INNOVATIVE COLD-FORMED STEEL I-JOIST

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Introduction

The use of cold-formed steel framing members as a method of both commercial and residential construction has increased markedly in recent years. Cold-formed steel members are used as the main framing members in low-rise and mid-rise commercial structures as well as for single and multiple family construction in the United States.

The predominant member of choice for the floor joist has been the C-section (Figure 1). The Csection possesses steel's many attributes to include high strength-to-weight-ratio; rapid construction times; high levels of dimensional stability; and favorable "green construction". Although the C-section's attributes are admirable, it does not lend itself to long spans and they are not utilities friendly. The standard web punching, typically 1.5 in by 4 in, does not readily accommodate mechanical, plumbing, and HVAC systems.

To provide a cold-formed steel member that addresses the short-comings of the standard Csection, research and development has been in progress to develop an I-shaped profile.

I-Shaped Joist Attributes

The I-shaped joist is a truss shaped profile that can more easily accommodate mechanical, plumbing, and HVAC systems (Figure 2). The joist would be fabricated by a continuous rollforming process with punched web openings and closed formed flanges that are mechanically clinched. The chords are pentagonal shaped that provide flat vertical surfaces for attachment to end closures, hangers, and

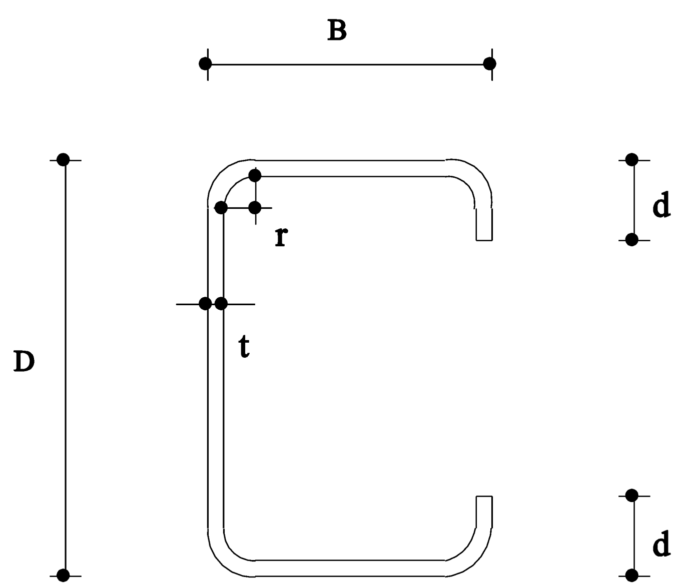

Fig. 1. Typical C-section joist.

M. Pandey et al. (eds), Advances in Engineering Structures, Mechanics & Construction, 393–399.

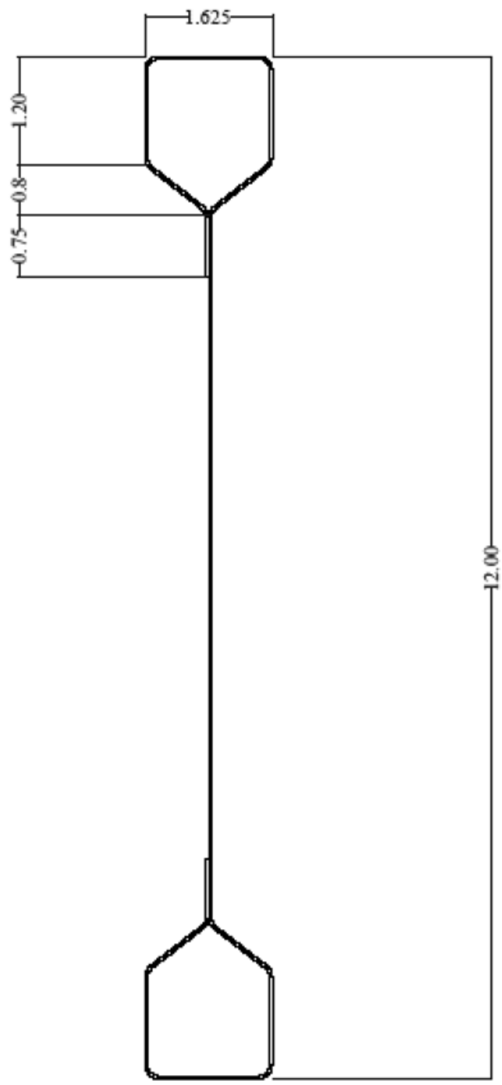

Fig. 2. Typical joist profile.

brackets (Figure 2). The trapezoidal shaped formed web openings along the length of the joist can accommodate large diameter utility passage within the floor cavity. The trapezoidal web openings are edge stiffened to provide for enhanced shear strength (Figure 3).

Experimental Study

The experimental study considered the varied strength issues related to the adequate performance of the joist to include clinching requirements for the closed chord, shear strength of the edge stiffened open web, and the flexure capacity of the closed chords.

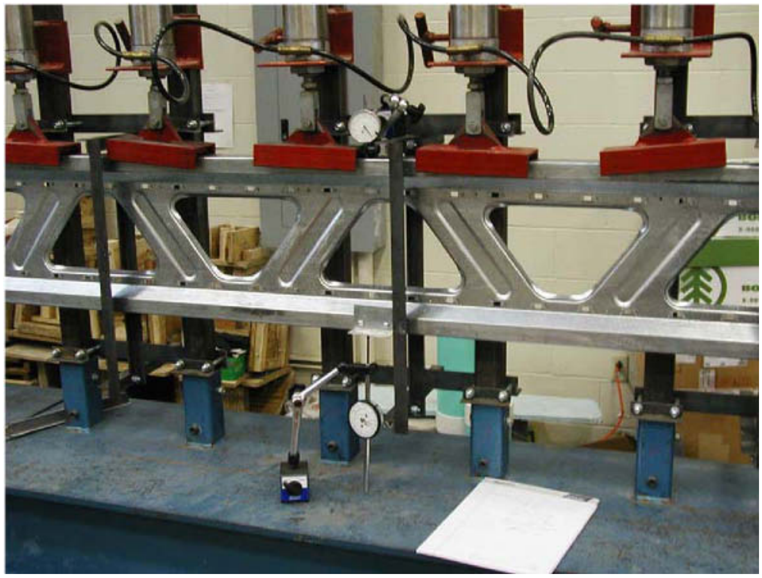

Fig. 3. Reinforced web opening.

Fig. 4. Test rig figure.

Using a simulated uniform loading test rig that enabled load to be applied by pneumatic cylinders spaced 12 inches on center, the joists were tested to failure (Figure 4). The experimental studies were performed in the structural engineering laboratory in the Department of Civil Engineering at the University of Missouri-Rolla.

Table 1. Mechanical properties.

Sheet thickness (in)	Yield strength (ksi)	Tensile strength (ksi)	Elongation %
0.046	51.4	61.5	31.5
0.035	51.3	60.8	33.7

Table 2. Clinch connection test results.

Test No.	Clinch Type	Failure Load (lb/ft)
1	"A"	129
2	"R"	130
3	"A" & screws	149
4	"R" & screws	377

Clinch Requirements

The performance of the closed joist chord to achieve a bending compression flange failure is dependent upon the structural performance of the clinch connection. For this investigation, tests were performed on joists fabricated by using two different clinch geometries, Type A and Type R. The clinches were spaced at six inches on center. Figure 3 illustrates the clinch location within the cross section.

Two joist thicknesses were considered in this study, 0.046 in and 0.035 in. Table 1 summarizes the mechanical properties of the sheet steels used to fabricate the joists profile. Table 2 summarizes the test results.

Test specimen Nos. 1 and 2, had clinches spaced at six inches on center. For Test No. 1, failure was initiated by release of the clinch at an applied load of 90.6 lb/ft and subsequent failure of the compression web at a load of 129 lb/ft. For Test No. 2 the failure was sudden with simultaneous failure of the clinch and buckling of the compression web. Figure 5 shows a typical clinch failure.

To evaluate the performance of the joist with a closer spaced clinch pattern, self-drilling screws were added between the clinches. Thus, the connectors were spaced at three inches on center. Test Nos. 3 and 4 achieved an increase in strength which is indicative of the enhanced performance to be achieved by a closer spaced clinch connector. The failure mode for both tests was a buckling of the compression web, not a failure of the clinch connection.

Based on the test results, to achieve an adequate connection, a connector spacing of three inches is required. Although the closed joist chord did not achieve a bending compression flange failure, the tests demonstrated that clinch type A was superior to clinch type R when the connector spacing was reduced to three inches.

Flexure Capacity of Compression Chord

Two joist thicknesses were considered in this study, 0.046 in and 0.035 in. Table 1 summarizes the mechanical properties of the sheet steels used to fabricate the joists. To preclude failure of the

Fig. 5. Typical clinch failure.

Table 3. Flexure test results.

Test No.	Joist Thickness (in)	Joist Depth (in)	Joist Span (ft)	w_{test} (lb/ft)	w_{comp} (lb/ft)	w_{test}/w_{comp}
2-5	0.035	12	20	176.8	178.5	0.991
2-6	0.035	12	20	203.0	178.5	1.137
3-8	0.035	12	18	202.0	221.0	0.914
3-9	0.035	12	18	216.0	221.0	0.977
3-5	0.046	12	20	249.0	239.0	1.042
3-7	0.046	12	20	249.0	239.0	1.042

compression web, as occurred in the clinch study, the web was reinforced or embossed as shown by Figure 3. Clinches were of type "R" spaced three inches on center.

A total of six tests were performed in this study as summarized in Table 3. Figure 6 shows a typical joist failure. The tested capacity, w_{test}, was compared with the computed capacity, w_{comp}, where the computed capacity was based on the AISI specification (North, 2001). On the average, the flexure capacity of the joist was achieved for both thicknesses of joist. Also, the tests verified that the joist behavior is best modeled as a beam and not a truss.

Web Shear Capacity

A series of ten tests were performed to assess the affect of shear on the performance of the open-web I-joist. Two material thicknesses, 0.047 in and 0.060 in, were considered in the test program (Table 4). Clinches were of type "R" spaced three inches on center.

The load application was a simulated uniform loading condition (Figures 3 and 4) and for each test specimen the maximum applied uniform load, w_{test}, is listed in Table 4. The failure for each test

Fig. 6. Flexure failure.

Table 4. Shear test results.

Test No. (in)	Joist Thickness (in)	Joist Depth (ft)	Joist Span (lb/ft)	w_{test} (kips)	V_2 (kips)	V_n	V_2/V_n
4-1	0.035	18	20	242	2.26	2.12	1.07
4-2	0.35	18	20	241	2.25	2.12	1.06
4-3	0.60	18	20	300	2.80	2.84	0.99
4-4	0.60	18	20	308	2.87	2.84	1.01
4-6	0.35	16	20	275	2.57	2.12	1.21
4-7	0.35	16	19.67	275	2.54	2.12	1.20
4-8	0.35	16	19.67	269	2.49	2.12	1.17
4-9	0.35	14	19.67	237	2.19	2.12	1.03
4-10	0.60	14	19.67	306	2.83	2.84	1.00

specimen occurred in the flat portion of the web between the junction of the chord and web and the edge of the stiffened hole (Figure 7). This web depth for the section was taken as 0.75 in for all test specimens, as indicated on Figure 2. The failure occurred at the location of the first compression web diagonal. The shear was assumed to be linearly varying along the length of the span, thus the computed shear force at the first compression diagonal, V_2, is listed in Table 4.

The nominal shear strength of the web, V_n, was evaluated by using the AISI specification (North, 2001). The controlling shear limit state for all test specimens was web yielding because the web flat width was defined as 0.75 in for test specimens. This flat width defined the corresponding h/t ratios. Web yielding is defined by the following equation:

$$V_n = 0.6F_y ht, \tag{1}$$

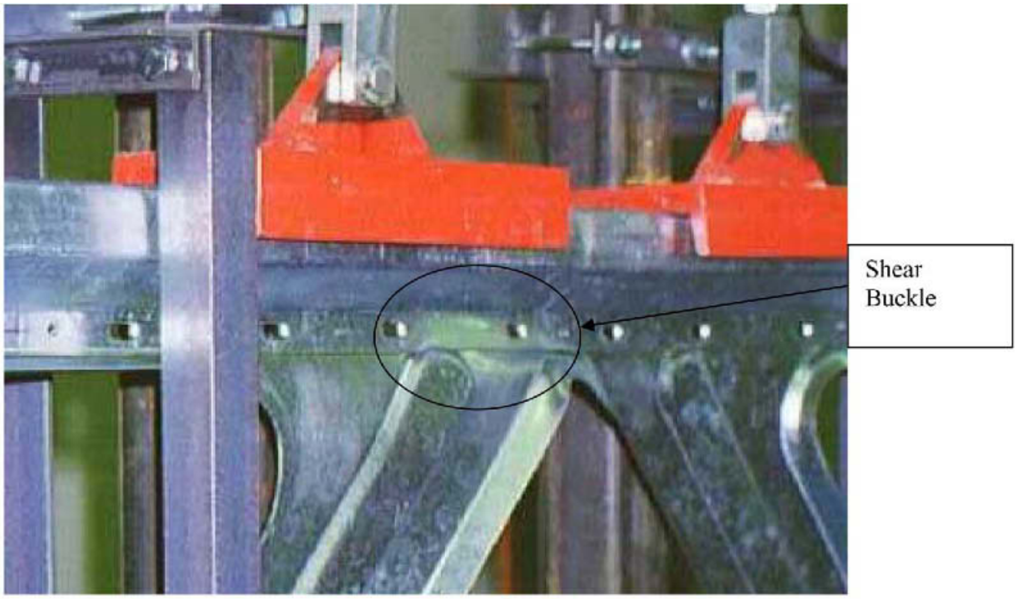

Fig. 7. Typical shear failure.

where $F_y = 50.2$ ksi and $t = 0.047$ in or $F_y = 52.9$ ksi and $t = 0.060$ and $h = 0.75$ in. The accuracy of Equation (1) to estimate the shear capacity of the web is shown by the ratio of V_2/V_n in Table 4. For the test specimens in this study, the V_2/V_n ratio ranged from 0.99 to 1.21 with an average value of 1.08.

Summary and Conclusions

An experimental study was performed to consider the varied strength issues related to the adequate performance of an I-joist having an open web configuration. The strength issues include clinching requirements to achieve the closed chord profile, the shear strength of the edge stiffened open web, and the flexure capacity of the closed chords.

Based on the test program, two clinch types were studied and it was determined that clinch type "R" was more structurally effective. Also, a maximum spacing of three inches on center was required to preclude a premature failure of the clinch connection.

Both the shear and the flexural capacity of the I-joist can be adequately predicted by using the design provisions of the North American Specification for the Design of Cold-Formed Steel Structural Members (2001).

Reference

North American Specification for the Design of Cold-Formed Steel Structural Members, 2001, American Iron and Steel Institute, Washington, DC.