Lateral-Torsional Buckling of Suspended Tee-Shape and Flat Plate Lifting Beams

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Introduction

The equations most commonly used in practice for the design of steel beams (e.g., AISC 2010) are based on the assumption that the members are restrained against lateral displacement and twist at the ends of the unbraced length. Beams that are suspended by wire rope, chains or other flexible elements, as is the case with beams used for lifting, are not restrained as such. Thus, the buckling behavior of suspended lifting beams can be expected to vary from that predicted by the common design equations.

A standard applicable to the design of lifting and spreader beams (ASME 2014) introduced in its 2011 edition buckling strength correction factors C_{LTB} to be used in the design of I-shape, tee-shape and flat plate beams that are suspended from flexible elements, rather than framed into a structure. The current (2014) edition refined the definitions of C_{LTB} as a result of additional study of beam buckling behavior. Otherwise, the basic beam design equations in ASME (2014) are similar to those in AISC (1989) and AISC (2010).

Duerr (2015) presents an evaluation of the C_{LTB} equation for the design of I-shape beams using finite element analysis (FEA). The FEA model was validated by comparison to published test data (Dux and Kitipornchai 1990). Fig. 1 shows the results of the Duerr (2015) FEA analyses of suspended vs. restrained beams and compares those results to the BTH-1 C_{LTB} factor for I-shape beams.

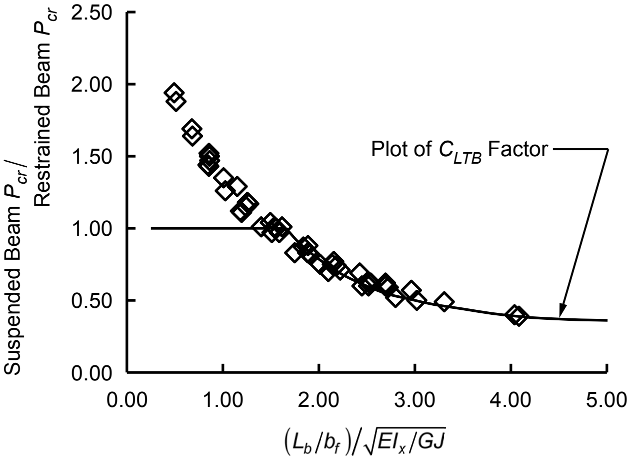

Fig. 1. Study Results for I-Shape Lifting Beams (from Duerr 2015)

The purpose of this note is to document the results of the application of this FEA model to a study of the lateral-torsional buckling behavior of tee-shape and flat plate lifting beams and to evaluate the C_{LTB} equations in ASME (2014) for these additional beam types.

FEA Elastic Buckling of Tee-Shape Lifting Beams

Elastic buckling analyses of tee-shape beams have been performed using BASP, a finite element analysis program that was developed at the University of Texas at Austin to solve elastic buckling problems (the program's name is an acronym for buckling analysis of stiffened plates). The models used for the buckling analyses of tee-shape beams are illustrated in Fig. 2. Beam cross sections were developed with depths of 305 mm with flange widths of 76 mm, 102 mm, 152 mm and 203 mm, 610 mm with flange widths of 76 mm, 102 mm, 152 mm and 203 mm, and 914 mm with flange widths of 102 mm and 152 mm. Flange and web thicknesses were 13 mm for all shapes. Various lengths of each cross section were modeled to provide a range of length/width ratios.

The model of the restrained beam (Fig. 2a) is consistent with the condition normally found in building structures. The load is applied downward at the top and the ends are supported vertically and are restrained laterally and torsionally. The model of the suspended beam with the stem in tension (Fig. 2b) is consistent with a lifting beam. The beam is lifted from a mid-span attachment at the top and rigging to the payload is attached at the bottom at each end. The ends of the beam as modeled are laterally restrained only at the bottom.

The model of the suspended tee-shape beam with the stem in compression is simply the Fig. 2b model flipped upside down. That is, the end restraints are placed at the corners of the stem and the load is applied mid-span to the flange.

Thirty-one models were analyzed with both support configurations and loaded to place the stem in tension and the stem in compression. All models used elastic properties for steel (as shown in Duerr 2015, the elastic buckling behavior

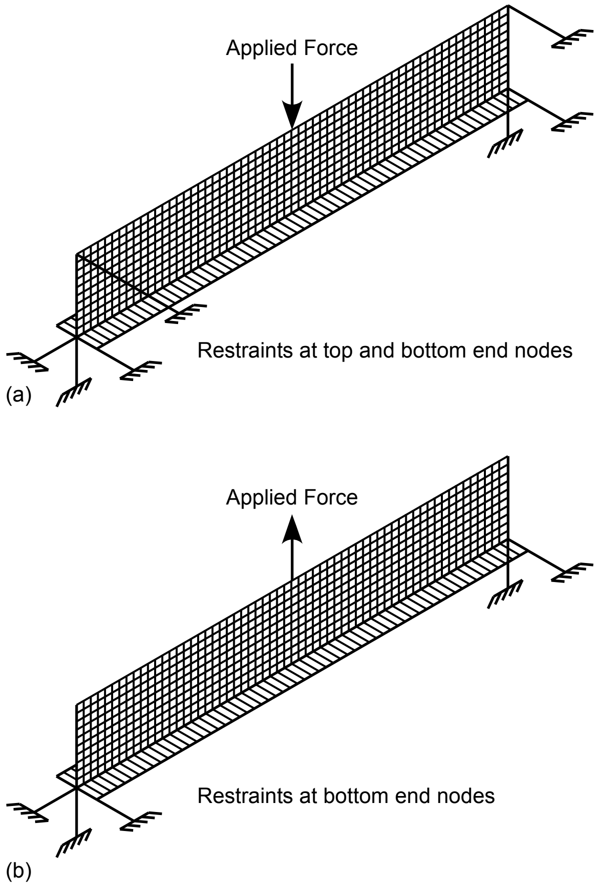

Fig. 2. Models for Tee-Shape Beam Buckling Analyses

was found to be identical for the elastic properties of steel and the elastic properties of aluminum). The difference in the buckling behavior of the suspended beam relative to that of the restrained beam is quantified by the ratio of the buckling loads calculated using BASP. These ratios are plotted against an expression that relates cross sectional properties to the length. Fig. 3 shows the results for beams with the stem in tension and Fig. 4 shows the results for beams with the stem in compression. Unlike the results found in the study of I-shape beams, the suspended tee-shape beams show a reduction in elastic buckling strength at all proportions investigated.

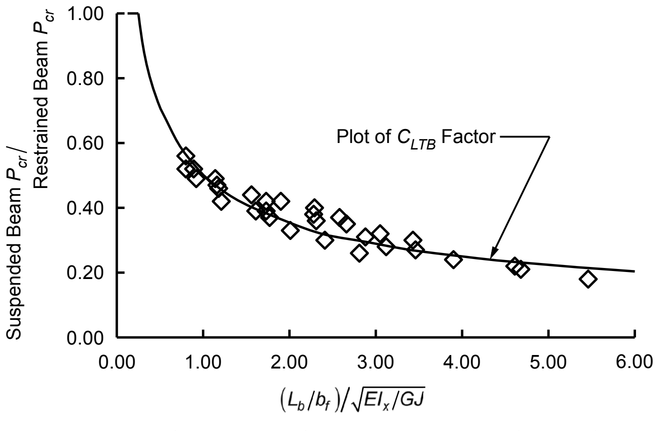

Fig. 3. Results for Tee-Shape Beams - Stem in Tension

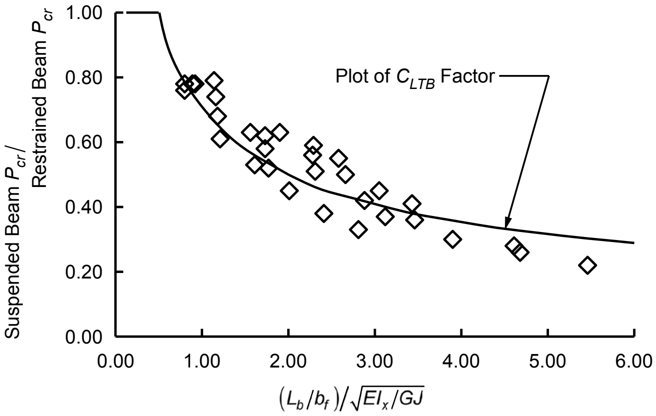

Fig. 4. Results for Tee-Shape Beams - Stem in Compression

FEA Elastic Buckling of Flat Plate Lifting Beams

Elastic buckling analyses of flat plate beams have been performed using BASP. The flat plate beam models used for the buckling analyses are illustrated in Fig. 5. The plate

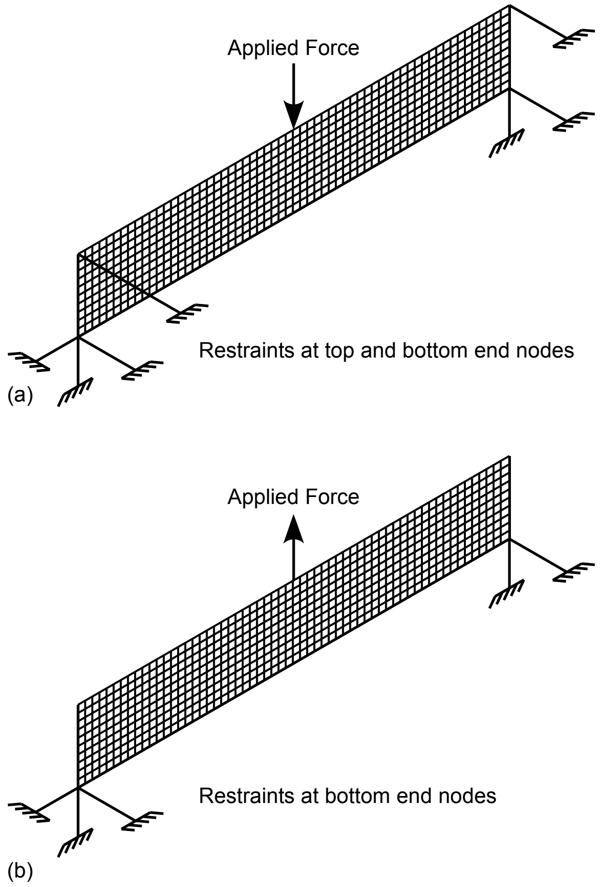

Fig. 5. Models for Flat Plate Beam Buckling Analyses

beams analyzed had depths of 152 mm with thicknesses of 13 mm, 19 mm and 25 mm, 305 mm with thicknesses of 13 mm and 25 mm, 610 mm with thicknesses of 25 mm and 51 mm, and 914 mm with a thickness of 25 mm. Again, various lengths of each cross section were modeled to provide a range of length/thickness ratios.

Twenty-six models were analyzed with both support and load configurations. All models used elastic properties for steel. The difference in the buckling behavior of the suspended beam relative to that of the restrained beam is again quantified by the ratio of the buckling loads calculated using BASP. These ratios are plotted against an expression that relates cross sectional properties to the length (Fig. 6). As with the tee-shape beams, the flat plate beams show a reduction in elastic buckling strength at all proportions investigated.

ASME (2014) C_{LTB} Correction Factors

The reduced buckling strength of a suspended beam can be accounted for in design through the addition of a correction factor to the standard design equations. ASME (2014) is an allowable strength design standard in which the allowable major axis moment (for tee-shape beams) and allowable major axis bending stress (for flat plate beams) are defined by equations similar to those in AISC (2010). These equations are modified by the addition of a buckling correction factor C_{LTB} that accounts for the lateral-torsional buckling behavior of suspended beams. C_{LTB} is defined by Eq. 1 for tee-shape beams in which the stem is in tension, by Eq. 2 for tee-shape beams in which the stem is in compression, and by Eq. 3 for flat plate beams.

$$C_{LTB} = \sqrt{\frac{0.25\sqrt{EI_x/GJ}}{L_b/b_f}} \le 1.00 \qquad (1)$$

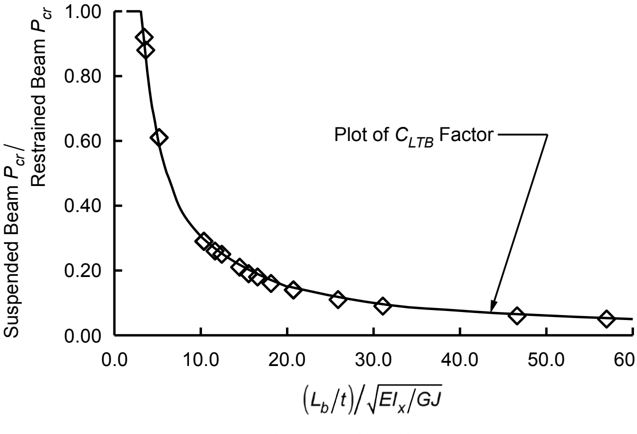

Fig. 6. Results for Flat Plate Beams

$$C_{LTB} = \sqrt{\frac{0.50\sqrt{EI_x/GJ}}{L_b/b_f}} \le 1.00 \qquad (2)$$

$$C_{LTB} = \frac{3.00\sqrt{EI_x/GJ}}{L_b/t} \le 1.00 \qquad (3)$$

C_{LTB} is taken as 1.00 for a beam that is braced against twist or lateral displacement of the compression flange at the ends of the unbraced length. The curves in Figs. 3, 4, and 6 are plot of Eqs. 1, 2, and 3, respectively.

The performance of the C_{LTB} factor with respect to the FEA analyses can be evaluated by means of the ratio R_c as defined by Eq. 4.

$$R_c = \frac{\text{Suspended Beam BASP } P_{cr}}{C_{LTB}\left(\text{Restrained Beam BASP } P_{cr}\right)} \qquad (4)$$

The mean values of R_c and the corresponding coefficients of variation computed from the FEA analyses are shown in Table 1. The results for I-shape beams from Duerr (2015) are included for reference.

Conclusions

The study presented in this note examines the lateral-torsional buckling behavior of suspended tee-shape and flat plate beams, such as those used as lifting beams. The buckling strength of suspended beams has been analyzed through the analysis of beams of various proportions using a suitable finite element analysis program. The methodology has been validated by comparison to experimental results in a previous study of suspended I-shape beams. Correction factors by which existing beam design equations can be modified to provide a practical means of accounting for the buckling behavior of suspended beams are evaluated.

References

American Institute of Steel Construction (AISC) (1989). *Specification for Structural Steel Buildings – Allowable Stress Design and Plastic Design*, 9th ed., Chicago, IL.

Table 1. Summary of R_c Results

Beam Type	Mean R_c	C.O.V.
I-Shape (ref.)	1.03	0.05
Tee-Shape - stem in tension	1.02	0.09
Tee-Shape - stem in compression	1.02	0.14
Flat Plate	1.00	0.03

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