International Specialty Conference on Cold-Formed Steel Structures
(2008) - 19th International Specialty Conference on Cold-Formed Steel Structures

Oct 14th, 12:00 AM

Strength of Cold-formed Steel Jamb Stud-to-track Connections

A. V. Lewis

R. M. Schuster

S. R. Fox

Nineteenth International Specialty Conference on Cold-Formed Steel Structures
St. Louis, Missouri, U.S.A, October 14 & 15 2008

STRENGTH OF COLD-FORMED STEEL JAMB STUD-TO-TRACK CONNECTIONS

A.V, Lewis[1], S.R. Fox[2] and R.M. Schuster[3]

Abstract

Cold-formed steel structural members are often used in building construction, with a common application being wind loadbearing steel studs. The studs frame into horizontal steel track members at the top and bottom of the wall assembly, with the stud-to-track connection typically being made with self-drilling screws. The design of the wall stud must include a check of the web crippling capacity at the end reactions, and there are design rules in place for the typical stud-to-track connection. However, at every opening in the wall assembly such as a window or door, there are jamb stud members that must also be designed for the stud-to-track connection strength. These jamb studs can occur at the termination of the bottom track or at an interior location, and can be single or multiple members. Reported in this paper are the results and analysis of a collection of end-one-flange loading tests of common jamb stud-to-track connections. Design expressions are proposed to predict the capacity of this connection for these structural members.

Introduction

Cold-formed steel structural members are used extensively in building construction throughout the world due to a combination of their high strength-to-weight ratio, stiffness, recyclability, and the relatively low cost associated

[1] Operations Manager, Structural Testing and Research Inc., Cambridge, Ontario, Canada
[2] General Manager, Canadian Sheet Steel Building Institute, Cambridge, Ontario, Canada
[3] Professor Emeritus of Structural Engineering and Director of the Canadian Cold-Formed Steel Research Group, Department of Civil Engineering, University of Waterloo, Waterloo, Ontario, Canada

with their supply and installation. Infill wall framing is a common application for a subset of cold-formed steel structural members referred to as 'wind loadbearing' studs used to support the exterior wall finish and transfer lateral loads, such as those imposed by wind pressure, to the main structure. These studs 'infill' the space between the main structural elements from floor-to-floor.

In wind loadbearing applications, there is some type of deflection connection at the top track to accommodate the anticipated movement of the upper floor and prevent the wall studs from being axially loaded. One type of deflection detail is illustrated in Figure 1, which uses a double top track arrangement. The behaviour of these deflection connections is not included in the scope of the experimental work reported in this paper.

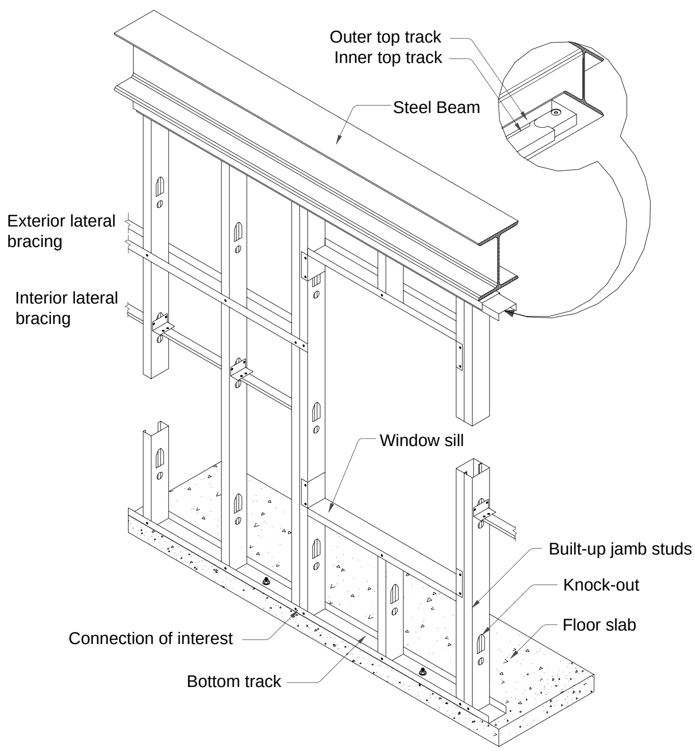

Figure 1: Typical Wind Loadbearing Wall Application

The research presented in this paper focuses on the connection between built-up jamb members and the bottom track, both at interior locations, as shown in Figure 1 for a window opening, and at end locations, such as would be found at a doorway or building corner.

The design of cold-formed steel structural members in North America is governed by the *North American Specification for the Design of Cold-Formed Steel Structural Members,* referred to as the NASPEC [ASISI 2007a; CSA 2007]. Previous research [Fox and Schuster 2000] has studied the single stud-to-track connection strength, and a design procedure has been adopted in the *North American Standard for Cold-Formed Steel Framing – Wall Stud Design* [AISI 2007b]. However, neither the NASPEC nor the Wall Stud Design standard have design expressions for determining the strength of the built-up stud-to-track connections used as jamb studs.

Experimental Investigation

An experimental study was performed at the University of Waterloo concentrating on the behaviour of jamb stud-to-track connections in curtain wall construction [Lewis 2008]. The objective of this investigation was to develop design provisions for calculating the strength of this connection. The parameters considered in the test program were as follows:

- stud and track thickness (0.8mm to 1.9mm);
- stud and track web depth (92mm and 152mm);
- configuration of jamb studs (back-to-back, toe-to-toe and single);
- location of jamb studs in the track (interior and end);
- screw size (#8, #10 and #12);
- screw location (both flanges and single flange);
- stud and track the same thickness;
- yield strengths from 300 to 450 MPa.

Test specimens were constructed of C-shaped studs with edge stiffened flanges and track sections with unstiffened flanges. For each different member type, tensile coupons were taken from the webs and tested in accordance with ASTM A370 [ASTM 2005] to determine the mechanical properties of the base steel material.

Test Specimen Configurations

Framing an opening in the wall for a window usually requires leaving a solid surface at the jambs for the attachment of the window itself. To save time and material, framers prefer using jamb studs in a toe-to-toe configuration to eliminate the need for an additional track section to close off the opening. However, in some cases due to the strength requirements or the framing methods, the jamb studs will be connected back-to-back. This configuration makes it easier to connect the members together to act as a built-up section, but does require an additional piece of track to close off the opening. Illustrated in Figure 2 are two jamb configurations at a window opening showing the studs framing into a bottom wall track that is continuous past the jamb.

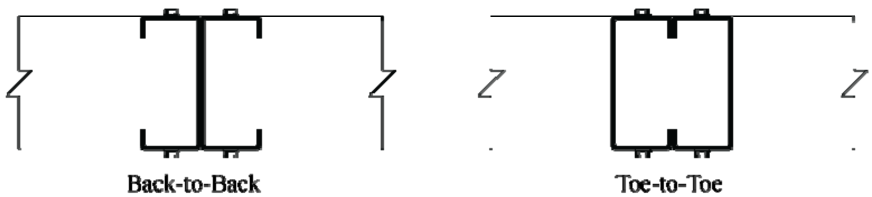

Figure 2: Jamb Studs at a Window Opening

When the jamb is made from back-to-back members, a piece of track is added to the inside stud to provide the solid surface in the opening required for the installation of the door or window. This track may be continuous along the length of the jamb stud, but is cut short at the top and bottom since a track section cannot frame into another track section as a stud can do. Consequently, while the track adds to the flexural strength of the jamb, since it is not connected to the top and bottom wall track, the jamb track does not transfer any shear at the ends. The entire reaction at each end of the jamb is taken through the members that frame into the top and bottom wall track, specifically the studs. Even though it is very common for a built-up jamb to include track sections, these members do not contribute to the strength of the jamb stud-to-track connection and so were not included in this test program.

In a similar manner to the window framing, the built-up jambs at a doorway can also be configured in toe-to-toe or back-to-back shapes, but in a door opening the bottom wall track terminates at the jamb stud. Given that the bottom track is no longer continuous, the strength of the stud-to-track connection will be affected. Illustrated in Figure 3 are the configurations of jamb studs at a door opening that were tested. In addition to the built-up configuration, two configurations of single member were also tested.

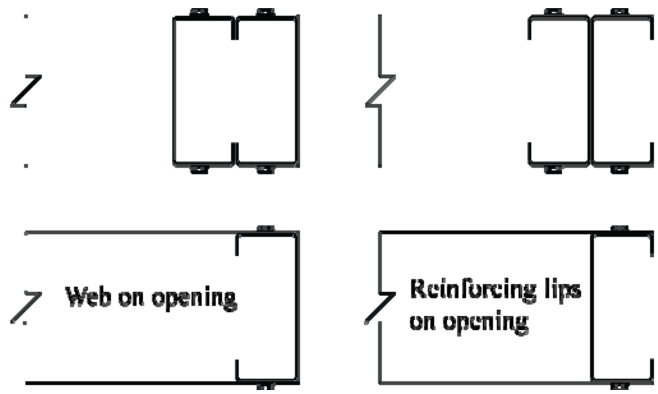

Figure 3: Jamb Studs at a Door Opening

Screw Size and Location

Standard practice for steel stud framing is to use a self drilling screw to connect both flanges of the stud to the track into which it frames, and the minimum size (diameter) for these screws is #8. For some of the thicker steel sections, a #8 screw is not recommended since the diameter is too small and it can shear off as it is being installed. To avoid this limitation, most of the tests in this program used #10 screws to make the connections. A series of tests were carried out with #8 and #12 screws to investigate whether the screw size does affect the strength of the connection.

In practice it may be possible to find installations where the screws had been inadvertently omitted from one side of the stud or the other. Without the screws connecting both flanges of the stud to the track, the load transfer within the connection will be different and the ultimate strength may change. A series of tests were run where screws were only installed in one flange of the stud. Illustrated in Figure 4 are the test configurations that investigated the various screw sizes and placement.

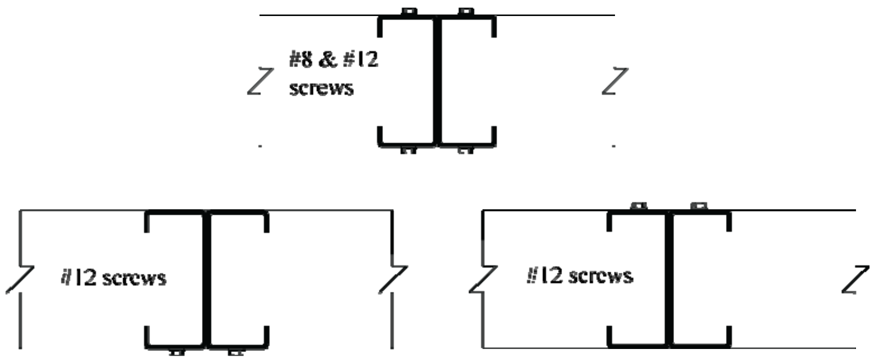

Figure 4: Test Configurations with Varying Screw Size and Placement

Test Procedure

The test procedure involved conducting a series of single point loading tests on simply supported built-up jamb assemblies. The jamb studs were cut to 1220mm lengths and connected in the toe-to-toe or back-to-back configuration. For the single stud tests, the single stud was reinforced with a second stud, but the end of the reinforcing stud was kept back 152mm from the track, and the single jamb stud made the stud-to-track connection.

To prevent a flexural failure or a web crippling failure of the jamb stud at the point of applied load, the assemblies were reinforced with additional pieces of track. The track into which the jamb studs framed was bolted to an 8mm thick steel angle with two 12.7mm steel bolts and 25mm washers, spaced no more than 152mm apart, with a bolt on either side of the stud-to-track connection. Connecting the track to the supporting structure in this manner avoided potential flexural failure of the track or failure of the track-to-structure connectors.

The unconnected end of the test specimen was supported on a load cell. The readings from this load cell subtracted from the load cell measuring the total applied load gave an accurate reading of the load at the stud-to-track connection. The photograph in Figure 5 and the sketch in Figure 6 illustrate the test setup.

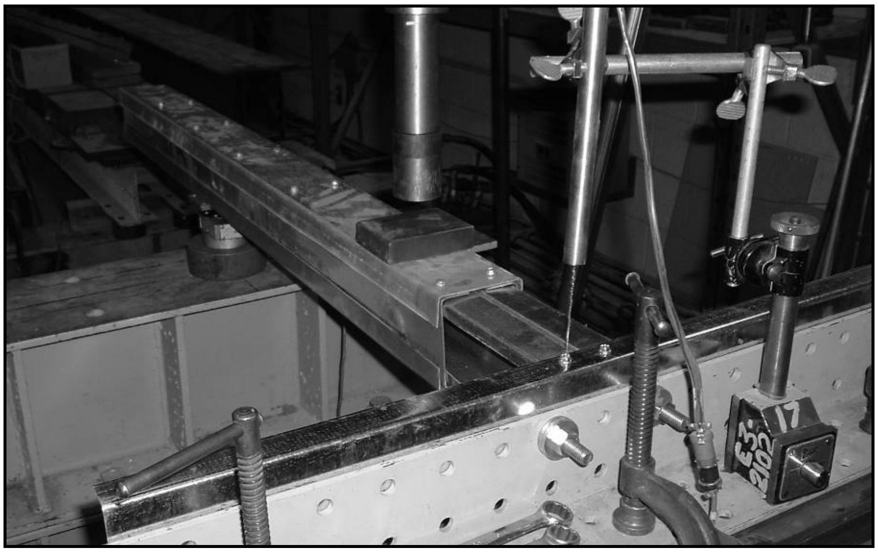

Figure 5: Photograph of a Typical Test Setup

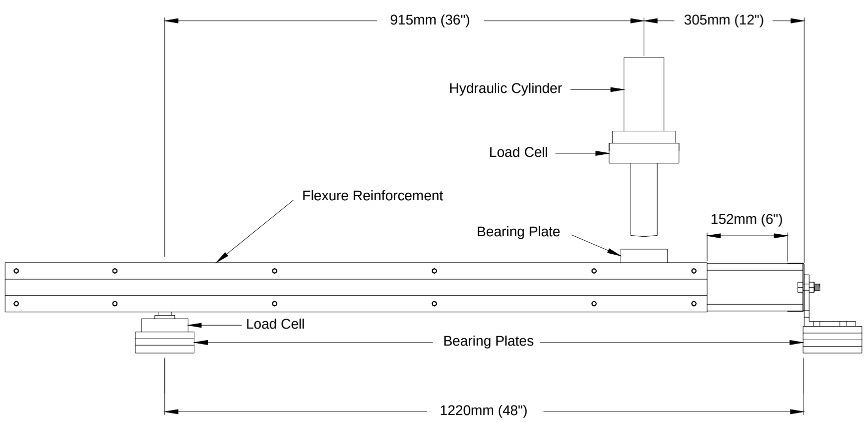

Figure 6: Schematic of a Typical Test Setup

The ultimate load recorded for each test was determined when the test specimen was no longer capable of carrying an increasing load or when the deflection was considered excessive. In addition to the ultimate load, an effort was made to record the onset of web crippling, and to record other failure modes as they occurred. For example, as some samples began to fail in web crippling, track punch-through began, and then screw failure occurred, effectively ending the test. The modes were noted, and the applied load at the onset of each mode recorded when possible.

The test fixture was not appropriate to assess the track deflection nor was that the intent of these tests; however, to qualify failure modes, it was decided to record the deflection of the connection itself—excessive deflection of the connection being considered a failure mode. The deflection data was obtained by placing a low-voltage displacement transducer (LVDT) directly above the junction of the stud and track connection (shown in Figure 5).

Failure Modes

The observed failure modes were:

(a) web crippling;
(b) track punch-through;
(c) excessive deflection at the stud-to-track connection;
(d) screw pull-out;
(e) combination of screw shear and tension failure.

Web crippling:
Web crippling of the jamb stud was the most common failure mode, and occurred in all cases where studs were paired toe-to-toe, or when single stud configurations were tested. Web crippling would also occur when the studs were paired back-to-back but only with the thinner stud sections. The photograph in Figure 7 shows the web crippling failure mode.

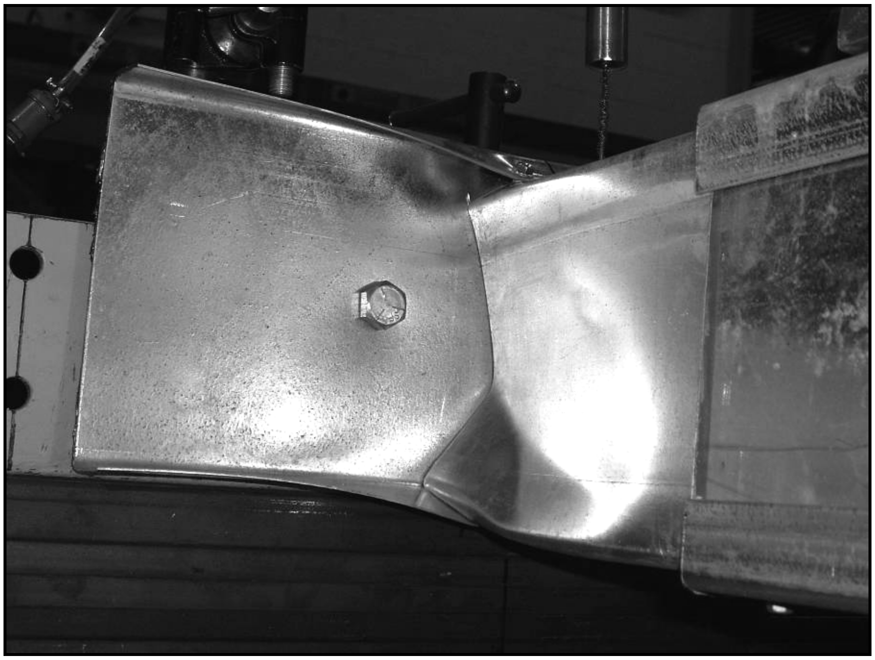

Figure 7: Photograph of Web Crippling Failure

Track Punch-through:
Track punch-through (where the corners of the jamb stud sheared through the track flange) occurred in the back-to-back configurations, both interior and end locations, where there were fasteners in both the top and bottom flanges. With one exception, punch-through failure only occurred in material 1.52mm and 1.91mm thick. Previous research [Fox and Schuster 2000] found that for single stud connections punch-through would not occur if the track was the same thickness as the stud or greater. In all the tests being described in this paper the track thickness was the same as the stud thickness. The photograph in Figure 6 shows the back-to-back studs punching through the track without web crippling.

Figure 8: Photograph of Track Punch-Through Failure

Deflection:

In some cases, the test specimen was able to carry additional load after web crippling had occurred, although with increased deflection at the stud-to-track connection. In the end location tests there was no web crippling and failure was due to track deformation alone. Illustrated in the photograph in Figure 9 is an example of excessive track deflection. Deflections in excess of 12.7mm were not uncommon and would certainly be considered unacceptable from a serviceability perspective.

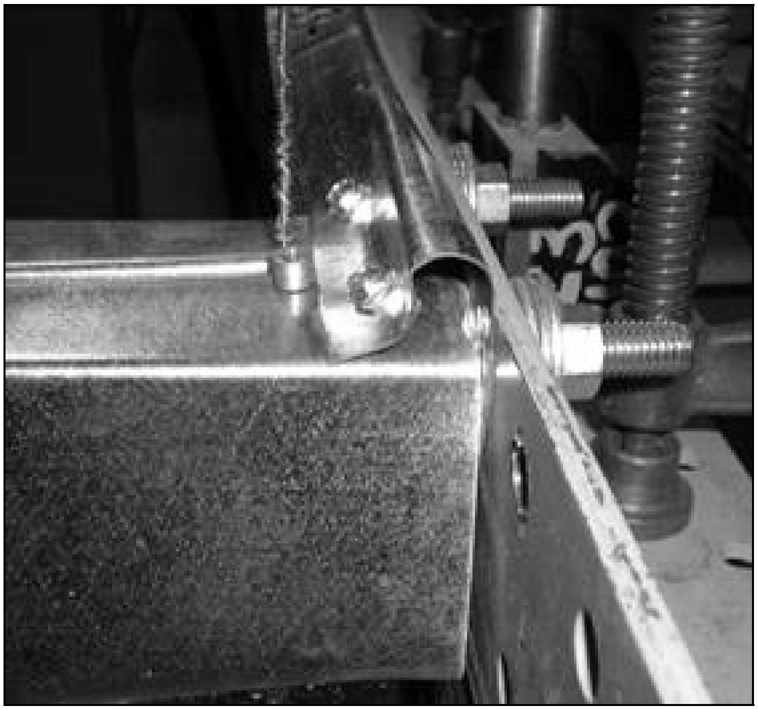

Figure 8: Photograph of Excessive Track Deflection

Screw Failure:
Of the three screw failure modes observed, screw pullout was the easiest to characterise, and always occurred in conjunction with web crippling and/or excessive deflection. The pull-out occurred in the screw loaded in tension connecting the top flange of the stud. With the thicker stud sections some configurations failed in a combination of screw tension and shear. Next to track punch through, screw shear was the most frequent failure mode.

Web Crippling Predictor Equation

The basic web crippling equation from the Wall Stud Design standard [AISI 2007b] was used with new regression coefficients determined from the test data. Web crippling coefficients are proposed for each test configuration that exhibited web crippling failure. The applicability of these design expressions should not be extended beyond the limits of the material properties and sizes of the tested specimens as shown. The web crippling predictor equation is given in

Eqn. 1 and the coefficients are provided in Table 2. Note that Eqn. 1 is non-dimensional and can be used with any consistent system of units.

$$P_n = Ct^2F_y\left(1 - C_R\sqrt{\frac{R}{t}}\right)\left(1 + C_N\sqrt{\frac{N}{t}}\right)\left(1 - C_h\sqrt{\frac{h}{t}}\right) \qquad \text{Eqn. 1}$$

where,

P_n	=	Nominal web crippling strength per stud web
C	=	Web crippling coefficient (see Table 2)
C_h	=	Web slenderness coefficient = 0.019
C_N	=	Bearing length coefficient = 0.74
C_R	=	Inside bend radius coefficient = 0.19
F_y	=	Yield strength of the stud material
h	=	Flat dimension of the stud web measured in the plane of the web
N	=	Bearing length = 32mm (track flange width)
R	=	Stud inside bend radius
t	=	Base steel thickness of stud
Ω	=	1.70 for ASD for single stud interior configuration
	=	1.90 for ASD for all other configurations listed in Table 2
ϕ	=	0.90 for LRFD for single stud interior configuration
	=	0.85 for LRFD for all other configurations listed in Table 2
	=	0.75 for LSD for single stud interior configuration
	=	0.70 for LSD for all other configurations listed in Table 2

Table 2: Web Crippling Coefficients for Jamb Stud-to-Track Connections

Configuration		**Web crippling coefficient, C**
Single stud	Interior	3.70
Single stud	Adjacent to wall opening with reinforcing lips facing opening	2.78
Single stud	Adjacent to wall opening with stud web facing opening	1.85
Double stud	Toe-to-Toe Interior	7.40
Double stud	Toe-to-Toe, Adjacent to opening	5.55
Double stud	Back-to-back, Interior	7.40
Double stud	Back-to-back, Adjacent to opening	7.40

Listed in Table 3 are averages of the tested web crippling failure loads (P_t) divided by the predicted web crippling strength (P_n), the coefficient of variation (COV) of these ratios, the number of tests and the geometric limits of applicability.

Table 3: Web Crippling Prediction Results

Test Configuration	Avg. P_t/P_n	COV	No. of tests	Stud Thickness (mm)	Stud Depth (mm)
Toe-to-Toe, Interior	0.980	0.058	14	0.8 – 1.9	92 - 152
Toe-to-Toe, End	0.988	0.083	16	0.8 – 1.9	92 - 152
Single, End (web on opening)	1.03	0.129	8	0.8 – 1.9	92
Single, End (reinforcing lips on opening)	0.995	0.138	8	0.8 – 1.9	92
Back-to-back, Interior	1.00	0.070	11	0.8 – 1.1	92
Back-to-back, End	1.00	0.002	3	0.8 – 1.1	92

Punch-Through Predictor Equation

The punch-through failure mode is a function of the material properties of the track. The Wall Stud Design standard includes a design expression for this failure mode based on determining an equivalent bearing width. A different approach is proposed here as shown in Eqn. 2.

$$P_{npt} = 15.2 t_t^2 F_{ut} \qquad \text{Eqn. 2}$$

where,

P_{npt}	=	Nominal track punch-through strength
F_{ut}	=	Tensile strength of the track material
t_t	=	Base steel thickness of track
Ω	=	2.10 for ASD
ϕ	=	0.75 for LRFD
	=	0.65 for LSD

Listed in Table 4 are averages of the tested punch-through failure loads (P_t) divided by the predicted strength (P_{npt}), the coefficient of variation (COV) of these ratios, the number of tests and the geometric limits of applicability.

Table 4: Punch-Through Prediction Results

Test Configuration	Avg. P_t/P_{npt}	COV	No. of tests	Stud Thickness (mm)	Stud Depth (mm)
Back-to-back, Interior or End	1.00	0.192	19	1.1 – 1.9	92

Effect of Missing Screws

The other conditions investigated were the size and placement of the screws. The standard screw used for the majority of the tests was a #10. The failure mode varied depending on the test specimen configuration, but with a couple of exceptions, screw failure did not occur before one of the other limit states. In the test series with the #8 screws, screw shear became the failure mode for the thicker sections at a reduced load compared to the #10 screws. When the #12 screws were used (in both flanges) the failure mode and load were comparable to the same configuration with the #10 screws. When a single screw was put in the bottom flange, this was sufficient to restrain the assembly and the failure mode was punch-through. When the single screw was put in the top flange, the failure mode was excessive deflection caused by the bottom flange of the track being unrestrained and bending under load.

Conclusions

The general conclusions from this work are as follows:

- Design expressions are proposed for a range of jamb stud configurations based on a web crippling or punch-through failure mode. These design expressions should not be used beyond the limits of the material properties and sizes of the tested specimens.
- The size of screws should be selected based on the thickness of members being connected. Screws should be placed in both flanges, but some usable capacity is available when only a single screw is used.

Presented in the paper is a summary of a test program. For a complete presentation of the test data and analysis, refer to the original work [Lewis, 2008].

References

AISI, 2007a, *North American Specification for the Design of Cold-Formed Steel Structural Members*, AISI S100-07, American Iron and Steel Institute, Washington, DC, 2007.

AISI, 2007b, *North American Standard for Cold-Formed Steel Framing – Wall Stud Design*, AISI 211-07, American Iron and Steel Institute, Washington, DC, 2007.

ASTM, 2005, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*, ASTM A370-05. American Society for Testing and Materials, West Conshohocken, PA, 2005.

(CSA, 2007), *North American Specification for the Design of Cold-Formed Steel Structural Members,* CAN/CSA-S136-077, Canadian Standards Association, Mississauga, ON, 2007.

Fox, S.R. and Schuster, R.M. (2000), "Lateral Strength of Wind Load Bearing Wall Stud-to-Track Connections", *Proceedings of the Fifteenth International Specialty Conference on Cold-Formed Steel Structures*, University of Missouri-Rolla, Rolla, MO, 2000.

Lewis, A.V. (2008), *Strength of Cold-Formed Steel Jamb Stud to Track Connections*, MASc Thesis, Department of Civil Engineering, University of Waterloo, Waterloo, ON, 2008.