

Strength of Cold-Formed Steel Jamb Stud-To-Track Connections

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PREFACE

The *North American Standard for Cold-Formed Steel Framing - Wall Stud Design*, AISI S211-07, provides a design expression for web crippling at the end reaction of the single stud-to-track connection. The subject of this report is an experimental investigation that was carried out at the University of Waterloo to establish a similar design expression for multiple jamb stud members.

It is anticipated that the AISI Committee on Framing Standards will consider the results of this study in the development of future standards and the Cold-Formed Steel Engineers Institute in the development of design aids. The American Iron and Steel Institute and Steel Framing Alliance wish to express their appreciation to the researchers and project sponsors for this report.

Strength of Cold-Formed Steel Jamb Stud-To-Track Connections

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Abstract

Cold-formed steel structural members are used extensively in building construction, with a common application being wind load bearing 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 or welds. The wall studs are designed to carry lateral loads only and must be checked for web crippling at the end reactions. While a design expression currently exists for the single stud-to-track connection, there is no similar design expression for multiple jamb stud members.

An experimental investigation was carried out, consisting of 94 jamb stud assembly tests subjected to end-one-flange loading. The stud-to-track connections consisted of single C-section studs located at the end of a track simulating a door opening, and a built-up jamb made up of two studs simulating framing at either a window or door opening. The members were attached to the track with self-drilling screws. The research objective was to determine the failure modes and develop a design expression for these structural assemblies.

The scope of the experimental investigation covered the following range of parameters:

- i) Stud and track depths of 92 mm and 152 mm;
- ii) Stud and track thickness (0.84 mm, 1.12 mm, 1.52 mm and 1.91 mm);
- iii) Configuration of jamb studs (back-to-back, toe-to-toe and single);
- iv) Location of jamb studs in the track (interior and end);

- v) Screw size (#8, #10 and #12);
- vi) Screw location (both flanges and single flange).

Based on the findings of this investigation, design expressions are proposed to predict the capacity of this connection for two limit states: web crippling of the jamb stud; and, punch-through of the track. The web crippling design expression was taken from the North American Specification for the Design of Cold-Formed Steel Structural Members [AISI 2007a; CSA 2007] with new coefficients developed from the test data of the jamb stud-to-track assemblies. A new design expression is also proposed for the track punch-through failure mode, which differs from the approach currently used in the North American Standard for Cold-Formed Steel Framing – Wall Stud Design [AISI 2007b]. A proposal is also recommended to revise the wording in the North American Standard for Cold-Formed Steel Framing – Wall Stud Design [AISI 2007b] to include provisions for the design of jamb studs based on the results of this research.

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Chapter 1

Introduction

1.1 Cold-Formed Steel Construction

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 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 load bearing” studs. Shown in the photograph of Figure 1-1, are typical wind load bearing walls or ‘curtain walls’, which are used to support the exterior wall finishes and to transfer the lateral loads, such as those imposed by wind pressure. These studs ‘infill’ the space between the main structural elements framing the floor, such as hot-rolled steel beams or concrete slabs, which carry the gravity loads.



Figure 1-1: Curtain Wall Construction

Cold-formed steel stud walls are constructed with a combination of stud and track sections as illustrated in Figure 1-2. A stud is a 'C'-shaped section that typically ranges from 92 mm to 203 mm in depth with flanges from 32 mm to 41 mm in width and with stiffening lips on the outside edges of the flanges. Studs are commonly available in steel thicknesses ranging from 0.84 mm to 1.91 mm. The track sections are of the same nominal size and thickness as the studs, but without the stiffening lips on the outside edge of the flanges. A steel stud wall assembly is constructed with a top and bottom track into which the steel studs are fastened at regular intervals. The track is anchored to the structure and the studs are usually connected to the track with self-drilling screws through each flange at both the top and bottom stud-to-track connection. The stud is designed to carry a uniform lateral load, which is transferred at the ends of the stud to the track, and then through the anchors to the supporting structure.

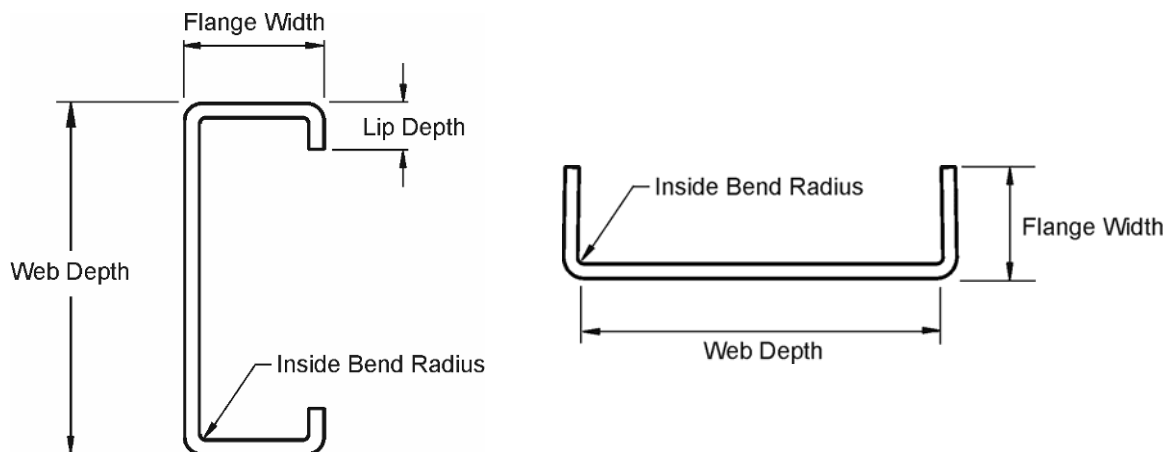


Figure 1-2: Stud and Track

In wind load bearing applications, there is some type of deflection assembly installed at the top track to accommodate the anticipated movement of the upper floor so that the wall studs do not become axially loaded. One type of deflection detail is illustrated in Figure 1-3, which uses a double top track arrangement, where the length of the flanges of the outer top track is determined by the amount of deflection anticipated. One leg of the outer top track is assumed to be loaded uniformly by the inner top track, which distributes the reactions from the studs. A description of a design procedure is provided by the Lightweight Steel Framing Design Manual [CSSBI 2006]. The behaviour of these deflection type connections was not included in the scope of the experimental work reported herein.

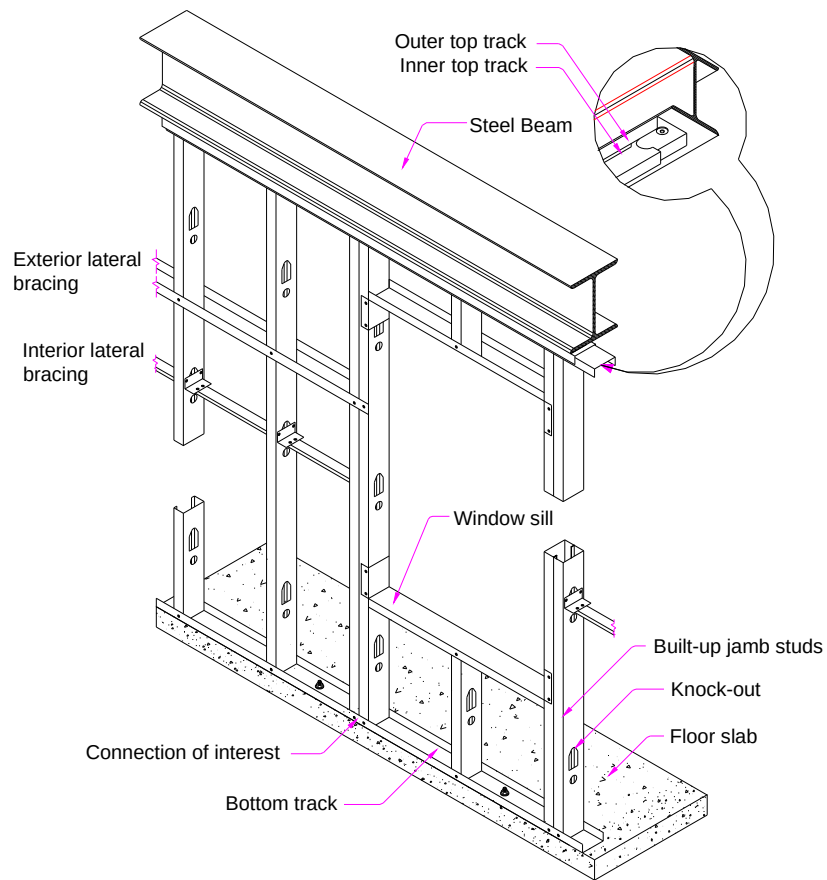


Figure 1-3: Typical Infill Wall Application

1.2 Description of the Problem

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 [AISI 2007a; CSA 2007], hereafter referred to as the NASPEC. In Canada, this document is published by the Canadian Standards Association as CAN/CSA-S136-07 [CSA 2007], and in the United States by the American Iron and Steel Institute as AISI-S100-07 [AISI 2007a]. These design documents include provisions that cover the design of many common cold-formed steel structural elements and members, but do not have design criteria for the design of the stud-to-track connections commonly used in cold-formed wind load bearing steel stud construction.

The design of a wind load bearing steel stud takes into account the following limit states: flexure, shear, deflection and web crippling. Designing for the first three of these limit states can be performed by using the NASPEC. The web crippling limit state, however, poses special problems with wind load bearing steel stud applications. The web crippling expressions in the NASPEC assume that the flexural member (i.e. the steel stud) is resting on a rigid bearing surface. The stud-to-track connection in a wind load bearing wall, while it is an end-one-flange loading, is a condition that is not covered by the NASPEC. This difference is illustrated in Figure 1-4. As a consequence, testing is required to determine the appropriate design resistances for this type of connection.

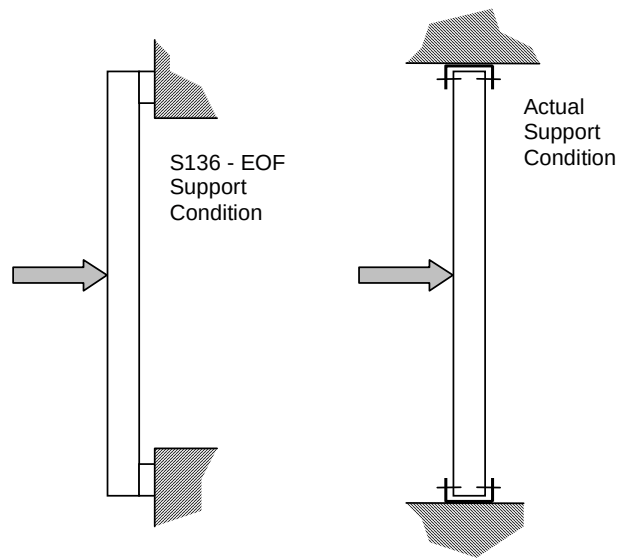


Figure 1-4: Idealized Web Crippling Compared to Stud-to-Track Connection

There are a number of parameters that affect the capacity of the stud-to-track connection, including:

- i) The geometric and mechanical properties of the stud and track material;
- ii) The thickness of the stud and track members relative to one another;
- iii) The size of the gap between the end of the stud and the web of the track;
- iv) Size and location of the fasteners making the stud-to-track connection;
- v) Continuity of the track near the stud (i.e. jamb stud at a wall opening);
- vi) Built-up stud members (i.e. jamb studs); and
- vii) Axial load on the stud.

Tests on items i) through v) have been carried out by various researchers, leading to the design provisions that are currently contained in the North American Standard for Cold-Formed Steel Framing – Wall Stud Design, AISI S211-07 [AISI 2007b], hereafter referred to as the WSD. These design provisions are limited to single stud-to track connections where sufficient test data was available. Until now, no testing has been done on the strength of the built up jamb stud-to-track connections that are also common elements of a cold-formed steel wind load bearing wall assembly. The effect of axial load on the strength of the stud-to-track connection has not as yet been investigated.

1.3 Scope of Study

The research presented in this thesis is focused on the connection between built-up stud members and the bottom track, both at interior locations, as shown in Figure 1-3 above, and at end locations, such as would be found at a doorway or the corner of a building. The scope of the work was primarily experimental, with a total of 94 tests being conducted. The experimental work covered the following range of parameters:

- i) Stud and track depths of 92 mm and 152 mm;
- ii) Stud and track thickness (0.84 mm to 1.91 mm);
- iii) Configuration of jamb studs (back-to-back, toe-to-toe and single);
- iv) Location of jamb studs in the track (interior and end);
- v) Screw size (#8, #10 and #12);
- vi) Screw location (both flanges and single flange);

- vii) Stud and track the same thickness;
- viii) Yield strengths from 300 to 450 MPa.

After the experimental work was completed and the results were analyzed, design expressions were derived covering the two principal failure modes: web crippling of the stud, and punch-through of the track.

1.4 Organization of Thesis

An overview of previous research is presented in Chapter 2. The University of Waterloo has been the site of much of this earlier work that has led to the current design expressions.

The parameters of the experimental investigation and the test procedure are described in Chapter 3. The research scope comprised a total of 94 tests on various combinations of parameters relevant to these jamb stud connections.

Provided in Chapter 4 is a discussion of the various failure modes observed during the test program and a summary of the test results. Also included in this section is a discussion of the effects of screw size and placement on the strength and behaviour of the assembly.

The culmination of this research was the development of equations to predict the capacity of these connections as observed in the test program. These predictor equations are provided in Chapter 5 along with the calibrated resistance factors needed for design.

Another contribution of this work was to propose changes to the WSD to recognize these jamb stud members. Included in Chapter 6 is the current wording of the WSD related to

the stud-to-track connections with the proposed changes to incorporate the jamb stud members. This proposal will be forwarded to the AISI Committee on Framing Standards for their adoption consideration.

Listed in Chapter 7 is a summary of the conclusions, and presented in the Appendices are the detailed test data.

Chapter 2

Literature Review

2.1 Previous Research on Stud-To-Track Connections

The lateral strength and behaviour of stud-to-track connections has been studied by a number of earlier researchers, resulting in a valuable collection of data and observations. In this chapter, this previous research is reviewed as it pertains to this current investigation.

2.2 Drysdale and Breton (1991)

As part of a larger study on the performance of steel stud brick veneer wall assemblies, 109 stud-to-track connection tests were conducted at McMaster University by Drysdale and Breton [1991]. Of these tests, 70 were screwed stud-to-track connections, while the remaining tests were welded connections, deflection track connections which used double sections of track, and connections reinforced with various clips and box sections. Only the screwed stud-to-track connections will be discussed here, since the others are not germane to this investigation.

A number of parameters with the screwed stud-to-track connections were varied by Drysdale and Breton. These include the stud and track web depth and thickness, the distance (end gap) between the end of the stud and the web of the track, the location of the connection relative to its placement within a section of track, and whether the compression, tension, or both flanges of the stud and track were connected. Of the different number of test series, a number of tests were conducted in each series, and the parameters that were varied for each series are presented in Table 2-1.

Table 2-1: Stud-to-Track Screw-Fastened Connection Test Parameters [Drysdale and Breton, 1991]

Test Series	Connected Flange		End Gap	Connection Location	Stud		Track		Num. of Tests
	Comp.	Tension			Web	t _{stud}	Web	t _{track}	
20A-D1	Y	Y	min.	Interior	92mm	20 gauge	92mm	20 gauge	9
18A-D1	Y	Y	min.	Interior	92mm	18 gauge	92mm	18 gauge	5
20B-D1	Y	Y	min.	Interior	152mm	20 gauge	152mm	20 gauge	6
18B-D1	Y	Y	min.	Interior	152mm	18 gauge	152mm	18 gauge	6
20A-D2	Y	Y	12mm	Interior	92mm	20 gauge	92mm	20 gauge	4
20B-D2	Y	Y	12mm	Interior	152mm	20 gauge	152mm	20 gauge	4
18A-D2	Y	Y	12mm	Interior	92mm	18 gauge	92mm	18 gauge	4
18B-D2	Y	Y	12mm	Interior	152mm	18 gauge	152mm	18 gauge	3
20A-D3	N	Y	min.	Interior	92mm	20 gauge	92mm	20 gauge	3
18A-D3	N	Y	min.	Interior	92mm	18 gauge	92mm	18 gauge	4
20B-D3	N	Y	min.	Interior	152mm	20 gauge	152mm	20 gauge	3
18B-D3	N	Y	min.	Interior	152mm	18 gauge	152mm	18 gauge	3
18A-D4	Y	N	min.	Interior	92mm	18 gauge	92mm	18 gauge	4
20A-D5	N	Y	12mm	Interior	92mm	20 gauge	92mm	20 gauge	4
20B-D6	Y	Y	min.	End	152mm	20 gauge	152mm	20 gauge	2
20A-D10	Y	Y	min.	Interior	92mm	20 gauge	92mm	14 gauge	3
20B-D11	Y	Y	min.	Interior	152mm	20 gauge	152mm	18 gauge	3

The following observations are noteworthy:

1. #6 pan-head self-drilling screws were used for the stud-to-track connections, and in many cases, the screw pulled completely out of the stud compression flange at failure.
2. The data indicates that the connection between the stud and the track on the compression flange (bottom) influences the strength of the assembly more than a missing screw in the tension flange (top). The capacity of those assemblies without a screw in the compression flange had an average of only 88% of the capacity of an assembly with two screws.

3. Drysdale and Breton did not propose predictor equations for these types of connections.

2.3 Marinovic (1994)

Research was conducted at Cornell University by Marinovic [1994] on screw-connected stud-to-track connections that resulted in the development of the following predictor equation for the nominal resistance of a track punch-through failure:

$$P_n = 0.6twF_u \quad (2.1)$$

Where:

P_n	=	Nominal stud capacity
t	=	Base steel thickness of track material
w	=	Stud flange width
F_u	=	Tensile strength of track material

The diameter of the screws used in these tests was 6 mm, and screw pull-out was not a failure mode with these tests.

Unfortunately, the test setup used for this study was unable to carry web crippling loads for many of these connections; consequently web crippling results and associated conclusions were not reported. While the test setup was sufficient to allow loads to develop that caused track punch-through failure in a number of tests, the higher loads required to cause a web crippling failure often resulted in the track tearing through the fasteners that held the track to the test frame, prematurely ending the test.

2.4 Schumacher (1998)

Schumacher et al. [1998] investigated combinations of built-up members typical of jamb studs. Two sizes of stud and track, 92 mm and 152 mm, with nominal thicknesses of 0.85 mm and 1.52 mm, respectively, were used to construct six different types of test specimen configurations. These configurations included pairs of single studs and built-up 'I' sections, with or without track sections nested and screw-fastened onto the studs. Where track was nested over the stud(s), it was kept back 5 mm from the flange of the base track. In practice, it is impossible to fasten the track to the base track using screws; since they have the same cross-section, one cannot be nested inside the other.

Connections between built-up stud members were made using #10 hex-head screws, while track nested to the stud and the stud to base track connections used #8 wafer-head screws.

The effect of fastener location attaching the track to the substrate was investigated by varying the location to either directly between studs or adjacent to the studs. The fastener locations and the different configuration of test specimens are shown in Figure 2-1.

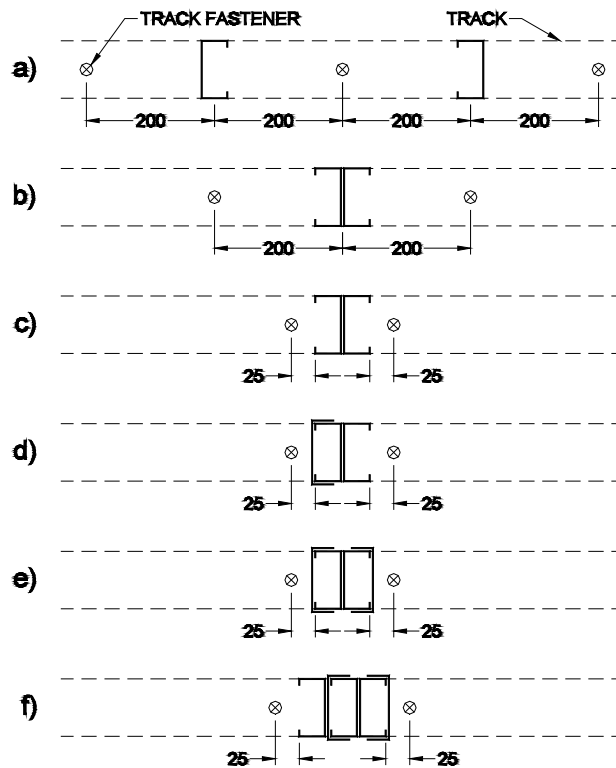


Figure 2-1: Built-up Stud Combinations with Track Fastener Locations [Schumacher et al., 1998]

The observed failure mode was typically web crippling followed by screw pullout of the compression flange (upper) screw. In most tests, the ultimate load directly preceded screw pullout.

The most noteworthy conclusions from this study were that that a single #10 screw between each stud connecting the track to the supporting frame was adequate for the lighter thickness single stud assemblies, but built-up members required a fastener at each side of the member to adequately transfer the load through the track to the supporting structure. As well, nesting track sections onto studs did not increase the strength of the connection, since the nested track could not be directly attached to the base track to transfer any shear.

2.5 Lewis (1999)

The web crippling equation used to design the stud-to-track connection was based on research into web crippling for a rigidly supported member. Lewis et al. [1999] concluded that since, in general practice, the wall track is attached to the substrate with a single fastener at intervals of up to 900 mm, it cannot be considered to be rigidly supported. The position of the fastener in the centre of the track web, as illustrated in Figure 2-2, cannot be considered to restrain the track flanges from deflecting and deforming under load.

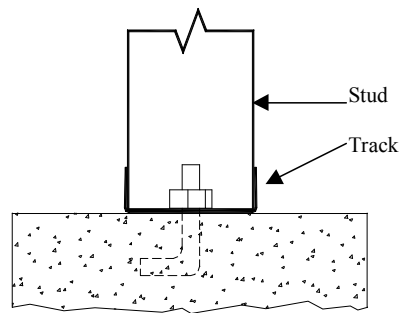


Figure 2-2: Stud-to-Track Connection

A series of end-one-flange tests on pairs of single stud-to-track connections was carried out using a single C-clamp directly between two adjacent studs to connect the track to the substrate, as shown on Figure 2-3.

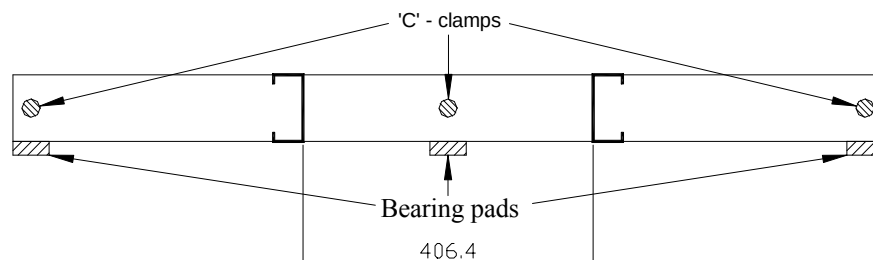


Figure 2-3: Test Apparatus--Clamping and Bearing Pad Detail

Stud and track sections with a nominal web depth of 92 mm, and standard thicknesses of 20, 18, 16, and 14 gauge (0.84 mm, 1.12 mm, 1.52 mm and 1.91 mm), were used to construct the test specimens. Each stud thickness was tested with track material of the same thickness, and with all thinner track thicknesses. The purpose of varying the stud-to-track thickness was to determine the effect on the connection behaviour of using thinner track than stud. One additional configuration was tested, incorporating a large end gap of 9.53 mm (3/8 in.), as shown on Figure 2-4. For all other specimens, the end gap was closed as tightly as possible, and the measured gap recorded.

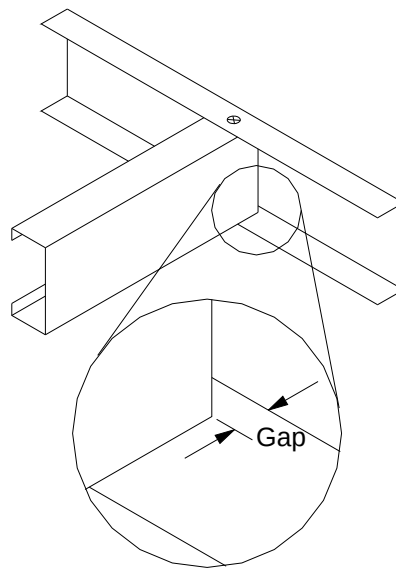


Figure 2-4: Test Procedure-Gap Measurement [Lewis 1999]

A total of 25 different assemblies were tested, and a designator system was established for ease of identification. For example, specimen **75S60T-1** is to be interpreted as follows:

‘75’ refers to the member thickness in one thousandth of an inch, i.e. 0.075 in. (1.91 mm)

‘S’ refers to the member type. In this case, it is a stud

‘60’ refers to the member thickness in one thousandth of an inch, i.e. 0.060 in. (1.52 mm)

‘T’ refers to the member type. In this case, it is a track

‘1’ refers to the test number for this series.

For specimen 36S33T-0.0375-1 & -2, the extra ‘0.375’ term refers to the large end gap built into the specimen. The test matrix and results are shown in Table 2-2.

Table 2-2: Test Results [Lewis, 1999]

Test Series	Gap (mm)		Observed Failure Mode	Load / Web (kN)
	Left	Right		
36S33T-0.375-1	9.53	9.53	Web Crippling	2.670
36S33T-0.375-2	9.53	9.53	Web Crippling	2.596
36S33T-1	1.22	1.73	Web Crippling	3.222
36S33T-2	1.52	0.94	Web Crippling	2.780
36S33T-3	1.14	1.14	Web Crippling	2.743
48S33T-1	0.76	0.86	Web Crippling	4.695
48S33T-2	0.51	0.76	Web Crippling	4.585
48S44T-1	0.76	0.64	Web Crippling	4.787
48S44T-2	1.27	1.09	Web Crippling	4.640
48S44T-3	0.86	1.02	Web Crippling	4.824
60S33T-1	0.64	1.52	Punch through	5.358
60S33T-2	1.52	1.40	Punch through	5.284
60S44T-1	1.73	0.20	Web Crippling & Punch Through	8.010
60S44T-2	1.65	1.02	Punch through	8.341
60S60T-1	0.00	1.93	Web Crippling, Excessive Deflection	8.267
60S60T-2	0.20	1.02	Web Crippling, Excessive Deflection	9.096
75S33T-1	0.10	0.20	Punch through	5.763
75S33T-2	1.78	0.51	Punch through	5.690
75S44T-1	2.03	1.35	Punch through	8.470
75S44T-2	0.64	1.65	Punch through	7.899
75S60T-1	0.51	0.10	Web Crippling	12.318
75S60T-2	0.00	0.00	Web Crippling	11.839
75S75T-2	0.00	0.00	Web Crippling, Excessive Deflection, Screw Pull-out	13.644
75S75T-3	0.91	0.51	Web Crippling	13.165

The results of this study indicated that there are two modes of failure; web crippling and track punch-through. Track punch-through occurred before the full web crippling

strength of the stud could be developed, and was a mode of failure only where the thickness of the track was less than the thickness of the stud. With the exception of the 60S44T series, for punch-through to occur, the track had to be 2 gauges thinner than the stud.

Hex-head self-drilling #10 screws for studs up to 1.52 mm thick, and #12 screws for the 1.91 mm thick studs, were used to connect the stud flanges to the track flanges. Only in the case with a 1.91 mm stud, was screw pull-out observed.

The main conclusion from this study was that to avoid a premature track punch-through failure, the track thickness must be greater than or equal to the thickness of the stud.

2.6 Fox and Schuster (2000)

In 2000 at the University of Waterloo, Fox and Schuster [2000] compiled test data for lateral load capacities of screw-attached stud-to-track connections from a variety of sources. From these tests, two different failure patterns were observed: web crippling of the stud and punch-through of the track flange.

Based on an analysis of the test data, the existing equations for nominal web crippling resistance and track punch-through failure were refined to better predict the failure capacity of screw-attached connections:

When the track thickness was greater than or equal to that of the stud thickness, end-one-flange web crippling of a C-section stud controlled, resulting in the nominal web crippling resistance as expressed in Eq. 2.2:

$$P_n = C t_s^2 F_{ys} \left(1 - C_R \sqrt{R}\right) \left(1 + C_N \sqrt{N}\right) \left(1 - C_H \sqrt{H}\right) \quad (2.2)$$

Where:

C	=	Web crippling coefficient = 5.6
C_R	=	Inside bend radius coefficient = 0.14
C_N	=	Bearing length coefficient = 0.30
C_H	=	Web slenderness coefficient = 0.01
F_{ys}	=	Yield strength of stud material
H	=	h/t_s
h	=	Flat dimension of stud web measured in plane of web
N	=	n/t_s
n	=	Stud bearing length
R	=	r/t_s
r	=	Stud inside bend radius
t_s	=	Stud thickness

When the track thickness was less than the stud thickness, punch-through shear failure of the track controlled, resulting in the nominal punch-through resistance as expressed in Eq. 2.3:

$$P_n = 0.7t_t w_b F_{ut} \quad (2.3)$$

Where:

F_{ut}	=	Ultimate strength of track material
t_t	=	Track thickness
w_b	=	Track shear width
	=	$(20t_t + 14)$ in mm
	=	$(20t_t + 0.56)$ in inches

2.7 Daudet (2001)

Pilot tests were undertaken at Dietrich Industries where the stud-to-track connection was located at the end of the track, such as at an opening of a doorway. Daudet [2001] reported that for these connections, web crippling of the stud appeared to be the governing mode of failure, and that the connection strength was about one half the value predicted by using the method outlined by Fox and Schuster [2000].

2.8 Bolte (2003)

An experimental investigation was conducted at the University Of Missouri-Rolla by Bolte [2003] to determine the lateral load capacity of two stud-to-track connections found in wind load bearing cold-formed steel stud walls. The capacities of both deflection-track and screw-attached track connections typically found in curtain wall systems were examined.

Data from both this study and from Fox and Schuster [2000] were analyzed, and the following equation was developed to predict the nominal stud-to-track connection resistance, P_{nst} , where the connection is not adjacent to wall openings and where the track thickness is greater than or equal to the stud thickness:

$$P_{nst} = P_n + \Delta P_{not} \quad (2.4)$$

Where:

Δ	=	0.756
P_n	=	Web crippling capacity in accordance with Section C3.4.1 of the AISI Specification (2001) for end-one-flange loading
P_{nst}	=	Nominal strength for the stud to track connection when subjected to transverse loads
P_{not}	=	Screw pull-out capacity in accordance with Section E4.4.1 of the AISI Specification (2001)

The original research report should be consulted for a listing and explanation of the parameters within which this equation is valid.

2.9 NASPEC (2007)

The North American Specification for the Design of Cold-Formed Steel Structural Members (NASPEC) [AISI 2007a, CSA 2007] does not give a design equation specifically for stud-to-track assemblies. Instead, the capacity of the screw-attached stud-to-track

connection is calculated based upon the nominal web crippling strength of the wall stud acting alone using the following equation.

$$P_n = Ct^2F_y \sin \theta \left(1 - C_R \sqrt{\frac{R}{t}}\right) \left(1 + C_N \sqrt{\frac{N}{t}}\right) \left(1 - C_h \sqrt{\frac{h}{t}}\right) \quad (2.5)$$

Where:

P_n	=	Nominal web crippling strength
C	=	Web crippling coefficient (see Table 2-3)
C_h	=	Web slenderness coefficient (see Table 2-3)
C_N	=	Bearing length coefficient (see Table 2-3)
C_R	=	Inside bend radius coefficient (see Table 2-3)
F_y	=	Yield strength of stud material
h	=	Flat dimension of stud web measured in plane of web
N	=	Bearing length
R	=	Stud inside bend radius
t	=	Stud web thickness
θ	=	Angle between plane of web and plane of bearing surface, $45^\circ < \theta \leq 90^\circ$

Table 2-3: Web Crippling Coefficients, NASPEC (2007)

	C	C_R	C_N	C_h
Single Web Channel & C-Sections	4	0.14	0.35	0.02
Built-up Sections	10	0.14	0.28	0.001

P_n represents the nominal web crippling strength of a load or end reaction for one solid web element. The coefficients for screw-attached stud-to-track connections are based upon an end-one-flange loading case with stiffened or partially stiffened flanges fastened to the support, and are given in Table 2-3.

2.10 WSD (2007)

The North American Standard for Cold-Formed Steel Framing – Wall Stud Design (WSD) [AISI 2007b] does provide design equations specifically for curtain wall stud-to-track assemblies. In all cases, this document requires the designer to first check that the stud-to-track connection satisfies the web crippling strength of the stud, according to Section C3.4 of the NASPEC, and that the maximum gap between the end of the stud and the web of the track be less than 6.35 mm (1/4 in.).

For cases where the connection is not adjacent to a wall opening, both stud flanges are connected to both track flanges, and the track thickness is greater than or equal to the stud thickness, the following web crippling equation is used:

$$P_{nst} = Ct^2F_y \left(1 - C_R \sqrt{\frac{R}{t}} \right) \left(1 + C_N \sqrt{\frac{N}{t}} \right) \left(1 - C_h \sqrt{\frac{h}{t}} \right) \quad (2.6)$$

Where:

- C = Web crippling coefficient = 3.7
- C_R = Inside bend radius coefficient = 0.19
- C_N = Bearing length coefficient = 0.74
- C_h = Web slenderness coefficient = 0.019
- R = Stud inside bend radius
- N = Stud Bearing Length
- h = depth of flat portion of stud measured along plane of web
- t = Stud thickness
- F_y = Yield strength of stud material
- P_{nst} = Nominal strength of stud-to-track connection when subjected to transverse loads

For cases where the connection is not adjacent to a wall opening, both stud flanges are connected to both track flanges, but the track thickness is less than the stud thickness, the following track punch-through equation is used:

$$P_{nst} = 0.6t_t w_{st} F_{ut} \quad (2.7)$$

Where:

- t_t = Design track thickness
- w_{st} = $20 t_t + 0.56\alpha$
- α = Coefficient for conversion of units
 - = 1.0 when t_t is in inches
 - = 25.4 when t_t is in mm
- F_{ut} = Tensile (ultimate) strength of track
- P_{nst} = Nominal strength of stud-to-track connection when subjected to transverse loads

For cases where the connection is adjacent to a wall opening, both stud flanges are connected to both track flanges, and the track terminates at the opening, the nominal resistance shall be taken as $0.5P_{nst}$, calculated using one of the equations above, depending on the ratio of track to stud thickness. The adoption of the $0.5P_{nst}$ factor at end-of-track locations is based on the results of the study by Daudet [2001].

For cases where both stud flanges are not attached to both track flanges, this standard offers two more methods for calculating stud-to-track connection resistance. Where the connection is not adjacent to a wall opening, and the track thickness is greater than or equal to the stud thickness, P_{nst} is set equal to P_n as calculated by using Section C3.4 of the NASPEC. In those cases where the connection is adjacent to a wall opening, and the track thickness is greater than or equal to the stud thickness, P_{nst} is set equal to $0.5P_n$ as calculated by using Section C3.4 of the NASPEC.

Chapter 3

Experimental Investigation

3.1 Experimental Parameters

The parameters that were varied in the test program consisted of the stud and track thickness, stud and track web depth, screw size, screw location, and the location and configuration of the studs in the test samples. These parameters are described in more detail in the following sections.

3.1.1 Mechanical Properties

For each type of section (i.e. stud and track) three tensile coupons were taken from the web elements for the determination of the mechanical properties. The coupon specimens were tested according to the American Standard of Testing and Materials A370 [ASTM 2005]. The galvanized coating was removed from the specimens using a solution of hydrochloric acid and water to allow for measurement of the base steel thickness. Listed in Table A-1 of Appendix A are the mechanical properties for each specimen tested.

3.1.2 Stud and Track Sizes

The test specimens used in this study were constructed of C-shaped stud and track sections as illustrated in Figure 3-1. Listed in Table B-1 of Appendix B are the web depth, flange length, lip length, inside bend radius at the flange-web junction and base steel thickness of the stud and track specimens used in each of the test assemblies.

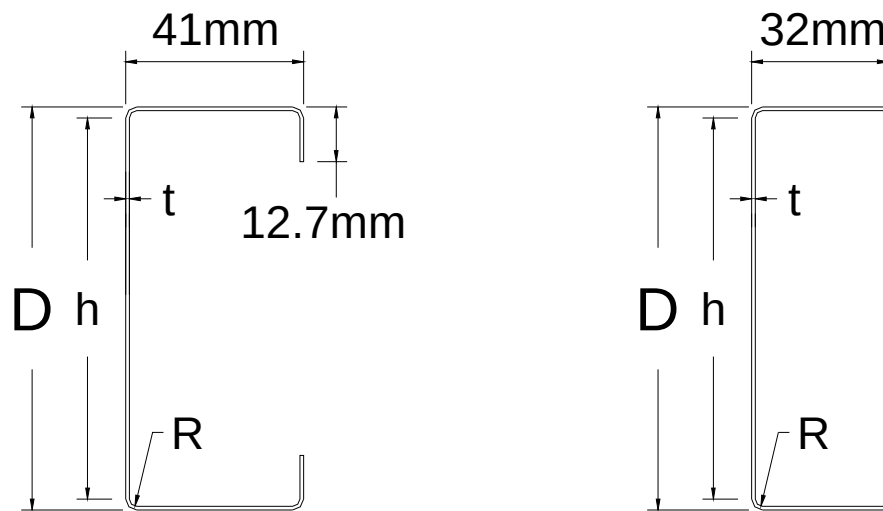


Figure 3-1: Geometric Section Parameters

To limit the number of test specimen configurations, various combinations of stud and track thicknesses were considered and reviewed. In earlier tests with single studs, it was discovered that when the track thickness was as thick, or thicker, than the stud, the failure mode was web crippling of the stud [Fox and Schuster 2000]. Since the web crippling failure mode is not dependent on the thickness of the track, it was decided that test combinations with the track thicker than the studs was unnecessary. Fox and Schuster also found that track punch-through by a single stud did not occur when the thickness of the track was at least as thick as the stud. It is common practice for load bearing stud applications to specify the thickness of the stud and track to be the same. Therefore, based on these considerations it was decided to test only combinations of stud and track with equal nominal thickness.

The standard thicknesses for steel stud framing in Canada at the time of testing were as follows:

- 0.84 mm (33 mil, 20 gauge);

- 1.12 mm (44 mil, 18 gauge);
- 1.52 mm (60 mil, 16 gauge); and,
- 1.91 mm (75 mil, 14 gauge).

Test assemblies were constructed with stud and track sections in all four sizes.

The web crippling capacity of a member is partly a function of the slenderness of the member's web (web depth divided by the thickness). Consequently, the strength of the stud-to-track connection is also partly a function of the depth of the stud. The most common sizes of studs are 92 mm and 152 mm deep, although the 203 mm deep sections may sometimes be necessary in higher walls. A decision was made to limit the web depths of the test specimens to 92 mm and 152 mm, which represent the majority of the sizes used in practice, and also reduced the number of assembly combinations. Of the 152 mm sections tested, only the toe-to-toe configuration was tested.

Stud sections can also be manufactured with varying flange widths to meet certain structural requirements, with flange widths from 32 mm to 76 mm. Since the primary failure modes that occur in these stud-to-track connections are web crippling and track punch-through, neither of which are a function of the flange width, it was decided to limit the test assemblies to only the 41 mm stud flange width, and to the standard 32 mm track flange width.

3.1.3 Built-Up Jamb Studs at an Interior Track Location

Framing an opening in a 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 the opening. However, in some cases due to the strength requirements or the framing methods, 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 3-2 are two jamb configurations at a window opening showing the studs framing into a bottom wall track that is continuous past the jamb.

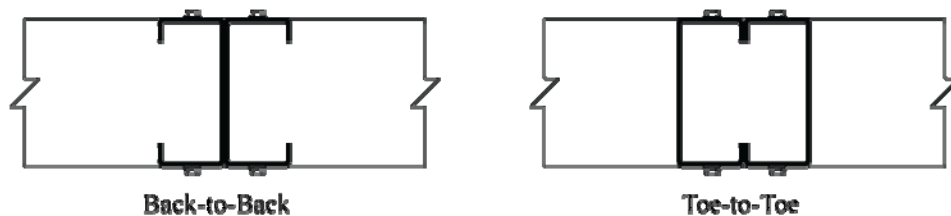


Figure 3-2: Jamb Studs at Interior Location

When the jamb is made from back-to-back members, a piece of track is added to the inside stud to provide a 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 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.