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ISpan a Light Steel Floor System

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iSPAN™, A Light Steel Floor System

D.M. Fox[1], R.M. Schuster[2], and M.R. Strickland[3]

Abstract

Described in this paper is a cold-formed steel floor system called 'iSPAN'. The system is comprised of multi-functional components including the iSPAN Floor Joist, which is fabricated by fastening two cold-formed chord elements to a flat web element resulting in a visual I-type cold-formed steel section. This makes it possible to create a section where the chord elements can be of a different steel thickness with respect to the web element, resulting in a most structurally efficient cross section. The section has lip-reinforced web openings along the joist length to accommodate the usual service elements. Extensive tests have been carried out to substantiate the structural performance in comparison to the calculated values for flexure, shear, and web crippling. It can be concluded that the iSPAN Floor System has one of the highest mass to strength ratios in the industry.

Introduction

The iSPAN Floor System, shown in Figure 1, has been developed in response to the need for a simple, long spanning floor system with superior fire resistance and acoustic ratings. It is comprised of multi-functional components including

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the iSPAN Floor Joist, End Connector, Snap-In Bridging, and Blocking. It is the first light weight floor system that is able to achieve a 1 hour Fire Resistance Rating (FRR) with only one layer of 5/8in. gypsum board and plywood or OSB sheathing while maintaining a Sound Transmission Coefficient (STC) of 50 when constructed as per UL L575 / ULC M513.

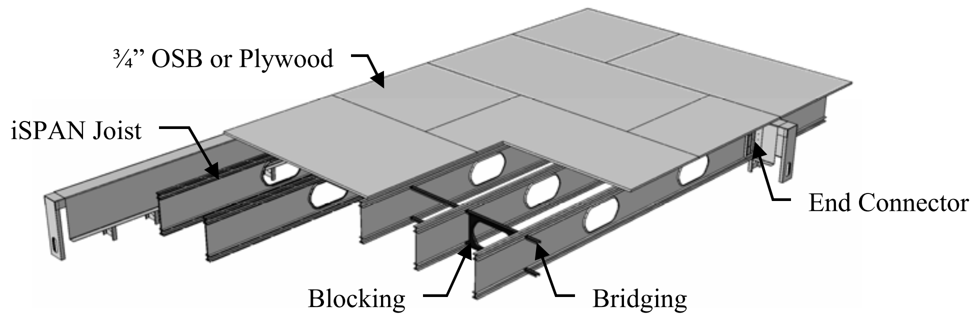
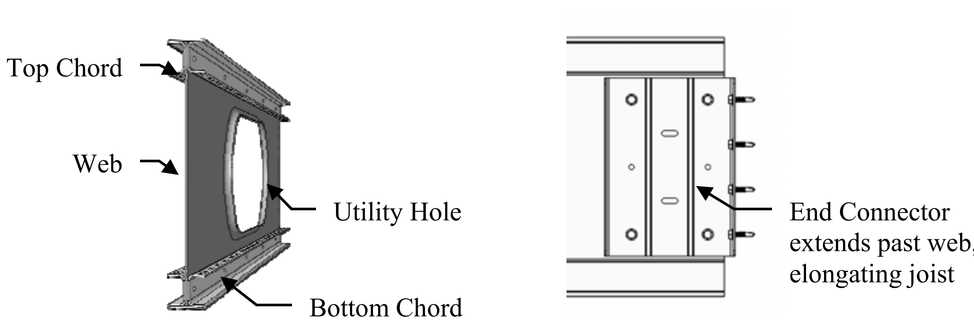


Figure 1 - iSPAN Floor System

The joist, shown in Figure 2(a), is comprised of a top and bottom chord riveted to a web element, allowing for structural optimization of the joist. Lip-reinforced utility holes are provided at regular intervals in the web along the member to facilitate service installation for follow-up trades. Shown in Figure 2(b) is an integrated end connector that connects the joist to a rim joist as well as stiffens the web element at bearing locations. Furthermore, the end connector is able to extend past the end of the joist, accommodating on-site tolerances. The wings of the chords have bridging holes that accept iSPAN Snap-In Bridging.



(a) iSPAN Joist (b) Integrated End Connector

Figure 2 - iSPAN Floor Joist

iSPAN Bridging, shown in Figure 3, snaps into the wings of the chord elements. As well as providing lateral stability of the joist, the bridging allows for proper joist alignment without the need of a measuring tape or a square after proper installation of the initial joist in a floor. The bridging elements also provide a surface to attach iSPAN Blocking. The blocking, shown in Figure 3, provides additional lateral stability and resistance against racking while maintaining a service corridor with the same utility holes as found on the joist web.

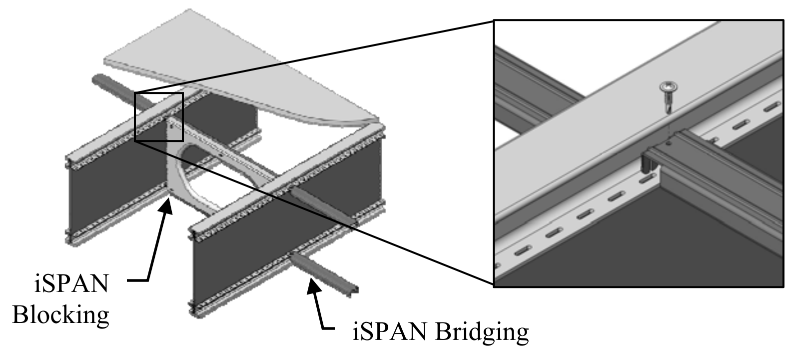


Figure 3 - iSPAN Bridging and Blocking

iSPAN Joist Tests

Presented in the following sections is an overview of the tests performed on the joist along with appropriate comparisons based on the 2001 North American Specification for the Design of Cold Formed Steel Structural Members (herein referred to as the NAS) (NAS, 2002). All tests were carried out in Richmond Hill, Canada. All tested joists were fabricated from ASTM A653 steel from which coupon tests were taken, the results of which are shown in Table 1.

Table 1 - Material Properties

Gauge Thickness	Base Steel Thickness (in)	F_y (ksi)	F_u (ksi)
16	0.0570	57.5	72.5 [500]
18	0.0475	58.5	68.0

Flexural Tests

Flexural tests were performed on 12in. deep joist, the dimensional properties of which are shown in Table 2 and the test setup is shown in Figure 4. The shear spans of the joists were reinforced to prevent preliminary failure and the joists were fully supported laterally during loading.

In each test, the total load, P_t was electronically recorded and the results of the tests are summarised in Table 3. In all tests, the joists failed away from the location of the lip-reinforced hole by chord/web local buckling, as shown in Figure 5. Failure always occurred between rivets. Neither rivet failure nor localized failure of the material around the rivets was ever observed.

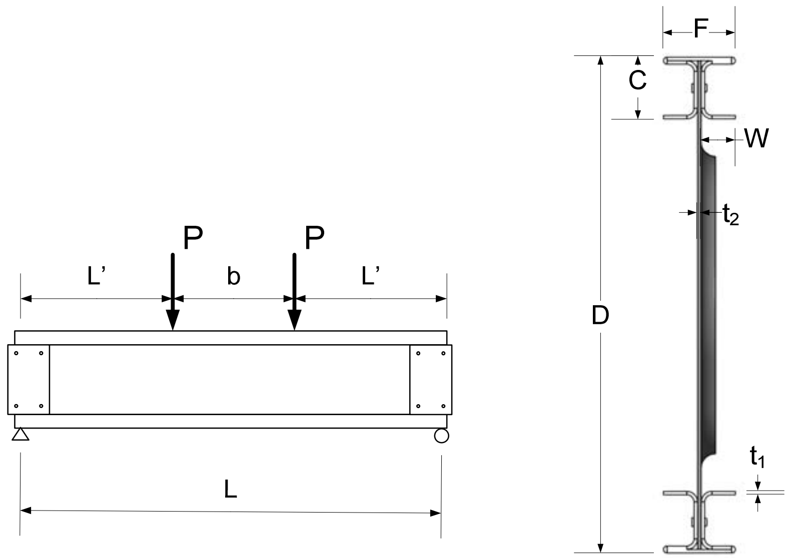
The NAS was used to calculate the nominal flexural capacities of the joists, P_c, with modified stiffened and unstiffened plate buckling coefficients of 2.50 and 0.30. Test to calculated ratios, P_t/P_c, for the specimens were on average equal to or greater than 1.0 and are shown in Table 3.

Table 2 - Flexural Specimen Dimensions

ID	D (in)	F (in)	C (in)	W (in)	Gauge t_1	Gauge t_2	L' (in)	b (in)	L (in)
FH1	12	2.0	1.75	1.0	18	18	57	30	144
FH2	12	2.0	1.75	1.0	18	18	54	36	144
FH3	12	2.0	1.75	1.0	16	18	60	24	144
FH4	12	2.0	1.75	1.0	16	18	54	36	144

Table 3 - Comparison of Flexural Test Results to Calculated

ID	*P_t (kip)*	*P_c (kip)*	*P_t/P_c*
H1	7.81	7.69	1.02
H2	8.28	8.12	1.02
H3	9.45	9.10	1.04
H4	10.1	10.1	0.99



(a) Test Setup (b) Joist Cross Section

Figure 4 - Test Setup

Figure 5 - Photograph of Typical Flexural Failure of iSPAN Joist

Shear Strength

The shear strength of the joist web was established using the test setup shown in Figure 4. The constant moment region of the joist was reinforced to prevent a premature failure and the joists were fully supported laterally during loading. Joists with and without lip-reinforced holes were tested, the properties of which are shown in Table 4 and Table 5, respectively. The web was fully reinforced along the length of the joist except within the shear panel, a.

In each test, the total load, P_t, and the mid-span deflection were electronically recorded, the results of which are shown in Table 6 and Table 7 for joists with and without holes, respectively. Each test failed in diagonal shear buckling, originating from the corners of the shear panel inside the chord elements, as shown in Figure 6 and Figure 7 for specimens with and without holes, respectively. The NAS was used to calculate the nominal shear capacity of the web, the results of which are included in Table 6 and Table 7 as P_c. As a result of the shear buckling being confined between the wings of the chords, the effective height of the web, h, can be assumed to be the distance between the wings of the chords, reducing the web slenderness ratio relative to a C-section of similar overall depth. As such, P_c was calculated on the basis of the web area, slenderness ratio, and aspect ratio as follows:

$$\textit{Web Area}, A_w = [D - 2t_1]t_2 \tag{1}$$

$$\textit{Slenderness Ratio}, h/t = [D - 2C]/t_2 \tag{2}$$

$$\textit{Aspect Ratio}, a/h = a/[D - 2C] \tag{3}$$

The tested web shear strength of the ranged from 13% to 96% for webs with holes and 63% to 309% for webs without holes greater than the predicted capacity calculated as per the NAS.

The shear buckling equations found in the NAS were calibrated from test results of C-sections. Due to the profile of the C-section, the support conditions along the edges of the web tend to behave in a simply supported manner with a shear buckling coefficient, k_v, of 5.34, as shown in Figure 8(a). In the iSPAN Floor Joist, the web is held in place at the top and bottom by the chords. This provides a rotationally stiffer edge support, as shown in Figure 8(b), and is supported by the fact that no web distortion is observed within the chords during shear failure. The theoretical shear buckling coefficient, k_v, for fixed edges is 8.98.

However, setting k_v equal to 8.98 and calculating the shear capacities, shown as P_{c2} in Table 7, is still a conservative approach for the specimens without holes. The tested capacities ranged from 3% to 172% greater than the calculated capacities, P_{c2}. Further work is required to fully develop a suitable design equation.

Table 4 - Shear Specimen Dimensions WITH Utility Holes

ID	D (in.)	F (in.)	C (in.	W (in.)	Gauge		L' (in.)	Shear Panel, a (in.)	L (in)
					t_1	t_2			
SH1	12	2.0	1.75	1.0	18	18	30.0	22.5	72
SH2	12	2.0	1.75	1.0	18	18	26.5	23.0	77
SH3	12	2.0	1.75	1.0	18	18	30.0	28.5	72
SH4	12	2.0	1.75	1.0	18	18	30.0	28.5	72
SH5	12	2.0	1.75	1.0	16	16	29.5	28.5	71
SH6	12	2.0	1.75	1.0	16	16	29.5	28.5	71
SH7	12	2.0	1.75	1.0	16	18	30.0	22.5	72

Table 5 - Shear Specimen Dimensions WITHOUT Utility Holes

ID	D (in.)	F (in.)	C (in.	W (in.)	Gauge		L' (in.)	Shear Panel, a (in.)	L (in)
					t_1	t_2			
S1	12	2.0	1.75	1.0	16	18	25.0	22.0	72
S2	12	2.0	1.75	1.0	18	18	27.0	12.0	72
S3	12	2.0	1.75	1.0	18	18	27.5	22.0	71
S4	12	2.0	1.75	1.0	16	16	27.5	22.0	71
S5	12	2.0	1.75	1.0	16	16	27.5	22.0	71
S6	14	2.0	1.75	1.0	18	18	27.5	22.0	71
S7	14	2.0	1.75	1.0	18	18	27.5	22.0	71
S8	14	2.0	1.75	1.0	18	18	27.5	22.0	71
S9	14	2.0	1.75	1.0	16	16	27.5	22.0	71
S10	14	2.0	1.75	1.0	16	16	27.5	22.0	71
S11	14	2.0	1.75	1.0	16	16	25.5	16.5	71
S12	16	2.0	1.75	1.0	18	18	25.5	22.0	71
S13	16	2.0	1.75	1.0	18	18	25.5	22.0	71

Table 6 - Results of shear tests on specimens WITH Holes

ID	*h/t*	*a/h*	*P_t (kip)*	*P_c (kip)*	*P_t/P_c*
SH1	179	3.53	9.04	5.54	1.63
SH2	179	3.12	9.64	5.52	1.75
SH3	179	3.53	8.41	5.35	1.57
SH4	179	3.53	8.38	5.35	1.57
SH5	149	3.47	10.4	9.22	1.13
SH6	149	3.47	10.5	9.22	1.14
SH7	179	3.53	10.8	5.54	1.96

Table 7 - Results of shear tests on specimens WITHOUT Holes

ID	*h/t*	*a/h*	*P_t (kip)*	*P_c (kip)*	*P_t/P_c*	*P_{c2} (kip)*	*P_t/P_{c2}*
S1	179	2.94	13.3	5.54	2.41	8.86	1.51
S2	179	3.18	12.2	6.86	1.78	8.81	1.39
S3	179	3.24	13.0	5.57	2.33	8.80	1.47
S4	149	3.24	15.6	9.60	1.63	15.2	1.03
S5	149	3.24	15.7	9.60	1.63	15.2	1.03
S6	221	2.62	14.4	4.49	3.20	6.88	2.09
S7	221	2.62	13.3	4.49	2.96	6.88	1.93
S8	221	2.62	13.7	4.49	3.05	6.88	1.99
S9	184	2.62	17.7	7.74	2.29	11.9	1.49
S10	184	2.62	17.0	7.74	2.20	11.9	1.43
S11	184	2.43	19.3	8.60	2.24	12.0	1.61
S12	263	2.04	15.1	3.84	3.94	5.77	2.62
S13	263	2.04	15.7	3.84	4.09	5.77	2.72

Figure 6 - Typical Shear Failure WITH Holes

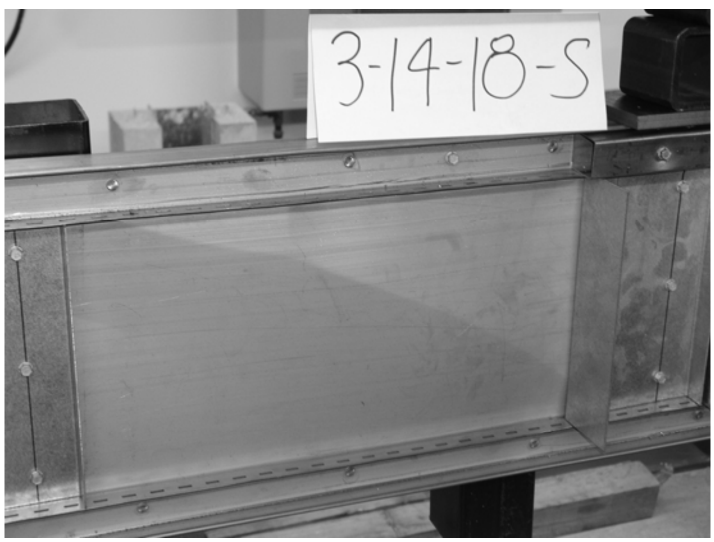


Figure 7 - Typical Shear Failure WITHOUT Holes

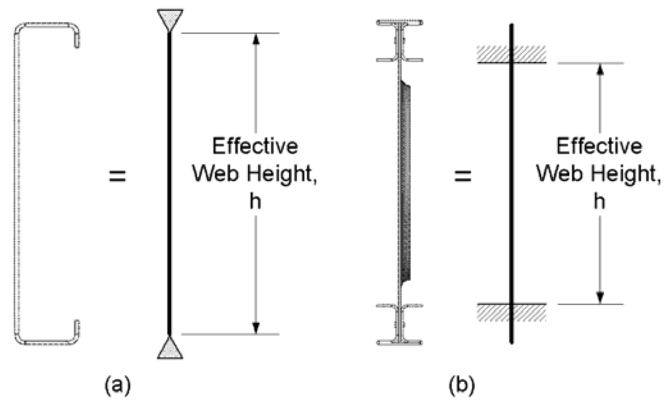


Figure 8 - Web Support Conditions for (a) C-section, and (b) iSPAN Joist

Web Crippling Capacity

Some preliminary web crippling tests have been carried out considering the four typical loading cases contained in the NAS. Early indications show that the basic web crippling equation in the NAS can be applied to the joist with newly established coefficients based on test results.

Floor System Comparisons

Comparison Tests

The primary objective of the comparison tests was to establish the structural capacity of an iSPAN Floor System in comparison with an equivalent typical C-section floor system. The overall dimensions of both floor systems were the same, i.e., 22 ft x 4 ft. In the case of the C-section floor, four 22 ft long 16 gauge joists were spaced at 16 in. on center while the iSPAN Floor System was made up of three 22 ft long 18 gauge joist sections spaced at 24 in. on center. In both cases, ASTM A653 (Grade 50) steel and 5/8 in. OSB sub flooring was used. The OSB sub floor was attached with 1 1/2 in. long # 10 self-drilling screws, spaced at 6 in. o.c. along each joist length.

In each case, the floor specimens were positioned in the test frame as shown in Figure 9 and Figure 10. After proper alignment of the floor specimens in the test frame, a string-pot deflection transducer was attached at centre span to record the deflections during loading. A line load was then applied at the centre of the 22 ft span until failure. Each steel assembly, without the OSB subfloor, was also weighed to establish the proper strength to weight ratio. In both cases, failure was experienced by local buckling in the compression flanges, as shown in Figure 11 and Figure 12.

Shown in Figure 13 are the load deflection curves for each floor system tested. The weight of the C-section floor was 352 lbs and the failure load was 6624 lbs, resulting in a strength to weight ratio of 6,624/352 = 18.8. For the iSPAN floor, the failure load was 10,724 lb and the weight was 366 lb, which resulted in a strength to weight ratio of 10724/366 = 29.3.

As well, it can be observed that the iSPAN floor has an increased stiffness in comparison to the C-section floor. In fact, at both the L/360 and L/480 deflection levels (0.73in. and 0.55in., respectively) the iSPAN Floor System carried 25% more load than the C-section floor at the same deflection.

Figure 9 C-section Floor in Test Frame

Figure 10 - iSPAN Floor System in Test Frame

Figure 11 Photograph of failure in C-section Floor

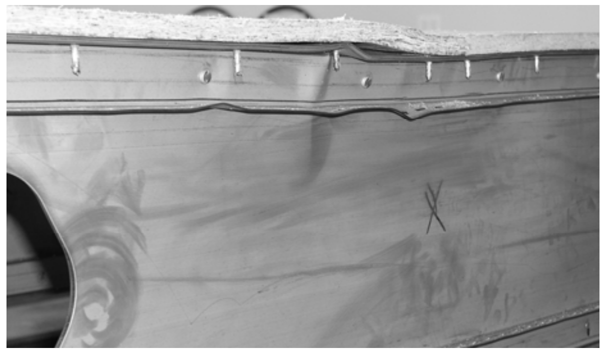


Figure 12 - Photograph of failure in iSPAN Floor System

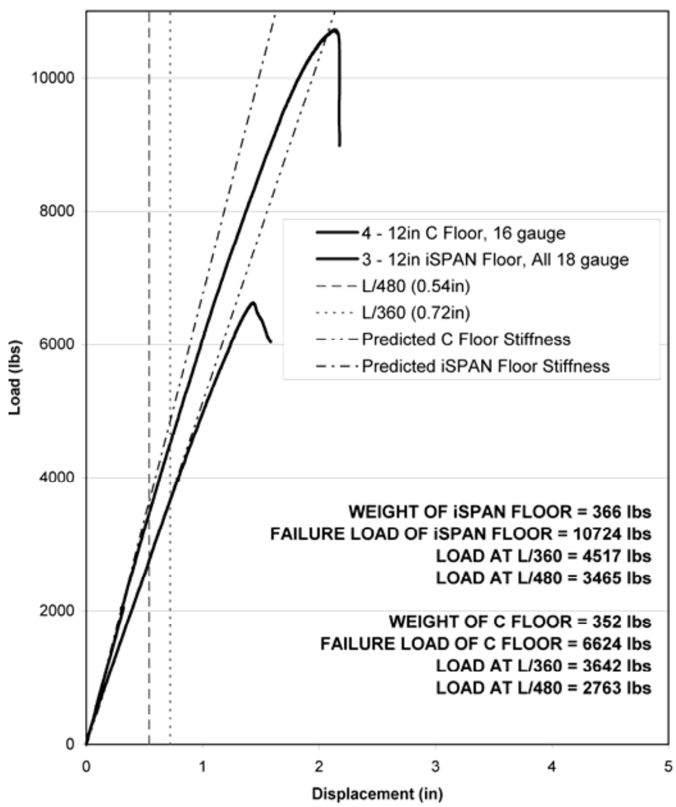


Figure 13 - Load Displacement Plots of Assembly Tests

Weight to Span Comparison

To extend the comparison of the test assemblies, an analysis was performed to determine the weight savings that could be achieved by using the iSPAN Floor System with respect to typical C-section floor system.

For the iSPAN Floor System, joist depths of 10in. to 16in. were assumed, using 20ga. (0.036in.) to 14 ga. (0.075in.) steel thicknesses. The flange width (F), chord depth (C), and the wing length (W) were kept constant at 2.0in., 1.75in., and 1.0in., respectively. The yield strength of the steel in all cases was 50ksi.

For the C-section floor, typical configurations offered by current manufacturers were used. Joists depths ranged between 10in. to 16in. Gauge thicknesses ranged from 18 ga. (0.048in.) to 14ga. (0.075in.). Flange widths ranged from 1 5/8in. to 3 1/2in. Lip depths ranged from 1/2in. to 1.0in. Finally, the grade of steel assumed was 33ksi for gauge thickness thinner than 16 ga. and 50ksi for gauge thickness of 16ga. and thicker.

Criteria used to determine maximum span were:

1. Strength = Flexure

2. Serviceability = Deflection Limit of L/480

The result of the analysis is graphically shown in Figure 14. It can be seen that the iSPAN Floor System with 24in. on center joist spacing provides weight savings throughout the entire span range under consideration (16 feet to approximately 33 feet) relative to the C-section floor at 16in. o. c., with a maximum weight savings of 46% at a span of 26 feet. Comparing the C-section floor with a joist spacing of 24in. o. c. shows that the iSPAN Floor System exhibits weight savings after a span of approximately 20 feet, with the maximum weight saving being 17% at a span of 26 feet. The iSPAN Floor System results in a 17% larger span than the C-section floor at the same joist spacing.

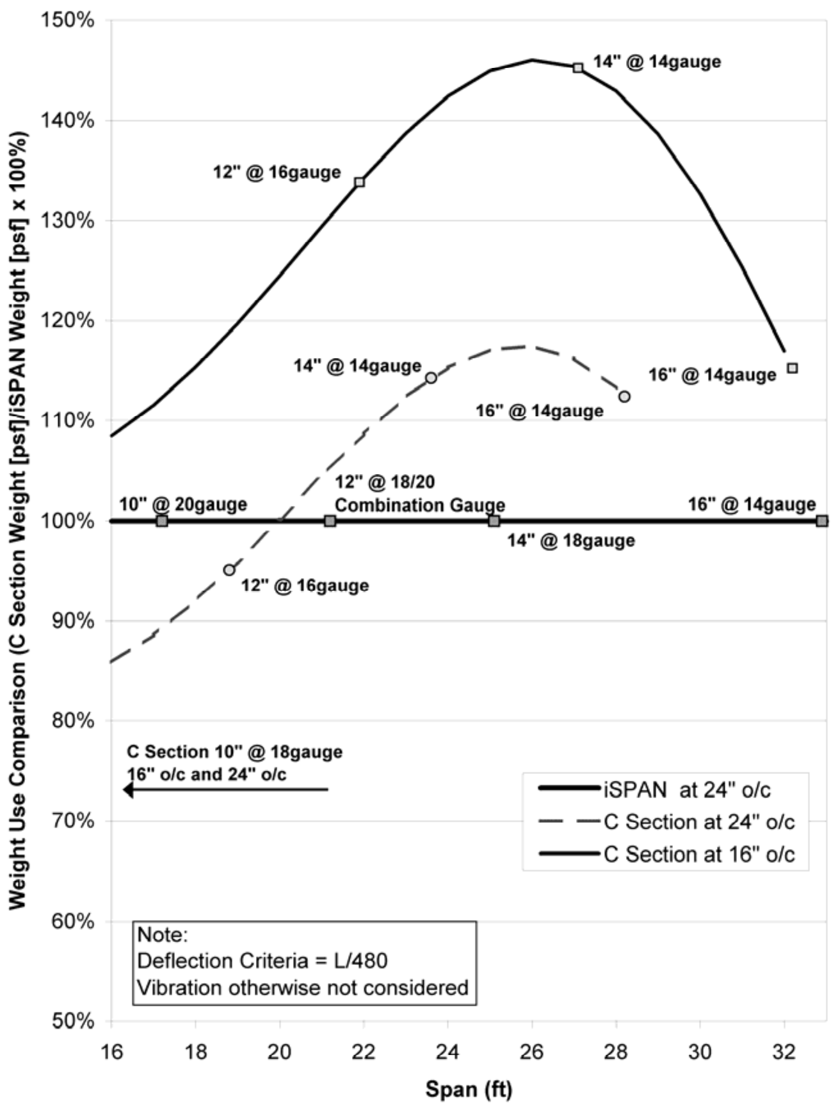


Figure 14 - Weight Comparison of iSPAN Floor with C-section Floor

Conclusions

Contained in this paper is a summary of the tests performed on the iSPAN joist and Floor System. More specifically, flexural, shear and web crippling tests were carried out on the joist and respective comparisons were made with the calculated values based on the NAS. In addition, two floor assembly tests were performed, one with the iSPAN joists and the other with typical C-section joists.

Based on the tests and respective calculated results, the following observations can be made:

1. The flexural capacity of the joist can be predicted accurately with some modifications in the plate buckling coefficients.
2. The slenderness ratio of the joist, for web shear buckling calculations, can be reduced to the height between the chords. Furthermore, the web edge supports are rotationally stiffer due to the fact that they are held in place by the chords, resulting in an increased shear-buckling strength.
3. Web crippling tests have been carried out considering the four typical loading cases contained in the NAS. Early indications show that the basic web crippling equation in the NAS can be applied to the joist with newly established coefficients based on test results.

The following observations can be reached for the two floor assembly tests:

1. The iSPAN Floor System with 24in. o. c. joist spacing can save up to 46% in weight with respect to a C-section floor with 16in. o. c. joist spacing, which is the typical cold-formed steel joist in the marketplace today.
2. The iSPAN Floor with 24in. o. c. joist spacing can span up to 17% further than the C-section Floor with the same joist spacing, and save up to 17% in weight.

Appendix I - Reference

American Iron and Steel Institute. (2002). *North American Specification for the Design of Cold-Formed Steel Structural Members*. Washington DC

Appendix II - Notation

a	Aspect Ratio of Shear Panel
A_w	Cross-sectional area of web
b	Length of Constant Moment Region
C	Overall Chord Depth
D	Overall Joist Depth
k_v	Shear Buckling Coefficient
F	Overall Flange Width
F_y	Yield Strength
F_u	Ultimate strength
L	Length of Joist Span
L'	Length of Shear Span
P	Applid Load
P_c , P_{c2}	Calculated Strength of Specimen
P_t	Tested Strength of Specimen
t_1	Thickness of Chord Element
t_2	Thickness of Web Element
W	Wing Width