Steel Systems
Innovation Research Lab

Modified Slenderness Ratio of Joist Chord Members

Report to Steel Joist Institute, May 2024 (Revised August 2024)

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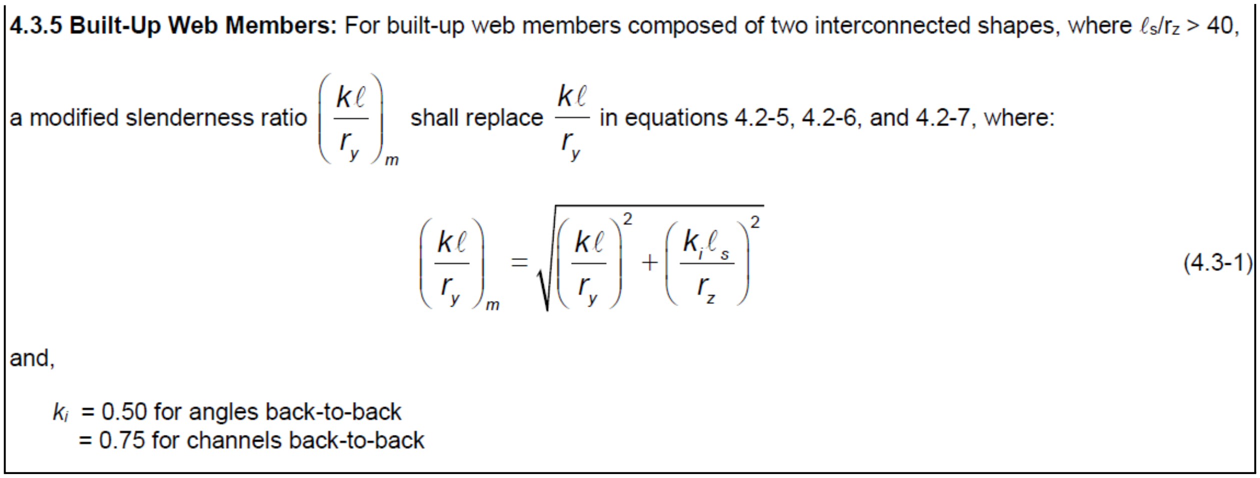
Introduction

The goal of this research project was to determine if a modified slenderness approach that is currently used for web members should be applied to chords in compression. The specific application is to bottom chords in compression due to wind uplift, with bracing provided by bridging.

Current and Proposed Slenderness Approach

The current SJI approach for global buckling of bottom chords in compression is to consider the unbraced length between lines of bridging, with an effective length factor (K) of 0.94, and the radius of gyration being r_y of the composite bottom chord.

This study considered using a modified slenderness approach for the bottom chord slenderness using the same method as found in Section 4.3.5 of the SJI Standard (SJI 2020) for web members as shown in Figure 1.



4.3.5 Built-Up Web Members: For built-up web members composed of two interconnected shapes, where $\ell_s/r_z > 40$, a modified slenderness ratio $\left(\frac{k\ell}{r_y}\right)_m$ shall replace $\frac{k\ell}{r_y}$ in equations 4.2-5, 4.2-6, and 4.2-7, where:

$$\left(\frac{k\ell}{r_y}\right)_m = \sqrt{\left(\frac{k\ell}{r_y}\right)^2 + \left(\frac{k_i\ell_s}{r_z}\right)^2} \qquad (4.3\text{-}1)$$

and,

k_i = 0.50 for angles back-to-back
= 0.75 for channels back-to-back

Figure 1. Modified slenderness for compression web members (SJI, 2020)

Modeling

A single K-series open web steel joist with a length of 50 feet and a depth of 30 inches (30K) was used as the model for this study. The top and bottom chords were hot rolled steel angles with a clear space of 1.0 inches. The web members (except for the end bar) were crimped-end hot rolled angles, and the end bar was a 7/8" diameter solid round bar. The steel yield stress was 50 ksi. Both top and bottom chord angles had panel points at 48 inches on center, and where required, fillers were inserted between the chord angles at the panel mid-point.

The joists were modeled both in Abaqus and MASTAN2, however it became clear that the results from the MASTAN2 model provided more useful information, and therefore this report is based upon those results. When modeled in MASTAN2, the modeling assumptions previously developed and verified by Sippel et al. in AISI (2021) were used.

For purposes of this report, the axes are defined as used in the SJI Standard (SJI 2020), where X-axis buckling is in the vertical plane, Y-axis buckling is out of the plane of the joist, and Z-axis buckling is about the least principal axis of an individual angle. This is illustrated in Figure 2.

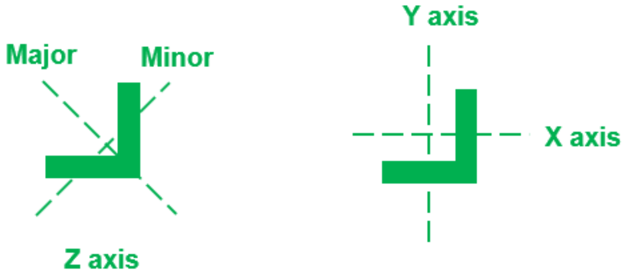


Figure 2. Axis definitions

Two bottom chord bridging spacings were considered:

1. A midspan bridging line, with adjacent bridging lines spaced 240 inches to each side, and a line of bridging at the first bottom chord panel point at each end of the joist. (L_y = 240 inches)

2. A midspan bridging line, with adjacent bridging lines spaced 150 inches to each side, and a line of bridging at the first bottom chord panel point at each end of the joist. (L_y = 150 inches)

Fillers were either present or not present for both bridging spacings (L_z = 48 or 24 inches). The top chord was braced at each panel point (24 inches on center) to simulate deck attachment. To ensure that the buckling limit was in the bottom chord and not the end bar, the ends of the end bar were both fixed against rotation. All other web end connections were modeled with a small semi-rigidity as recommended by Sippel et al. in AISI (2021) to promote analysis convergence.

MASTAN2 Buckling Analysis

For both bridging spacings, the mode of global buckling was elastic buckling out of the plane of the joist as shown in Figure 3.

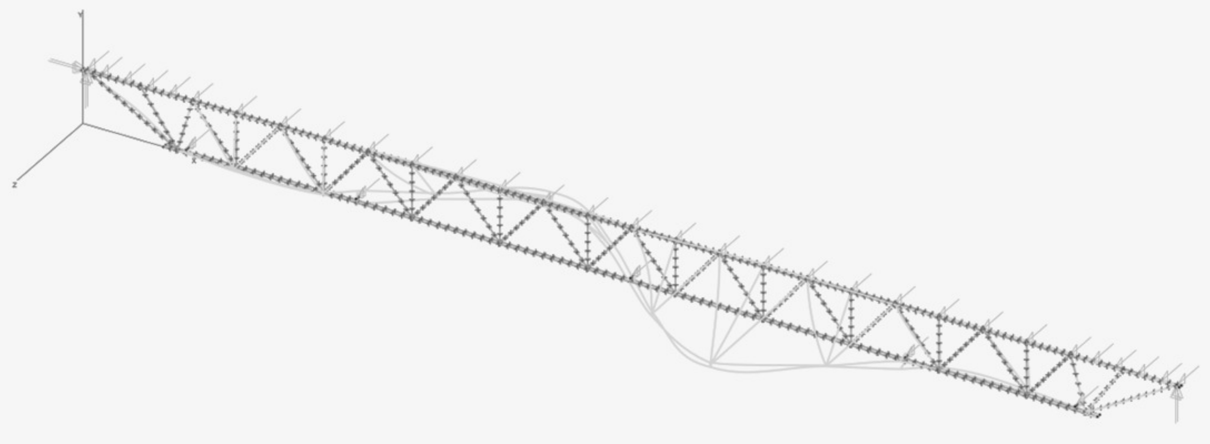


Figure 3. First mode buckling of joist with 150-inch bottom chord bridging spacing

For each model, the force in the bottom chord both at the midspan between bridging lines and at the location of highest axial force (at the bridging location) was recorded for the first mode buckling. This buckling force was used to back calculate the effective slenderness ratio (KL/r) for that model.

MASTAN2 has both *Basic* and *Advanced* section properties. The *Advanced* properties incorporate the z-axis properties of the individual angle, whereas the *Basic* properties do not. In a general way, the *Basic* properties are what is considered in the current SJI model, and the *Advanced* properties would be analogous to the Modified Slenderness model.

Analysis of MASTAN2 Results

Table 1 is a condensed report of the results using the highest force in the unbraced span between the bridging lines (closest to the joist midspan).

L_y (in.)	L_z (in)	Basic Section Properties (w/o r_z)		Advanced Section Properties (w/ r_z)	
		F_{cr} (psi)	Back calculated slenderness ratio	F_{cr} (psi)	Back calculated slenderness ratio
150	48	11961	145	11014	151
240	48	5395	216	5018	224
150	24	12538	141	12121	144
240	24	5671	210	5300	218
		Note: F_{cr} recorded at highest chord force (at bridging location)			

Table 1. MASTAN2 buckling results

For both the 150 inch and 240-inch bridging spacings (L_y), the presence of fillers (L_z = 24 inches) or absence of fillers (L_z = 48 inches) makes a small difference in the buckling stress and effective slenderness ratio, indicated in Table 2. Furthermore, the *Advanced* section properties model is the correct consideration of section properties.

L_y (in.)	Basic Section Properties (w/o r_z)		Advanced Section Properties (w/ r_z)	
	F_{cr} (psi) increase with fillers	Back calculated slenderness ratio reduction with fillers	F_{cr} (psi) increase with fillers	Back calculated slenderness ratio reduction with fillers
150	4.83%	-2.33%	10.05%	-4.68%
240	5.12%	-2.46%	5.62%	-2.70%

Table 2. Effect of fillers increases buckling stress and reduced slenderness ratio

Table 1 also shows the back calculated slenderness ratio from the MASTAN2 buckling analysis using both the *Basic* and *Advanced* section properties. These results are further described in Table 3.

L_y (in.)	L_z (in)	*Advanced* / *Basic* slenderness ratio
150	48	1.04
240	48	1.04
150	48	1.02
240	48	1.03
MEAN		**1.03**

Table 3. Generalized slenderness ratio results

The main observations are as follows:

1. The difference between the back calculated slenderness ratio using the *Basic* versus *Advanced* section properties is small, with a mean difference of 1.03. This indicates that joist modeling neglecting the r_z axis buckling is minimally unconservative.
2. Complications to applying the modified slenderness approach for the chord include:
    a. The presence or absence of fillers vary along the unbraced length, whereas this complication does not exist for webs which either have or do not have fillers.
    b. The varying axial force in the chord unbraced length, versus a constant axial force along the length of a web. Refer to Shrivastava (1980), Timoshenko (1952), and Bleich (1952) for further details.

Recommendation

The modified slenderness approach for web members should not be applied to unbraced chords. The current approach for chords in SJI 100 is adequate (3% difference when considering z-axis buckling).

References

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