research report

Self - Drilling Screw Connections Subject to Combined Shear and Tension

RESEARCH REPORT RP02-4

APRIL 2002
REVISION 2006

Committee on Specifications
for the Design of Cold-Formed
Steel Structural Members

American Iron and Steel Institute

The material contained herein has been developed by researchers based on their research findings. The material has also been reviewed by the American Iron and Steel Institute Committee on Specifications for the Design of Cold-Formed Steel Structural Members. The Committee acknowledges and is grateful for the contributions of such researchers.

The material herein is for general information only. The information in it should not be used without first securing competent advice with respect to its suitability for any given application. The publication of the information is not intended as a representation or warranty on the part of the American Iron and Steel Institute, or of any other person named herein, that the information is suitable for any general or particular use or of freedom from infringement of any patent or patents. Anyone making use of the information assumes all liability arising from such use.

Self-Drilling Screw Connections Subject to Combined Shear and Tension

Katherine Zwick and Roger LaBoube

April 2002

Introduction

The behavior of self-drilling screw connections when they are subjected to either tension or shear forces has been established in the *Specification for the Design of Cold-Formed Steel Structural Members* (1996). However, a combination of the two is a very plausible situation, yet not cited in the specification. Therefore, the objective of this study was to develop a design equation that will represent the behavior of a self-drilling screw connection when it is exposed to combined shear and tension.

Previous Research

Research pertaining to the behavior of a screw connection has been conducted at the University of West Virginia (Luttrell, 1999). The West Virginia research study considered three different screws: a No. 12 HWH, a No. 14 HWH, and a No. 14 HH (includes a washer). For each screw type, the sheet thickness and/or washer size was varied. To establish a situation where the screw would be under both shear and tensile forces, the angle, or direction, from which the force was applied was varied. The load at which the screw failed (P) at a certain angle (θ) was recorded. In the following evaluation of the data, only the pullover failure patterns will be considered. Some failures were identified as head separation. The test data is summarized in Table 1.

Analysis of Data

Critical parameters for this analysis are the following: the test shear strength (Q), the nominal shear strength (Q_n), the test tensile strength (T), and the nominal tensile strength (T_n). Both Q and T are listed in Table 1. The test shear strength was determined by

$$Q = P\sin\theta \qquad (1)$$

where P is the ultimate load at failure, and θ is the angle at which the load was applied.

The nominal shear strength was found by using Equation 2 which is Equation E4.3.1-2 in the specification (1996),

$$Q_n = 2.7\ t\ d\ F_u \qquad (2)$$

where t is the base thickness of the steel sheet, d is the nominal diameter of the screw, and F_u is the tensile strength of the steel sheet.

The tensile strength of the screw connection was determined by using the following equation:

$$T = P\cos\theta \qquad (3)$$

where T and θ have been previously defined.

The nominal tensile strength, T_n, is given by Equation 4, which is Equation E4.4.2.1 from the specification (1996),

$$T_n = 1.5\ t\ d_w F_u \qquad (4)$$

Where d_w is the washer diameter or screw diameter when no washer was present. The other parameters have been previously defined.

The specification states that the value of d_w “shall not be taken larger than ½”. As indicated by Table 1, for some tests the d_w was greater than ½”. Thus, Equation 4 was evaluated two different ways. The data was first evaluated using the actual diameter of the washer (or screw, as the case may be), whether it exceed ½” or not. The data was also evaluated conforming to the specifications where d_w was taken not to exceed ½”.

Analysis Using Actual d_w

Using the calculated Q, Q_n, T, and T_n the ratios of Q/Q_n and T/T_n were determined (Table 2). Figures 1 and 2 show the interaction of the shear and tension forces on the sheet capacity. The figures also show the results of a linear regression analysis with an equation that best fit the data. For the data where d_w was the actual washer or screw diameter (Fig. 1), the best fit equation is

$$Q/Q_n = 0.5041\ (T/T_n)^{-0.4389} \qquad (5)$$

Using Equation 5, the ratio of $(Q/Q_n)_{compute}$ was calculated using the T/T values determined from the test data. The $(Q/Q_n)_{computed}$ was then divided by the Q/Q_n ratio determined from the test data. The ratio of $(Q/Q_n)_{computed}/(Q/Q_n)$ is a measure of the accuracy of Equation 5 to predict the connection capacity. As given by Table 2, the mean and coefficient of variation are 1.009 and 0.134, respectively.

For simplicity, Equation 5 was modified as follows:

$$Q/Q_n = 0.5\ (T/T_n)^{-0.4} \qquad (6)$$

Table 2 lists the mean and coefficient of variation as 1.036 and 0.133. The statistical data indicates that the simplification will not unduly compromise the accuracy of the strength prediction.

Analysis Using $d_w \leq$ ½”

When the specification limitation $d_w \leq$ ½” was imposed on the analysis (Fig. 2), the equation for the combined tension and shear on the screw was found to be

$$Q/Q_n = 0.517\ (T/T_n)^{-0.5317} \qquad (7)$$

Using Equation 7, the ratio of $(Q/Q_n)_{compute}$ was calculated using the T/T_n values determined from the test data. The $(Q/Q_n)_{computed}$ was then divided by the Q/Q_n ratio determined from the data. The ratio of $(Q/Q_n)_{computed}/(Q/Q_n)$ is a measure of the accuracy of Equation 7 to predict the connection capacity. As given by Table 3, the mean and coefficient of variation are 1.009 and 0.135, respectively.

For simplicity, Equation 7 was modified as follows:

$$Q/Q_n = 0.5\ (T/T_n)^{-0.5} \tag{8}$$

Table 3 lists the mean and coefficient of variation as 0.963 and 0.135. The statistical data indicates that the simplification will not unduly compromise the accuracy of the strength prediction.

In lieu of the non-linear relationship given by Equation 8, the following linear equation (Figure 3) was developed:

$$Q/Q_n = 1.106 - 0.706\ (T/T_n) \tag{9}$$

The corresponding mean and coefficient of variation are 1.002 and 0.243.

Phi Factor and Factor of Safety

Equation 9 is the preferred design equation because it provides regions in which the ratios of Q/Q_n and T/T_n are equal to unity. Using the statistics from Table 4, the following values were determined for the phi factor and factor of safety:

USA $\varphi = 0.49$ and $\Omega = 3.11$

Canada $\varphi = 0.41$

Mexico $\varphi = 0.45$ and $\Omega = 3.11$

However, Equation 9 is a lower bound solution to the test data, Equations 7 or 8 represent a regression analysis fit to the data. Using the statistics for Equation 8 as given in Table 3, the following phi factor and factor of safety were determined:

USA	$\varphi = 0.65$ and $\Omega = 2.36$	(10a)
Canada	$\varphi = 0.57$	(10b)
Mexico	$\varphi = 0.59$ and $\Omega = 2.36$	(10c)

Using Equations 10a, 10b and 10c the following design equations are proposed:

For ASD,

$$Q/Q_n + 0.71\ (T/T_n) = 1.10/\ \Omega \qquad (11)$$

For LRFD and LSD,

$$Q/Q_n + 0.71\ (T/T_n) = 1.10\ \varphi \qquad (12)$$

where $Q_n = 2.7\ t\ d\ F_u$ and $T_n = 1.5\ t\ d_w F_u$.

Conclusion

Based on a review and analysis of the University of West Virginia data for the behavior of a screw connection subject to combined shear and tension, equations were derived that enable the evaluation of the strength of a screw connection when subjected to combined shear and tension. Although both non-linear and linear equations were developed, for ease of computation and because the linear equation provides regions of Q/Q_n and T/T_n equal to unity, the linear equation, Equation 9 is recommended for design The proposed equations, Equations 11 and 12, are applicable within the following limits:

$0.0285 \text{ in.} \leq t \leq 0.0445 \text{ in.}$

No. 12 and No. 14 self-drilling screws with or without washers

$d_w \leq 0.75$ in.

$62 \text{ ksi} \leq F_u \leq 70.7 \text{ ksi}$

It is recommended that Equations 11 and 12 and the phi factor and factor of safety based on Equation 8, Equations 10, be adopted for the North American Specification.

References

Specification for the Design of Cold-Formed Steel Structural Members (1996), American Iron and Steel Institute, Washington, D.C.

Luttrell, L.D. (1999), "Metal Construction Association Diaphragm Test Program,", West Virginia University.

TABLE 1

Test	Angle (deg)	d (in)	dw (in)	Ult. Load (lbs) (P)	Q Psin(theta)	T Pcos(theta)	t (in)	Fu (kips)
1	30	0.216	0.4	1270	635.0	1099.9	0.0285	70.7
2	30	0.216	0.4	1180	590.0	1021.9	0.0285	70.7
3	30	0.216	0.4	1700	850.0	1472.2	0.0345	67.8
4	30	0.216	0.4	1770	885.0	1532.9	0.0345	67.8
5	30	0.216	0.4	1730	865.0	1498.2	0.0345	67.8
6	30	0.216	0.4	1380	690.0	1195.1	0.0345	67.8
7	30	0.216	0.4	1390	695.0	1203.8	0.0345	67.8
8	45	0.216	0.4	1400	989.9	989.9	0.0345	67.8
9	45	0.216	0.4	1380	975.8	975.8	0.0345	67.8
10	30	0.25	0.75	1420	710.0	1229.8	0.0285	70.7
11	30	0.25	0.75	1460	730.0	1264.4	0.0285	70.7
12	30	0.25	0.625	1390	695.0	1203.8	0.0285	70.7
13	30	0.25	0.625	1420	710.0	1229.8	0.0285	70.7
14	30	0.25	0.75	1660	830.0	1437.6	0.0345	67.8
15	30	0.25	0.625	1640	820.0	1420.3	0.0345	67.8
16	30	0.25	0.625	1630	815.0	1411.6	0.0345	67.8
17	30	0.25	0.75	1940	970.0	1680.1	0.0445	62.0
18	30	0.25	0.625	1980	990.0	1714.7	0.0445	62.0
19	30	0.25	0.625	1960	980.0	1697.4	0.0445	62.0
20	45	0.25	0.75	1400	989.9	989.9	0.0285	70.7
21	45	0.25	0.75	1430	1011.2	1011.2	0.0285	70.7
22	45	0.25	0.625	1420	1004.1	1004.1	0.0285	70.7
23	45	0.25	0.625	1430	1011.2	1011.2	0.0285	70.7
24	45	0.25	0.75	1460	1032.4	1032.4	0.0345	67.8
25	45	0.25	0.75	1530	1081.9	1081.9	0.0345	67.8
26	45	0.25	0.625	1510	1067.7	1067.7	0.0345	67.8
27	45	0.25	0.625	1550	1096.0	1096.0	0.0345	67.8
28	45	0.25	0.625	1920	1357.6	1357.6	0.0445	62.0
29	45	0.25	0.625	2030	1435.4	1435.4	0.0445	62.0
30	60	0.25	0.625	1460	1264.4	730.0	0.0285	70.7
31	60	0.25	0.75	1420	1229.8	710.0	0.0285	70.7
32	60	0.25	0.625	1380	1195.1	690.0	0.0285	70.7
33	60	0.25	0.625	1310	1134.5	655.0	0.0285	70.7
34	60	0.25	0.75	1680	1454.9	840.0	0.0345	67.8
35	60	0.25	0.75	1670	1446.3	835.0	0.0345	67.8
36	60	0.25	0.625	1650	1428.9	825.0	0.0345	67.8
37	60	0.25	0.625	1620	1403.0	810.0	0.0345	67.8
38	60	0.25	0.75	1940	1680.1	970.0	0.0445	62.0
39	60	0.25	0.625	1960	1697.4	980.0	0.0445	62.0
40	30	0.25	0.4	1730	865.0	1498.2	0.0345	67.8
41	30	0.25	0.4	1670	835.0	1446.3	0.0345	67.8
42	30	0.25	0.4	1580	790.0	1368.3	0.0345	67.8
43	30	0.25	0.4	1450	725.0	1255.7	0.0345	67.8
44	30	0.25	0.4	1510	755.0	1307.7	0.0345	67.8
45	45	0.25	0.4	1230	869.7	869.7	0.0345	67.8
46	45	0.25	0.4	1240	876.8	876.8	0.0345	67.8
47	45	0.25	0.4	1260	891.0	891.0	0.0345	67.8
48	45	0.25	0.4	1200	848.5	848.5	0.0345	67.8
49	45	0.25	0.4	1330	940.5	940.5	0.0345	67.8
50	45	0.25	0.4	1320	933.4	933.4	0.0345	67.8
51	45	0.25	0.4	1210	855.6	855.6	0.0285	70.7
52	45	0.25	0.4	1160	820.2	820.2	0.0285	70.7
53	45	0.25	0.4	1230	869.7	869.7	0.0285	70.7
54	60	0.25	0.4	1130	978.6	565.0	0.0285	70.7
55	60	0.25	0.4	1200	1039.2	600.0	0.0285	70.7
56	60	0.25	0.4	1030	892.0	515.0	0.0285	70.7
57	60	0.25	0.4	1020	883.3	510.0	0.0285	70.7
58	60	0.25	0.4	1050	909.3	525.0	0.0285	70.7
59	60	0.25	0.4	1080	935.3	540.0	0.0285	70.7
60	60	0.25	0.4	1120	969.9	560.0	0.0285	70.7
61	60	0.25	0.4	1140	987.3	570.0	0.0285	70.7

TABLE 2

Test	Qn 2.7*t*d*Fu (kips)	Tn 1.5*t*dw*Fu (kips)	Q/Qn (test)	T/Tn (test)	Q/Qn (compute) Equation 5	Q/Qn Ratio (test/compute) Equation 5	Q/Qn (compute) Equation 6	Q/Qn Ratio (test/compute) Equation 6
1	1.175	1.209	0.540	0.910	0.525	1.028	0.519	1.041
2	1.175	1.209	0.502	0.845	0.543	0.925	0.535	0.939
3	1.364	1.403	0.623	1.049	0.494	1.262	0.491	1.270
4	1.364	1.403	0.649	1.092	0.485	1.338	0.483	1.344
5	1.364	1.403	0.634	1.068	0.490	1.294	0.487	1.302
6	1.364	1.403	0.506	0.852	0.541	0.935	0.533	0.949
7	1.364	1.403	0.509	0.858	0.539	0.945	0.532	0.958
8	1.364	1.403	0.726	0.705	0.588	1.235	0.575	1.262
9	1.364	1.403	0.715	0.695	0.591	1.210	0.578	1.237
10	1.360	2.267	0.522	0.543	0.659	0.792	0.639	0.817
11	1.360	2.267	0.537	0.558	0.651	0.824	0.632	0.850
12	1.360	1.889	0.511	0.637	0.614	0.832	0.599	0.853
13	1.360	1.889	0.522	0.651	0.609	0.858	0.594	0.879
14	1.579	2.631	0.526	0.546	0.657	0.800	0.637	0.826
15	1.579	2.193	0.519	0.648	0.610	0.851	0.595	0.873
16	1.579	2.193	0.516	0.644	0.612	0.844	0.596	0.866
17	1.862	3.104	0.521	0.541	0.660	0.789	0.639	0.815
18	1.862	2.587	0.532	0.663	0.604	0.880	0.589	0.902
19	1.862	2.587	0.526	0.656	0.606	0.868	0.592	0.889
20	1.360	2.267	0.728	0.437	0.725	1.004	0.696	1.045
21	1.360	2.267	0.743	0.446	0.718	1.035	0.691	1.077
22	1.360	1.889	0.738	0.532	0.665	1.110	0.644	1.147
23	1.360	1.889	0.743	0.535	0.663	1.121	0.642	1.158
24	1.579	2.631	0.654	0.392	0.760	0.860	0.727	0.899
25	1.579	2.631	0.685	0.411	0.745	0.920	0.713	0.960
26	1.579	2.193	0.676	0.487	0.691	0.978	0.667	1.014
27	1.579	2.193	0.694	0.500	0.683	1.016	0.660	1.052
28	1.862	2.587	0.729	0.525	0.669	1.090	0.647	1.127
29	1.862	2.587	0.771	0.555	0.653	1.181	0.633	1.218
30	1.360	1.889	0.930	0.386	0.765	1.215	0.731	1.271
31	1.360	2.267	0.904	0.313	0.839	1.078	0.795	1.137
32	1.360	1.889	0.879	0.365	0.784	1.120	0.748	1.175
33	1.360	1.889	0.834	0.347	0.802	1.040	0.764	1.092
34	1.579	2.631	0.921	0.319	0.832	1.107	0.789	1.167
35	1.579	2.631	0.916	0.317	0.834	1.098	0.791	1.157
36	1.579	2.193	0.905	0.376	0.774	1.169	0.739	1.224
37	1.579	2.193	0.889	0.369	0.780	1.139	0.745	1.193
38	1.862	3.104	0.902	0.313	0.840	1.074	0.796	1.133
39	1.862	2.587	0.911	0.379	0.772	1.181	0.737	1.236
40	1.579	1.403	0.548	1.068	0.490	1.118	0.487	1.125
41	1.579	1.403	0.529	1.030	0.497	1.063	0.494	1.070
42	1.579	1.403	0.500	0.975	0.510	0.982	0.505	0.991
43	1.579	1.403	0.459	0.895	0.529	0.867	0.523	0.878
44	1.579	1.403	0.478	0.932	0.520	0.920	0.514	0.930
45	1.579	1.403	0.551	0.620	0.622	0.886	0.605	0.910
46	1.579	1.403	0.555	0.625	0.620	0.896	0.604	0.920
47	1.579	1.403	0.564	0.635	0.615	0.917	0.600	0.941
48	1.579	1.403	0.537	0.605	0.629	0.855	0.611	0.879
49	1.579	1.403	0.596	0.670	0.601	0.991	0.587	1.015
50	1.579	1.403	0.591	0.665	0.603	0.980	0.589	1.004
51	1.360	1.209	0.629	0.708	0.587	1.072	0.574	1.096
52	1.360	1.209	0.603	0.678	0.598	1.009	0.584	1.033
53	1.360	1.209	0.639	0.719	0.582	1.098	0.570	1.121
54	1.360	1.209	0.720	0.467	0.704	1.022	0.678	1.062
55	1.360	1.209	0.764	0.496	0.686	1.115	0.662	1.155
56	1.360	1.209	0.656	0.426	0.733	0.895	0.703	0.932
57	1.360	1.209	0.649	0.422	0.736	0.882	0.706	0.920
58	1.360	1.209	0.669	0.434	0.727	0.920	0.698	0.958
59	1.360	1.209	0.688	0.447	0.718	0.958	0.690	0.996
60	1.360	1.209	0.713	0.463	0.707	1.009	0.680	1.048
61	1.360	1.209	0.726	0.471	0.701	1.035	0.675	1.075
					Mean =	1.009	Mean =	1.036
					Std. Dev =	0.135	Std. Dev =	0.138
					Coeff. Var.=	0.134	Coeff. Var.=	0.133

TABLE 3

Test	Qn	Tn	Q/Qn	T/Tn	Q/Qn	Q/Qn Ratio	Q/Qn	Q/Qn Ratio
	2.7*t*d*Fu	1.5*t*dw*Fu	(test)	(test)	(compute)	(test/compute)	(compute)	(test/compute)
	(kips)	(kips)			Equation 7		Equation 8	
1	1.175	1.209	0.540	0.910	0.544	1.006	0.524	1.031
2	1.175	1.209	0.502	0.845	0.565	1.126	0.544	0.923
3	1.364	1.403	0.623	1.049	0.504	0.809	0.488	1.276
4	1.364	1.403	0.649	1.092	0.493	0.760	0.478	1.356
5	1.364	1.403	0.634	1.068	0.499	0.788	0.484	1.310
6	1.364	1.403	0.506	0.852	0.563	1.113	0.542	0.934
7	1.364	1.403	0.509	0.858	0.561	1.101	0.540	0.944
8	1.364	1.403	0.726	0.705	0.622	0.858	0.595	1.219
9	1.364	1.403	0.715	0.695	0.627	0.877	0.600	1.193
10	1.360	1.511	0.522	0.814	0.577	1.105	0.554	0.942
11	1.360	1.511	0.537	0.837	0.568	1.059	0.547	0.982
12	1.360	1.511	0.511	0.797	0.583	1.142	0.560	0.912
13	1.360	1.511	0.522	0.814	0.577	1.105	0.554	0.942
14	1.579	1.754	0.526	0.819	0.575	1.093	0.552	0.952
15	1.579	1.754	0.519	0.810	0.578	1.114	0.556	0.935
16	1.579	1.754	0.516	0.805	0.580	1.124	0.557	0.926
17	1.862	2.069	0.521	0.812	0.578	1.109	0.555	0.939
18	1.862	2.069	0.532	0.829	0.571	1.075	0.549	0.968
19	1.862	2.069	0.526	0.820	0.574	1.092	0.552	0.953
20	1.360	1.511	0.728	0.655	0.647	0.889	0.618	1.178
21	1.360	1.511	0.743	0.669	0.640	0.861	0.611	1.216
22	1.360	1.511	0.738	0.664	0.643	0.870	0.613	1.204
23	1.360	1.511	0.743	0.669	0.640	0.861	0.611	1.216
24	1.579	1.754	0.654	0.588	0.685	1.048	0.652	1.003
25	1.579	1.754	0.685	0.617	0.669	0.976	0.637	1.076
26	1.579	1.754	0.676	0.609	0.673	0.995	0.641	1.055
27	1.579	1.754	0.694	0.625	0.664	0.956	0.633	1.097
28	1.862	2.069	0.729	0.656	0.647	0.887	0.617	1.181
29	1.862	2.069	0.771	0.694	0.628	0.815	0.600	1.284
30	1.360	1.511	0.930	0.483	0.761	0.819	0.719	1.292
31	1.360	1.511	0.904	0.470	0.773	0.854	0.729	1.240
32	1.360	1.511	0.879	0.457	0.784	0.893	0.740	1.187
33	1.360	1.511	0.834	0.433	0.806	0.967	0.759	1.098
34	1.579	1.754	0.921	0.479	0.765	0.830	0.723	1.275
35	1.579	1.754	0.916	0.476	0.767	0.838	0.725	1.264
36	1.579	1.754	0.905	0.470	0.772	0.853	0.729	1.241
37	1.579	1.754	0.889	0.462	0.780	0.878	0.736	1.208
38	1.862	2.069	0.902	0.469	0.773	0.857	0.730	1.235
39	1.862	2.069	0.911	0.474	0.769	0.844	0.727	1.254
40	1.579	1.403	0.548	1.068	0.499	0.911	0.484	1.132
41	1.579	1.403	0.529	1.030	0.509	0.962	0.493	1.074
42	1.579	1.403	0.500	0.975	0.524	1.047	0.506	0.988
43	1.579	1.403	0.459	0.895	0.548	1.195	0.529	0.869
44	1.579	1.403	0.478	0.932	0.537	1.123	0.518	0.923
45	1.579	1.403	0.551	0.620	0.667	1.210	0.635	0.867
46	1.579	1.403	0.555	0.625	0.664	1.196	0.633	0.878
47	1.579	1.403	0.564	0.635	0.658	1.167	0.628	0.899
48	1.579	1.403	0.537	0.605	0.676	1.257	0.643	0.836
49	1.579	1.403	0.596	0.670	0.640	1.074	0.611	0.975
50	1.579	1.403	0.591	0.665	0.642	1.086	0.613	0.964
51	1.360	1.209	0.629	0.708	0.621	0.988	0.594	1.058
52	1.360	1.209	0.603	0.678	0.635	1.054	0.607	0.994
53	1.360	1.209	0.639	0.719	0.616	0.963	0.589	1.085
54	1.360	1.209	0.720	0.467	0.775	1.077	0.731	0.984
55	1.360	1.209	0.764	0.496	0.750	0.982	0.710	1.077
56	1.360	1.209	0.656	0.426	0.814	1.241	0.766	0.856
57	1.360	1.209	0.649	0.422	0.818	1.260	0.770	0.844
58	1.360	1.209	0.669	0.434	0.806	1.205	0.759	0.881
59	1.360	1.209	0.688	0.447	0.794	1.154	0.748	0.919
60	1.360	1.209	0.713	0.463	0.778	1.091	0.735	0.971
61	1.360	1.209	0.726	0.471	0.771	1.062	0.728	0.997
					Mean =	1.009	Mean =	1.058
					Std.Dev =	0.136	Std.Dev =	0.146
					Coeff.Var.=	0.135	Coeff.Var.=	0.138

TABLE 4

Test	Qn 2.7*t*d*Fu (kips)	Tn 1.5*t*dw*Fu (kips)	Q/Qn (test)	T/Tn (test)	Q/Qn (compute) y = - 0.706x+1.106	Q/Qn Ratio (test/compute)
1	1.175	1.209	0.540	0.910	0.464	1.165
2	1.175	1.209	0.502	0.845	0.509	0.986
3	1.364	1.403	0.623	1.049	0.365	1.705
4	1.364	1.403	0.649	1.092	0.335	1.937
5	1.364	1.403	0.634	1.068	0.352	1.800
6	1.364	1.403	0.506	0.852	0.505	1.002
7	1.364	1.403	0.509	0.858	0.500	1.018
8	1.364	1.403	0.726	0.705	0.608	1.194
9	1.364	1.403	0.715	0.695	0.615	1.163
10	1.360	2.267	0.522	0.543	0.723	0.722
11	1.360	2.267	0.537	0.558	0.712	0.754
12	1.360	1.889	0.511	0.637	0.656	0.779
13	1.360	1.889	0.522	0.651	0.646	0.808
14	1.579	2.631	0.526	0.546	0.720	0.730
15	1.579	2.193	0.519	0.648	0.649	0.801
16	1.579	2.193	0.516	0.644	0.652	0.792
17	1.862	3.104	0.521	0.541	0.724	0.720
18	1.862	2.587	0.532	0.663	0.638	0.833
19	1.862	2.587	0.526	0.656	0.643	0.819
20	1.360	2.267	0.728	0.437	0.798	0.912
21	1.360	2.267	0.743	0.446	0.791	0.940
22	1.360	1.889	0.738	0.532	0.731	1.010
23	1.360	1.889	0.743	0.535	0.728	1.021
24	1.579	2.631	0.654	0.392	0.829	0.789
25	1.579	2.631	0.685	0.411	0.816	0.840
26	1.579	2.193	0.676	0.487	0.762	0.887
27	1.579	2.193	0.694	0.500	0.753	0.922
28	1.862	2.587	0.729	0.525	0.735	0.991
29	1.862	2.587	0.771	0.555	0.714	1.079
30	1.360	1.889	0.930	0.386	0.833	1.116
31	1.360	2.267	0.904	0.313	0.885	1.022
32	1.360	1.889	0.879	0.365	0.848	1.036
33	1.360	1.889	0.834	0.347	0.861	0.969
34	1.579	2.631	0.921	0.319	0.881	1.046
35	1.579	2.631	0.916	0.317	0.882	1.039
36	1.579	2.193	0.905	0.376	0.840	1.077
37	1.579	2.193	0.889	0.369	0.845	1.051
38	1.862	3.104	0.902	0.313	0.885	1.019
39	1.862	2.587	0.911	0.379	0.839	1.087
40	1.579	1.403	0.548	1.068	0.352	1.555
41	1.579	1.403	0.529	1.030	0.378	1.397
42	1.579	1.403	0.500	0.975	0.418	1.198
43	1.579	1.403	0.459	0.895	0.474	0.968
44	1.579	1.403	0.478	0.932	0.448	1.067
45	1.579	1.403	0.551	0.620	0.668	0.824
46	1.579	1.403	[illegible]	0.625	0.665	0.835
47	1.579	1.403	0.564	0.635	[illegible]	0.858

FIGURE 12

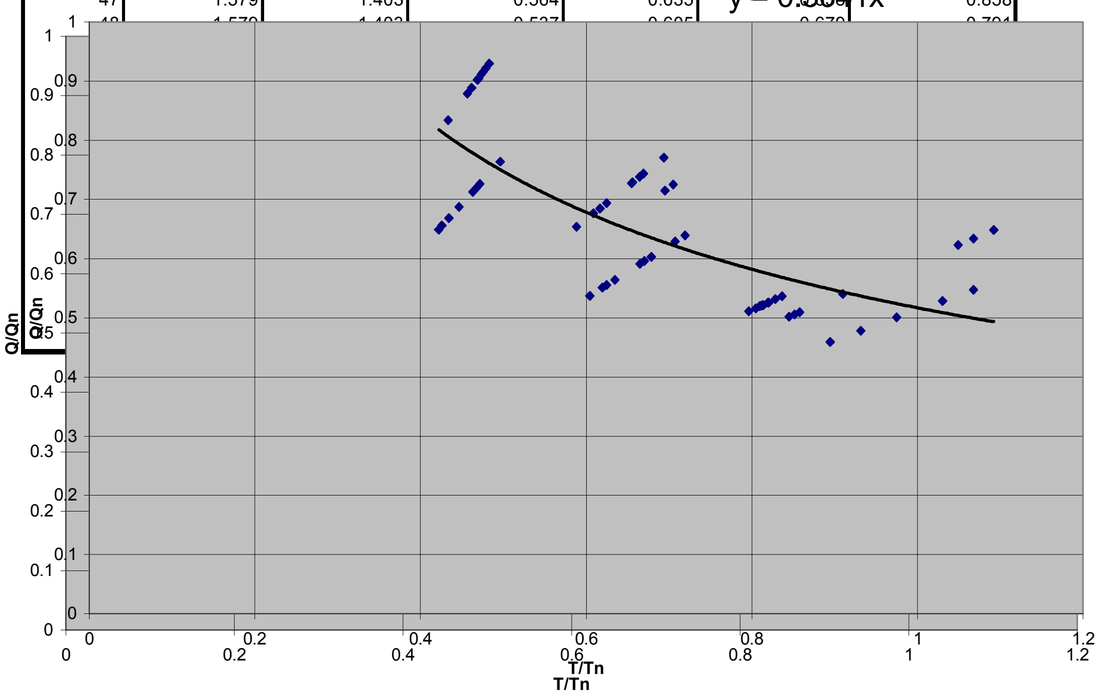
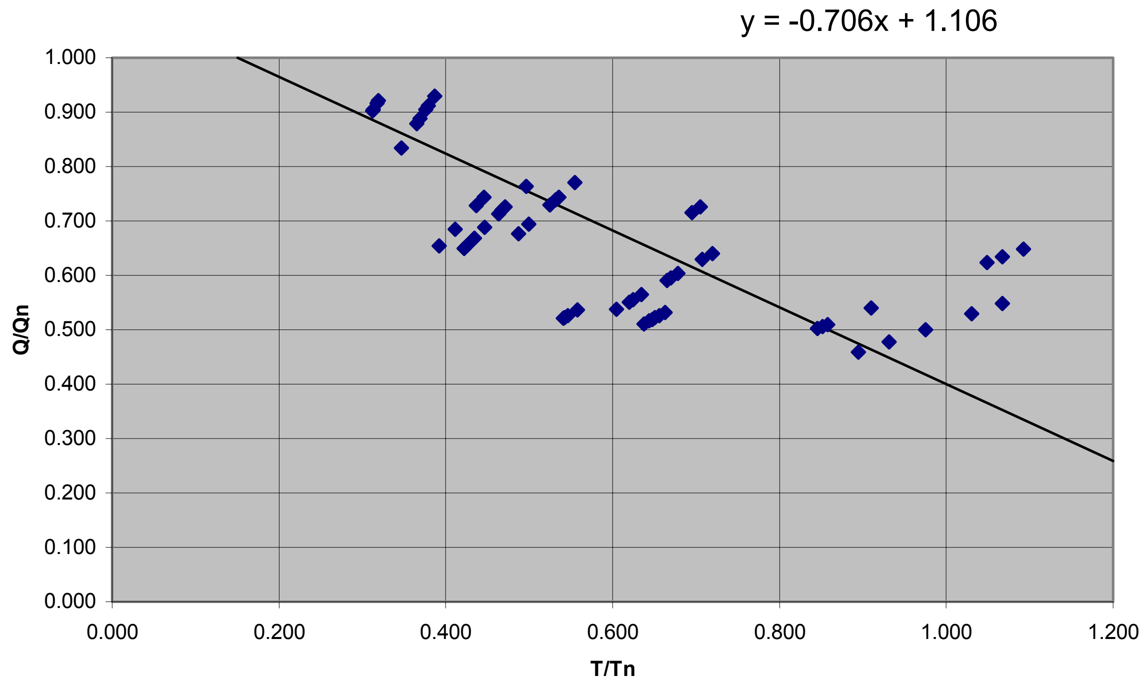


FIGURE 3


y = -0.706x + 1.106
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
Q/Qn
0.000
0.200
0.400
0.600
0.800
1.000
1.200
T/Tn

American Iron and Steel Institute

1140 Connecticut Avenue, NW
Suite 705
Washington, DC 20036

www.steel.org

Research Report RP-02-4

The New Steel