

The Strength of Stiffened CFS Floor Joist Assemblies with Offset Loading

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PREFACE

This report was developed by Dr. Steven Fox for the General Provisions Subcommittee of the AISI Committee on Framing Standards. The objectives of this project were to gain a more thorough understanding of floor joist behavior when there is misalignment in the load path for the range of products and limitations of the AISI *Standard for Cold-Formed Steel Framing - Prescriptive Method for One and Two Family Dwellings*.

This project involved a total of 110 tests of various floor joist assemblies that were carried out to check and compare a wide range of variables. This study confirmed suspicions that offset loading limitations are essential due to the impact that “non-in-line” framing has on strength and serviceability of a steel floor system. The findings provided a basis for the AISI Committee on Framing Standards to modify the AISI *Standard for Cold-Formed Steel Framing - General Provisions* to limit the amount of offset that would be allowed.

Research Team
Steel Framing Alliance

The Strength of Stiffened CFS Floor Joist Assemblies with Offset Loading

Prepared for
American Iron and Steel Institute
Committee on Framing Standards

and

Steel Framing Alliance

by
Steven R. Fox, PhD, P.Eng.
Canadian Cold Formed Steel Research Group
University of Waterloo
Waterloo, Ontario, Canada

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Executive Summary

Described in this report are the results of an experimental investigation into the response of cold-formed steel floor assemblies to variations in the alignment of the components. One of the requirements common in cold-formed steel construction is for “in-line” framing. In-line framing means that the joist, rafter, truss and structural wall stud shall be aligned so that the centerline (mid-width) is within $\frac{3}{4}$ inch of the centerline (mid-width) of the loadbearing members beneath. The $\frac{3}{4}$ inch allowable offset creates the possibility for a misalignment in the load path from an upper story loadbearing stud wall, through a joist with a bearing stiffener and onto a loadbearing stud or foundation wall below. Preliminary testing indicated a significant reduction in capacity under certain alignment conditions, so a more extensive investigation was warranted.

A total of 110 tests of various floor joist assemblies were carried out to check and compare a wide range of variables. The investigation was experimental and consisted of both end- and interior-two-flange loading of typical assemblies. The following are some of the variables considered:

- joist and rim track depth and thickness;
- wall track size and thickness;
- stud and track bearing stiffeners;
- in-line and $\frac{3}{4}$ inch offset loading;
- OSB sub-floor;
- joist bearing width and location.

These are some of the more significant conclusions:

- The $\frac{3}{4}$ inch offset can cause a significant reduction in the strength of the assembly compared to the in-line conditions, and at a capacity lower than what would be predicted for a joist with a bearing stiffener alone.
- Having a thicker wall track or an OSB sub-floor will help distribute the load to the bearing stiffener and increase the strength of an assembly with the offset load path.
- The web crippling and deformation of the rim track affects the loading of the bearing stiffener and can reduce its capacity.
- There can be significant deformation (up to 1 inch) associated with the failure of assemblies with the $\frac{3}{4}$ inch offset loading, more so with the thinner wall tracks and no sub-floor. The *AISI Committee on Framing Standards* may want to consider adopting some serviceability limit states.

Based on the findings of this work a change is recommended to the wording of the *AISI General Provisions Standard* that will limit the amount of offset that is allowed. The proposed wording is as follows:

“Each joist, rafter, truss and structural wall stud shall be aligned so that the centerline (mid-width) is within $\frac{3}{4}$ inch (19 mm) of the centerline (mid-width) of the load bearing members beneath, but not more than 1-5/8 inch from the centerline of the bearing stiffener when one is present.”

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1 Introduction

The AISI Committee on Framing Standards (AISI COFS) has published the *Standard for Cold-Formed Steel Framing – General Provisions* (AISI 2001a). This document gives the requirements for construction with cold-formed steel framing that are common to prescriptive and engineered designs. One of the requirements in the *General Provisions* standard calls for “in-line” framing unless a structural load distribution member is included. In-line framing means that the “joist, rafter, truss and structural wall stud shall be aligned so that the centerline (mid-width) is within $\frac{3}{4}$ inch (19 mm) of the centerline (mid-width) of the load bearing members beneath”.

The research project described in this report was initiated to investigate the response of cold-formed steel floor assemblies to variations in the alignment of the components. Based on the details in the *AISI Standard for Cold-Formed Steel Framing – Prescriptive Method for One and Two Family Dwellings* (AISI 2001b), and the $\frac{3}{4}$ inch allowable offset, there is the possibility for a sizable misalignment in the load path coming from a loadbearing stud above, through the stiffened joist and onto a loadbearing stud or foundation wall below. One such alignment path is illustrated in Figure 1.1.

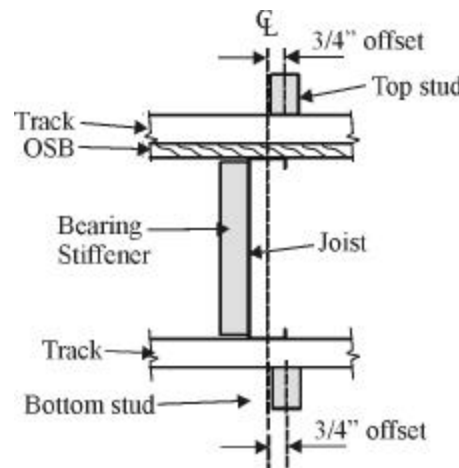


Figure 1.1: Alignment Limits Allowed in the AISI Standards

Preliminary tests on floor joist assemblies carried out at the University of Waterloo (Black et. al., 2002) revealed that there could be a significant reduction in the strength of the assembly with an offset load path such as that shown in Figure 1.1. Based on these findings, it was decided that a more extensive investigation of these assemblies needed to be carried out to determine the actual behaviour, and to define more appropriate alignment rules as needed.

2 Objective

The objective of this project was to gain a more thorough understanding of the behavior of a floor joist assembly when there is misalignment in the load path. The parameters that affect the strength of the assembly (e.g. member sizes) were varied to determine their influence. The variations in the assemblies were within the range of products and limitations defined in the *Prescriptive Method*. The results of this work will be used to propose modifications as necessary to the rules in the *General Provisions* standard for in-line framing limitations.

3 Scope

The scope of the project entailed carrying out a total of 110 tests of various floor joist assemblies to check and compare a wide range of variables. The investigation was experimental and consisted of both end- and interior-two-flange loading of typical floor joist assemblies. The alignment conditions considered are illustrated in Figures 3.1 and 3.2. In all cases the bearing stiffener was attached to the back of the joist and the $\frac{3}{4}$ inch offset was toward the joist flange lip. From the earlier work (Black et. al., 2002) this alignment configuration was determined to be the worst case.

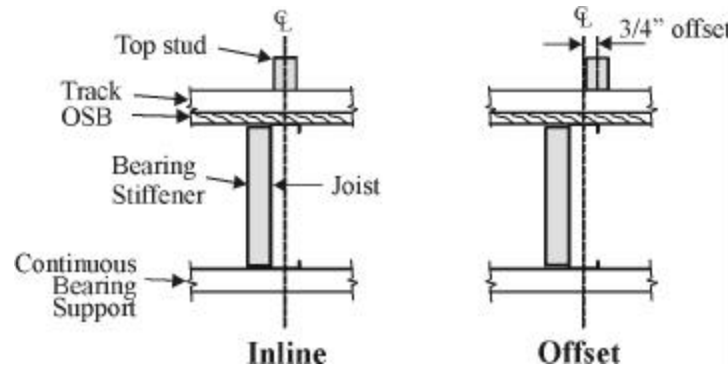


Figure 3.1: Joist Bearing on Foundation Wall

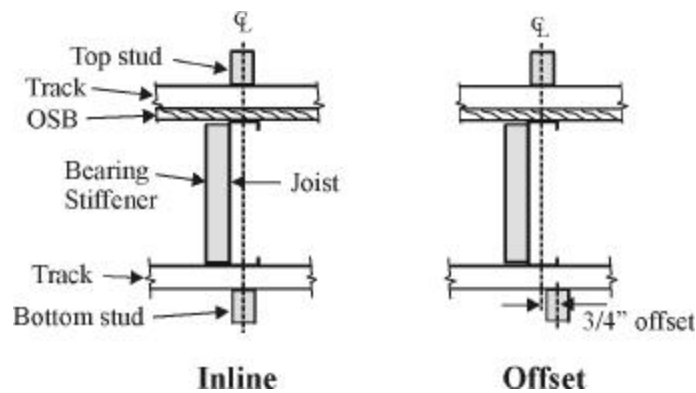


Figure 3.2: Joist Bearing on Loadbearing Wall

4 Test Specimens and Experimental Set-Up

4.1 Test Specimens

The test specimens were 4-foot square sections of a floor assembly constructed in accordance with the requirements of the *Prescriptive Method* (AISI 2001b). The assembly was sufficiently large to allow tests to be conducted at each end of the two interior joists, as well as additional tests at the mid-span of each joist. Six tests could be carried out on each specimen. In all cases the bearing stiffener was attached to the back of the joist web and was cut to the full joist depth. All connections were made with #10 hex head self-drilling screws.

The following is a summary of the range of variables covered:

- joist depth (8, 10 and 12 inches);
- joist thickness (0.037 to 0.097 inches);
- rim track thickness (0.047 to 0.071 inches);
- wall stud and track sizes (3-5/8 and 6 inches);
- wall track thickness (0.033 to 0.075 inches);
- bearing stiffener type (stud and track);
- bearing stiffener thickness (0.033 to 0.047 inches);
- in-line and 3/4 inch offset loading (as illustrated in Figures 3.1 and 3.2);
- sub-floor (19/32 inch OSB);
- joist bearing width (1-1/2 and 3-5/8 inches);
- bearing condition (joist bearing on a foundation wall, a continuous joist on an interior loadbearing stud wall, and a joist bearing on a second floor exterior stud wall).

4.2 Mechanical Properties

Standard tensile coupons were cut from each thickness and type of joist, rim track and bearing stiffener material. The coupons were subjected to standard tensile tests in accordance with ASTM A370. The results are summarized in Table 4.1.

Table 4.1: Mechanical Properties⁽¹⁾

Specimen	Thickness (in.)	Yield Stress F_y (ksi)	Tensile Stress F_u (ksi)	% Elong. ⁽²⁾
Bearing Stiffeners				
362S125-33	0.0320	47.2	53.3	32.3
362S162-36	0.0346	46.9	50.9	36.9
362S162-44	0.0418	33.0	45.0	44.1
362T125-44	0.0425	46.5	51.3	35.7
362S162-48	0.0469	43.5	56.1	28.9
Joists				
800S162-48	0.0465	47.1	55.1	36.4
800S162-75	0.0717	55.8	75.0	31.9
1000S162-36	0.0370	45.1	57.1	31.5
1000S162-54	0.0535	54.1	66.8	24.2
1000S162-97	0.0969	55.4	71.6	13.2
1200S162-54	0.0535	61.2	74.1	25.0
1200S162-97	0.0969	58.6	73.4	16.1
Rim Track				
800T125-48a	0.0465	50.6	55.7	30.7
800T125-48b	0.0459	50.5	59.5	28.3
800T125-75	0.0709	47.4	60.2	31.1
1000T125-48	0.0460	50.5	58.9	29.0
1200T125-48	0.0461	50.3	59.1	29.5

(1) Values are the average of three tests.

(2) Elongation measured over a 2 in. gauge length.

4.3 Test Set-Up

Shown in Figure 4.1 is the set-up and specimen used for a second floor condition test. The assembly is inverted from what would be the actual construction (as shown in Figure 3.2) to simplify the experimental set-up. The specimen rested on a continuous bearing surface (track and sill plate). The continuous bearing simulates the load distribution offered by the sub-floor (not present in these tests), and ensures that the failure would occur be at the point of load application. The objective was to study the behaviour of the joist where it rests on the loadbearing stud wall below.

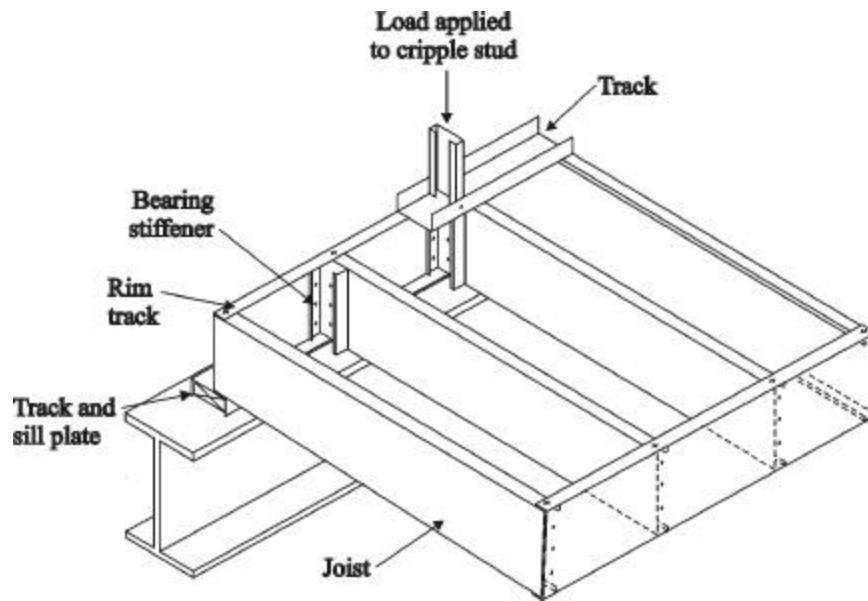


Figure 4.1: Test Configuration for a 2nd Floor Joist

Shown in Figure 4.2 is the set-up for testing a floor assembly resting on the foundation. In this case the failure will occur at the top of the joist, and the sub-floor will contribute to the strength of the assembly. The photograph in Figure 4.3 shows the test set-up for an end-loading test specimen, and the photograph in Figure 4.4 shows the test set-up for an interior loading condition. The interior loading simulates a continuous floor joist over an interior support.

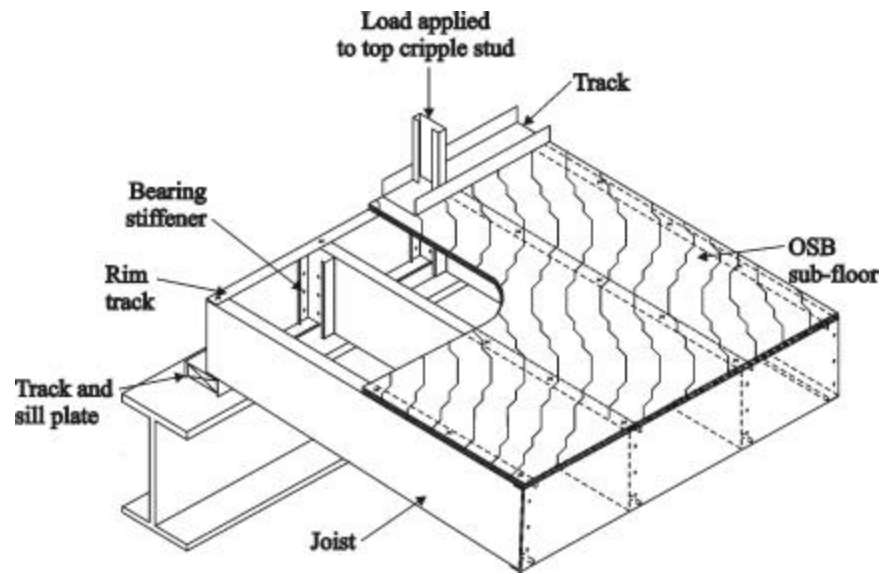


Figure 4.2: Test Configuration for a Joist on a Foundation



Figure 4.3: Photograph of the Test Set-Up for an End Loading

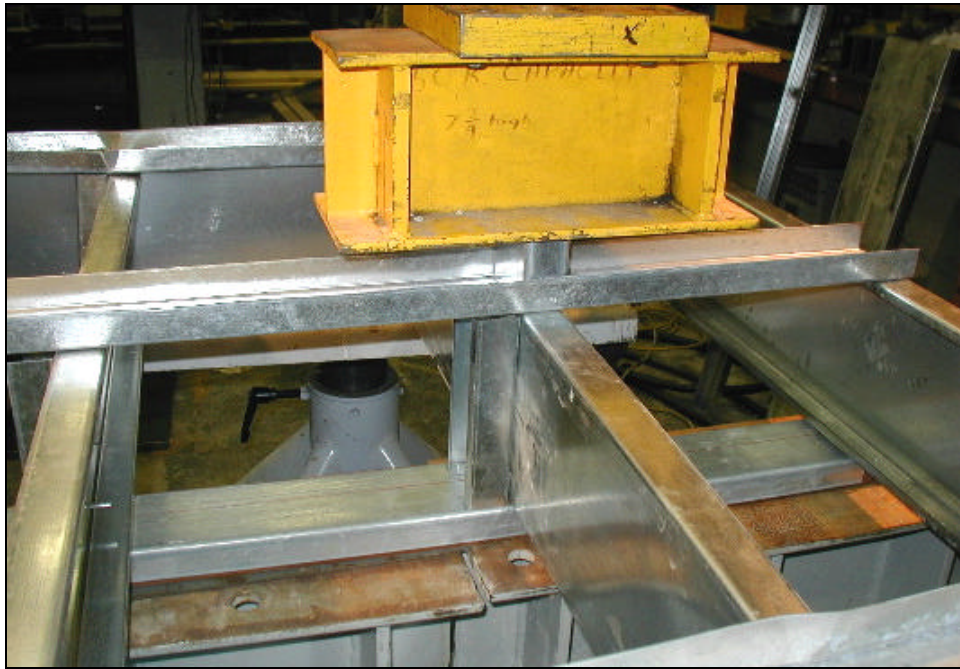


Figure 4.4: Photograph of the Test Set-Up for an Interior Loading

5 Discussion of Test Results

5.1 Test Results

A total of 110 tests were carried out. The results are summarized in Tables A1 through A7 of Appendix A. The tables have been colour coded to help interpret the results. The colour coding corresponds to the thickness of the component. The thickness used in the section designator is the nominal thickness. The mechanical properties of the various components are given in Table 4.1.

5.2 Failure Modes

In general there were two basic failure modes: excessive deformation and bearing stiffener failure. The photograph in Figure 5.1 illustrates a failure accompanied by excessive deformation. There are a number of variables that will lead to this type of failure. These variables include:

- When the applied load is offset from the centerline of the joist (as illustrated in Figure 5.1) the load is transferred through the joist flange. This cantilevered element will rotate and contribute significantly to the deformation. If the load is applied in-line with the joist, the bearing stiffener will carry more of the applied load and restrain the deformation.
- The thickness of the wall track influences the deformation. The thicker the track, the more load sharing and the less deformation at failure.
- If there is a sub-floor present (simulating the ground floor location) the deformation will also be reduced.
- The lower the joist and rim track web slenderness ratios, the less deformation there will be at failure.

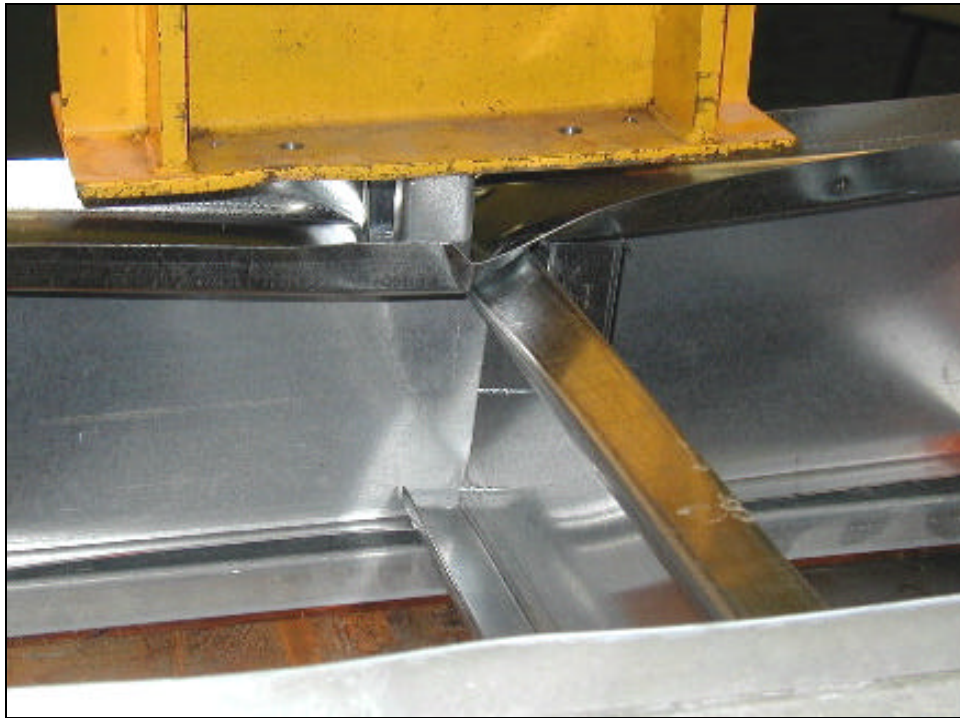


Figure 5.1: Photograph of Failure due to Excessive Deformation

The second common mode of failure was of the bearing stiffener. In those situations where excessive deformation was not the primary cause of failure, the assembly was stiff enough that the load was transferred through the bearing stiffener, which eventually would fail in some form of local buckling. The photograph in Figure 5.2 illustrates a case where the bearing stiffener failed. The bearing stiffener would fail in a number of different ways depending on the size of the components in the assembly. Typically, when the stiffener failed it was local buckling of one of the flanges, at either the upper or lower ends. In some situations, however, the failure of the stiffener was precipitated prematurely by the buckling of the rim track. When the rim track depth increased (e.g. up to 12 inch), and the stiffener was small (362S125-33) the stiffener was not strong enough to restrain the rim track from buckling (web crippling). Consequently, the rim track would pull the flange of the stiffener out of plane and precipitate the failure. This case is illustrated in Figure 5.2. In many cases the fasteners connecting the rim track to the stiffener pulled out of the stiffener.



Figure 5.2: Photograph of a Stiffener Failure

Another type of failure was punch-through of the sub-floor in those tests where the assembly included a sub-floor under the wall track. This type of failure is illustrated in the photograph in Figure 5.3 and only occurred when the load was offset from the joist and the track was thin (i.e. 33 mil). If the track was thick enough to distribute the load, or the load was in-line with the joist, failure occurred in the bearing stiffener without excessive deformation.



Figure 5.3: Photograph of a Punch-Through Failure of the OSB

5.3 Load-Deflection Characteristics

The graph shown in Figure 5.4 provides load-versus-deflection plots for three representative tests. Comparing these three plots illustrates a number of features of the behaviour of these assemblies:

- The in-line, end test has a higher stiffness than the other two tests as indicated by the steeper slope in the curve. This is expected since the load is applied closer to the bearing stiffener and there is less resulting deformation.
- The interior test has a lower ultimate load than the end test. Even though the web crippling capacity of the joist at an interior location is greater than the end, the interior location does not have the added capacity associated with the rim track.
- The deflection at the ultimate load for both the tests with the $\frac{3}{4}$ inch offset is considerably more than the in-line test. This is to be expected based on the failure modes discussed in the previous section.

All of the load-deflection curves recorded are provided in Appendix B. The test data listed in Tables A1 through A7 of Appendix A also includes the deflection at the ultimate load. The series of photographs in Figures 5.5 through 5.8 show the stages of the deformation. These photos can be used to assess how significant a certain deformation is visually, which may be useful for setting serviceability limit states in the future.

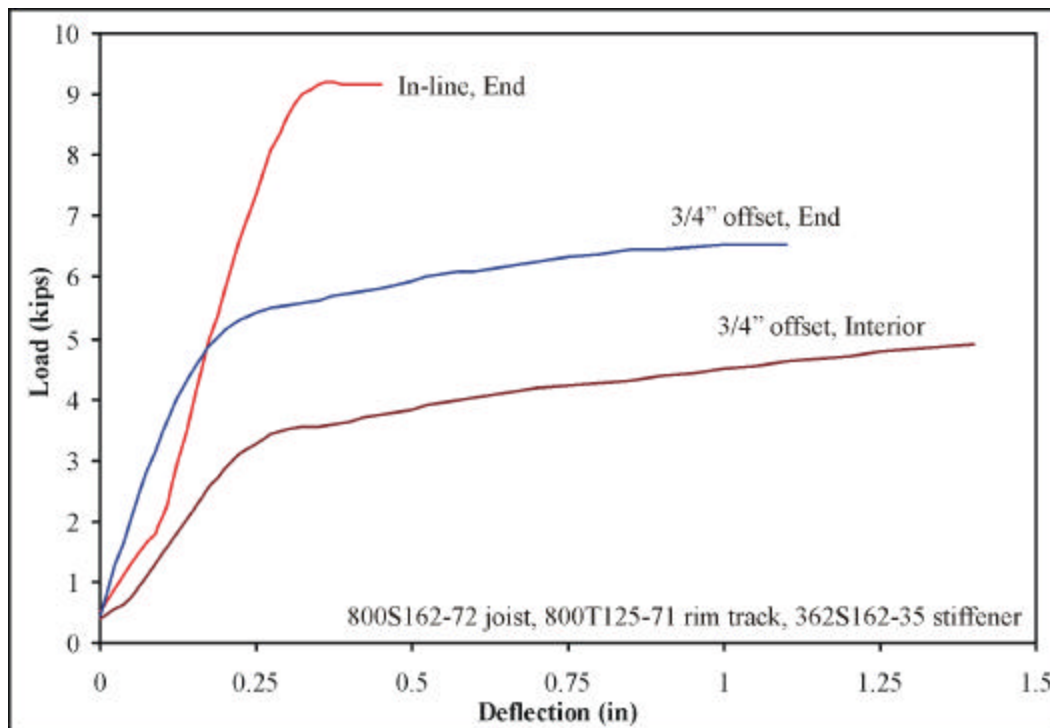


Figure 5.4: Typical Load versus Deflection Plots

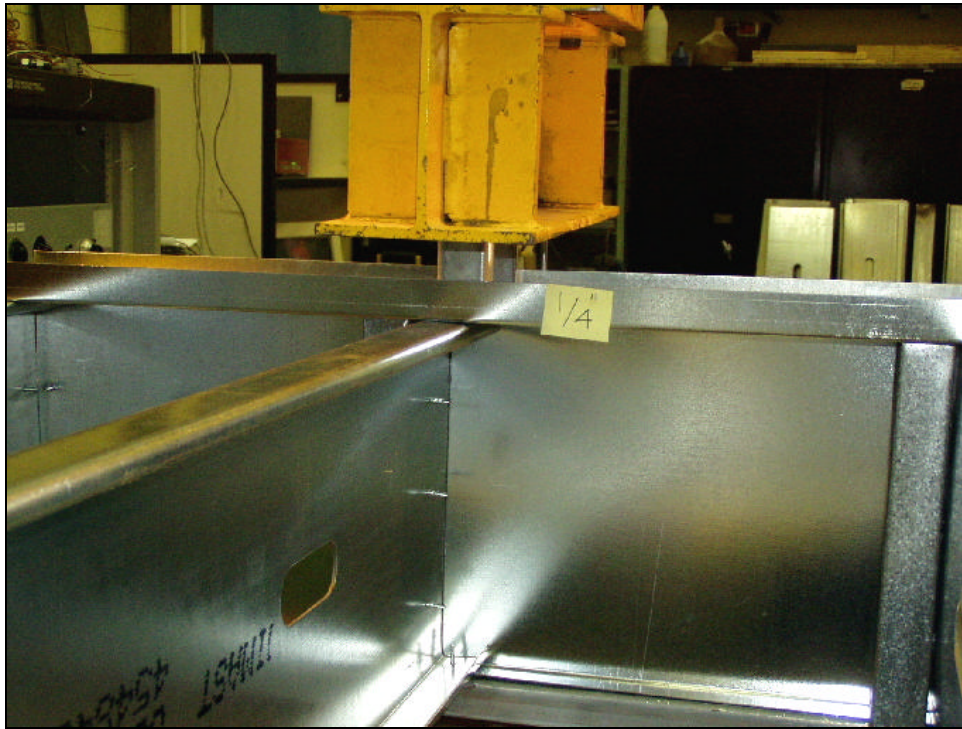


Figure 5.5: Photograph of the Deformation at $\frac{1}{4}$ " Deflection (Offset Loading)



Figure 5.6: Photograph of the Deformation at $\frac{1}{2}$ Deflection (Offset Loading)

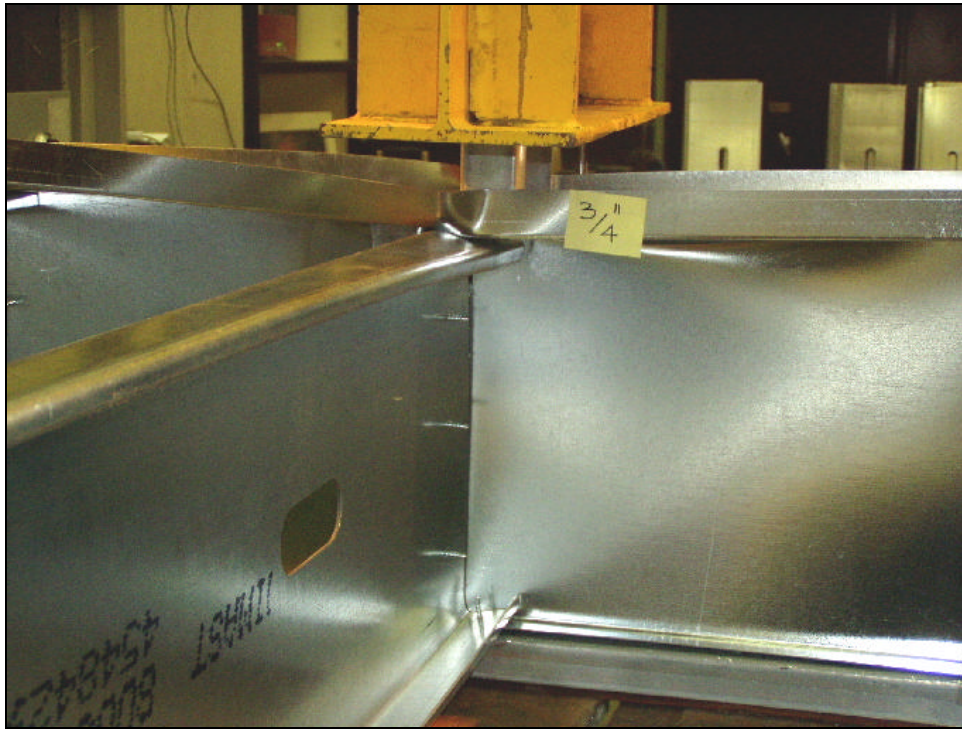


Figure 5.7: Photograph of the Deformation at $\frac{3}{4}$ " Deflection (Offset Loading)



Figure 5.8: Photograph of the Deformation at 1" Deflection (Offset Loading)

6 Analysis of Results

6.1 Predictor Equations

The data that has been collected and reported in the previous sections describes how the floor joist assemblies behave, but it is also necessary to determine whether any of these configurations fall below the required or predicted strength levels. This project has used the *AISI Prescriptive Method* (AISI 2001b) as the basis for determining the assemblies to be tested, however, the stiffener alignment issue is not limited to a prescriptive design but applies to all cold-formed steel framing falling under the *General Provisions* standard (AISI 2001a).

There are two comparisons that could be made based on either the *Prescriptive Method* or an engineered design. These would be:

1. Compare the tested capacities to the strength of a 33 mil thick C-section stud or 42 mil track stiffener as specified in the *Prescriptive Method*; or,
2. Compare the tested capacities to the strength of the stiffened joist based on currently accepted design provisions.

Alternative 1 would be acceptable if the application of this work was only limited to the *Prescriptive Method*. This assumes that the minimum bearing stiffener requirement in the *Prescriptive Method* is adequate for all building configurations allowed: an assumption that has not been verified. Alternative 2 is the preferred approach since the tested capacities can be compared to a predicted capacity that recognizes some of the components in the assembly (e.g. joist and stiffener sizes). The predictor equation to be used for the comparison is that proposed by the author (Fox 2002) for determining the strength of a cold-formed C-section joist with a stud or track type bearing stiffener attached. This predictor does not include the other components in the assembly such as the rim track and sub-floor, but there is currently no other predictor method that would apply.

The AISI Committee on Specifications has accepted (July 2003) a ballot that would add design provisions for stud and track type bearing stiffeners based on the work by the author. The following is the ultimate strength predictor equation for the two-flange loading of C-section members with stud or track bearing stiffeners:

$$P_n = 0.7(P_{wc} + A_e F_y) \quad (\text{Eq. 6.1})$$

Where,

- A_e = effective area of bearing stiffener subjected to uniform compressive stress equal to the yield stress, calculated in accordance with the NA Specification
- F_y = yield strength of stiffener steel
- P_{wc} = web crippling strength for C-section joist calculated in accordance with the NA Specification for single web members, end or interior locations

The design expression currently used in the NA Specification (AISI 2001c) for determining the nominal web crippling capacity is:

$$P_{wc} = C t^2 F_y \left(1 - C_R \sqrt{R/t}\right) \left(1 + C_N \sqrt{N/t}\right) \left(1 - C_H \sqrt{h/t}\right) \quad (\text{Eq. 6.2})$$

Where,

- C = web crippling coefficient (see Table 6.1)

- C_H = web slenderness coefficient (see Table 6.1)
 C_N = bearing length coefficient (see Table 6.1)
 C_R = inside bend radius coefficient (see Table 6.1)
 F_y = yield strength of material
 h = flat dimension of web measured in plane of web
 N = bearing length
 R = inside bend radius
 t = thickness of web

Table 6.1: Web Crippling Equation Coefficients
(Single web C-section, stiffened flanges, two-flange loading)

Configuration		C	C_R	C_N	C_h
Fastened to Support	End	7.5	0.08	0.12	0.048
	Interior	20	0.10	0.08	0.031
Unfastened	End	13	0.32	0.05	0.04
	Interior	24	0.52	0.15	0.001

The test results have been compared to the strength predicted using Equation 6.1. These test-to-predicted ratios provide a type of normalized basis for comparing different assemblies. The specific data is provided in Appendix C. Presented in the following sections are comparisons that describe the influence of the various parameters on the capacity of the assemblies.

6.2 Comparisons

6.2.1 Effect of Wall Track Thickness

One of the significant parameters that affects the strength of the assembly was found to be the thickness of the wall track. The data plotted in Figures 6.1 and 6.2 illustrates the significance of this variable. The following insights can be drawn from these two plots:

- The trend line for the in-line tests is not affected significantly by the wall track thickness. Failure of the in-line tests is typically associated with some form of local buckling in the stiffener. Consequently, the wall track and OSB sub-floor (if present) should not contribute significantly to the strength of the assembly since the load is already being transferred directly into the stiffener and the load distribution by the wall track is not necessary.
- The track thickness has a significant influence on the strength of the offset tests as indicated by the trend line for these tests. The load sharing caused by the thicker track will reduce the deformation of the assembly, increase the load transferred to the stiffener and increase the strength of the assembly.
- The influence of the track thickness is more pronounced for the interior tests than the end tests. This is logical since the end tests have the rim track that would also stiffen the assembly, whereas this component is not present in the interior tests making it more susceptible to misalignments in the load path.

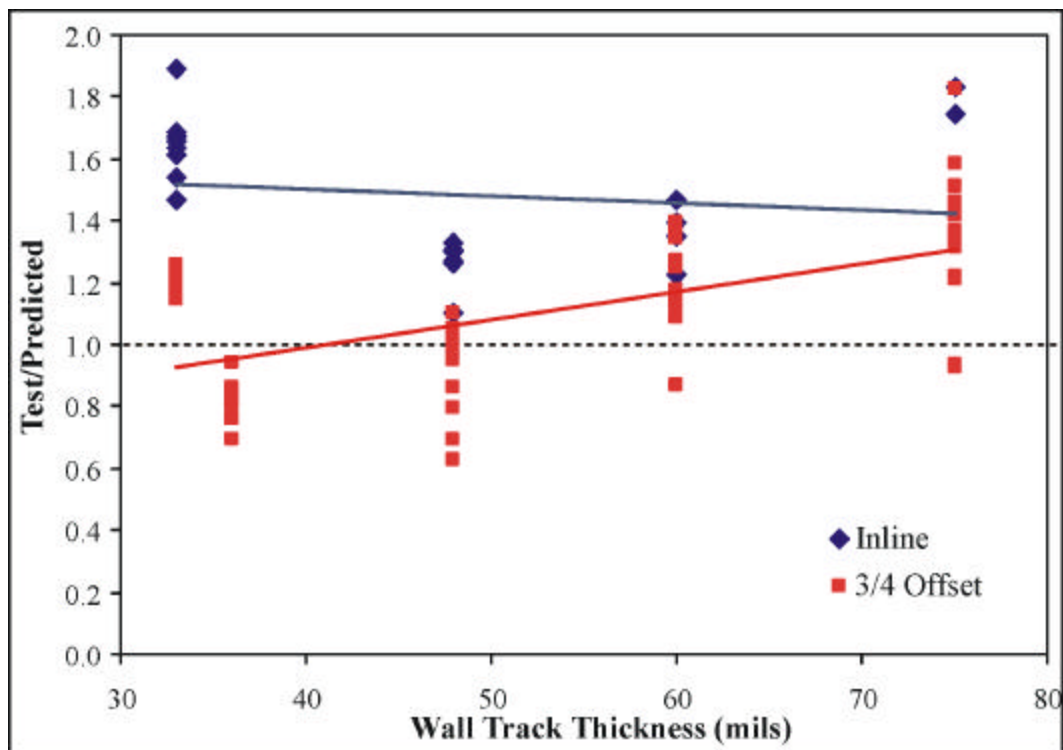


Figure 6.1: Effect of Wall Track Thickness on Joist End Tests

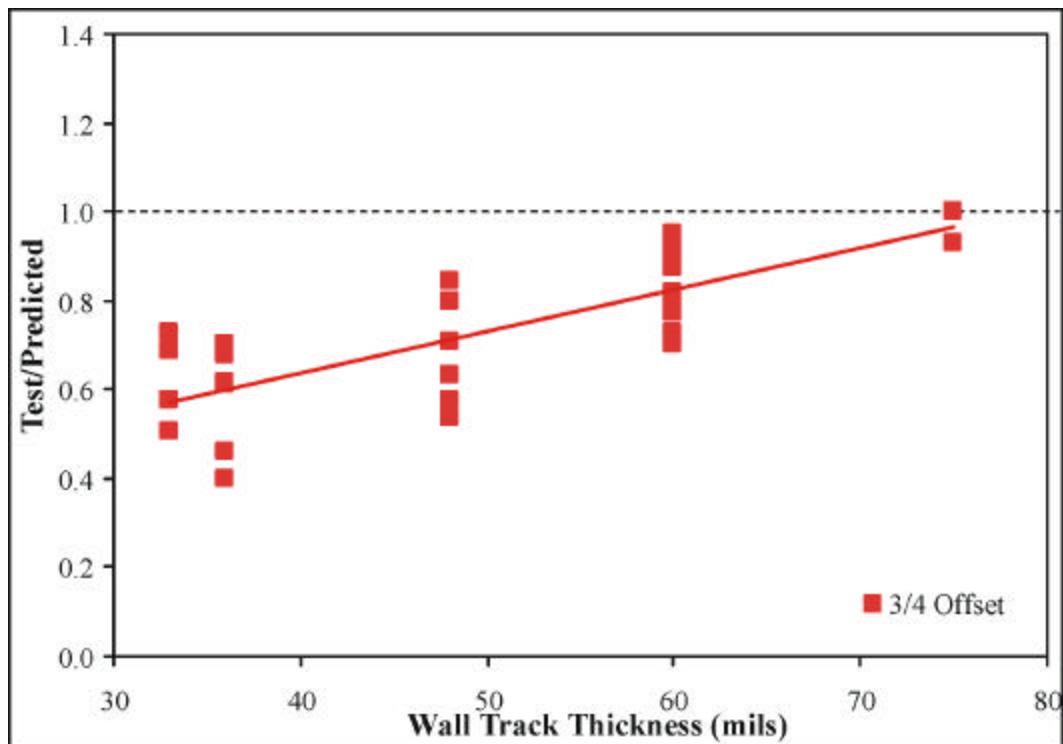


Figure 6.2: Effect of Wall Track Thickness on Joist Interior Tests

6.2.2 Effect of Joist Web Slenderness

The test results indicate that the capacity of the assembly is affected by the web slenderness ratio or depth of the joist. The data shown in Figures 6.3 and 6.4 illustrate the significance of this parameter on the strength of the assembly. The following insights can be drawn from these two plots:

- The data shown in Figure 6.3 indicates that the test-to-predicted ratios decrease as the web slenderness increases. The predicted capacity assumes that the bearing stiffener acts as a short stub-column. However, as the web depth increases the rim track pulls on the stiffener through the connecting fasteners and may cause it to failure at a lower load. The photograph in Figure 5.2 illustrates this behaviour. The same relationship holds true if the data is plotted against the joist depth or the web slenderness of the rim track.
- The interior assemblies are less sensitive to the increase in web slenderness compared to the end tests. This would support the proposition that the reduction in capacity is a function of the rim track pulling on the bearing stiffener.

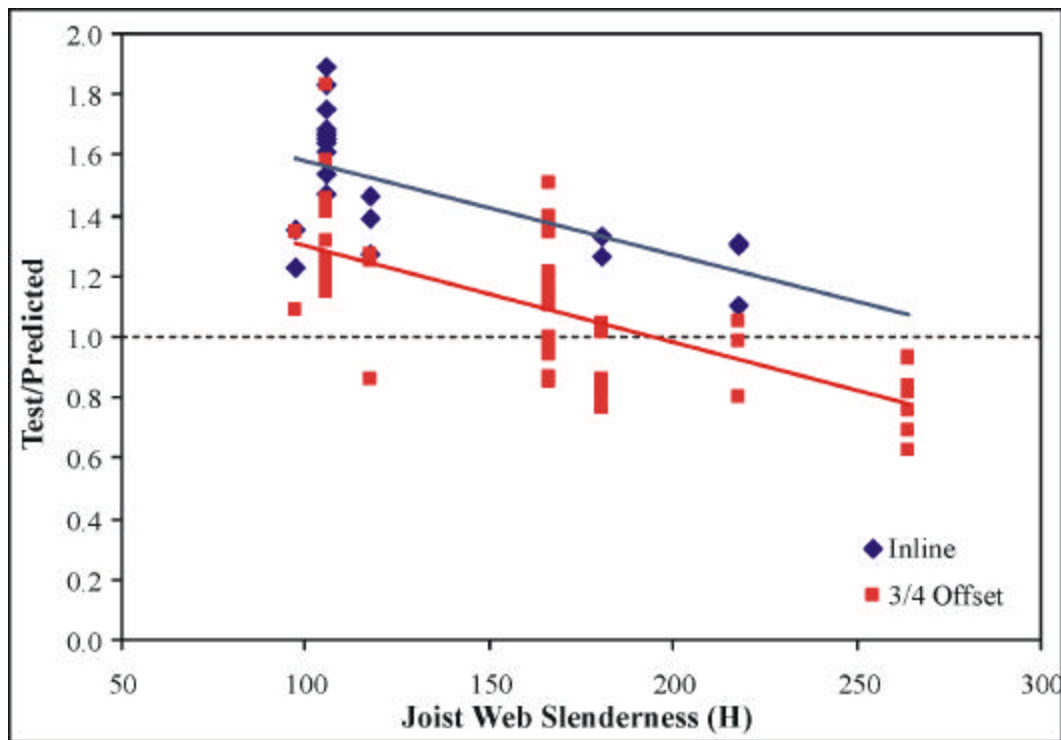


Figure 6.3: Effect of Joist Web Slenderness on Joist End Tests

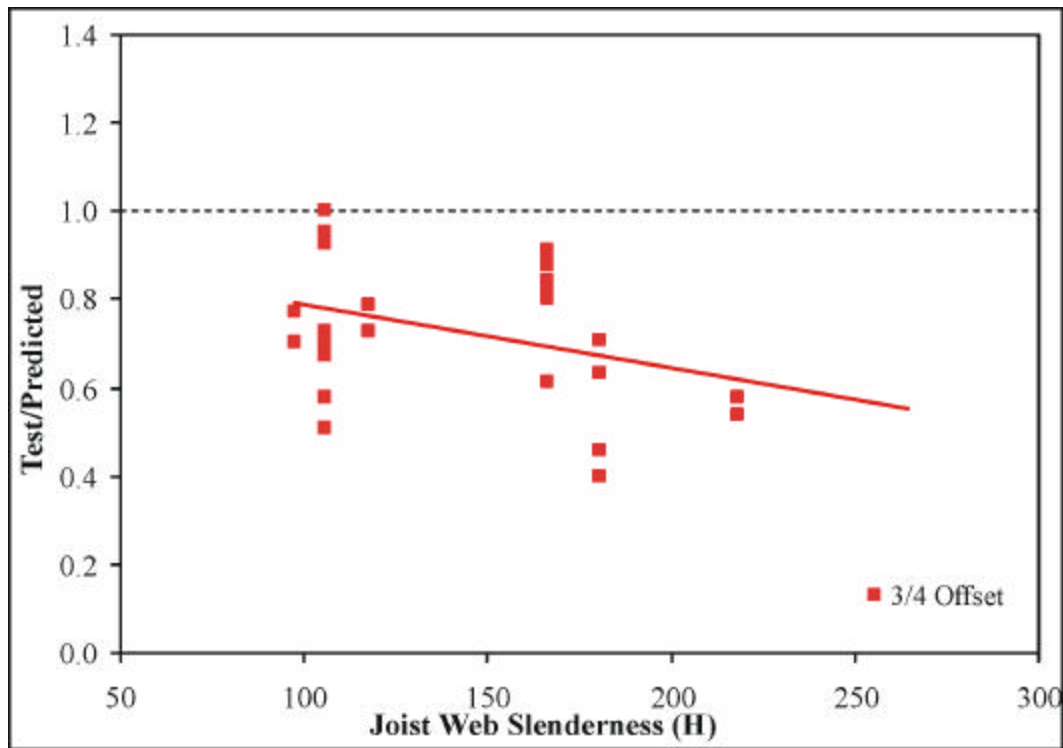


Figure 6.4: Effect of Joist Web Slenderness on Joist Interior Tests

6.2.3 *Effect of 3/4" Offset*

Comparing the trend lines provided in Figures 6.1 and 6.3 illustrates the effects of the 3/4 inch offset on the strength of the assembly. This result is not surprising since the offset load path is expected to influence the behaviour. Depending on the size of the components in the assembly, there are many assemblies with a 3/4 inch offset that still have a tested strength greater than what would be predicted by the NA Specification (AISI 2001c). If some limitations could be placed on the other components (i.e. wall track thickness) then the 3/4 inch offset could be allowed. However, without these controls, some limitation needs to be placed on the offset to prevent a failure at a load less than would be predicted by an engineered design.

6.2.4 *Interior versus End Loading Conditions*

The interior loading cases have a significantly lower ultimate load than the ends. This is logical since the rim joist contributes to the strength at the end, which is not present to the interior. The data presented in Table 6.2 supports this position, although there is insufficient data to develop a predictor expression.

Table 6.2: Interior versus End Loading Conditions

Test No.	Joist	Rim Track	Stiffener	Wall Track	Offset	Avg. Failure Load (kips)	Difference
1-2	800S162-48	800T125-48b	362S162-36	362T125-36	3/4" off	4.23	-21%
43-44	800S162-48	N/A (Interior)	362S162-36	362T125-36	3/4" off	3.35	
3-6	800S162-48	800T125-48b	362S162-36	362T125-48	3/4" off	4.76	-6%
49-50	800S162-48	N/A (Interior)	362S162-36	362T125-48	3/4" off	4.48	
7-12	800S162-48	800T125-48a	362S162-36	362T125-57	3/4" off	5.57	-14%
45-48	800S162-48	N/A (Interior)	362S162-36	362T125-57	3/4" off	4.79	
17-21	800S162-75	800T125-75	362S162-36	362T125-33	In-line	9.02	-22%
51-52	800S162-75	N/A (Interior)	362S162-36	362T125-33	In-line	7.03	
23-28	800S162-75	800T125-75	362S162-36	362T125-33	3/4" off	6.52	-25%
53-56	800S162-75	N/A (Interior)	362S162-36	362T125-33	3/4" off	4.90	
31-32	800S162-75	800T125-75	362T162-44	362T125-33	3/4" off	6.60	-42%
57-58	800S162-75	N/A (Interior)	362T162-44	362T125-33	3/4" off	3.86	
33-34	800S162-75	800T125-48b	362S162-36	362T125-75	3/4" off	7.17	-6%
41-42	800S162-75	N/A (Interior)	362S162-36	362T125-75	3/4" off	6.77	

6.2.5 Effect of Bearing Width

The majority of the end location tests were constructed so that the bearing of the joist onto the supporting frame had 1-1/2 inch bearing width. This spacing was chosen because it is the minimum bearing width allowed by the *Prescriptive Method* (AISI 2001b). For the tests simulating a joist on a foundation, this 1-1/2 inch bearing is a reasonable dimension. For the tests simulating the 2nd floor joist, the 1-1/2 inch bearing is conservative since in reality these floor joists would be resting on a loadbearing wall below that would be at least as wide as the wall studs. Listed in Table 6.3 are the results of tests carried out to check on the significance of the bearing width on the capacity of the assembly. From this data it does not appear that there is a significant, consistent influence of bearing width on the capacity. The results are within the experimental error expected in this type of research.

Table 6.3: Effect of Bearing Width

Test No.	Joist	Rim Track	Stiffener	Wall Track	Bearing Width	Avg. Failure Load (kips)	Difference
33-34	800S162-75	800T125-48b	362S162-36	362T125-75	1.5	7.17	+9%
35-36	800S162-75	800T125-48b	362S162-36	362T125-75	3.625	7.85	
103-104	1200S162-97	1200T125-48	362S162-44	362T125-75	1.5	8.30	-5%
105-106	1200S162-97	1200T125-48	362S162-44	362T125-75	3.625	7.92	

6.2.6 Effect of Fastening Joist to Support

One of the factors that can influence the web crippling behaviour of a member is whether the flanges are fastened to the support. The data provided in Table 6.4 shows a comparison of tests fastened to the support and not. In one test there was a significant increase in capacity, but not in the other cases. The lower values in tests 9-10 could have been the result of experimental error or some other unrecognized influence. While there will probably be some influence on the capacity of the assembly by fastening the member to the support, the effect should not significantly affect the validity of the interpretation of these results. Of the 80 end location tests carried out, 28 tests were not fastened to the support, and the remainder were fastened. None of the interior location tests were fastened to the support.

Table 6.4: Effect of Fastening to Support

Test No.	Joist	Rim Track	Stiffener	Wall Track	Fastened	Avg. Failure Load (kips)	Difference
13-14	800S162-48	800T125-48b	362S162-36	362T125-75	No	6.41	+0%
15-16	800S162-48	800T125-48b	362S162-36	362T125-75	Yes	6.42	
9-10	800S162-48	800T125-48b	362S162-36	362T125-60	No	4.33	+24%
11-12	800S162-48	800T125-48b	362S162-36	362T125-60	Yes	5.39	

6.2.7 Effect of OSB Sub-Floor

Adding the OSB sub-floor is expected to increase the capacity of the assembly, and the results shown in Table 6.5 seem to confirm this. These results could be over-estimating the impact since only one stud in the assembly is loaded. If all adjacent studs were loaded simultaneously, the significance of the OSB may be reduced. The data plotted in Figure 6.5 also shows that the assemblies with the thinner wall track sections and a $\frac{3}{4}$ inch offset can still give tested capacities below the predicted even with the sub-floor.

Table 6.5: Effect of OSB Sub-Floor

Test No.	Joist	Rim Track	Stiffener	Wall Track	OSB	Avg. Failure Load (kips)	Difference
93	1200S162-97	1200T125-48	362S162-44	362T125-48	No	5.88	+19%
99-100	1200S162-97	1200T125-48	362S162-44	362T125-48	Yes	7.01	

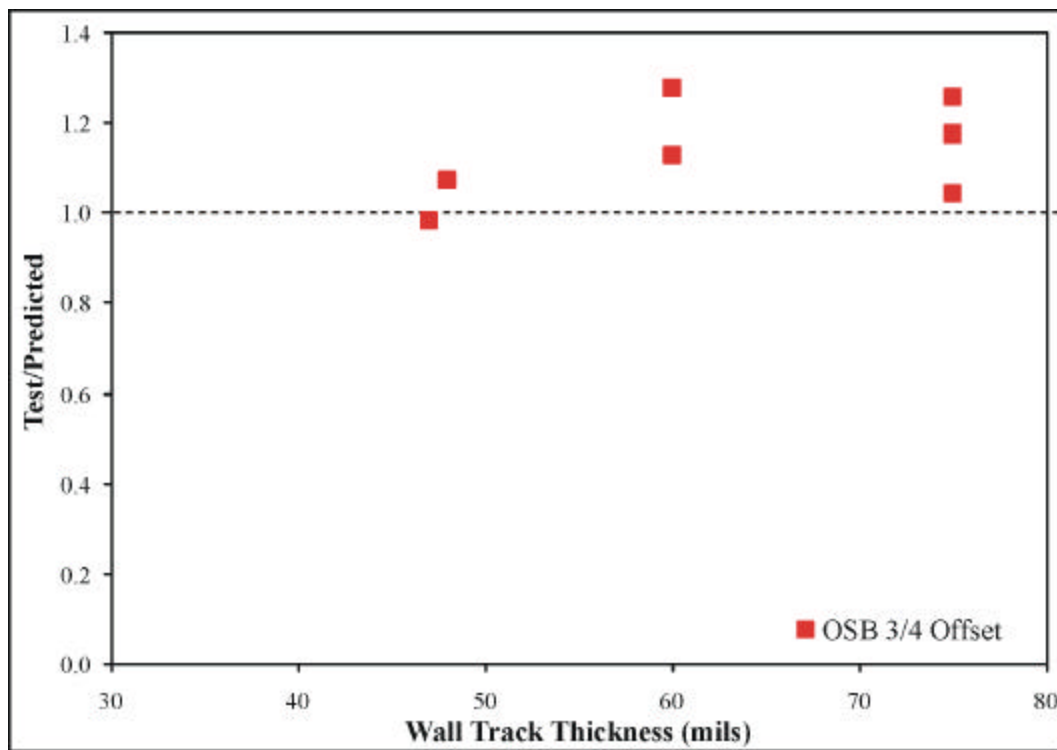


Figure 6.5: Effect of Wall Track Thickness with OSB Sub-Floor

6.2.8 Effect of Double Stud Offset

For the 2nd floor configuration there is the possibility that both the upper and lower wall studs could be offset by $\frac{3}{4}$ inch. Two sets of tests were carried out to determine if this had a significant impact on the strength of the assembly. The test results presented in Table 6.6 shows that there is some loss in capacity with the double offset, but not a large amount. This configuration will actually not occur in practice because there will always be some type of sub-floor under the upper story wall stud that will distribute the load. Consequently, the weakest point will be the lower stud location, which was the configuration used in the majority of the tests.

Table 6.6: Effect of Double Offset

Test No.	Joist	Rim Track	Stiffener	Wall Track	Offset	Avg. Failure Load (kips)	Difference
63-64	1000S162-36	1000T125-48	362S162-36	362T125-36	Single	3.60	-5%
61-62	1000S162-36	1000T125-48	362S162-36	362T125-36	Double	3.43	
69-70	1000S162-54	1000T125-48	362S162-36	362T125-36	Single	4.13	-6%
71-72	1000S162-54	1000T125-48	362S162-36	362T125-36	Double	3.88	

6.2.9 Behaviour of 6" Wall Stud

There are many applications where a 6 inch wall stud bears on a floor joist with a 3-5/8 inch bearing stiffener. A total of six tests were carried out (test numbers 73-76, 83-84) to determine if these assemblies behaved in any way different. A comparison between the 6 inch and 3-5/8 inch wall studs

are given in Table 6.7. This data shows a slight increase in capacity for the 6 inch wall studs, which is likely due to the increased load-distribution from the wider track. During the tests these assemblies did not behave differently than the 3-5/8 inch specimens.

Table 6.7: Effect of 6" Wall Studs

Test No.	Joist	Rim Track	Stiffener	Wall Track	Offset	Avg. Failure Load (kips)	Difference
69-70	1000S162-54	1000T125-48	362S162-36	362T125-36	$\frac{3}{4}$ off	4.13	+8%
75-76	1000S162-54	1000T125-48	362S162-33	600T125-36	$\frac{3}{4}$ off	4.47	

6.3 Serviceability Limit State

One of the factors that became apparent during the testing was the deformation associated with failure. The values provided in Table 6.8 are the average measured deformations at failure for the different types of tests. This gives some indication of the deflections that occurred. The photographs provided in Figures 5.5 to 5.8 show how significant these deformations are visually. There is insufficient data to develop explicit deformation limits, nor is there enough data to be able to predict the deformation associated with service loads. However, if some restriction is placed on the amount of offset, this will have the advantage of reducing the deformations to a maximum value less than 0.75 inches. This order of magnitude would probably be acceptable as a serviceability limit state. Additional research would be needed to form a more specific recommendation. It would be worthwhile computing the design load for typical 8-foot wall studs and comparing these loads to the capacity of a typical stiffened assembly. It might show that the range of loads these assemblies would experience in service is well below the loads where significant deformation would occur.

Table 6.8: Average Deformation at Failure

Configuration	Avg. Deformation at Failure (in.)
End, In-line	0.62
End, $\frac{3}{4}$ offset	0.89
Interior, $\frac{3}{4}$ offset	1.02
End, $\frac{3}{4}$ offset with OSB	0.89

7 Conclusions and Recommendations

The following summarizes the conclusions resulting from the behaviour of the assemblies as they were tested and the comparisons of the various test results.

- The $\frac{3}{4}$ inch offset can cause a significant reduction in the strength of the assembly compared to the in-line conditions, at a capacity less than what would be predicted for a joist with a bearing stiffener.
- Some form of load distribution is necessary if there is an offset in the load path. This load sharing can come from a thicker track or OSB sheathing.

- The assembly is made up of a number of components that all influence the strength and behaviour of the collection (e.g. joist size, rim track size, sub-floor, wall track thickness, offset). In addition, for each variable, there are many variations (e.g. depth, thickness and yield strength of the joist). Given the large number of possible combinations of variables, developing a predictor equation for the strength of the assembly would require extensive testing beyond the scope of this current project. Consequently, it is proposed that a conservative design approach be used which is to determine the requirements of the assembly so that the capacity exceeds the strength calculated for a stiffened floor joist based on the AISI Specification (AISI 2001c).
- The test-to-predicted ratios provided in Table C1 vary between 0.44 and 1.50. A scatter this large would generally raise questions about the validity of the predictor method. It must be remembered that in this work a predictor equation is not being proposed to calculate the strength of these stiffened assemblies. The predicted capacities are for the stiffened joist alone and are only being used to identify trends in the data. Consequently, a large scatter is expected and justifiable.
- There can be significant deformation associated with the ultimate capacity of the assemblies, particularly with load applied at the $\frac{3}{4}$ inch offset. The thickness of the loadbearing wall track is significant to the deformation behaviour of the assembly. If the track is thin (i.e. 33 mil) the failure is often accompanied by excessive deformation under the load. When the wall track is thicker it will spread the load more and the subsequent failure of the assembly is caused by a failure of the bearing stiffener.
- It would be worthwhile computing the design load for typical 8-foot wall studs and comparing these loads to the capacity of a typical stiffened assembly. It might show that the range of loads these assemblies would experience in service is well below the loads where significant deformation would occur.
- The interior location is more sensitive to the offset in the load path than the end location since there is no rim track to help distribute the load.
- Fastening the floor joist to the support, increasing the bearing width, using a 6 inch wall stud, and having a double stud offset all have only a small impact on the strength of the assembly.

Based on the results and conclusions presented in this report, the following recommendations are put forward:

- The $\frac{3}{4}$ inch offset needs to be limited in those assemblies where the bearing stiffener is attached to the back of the joist. In this case, the framing should not be allowed to be offset from the centerline of the joist towards to the joist flange lips. If the bearing stiffener is attached between the joist flanges, the current $\frac{3}{4}$ inch offset limits would be satisfactory.
- Review the PM and determine if the minimum bearing stiffener requirements are appropriate for all building configurations and load cases.

8 Recommended Change to the AISI General Provisions Standard

Based on the conclusions presented in the preceding section, the AISI *General Provisions* (AISI 2001a) needs to be revised to limit the offset in those cases when the bearing stiffener is attached to the back of the joist. The wording provided below should accomplish this and provide an assembly with a capacity that is at least equal to what would be predicted of a stiffened joist. A 1-5/8 inch maximum offset is based on the center-to-centre distance between a stiffener with 1-5/8 inch flanges and a joist with 1-5/8 inch flanges. A track stiffener, or a stud stiffener with 1-1/4 inch flanges, would have an

offset between the center of the joist and the loadbearing stud of 3/16 inch: a tolerance that should be acceptable.

C1 In-Line Framing

Each joist, rafter, *truss* and structural wall *stud* shall be aligned so that the centerline (mid-width) is within 3/4 inch (19 mm) of the centerline (mid-width) of the load bearing members beneath, but not more than 1-5/8 inch (41 mm) from the centerline of the bearing stiffener when one is present, per Figure C1-1. The ~~3/4 inch (19 mm) maximum~~ alignment tolerance is not required when a structural load distribution member is specified in accordance with an *approved* design or a recognized design standard.

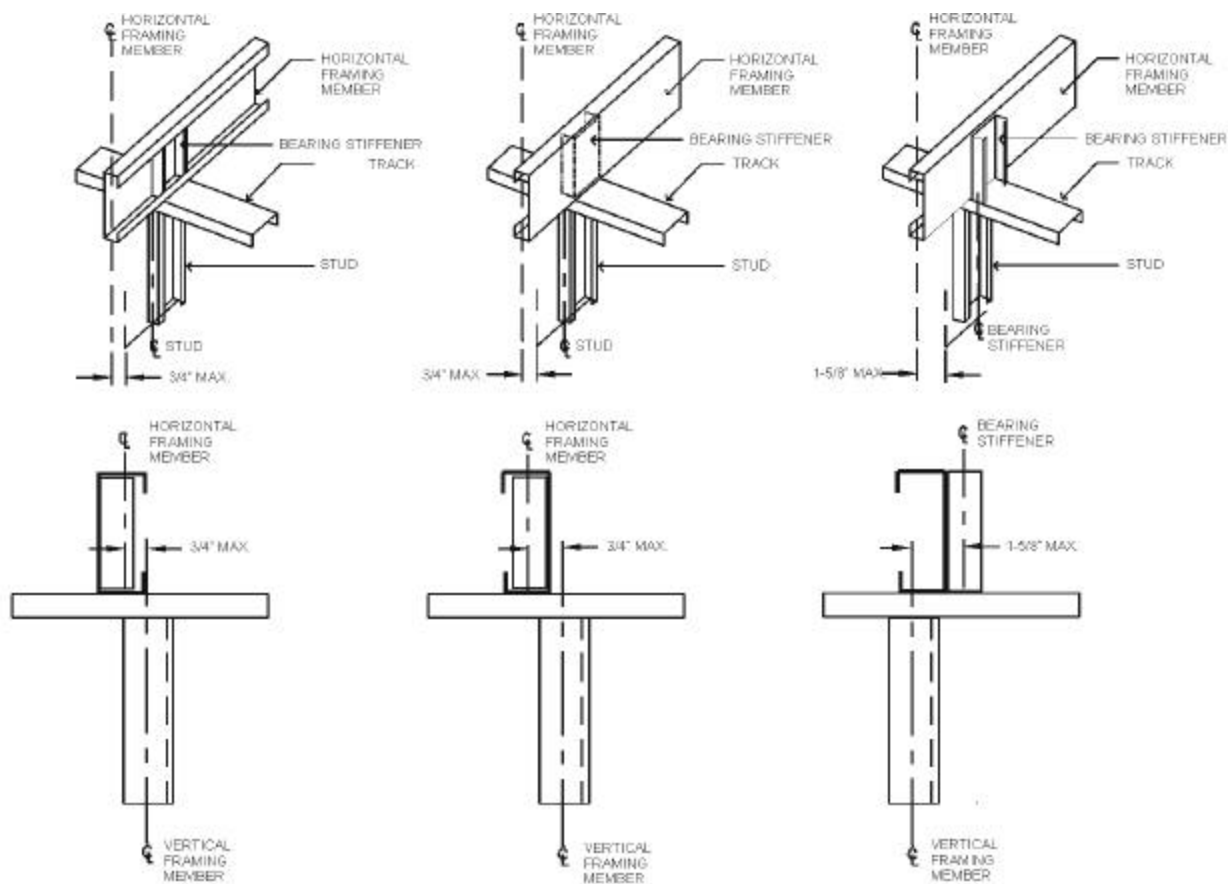


Figure C1-1 In-Line Framing

9 Acknowledgment

The American Iron and Steel Institute must be acknowledged for financially supporting this project, and the AISI Committee on Framing Standards for their input and guidance.

10 References

1. AISI (2001a). *Standard for Cold-Formed Steel Framing – General Provisions*. American Iron and Steel Institute, Washington, D.C.
2. AISI (2001b). *Standard for Cold-Formed Steel Framing – Prescriptive Method for One and Two Family Dwellings*. American Iron and Steel Institute, Washington, D.C.
3. AISI (2001c). *North American Specification for the Design of Cold-Formed Steel Structural Members*. American Iron and Steel Institute, Washington, D.C., USA.
4. Black, C., Froese, W., Ready, P. and Fox, S.R., (2002). *Strength of Floor Joists With Offset Loading on Bearing Stiffeners*, Canadian Cold Formed Steel Research Group report, University of Waterloo, Waterloo, Ontario.
5. Fox, S.R., (2002). *Bearing Stiffeners in Cold Formed Steel C-Sections*, PhD Thesis, University of Waterloo, Waterloo, Ontario.

Appendix A

Test Data

Table A1: Test Data for 8 inch Joists, End Location

Test No.	Joist	Rim Track	Stiffener	Wall Track	Bearing Width (in.)	Offset	Failure Loads (kips)	Maximum Deflection (in)
1	800S162-48	800T125-48b	362S162-36	362T125-36	1.5	3/4 off	4.02	0.82
2	800S162-48	800T125-48b	362S162-36	362T125-36	1.5	3/4 off	4.44	1.10
						Avg	4.23	0.96
3	800S162-48	800T125-48a	362S162-36	362T125-43	1.5	3/4" off	4.47	n/r
4	800S162-48	800T125-48a	362S162-36	362T125-43	1.5	3/4" off	5.23	n/r
5	800S162-48	800T125-48b	362S162-36	362T125-48	1.5	3/4 off	4.73	0.56
6	800S162-48	800T125-48b	362S162-36	362T125-48	1.5	3/4 off	4.63	0.58
						Avg	4.76	0.57
7	800S162-48	800T125-48a	362S162-36	362T125-57	1.5	3/4" off	6.60	n/r
8	800S162-48	800T125-48a	362S162-36	362T125-57	1.5	3/4" off	6.42	n/r
9	800S162-48	800T125-48b	362S162-36	362T125-60	1.5	3/4 off	5.55	0.59
10	800S162-48	800T125-48b	362S162-36	362T125-60	1.5	3/4 off	4.10	n/r
11	800S162-48	800T125-48b	362S162-36	362T125-60	1.5	3/4 off	5.42	0.62
12	800S162-48	800T125-48b	362S162-36	362T125-60	1.5	3/4 off	5.35	0.55
						Avg	5.57	0.59
13	800S162-48	800T125-48b	362S162-36	362T125-75	1.5	3/4 off	6.35	0.38
14	800S162-48	800T125-48b	362S162-36	362T125-75	1.5	3/4 off	6.46	0.37
15	800S162-48	800T125-48b	362S162-36	362T125-75	1.5	3/4 off	7.11	0.59
16	800S162-48	800T125-48b	362S162-36	362T125-75	1.5	3/4 off	5.73	0.66
						Avg	6.41	0.50
17	800S162-75	800T125-75	362S162-36	362T125-33	1.5	In-line	8.77	n/r
18	800S162-75	800T125-75	362S162-36	362T125-33	1.5	In-line	10.30	n/r
19	800S162-75	800T125-75	362S162-36	362T125-33	1.5	In-line	9.02	n/r
20	800S162-75	800T125-75	362S162-36	362T125-33	1.5	In-line	8.01	n/r
21	800S162-75	800T125-75	362S162-36	362T125-33	1.5	In-line	8.38	0.30
22	800S162-75	800T125-75	362S162-36	362T125-33	1.5	In-line	9.17	0.40
						Avg	9.02	0.35
23	800S162-75	800T125-75	362S162-36	362T125-33	1.5	3/4" off	6.84	n/r
24	800S162-75	800T125-75	362S162-36	362T125-33	1.5	3/4" off	6.78	n/r
25	800S162-75	800T125-75	362S162-36	362T125-33	1.5	3/4" off	6.31	n/r
26	800S162-75	800T125-75	362S162-36	362T125-33	1.5	3/4" off	6.28	n/r
27	800S162-75	800T125-75	362S162-36	362T125-33	1.5	3/4 off	6.37	1.00
28	800S162-75	800T125-75	362S162-36	362T125-33	1.5	3/4 off	6.53	1.05
						Avg	6.52	1.03
29	800S162-75	800T125-75	362T162-44	362T125-33	1.5	In-line	9.09	n/r
30	800S162-75	800T125-75	362T162-44	362T125-33	1.5	In-line	9.26	n/r
						Avg	9.17	
31	800S162-75	800T125-75	362T162-44	362T125-33	1.5	3/4" off	6.86	n/r
32	800S162-75	800T125-75	362T162-44	362T125-33	1.5	3/4" off	6.35	n/r
						Avg	6.60	
33	800S162-75	800T125-48b	362S162-36	362T125-75	1.5	3/4 off	7.71	0.72
34	800S162-75	800T125-48b	362S162-36	362T125-75	1.5	3/4 off	6.64	0.75
						Avg	7.17	0.74
35	800S162-75	800T125-48b	362S162-36	362T125-75	3.625	3/4 off	7.45	0.76
36	800S162-75	800T125-48b	362S162-36	362T125-75	3.625	3/4 off	8.25	0.67
						Avg	7.85	0.72
37	800S162-75	800T125-75	362S162-36	362T125-71	1.5	In-line	9.97	n/r
38	800S162-75	800T125-75	362S162-36	362T125-71	1.5	In-line	9.52	n/r
						Avg	9.74	
39	800S162-75	800T125-75	362S162-36	362T125-71	1.5	3/4" off	9.95	n/r
40	800S162-75	800T125-75	362S162-36	362T125-71	1.5	3/4" off	8.61	n/r
						Avg	9.28	

Table A2: Test Data for 8 inch Joists, Interior Location

Test No.	Joist	Rim Track	Stiffener	Wall Track	Bearing Width (in.)	Offset	Failure Loads (kips)	Maximum Deflection (in)
41	800S162-75	N/A (Interior)	362S162-36	362T125-75	3.625	3/4 off	7.03	0.61
42	800S162-75	N/A (Interior)	362S162-36	362T125-75	3.625	3/4 off	6.51	0.80
						Avg	6.77	0.71
43	800S162-48	N/A (Interior)	362S162-36	362T125-36	3.625	3/4 off	3.35	1.6
44	800S162-48	N/A (Interior)	362S162-36	362T125-36	3.625	3/4 off	3.35	1.6
						Avg	3.35	1.60
45	800S162-48	N/A (Interior)	362S162-36	362T125-57	3.625	3/4" off	4.77	n/r
46	800S162-48	N/A (Interior)	362S162-36	362T125-57	3.625	3/4" off	4.94	n/r
47	800S162-48	N/A (Interior)	362S162-36	362T125-60	3.625	3/4 off	4.97	0.43
48	800S162-48	N/A (Interior)	362S162-36	362T125-60	3.625	3/4 off	4.47	0.67
						Avg	4.79	0.55
49	800S162-48	N/A (Interior)	362S162-36	362T125-48	3.625	3/4 off	4.36	0.85
50	800S162-48	N/A (Interior)	362S162-36	362T125-48	3.625	3/4 off	4.59	0.62
						Avg	4.48	0.74
51	800S162-75	N/A (Interior)	362S162-36	362T125-33	3.625	In-line	8.05	n/r
52	800S162-75	N/A (Interior)	362S162-36	362T125-33	3.625	In-line	6.01	n/r
						Avg	7.03	
53	800S162-75	N/A (Interior)	362S162-36	362T125-33	3.625	3/4" off	4.81	n/r
54	800S162-75	N/A (Interior)	362S162-36	362T125-33	3.625	3/4" off	5.11	n/r
55	800S162-75	N/A (Interior)	362S162-36	362T125-36	3.625	3/4 off	4.74	1.10
56	800S162-75	N/A (Interior)	362S162-36	362T125-36	3.625	3/4 off	4.92	1.45
						Avg	4.90	1.28
57	800S162-75	N/A (Interior)	362T162-44	362T125-33	3.625	3/4" off	3.60	n/r
58	800S162-75	N/A (Interior)	362T162-44	362T125-33	3.625	3/4" off	4.12	n/r
						Avg	3.86	
59	800S162-75	N/A (Interior)	362S162-36	362T125-57	3.625	3/4" off	6.56	n/r
60	800S162-75	N/A (Interior)	362S162-36	362T125-57	3.625	3/4" off	6.68	n/r
						Avg	6.62	

Table A3: Test Data for 10 inch Joists, End Location

Test No.	Joist	Rim Track	Stiffener	Wall Track	Bearing Width (in.)	Offset	Failure Loads (kips)	Maximum Deflection (in)
61	1000S162-36	1000T125-48	362S162-36	362T125-36	3.625	Double offset	3.71	n/r
62	1000S162-36	1000T125-48	362S162-36	362T125-36	3.625	Double offset	3.15	n/r
Avg							3.43	
63	1000S162-36	1000T125-48	362S162-36	362T125-36	1.5	3/4 off	3.42	1.23
64	1000S162-36	1000T125-48	362S162-36	362T125-36	1.5	3/4 off	3.78	1.68
Avg							3.60	1.46
65	1000S162-36	1000T125-48	362S162-48	362T125-48	1.5	3/4 off	4.414	0.98
66	1000S162-36	1000T125-48	362S162-48	362T125-48	1.5	3/4 off	4.855	1.20
Avg							4.634	1.09
67	1000S162-36	1000T125-48	362S162-48	362T125-75	1.5	3/4 off	6.591	1.20
68	1000S162-36	1000T125-48	362S162-48	362T125-75	1.5	3/4 off	6.497	0.80
Avg							6.544	1.00
69	1000S162-54	1000T125-48	362S162-36	362T125-36	1.5	3/4 off	4.10	1.22
70	1000S162-54	1000T125-48	362S162-36	362T125-36	1.5	3/4 off	4.15	1.35
Avg							4.13	1.29
71	1000S162-54	1000T125-48	362S162-36	362T125-36	3.625	Double offset	4.00	n/r
72	1000S162-54	1000T125-48	362S162-36	362T125-36	3.625	Double offset	3.77	n/r
Avg							3.88	
73	1000S162-54	1000T125-48	362S125-33	600T125-48	3.625	In-line	5.50	0.54
74	1000S162-54	1000T125-48	362S125-33	600T125-48	3.625	In-line	5.78	0.53
Avg							5.64	0.54
75	1000S162-54	1000T125-48	362S125-33	600T125-48	3.625	3/4 off	4.54	1.15
76	1000S162-54	1000T125-48	362S125-33	600T125-48	3.625	3/4 off	4.39	0.75
Avg							4.47	0.95
77	1000S162-97	1000T125-48	362S162-36	362T125-60	1.5	In-line	8.51	0.84
78	1000S162-97	1000T125-48	362S162-36	362T125-60	1.5	In-line	7.72	0.75
Avg							8.12	0.80
79	1000S162-97	1000T125-48	362S162-36	362T125-60	1.5	3/4 off	8.45	0.92
80	1000S162-97	1000T125-48	362S162-36	362T125-60	1.5	3/4 off	6.82	0.65
Avg							7.64	0.79

Table A4: Test Data for 10 inch Joists, Interior Location

Test No.	Joist	Rim Track	Stiffener	Wall Track	Bearing Width (in.)	Offset	Failure Loads (kips)	Maximum Deflection (in)
81	1000S162-54	N/A (Interior)	362S162-36	362T125-36	3.625	3/4 off	2.37	1.24
82	1000S162-54	N/A (Interior)	362S162-36	362T125-36	3.625	3/4 off	2.73	1.13
Avg							2.55	1.19
83	1000S162-54	N/A (Interior)	362S125-33	600T125-48	3.625	3/4 off	3.80	0.82
84	1000S162-54	N/A (Interior)	362S125-33	600T125-48	3.625	3/4 off	3.37	n/r
Avg							3.59	0.82
85	1000S162-97	N/A (Interior)	362S162-36	362T125-60	3.625	3/4 off	6.80	0.82
86	1000S162-97	N/A (Interior)	362S162-36	362T125-60	3.625	3/4 off	6.19	0.78
Avg							6.50	0.80

Table A5: Test Data for 12 inch Joists, End Location

Test No.	Joist	Rim Track	Stiffener	Wall Track	Bearing Width (in.)	Offset	Failure Loads (kips)	Maximum Deflection (in)
87	1200S162-54	1200T125-48	362S125-33	362T125-48	1.5	In-line	5.52	0.80
88	1200S162-54	1200T125-48	362S125-33	362T125-48	1.5	In-line	5.48	0.62
						Avg	5.50	0.71
89	1200S162-54	1200T125-48	362S125-33	362T125-48	1.5	3/4 off	4.16	1.25
90	1200S162-54	1200T125-48	362S125-33	362T125-48	1.5	3/4 off	4.44	0.82
						Avg	4.30	1.04
91	1200S162-54	1200T125-48	362S162-44	362T125-48	1.5	3/4 off	4.323	0.70
92	1200S162-54	1200T125-48	362S162-44	362T125-48	1.5	In-line	5.964	0.55
93	1200S162-97	1200T125-48	362S162-44	362T125-48	1.5	3/4 off	5.88	0.70
94	1200S162-97	1200T125-48	362S162-44	362T125-48	1.5	In-line	8.66	0.65
95	1200S162-97	1200T125-48	362S125-33	362T125-60	1.5	In-line	8.26	0.83
96	1200S162-97	1200T125-48	362S125-33	362T125-60	1.5	In-line	7.84	0.57
						Avg	8.05	0.70
97	1200S162-97	1200T125-48	362S125-33	362T125-60	1.5	3/4 off	7.04	0.86
98	1200S162-97	1200T125-48	362S125-33	362T125-60	1.5	3/4 off	7.15	0.76
						Avg	7.10	0.81

Table A6: Test Data for 12 inch Joists, End Location, with OSB Sheathing

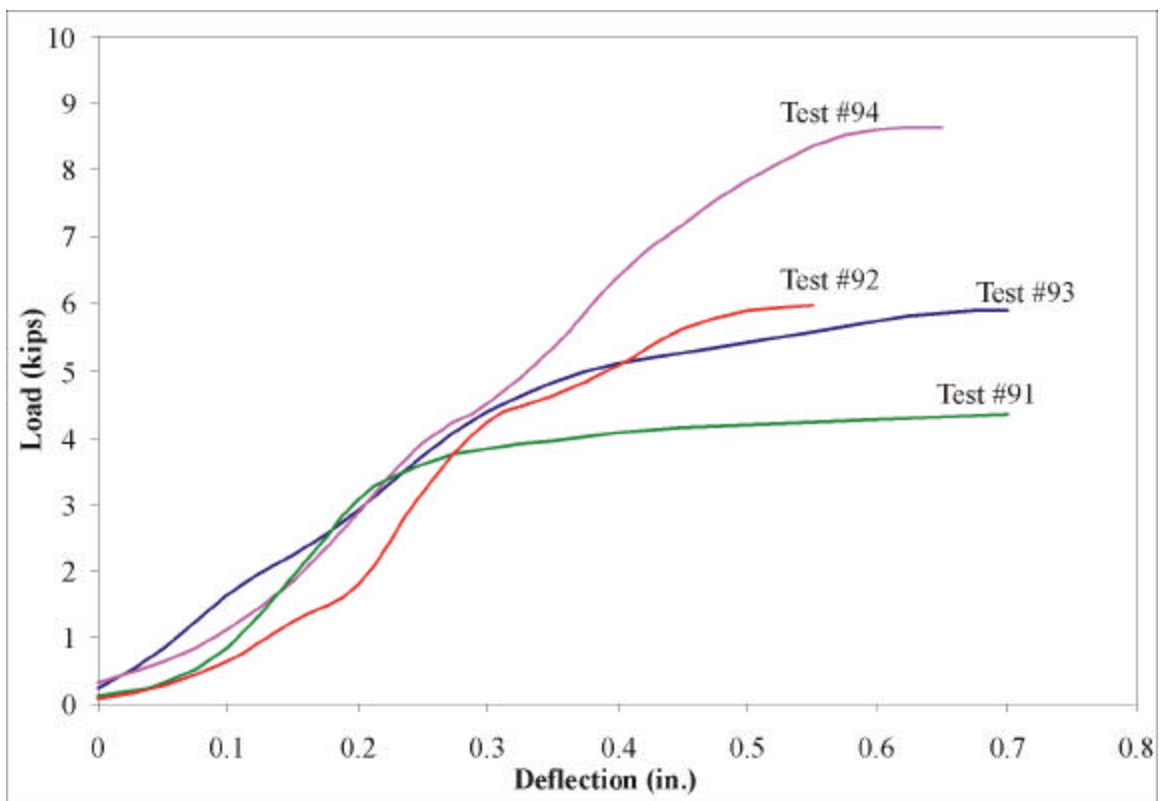
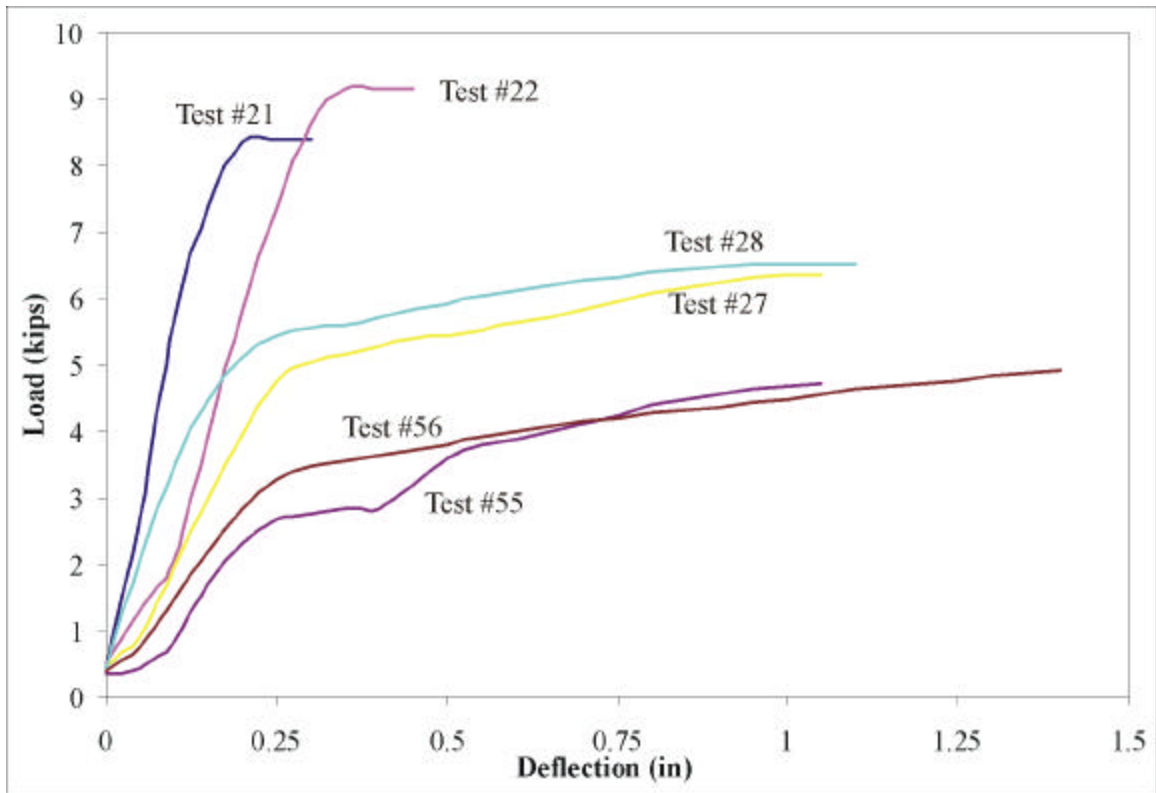
Test No.	Joist	Rim Track	Stiffener	Wall Track	Bearing Width (in.)	Offset	Failure Loads (kips)	Maximum Deflection (in)
99	1200S162-97	1200T125-48	362S162-44	362T125-48	1.5	3/4 off	7.32	1.00
100	1200S162-97	1200T125-48	362S162-44	362T125-48	1.5	3/4 off	6.70	1.00
						Avg	7.01	1.00
101	1200S162-97	1200T125-48	362S162-44	362T125-60	1.5	3/4 off	8.70	0.85
102	1200S162-97	1200T125-48	362S162-44	362T125-60	1.5	3/4 off	7.68	0.90
						Avg	8.19	0.88
103	1200S162-97	1200T125-48	362S162-44	362T125-75	1.5	3/4 off	8.57	0.80
104	1200S162-97	1200T125-48	362S162-44	362T125-75	1.5	3/4 off	8.03	0.80
						Avg	8.30	0.80
105	1200S162-97	1200T125-48	362S162-44	362T125-75	3.625	3/4 off	8.38	n/r
106	1200S162-97	1200T125-48	362S162-44	362T125-75	3.625	3/4 off	7.46	n/r
						Avg	7.92	

Table A7: Test Data for 12 inch Joists, Interior Location

Test No	Joist	Rim Track	Stiffener	Wall Track	Bearing Width (in.)	Offset	Failure Loads (kips)	Maximum Deflection (in)
107	1200S162-54	N/A (Interior)	362S125-33	362T125-48	3.625	3/4 off	3.19	0.8
108	1200S162-54	N/A (Interior)	362S125-33	362T125-48	3.625	3/4 off	2.98	0.6
						Avg	3.09	0.70
109	1200S162-97	N/A (Interior)	362S125-33	362T125-60	3.625	3/4 off	6.16	0.95
110	1200S162-97	N/A (Interior)	362S125-33	362T125-60	3.625	3/4 off	6.68	0.59
						Avg	6.42	0.77

Appendix B

Load – Deflection Plots



Appendix C

Capacity Calculations

Table C1: Capacity Calculations

Test No	Joist			N	R/t	N/t	h/t	Web Crippling (kips)	Stiffener			Predicted (kips)	Test (kips)	Test/Predicted
	h (in)	t (in)	F _y (ksi)						t (in)	F _y (ksi)	A _e (in ²)			
1	8	0.0465	47.1	1.5	2	32.3	166	0.450	0.0346	46.9	0.1344	4.72	4.02	0.85
2	8	0.0465	47.1	1.5	2	32.3	166	0.450	0.0346	46.9	0.1344	4.72	4.44	0.94
3	8	0.0465	47.1	1.5	2	32.3	166	0.450	0.0346	46.9	0.1344	4.72	4.47	0.95
4	8	0.0465	47.1	1.5	2	32.3	166	0.450	0.0346	46.9	0.1344	4.72	5.23	1.11
5	8	0.0465	47.1	1.5	2	32.3	166	0.450	0.0346	46.9	0.1344	4.72	4.73	1.00
6	8	0.0465	47.1	1.5	2	32.3	166	0.450	0.0346	46.9	0.1344	4.72	4.63	0.98
7	8	0.0465	47.1	1.5	2	32.3	166	0.450	0.0346	46.9	0.1344	4.72	6.60	1.40
8	8	0.0465	47.1	1.5	2	32.3	166	0.450	0.0346	46.9	0.1344	4.72	6.42	1.36
9	8	0.0465	47.1	1.5	2	32.3	166	0.450	0.0346	46.9	0.1344	4.72	5.55	1.18
10	8	0.0465	47.1	1.5	2	32.3	166	0.450	0.0346	46.9	0.1344	4.72	4.10	0.87
11	8	0.0465	47.1	1.5	2	32.3	166	0.434	0.0346	46.9	0.1344	4.72	5.42	1.15
12	8	0.0465	47.1	1.5	2	32.3	166	0.434	0.0346	46.9	0.1344	4.72	5.35	1.13
13	8	0.0465	47.1	1.5	2	32.3	166	0.450	0.0346	46.9	0.1344	4.72	6.35	1.34
14	8	0.0465	47.1	1.5	2	32.3	166	0.450	0.0346	46.9	0.1344	4.72	6.46	1.37
15	8	0.0465	47.1	1.5	2	32.3	166	0.434	0.0346	46.9	0.1344	4.72	7.11	1.51
16	8	0.0465	47.1	1.5	2	32.3	166	0.434	0.0346	46.9	0.1344	4.72	5.73	1.21
17	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	8.77	1.61
18	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	10.30	1.89
19	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	9.02	1.66
20	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	8.01	1.47
21	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	8.38	1.54
22	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	9.17	1.68
23	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	6.84	1.26
24	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	6.78	1.25
25	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	6.31	1.16
26	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	6.28	1.15
27	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	6.37	1.17
28	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	6.53	1.20
29	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0425	46.5	0.1386	5.56	9.09	1.64
30	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0425	46.5	0.1386	5.56	9.26	1.67
31	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0425	46.5	0.1386	5.56	6.86	1.24
32	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0425	46.5	0.1386	5.56	6.35	1.14
33	8	0.0717	55.8	1.5	2	20.9	106	1.496	0.0346	46.9	0.1344	5.46	7.71	1.41
34	8	0.0717	55.8	1.5	2	20.9	106	1.496	0.0346	46.9	0.1344	5.46	6.64	1.22
35	8	0.0717	55.8	3.625	2	50.6	106	1.790	0.0346	46.9	0.1344	5.67	7.45	1.32
36	8	0.0717	55.8	3.625	2	50.6	106	1.790	0.0346	46.9	0.1344	5.67	8.25	1.46
37	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	9.97	1.83
38	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	9.52	1.75
39	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	9.95	1.83
40	8	0.0717	55.8	1.5	2	20.9	106	1.476	0.0346	46.9	0.1344	5.46	8.61	1.58
41	8	0.0717	55.8	3.625	2	50.6	106	3.724	0.0346	46.9	0.1344	5.67	7.03	1.00
42	8	0.0717	55.8	3.625	2	50.6	106	3.724	0.0346	46.9	0.1344	5.67	6.51	0.93
43	8	0.0465	47.1	3.625	2	78.0	166	1.482	0.0346	46.9	0.1344	4.78	3.35	0.61
44	8	0.0465	47.1	3.625	2	78.0	166	1.482	0.0346	46.9	0.1344	4.78	3.35	0.61
45	8	0.0465	47.1	3.625	2	78.0	166	1.482	0.0346	46.9	0.1344	5.66	4.77	0.88
46	8	0.0465	47.0	3.625	2	78.0	166	1.479	0.0346	46.9	0.1344	5.66	4.94	0.91
47	8	0.0465	47.1	3.625	2	78.0	166	1.482	0.0346	46.9	0.1344	4.78	4.97	0.91
48	8	0.0465	47.1	3.625	2	78.0	166	1.482	0.0346	46.9	0.1344	4.78	4.47	0.82

Table C1: Capacity Calculations (Cont'd)

Test No	Joist			N	R/t	N/t	h/t	Web Crippling (kips)	Stiffener			Predicted (kips)	Test (kips)	Test/Predicted
	h (in)	t (in)	F _y (ksi)						t (in)	F _y (ksi)	A _e (in ²)			
49	8	0.0465	47.1	3.625	2	78.0	166	1.482	0.0346	46.9	0.1344	4.78	4.36	0.80
50	8	0.0465	47.1	3.625	2	78.0	166	1.482	0.0346	46.9	0.1344	4.78	4.59	0.84
51	8	0.0717	55.8	3.625	2	50.6	106	3.724	0.0346	46.9	0.1344	8.10	8.05	1.15
52	8	0.0717	55.8	3.625	2	50.6	106	3.724	0.0346	46.9	0.1344	8.10	6.01	0.86
53	8	0.0717	55.8	3.625	2	50.6	106	3.724	0.0346	46.9	0.1344	8.10	4.81	0.69
54	8	0.0717	55.8	3.625	2	50.6	106	3.724	0.0346	46.9	0.1344	8.10	5.11	0.73
55	8	0.0717	55.8	3.625	2	50.6	106	3.724	0.0346	46.9	0.1344	5.67	4.74	0.67
56	8	0.0717	55.8	3.625	2	50.6	106	3.724	0.0346	46.9	0.1344	5.67	4.92	0.70
57	8	0.0717	55.8	3.625	2	50.6	106	3.724	0.0425	46.5	0.1386	8.20	3.60	0.51
58	8	0.0717	55.8	3.625	2	50.6	106	3.724	0.0425	46.5	0.1386	8.20	4.12	0.58
59	8	0.0717	55.8	3.625	2	50.6	106	3.724	0.0346	46.9	0.1344	8.10	6.56	0.93
60	8	0.0717	55.8	3.625	2	50.6	106	3.724	0.0346	46.9	0.1344	8.10	6.68	0.95
61	10	0.0370	45.1	3.625	2	98.0	264	0.198	0.0346	46.9	0.1344	4.55	3.71	0.82
62	10	0.0370	45.1	3.625	2	98.0	264	0.198	0.0346	46.9	0.1344	4.55	3.15	0.69
63	10	0.0370	45.1	1.5	2	40.5	264	0.159	0.0346	46.9	0.1344	4.52	3.42	0.76
64	10	0.0370	45.1	1.5	2	40.5	264	0.159	0.0346	46.9	0.1344	4.52	3.78	0.84
65	10	0.0370	45.1	1.5	2	40.5	264	0.159	0.0469	43.5	0.2272	7.03	4.41	0.63
66	10	0.0370	45.1	1.5	2	40.5	264	0.159	0.0469	43.5	0.2272	7.03	4.85	0.69
67	10	0.0370	45.1	1.5	2	40.5	264	0.159	0.0469	43.5	0.2272	7.03	6.59	0.94
68	10	0.0370	45.1	1.5	2	40.5	264	0.159	0.0469	43.5	0.2272	7.03	6.50	0.92
69	10	0.0535	54.1	1.5	2	28.0	181	0.598	0.0346	46.9	0.1344	4.83	4.10	0.85
70	10	0.0535	54.1	1.5	2	28.0	181	0.598	0.0346	46.9	0.1344	4.83	4.15	0.86
71	10	0.0535	54.1	3.625	2	67.7	181	0.727	0.0346	46.9	0.1344	4.92	4.00	0.81
72	10	0.0535	54.1	3.625	2	67.7	181	0.727	0.0346	46.9	0.1344	4.92	3.77	0.77
73	10	0.0535	54.1	3.625	2	67.7	181	0.727	0.0320	47.2	0.1159	4.34	5.50	1.27
74	10	0.0535	54.1	3.625	2	67.7	181	0.727	0.0320	47.2	0.1159	4.34	5.78	1.33
75	10	0.0535	54.1	3.625	2	67.7	181	0.727	0.0320	47.2	0.1159	4.34	4.54	1.05
76	10	0.0535	54.1	3.625	2	67.7	181	0.727	0.0320	47.2	0.1159	4.34	4.39	1.01
77	10	0.0969	55.4	1.5	2	15.5	97	2.679	0.0346	46.9	0.1344	6.29	8.51	1.35
78	10	0.0969	55.4	1.5	2	15.5	97	2.679	0.0346	46.9	0.1344	6.29	7.72	1.23
79	10	0.0969	55.4	1.5	2	15.5	97	2.679	0.0346	46.9	0.1344	6.29	8.45	1.34
80	10	0.0969	55.4	1.5	2	15.5	97	2.679	0.0346	46.9	0.1344	6.29	6.82	1.09
81	10	0.0535	54.1	3.625	2	67.7	181	2.170	0.0346	46.9	0.1344	4.92	2.37	0.40
82	10	0.0535	54.1	3.625	2	67.7	181	2.170	0.0346	46.9	0.1344	4.92	2.73	0.46
83	10	0.0535	54.1	3.625	2	67.7	181	2.170	0.0320	47.2	0.1159	4.34	3.80	0.71
84	10	0.0535	54.1	3.625	2	67.7	181	2.170	0.0320	47.2	0.1159	4.34	3.37	0.63
85	10	0.0969	55.4	3.625	2	37.4	97	6.265	0.0346	46.9	0.1344	6.62	6.80	0.77
86	10	0.0969	55.4	3.625	2	37.4	97	6.265	0.0346	46.9	0.1344	6.62	6.19	0.70
87	12	0.0535	61.2	1.5	2	28.0	218	0.555	0.0320	47.2	0.1159	4.22	5.52	1.31
88	12	0.0535	61.2	1.5	2	28.0	218	0.555	0.0320	47.2	0.1159	4.22	5.48	1.30
89	12	0.0535	61.2	1.5	2	28.0	218	0.555	0.0320	47.2	0.1159	4.22	4.16	0.99
90	12	0.0535	61.2	1.5	2	28.0	218	0.555	0.0320	47.2	0.1159	4.22	4.44	1.05
91	12	0.0535	61.2	1.5	2	28.0	218	0.555	0.0418	33.0	0.2175	5.41	4.32	0.80
92	12	0.0535	61.2	1.5	2	28.0	218	0.555	0.0418	33.0	0.2175	5.41	5.96	1.10
93	12	0.0969	58.6	1.5	2	15.5	118	2.576	0.0418	33.0	0.2175	6.83	5.88	0.86
94	12	0.0969	58.6	1.5	2	15.5	118	2.576	0.0418	33.0	0.2175	6.83	8.66	1.27
95	12	0.0969	58.6	1.5	2	15.5	118	2.576	0.0320	47.2	0.1159	5.63	8.26	1.47
96	12	0.0969	58.6	1.5	2	15.5	118	2.576	0.0320	47.2	0.1159	5.63	7.84	1.39

Table C1: Capacity Calculations (Cont'd)

Test No	Joist			N	R/t	N/t	h/t	Web Crippling (kips)	Stiffener			Predicted (kips)	Test (kips)	Test/Predicted
	h (in)	t (in)	F _y (ksi)						t (in)	F _y (ksi)	A _e (in ²)			
97	12	0.0969	58.6	1.5	2	15.5	118	2.576	0.0320	47.2	0.1159	5.63	7.04	1.25
98	12	0.0969	58.6	1.5	2	15.5	118	2.576	0.0320	47.2	0.1159	5.63	7.15	1.27
99	12	0.0969	58.6	1.5	2	15.5	118	2.576	0.0418	33.0	0.2175	6.83	7.32	1.07
100	12	0.0969	58.6	1.5	2	15.5	118	2.576	0.0418	33.0	0.2175	6.83	6.70	0.98
101	12	0.0969	58.6	1.5	2	15.5	118	2.576	0.0418	33.0	0.2175	6.83	8.70	1.27
102	12	0.0969	58.6	1.5	2	15.5	118	2.576	0.0418	33.0	0.2175	6.83	7.68	1.12
103	12	0.0969	58.6	1.5	2	15.5	118	2.576	0.0418	33.0	0.2175	6.83	8.57	1.25
104	12	0.0969	58.6	1.5	2	15.5	118	2.576	0.0418	33.0	0.2175	6.83	8.03	1.18
105	12	0.0969	58.6	3.625	2	37.4	118	3.035	0.0418	33.0	0.2175	7.15	8.38	1.17
106	12	0.0969	58.6	3.625	2	37.4	118	3.035	0.0418	33.0	0.2175	7.15	7.46	1.04
107	12	0.0535	61.2	3.625	2	67.7	218	2.452	0.0320	47.2	0.1159	4.30	3.19	0.58
108	12	0.0535	61.2	3.625	2	67.7	218	2.452	0.0320	47.2	0.1159	4.30	2.98	0.54
109	12	0.0969	58.6	3.625	2	37.4	118	6.619	0.0320	47.2	0.1159	5.95	6.16	0.73
110	12	0.0969	58.6	3.625	2	37.4	118	6.619	0.0320	47.2	0.1159	5.95	6.68	0.79



American Iron and Steel Institute

1140 Connecticut Avenue, NW
Suite 705
Washington, DC 20036
www.steel.org



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