and the varying coefficient **(C),** the nominal shear strength per screw was the smallest of the computed values. The ratio of the failure shear strength for test to computed results (P_t/P_{ns}) was recorded for all the samples. The Mean (0.854), Standard Deviation (0.126) and Coefficient of Variation (0.147) for (P_t/P_{ns}) were recorded for all the samples.

3.12 DAUDET DATA COMPARED WITH AISI METHOD

Daudet's test results used in this study were from tests using low ductility steel. A total of 111 tests was performed.

For the comparison analysis between Daudet's test results and the AISI Method, the governing parameter is t_2/t_1; the nominal shear strength per screw was the smallest of the five computed values.

The ratio of failure shear strength for the test to computed results (P_t/P_{ns}) was recorded for the 111 samples tested. The Mean (0.866), Standard Deviation (0.168) and Coefficient of Variation (0.193) for ratio P_t/P_{ns} of the 114 samples were also computed.

3.13 DAUDET DATA COMPARED WITH ROGERS AND HANCOCK METHOD

For the comparison analysis between Daudet's test results and the Rogers and Hancock Method, the governing principal parameters are t_2/t_1, d/t and the varying coefficient **(C)**; the nominal shear strength per screw was the smallest of the computed values.

The ratio of failure shear strength for test to computed results (P_t/P_{ns}) was recorded for the 114 samples tested. The Mean (0.866), Standard Deviation (0.168**)** and Coefficient of Variation (0.193) for (P_t/P_{ns}) of the 114 samples were also computed.

4. EVALUATION OF DATA

4.1 INTRODUCTION

Tests were compiled from a variety of sources for the shear strength of single-lap screw connections. Between the six different sets of data, there were a total of 1890 test data points considered in the analysis. To analyze each of the different equations, a spreadsheet was developed to evaluate the nominal shear strength. This value was then compared to the tested value of shear strength, forming a ratio of P_{test}/P_{ns}. The mean, standard deviation and coefficient of variation were determined for each set of data.

4.2 BUILDEX RESULTS WITH AISI AND ROGERS AND HANCOCK RESULTS

In addition to all the test data from Buildex being evaluated together, the data was divided into sub-groups according to screw-sizes and also evaluated.

Table 4.1 summarizes the statistical data, showing the number of tests, the mean, standard deviation and coefficient of variation for the Buildex test data for each screw sizes.

The statistical parameters in Table 4.1 show a smaller coefficient of variation and a higher ratio of P_{test}/P_{ns} when the Rogers and Hancock equations are used. This indicates that for data from Buildex the Rogers and Hancock equations are in fact more accurate at predicting the shear strength of the screw connection.

TABLE 4.1- Buildex test data comparison

AISI METHOD	P_t/P_{ns}	ROGERS & HANCOCK METHOD	P_t/P_{ns}
ALL DATA		**ALL DATA**	
No	141	No	141
Mean	1.054	Mean	1.109
Standard Deviation	0.240	Standard Deviation	0.232
Coefficient of Variation	0.228	Coefficient of Variation	0.209
0.186in (Screw diameter)		**0.186in (Screw diameter)**	
No	30	No	30
Mean	1.070	Mean	1.109
Standard Deviation	0.298	Standard Deviation	0.300
Coefficient of Variation	0.278	Coefficient of Variation	0.278
0.212in (Screw diameter)		**0.212in (Screw diameter)**	
No	55	No	55
Mean	1.035	Mean	1.095
Standard Deviation	0.192	Standard Deviation	0.197
Coefficient of Variation	0.185	Coefficient of Variation	0.180
0.251in (Screw diameter)		**0.251in (Screw diameter)**	
No	6	No	6
Mean	0.765	Mean	0.930
Standard Deviation	0.092	Standard Deviation	0.079
Coefficient of Variation	0.120	Coefficient of Variation	0.085
0.137in (Screw diameter)		**0.137in (Screw diameter)**	
No	5	No	5
Mean	1.453	Mean	1.486
Standard Deviation	0.189	Standard Deviation	0.151
Coefficient of Variation	0.130	Coefficient of Variation	0.102
0.164in (Screw diameter)		**0.164in (Screw diameter)**	
No	20	No	20
Mean	1.142	Mean	1.174
Standard Deviation	0.222	Standard Deviation	0.211
Coefficient of Variation	0.194	Coefficient of Variation	0.180
0.246in (Screw diameter)		**0.246in (Screw diameter)**	
No	19	No	19
Mean	1.008	Mean	1.048
Standard Deviation	0.177	Standard Deviation	0.179
Coefficient of Variation	0.175	Coefficient of Variation	0.170

TABLE 4.1- Buildex test data comparison (cont.)

0.243in (Screw diameter)		**0.243in (Screw diameter)**	
No	6	No	6
Mean	0.953	Mean	1.132
Standard Deviation	0.204	Standard Deviation	0.156
Coefficient of Variation	0.214	Coefficient of Variation	0.138

4.3 DOFASCO RESULTS WITH AISI AND ROGERS AND HANCOCK RESULTS

The data from DOFASCO indicated both self-drilling and self-tapping screws were used in the test program. The screw data was analyzed by dividing the data into sub-groups according to screw-types and sizes also evaluated.

Table 4.2 summarizes the statistical data, showing the number of tests, the mean, standard deviation and coefficient of variation for the DOFASCO test data for each screw sizes.

The statistical parameters in Tables 4.2, 4.3 and 4.4 show a smaller coefficient of variation and a higher ratio of P_{test}/P_{ns} when the Rogers and Hancock equations are used. This indicates that for the data from DOFASCO, the University of Sydney is in fact more accurate at predicting the shear strength of the screw connection.

DOFASCO data indicated that the screw type, self-tapping or self-drilling, had little influence on the strength of the connection.

TABLE 4.2- Dofasco test data comparison

AISI METHOD	P_t/P_{ns}	ROGERS & HANCOCK METHOD	P_t/P_{ns}
ALL DATA		**ALL DATA**	
No	160	No	160
Mean	0.984	Mean	0.996
Standard Deviation	0.182	Standard Deviation	0.181
Coefficient of Variation	0.185	Coefficient of Variation	0.182
SCREW A		**SCREW A**	
No	48	No	48
Mean	0.989	Mean	1.001
Standard Deviation	0.180	Standard Deviation	0.180
Coefficient of Variation	0.182	Coefficient of Variation	0.180
SCREW AB		**SCREW AB**	
No	56	No	56
Mean	0.956	Mean	0.970
Standard Deviation	0.178	Standard Deviation	0.180
Coefficient of Variation	0.186	Coefficient of Variation	0.186
TEKS/2F		**TEKS/2F**	
No	16	No	16
Mean	1.032	Mean	1.035
Standard Deviation	0.220	Standard Deviation	0.221
Coefficient of Variation	0.213	Coefficient of Variation	0.214
TEKS/1 STITCH		**TEKS/1 STITCH**	
No	32	No	32
Mean	1.000	Mean	1.014
Standard Deviation	0.181	Standard Deviation	0.171
Coefficient of Variation	0.181	Coefficient of Variation	0.168
TEKS/2 MBHT		**TEKS/2 MBHT**	
No	8	No	8
Mean	0.980	Mean	0.994
Standard Deviation	0.153	Standard Deviation	0.159
Coefficient of Variation	0.156	Coefficient of Variation	0.160

TABLE 4.3- Dofasco test data comparison (self-drilling screws)

AISI METHOD	P_t/P_{ns}	ROGERS & HANCOCK METHOD	P_t/P_{ns}
ALL DATA		**ALL DATA**	
No	56	No	56
Mean	1.006	Mean	1.017
Standard Deviation	0.187	Standard Deviation	0.182
Coefficient of Variation	0.186	Coefficient of Variation	0.179
0.164in (Screw diameter)		**0.164in (Screw diameter)**	
No	16	No	16
Mean	1.032	Mean	1.035
Standard Deviation	0.220	Standard Deviation	0.221
Coefficient of Variation	0.213	Coefficient of Variation	0.214
0.186in (Screw diameter)		**0.186in (Screw diameter)**	
No	16	No	16
Mean	1.003	Mean	1.010
Standard Deviation	0.189	Standard Deviation	0.189
Coefficient of Variation	0.188	Coefficient of Variation	0.187
0.212in (Screw diameter)		**0.212in (Screw diameter)**	
No	8	No	8
Mean	0.980	Mean	0.994
Standard Deviation	0.153	Standard Deviation	0.159
Coefficient of Variation	0.156	Coefficient of Variation	0.160
0.243in (Screw diameter)		**0.243in (Screw diameter)**	
No	16	No	16
Mean	0.996	Mean	1.018
Standard Deviation	0.178	Standard Deviation	0.157
Coefficient of Variation	0.179	Coefficient of Variation	0.154

TABLE 4.4- Dofasco test data comparison (self-tapping screws)

AISI METHOD	P_t/P_{ns}	ROGERS & HANCOCK METHOD	P_t/P_{ns}
ALL DATA		**ALL DATA**	
No	104	No	104
Mean	0.972	Mean	0.985
Standard Deviation	0.179	Standard Deviation	0.180
Coefficient of Variation	0.184	Coefficient of Variation	0.183
0.164in (Screw diameter)		**0.164in (Screw diameter)**	
No	32	No	32
Mean	1.032	Mean	1.034
Standard Deviation	0.198	Standard Deviation	0.198

TABLE 4.4- Dofasco test data comparison (self-tapping screws) (cont.)

Coefficient of Variation	0.192	Coefficient of Variation	0.191
0.186in (Screw diameter)		**0.186in (Screw diameter)**	
No	32	No	32
Mean	0.990	Mean	0.996
Standard Deviation	0.180	Standard Deviation	0.178
Coefficient of Variation	0.182	Coefficient of Variation	0.179
0.243in (Screw diameter)		**0.243in (Screw diameter)**	
No	40	No	40
Mean	0.909	Mean	0.935
Standard Deviation	0.146	Standard Deviation	0.157
Coefficient of Variation	0.156	Coefficient of Variation	0.167

4.4 ROGERS AND HANCOCK RESULTS WITH AISI AND ROGERS AND HANCOCK RESULTS

Rogers and Hancock used low ductility steels in carrying out many of their test on the shear strength of a screw connection. Besides all the test data from University of Sydney being evaluated together, the data was divided into sub-groups according to screw-sizes and also evaluated.

Table 4.5 summarizes all of this data, showing the number of tests, the mean, standard deviation and coefficient of variation for the University of Sydney test data for each screw sizes.

The statistical analysis shows a higher mean value for the Rogers and Hancock method compared with AISI method but again has a lower standard deviation and coefficient of variation.

TABLE 4.5- Rogers and Hancock test data comparison

AISI METHOD	P_t/P_{ns}	ROGERS & HANCOCK METHOD	P_t/P_{ns}
ALL DATA		**ALL DATA**	
No	150	No	150
Mean	0.997	Mean	1.019
Standard Deviation	0.204	Standard Deviation	0.194
Coefficient of Variation	0.206	Coefficient of Variation	0.190
0.165in (Screw diameter)		**0.165in (Screw diameter)**	
No	41	No	41
Mean	1.003	Mean	1.021
Standard Deviation	0.203	Standard Deviation	0.203
Coefficient of Variation	0.203	Coefficient of Variation	0.199
0.192in (Screw diameter)		**0.192in (Screw diameter)**	
No	67	No	67
Mean	1.068	Mean	1.092
Standard Deviation	0.222	Standard Deviation	0.200
Coefficient of Variation	0.208	Coefficient of Variation	0.183
0.214in (Screw diameter)		**0.214in (Screw diameter)**	
No	34	No	34
Mean	0.869	Mean	0.896
Standard Deviation	0.097	Standard Deviation	0.097
Coefficient of Variation	0.112	Coefficient of Variation	0.108
0.252in (Screw diameter)		**0.252in (Screw diameter)**	
No	8	No	8
Mean	0.926	Mean	0.926
Standard Deviation	0.093	Standard Deviation	0.093
Coefficient of Variation	0.101	Coefficient of Variation	0.101

4.5 VICWEST RESULTS WITH AISI AND ROGERS AND HANCOCK RESULTS

The data from Vicwest indicated both self-drilling and self-tapping screws were used in the test program. The screw connection data was divided into sub-groups according to screw-types and sizes and also was evaluated.

Tables 4.6 and 4.7 summarizes all of this data, showing the number of tests, the mean, standard deviation and coefficient of variation for Vicwest test data for each screw sizes.

The statistical analysis shows a higher mean value of the Rogers and Hancock method compared with AISI method and again a lower standard deviation and coefficient of variation.

TABLE 4.6- Vicwest test data comparison (self-drilling screws)

AISI METHOD	P_t/P_{ns}	**ROGERS & HANCOCK METHOD**	P_t/P_{ns}
ALL DATA		**ALL DATA**	
No	680	No	680
Mean	1.035	Mean	1.043
Standard Deviation	0.199	Standard Deviation	0.207
Coefficient of Variation	0.193	Coefficient of Variation	0.198
0.189in (Screw diameter)		**0.189in (Screw diameter)**	
No	90	No	90
Mean	1.036	Mean	1.048
Standard Deviation	0.164	Standard Deviation	0.172
Coefficient of Variation	0.158	Coefficient of Variation	0.164
0.215in (Screw diameter)		**0.215in (Screw diameter)**	
No	340	No	340
Mean	1.082	Mean	1.087
Standard Deviation	0.227	Standard Deviation	0.235
Coefficient of Variation	0.210	Coefficient of Variation	0.216
0.246in (Screw diameter)		**0.246in (Screw diameter)**	
No	250	No	250
Mean	0.970	Mean	0.982
Standard Deviation	0.146	Standard Deviation	0.156
Coefficient of Variation	0.151	Coefficient of Variation	0.159

TABLE 4.7- Vicwest test data comparison (self-tapping screws)

AISI METHOD	P_t/P_{ns}	ROGERS & HANCOCK METHOD	P_t/P_{ns}
ALL DATA		**ALL DATA**	
No	520	No	520
Mean	1.111	Mean	1.123
Standard Deviation	0.261	Standard Deviation	0.252
Coefficient of Variation	0.235	Coefficient of Variation	0.225
0.246in (Screw diameter)		**0.246in (Screw diameter)**	
No	310	No	310
Mean	1.159	Mean	1.171
Standard Deviation	0.244	Standard Deviation	0.232
Coefficient of Variation	0.211	Coefficient of Variation	0.198
0.254in (Screw diameter)		**0.254in (Screw diameter)**	
No	150	No	150
Mean	1.108	Mean	1.128
Standard Deviation	0.286	Standard Deviation	0.273
Coefficient of Variation	0.258	Coefficient of Variation	0.242
0.290in (Screw diameter)		**0.290in (Screw diameter)**	
No	60	No	60
Mean	0.870	Mean	0.865
Standard Deviation	0.098	Standard Deviation	0.101
Coefficient of Variation	0.113	Coefficient of Variation	0.116

4.6 SOKOL RESULTS WITH AISI AND ROGERS AND HANCOCK RESULTS

Normal ductility steel was used in the Civil Engineering Study 98-3 and the screw sizes were No.8 (0.165 in.), No.10 (0.186 in.) and No.12 (0.215 in.) with spacing of 2d and 3d (d is the diameter of the screw threads).

In this study, only the 3d spacing test data were evaluated against the AISI and Australian equations. Besides all the test data from Sokol being evaluated together, the data was divided into sub-groups according to screw-sizes and also evaluated.

Table 4.8 summarizes all of this data, showing the number of tests, the mean, standard deviation and coefficient of variation for Sokol test data for each screw sizes.

The statistical analysis shows less than 1% difference in the mean, standard deviation and coefficient of variation values for all the 128 tests data using the two methods in question. In analyzing the screws by there sizes, it shows a less than 0.1% difference in any of the two methods consider.

The statistical parameters listed in Table 4.8 shows no difference in the two different methods.

TABLE 4.8- University of Missouri-Rolla (Sokol) test data comparison

AISI METHOD		**ROGERS & HANCOCK METHOD**	**P_t/P_{ns}**
ALL DATA		**ALL DATA**	
No	128	No	128
Mean	0.855	Mean	0.855
Standard Deviation	0.126	Standard Deviation	0.126
Coefficient of Variation	0.147	Coefficient of Variation	0.147
0.165in (Screw diameter)		**0.165in (Screw diameter)**	
No	42	No	42
Mean	0.833	Mean	0.834
Standard Deviation	0.134	Standard Deviation	0.134
Coefficient of Variation	0.161	Coefficient of Variation	0.161
0.186in (Screw diameter)		**0.186in (Screw diameter)**	
No	36	No	36
Mean	0.856	Mean	0.856
Standard Deviation	0.139	Standard Deviation	0.139
Coefficient of Variation	0.162	Coefficient of Variation	0.162
0.215in (Screw diameter)		**0.215in (Screw diameter)**	
No	50	No	50
Mean	0.873	Mean	0.873
Standard Deviation	0.108	Standard Deviation	0.108
Coefficient of Variation	0.124	Coefficient of Variation	0.124

4.7 DAUDET RESULTS WITH AISI AND ROGERS AND HANCOCK RESULTS

Daudet' s work is summarized in his Master's Thesis, titled, Self-Drilling Screw connections in Low Ductility Light Gage Steel. Daudet investigated double-lap and single-lap shear connections that used self-drilling screws. The steel used in the study included both normal and low ductility sheets with thickness of 0.029 in., 0.037 in., 0.04 in., 0.043 in., 0.050 in. and 0.054 in.

The studies include both single- screw and two- screw connections with screw sizes of No. 10, No. 12 and 0.25 in. screws.

In this study, the low ductility steel sheet tests data were evaluated with AISI and Australian equations. Besides all the tests data from Daudet being evaluated together, the data was divided into sub-groups according to screw-sizes and also evaluated.

Table 4.9 summarizes all of this data, showing the number of tests, the mean, standard deviation and coefficient of variation for the Daudet tests data for each screw sizes.

The statistical analysis shows the same Mean, Standard deviation and Coefficient of variation values for all the 111 tests data using the two methods in question. In analyzing the screws by there sizes, it shows also the same values for the two methods in question.

TABLE 4.9- University of Pittsburgh (Daudet) test data comparison

AISI METHOD	P_t/P_{ns}	ROGERS & HANCOCK METHOD	P_t/P_{ns}
ALL DATA		**ALL DATA**	
No	111	No	111
Mean	0.866	Mean	0.866
Standard Deviation	0.168	Standard Deviation	0.168
Coefficient of Variation	0.193	Coefficient of Variation	0.193
0.188in (Screw diameter)		**0.188in (Screw diameter)**	
No	24	No	24
Mean	0.847	Mean	0.847
Standard Deviation	0.169	Standard Deviation	0.169
Coefficient of Variation	0.199	Coefficient of Variation	0.199
0.190in (Screw diameter)		**0.190in (Screw diameter)**	
No	18	No	18
Mean	0.854	Mean	0.854
Standard Deviation	0.169	Standard Deviation	0.169
Coefficient of Variation	0.198	Coefficient of Variation	0.198
0.210in (Screw diameter)		**0.210in (Screw diameter)**	
No	12	No	12
Mean	0.848	Mean	0.848
Standard Deviation	0.150	Standard Deviation	0.150
Coefficient of Variation	0.177	Coefficient of Variation	0.177
0.212in (Screw diameter)		**0.212in (Screw diameter)**	
No	30	No	30
Mean	0.916	Mean	0.916
Standard Deviation	0.172	Standard Deviation	0.172
Coefficient of Variation	0.188	Coefficient of Variation	0.188
0.240in (Screw diameter)		**0.240in (Screw diameter)**	
No	12	No	12
Mean	0.926	Mean	0.926
Standard Deviation	0.126	Standard Deviation	0.126
Coefficient of Variation	0.136	Coefficient of Variation	0.136
0.243in (Screw diameter)		**0.243in (Screw diameter)**	
No	15	No	15
Mean	0.780	Mean	0.780
Standard Deviation	0.173	Standard Deviation	0.173
Coefficient of Variation	0.222	Coefficient of Variation	0.222

5. CONCLUSIONS

A total of 1890 test data from six different sources (235 in low ductility and 1655 in normal ductility steels) were analyzed using both the AISI equations and the equations from Rogers and Hancock at the University of Sydney.

Based on the data analysis, the following design recommendations were deduced:

1. For connections within two to seven screws in low or normal ductility steels, Rogers and Hancock equations provide a marginally more accurate prediction of the connection strength.
2. For connection with more than seven screws in low and normal ductility steels, Rogers and Hancock equations should be multiplied by a reduction of 0.85. The 0.85 reduction factor is based on tests by Sokol in which it was determined that as the number of screws increased the connection capacity was not proportional to the number of screws in the connection. Although Rogers and Hancock tested connections with four or fewer screws, based on engineering judgment the 0.85 reduction is recommended to be applied to the Rogers and Hancock equations.
3. For single screw connections with normal ductility steels, Rogers and Hancock equations are marginally more accurate prediction of the connection strength.
4. For connections with a single screw in low ductility steel, Rogers and Hancock equations should be multiplied by a reduction of 0.85.
5. The equations are valid for self-drilling and self-tapping screws.

BIBLIOGRAPHY

American Iron and Steel Institute (2001), North American Specification for the Design of Cold-Formed Steel Structural Members, Washington, D.C.

Daudet, R.L. (1996), “Self-Drilling Screw Connections in Low Ductility Light Gage Steel,” submitted to the Graduate Faculty at the University of Pittsburgh in partial fulfillment for the degree Master of Science in Civil Engineering.

Eastman, R.W. (1976), Report on Screw Fastened Sheet Steel Connections, Two Volumes, Report for Canadian Steel Industries Construction Council, DOFASCO, Hamilton, Canada.

Janusz, M., Sledz, M. and Moravek, S. (1979), Teks Fasteners, Pullout and Shear Characteristics In Various Thicknesses of Steels, Second Edition, Buildex Division-Illinois Tools Works, Inc.

Pekoz, T. (1990), “Design of Cold-Formed Steel Screw Connections, Proceedings of the Tenth International Specialty Conference on Cold-Formed Steel Structures, Department of Civil Engineering, University of Missouri-Rolla

Rogers, C.A.and Hancock, G.J.(1997) “Screwed Connection tests of Thin G550 and G300 Sheet Steels,” Centre for Advanced Structural Engineering, Department of Civil Engineering, University of Sydney, Australia, December.

SAE J78 Self Drilling Tapping Screws (SAE, REV 1998) Society of Automotive Engineers, Warrendale, Pennsylvania.

Sokol, A.M (1998)., “Determination of the Tensile and Shear Strengths of Screws And The Effect of Screw Patterns on Cold-Formed Steel Connections,” Civil Engineering Study 98-3, University of Missouri-Rolla.

Sommerstein, M. and Mandelzys, B. (1996). Vicwest Fasteners Manual, Vicwest- A Division of Jannock Steel Fabricating Company.

Test Method for Mechanically Fastened Cold-Formed Steel Connections (2002), American Iron and Steel Institute, Washington, D.C.

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