International Specialty Conference on Cold-Formed Steel Structures

(2004) - 17th International Specialty Conference on Cold-Formed Steel Structures

Oct 26th, 12:00 AM

Cold-formed Steel Slip-track Connection

James R. Gerloff

Peter Huttelmaier

Patrick W. Ford

Seventeenth International Specialty Conference on Cold-Formed Steel Structures
Orlando, Florida, U.S.A, November 4-5, 2004

Cold-Formed Steel Slip-Track Connection

James R. Gerloff [1], Peter Huttelmaier, Ph.D., P.E.[2],
and Patrick W. Ford, P.E.[3]

Abstract

The slip-track connection is one of the most commonly used connections when designing curtain wall systems. There is little guidance in the American Iron and Steel Institutes' *North American Specification for the Design of Cold-Formed Steel Structural Members* (AISI 2001). During this research a parametric study of the slip-track connection was conducted. Nominal strength for the slip-track connections were investigated, along with the effective distribution width of the track, which is a critical aspect of the analytical solution for the strength of the connection. Proposed design procedures based on the results of this project are provided. This paper is a condensed version of the Cold-Formed Steel Slip-Track Connection (Gerloff 2004).

Introduction

The slip-track connection consists of a cold-formed track that is attached to the underside of a structural member, slab, or deck. Cold-formed studs are placed in this track but are typically not attached to it by any mechanical means (see Figure 1). There is a gap between the top of the stud and the web of the track, and the flanges of the track transfer the lateral load from the studs into the

---

1. Project Engineer, Computerized Structural Design, Milwaukee, Wisconsin, U.S.A. (jgerloff@csd-eng.com)
2. Professor, Architectural Engineering and Building Construction Department, Milwaukee School of Engineering, Milwaukee, Wisconsin, U.S.A. (huttelma@msoe.edu)
3. Principal, Matsen Ford Design, Pewaukee, Wisconsin, U.S.A. (pat@matsenford.com)

structure. The track will move with the structure, and as the structure deflects vertically, the studs will not be loaded axially unless the structure deflects greater than the gap provided. The studs are only designed to withstand lateral loads and not designed to carry any axial loads other than self weight of the wall, so the gap specified is very important. Per Section D4 of the AISI Specification, "both ends of the stud shall be connected to restrain rotation about the longitudinal stud axis and horizontal displacement perpendicular to the stud axis" (AISI 2001). This can be satisfied by attaching bridging near the top of the studs to provide lateral and rotational stability to the top of the stud.

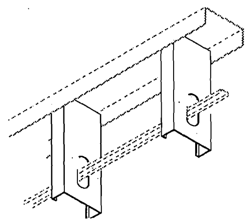
Figure 1: Slip-Track Assembly

Literature Review / Present Practices

There has been minimal research of the slip-track connection. There has been no finite element modeling and limited testing. Current practices are based on basic elementary theory. The Army Corps of Engineers (Army 1992) design procedure for the track thickness is presented in an allowable stress format. The track thickness is typically greater than the thickness of the steel stud used in the wall. The minimum base metal thickness for the track is determined by the following equation:

$$t = \left[\frac{1.67 \times 6 \times P \times e}{1.33 \times F_y \times b_{eff}} \right]^{1/2} \qquad (1)$$

where:

- t = required thickness of track, in.
- 1.67 = Safety factor
- P = the reaction of the stud due to wind, lbs
- e = the gap between the stud and the top channel, in.
- 1.33 = Stress increase for wind loading
- F_y = the yield strength of the track metal, psi
- b_{eff} = the effective width of the top channel flange for analysis, also, the effective width is less than the stud spacing, in.

For a single track system:

$$b_{eff} = W_{stud} + 2 \times \left[\frac{e + 1.25}{\tan(30)} \right] \qquad (2)$$

where:

W_{stud} = the width of the stud flange, in.
1.25 = depth of track overlap in a slip-track connection, in.

Figure 2 schematically shows the load distribution of the track due to the load applied from the stud according to the Army Corps of Engineers procedure.

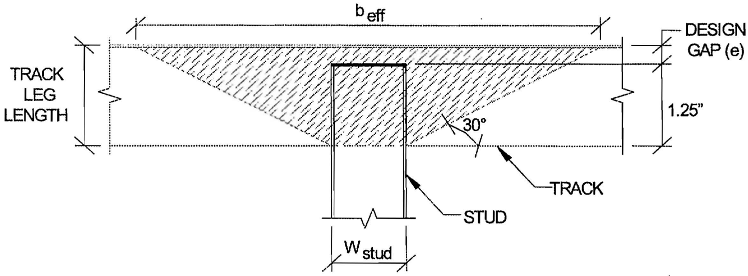

Figure 1: Army Corps of Engineers Stress Distribution

The Metal Stud Manufacturers Association (MSMA 1998), now called the Steel Stud Manufacturers Association (SSMA 2000) procedure and the example procedure given in the "Design of Single Deep Leg Track to Accommodate Vertical Deflections" (Rahman 2003) are based on the Army Corps of Engineers procedure with slight modifications. Testing was conducted at the University of Missouri-Rolla (Bolte 2003) and a procedure was developed from these results along with the results from 12 tests conducted at Milwaukee School of Engineering (Gerloff 2004).

Experimental Program

Testing was conducted at the Milwaukee School of Engineering's Construction Science and Engineering Center (CSEC) Laboratory to determine the strength of the slip-track connection.

The parameters chosen for investigation were as follows:

- Track Thickness: 18, 16 and 14 gage

(43, 54, and 68 mils)

- Track Leg Length: 2" and 3"
- Track Nominal Depth: 3 5/8"
- Slip Gap: 1/2" and 1"
- Stud Flange Width: 1 5/8" and 2 1/2"
- Stud Spacing: 16" and 24"
- Stud Nominal Depth: 3 5/8"
- Stud Thickness: 14 gage (68 mils)

To ensure that the track would fail prior failure of the studs, 14 gage (68 mils) studs were used for testing. Fasteners were placed in the center of the web of the track at the stud locations (see Figure 3). Some additional tests were conducted with the fasteners located between the studs, which resulted in slightly higher ultimate loads. In the interest of being more conservative, the tests with track connections at the stud locations were used in determining the nominal strength.

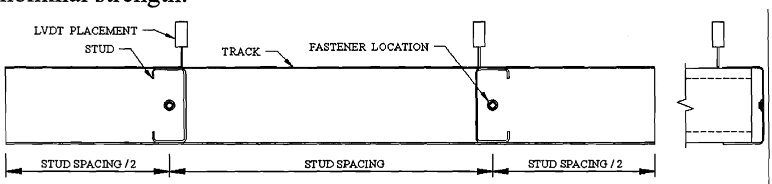

Figure 2: Fastener and LVDT Placement

Test Assembly

The test setup shown in Figure 4, consisted of two 4'-0" cold-formed studs assembled so that the open ends of the studs were facing outward. Since the shear center of the stud is located outside the web, the stud had a tendency to roll about its longitudinal axis. Facing the studs in the opposite direction, along with adding blocking for torsional restraints, removed the tendency to roll and ensured only vertical displacement - not lateral translation. Each stud was attached to a track at the bottom of the stud to provide a torsional restraint and ensure a uniformity of length, loading, and end reaction. Remnant pieces of studs were used as reinforcement at the opposite bearing end of the studs and at the transfer beam load application location to ensure that the studs would not fail locally due to the high concentration of loads. Blocking was attached near the end of the studs to provide rotational restraint to the studs. This connection was placed as close to the slip-track as possible so that stud rotation was kept to a minimum.

Tracks were cut to a length of 32" for the 16" stud spacing and 48" for the 24" stud spacing. To bolt the track to the test frame, holes were drilled into the center of the web of the track, at the stud location (see Figure 3).

Test Procedure and Observation

Linear variable differential transducers (LVDT's) were placed at the top of each stud, near the web of the stud (see Figure 3). The reason they were not placed underneath the track is due to the fact that large deflections would occur, possibly causing damage to the LVDT's.

Each specimen was tested to the ultimate load. The ultimate load was defined as the point at which any increase in displacement of the track and stud assembly did not yield any additional increase in load. Large deflections and rotation of the track and stud assembly were witnessed at ultimate loads. When the load was applied to the studs, observations showed that the flange and lip of the stud rotated along with the track.

The typical assumption from current design methods shows that stud width contributed to the effective width of the track. From the data analyzed, it can be seen that minimal load increase, and in some cases, decrease in load, was attained with a larger stud flange width. Local yielding of the track occurred where the stud end was loading the track and at the web/flange intersection (see Figure 5). Figure 6 shows a typical load versus displacement plot of the tests performed, as well as the nominal load strength (P_n) from equation (D4.4-1), as well as Pn / Ω.

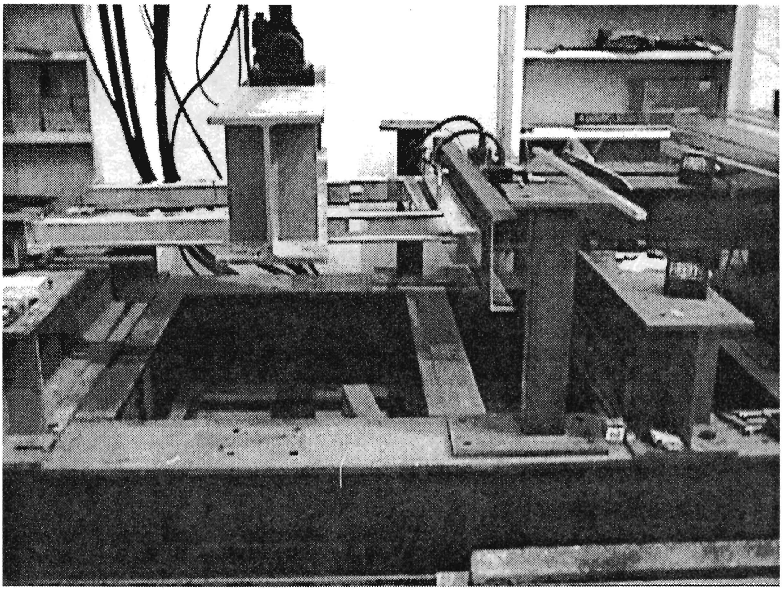

Figure 3: Overall Test Setup

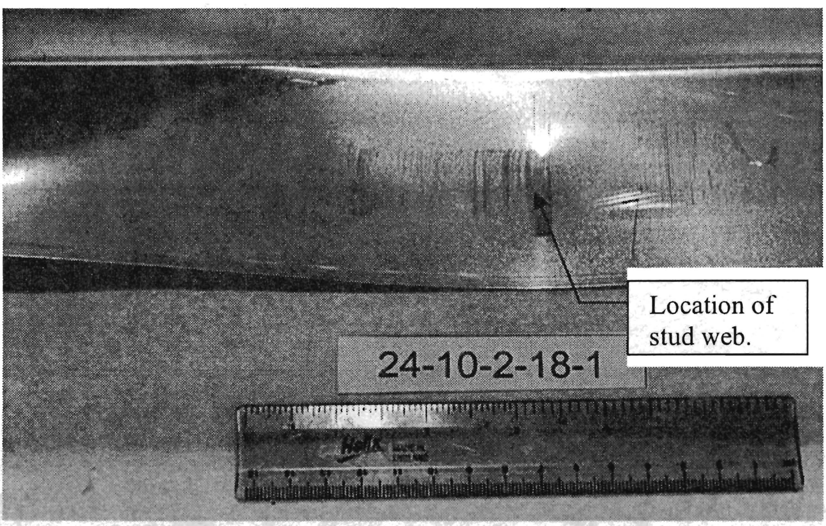

Figure 4: Stud Indentation on Track after Test

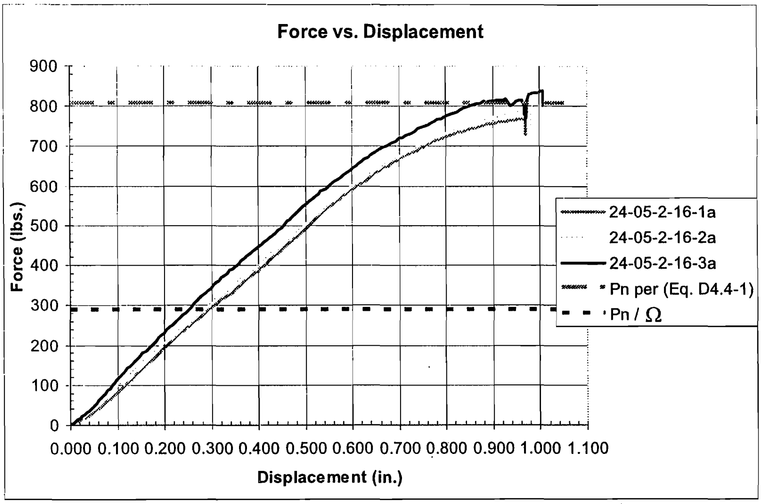

Figure 5: Typical Load versus Displacement Plot

Test Results

Table 1 (see Appendix) is a summary of average nominal loads from each of the three tests of each specific setup conducted. The ultimate loads (P_{test}) given are the loads applied to the slip track (ie: the reactions) at the end of each stud. These values were used in determining the proposed design procedure.

Test Evaluation

The previous methods of analysis base the load on the moment divided by the elastic section modulus or plastic section modulus of the flange in transverse bending, depending on whether the load is an allowable strength or an ultimate strength design. The basis for the design method herein will use ultimate loads, so analysis of the connection will be based on the plastic section modulus of the plate (track) in bending. Limiting the bending stress to yield of the track material, the following equation is derived:

$$\frac{M}{Z_x} = \frac{P_n \times e}{\frac{1}{4} \times b_{eff} \times t^2} = F_y \qquad (3)$$

where:

M	= bending moment, kip-in (N-mm)
Z_x	= plastic section modulus, in.^{3} (mm^3)
P_n	= nominal connection strength, kip (N)
e	= design gap, in. (mm)
b_{eff}	= effective width of track, in. (mm)
t	= track thickness, in. (mm)
F_y	= yield strength of track, ksi (MPa)

The nominal connection strength can be derived from Equation 3 as follows:

$$P_n = \frac{b_{eff} \times t^2 \times F_y}{4 \times e} \quad (4)$$

To empirically determine the effective width from the tests, Equation 4 can be rearranged as follows:

$$b_{eff} = \frac{P_{test} \times 4 \times e}{t^2 \times F_y} \quad (5)$$

Effective widths calculated from each test are given in Table 2.

Estimation of Effective Width

Through a parametric study, it was determined that the main contributing factors to the effective width are the design gap and the thickness of the track. Stud spacing was found to have no considerable effect on the effective width. Flange width was found to have only a slight correlation with the effective width. A relationship between the design gap and the track thickness was developed through curve fitting and regression analysis that closely determined the effective width of the track in bending.

Figure 7 shows the effective width calculated from the test results using Equation 5 versus $e^{0.5}/t^{1.5}$. The proposed equation for the effective width from Equation D4.4-2 is also shown. Figure 8 shows the nominal connection strength per Equation D4.4-1 versus the test results. Table 2 (see Appendix) shows the test strength, effective width using Equation 5, the proposed effective width and proposed nominal strength. Also, statistical information about the reliability of the proposed equations are shown.

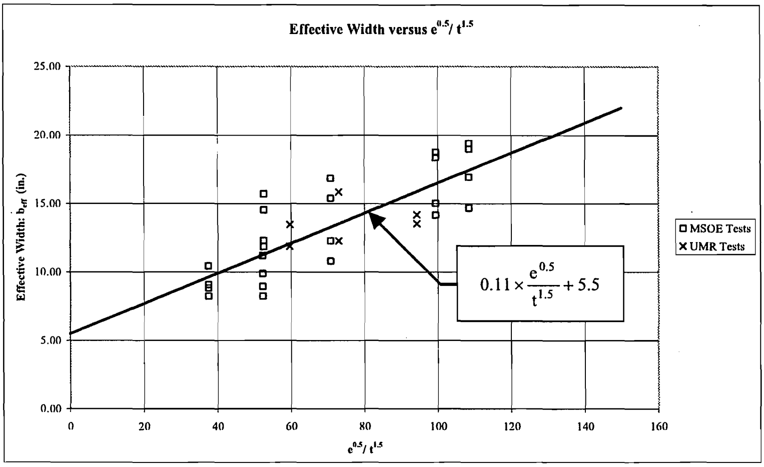

Figure 6: Effective Width versus $e^{0.5}/t^{1.5}$

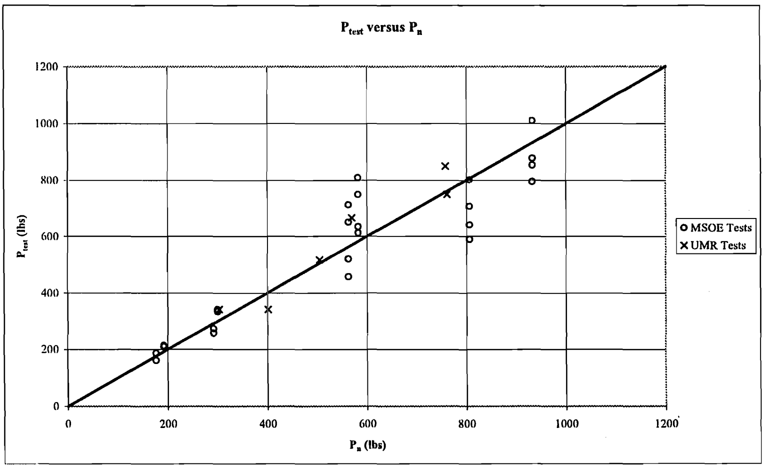

Figure 7: P_{test} versus P_n

Design Recommendations

The following has been proposed as a future addition to the appropriate AISI *Specification* Standard, or to the North American Specification.

D4.4 Slip-Track Strength

The nominal strength, P_n, of a single deflection track shall be calculated as follows:

$$P_n = \frac{b_{eff} \times t^2 \times F_y}{4 \times e} \qquad \text{(Eq. D4.4-1)}$$

Where:

P_n = nominal strength of the track when subjected to transverse loads, kips (N)
e = design end or slip gap (distance between the end of stud and track web), in. (mm)
t = track design thickness, in. (mm)
F_y = design yield strength of track material, ksi (MPa)
b_{eff} = effective width of resisting track flange, in. (mm)

$$b_{eff} = 0.11(\alpha^2)\frac{e^{0.5}}{t^{1.5}} + 5.5\alpha \le S \qquad \text{(Eq. D4.4-2)}$$

α = coefficient for conversion of units
= 1.0 when e, t and S are in inches
= 25.4 when e, t and S are in mm
S = center-to-center spacing of studs, in. (mm)
Ω = 2.80
ϕ = 0.55

The above equation is valid within the following range of parameters:

<u>Stud Section</u>	
Design Thickness:	0.0451" to 0.0713" (1.14 mm to 1.81 mm)
Design Yield Strength:	33 ksi to 50 ksi (228 MPa to 345 MPa)
Nominal Depth:	3.5" to 6.0" (88.9 mm to 152.4 mm)
Nominal Flange Width:	1 5/8" to 2 1/2" (41.3 mm to 63.5 mm)
Stud Spacing:	12" to 24" (305 mm to 610 mm)

<u>Track Section</u>
Design Thickness: 0.0440” to 0.0713” (1.14 mm to 1.81 mm)
Design Yield Strength: 23 ksi to 50 ksi (228 MPa to 345 MPa)
Nominal Depth: 3.5” to 6.0” (88.9 mm to 152.4 mm)
Nominal Flange Width: 2” to 3” (50.8 mm to 76.2 mm)

Conclusions

1. The equations yield a greater formulated safety factors and reliability. The proposed design procedure has a standard deviation of 16.7% and coefficient of variation of 16.6% which are more reliable than previous methods.
2. Displacements of the track at the stud location are excessive at the ultimate loads. Under normal service loads, the load is in the elastic range of the connection and as a result there is no permanent deflection of the slip-track.
3. Engineering judgment should be used to determine if the proposed design equations are valid for those connections outside the scope of the testing.

Acknowledgments

This work is sponsored in part by Matsen Ford Design and Dietrich Industries. Thanks to all those involved at Milwaukee School of Engineering and Computerized Structural Design for their guidance and expertise on this subject.

Appendix. – References

(AISI 2001) American Iron and Steel Institute. 2001. North American Specification for the Design of Cold-Formed Steel Structural Members. AISI Standard, 2001 Edition. Washington, DC: AISI.

(AISI 2002) American Iron and Steel Institute. 2002. Cold-Formed Steel Framing Design Guide. AISI Design Guide CF02-1. Washington, DC: AISI.

(Army 1992) U.S. Army Corps of Engineers. July 1992. Masonry Veneer/Steel Stud Walls (Nonbearing Construction). Engineering Technical Letter 1110-3-439. Washington, DC: U.S. Army Corps of Engineers.

(Bolte 2003) Bolte, William G. 2003. "Behavior of Cold-Formed Steel Stud-to-Track Connections" Master's Thesis, University of Missouri-Rolla.

(Gerloff 2004) Gerloff, James R. 2004. : "Cold-Formed Steel Slip-Track Connection" Master's Thesis, Milwaukee School of Engineering.

(MSMA 1998) Metal Stud Manufacturers Association. March 1998. "Single Deflection Track Selection." Construction Dimensions, pp. 66-73.

(Rahman 2003) Rahman, N. A. March 2003. "Design of Single Deep Leg Track to Accommodate Vertical Deflections." Raleigh, NC: The Steel Network, Inc.

(SSMA 2000) Steel Stud Manufacturers Association. January 2000. "Single Deflection Track Selection." Technical Note 1.

Appendix. - Tables

Table 1: Average MSOE Test Results

Specimen Name	Track Thickness t (in.)	Track Leg Length L (in.)	Slip Gap e (in.)	Stud Spacing S (in.)	Stud Flange Width b_f (in.)	F_y (ksi)	P_{test} (lbs)
16-05-1-14	0.0709	2	0.5	16	1 5/8	38.6	796
16-05-1-16	0.0568	2	0.5	16	1 5/8	44.5	590
16-05-1-18	0.0464	2	0.5	16	1 5/8	39.4	458
24-05-1-14	0.0709	2	0.5	24	1 5/8	38.6	854
24-05-1-16	0.0568	2	0.5	24	1 5/8	44.5	708
24-05-1-18	0.0464	2	0.5	24	1 5/8	39.4	651
16-05-2-14	0.0709	2	0.5	16	2 1/2	38.6	879
16-05-2-16	0.0568	2	0.5	16	2 1/2	44.5	642
16-05-2-18	0.0464	2	0.5	16	2 1/2	39.4	520
24-05-2-14	0.0709	2	0.5	24	2 1/2	38.6	1010
24-05-2-16	0.0568	2	0.5	24	2 1/2	44.5	802
24-05-2-18	0.0464	2	0.5	24	2 1/2	39.4	713
16-10-1-14	0.0713	3	1.0	16	1 5/8	40.6	612
16-10-1-16	0.0466	3	1.0	16	1 5/8	33.6	258
16-10-1-18	0.0440	3	1.0	16	1 5/8	22.8	162
24-10-1-14	0.0713	3	1.0	24	1 5/8	40.6	810
24-10-1-16	0.0466	3	1.0	24	1 5/8	33.6	342
24-10-1-18	0.0440	3	1.0	24	1 5/8	22.8	214
16-10-2-14	0.0713	3	1.0	16	2 1/2	40.6	635
16-10-2-16	0.0466	3	1.0	16	2 1/2	33.6	274
16-10-2-18	0.0440	3	1.0	16	2 1/2	22.8	187
24-10-2-14	0.0713	3	1.0	24	2 1/2	40.6	750
24-10-2-16	0.0466	3	1.0	24	2 1/2	33.6	335
24-10-2-18	0.0440	3	1.0	24	2 1/2	22.8	209

Table 2: P_n using Proposed Design Equations

Specimen Name	Design Gap e (in.)	Track Thickness t (in.)	$\frac{e^{0.5}}{t^{1.5}}$	b_{eff} (in.) Using Eq. 5	b_{eff} (in.) Using Eq. D4.4-2	P_n (lbs) Using Eq. D4.4-1	P_{test} (lbs)	$\frac{P_{test}}{P_n}$
16-05-1-14	0.5	0.0709	37.5	9.62	8.21	932	796	0.85
16-05-1-16	0.5	0.0568	52.3	11.25	8.24	806	590	0.73
16-05-1-18	0.5	0.0464	70.8	13.29	10.80	5639	458	0.81
24-05-1-14	0.5	0.0709	37.5	9.62	8.81	932	854	0.92
24-05-1-16	0.5	0.0568	52.3	11.25	9.89	806	708	0.88
24-05-1-18	0.5	0.0464	70.8	13.29	15.37	563	651	1.16
16-05-2-14	0.5	0.0709	37.5	9.62	9.07	932	879	0.94
16-05-2-16	0.5	0.0568	52.3	11.25	8.96	806	642	0.80
16-05-2-18	0.5	0.0464	70.8	13.29	12.29	563	520	0.92
24-05-2-14	0.5	0.0709	37.5	9.62	10.43	932	1010	1.08
24-05-2-16	0.5	0.0568	52.3	11.25	11.20	806	802	1.00
24-05-2-18	0.5	0.0464	70.8	13.29	16.84	563	713	1.27
16-10-1-14	1	0.0713	52.6	11.28	11.86	582	612	1.05
16-10-1-16	1	0.0466	99.4	16.00	14.16	292	258	0.88
16-10-1-18	1	0.0440	108.5	16.00	14.68	176	162	0.92
24-10-1-14	1	0.0713	52.6	11.28	15.69	582	810	1.39
24-10-1-16	1	0.0466	99.4	16.43	18.75	299	342	1.14
24-10-1-18	1	0.0440	108.5	17.43	19.41	192	214	1.11
16-10-2-14	1	0.0713	52.6	11.28	12.30	582	635	1.09
16-10-2-16	1	0.0466	99.4	16.00	15.01	292	274	0.94
16-10-2-18	1	0.0440	108.5	16.00	16.93	176	187	1.06
24-10-2-14	1	0.0713	52.6	11.28	14.53	582	750	1.29
24-10-2-16	1	0.0466	99.4	16.43	18.36	299	335	1.12
24-10-2-18	1	0.0440	108.5	17.43	19.01	192	209	1.09
UMR: 18-01-1-16	0.125	0.0520	29.8	8.78	3.73	2217	942	0.42*
UMR: 12-05-1-16	0.5	0.0520	59.6	12.00	13.46	758	850	1.12
UMR: 18-05-1-16	0.5	0.0520	59.6	12.06	11.88	761	750	0.99
UMR: 12-07-1-16	0.75	0.0520	73.0	12.00	12.27	505	517	1.02
UMR: 18-07-1-16	0.75	0.0520	73.0	13.53	15.83	570	667	1.17
UMR: 12-12-1-16	1.25	0.0520	94.3	12.00	13.54	303	3420	1.13
UMR: 18-12-1-16	1.25	0.0520	94.3	15.87	14.20	401	342	0.85

Average	1.006
Standard Deviation	0.167
Coefficient of Variation	0.166

Value removed from Average and Standard Deviation and graphic representation. Ultimate load is assumed to be a stud failure, not a track failure at the load specified.
Average and Standard Deviation are computed using the ultimate loads of the 72 tests performed by MSOE and 12 tests from UMR study, for a total of 84 tests.