Cold Formed Steel
CSSBI Canadian Sheet Steel Building Institute
Research Note
652 Bishop St. N., Unit 2A, Cambridge, ON, Canada, N3H 4V6 Tel: (519) 650-1285 Fax: (519) 650-8081 Web Site: www.cssbi.ca

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The Strength of Stiffened CFS Floor Joist Assemblies with Offset Loading

by
Steven R. Fox, PhD, P.Eng.

Abstract

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 ¾inch (19 mm) of the centerline (mid-width) of the loadbearing members beneath. The ¾inch 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. A total of 110 end- and interior-two-flange loading tests of various floor joist assemblies were carried out at the University of Waterloo to determine the effect that an offset loading has on the strength of typical floors. It was concluded that the ¾inch offset could cause a significant reduction in the strength of the assembly compared to the in-line loading, and at a capacity lower than what would be predicted for a joist with a bearing stiffener alone. In addition, there can be significant deformation (up to 1 inch) associated with the failure of assemblies with the ¾inch offset loading. Based on these findings, a change has been recommended to the wording of the AISI *General Provisions Standard* that would 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 ¾inch (19 mm) of the centerline (mid-width) of the load bearing members beneath, <u>but not more than 1-5/8 inch from the centerline of the bearing stiffener when one is present.</u>"

Background

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 ¾inch (19 mm) of the centerline (mid-width) of the load bearing members beneath".

A research project was initiated at the University of Waterloo to investigate the behaviour of cold-formed steel floor assemblies subjected 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 ¾inch 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.

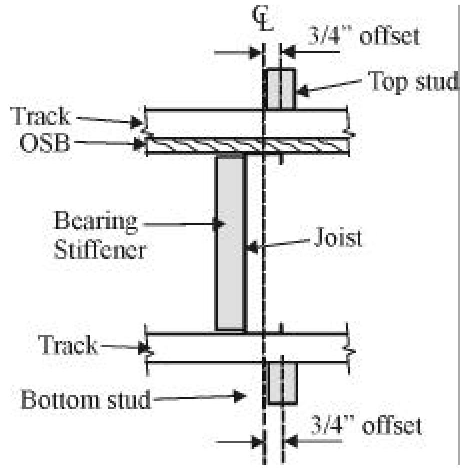

Figure 1: Alignment Offset Limits Allowed in the AISI Standards

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. Based on these findings, it was decided that a more extensive investigation of these assemblies was needed to determine the actual behaviour, and to define more appropriate alignment rules as needed.

Test Configurations

The test assemblies were constructed to model actual floor assemblies following the AISI *Prescriptive Method* (AISI 2001b). Each specimen consisted of four floor joist pieces and was 4-foot square. The drawings in Figure 2 show the test specimens for the 2nd floor and bottom floor conditions. The 2nd floor tests investigated the bearing of the joist on the lower loadbearing wall stud, so the test assembly as shown in Figure 2 is inverted from what would be the actual construction. The bottom floor specimens simulated a floor joist assembly resting on a continuous bearing wall. Tests were also carried out where the load was applied at the mid-span of the joist to simulate a continuous member over an interior support.

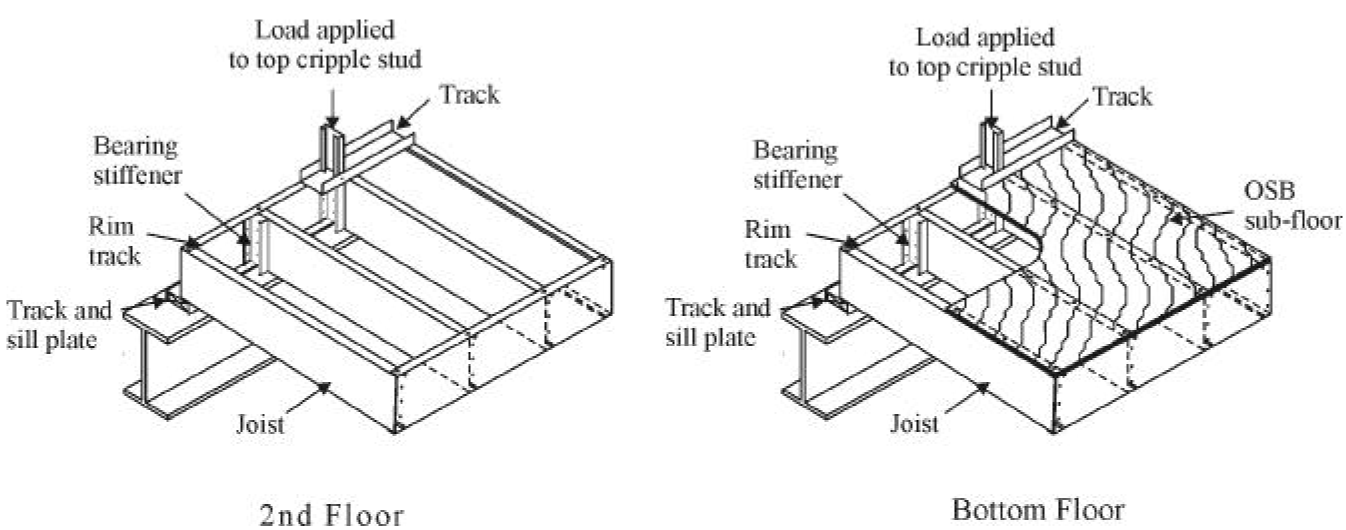

Figure 2: Sketch of Test Set-up and Specimens

The following are the range of variables investigated in the experimental program:

- 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 ¾" offset loading;
- sub-floor (19/32 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).

Discussion of Results

Failure Modes

In general there were two basic failure modes: excessive deformation and bearing stiffener failure. The failures accompanied by excessive deformation (up to 1 inch) were usually those assemblies that had the applied load offset from the centerline of the joist, with a thin wall track and without a sub-floor. When 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. Another type of failure occurred in some of the tests that included a sub-floor under the wall track. This mode was punch-through of the sub-floor prior to failure of the bearing stiffener or excessive deformation. This punch-through type of failure only occurred when the load was offset from the joist and the track was thin (i.e. 33 mil).

Predicted Capacity

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

$$P_n = 0.7(P_{wc} + A_e F_y) \qquad \text{(Eq. 1)}$$

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 (AISI 2001c)

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 test results were compared to the capacity predicted using Equation 1. These test-to-predicted ratios provided a type of normalized basis for comparing different assemblies.

Effect of Wall Track Thickness

One of the most significant parameters affecting the strength of the assembly is the thickness of the wall track. The in-line tests were not affected significantly by the wall track thickness since failure was typically associated with some form of local buckling in the stiffener. Consequently, the wall track and OSB sub-floor (if present) did not contribute significantly to the strength of the assembly. The track thickness does have a significant influence on the strength of the assemblies with the ¾" offset. The load sharing caused by a thicker track reduces the deformation of the assembly, increases the load transferred to the stiffener and increases the strength of the assembly. The influence of the track thickness is more pronounced for the interior tests than the end tests. The scatter plot shown in Figure 3 illustrates these findings.

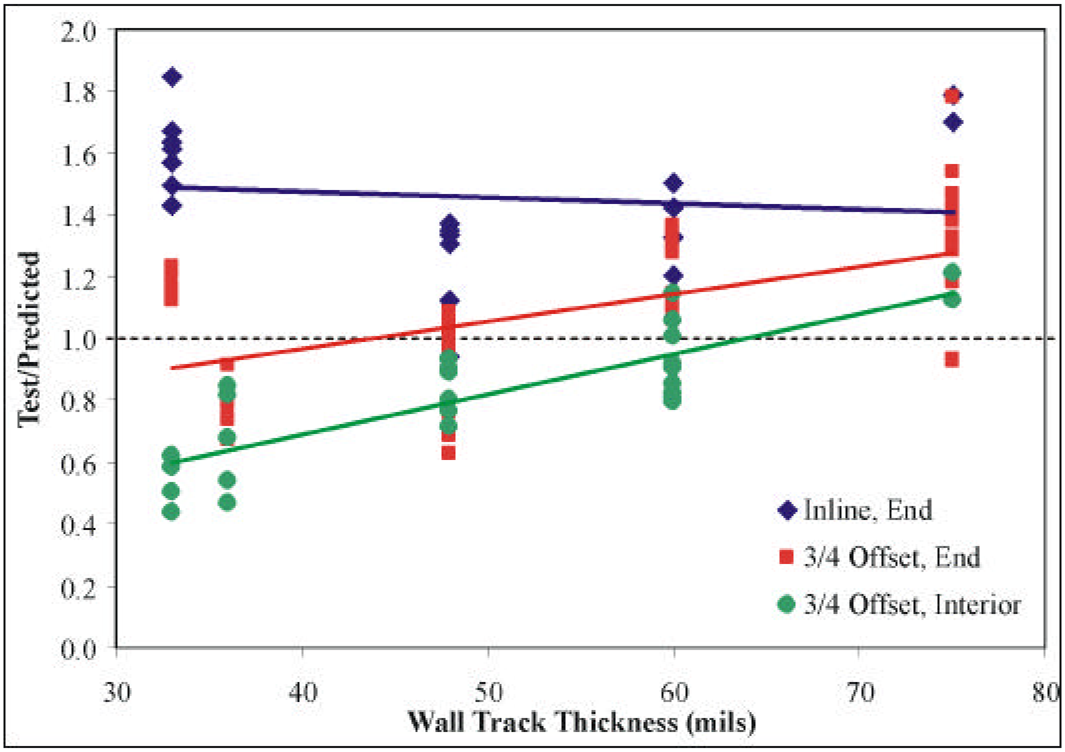

Figure 3: Effect of Wall Track Thickness

Effect of ¾" Offset

Comparing the trend lines provided in Figure 3 illustrates the effects of the ¾inch offset on the strength of the assembly. Depending on the size of the components in the assembly, there are some configurations with a ¾inch offset that have a tested strength less than would be predicted by the NA Specification (AISI 2001c) for the stiffened joist alone. The offset has a more significant influence on the strength of the interior tests since the rim tack is not present to help share the load.

Interior versus End Loading Conditions

The interior loading cases have a significantly lower ultimate load than the ends since the rim joist contributes to the strength at the end, which is not present at the interior.

Effect of Joist Web Depth

The test results show that the test-to-predicted ratios decrease as the web depth and web slenderness increases. The predicted capacity assumes that the bearing stiffener acts as a short stub-column. However, as the web depth increases the buckling of the rim track pulls on the stiffener through the connecting fasteners and causes it to failure prematurely. The interior assemblies are less sensitive to the increase in web depth compared to the end tests since there is no rim track pulling on the bearing stiffener.

Effect of OSB Sub-Floor

Adding the OSB sub-floor will increase the capacity of the assembly, although the assemblies with the thinner wall track sections and a ¾inch offset can still give tested capacities below the predicted values even with the sub-floor.

Serviceability Limit State

One of the factors that became apparent during the testing was the deformation associated with failure. 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.

Conclusions and Recommendations

Based on the results and conclusions, it is recommended that the ¾inch 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 ¾inch offset limits would be satisfactory. Refer to the AISI report (Fox 2003) for the complete research details.

Acknowledgment

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References

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