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The Strength of Stiffened CFS Floor Joist Assemblies with Offset Loading

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Abstract

Described in this paper are the results of an experimental investigation into the behavior of cold-formed steel floor assemblies subjected to variations in the alignment of the loadbearing wall stud with the supporting floor joist. One of the requirements common in cold-formed steel construction is for "in-line" framing. In-line framing has typically meant that the centerline (mid-width) of the joist, rafter, truss and structural wall stud is not offset more than ¾ inch. This allowable offset creates the possibility for a misalignment in the load path through the assembly, with consequences for the strength of the stiffened floor joist. A total of 110 end- and interior-two-flange loading tests were carried out to check a range of variables. This work concluded that a ¾ inch offset can cause a significant reduction in the strength of the assembly compared to the in-line conditions, and that the important parameter was the offset of the loadbearing stud from the bearing stiffener. There can also be significant deformations associated with the failure of assemblies with the offset loading. The results of this work have been incorporated in the 2004 edition of the AISI *Standard for Cold-Formed Steel Framing - General Provisions*.

Introduction

In 2001 the AISI Committee on Framing Standards published the *Standard for Cold-Formed Steel Framing – General Provisions* (AISI, 2001a) that specified requirements for construction with cold-formed steel framing that are common to prescriptive and engineered designs. One of the requirements called for "in-line" framing unless a structural load distribution member is included. In-line

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framing meant that the “joist, rafter, truss and structural wall stud shall be aligned so that the centerline (mid-width) is within ¾ inch (19 mm) of the centerline (mid-width) of the load bearing members beneath”.

The work described in this report was done to investigate the behavior of cold-formed steel floor assemblies subjected to variations in the alignment of the components. For the type of construction standardized in the *AISI Standard for Cold-Formed Steel Framing – Prescriptive Method for One and Two Family Dwellings* (AISI, 2001b), and the ¾ 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. Preliminary tests (Black et. al., 2002) showed that there could be a significant reduction in the strength of the assembly with an offset load path. Therefore, a more extensive investigation of these assemblies was warranted.

Objective and Scope

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 scope of the project entailed carrying out a total of 110 tests of various floor joist assemblies to check and compare a range of variables. The investigation was experimental and consisted of both end- and interior-two-flange loading of typical floor assemblies. The alignment conditions considered are illustrated in Figures 2 and 3. In all cases the bearing stiffener was attached to the back of the joist and the ¾ inch offset was toward the joist flange lip. From earlier work (Black et. al., 2002) this alignment configuration was determined to be the worst case.

Test Specimens

The test specimens where 4-foot square sections of a floor assembly constructed in accordance with the requirements of the AISI *Prescriptive Method*. 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. The bearing stiffener was cut to the full joist depth, and all connections were made with #10 hex head self-drilling screws. A typical test assembly is illustrated in

Figure 4 for an end test of a joist bearing on a foundation wall. The other test configurations were similar.

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 ¾ inch offset loading (as illustrated in Figures 2 and 3);
- 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).

Experimental Results - Failure Modes

The results of all the tests are available in the research report published by AISI (AISI, 2003). In general there were three failure modes: local buckling of the bearing stiffener, excessive deformation, and punch-through of the sub-floor.

When the stiffener failed in local buckling it usually occurred in one of the flanges, at either the upper or lower end. In some situations, however, the failure of the stiffener was precipitated prematurely by buckling of the rim track. When the rim track depth increased (e.g. up to 12 inch), and the stiffener material was thin (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. For some of the thinner sections, the fasteners pulled out of the stiffener.

The photograph in Figure 5 illustrates a failure accompanied by excessive deformation. There are a number of variables that lead to this type of failure including:

- When the applied load is offset from the centerline of the joist (as illustrated in Figure 5) the load is transferred through the joist flange. This cantilever 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 the deformation will also be reduced.
- The lower the joist and rim track web slenderness ratios, the less deformation there will be at failure.

The third mode of failure was punch-through of the loadbearing wall stud through the sub-floor. This type of failure occurred when the load was offset from the joist and the wall 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 or punch-through.

Load-Deflection Characteristics

The graph shown in Figure 6 provides load-versus-deflection plots for three representative tests. Comparing these three plots illustrates a number of features of the behavior of these assemblies:

- The in-line, end test has a higher stiffness than the other two tests. 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 ¾ 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.

Calculated Capacity

The tests showed how the floor joist assemblies behaved, but it was also necessary to determine whether the capacity of any configuration fell below the strength level calculated using the AISI *Specification* (AISI, 2004b). The test results were compared to the capacities predicted using the AISI *Specification* with the 2004 Supplement (AISI, 2004b), even though the *Specification* does not recognize the other components in the assembly such as the rim track and sub-floor. The ultimate strength for the two-flange loading of C-section members with stud or track bearing stiffeners is:

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

Where,

A_e = effective area of bearing stiffener subjected to uniform compressive stress equal to the yield stress, calculated in accordance with the *Specification*

F_y = yield strength of stiffener steel

P_{wc} = web crippling strength for C-section joist calculated in accordance with the *Specification* for single web members, end or interior locations

The test-to-predicted ratios provide a basis for comparing different assemblies. Presented in the following sections are descriptions of the influence of the various parameters on the capacity of the assembly.

Effect of Wall Track Thickness

One of the significant parameters that affect the strength of the assembly was found to be the thickness of the wall track. The data plotted in Figure 7 illustrates the significance of this variable. The behavior of the interior offset load tests was similar to the end offset tests. The following insights can be drawn from this plot:

- 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) do 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. 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 (not shown) 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 sensitive to misalignments in the load path.

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 Figure 8 illustrates the significance of this parameter on the strength of the assembly. The following insights can be drawn from this plot:

- 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 fail at a lower load. 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.

Effect of ¾" Offset

Comparing the trend lines provided in Figures 7 and 8 illustrates the effects of the ¾ inch offset on the strength of the assembly. This result is not surprising since the offset load path is known to influence the behaviour. Depending on the size of the components in the assembly, there are many assemblies with a ¾ inch offset that still have a tested strength greater than what would be predicted by the *Specification* (AISI, 2004b). If some limitations could be placed on the other components (i.e. wall track thickness) then the ¾ 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 the *Specification*.

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 at the interior.

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. Analyzing the test results did not reveal a significant, consistent influence of bearing width on the capacity.

Effect of OSB Sub-Floor

Adding the OSB sub-floor would be expected to increase the capacity of the assembly, and the test results seem to confirm this. These results might be over-estimating the influence of the sheathing 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 also shows that the assemblies with the thinner wall track sections and a ¾ inch offset can still give tested capacities below the predicted even with the sub-floor.

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 ¾ inch. Two sets of tests were carried out to determine if this had a significant impact on the strength of the assembly. The results of Test Nos. 61-62 compared to 63-64, and 69-70 compared to 71-72 show 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.

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 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.

Serviceability Limit State

One of the factors that became apparent during testing was the deformation associated with failure. There was insufficient data to develop explicit deformation limits, nor 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 would have the advantage of reducing the deformations to an acceptable magnitude. Additional research would be needed to form a more specific recommendation.

Conclusions

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 ¾ 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 alone.
- Some form of load distribution is necessary if there is an offset in the load path. This load distribution 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 assembly (e.g. joist, rim track, sub-floor, wall track). In addition, for each variable, there are many variations (e.g. depth, thickness and yield strength). Given the large number of possible combinations of variables, developing a predictor equation for the strength of the assembly would require extensive testing. 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, 2004b).
- The test-to-predicted ratios 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.
- There can be significant deformation associated with the ultimate capacity of the assemblies, particularly with load applied at the ¾ 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.

- 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.

Recommendations

Based on the conclusions presented in the preceding section, a recommendation was made that the AISI *General Provisions* (AISI, 2001a) be revised to limit the offset in those cases when the bearing stiffener is attached to the back of the joist. The sketch in Figure 9 shows the offset limitations in 2004 Edition of the AISI *General Provisions* (AISI, 2004a). These limits still provide an assembly with a capacity that is at least equal to what would be predicted of a stiffened joist.

Acknowledgment

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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 (2003). *The Strength of Stiffened CFS Floor Assemblies with Offset Loading*. Research Report RP03-6. American Iron and Steel Institute, Washington, D.C.
4. AISI (2004a). *Standard for Cold-Formed Steel Framing – General Provisions*. 2004 Edition. American Iron and Steel Institute, Washington, D.C.

5. AISI (2004b). *North American Specification for the Design of Cold-Formed Steel Structural Members*, with 2004 Supplement. American Iron and Steel Institute, Washington, D.C., USA.
6. 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.

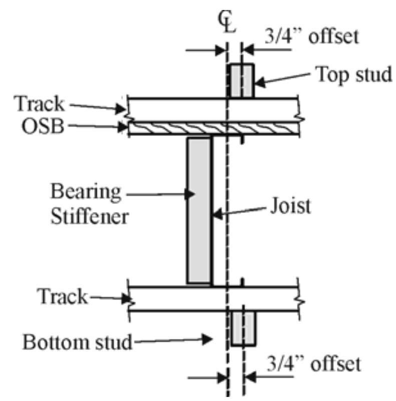

Figure 1: Load Offset Allowed in AISI General Provisions (2001)

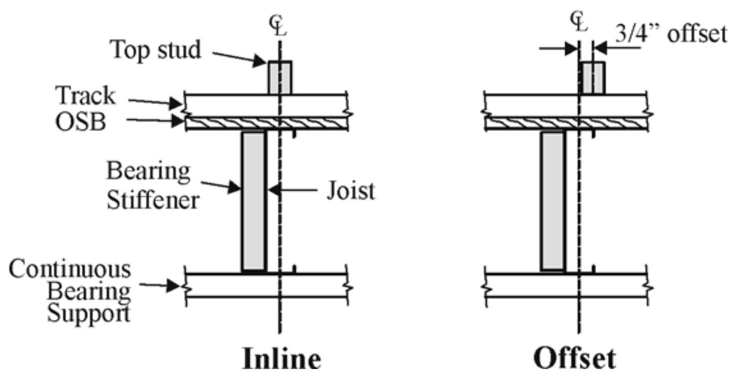

Figure 2: Joist Bearing on Foundation Wall

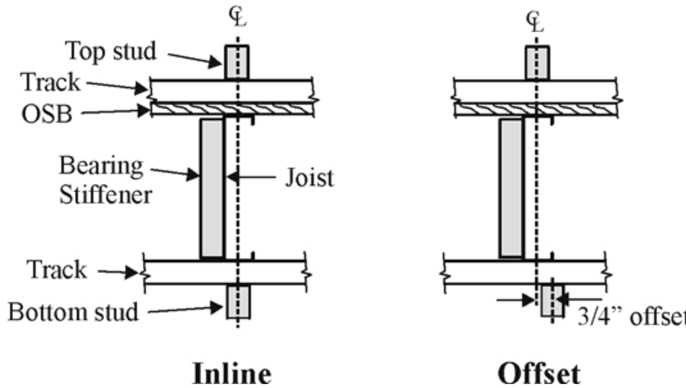

Figure 3: Joist Bearing on Loadbearing Wall

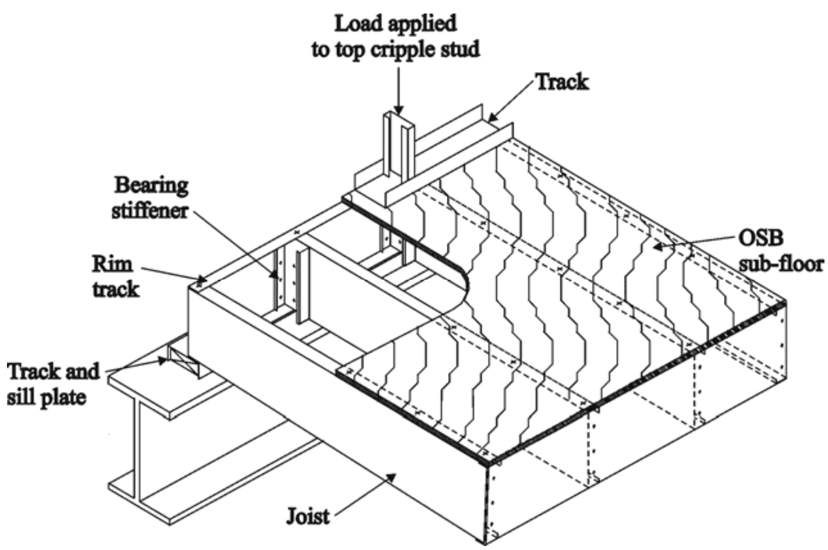

Figure 4: Test Configuration for a Joist on a Foundation

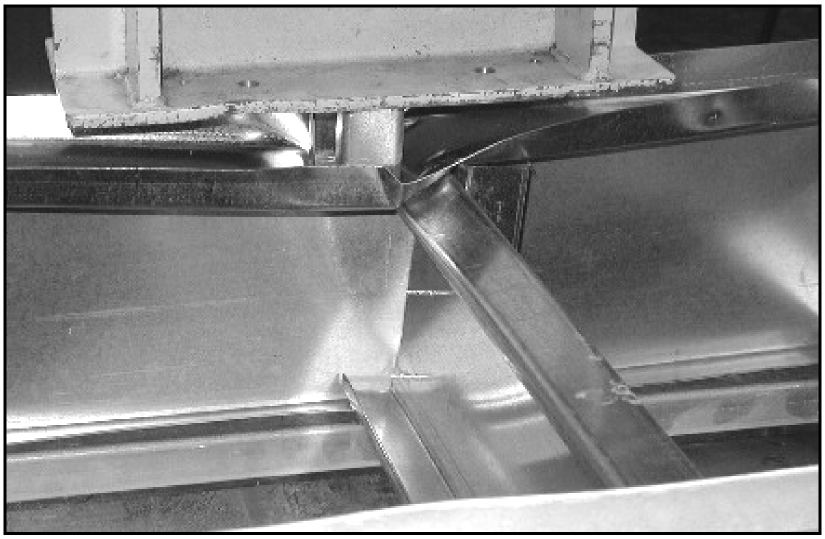

Figure 5: Photograph of Failure due to Excessive Deformation

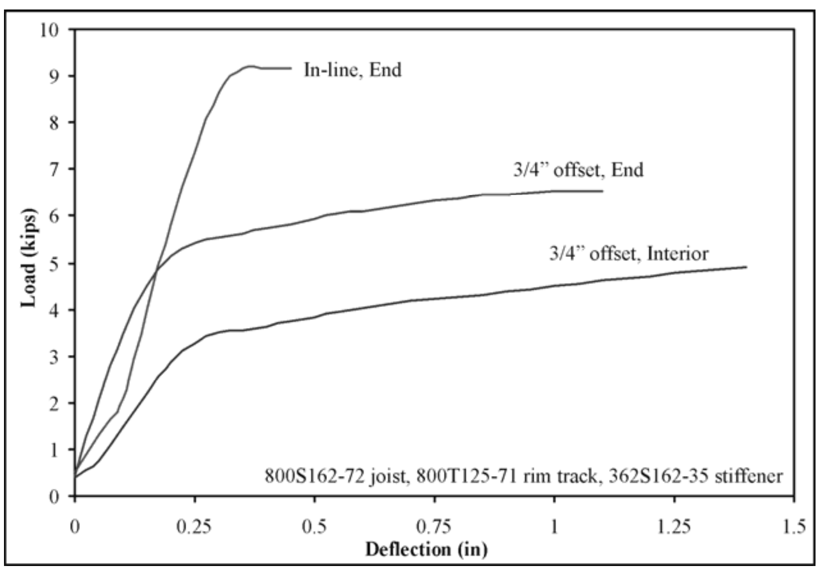

Figure 6: Typical Load versus Deflection Plots

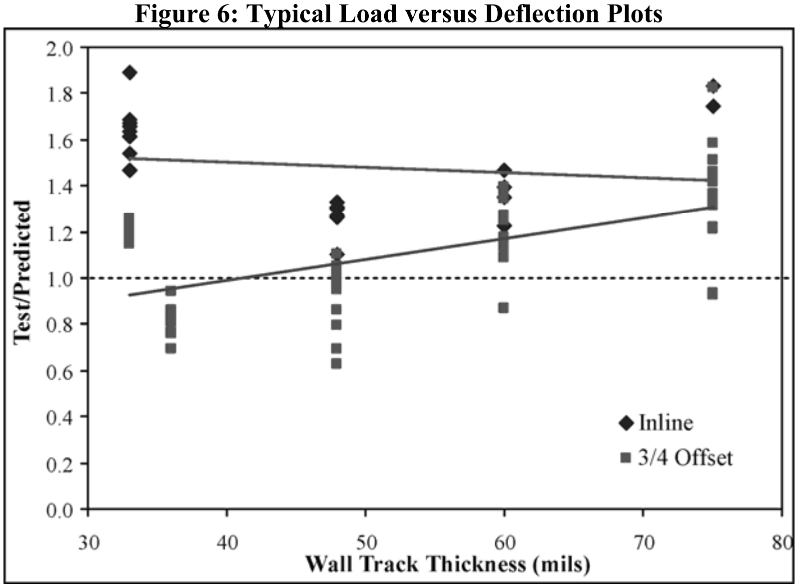

Figure 7: Effect of Wall Track Thickness on Joist End Tests

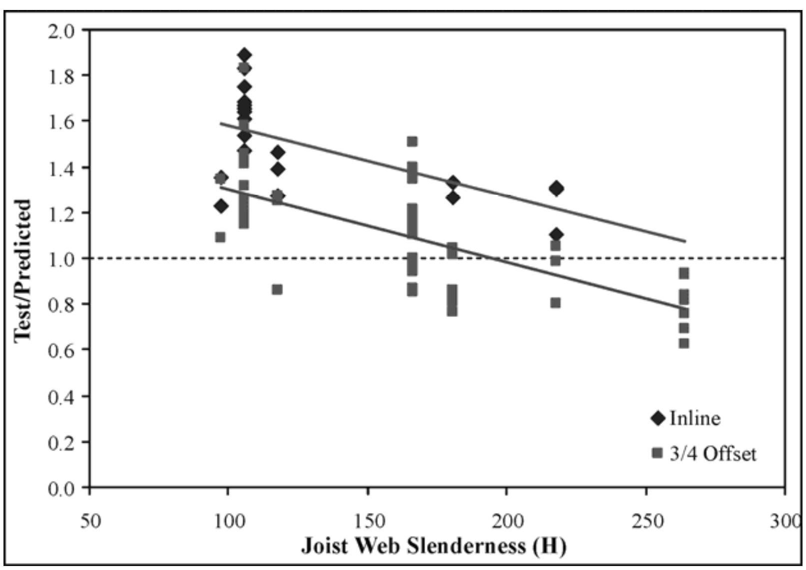

Figure 8: Effect of Joist Web Slenderness on Joist End Tests

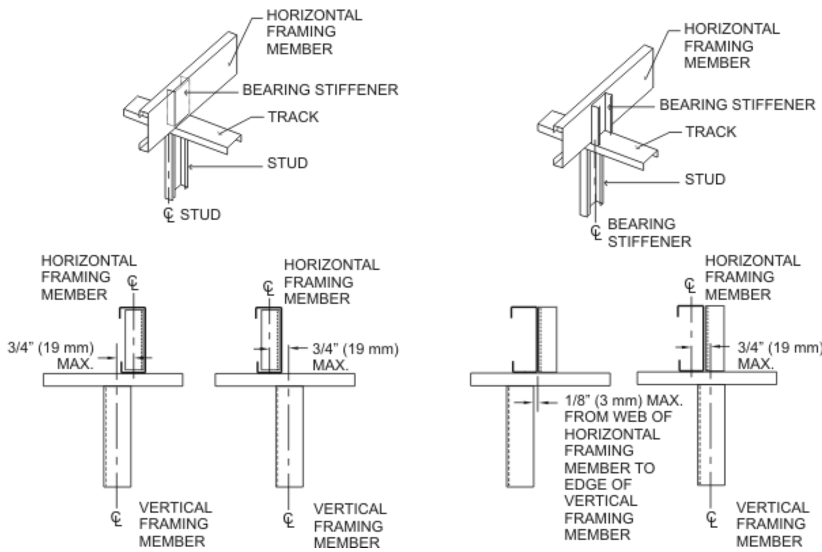

Figure 9: AISI General Provisions 2004 Framing Offset Limits