Lateral Strength of Wind Load Bearing Wall Stud-to-track Connection

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LATERAL STRENGTH OF WIND LOAD BEARING WALL STUD-TO-TRACK CONNECTION

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ABSTRACT

A common application of cold formed steel in building construction is for wind load bearing steel studs (curtain walls). These wall studs are designed to carry lateral load only, and frame into horizontal steel track members at the top and bottom of the wall assembly. The stud-to-track connection consists of studs framing perpendicularly into the track and are connected with sheet metal screws. The design of the wall stud must include a check of the web crippling capacity at the end reactions. The current design expressions, however, do not apply to the type of bearing in these stud-to-track connections. Reported in this paper are the results and analysis of a collection of end-one-flange web crippling tests of common stud-to-track connections. The analysis shows that there are two failure modes: web crippling of the stud and punch-through of the track flange. Design expressions have been developed to predict the ultimate capacity of the connection based on these two modes of failure. The effects of increasing the gap between the end of the stud and the web of the track, as well as the effects of missing screws in the stud-to-track connection are also discussed.

INTRODUCTION

Cold formed steel structural members are used extensively in building construction throughout the world, and a common application is for wind load bearing steel studs (curtain walls). A wind load bearing stud is a structural framing member used to support the exterior wall finish and transfer to lateral loads, such as wind, to the main structure. The studs are not axial load bearing in this application, and a typical assembly is illustrated in Figure 1.

A steel stud wall is constructed with a combination of stud and track sections. A stud is a C-section typically 92 to 152 mm (3-5/8 to 6 in.) in depth with flanges 32 to 42 mm (1-1/4 to 1-5/8 in.) in width with stiffening lips on the free edges of the flanges. The steel thickness ranges from 0.84 to 1.91 mm (0.033 to 0.075 in.). The track sections are of the same basic sizes and configuration as the studs, except the flanges do not have stiffening lips. A steel stud wall assembly is constructed with a top and bottom track into which the steel studs are fixed at regular intervals (see Figure 1). The track is anchored to the structure and the studs are connected to the track with screws through each flange at both the top and bottom. The stud is typically designed to carry a uniform lateral load, which is transferred through the track into the supporting structure.

The design of cold formed steel structural members in North America is governed in Canada by the Canadian Standards Association CSA-S136 *Cold Formed Steel Structural Members* [1], and in the United States by the American Iron and Steel Institute *Specification for the Design of Cold-Formed Steel Structural Members* [2]. These standards have extensive provisions covering

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the design of most common cold formed steel structural elements. The standards do not, however, have rules for the design of the stud-to-track connection predominant in cold formed wind load bearing steel stud construction.

Described in this paper are the results and analysis of stud-to-track end condition tests from four different sources [3, 4, 5, 6]. This data has been used to develop design recommendations for the ultimate strength limit states.

RESEARCH SCOPE

The design of a wind load bearing steel stud commonly takes into account the following limit sates: flexure, shear, deflection and web crippling. Designing for the first three of these limit states is straightforward using the current design documents [1,2]. The web crippling limit state, however, poses special problems in the wind load bearing steel stud application. The calculation of the web crippling capacity of a cold formed steel member can be determined for one of the four load cases: end-one-flange [EOF], end-two-flange [ETF] interior-one-flange [IOF] and interior-two-flange [ITF]. The definitions of each loading case are clearly given in the design documents. The web crippling expressions assume that the flexural member (i.e. the steel stud) is resting on a rigid bearing surface. The stud-to-track end connection in a wind load bearing wall, while it is a end-one-flange loading, is a condition that is not covered by the current web crippling design methods. This difference is illustrated in Figure 2. As a consequence, testing is needed to determine the appropriate design capacity for this type of connection.

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

i) The physical properties of the stud and track material (i.e. thickness and strength).
ii) The relative thicknesses of the stud and track members (i.e. studs thicker than the track).
iii) Amount of gap between the end of the stud and the web of the track.
iv) Size and location of the screws 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).

Tests on each of these parameters have been carried out [3,4,5,6], however, design recommendations are only provided for the first three where sufficient test data is available.

TYPICAL TEST SET-UP

The basic test procedure used by all of the researchers involved conducting a series of end-one-flange loading tests on stud-to-track connections of different configurations. The Schumacher and Lewis tests [3,4] are typical and used 1.22 m (4 ft) lengths of stud. One end of the stud framed into a length of track and the other end was supported on a roller. The track section was fixed to a vertical support to simulate common framing practice. Two studs were tested as a pair (oriented back to back) and were connected together to restrain the torsional forces developed in the C-sections. The studs were also reinforced to prevent a flexural failure, and a bearing stiffener was attached under the load application to avoid web crippling at this location. A typical test set-up is shown in Figure 3. The failure load reported is the reaction at the track location for an individual stud.

SUMMARY OF TEST RESULTS

The origin of the test results are identified as follows: Schumacher [3], Lewis [4], McMaster [5] and Cornell [6]. Sufficient data is provided in this paper to verify the conclusions proposed, but the original research reports should be consulted for more detailed descriptions of the specific test series. There are additional test results reported in these references on other types of assemblies that may also be of interest.

Failure Modes

In the tests of a typical stud-to-track connection, two different failure modes were observed: web crippling of the stud and punch-through of the track flange. These are shown in the photographs in Figures 4 and 5.

Failure Loads and Material Properties

The failure loads, material properties and relevant dimensions for all of the tests included in the analysis are provided in Tables 1 and 2.

Screw Connections and Placement

The Schumacher tests [3] used #8 screws to connect the stud to track. In most of the tests the screw in the upper flange (stud compression flange) pulled out of the stud flange prior to the ultimate load being reached. The McMaster tests [5] used only #6 screws, and in all cases the screw pulled out of the stud flange prior to failure. The Cornell tests [6] used ¼" screws, and there was no screw pull-out in their tests. The Lewis tests [4] used #10 screws for studs up to 1.52 mm (0.060 in.) and #12 screws for the 1.91 mm (0.075 in.) studs. In only one case with the 1.91 mm (0.075 in.) stud did the screw pull-out.

The screw pull-out is not considered significant to the ultimate load since the stud had either failed in web crippling or the track had failed in punch-through prior to screw failure. There may be some residual capacity carried by the screw after the stud has failed in web crippling, but the large deformations that occur prior to the screw pull-out make this added strength essentially irrelevant.

The McMaster tests also checked the effects of screws missing from either the compression or tension side of the connection. These results are summarized in Table 3.

Other Findings Reported in the Research

- Schumacher investigated combinations of built-up members typical of jamb studs.
- Schumacher found 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 on each side of the member to adequately transfer the load.
- Drysdale and Breton tested different stud to track connection types: welded, double track.
- Schumacher found that track deflection was only significant in the tests of built-up members without screws immediately adjacent to the member.
- The Cornell data was reviewed, unfortunately, since the necessary material properties were not reported, this data could not be incorporated into the analysis.

ANALYSIS

Web Crippling Failure

Summarized in Table 1 are those tests that failed by web crippling of the stud. The relevant material properties for stud and track are provided in columns 2 through 6. Column 7 gives the tested failure loads (end reaction) per stud. Column 8 gives the bearing width assumed in the analysis, which was taken as the width of the track flange minus the end gap reported in Column 1. Column 9 gives the predicted failure loads using the proposed design expression. Column 10 gives the ratios of the test-to-predicted capacities along with the mean and coefficient of variation. The table is divided into three sections: 92 mm (3-5/8 in.) studs, 152 mm (6 in.) studs, and studs with a 12 mm (1/2 in.) nominal end gap. Mean test-to-predicted and coefficient of variation are provided for each group as well as for the whole data set.

The prediction of the nominal web crippling resistance, P_n, is based on the following design method currently being used in the CSA-S136 Standard [1].

$$P_n = Ct^2F_y\left(1 - C_R\sqrt{R}\right)\left(1 + C_N\sqrt{N}\right)\left(1 - C_H\sqrt{H}\right) \qquad \textit{(Eq. 1)}$$

Where,

C = web crippling coefficient
C_R = inside bend radius coefficient
C_N = bearing length coefficient
C_H = web slenderness coefficient
F_y = yield strength of stud material
H = h/t
h = flat dimension of stud web measured in plane of web
N = n/t
n = stud bearing length
R = r/t
r = stud inside bend radius
t = thickness of web

This web crippling equation is also being considered at this time for adoption by the AISI Specification [2]. The coefficients to be used in this predictor equation were derived through a regression analysis of the test data and are as follows:

C = 5.6
C_R = 0.14
C_N = 0.30
C_H = 0.01

The overall mean of 1.008 and a coefficient of variation of 0.085 of the test-to-predicted ratios indicate that this is a reasonable predictor within the limits of the test series.

Track Punch-Through Failure

Summarized in Table 2 are those tests that failed by track punch-through. The relevant material properties for stud and track are provided in columns 2 through 6. Column 7 gives the tested failure loads (end reaction) per stud. Column 8 gives the bearing width assumed in the analysis, which was determined based on the analysis of the test results. Column 9 gives the predicted failure loads using the proposed design expression. Column 10 gives the ratios of the test-to-predicted capacities along with the mean and coefficient of variation.

The nominal resistance of the track punch-through failure was based on the following design expression proposed in the Cornell [6] work:

$$P_n = 0.6twF_u \qquad \textit{(Eq. 2)}$$

Where,

t = track thickness
w = stud flange width
F_u = ultimate strength of track material

This method assumes a shear failure in the track along a length equal to the stud flange width. A review of the test-to-predicted ratios using Eq. 2 as the predictor equation showed that the capacity also varied with the track/stud thickness. To model this behavior, a variable shear width, w_b, was incorporated into Eq. 2. A simple linear regression analysis was used to develop the expression for w_b based on both the track thickness and the stud thickness. The expression that was based on the track thickness provided the best correlation with the test results. The proposed design expression is as follows:

$$P_n = 0.6t_t w_b F_{ut} \qquad \textit{(Eq. 3)}$$

Where,

t_t = track thickness
w_b = track shear width
= $(20t_t + 14)$ in mm
= $(0.78t_t + 0.56)$ in inches
F_{ut} = ultimate strength of track material

It is important to note that track punch-through only occurred in those assemblies where there was only a small gap between the stud and the track, (i.e. 1.5 mm or 1/16 in.). There is no data available to be able to predict when the web crippling failure mode takes over from the punch-through failure mode as the end gap is increased. Consequently, the design recommendations have been limited to a gap of 1.5 mm (1/16 in.).

It is also worthwhile noting that the punch-through failure mode did not occur when the track and stud were the same thickness, or in many cases even when the track was one "gauge" thinner. The exception being the 1.46 mm (0.057 in.) stud with the 1.08 mm (0.043 in.) track. The difference in thickness between the 16 gauge stud and the "light" 18 gauge track was enough to cause a track punch-through failure. The practice of supplying the track one gauge thinner that the stud should be reviewed in the light of a possible limiting failure mode in the track.

Effect of Stud End Gap

The data provided in Table 1 also shows the results for those tests that failed in web crippling and had a gap between the end of the stud and the track of approximately 12 mm (1/2 in.). When the predictor equation (Eq. 1) was applied to this test data, the test-to-predicted ratios had a mean of 1.047 and coefficient of variation of 0.079. This correlation agrees well with the data for tests without any gap and would support the application of this design method to gaps up to 12 mm (1/2 in.). When there is an end gap, the bearing width used in Eq. 1 is the track flange width minus the gap, which is the bearing length for the stud. There still remains, however, the question of the end gap where the track punch-through failure mode starts to occur.

Missing Screws

The McMaster work also looked at the effects of connecting only one of the stud flanges. The results are reported in Table 3, and as expected, show a decrease in ultimate capacity when one of the screws is missing from either the compression side or the tension side of the connection. There are insufficient tests to be able to develop a reliable predictor expression, however, the results illustrate the general behavior and may be useful in specific circumstances.

Bearing Length

An important variable that has not yet been well investigated is the effect that the screw placement has on the effective bearing length of the stud. Considering the situation where a long-leg track is used, which has a flange width of 75 mm (3 in.), would the predictor equation still be valid based on this longer bearing length? Would there be a difference in capacity if the screw were located near the end of the stud or near the edge of the track flange? How does the screw location affect the bearing length of the stud? Questions such as these support the limitation of the design recommendations for the specific configurations tested and indicate areas for further study.

Calibration

To be useful design expressions, the predictor equation needs to have associated resistance factors or safety factors. In Canada the Limit States Design (LSD) method is used, while in the United States both the Load and Resistance Factor Design (LRFD) and Allowable Stress Design (ASD) methods are used. The load factors, live to dead load ratios and target reliability indices, β, are different in the two countries. Consequently, the expression for determining the resistance factors will also be different. Chapter F1, Tests for Determining Structural Performance, of the AISI Specification [2] was used to determine the Ω and ϕ values based on the following country-specific parameters:

	Canada	United States
Target β	3.0	2.5
Live/Dead Load Ratio	1/3	1/5
Live load factor	1.5	1.6
Dead load factor	1.25	1.2

DESIGN RECOMMENDATIONS

The nominal strength of a single stud-to-track connection is the lesser of the following two conditions:

(a) End-one-flange web crippling of the C-section stud:

$$P_n = Ct_s^2F_{ys}\left(1 - C_R\sqrt{R}\right)\left(1 + C_N\sqrt{N}\right)\left(1 - C_H\sqrt{H}\right) \qquad \textit{(Eq. 4)}$$

(b) Punch-through shear failure of the track:

$$P_n = 0.6t_t w_b F_{ut} \qquad \textit{(Eq. 5)}$$

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
F_{ut} = ultimate strength of track 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
t_t = track thickness
w_b = track shear width
= $(20t_t + 14)$ in mm
= $(0.78t_t + 0.56)$ in inches
Ω = safety factor = 1.69 (for AISI ASD design)
ϕ = resistance factor = 0.90 (for AISI LRFD design)
ϕ = resistance factor = 0.78 (for S136 LSD design)

These design provisions are applicable within the following limits determined by the test program.
(a) Depth: 92 to 152 mm (3-5/8 to 6 in.)
(b) Thickness: 0.84 to 1.91 mm (0.033 to 0.075 in.)
(c) Inside bend radius: R = 2
(d) Bearing width: n = 32 mm (1-1/4 in.)
(e) A screw must connect each flange of the stud to the track.
(f) The stud must be at least 200 mm from the end of the track
(g) The track must be adequately fastened to the support between each stud.
(h) The gap between the end of the stud and the track shall not exceed 1.5 mm (1/16 in.).

CONCLUSIONS

A design procedure has been presented to calculate the lateral capacity of a stud-to-track connection. This procedure recognizes the two observed failure modes: web crippling of the stud and punch-through of the track. This method applies to the 92 mm (3-5/8 in.) and 152 mm (6 in.) stud and track in the thickness range from 0.84 to 1.91 mm (0.033 to 0.075 in.). The web crippling predictor equation also applies when there is a gap between the stud and track up to 12 mm (1/2 in.). Results are also reported for tests on connections with some of the screws missing.

The practice of supplying the track one gauge thinner that the stud should be reviewed in the light of a possible punch-through failure mode in the track. To ensure that web crippling of the stud is the limiting design criteria, the track should be the same thickness as the stud or greater.

Additional research is needed in the following areas:
(a) Develop equivalent design provisions for built-up members typically used as jamb studs.
(b) Investigate the capacity of the jamb studs at the end of a track section next to a door opening.
(c) Determine the effects of larger end gaps possible with long-leg track.
(d) Correlate the screw location on the track flange and develop an appropriate expression for the bearing width.
(e) Determine the influence of end gap on the track punch-through failure mode.

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Table 1: Summary of Test Data and Analysis for Web Crippling Failure

Reference	Test Designation	End Gap (mm)	Stud			Track		Failure Load per Web P_t (kN)	Bearing Width (mm)	Calculated Capacity P_c (kN)	P_t/P_c
			Thickness (mm)	Depth (mm)	Yield (MPa)	Thickness (mm)	Ultimate (MPa)				
		1	2	3	4	5	6	7	8	9	10
Lewis	36S33T-1	1.5	0.88	92	345	0.79	358	3.22	30.5	2.99	1.077
Lewis	36S33T-2	1.2	0.88	92	345	0.79	358	2.78	30.8	3.00	0.927
Lewis	36S33T-3	1.1	0.88	92	345	0.79	358	2.74	30.9	3.00	0.914
Lewis	48S33T-1	0.8	1.19	92	300	0.79	358	4.70	31.2	4.43	1.061
Lewis	48S33T-2	0.6	1.19	92	300	0.79	358	4.59	31.4	4.43	1.034
Lewis	48S44T-1	0.7	1.19	92	300	1.08	321	4.79	31.3	4.43	1.080
Lewis	48S44T-2	1.2	1.19	92	300	1.08	321	4.64	30.8	4.41	1.052
Lewis	48S44T-3	0.9	1.19	92	300	1.08	321	4.82	31.1	4.42	1.091
Lewis	60S60T-1	1.0	1.46	92	409	1.45	408	8.27	31.0	8.63	0.958
Lewis	60S60T-2	0.6	1.46	92	409	1.45	408	9.10	31.4	8.66	1.051
Lewis	75S60T-1	0.3	1.87	92	405	1.45	408	12.32	31.7	13.29	0.927
Lewis	75S60T-2	0	1.87	92	405	1.45	408	11.84	32.0	13.32	0.889
Lewis	75S75T-1	1.0	1.87	92	405	1.81	388	10.85	31.0	13.21	0.821
Lewis	75S75T-2	0	1.87	92	405	1.81	388	13.65	32.0	13.32	1.024
Lewis	75S75T-3	0.7	1.87	92	405	1.81	388	13.17	31.3	13.24	0.994
Schumacher	2 (36S36T)	N/R	0.85	92	321	0.86	331	2.27	32.0	2.66	0.853
Schumacher	3 (36S36T)	N/R	0.85	92	321	0.86	331	2.83	32.0	2.66	1.064
Schumacher	4 (36S36T)	N/R	0.85	92	321	0.86	331	2.63	32.0	2.66	0.989
Schumacher	5 (36S36T)	N/R	0.85	92	321	0.86	331	2.80	32.0	2.66	1.053
McMaster	20A-D1-1	1.5	0.95	92	288	0.91	N/R	3.00	30.5	2.85	1.051
McMaster	20A-D1-2	1.5	0.95	92	288	0.91	N/R	2.68	30.5	2.85	0.940
McMaster	20A-D1-3	1.5	0.95	92	288	0.91	N/R	3.01	30.5	2.85	1.056
McMaster	20A-D1-4	1.5	0.95	92	288	0.91	N/R	2.66	30.5	2.85	0.934
McMaster	20A-D1-5	1.5	0.95	92	288	0.91	N/R	3.04	30.5	2.85	1.068
McMaster	20A-D1-6	1.5	0.95	92	288	0.91	N/R	2.89	30.5	2.85	1.014
McMaster	20A-D1-7	1.5	0.95	92	288	0.91	N/R	2.60	30.5	2.85	0.912
McMaster	20A-D1-8	1.5	0.95	92	288	0.91	N/R	2.55	30.5	2.85	0.895
McMaster	20A-D1-9	1.5	0.95	92	288	0.91	N/R	2.99	30.5	2.85	1.048
McMaster	18A-D1-1	1.5	1.27	92	288	0.91	N/R	4.97	30.5	4.73	1.051
McMaster	18A-D1-2	1.5	1.27	92	288	0.91	N/R	4.77	30.5	4.73	1.007
McMaster	18A-D1-3	1.5	1.27	92	288	0.91	N/R	4.95	30.5	4.73	1.046
McMaster	18A-D1-4	1.5	1.27	92	288	0.91	N/R	4.47	30.5	4.73	0.945
McMaster	18A-D1-5	1.5	1.27	92	288	0.91	N/R	4.55	30.5	4.73	0.962
McMaster	20A-D10-1	1.5	0.95	92	288	1.90	N/R	3.13	30.5	2.85	1.099
McMaster	20A-D10-2	1.5	0.95	92	288	1.90	N/R	3.06	30.5	2.85	1.073
McMaster	20A-D10-3	1.5	0.95	92	288	1.90	N/R	3.02	30.5	2.85	1.060
										Mean for 92 mm studs	**1.001**
N/R = not reported										**COV**	**0.074**

Table 1: Summary of Test Data and Analysis (Cont'd)

Schumacher	21 (48S48T)	N/R	1.18	152	314	1.16	316	4.50	32.0	4.47	1.006
Schumacher	22 (48S48T)	N/R	1.18	152	314	1.16	316	4.87	32.0	4.47	1.089
McMaster	20B-D1-1	1.5	0.95	152	288	0.91	N/R	2.48	30.5	2.76	0.899
McMaster	20B-D1-2	1.5	0.95	152	288	0.91	N/R	2.63	30.5	2.76	0.953
McMaster	20B-D1-3	1.5	0.95	152	288	0.91	N/R	2.84	30.5	2.76	1.029
McMaster	20B-D1-4	1.5	0.95	152	288	0.91	N/R	2.47	30.5	2.76	0.895
McMaster	20B-D1-5	1.5	0.95	152	288	0.91	N/R	2.80	30.5	2.76	1.015
McMaster	20B-D1-6	1.5	0.95	152	288	0.91	N/R	2.67	30.5	2.76	0.969
McMaster	18B-D1-1	1.5	1.27	152	307	0.91	N/R	4.30	30.5	4.91	0.876
McMaster	18B-D1-2	1.5	1.27	152	307	0.91	N/R	4.74	30.5	4.91	0.966
McMaster	18B-D1-3	1.5	1.27	152	307	0.91	N/R	4.55	30.5	4.91	0.926
McMaster	18B-D1-4	1.5	1.27	152	307	0.91	N/R	4.29	30.5	4.91	0.875
McMaster	18B-D1-5	1.5	1.27	152	307	0.91	N/R	4.62	30.5	4.91	0.943
McMaster	18B-D1-6	1.5	1.27	152	307	0.91	N/R	4.08	30.5	4.91	0.832
McMaster	20B-D11-1	1.5	0.95	152	288	1.22	N/R	3.09	30.5	2.76	1.120
McMaster	20B-D11-2	1.5	0.95	152	288	1.22	N/R	3.06	30.5	2.76	1.107
McMaster	20B-D11-3	1.5	0.95	152	288	1.22	N/R	3.36	30.5	2.76	1.217
										Mean for 152 mm studs	**0.983**
										COV	**0.105**
Lewis	36S33T-0.375-1	10.2	0.88	92	345	0.79	358	2.67	21.8	2.70	0.990
Lewis	36S33T-0.375-2	10.2	0.88	92	345	0.79	358	2.60	21.8	2.70	0.963
McMaster	20B-D2-1	12	0.95	152	288	0.91	N/R	2.41	20.0	2.43	0.992
McMaster	20B-D2-2	12	0.95	152	288	0.91	N/R	2.65	20.0	2.43	1.091
McMaster	20B-D2-3	12	0.95	152	288	0.91	N/R	2.41	20.0	2.43	0.993
McMaster	20B-D2-4	12	0.95	152	288	0.91	N/R	2.52	20.0	2.43	1.037
McMaster	18B-D2-1	12	1.27	152	307	0.91	N/R	4.27	20.0	4.35	0.981
McMaster	18B-D2-2	12	1.27	152	307	0.91	N/R	4.10	20.0	4.35	0.943
McMaster	18B-D2-3	12	1.27	152	307	0.91	N/R	3.90	20.0	4.35	0.897
McMaster	20A-D2-1	12	0.95	92	288	0.91	N/R	2.59	20.0	2.51	1.032
McMaster	20A-D2-2	12	0.95	92	288	0.91	N/R	2.90	20.0	2.51	1.156
McMaster	20A-D2-3	12	0.95	92	288	0.91	N/R	2.77	20.0	2.51	1.104
McMaster	20A-D2-4	12	0.95	92	288	0.91	N/R	2.98	20.0	2.51	1.186
McMaster	18A-D2-1	12	1.27	92	288	0.91	N/R	4.82	20.0	4.20	1.148
McMaster	18A-D2-2	12	1.27	92	288	0.91	N/R	4.76	20.0	4.20	1.134
McMaster	18A-D2-3	12	1.27	92	288	0.91	N/R	4.57	20.0	4.20	1.088
McMaster	18A-D2-4	12	1.27	92	288	0.91	N/R	4.46	20.0	4.20	1.063
										Mean for assemblies with large end gap	**1.047**
N/R = not reported										**COV**	**0.079**
										MEAN FOR ALL TESTS	**1.008**
										COV	**0.085**

Table 2: Summary of Test Data and Analysis for Track Punch-Through Failure

Lewis Test Designation	End Gap (mm)	Stud			Track		Failure Load (kN)	Bearing Width, n 20t+14 (mm)	Calculated Capacity $P_c = 0.6F_{ut}nt_t$ (kN)	P_t/P_c
		Thickness (mm)	Depth (mm)	Yield (MPa)	Thickness (mm)	Ultimate (MPa)				
	1	2	3	4	5	6	7	8	9	10
60S33T-1	1.1	1.46	92	409	0.79	390	5.36	29.8	5.51	0.973
60S33T-2	1.5	1.46	92	409	0.79	390	5.28	29.8	5.51	0.958
60S44T-1	1.0	1.46	92	409	1.08	354	8.01	35.6	8.17	0.980
60S44T-2	1.3	1.46	92	409	1.08	354	8.34	35.6	8.17	1.021
75S33T-1	0.2	1.87	92	405	0.79	390	5.76	29.8	5.51	1.045
75S33T-2	1.1	1.87	92	405	0.79	390	5.69	29.8	5.51	1.033
75S44T-1	1.7	1.87	92	405	1.08	354	8.47	35.6	8.17	1.037
75S44T-2	1.1	1.87	92	405	1.08	354	7.90	35.6	8.17	0.967
									Mean	**1.002**
									COV	**0.036**

Table 3: Effect of Screw Placement

McMaster test Designation	Stud Depth (mm)	Stud Thickness (mm)	End Gap (mm)	Single Screw Placement on Stud	Avg. Tested Capacity for 1 Screw Connection	Avg. Tested Capacity for 2 Screw Connection	Ratio of 1 Screw to 2 Screw Capacities
20A-D3 (4 tests)	92	0.95	1.5	Tension Flange	2.58	2.82	0.912
18A-D3 (4 tests)	92	1.27	1.5	Tension Flange	4.36	4.74	0.921
20B-D3 (3 tests)	152	0.95	1.5	Tension Flange	2.30	2.65	0.867
18B-D3 (3 tests)	152	1.27	1.5	Tension Flange	3.62	4.43	0.817
18A-D4 (4 tests)	92	1.27	1.5	Comp. Flange	4.38	4.74	0.925
20A-D5 (4 tests)	92	0.95	12	Tension Flange	2.35	2.82	0.834

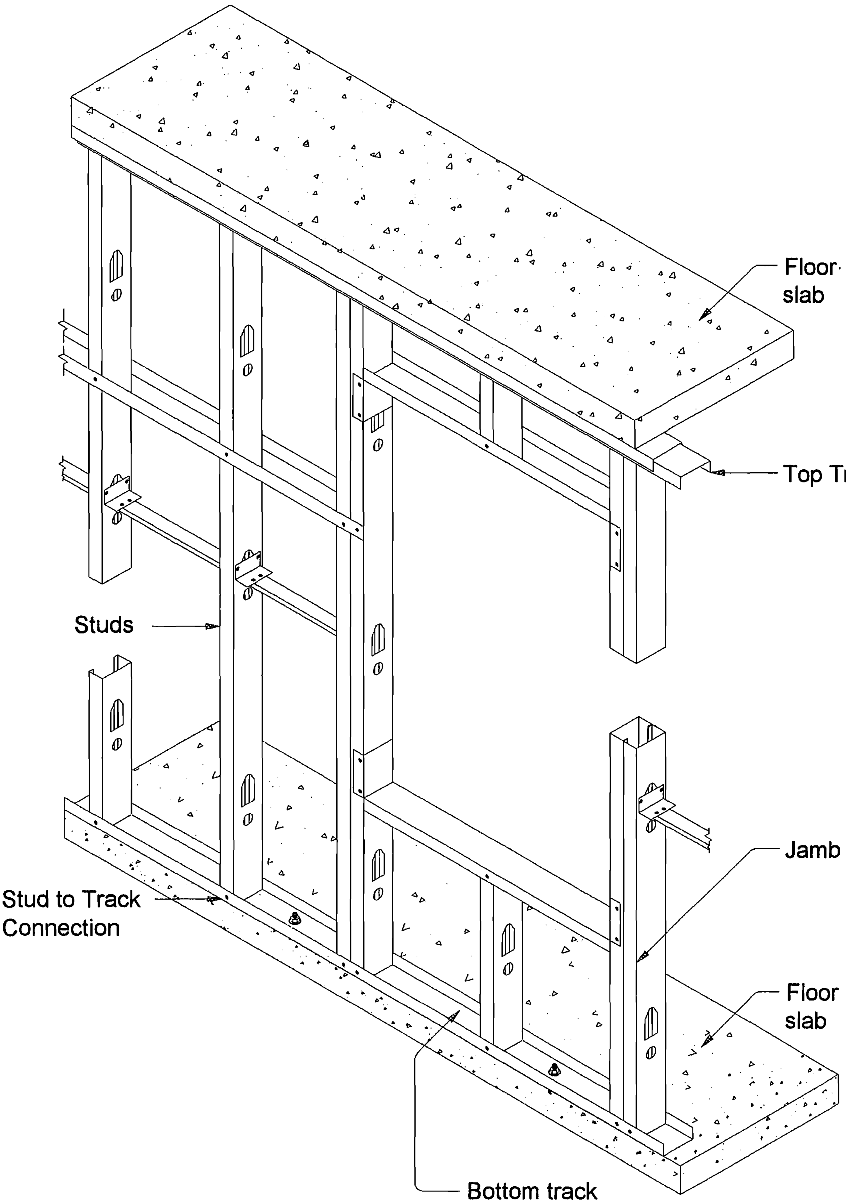

Figure 1: Schematic of Typical Wind Load Bearing Framing

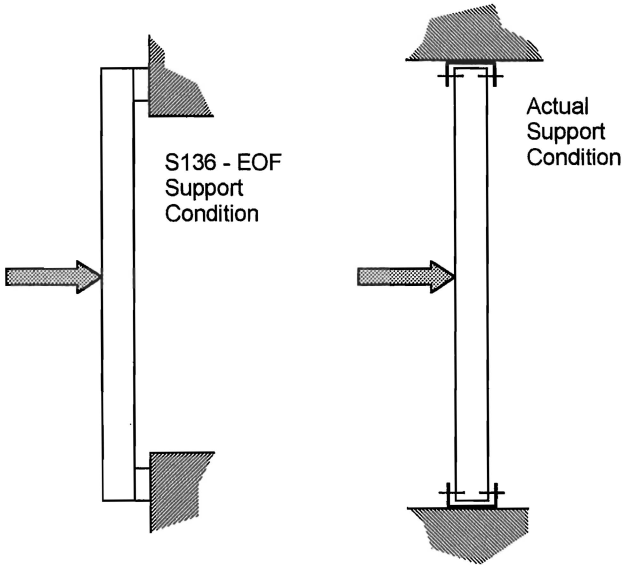

Figure 2: Idealized Web Crippling Compared to Stud-to-Track Connection

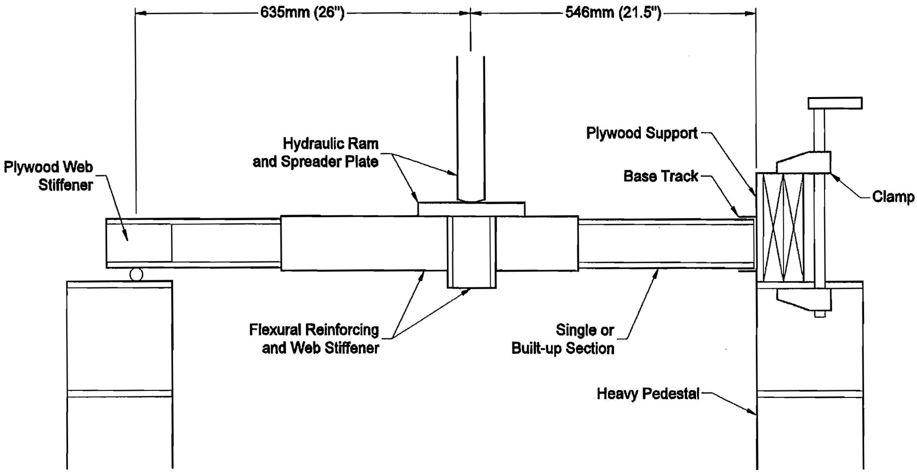

Figure 3: Schumacher and Lewis Test Set-Up [3, 4]

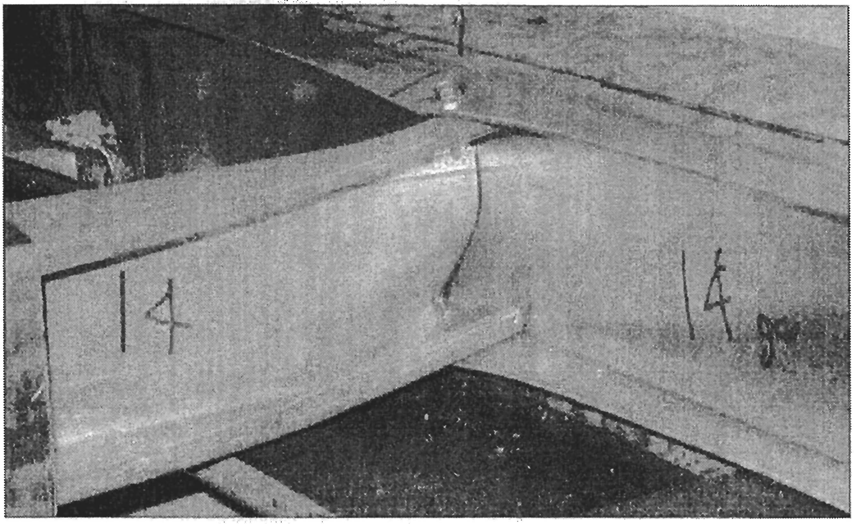

Figure 4: Stud Web Crippling Failure Mode

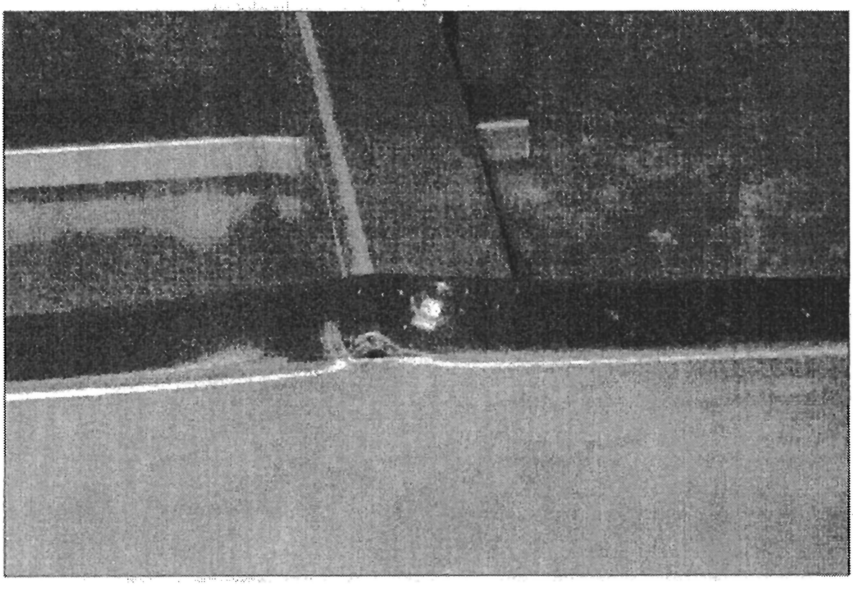

Figure 5: Track Punch-Through Failure Mode