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Lateral-Torsional Buckling Capacity of Tapered-Flange Moment Frame Shapes

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A thesis submitted to the faculty of
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Master of Science

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ABSTRACT

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While moment frames are a popular lateral-force resisting system, their constant cross-section can lead to inefficiencies in energy absorption and stiffness. By tapering the flange width linearly toward the center of the beam length, the energy absorption efficiency can be increased, leading to a better elastic response from the beam and more elastic stiffness per pound of steel used.

Lateral-torsional buckling is an important failure mode to be considered for tapered-flange moment frame shapes. No closed-form or finite element solutions have yet been developed for tapered-flange I-beams with a non-uniform, linear moment gradient and intermediate bracing conditions.

In this study, finite element analysis is used to find the buckling stress of each W-shape in the AISC Steel Construction Manual with both a standard straight-flange and the proposed tapered-flange at several lengths and with three intermediate lateral bracing conditions (no bracing, mid-span bracing, and third-span bracing). Plots are generated for each shape at each bracing condition as the buckling stress versus length for both beams and columns. Overall, the results indicate that lateral-torsional buckling of tapered-flange I-beams is not a problem that would prohibit the wide-scale use of this configuration in moment frames. Also, the buckling capacity tapered-flange moment frame shapes can be reasonably estimated as 20% of the corresponding straight-flange moment frame shape.

Keywords: steel moment frames, seismic design, lateral-torsional buckling

ACKNOWLEDGEMENTS

I would like to dedicate this thesis to my husband, Mark O'Neill. He saw me for who I could be and what I could do and encouraged me to be that person. Without his support, love, and respect, this thesis would never have even been an aspiration.

I thank Dr. Paul W. Richards for his guidance and advice. He took the role of advisor seriously and on many occasions helped me navigate not only my research, but my life.

I'd also like to thank my committee members Dr. Michael A. Scott and Dr. Fernando S. Fonseca. Both have encouraged me to be more than I am and have taught me valuable things about engineering.

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1 INTRODUCTION

One challenge in structural engineering is economically designing buildings to withstand earthquake loads. Since earthquake loads result in horizontal (lateral) inertial forces, systems designed to resist earthquakes are called lateral force-resisting systems. Great progress has been made in the past few decades in the development of effective lateral force-resisting systems.

The steel moment frame is a popular lateral force-resisting system used in seismic design. The moment frame design philosophy is to “provide safety by avoiding earthquake-induced collapse in severe events, while permitting extensive structural and nonstructural damage.” (Hamburger et al 2009). Special Moment-Resisting Frames (SMRFs) utilize compact beams and columns with full-strength beam-column connections to resist strong ground motions. The beams and columns are typically AISC Wide-Flange Shapes, bolted or welded together. Moment frames are easy to construct, can use a bolted or welded beam-to-column connection, and are architecturally versatile.

When moment frames undergo a lateral force, the moment experienced throughout the beam is non-uniform. The moment diagram for a moment frame with a lateral force is shown in Figure 1-1. The moment frame beam has a linear moment gradient with equal moments at each end. Figure 1-2 shows the f bending moment diagram of the beam alone.

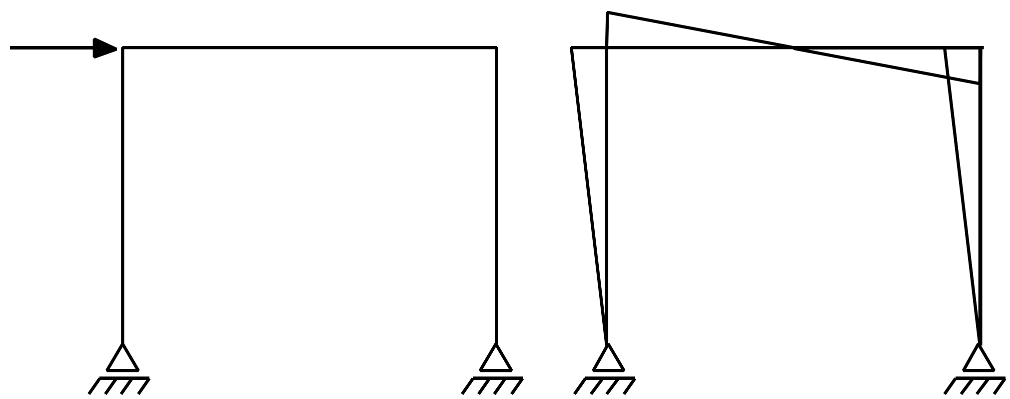

Figure 1-1: Moment Diagram of a Moment Frame under Lateral Force

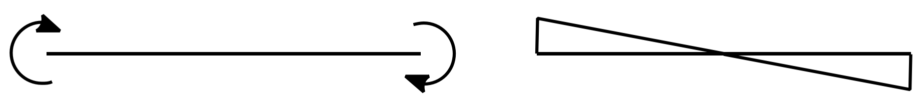

Figure 1-2: Moment Diagram of a Moment Frame Beam

One possible failure mode in moment frames is lateral-torsional buckling. Moment frame beams often have deep I-shaped cross-sections which are susceptible to lateral-torsional buckling. To mitigate this problem, lateral bracing is provided at specified intervals. Closed-form solutions have been derived for the lateral-torsional buckling of I-beams with the moment gradient shown in Figure 1-2 . This allows a direct solution for finding the required spacing of bracing to make lateral-torsional buckling capacity greater than the demand. Generally, sufficient bracing is provided so that the full plastic moment capacity of the cross-section can develop and lateral-torsional buckling is prevented altogether. Closed-form solutions for lateral-torsional buckling have also been developed for some beams with non-uniform cross-sections.

Beams with constant cross-section are inefficient for resisting moments that are not constant along the length of the beam. One measure of efficiency is the strain energy density. Figure 1-3 shows values for the strain energy density of beams with linear moment gradients.

The beam shapes used in the study were the standard wide-flange shapes listed in the AISC Manual (AISC 2011). For these commonly-used beam shapes, the strain energy density is only about 20% to 25% of what it would be if the material throughout the beam was uniformly stressed. This provides a sense of the inefficiency inherent in using I-shapes for moment frame beams.

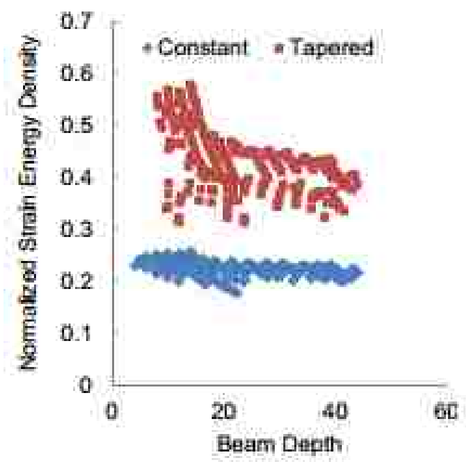

Figure 1-3: Strain Energy Density of Straight-Flange and Tapered-Flange Beams

Shapes with tapered flanges are more efficient for the moment frame beams. Figure 1-4 shows a standard beam and a beam with flanges that taper towards the center. By decreasing the flange width, the I-beams are more uniformly stressed, leading to a higher strain energy density and more energy absorption per pound of steel used. As seen in Figure 1-3 with the red markers, the strain energy density is increased, in some cases past 50% of the possible capacity, simply by tapering the flange width.

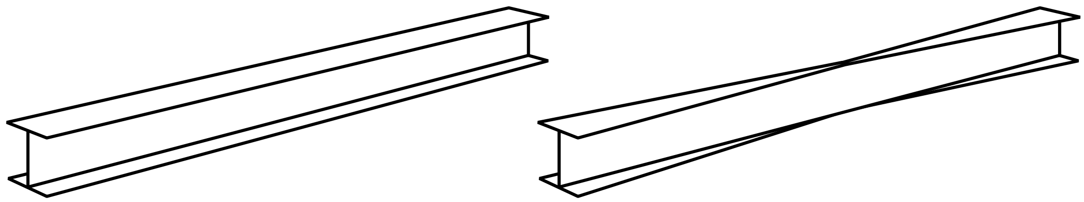

Figure 1-4: Straight-Flange and Tapered-Flange Beam

There are two straightforward methods for producing tapered-flange shapes. One approach is to start with a straight-flange beam and cut in the taper. The material that is removed can be sold for scrap, recovering much more than the cost of the labor to remove it (the price difference between rolled steel and scrap steel being surprisingly small). The other approach for producing beams with tapered flanges is to "build up" the beam by welding plates together.

Lateral-torsional buckling is still an important failure mode for these tapered-flange beams, but closed-form solutions for such geometries are limited. One barrier to the use of tapered-flange beams in moment frames is the inability to determine lateral-torsional buckling capacities or required lateral-brace spacing. Lateral-torsional buckling solutions do exist for some non-prismatic (varying cross-section) beams, but not for the conditions present in moment frame beams (linear moment gradient with intermediate lateral bracing). Finite element methods have been used to determine the critical moments for I-beams with varying cross sections and for I-beams under moment gradient, but, again, not for the conditions present in moment frame beams (linear moment gradient with intermediate lateral-bracing). There is a knowledge-gap in this area that must be filled before tapered-flange I-beams can be used in moment frames.

The objective of this work is to use finite element methods to quantify the lateral-torsional buckling capacity of tapered-flange I-beams for use in moment frames.

This thesis contains six chapters and three appendices. This section presented a brief description of the problem and the motivation for the work. Chapter 2 contains a review of literature concerning moment frame innovations and lateral-torsional buckling under moment-gradient. Previous work in these areas is investigated and related to this study. Chapter 3 contains studies modeling lateral-torsional buckling of straight-flange shapes in Abaqus, setting groundwork for the tapered-flange results via Abaqus solution procedure validation and comparison for the tapered-flange capacities. Chapter 4 contains the Methodology for the tapered-flange shapes, detailing the assumptions and procedures used to determine the lateral-torsional buckling capacity of tapered-flange moment frame shapes. In Chapter 5, the results of the finite element analyses are presented and discussed. Chapter 6 summarizes the work of the thesis and provides a conclusion.

2 LITERATURE REVIEW

This literature review covers two topics of research: moment frame innovation and lateral-torsional buckling under moment gradient.

Moment frame innovation is addressed first in Section 2.1, beginning with a brief history of the effects of Northridge on seismic design, followed by innovations in the field since.

Lateral-torsional buckling under moment gradient is discussed in Section 2.2. Studies involving lateral-torsional buckling of non-prismatic I-beams are reviewed, as well as the AISC (2011) moment gradient factor; the studies include finite element method and exact method developments.

2.1 Moment Frame Innovation

2.1.1 Northridge and the SAC Joint Venture

After excessive failure in the 1994 Northridge earthquake, design and construction procedures of steel Special Moment-Resisting Frames (SMRFs) were scrutinized. Particularly alarming was the evidence that many moment frames had sustained brittle failure, rather than behaving in the expected ductile manner. Brittle fracture of the welded beam-to-column connections, cracks in beam flanges, and cracks through column sections were observed damage. None of the buildings collapsed, but it was clear that the structures did not behave as expected.

In the years following the Northridge earthquake, much time was devoted to researching SMRFs, specifically by the SAC Joint Venture. The SAC Joint Venture was "a consortium of professional associations and researchers engaged in a federally funded, multi-year program of research and development to determine the causes of this unanticipated behavior and to develop recommendations for more robust moment-resisting frame construction" (Hamburger et al 2009). Much of the current design provisions for SMRFs come from the research conducted through this effort.

As part of the SAC Joint Venture, Roeder (2002) experimentally and analytically investigated many connection performance issues for steel moment frames. Yield mechanisms and failure modes were studied for welded-flange-welded-web, bolted-flange-plate, and reduced beam section (RBS) connections; these connections are shown in Figure 2-1. Roeder (2002) determined that at least one of the following three strategies should be used for good seismic design: completely evaluating the force path on the connection, designing a fuse, or improving connection elements which are less understood. Overall, Roeder (2002) emphasized understanding the failure modes of connections in a moment frame.

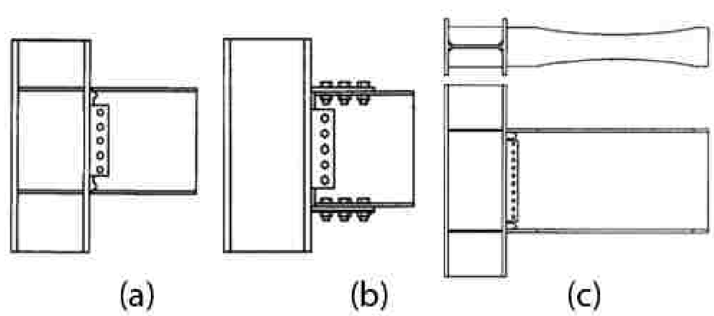

Figure 2-1: (a) Welded-Flange Connection, (b) Bolted-Flange-Plate Connection, and (c) Reduced Beam Section Connection (Roeder 2002)

Steel plates are commonly used to reinforce moment connections, so as part of the SAC project, Kim et al (2002) conducted a nonlinear finite element study on moment connections reinforced with steel plates. Two types of connections reinforced by plates were studied: cover plate (CP) and flange plate (FP). These connections are shown in Figure 2-2. Five of each connection was analyzed in Abaqus with the welds represented by constraints. In the CP connection, the reinforcing cover plate and beam flange are welded to the column flange. In the FP connection, just the plate is welded to the column flange. The results were compared with experimental results. It was determined that both CP and FP connections improve performance, with FP being marginally better than CP. Rectangular reinforcing plates were determined to be superior to trapezoidal plates. It was also determined that bracing the bottom flange of the beams in these connections beyond the plastic hinge zone to delay lateral-torsional buckling did not help.

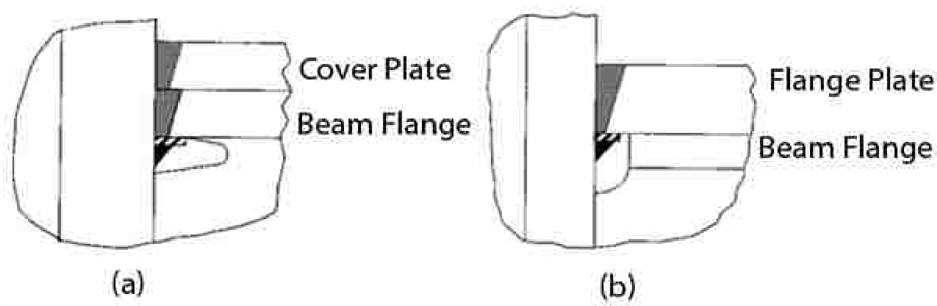

Figure 2-2: (a) Cover Plate (CP) Connection and (b) Flange Plate (FP) Connection (Kim et al 2002)

One of the most popular moment frame connections to emerge from the SAC Joint Venture was the reduced beam section (RBS). An RBS connection has part of the beam flange cut out at a calculated distance from the column face, creating a specific place for a plastic hinge to form when the frame is experiencing strong ground motions. An RBS connection is shown in Figure 2-3.

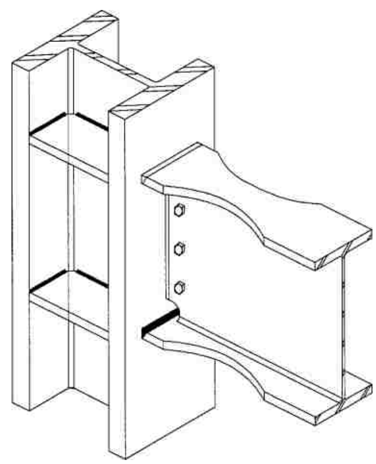

Figure 2-3: Radius-Cut Reduced Beam Section (Jones et al 2002)

Jones et al (2002) experimentally studied radius-cut RBS connections for SMRFs, more specifically they studied the effects of panel zone strength, composite behavior with a concrete slab, and the beam web-to-column flange connection. A radius-cut RBS has a radially-cut cross section removed, as seen in Figure 2-3, as opposed to a rectangular cut. The authors conducted experiments on eight different specimens with a standard quasi-static cyclic load pattern. Most of the specimens performed well and it was determined that weak panel zones had the most energy dissipation, but in this case the RBS section wasn't actually used. The composite slab improved stability of the beams against lateral torsional buckling without increasing strains in the bottom beam flange. Also, welding the beam web to the column flange was determined to sometimes decrease weld fracture.

Gilton and Uang (2002), also as part of the SAC study, conducted a full-scale experimental and a parametric finite element analysis study with RBS connections with the objective to improve and understand the weak-axis moment connections. Pre-Northridge weak-axis moment frame connections often failed with a brittle facture at the edge of the beam near the groove weld, which was due to the load path leading toward the stiffer columns flanges, resulting in large stress concentrations. The authors determined that the RBS connection prevented the weld fracture and reduced strain concentrations by a factor of 3.

Also as part of the SAC Joint Venture study, Chi and Uang (2002) experimentally studied steel RBS moment connections with deep columns. Deep columns are often used to reduce drift in moment frames. The authors tested deep-column RBS moment connections and then developed procedures and made recommendations for the seismic design of this type of connection. The testing revealed that deep columns are prone to twisting, which is due to lateral-torsional buckling of the beam, leading to eccentric beam flange force. Yielding and twisting of the column are shown in Figure 2-4. The analytical study indicated that the warping stress was highly dependent on the h/t_{cf}^3 ratio of the column section. The authors proposed a design procedure to determine if column twisting would occur, which would require additional bracing near the RBS region.

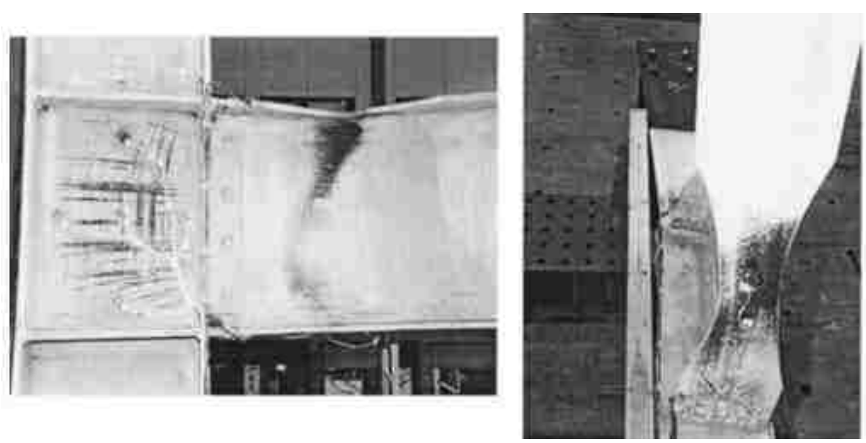

Figure 2-4: Yielding and Twisting of a Deep Column with Reduced Beam Section Connection (Chi and Uang 2002)

2.1.2 Design and Performance Evaluation of Moment Frames

Along with the studies and recommendations provided by the SAC Joint Venture, research continued to improve seismic design. The following literature deals with residual drift, an important parameter in determining seismic performance of a building.

Pettinga et al (2007) conducted a study with the objective of reducing residual drift by increasing post-yield stiffness. Residual drift plays an important role in the seismic performance of a building. Increasing the post-yield stiffness is the most important parameter for decreasing residual drift. Static and dynamic analytical methods were used to test reinforced concrete, steel moment frame, and buckling-restrained braced frame systems. The authors determined that the addition of a secondary system designed to remain elastic (even just as a gravity frame) improves post-yield stiffness and significantly reduces residual drift.

Erochko et al (2010) used nonlinear analyses to compare the peak and residual drifts of SMRFs and Buckling-Restrained Braced Frames (BRBFs) designed according to ASCE 7-05 (2005). The study used full moment-resisting connections, but did not consider panel zones. Pushover and nonlinear time-history analyses were used. Based on the pushover results, the SMRFs were three times overdesigned for strength, which is expected, since drift usually governs SMRF design with ASCE 7-05 (2005). The SMRFs experienced 2 to 4% drift under the Maximum Considered Earthquake and had a much lower residual drift than the BRBFs. However, the scatter in the residual drift results was large. When a second earthquake was used on the already-damaged buildings, the level of residual drift was larger than expected. The study indicated that moment frames are often overdesigned because of the drift limit, and when designed according to ASCE 7-05 (2005), the buildings don’t meet Immediate Occupancy at the Design Basis Earthquake.

2.1.3 Self-Centering Moment Frames

Self-centering moment frames that would eliminate residual drift and its consequences have been an innovation in moment frame design. Although not used widely, self-centering frame technology could be a real asset to seismic design with further study and development.

Ricles et al (2001) proposed a new self-centering, moment-resisting connection for steel SMRFs. The authors proposed post-tensioned connections with high-strength strands and seat angles at the top and bottom, as shown in Figure 2-5, with the intention that most of the moment frame damage would be confined to the angles which can be easily replaced without field welding. The self-centering nature of the frame theoretically eliminates residual drift. An analytical model which was calibrated with test results from experimental data was used for an inelastic static analysis and a dynamic time history analysis. The analytical and experimental results were in good agreement. The stiffness, strength, and ductility of the connection met expectations and the self-centering moment frame performed better than a similar moment frame with typical welded connections. The proposed self-centering post-tensioned moment connection has several advantages over a welded moment-resisting frame and is economically competitive.

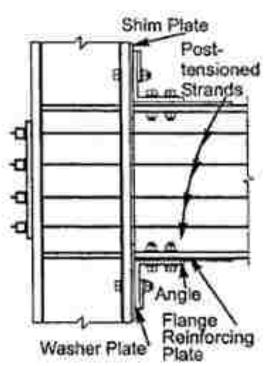

Figure 2-5: Post-Tensioned Moment-Resisting, Self-Centering Connection for SMRFs, with Seat Angles at Top and Bottom (Ricles et al 2001)

Christopoulos et al (2002) innovated moment frame technology with post-tensioned energy-dissipating connections, as shown in Figure 2-6. The authors analytically developed a procedure for predicting the moment-rotation relationship in these connections and a procedure for design. An experimental study was also conducted on the energy-dissipating bars and the beam-to-column connections. The results showed that these connections were able to undergo large inelastic deformations with no damage to beam or column and no residual drift. The experimental results were used to validate the analytical model.

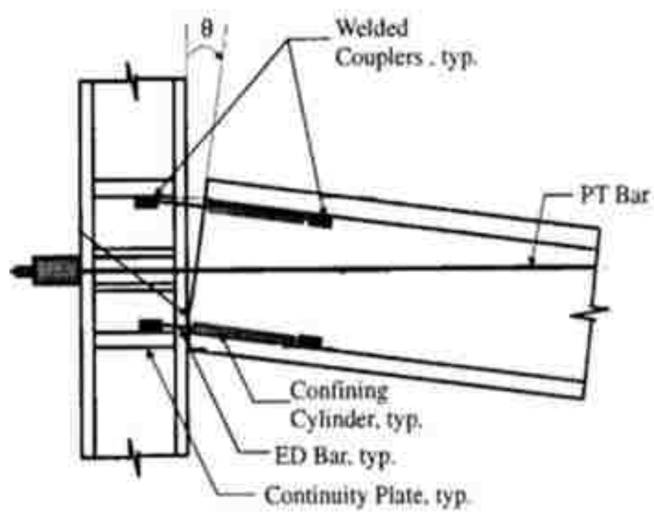

Figure 2-6: Post-Tensioned Energy-Dissipating Self-Centering Moment-Resisting Connection (Christopoulos et al 2002)

Kim and Christopoulos (2009) further developed self-centering moment frames by establishing the first comprehensive design procedure for self-centering friction-damped moment frames (SCFRs). The procedure accounts for the frame behavior and nonlinear dynamics. The mechanics of the self-centering friction-damped frames, shown in Figure 2-7, are fully described and a design example is shown. The authors performed cyclic pushover and time history analyses for both SCFR and typical welded MRFs. They determined that the two frames had similar initial stiffness, the SCFRs experienced the same or less acceleration as the MRFs, and the SCFR almost eliminated residual drift, although some ground motions did cause ductile deformation. Overall, the SCFR performed well, although there is room for improvement before practical implementation can be achieved.

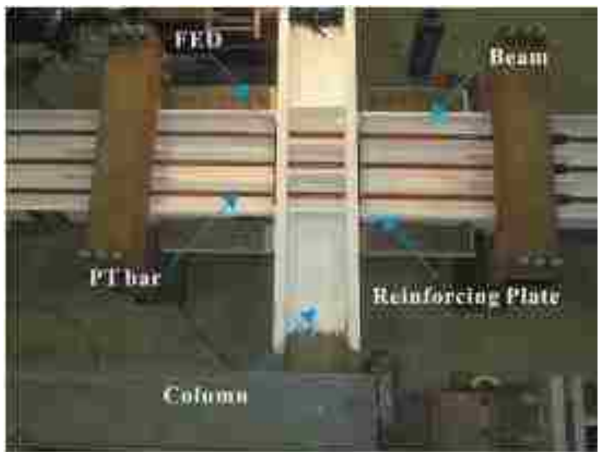

Figure 2-7: Self-Centering, Friction-Damped Moment Frames (Kim and Christopoulos 2009)

2.1.4 Moment Frames in Other Countries

Nakashima et al (2000) compared the history and (at the time written) current seismic design procedures of steel moment frames in Japan and the United States of America. Steel moment frames are used widely in both countries, but there are differences in design that stem from history. In the same way that the 1994 Northridge earthquake exposed weaknesses in the U.S. steel moment frame design, the 1995 Kobe earthquake exposed weaknesses in steel moment frames in Japan. The authors reviewed welding processes and materials in both countries, since this has a large impact on the effectiveness of steel moment frames. Short Japanese buildings designed according to the Japanese Building Code provisions result in stiffer and stronger buildings than these in the US. Japanese structures are more likely to use built-up members, requiring more labor during construction. Some connection detail differences between the United States and Japan are shown in Figure 2-8. When seeking to improve steel frame moment design, U.S. engineers design connections and geometries to work around the problems and reduce demands in critical areas, while Japanese engineers emphasize improving steel and welds for a standard geometry.

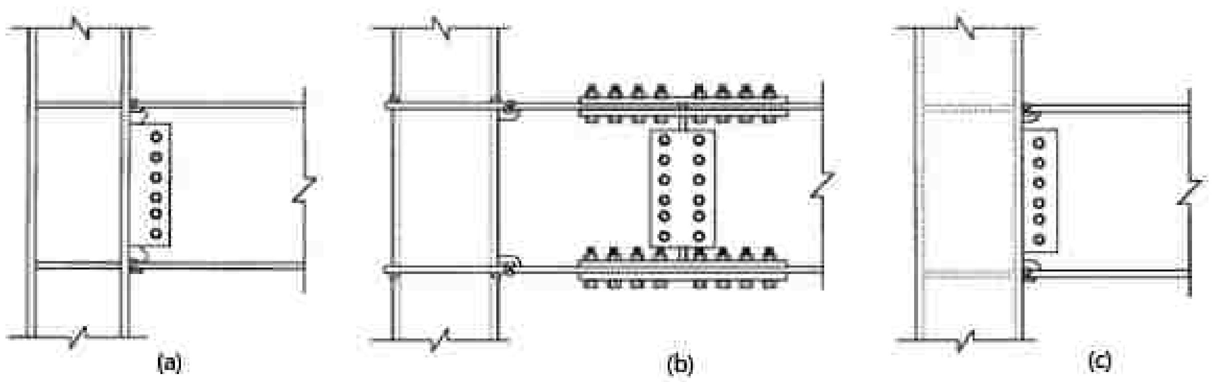

Figure 2-8: Welded Connection Details for (a) U.S. Pre-Northridge SMRF, (b) Japanese Cold-Formed Tubular Columns, and (c) Japanese Built-Up Box Columns (Nakashima et al 2000)

2.2 Lateral-Torsional Buckling under Moment Gradient

2.2.1 Finite Element Methods

Kitipornchai et al (1986) analytically studied the elastic lateral buckling of monosymmetric simply-supported I-beams under moment gradient. Monosymmetric I-beams are only symmetric about one axis, like in the cross-section shown in Figure 2-9. Using finite integral and energy methods, the authors investigated the effects of the degree of monosymmetry with an equal applied moment at both ends of the beam and determined that the degree of monosymmetry has a large effect on the buckling moment of the beam.

Figure 2-9: Monosymmetric I-beam Example (Kitipornchai et al 1986)

Yang and Yau (1987) used numerical methods to estimate the critical buckling load for I-beams with tapered flanges and tapered depths. Simply supported beams for several geometries were used with the load acting at the center of the web and at the top and bottom flanges. Beams with tapered depths, similar to the one shown in Figure 2-10, and tapered flanges were studied. Beams with tapered flanges had the full cross section at the center of the beam span, and the flange width decreased towards the ends of the beam with a set amount of taper. The study confirmed that a greater taper decreases the buckling load of the beam.

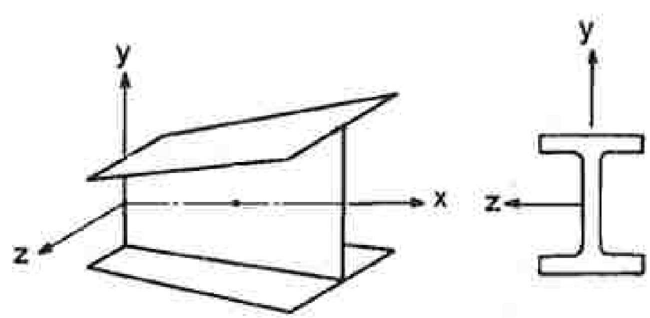

Figure 2-10: I-beam with Tapered Depth (Yang and Yau 1987)

Bradford and Cuk (1988) also used numerical methods to determine the elastic lateral-torsional buckling capacity of I-beams with tapered web depth, flange width, and flange thickness. The new method adopted the mid-height of the web as the axis of twist, which simplified bending and torsion coupling problems. Several studies were done: one with simply-supported monosymmetric I-beams with tapered flange-widths tapering in different directions and a mid-span concentrated load, as shown in Figure 2-11. Another analysis involved a cantilevered beam with a tapered flange width, as shown in Figure 2-12, and a concentrated load at the end of the beam. The effect of different degrees of taper was studied. No lateral bracing was addressed in the study.

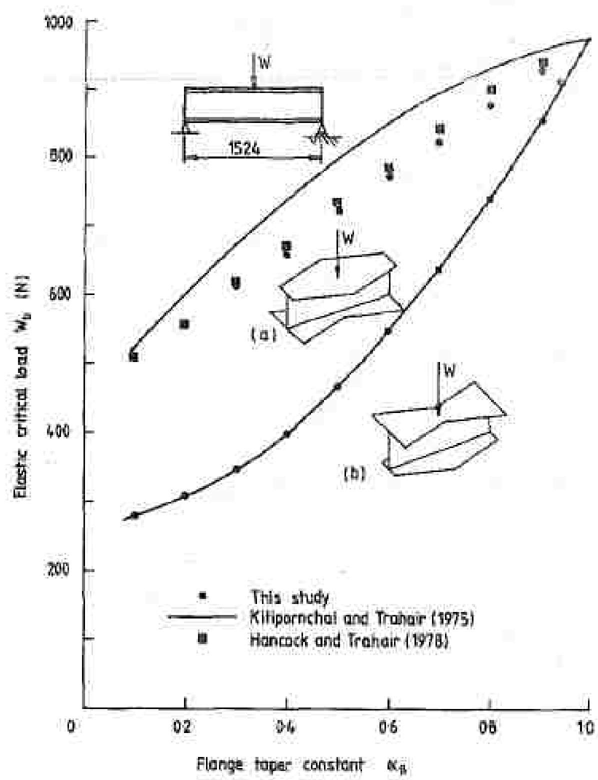

Figure 2-11: Finite Element Analysis Results for Monosymmetric Tapered-Flange I-beams with Mid-Span Load (Bradford and Cuk 1988)

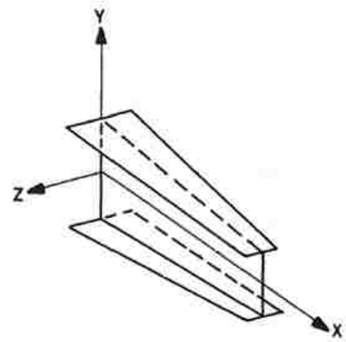

Figure 2-12: I-beam with Tapered Flange (Bradford and Cuk 1988)

Chan (1990) continued this line of research by studying the buckling capacity of tapered beam-column members. Chan derived tapered elements for beam-columns based on energy principles and developed a simple nonlinear frame analysis program to implement the derived elements. A cantilever flange-tapered beam with a concentrated end load was studied and determined to be in agreement with the results from Bradford and Cuk (1988), as shown in Figure 2-13, despite the difference in elements used. No bracing was considered, only different amounts of tapering.

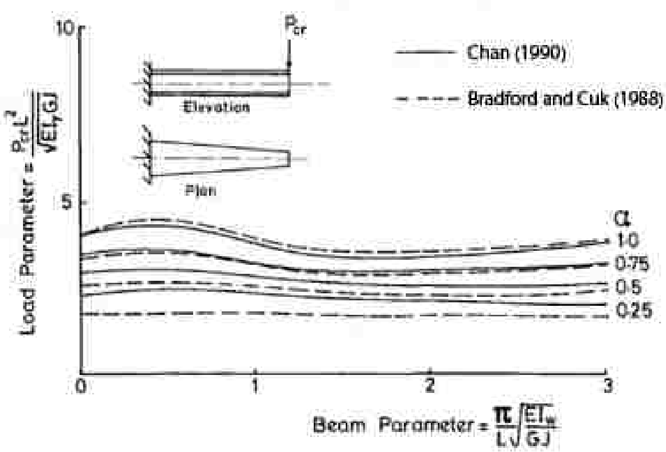

Figure 2-13: Finite Element Analysis Results for Cantilevered I-beam with Tapered Flange and Concentrated Load at Free End (Chan 1990)

Rajasekaran (1994) used the finite element method to examine buckling loads, natural frequencies, and mode shapes of thin-walled tapered I-beams with open sections. Cantilevered and simply-supported depth-tapered beams, as shown in Figure 2-14b, were considered, as well as I-beams with tapered flange widths (Figure 2-14a), where the width was largest in the center of the beam and decreased linearly towards the ends. Rajasekaran determined that the finite element model developed was in good agreement with results from Bradford and Cuk (1988).

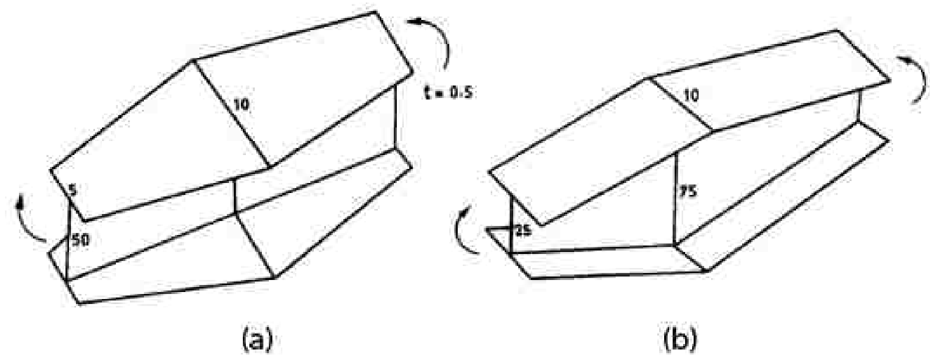

Figure 2-14: I-beams with (a) Tapered Flange Width and (b) Tapered Depth (Rajasekaran 1994)

Gupta, Wang and Blandford (1996) developed a finite-element formulation for lateral-torsional buckling analysis of linearly and quadratically tapered I-beams. As in previous studies, tapering of the web depth, flange width and flange thickness were considered. The authors also studied beams with varying amounts and types of taper and different boundary conditions (simple, clamped). Simple span and two-span were considered. Different linear and quadratic tapers were also studied, as shown in Figure 2-15. A uniform distributed load was used. The authors determined that the buckling capacity of the beam increased with the taper, and that a quadratic taper on a simply-supported beam led to the highest buckling capacity. Also, if warping is restrained, the buckling capacity increases significantly; furthermore two-span beams have a higher buckling capacity.

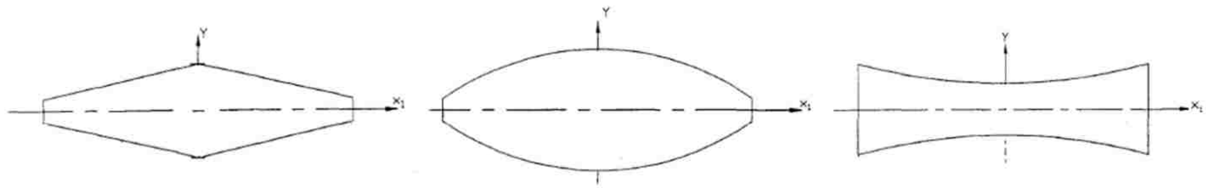

Figure 2-15: One Linear and Two Quadratic Taper Examples used in Gupta et al (1996)

Mohebkhah and Chegeni (2013) recently investigated both experimentally and analytically the interaction between lateral-torsional buckling and flange local buckling in I-beams with moment gradient. A flange local buckling failure is shown in Figure 2-16. Using Abaqus (2010) to model and analyze the lateral-torsional buckling and flange local buckling moments under non-uniform bending, the authors determined that the AISC (2011) equations accurately estimate compact and noncompact shapes (indicating no interacting between the two buckling states), but are too conservative for I-beams with slender flanges, since the interaction between buckling states is ignored.

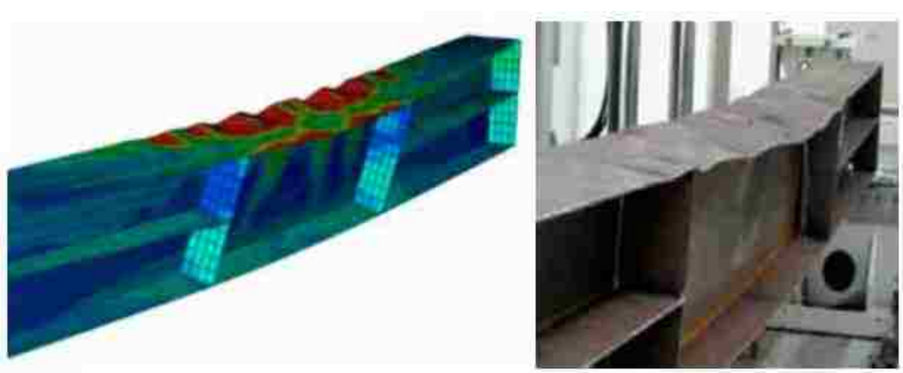

Figure 2-16: Flange Local Buckling Failure Mode Model and Testing (Mohebkhah and Chegeni 2013)

2.2.2 Exact Methods

Eisenberger (1991) developed exact solutions for buckling loads of columns with variable cross-section and variable axial force for several boundary conditions. Nonlinear finite element analysis theory was used to derive the solution, which was then verified by examples. Eisenberger (1991) determined that the boundary conditions at the lower end of the column are more influential in the buckling load result than the boundary condition at the top end of the column.

Al-Sadder (2004) derived exact elastic stability functions for any general non-prismatic beam-column members under uniform axial forces. The analytical solution used the power-series approach to solve the fourth-order ordinary differential equation. The accuracy, validity, and effectiveness of the method were compared and agreed with available results. The method can be used in an exact second-order elastic (P-delta) analysis.

2.2.3 AISC Moment Gradient Factor

Suryoatmono and Ho (2002) investigated the empirical moment-gradient factor equations of the AISC in the Steel Construction Manual (2011). The AISC equations are supposedly valid for any moment diagram, but the authors suspected the possibility of moment diagrams for which the equations give incorrect results. Using a finite-difference solution, several loading cases were investigated. The authors determined that the equations give incorrect values for some loading cases and can differ especially for lateral-torsional buckling under applied moments at the end. Using the results from the finite-difference method, the authors developed non-empirical moment-gradient equations, shown in Figure 2-17.

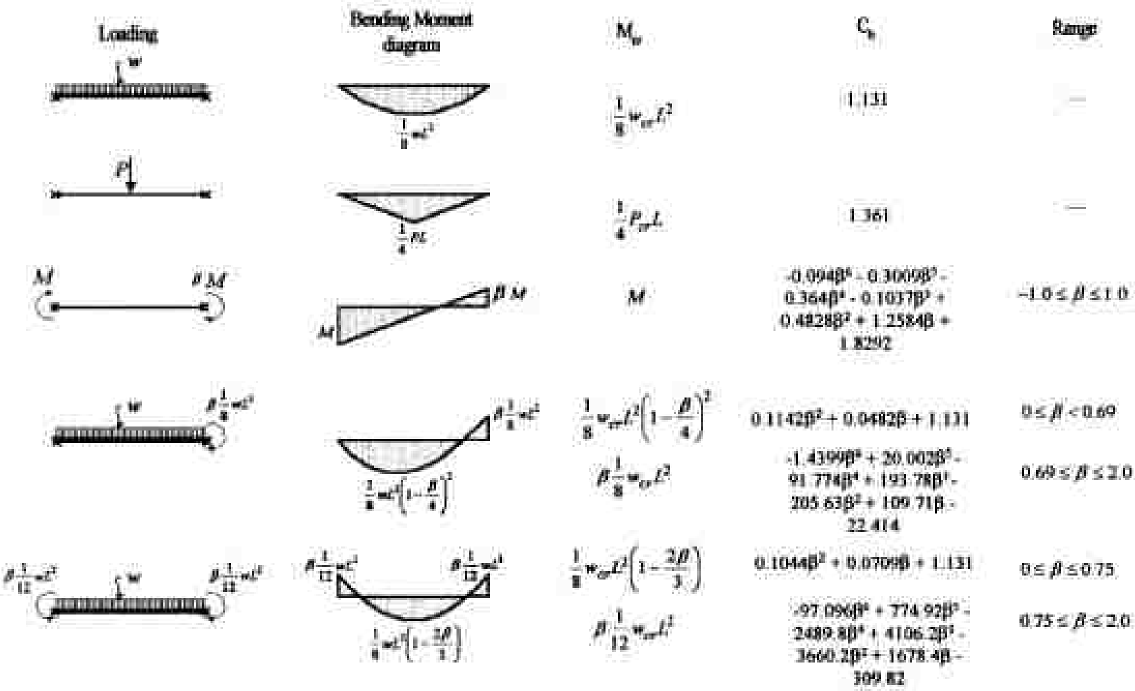

Figure 2-17: Moment-Gradient Equations Developed by Suryoatmono and Ho (2002)

Since end applied moments are used in the study presented herein, the moment gradient factor equation for end-moments provided by Suryoatmono and Ho (2002) and the moment gradient factor provided by the AISC equation were used when validating the models developed as part of this study.

3 MODELING LATERAL-TORSIONAL BUCKLING OF STRAIGHT-FLANGE SHAPES IN ABAQUS

Before tapered-flange shapes under non-uniform moment were analyzed, Euler columns and straight-flange shapes under uniform and non-uniform moments were analyzed; this was done for two reasons: for validating the Abaqus solution procedure and results and for comparison with tapered-flange capacities. In Section 3.1, the Abaqus linear perturbation buckling solution procedure that is used throughout this study is described. In Sections 3.2 and 3.3, the Euler buckling of a column and plate are validated, respectively. In Section 3.4, a single I-beam under uniform moment is analyzed and the methodology detailed. In Sections 3.5 and 3.6, all Wide-Flange shapes are analyzed and compared to equation results under uniform and non-uniform moments, respectively. These sections provide a validation and basis for comparison with tapered-flange shapes.

3.1 Determining Buckling Loads in Abaqus

The Abaqus (2010) linear perturbation buckle analysis is used to obtain the critical load as an eigenvalue. The buckle analysis estimates the critical bifurcation load by producing (through perturbation) an eigenvalue for each mode shape which, when multiplied by the applied loads, produces the buckling load. Since unit loads are used in each study, the eigenvalue is the critical buckling load.

3.2 Euler Buckling of a Column

The results of an Abaqus buckling analysis on a slender beam element were compared with the Euler buckling equation. The Euler buckling equation is

$$P_{cr} = \frac{\pi^2 EI}{L^2}. \qquad (3\text{-}1)$$

The slender beam element had a circular cross section with radius 0.5 in and length 25 in. A Modulus of Elasticity of 29,000 ksi and Poisson's ratio of 0.3 were used. The load was a unit point load at the top end of the column. All nodes were constrained about the x-axis, while one end was pinned in the x-, y-, and z-directions and the other end was pinned in the x- and y-directions. The eigenvalue results of the buckling analysis were compared with the value computed by the Euler buckling equation. The Abaqus and Euler buckling equation critical loads were 22,452 pounds and 22,479.6 pounds, respectively. The Abaqus critical buckling load was 0.1% lower than the Euler buckling load given by the equation. The column configuration and buckled mode shape are shown in Figure 3-1.

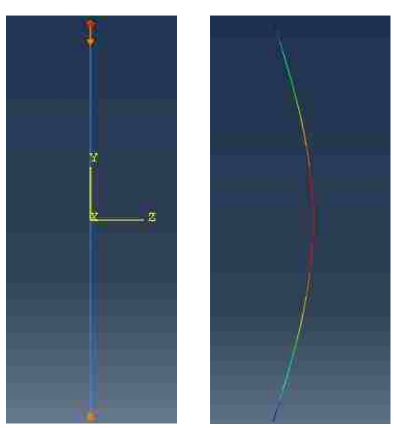

Figure 3-1: Euler Column Model (Left) and Buckled Mode Shape (Right)

3.3 Euler Buckling of a Plate

After validating a simple column, the Abaqus critical buckling load of a slender plate column was compared with the critical buckling load given by the Euler buckling equation. A rectangular cross section with a thickness of 0.25 in, a width of 1 in, and a length of 25 in were used. A Modulus of Elasticity of 29,000,000 psi and Poisson's ratio of 0.3 were used. The plate was modeled using S4R shell elements with a characteristic size of 1 in. The bottom was pinned in the x-, y-, and z-directions as well as about the x and y axes. The top was pinned in the x- and y- direction only, but still constrained from rotation about the x and y axes. A unit load was created at the top of the column by placing a downward force of 0.5 pounds on each end. The Abaqus buckling analysis and Euler buckling equation gave critical buckling loads of 597.7 pounds and 596.3 pounds, respectively. The Abaqus buckling load was 0.2% higher than the load given by the Euler buckling equation. The plate modeled and analyzed in Abaqus can be seen in Figure 3-2.

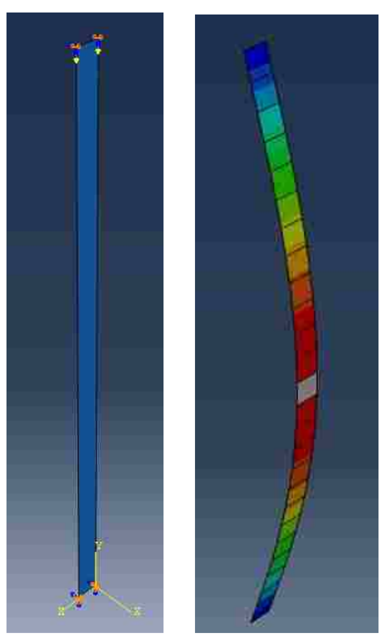

Figure 3-2: Plate Column Model (Left) and Buckling Mode Shape (Right)

3.4 Lateral-Torsional Buckling of an I-Beam

An Abaqus buckling analysis was done on a W21X68 Wide-Flange shape. Geometry, element, material properties, boundary conditions and comparison with the closed-form solution are reviewed in this section. Many of the methods described in this section are used for the rest of this study.

3.4.1 Geometry

A W21X68 Wide-Flange shape with the geometry set forth in the AISC Steel Construction Manual (2011) was used for this validation study. The shape was 25 feet in length, with a depth, flange width, flange thickness and web thickness of 21.1, 8.27, 0.685, and 0.43 inches, respectively.

In Abaqus, the geometry is modeled using shell extrusion. The cross section of the beam is first drawn, with flange width b_f and height $d\text{-}t_f$, as seen in Figure 3-3. The height is $d\text{-}t_f$ instead of d because the shell elements "condense" to the center of the thickness dimensions. The shell elements are described further in the following section. After the cross section geometry is created, the cross section is extruded to the length of the beam, L. Fillets are neglected.

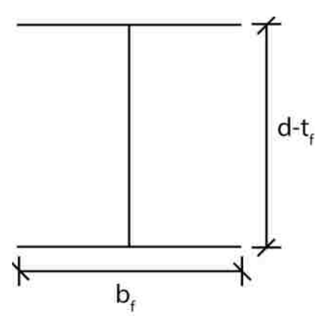

Figure 3-3 Cross Section of an I-beam as Modeled in Abaqus.

3.4.2 Shell Element S4R

The Abaqus (2010) shell element S4R was used for all analyses in this study. The S4R element is a shell element with 4 nodes (6 degrees of freedom per node, 3 translational and 3 rotational) and reduced integration. Shell elements approximate a three-dimensional shape in two dimensions. Since the thicknesses of the web and flanges are significantly smaller than the lengths and widths, using quadrilateral shell elements to approximate the results saves considerable effort and time relative to using solid elements. The thicknesses of the web and flanges are condensed to the center of the thickness dimensions. The reduced integration elements also have a computational advantage over fully integrated elements. In reduced integration, integration occurs at fewer points (as opposed to every point) and is extrapolated to other points by means of shape functions. Reduced integration helps prevent shear and membrane locking in the elements (Hughes & Liu 1981).

3.4.3 Mesh Convergence Study

To determine an appropriate mesh size, a mesh convergence study was done in Abaqus. Three different tapered-flange Wide-Flange shapes (W-Shapes), W14X233, W14X48, and W36X231, were each analyzed with four mesh sizes: 3.5, 1, 0.5, and 0.1 inches. Critical moments were determined for the three shapes at each mesh size. These moments were normalized by the moment predicted by the 0.1-inch mesh for each shape, since that moment the largest. The plots are shown in Figure 3-4 through Figure 3-6. It can be seen from each of the plots that a mesh size of 0.5 has converged well. Beams with a mesh size of 0.5 took several minutes to run, but beams with a mesh size of 0.1 took several hours. It was concluded that a mesh size of 0.5 inches would work well throughout this study.

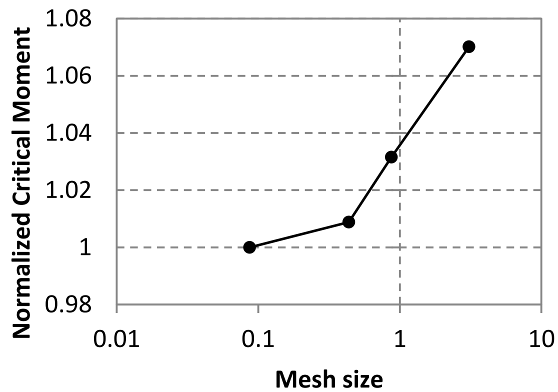

Figure 3-4: Normalized Critical Moment versus Mesh Size for W14X48

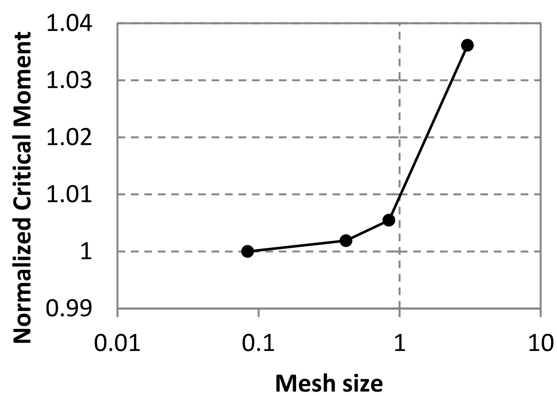

Figure 3-5: Normalized Critical Moment versus Mesh Size for W14X233

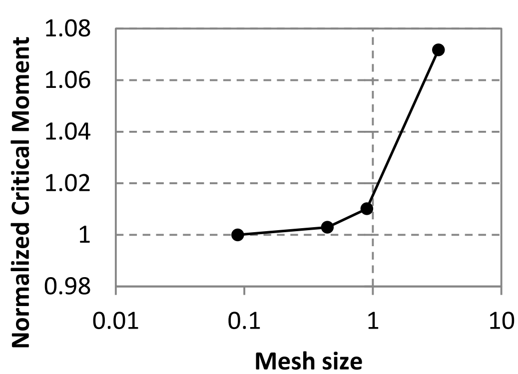

Figure 3-6: Normalized Critical Moment versus Mesh Size for W36X231

3.4.4 Modeling Assumptions and Material Properties

The W21X68 beam was modeled and analyzed using the finite element software Abaqus (Abaqus 2010). Elements with an approximate size of 0.5 inches were used, as shown in Figure 3-7.

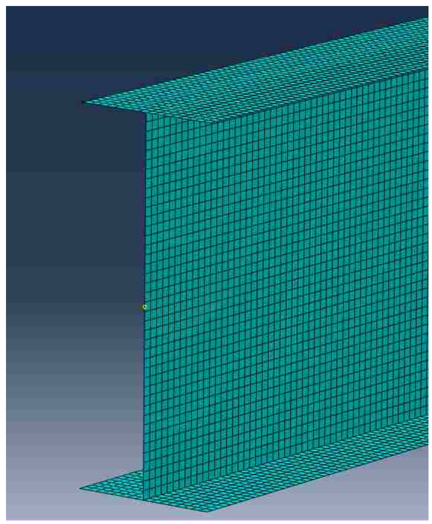

Figure 3-7: W21X68 with Approximate 0.5-inch Mesh

The beam was modeled using the same Young's Modulus and Poisson's ratio. The Young's Modulus and Poisson's ratio were 29000 ksi and 0.3, respectively. No other material parameters were required, since only an elastic buckling analysis was being performed.

3.4.5 Boundary Conditions and Loading

The W21X68 beam was modeled with simply supported end conditions; the ends are constrained from lateral deflection and twist rotation, but are free to rotate in horizontal planes, leaving the flange ends free to warp. Figure 3-8 shows a beam with different parts highlighted for displaying where the boundary conditions take place. Next to each beam is also shown the axis orientation, for reference. The nodes in the web at each end (Figure 3-8(a)) are fixed from translation in the x-direction. All nodes on each web and flange end (Figure 3-8(b)) are fixed from rotation about the z axis. The node closest to the midpoint of the web at each end (Figure 3-8(c)) is fixed from translation in the y-direction. The node nearest the midpoint of the web at a single end (Figure 3-8(d)) is fixed from translation in the z-direction. All nodes in the left and right web are constrained to a respective mid-web node highlighted in Figure 3-8(c). These boundary conditions were used for all analyses in this study.

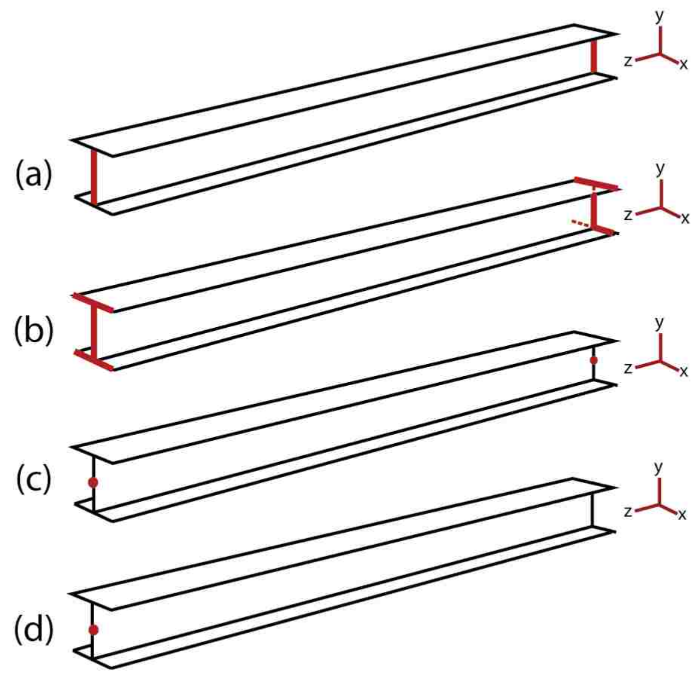

Figure 3-8: Boundary Conditions Used in Model

For this validation study, a uniform moment loading is used. Unit moments were applied at each end of the beam. The moments were applied about the x-axis, one in the positive direction and the other in the negative direction, generating a uniform moment. The moments were applied at the node nearest the midpoint of each web end (see Figure 3-8(d)), as recommended by Yang and Yau (1987).

3.4.6 Closed-Form Solution

The closed-form solution for elastic lateral-torsional buckling of an I-beam can be found in Equation 3-2:

$$M_{cr} = \frac{C_b \pi}{L}\sqrt{\left(\frac{\pi E}{L}\right)^2 C_w I_y + E I_y G J}\ . \qquad (3\text{-}2)$$

This equation yields the critical buckling moment. C_b is the moment gradient factor. For this case, the moment is uniform, and C_b is 1. L is the unbraced length, E is the modulus of elasticity, C_w is the torsional warping constant, I_y is the moment of inertia about the weak axis, G is the shear modulus of elasticity, and J is the torsion constant. These values can be found in the AISC Steel Construction Manual (2011).

A small-angle assumption is important to the development of this equation. The equation assumes a small angle at buckling, which leads to two independent out-of-plane bending equations. This assumption is valid if the moment of inertia about the strong axis of the beam, I_x, is much greater than the moment of inertia about the weak axis of the beam, I_y.

3.4.7 Comparison of Abaqus and Closed-Form Solution

The critical buckling moment determined by the Abaqus buckling analysis and the elastic lateral-torsional buckling equation were compared for the 25-ft long W21X68 beam under uniform moment. The critical buckling moment from Abaqus was 3144.9 kip-in. The critical buckling moment from Equation 3-2 was 3117.8 kip-in. The Abaqus critical moment was 0.9% higher than the moment predicted by the equation. The buckled W21X68 beam can be seen in Figure 3-9.

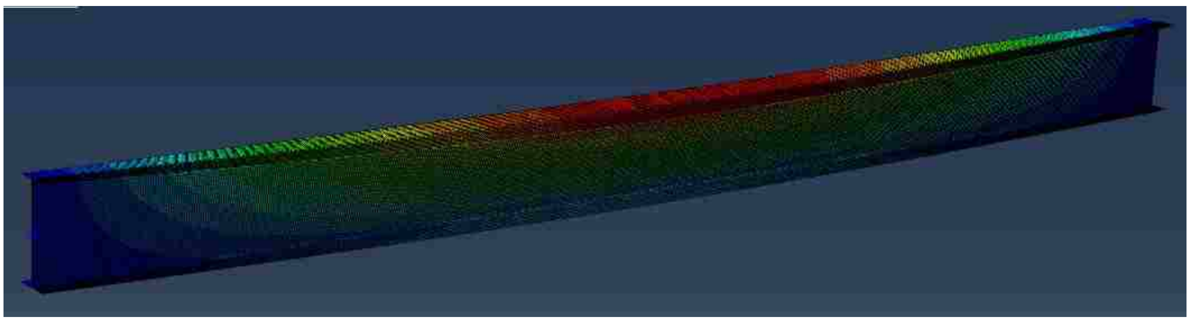

Figure 3-9: Abaqus Model of a W21X68 Beam Buckled under Uniform Moment

3.5 Lateral-Torsional Buckling of W-Shapes with a Uniform Moment

Each standard Wide-Flange shape listed in the AISC Steel Construction Manual was modeled and analyzed under a uniform moment in Abaqus, as described in Section 3.4.

3.5.1 Scripting and Batches

A Python script was used to run all of the analyses in Abaqus. Each shape was analyzed at 10 different lengths: 5 to 50 feet in 5 ft increments. A breakdown of the total number of analyses run can be seen in Table 3-1. The buckling moment for each shape at each length for the uniform moment was then exported to a CSV file. The critical moment equation was then used to compute the buckling moment for each shape at each length according to the equation.

Table 3-1: Breakdown of Uniform-Moment, Straight-Flange Analyses

273	W-Shapes
10	Lengths
2,730	Total analyses

3.5.2 Results

The elastic lateral-torsional critical buckling moment results from Abaqus for each shape at each length were compared with the elastic lateral-torsional critical buckling moment equation (Equation 3-2). A plot of the ratio of the Abaqus moment to the equation moment for each shape versus lengths 30 to 50 feet is given in Figure 3-10. Lengths shorter than 30ft could be susceptible to other buckling modes (flange local buckling and web local buckling) and inelastic buckling.

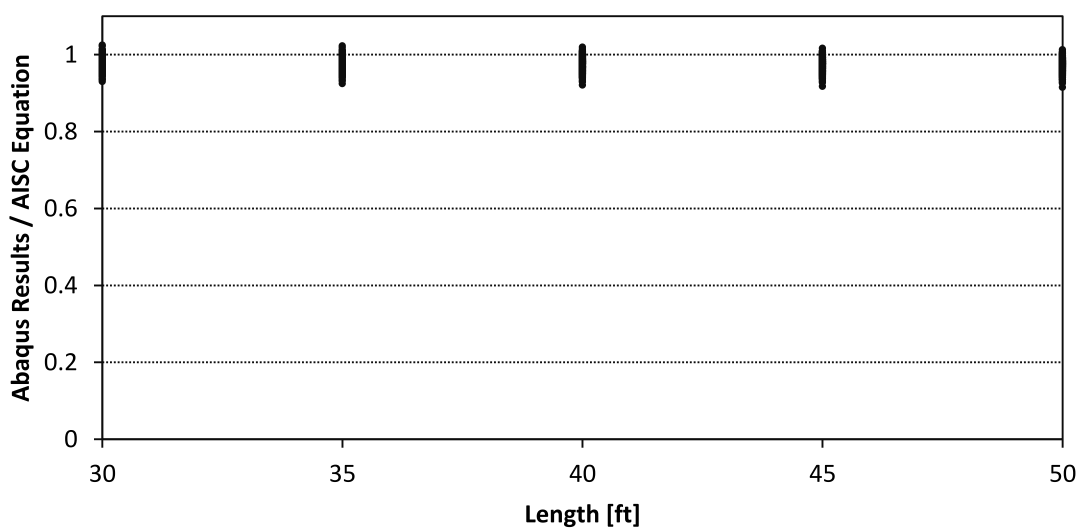

Figure 3-10: Comparison of Abaqus and Elastic Lateral-Torsional Buckling Equation Critical Moments for All W-Shapes under Uniform Moment

Based on these results, the Abaqus moment is close to the moment predicted by the equation, with some variability. The Abaqus moment is within 10% of the AISC moment for all W-shapes at lengths 30 to 50 feet; the Abaqus moment being up to 2% higher and 8% lower than the AISC equation moment.

3.5.3 Variability due to Equation Assumption

The variability seen in Figure 3-10 can be explained by the validity of the small-angle assumption presented in Section 3.4.6. The validity of the equation's assumption can be verified when I_x is much greater than I_y. Figure 3-11 shows a plot of the Abaqus/Equation results versus the moment of intertia ratio I_x/I_y with each shape depth highlighted a different color, to show how depth and geometry affect the small angle assumption as well. The lengths plotted have been filtered so that only elastic lateral-torsional buckling values are shown (lengths where $1.5\ L_r < L < 3\ L_r$).

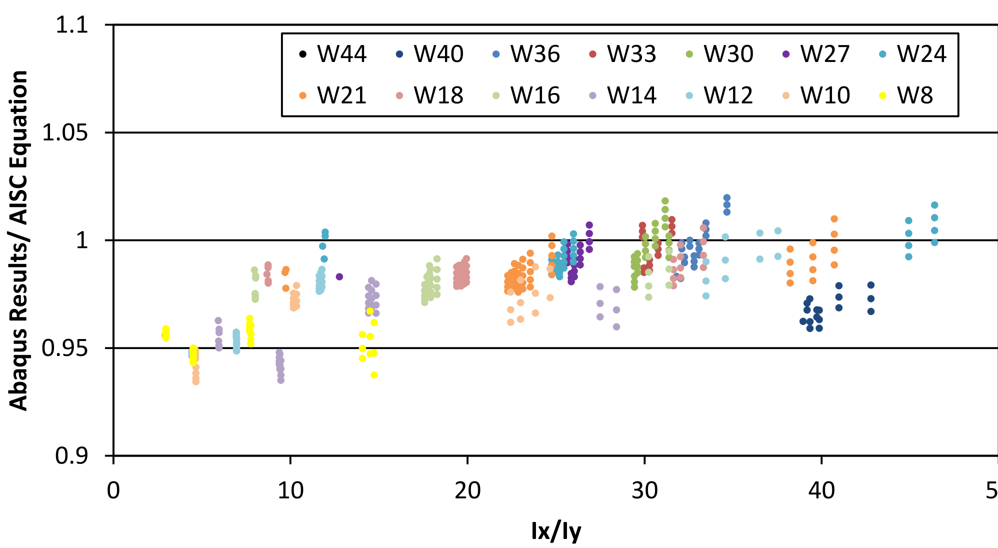

Figure 3-11: Comparison of Abaqus and Elastic Lateral-Torsional Buckling Equation Critical Moments versus I_x/I_y for each shape depth

A positive trend can be seen, where an increase in I_x/I_y leads to an increase in the precision between results. It can be seen that Abaqus and the AISC equation moments match less closely when I_x/I_y is small. The Abaqus results are closer to equation results when I_x/I_y is large. Also, shallower shapes tend to be less precise while deeper shapes match more closely. This indicates that the assumption in the equation is not always correct and that the variability in the results seen in Figure 3-10 comes from the equation.

3.6 Lateral-Torsional Buckling of W-Shapes with a Non-Uniform Moment

Each standard Wide-Flange shape listed in the AISC Steel Construction Manual (2011) was also modeled and analyzed under a non-uniform moment in Abaqus. Most of the methodology described in Section 3.4 was used in the analysis of the W-Shapes under non-uniform moment, with the main exception being in the loading. Instead of one positive and one negative moment being applied to the beam ends, both moments are equal and positive, creating a non-uniform moment with a linear moment gradient. The failure mode due to lateral-torsional buckling under non-uniform moment can be seen in Figure 3-12.

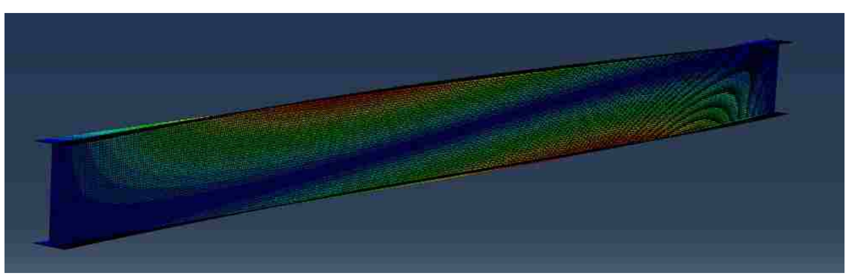

Figure 3-12: Lateral-Torsional Buckling of an I-Beam under Non-Uniform Moment

Each W-shape was analyzed with two varied parameters: length and bracing configuration. There were 11 different lengths: 5 to 50 feet in 5 ft increments, and also a 1-ft long beam. There were three different lateral bracing configurations: no bracing, mid-span bracing, and third-span bracing. These bracing conditions are further described in Section 4.4. A breakdown of the analyses run for straight-flange shapes with a non-uniform moment is shown in Table 3-2.

Table 3-2: Breakdown of Non-Uniform-Moment, Straight-Flange Analyses

273	W-Shapes
11	Lengths
3	Bracing conditions
9,009	Total analyses

The lateral-torsional critical buckling moment results from Abaqus for each of these shapes was compared with the elastic lateral-torsional critical buckling moment equation (Equation 3-2). A plot of the ratio of the Abaqus moment to the equation moment for each shape versus lengths 30 to 50 feet is given in Figure 3-13. Lengths shorter than 30 ft could be susceptible to other buckling modes (flange local buckling and web local buckling).

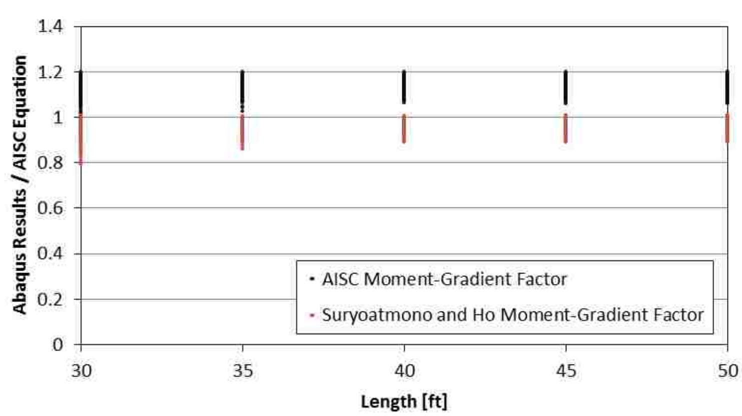

Figure 3-13: Comparison of Abaqus and Elastic Lateral-Torsional Buckling Equation Critical Moments for All W-Shapes under Non-Uniform Moment with AISC and Suryoatmono and Ho (2002) Moment Gradient Factors

Two different groups of ratios are shown in Figure 3-13 with two different moment-gradient factors (C_b). Since the moment is non-uniform, a moment gradient factor must be used in the equation to predict the critical buckling moment. Suryoatmono and Ho (2002) used a finite-difference solution to derive moment-gradient factor equations for several loading cases and found their factors to be more accurate than those provided by the empirical AISC moment-gradient factor equation. For a simply supported beam with no mid-span lateral bracing and equal moments applied at both ends, the AISC provides a C_b factor of 2.27 and Suryoatmono and Ho (2002) suggest a more accurate C_b factor of 2.708. Figure 3-13 provides Abaqus/Equation ratios using both moment-gradient factors for comparison.

It can be seen that the moment gradient factor used makes a large difference. While the Abaqus results are not always in agreement with the equation, the Abaqus results are consistently within 15-20% of the equation. Compared to the AISC moment gradient factor, Abaqus predicts a higher buckling moment than the equation. Compared to the Suryoatmono and Ho moment gradient factor, Abaqus predicts a lower, more conservative buckling moment than the equation, with a variability that can be explained by the I_x/I_y assumption discussed in Section 3.5.3. The consistency of these results provided the validation sought for the Abaqus buckling solution procedure.

4 METHODOLOGY

To investigate the lateral-torsional buckling capacities of different tapered-flange W-Shapes, I-beams were modeled and analyzed using finite element analysis. Each W-Shape in the AISC Steel Construction Manual (2011) was modeled with shell elements and as a simply supported beam with applied moments at the end, resulting in the same shear and moment distribution as a beam in a moment frame (see Figure 1-2). Each W-shape was analyzed with tapered-flanges for varied lengths and bracing configurations. A tapered-flange beam is shown in Figure 4-1. The buckling stress was calculated for each shape with equal applied moments at the ends and intermediate lateral-bracing.

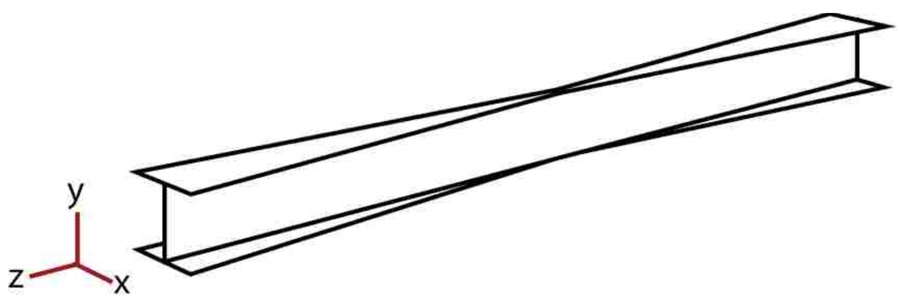

Figure 4-1: Tapered-Flange Shape

4.1 Geometry

For each W-Shape listed in the Steel Construction Manual, an analysis for a tapered-flange beam was conducted. The tapered-flange shapes differ from their straight-flange counterparts only in the flange width. The tapered shapes have the full cross section of the nominal shape at both ends and the width of the flange tapers linearly until the width is the same as the thickness of the web, t_w. This occurs at the mid-length of the beam, as seen in Figure 4-2.

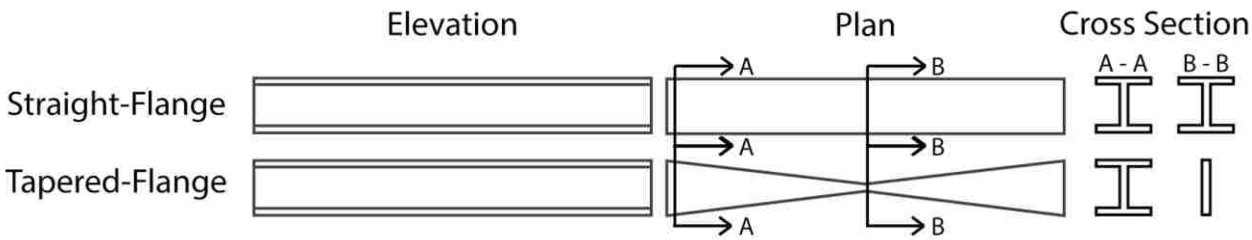

Figure 4-2: Elevation, Plan and Cross-Section Comparison for Straight-Flange and Tapered-Flange I-beams.

In Abaqus (2010), the geometry is modeled using shell extrusion, as described in Section 3.4.1. If the beam is tapered, then the taper is generated using the cut extrusion method, with the flange being tapered until its width is t_w at the center of the beam. Fillets are neglected.

4.2 Modeling Assumptions and Material Properties

Each I-beam was modeled and analyzed using the finite element software Abaqus (2010). The modeling assumptions and material properties are the same as those detailed in Section 3.4.2. The Abaqus shell element S4R was used.

4.3 Boundary Conditions and Loading

Each beam was modeled with simply supported end conditions; the ends are constrained from lateral deflection and twist rotation, but are free to rotate in horizontal planes, leaving the flange ends free to warp. Figure 4-3 shows a tapered-flange beam with different parts highlighted for displaying where the boundary conditions take place. Next to each beam is also shown the axis orientation, for reference. The nodes in the web at each end (Figure 4-3(a)) are fixed from translation in the x-direction. All nodes on each web and flange end (Figure 4-3(b)) are fixed from rotation about the z axis. The node closest to the midpoint of the web at each end (Figure 4-3(c)) is fixed from translation in the y-direction. The node nearest the midpoint of the web at a single end (Figure 4-3(d)) is fixed from translation in the z-direction. All nodes in the left and right web are constrained to a respective mid-web node highlighted in Figure 4-3(c).

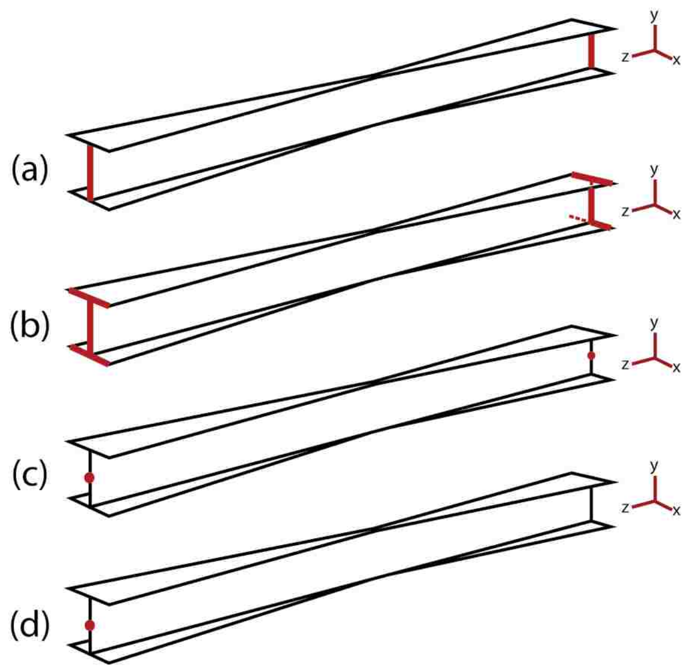

Figure 4-3: Boundary Conditions Used in Tapered-Flange Model

For some analyses, lateral bracing was modeled in addition to the simply supported end conditions. The lateral bracing was applied at the middle of the flange width to one node at each the top and bottom of the beam, as seen in Figure 4-4. These nodes were constrained from moving in the x-direction.

A loading condition used to represent lateral loading for moment frame beams was used at the beam ends. Equal unit moments were applied at each end of the beam, at the points highlighted in Figure 4-3(c). The moments were both applied in the positive direction about the x-axis, generating the moment gradient shown in Figure 1-2. The moments were applied at the node nearest the midpoint of each web end, as recommended by Yang and Yau (1987).

4.4 Varied Parameters

Each straight-flange and tapered-flange W-Shape profile was considered in combination with different lengths and intermediate lateral-bracing points. The lengths used were 1-ft and 5 to 50-ft in 5-ft increments, for a total of 11 different span lengths. The three different lateral-bracing conditions considered were no bracing, mid-span bracing, and third-span bracing, as shown in Figure 4-4.

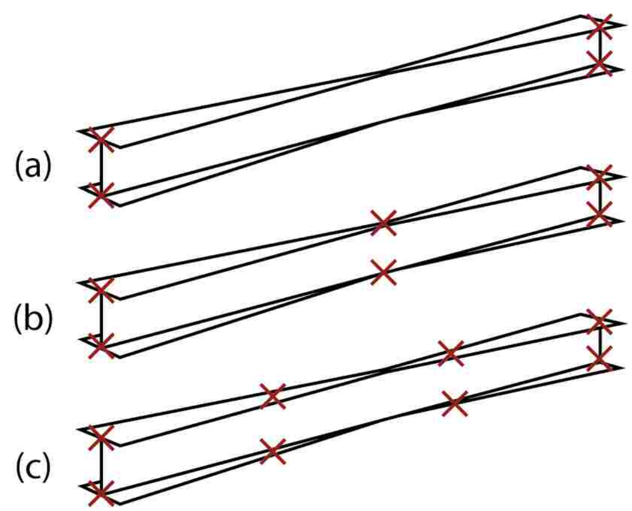

Figure 4-4: Tapered-Flange Beams with (a) No Bracing, (b) Mid-Span Bracing, and (c) Third-Span Bracing

.

4.5 Buckling Stress

The critical buckling moment was used to calculate the buckling stress for each beam, using Equation 4-1. In this equation, σ_{cr} is the critical buckling stress, M_{cr} is the critical buckling moment, d is the beam depth and I_x is the beam's moment of inertia about the x-axis. Both d and I_x for each shape are given in the AISC Manual (2011).

$$\sigma_{cr} = \frac{M_{cr} \cdot \frac{d}{2}}{I_x} \tag{4-1}$$

4.6 Scripting / Batches

A Python script was used to run all of the analyses in Abaqus. The buckling moment for each shape at each length and bracing condition was then exported to a CSV file. Excel was then used to generate plots for each shape. Table 4-1 shows the total number of analyses conducted. The Python scripts for running all tapered-flange shapes under non-uniform moments are provided in Appendix A. Example Abaqus input files are provided in Appendix B.

Table 4-1: Breakdown of Tapered-Flange Analyses

273	W-shapes
11	Lengths
3	Bracing conditions
9,009	Total analyses

5 RESULTS AND DISCUSSION

The results are shown in two kinds of plots: 1) buckling stress versus length for each tapered-flange shape and each lateral-bracing condition, and 2) a ratio of the tapered-flange to straight-flange buckling stress versus length for each shape.

5.1 Buckling Stress Plots for Tapered-Flange Shapes

Buckling stress versus length plots were generated for each tapered-flange shape, shown in Figure 5-1 through Figure 5-17. Each plot contains three lines: a solid line for the shape with no bracing, a long-dashed line for mid-span bracing, and a short-dashed line for third-span bracing. Shapes used as beams are typically deeper and longer, so Section 5.1.1, detailing beams, includes shapes W44 through W16 from lengths 20 to 40 feet. Columns are typically less deep and shorter, so Section 5.1.2 includes plots for W14 through W4 from lengths 10 to 30 feet. Since moment frame columns have the same moment gradient as moment frame beams, the same analysis pertains. The extent of the stress is held constant (to 100 ksi) across plots for comparison. Any part of a line (or whole line) above 100 ksi will not be within the range plotted. For some W14 and W12 column shapes, the buckling stress is never below 100 ksi for the plotted lengths for any bracing condition. For the shapes where this occurs, the plot is not shown. The results for every shape at every length analyzed are provided in Appendix C.

5.1.1 Buckling Stress Plots for Tapered-Flange Beams

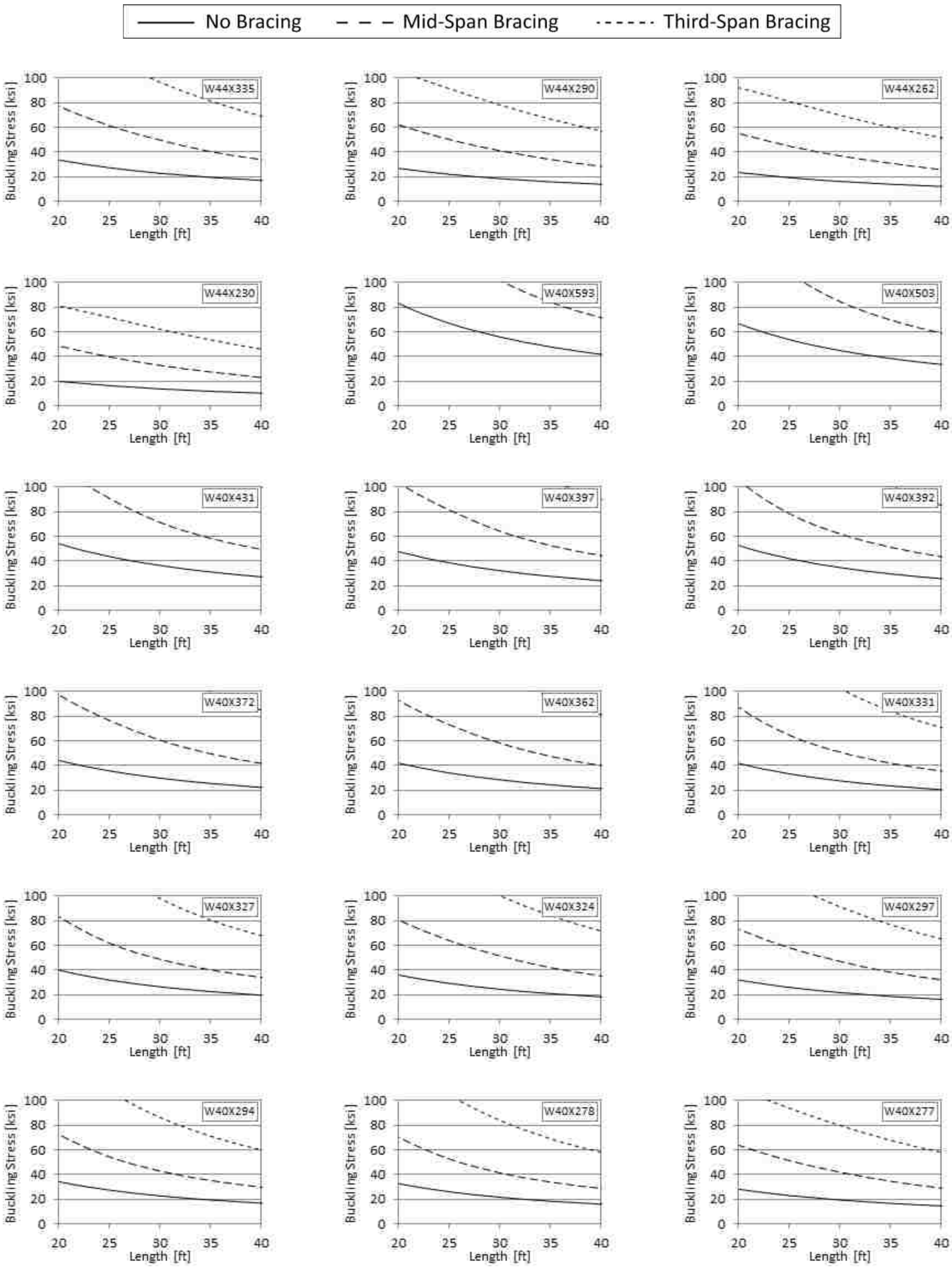

Figure 5-1: Buckling Stress Plot for W44X335 to W40X277 Beams

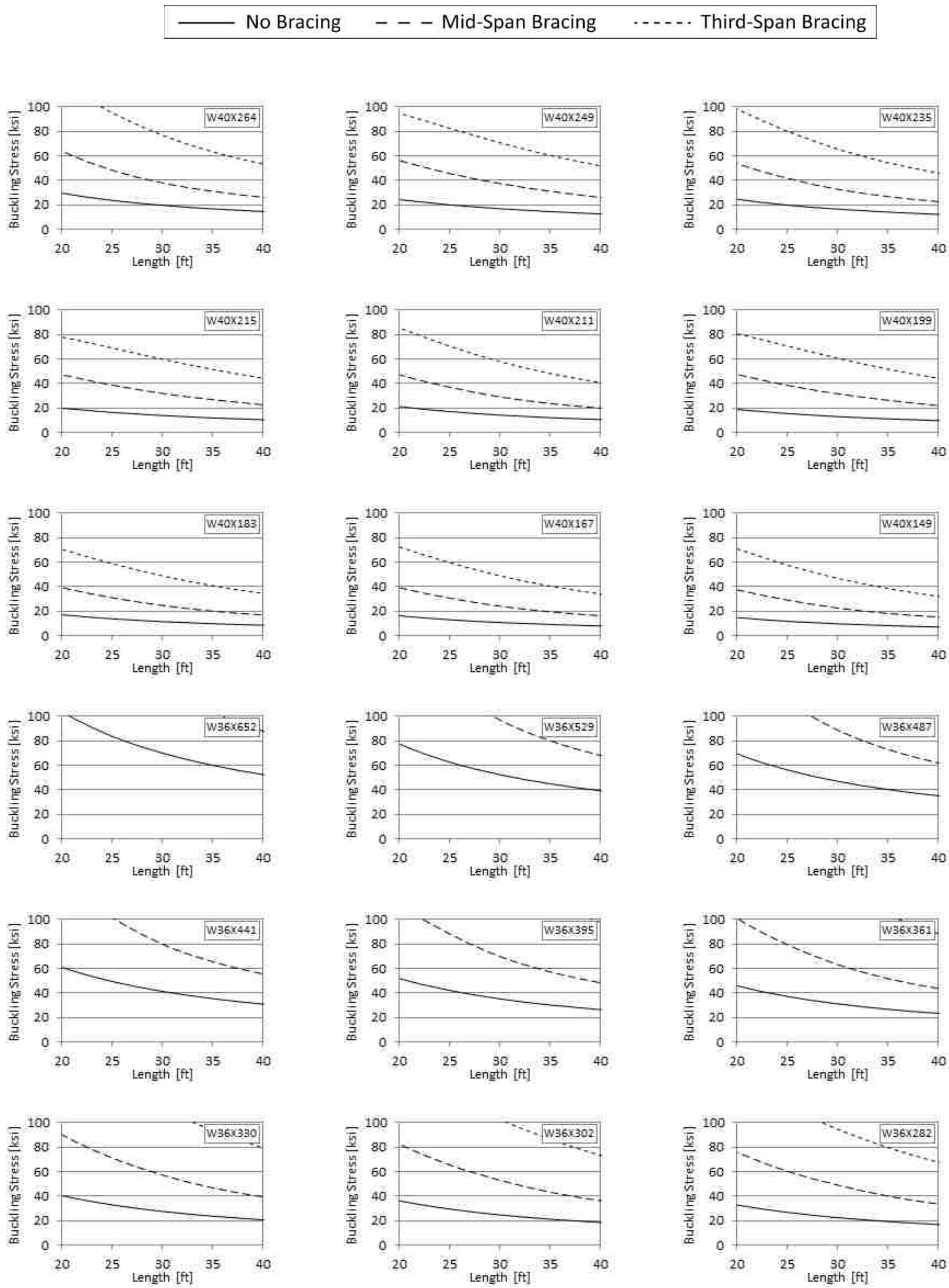

Figure 5-2: Buckling Stress Plot for W40X264 to W36X282 Beams

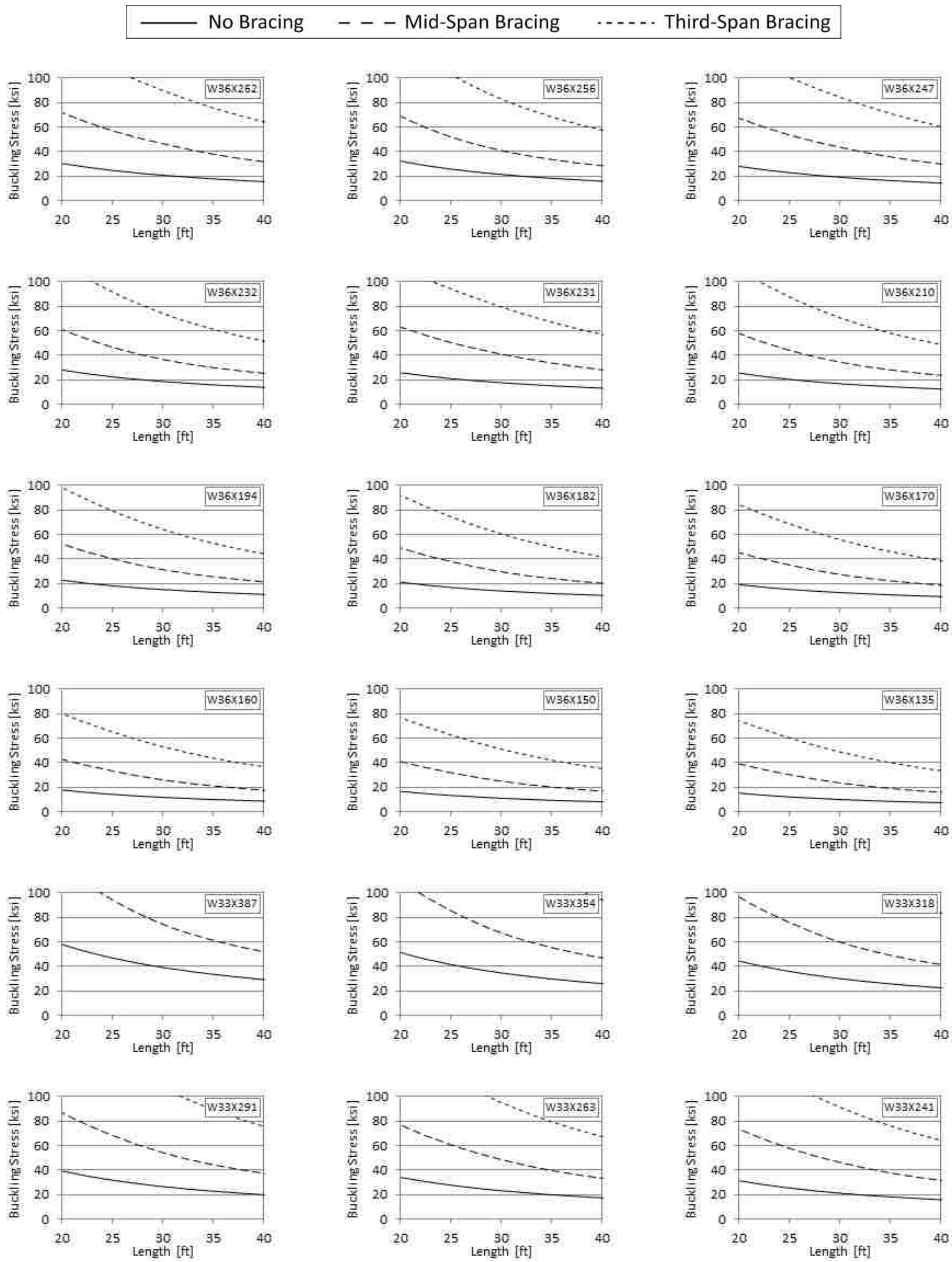

Figure 5-3: Buckling Stress Plot for W36X262 to W33X241 Beams

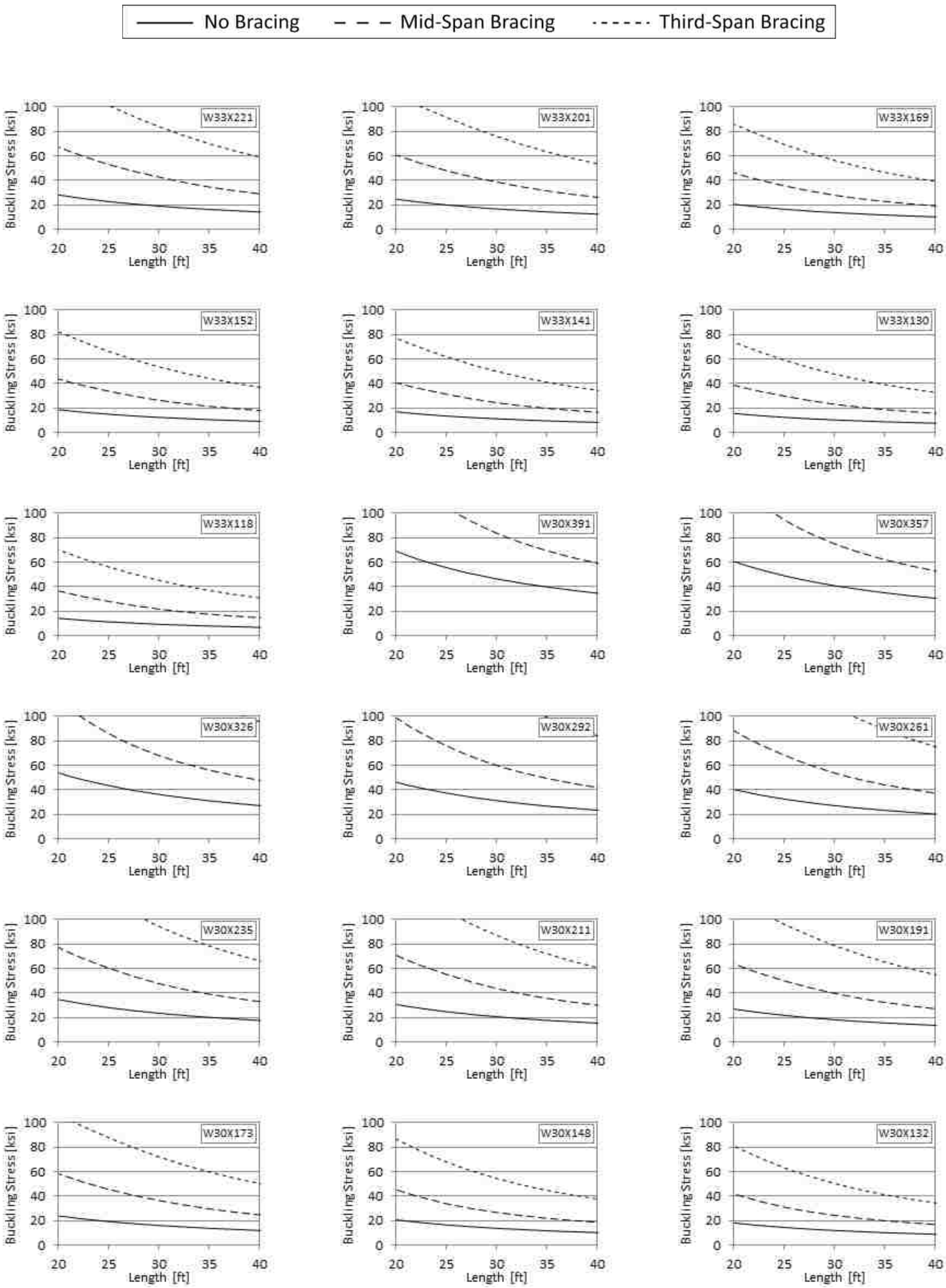

Figure 5-4: Buckling Stress Plot for W33X221 to W30X132 Beams

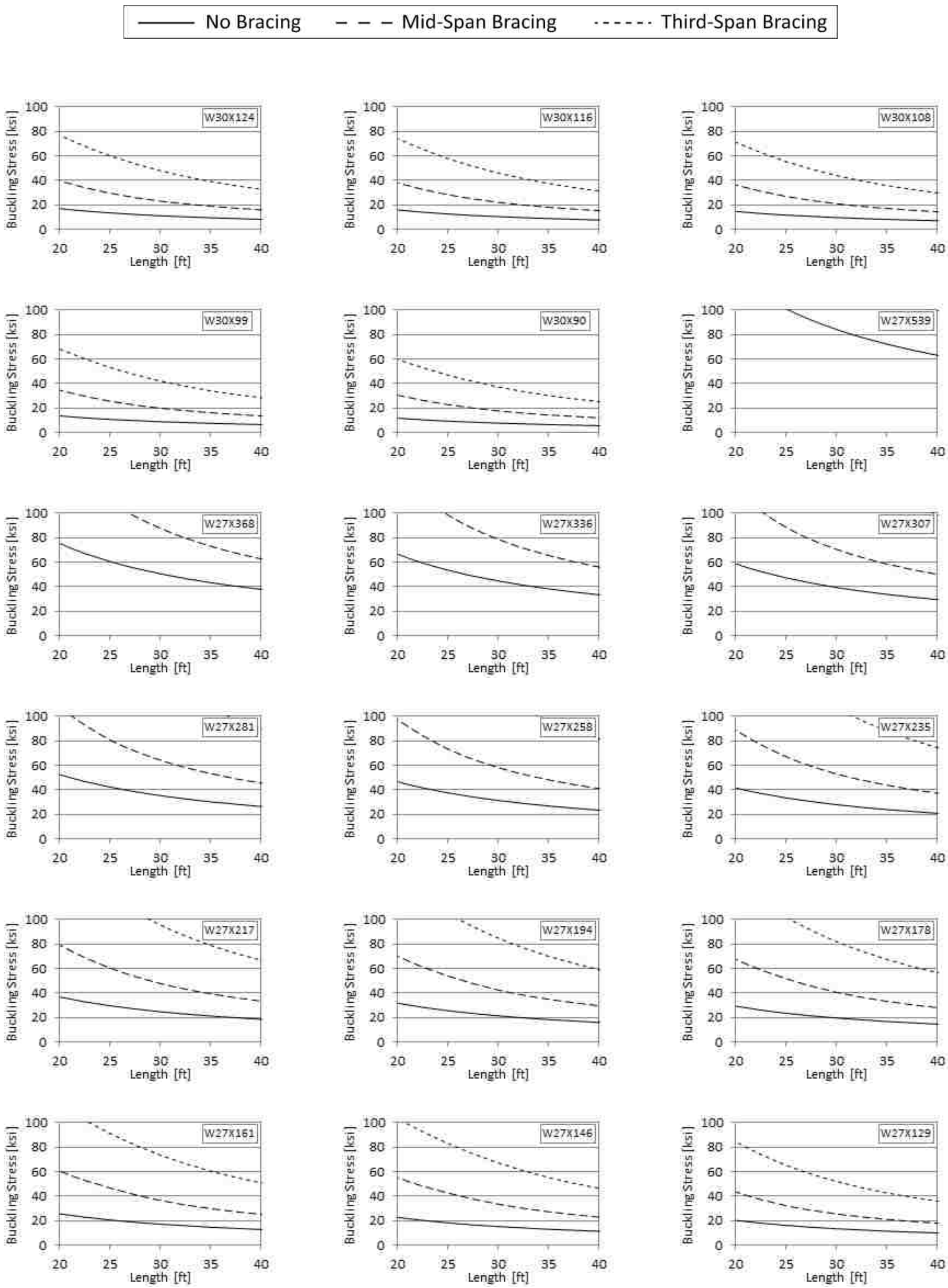

Figure 5-5: Buckling Stress Plot for W30X124 to W27X129 Beams

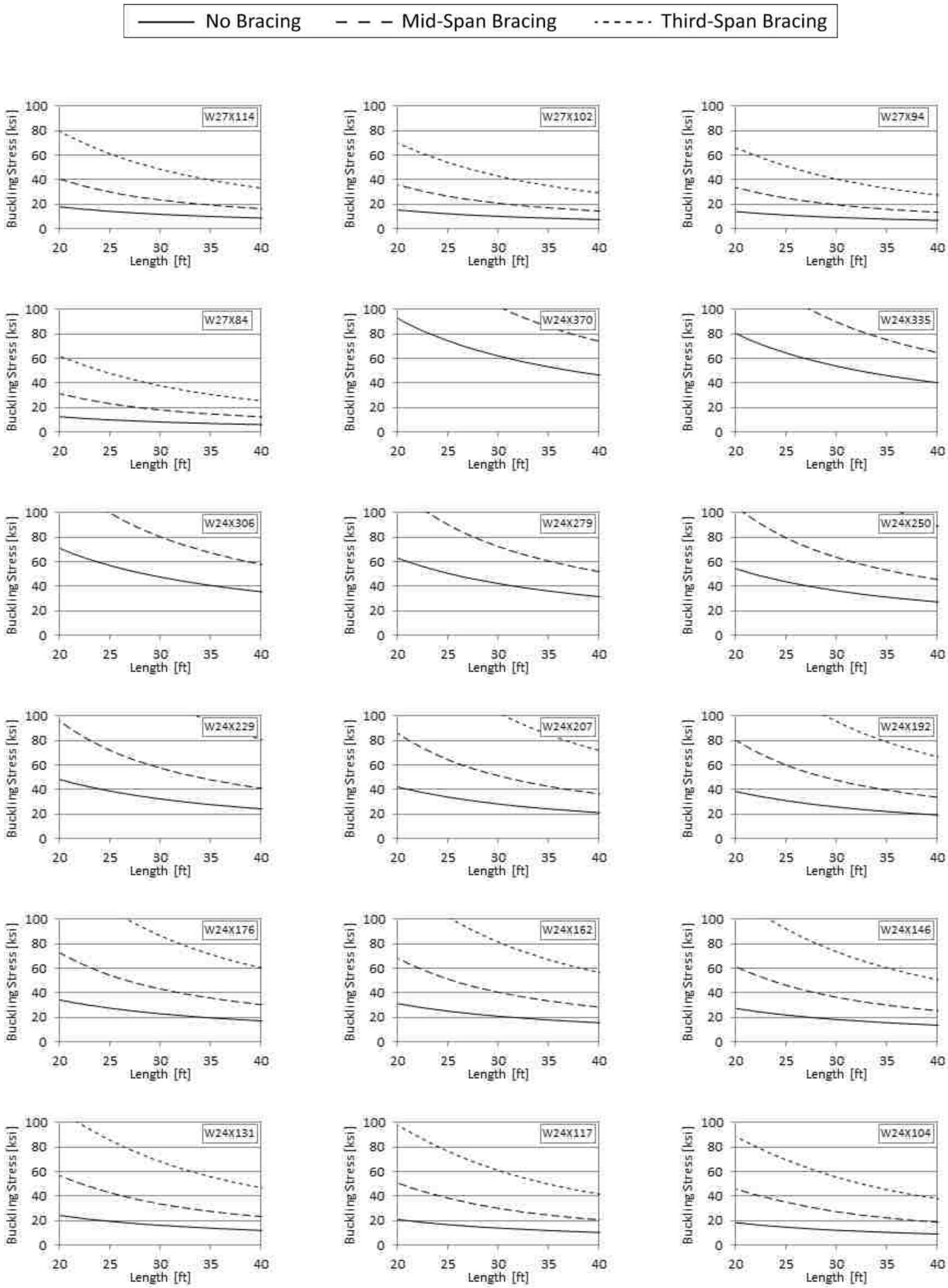

Figure 5-6: Buckling Stress Plot for W27X114 to W24X104 Beams

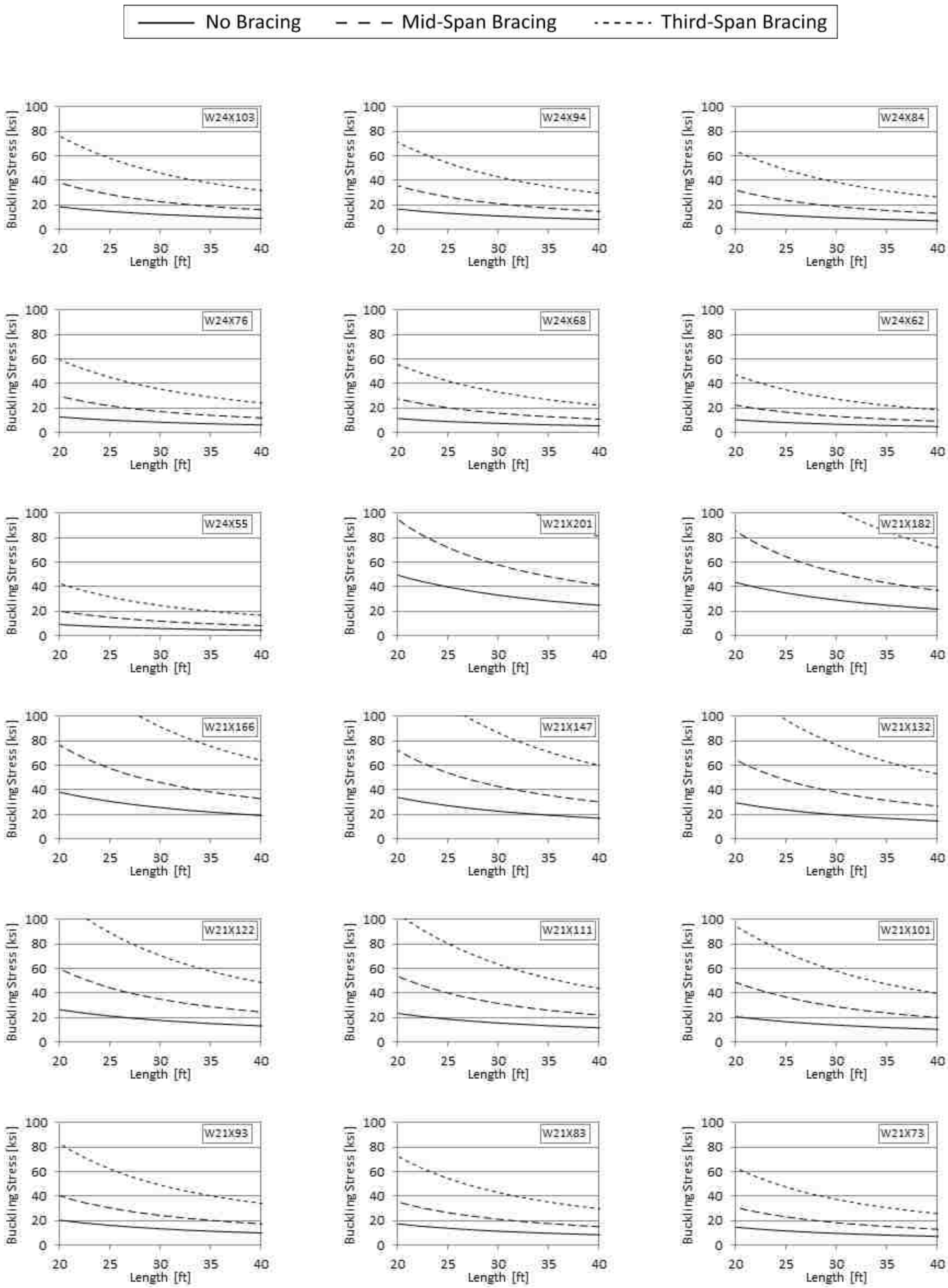

Figure 5-7: Buckling Stress Plot for W24X103 to W21X73 Beams

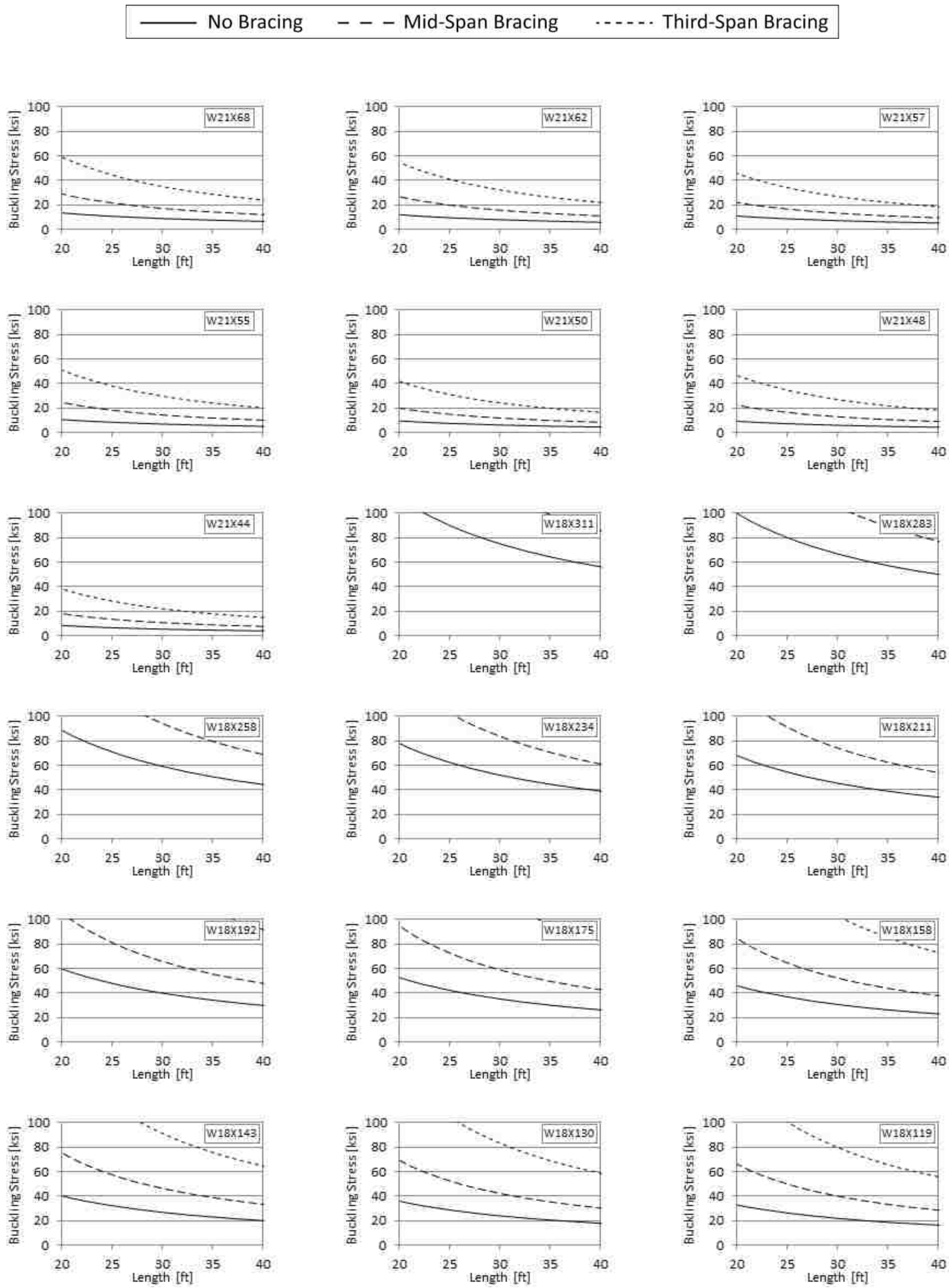

Figure 5-8: Buckling Stress Plot for W21X68 to W18X119 Beams

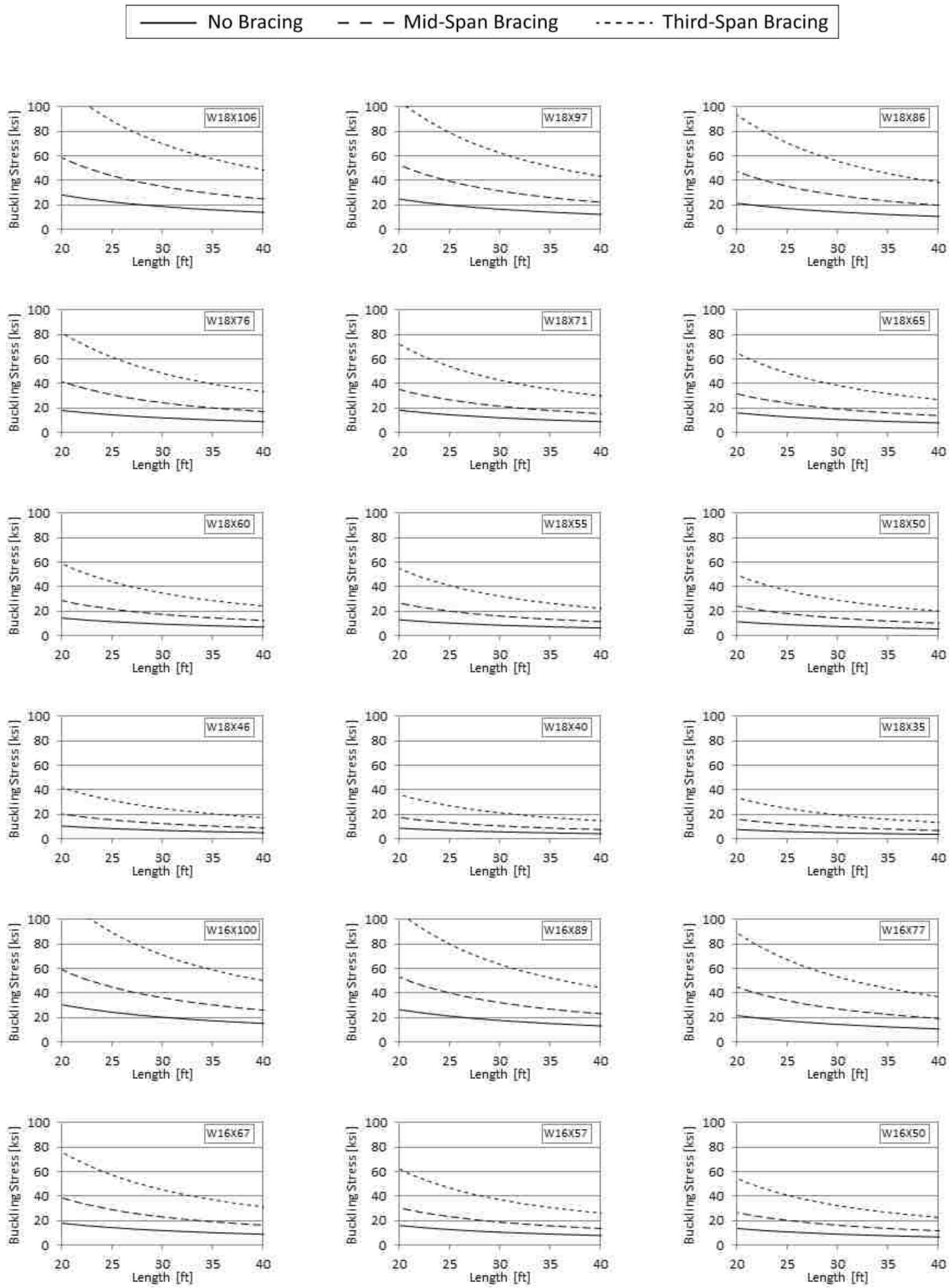

Figure 5-9: Buckling Stress Plot for W18X106 to W16X50 Beams

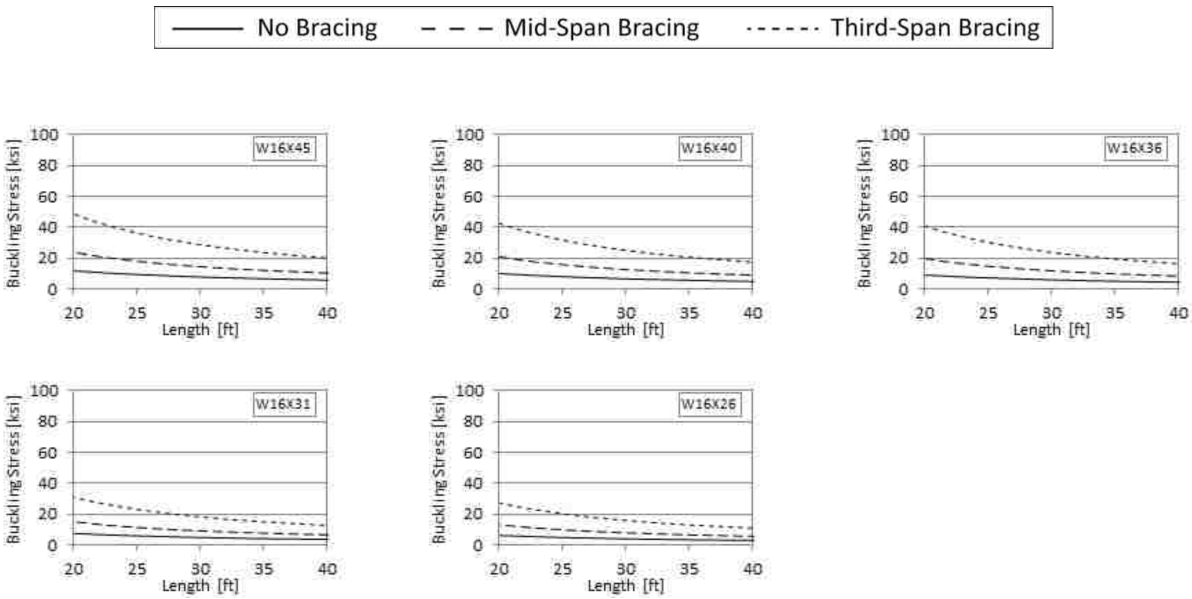

Figure 5-10: Buckling Stress Plot for W16X45 to W16X26 Beams

The plots reveal lateral-torsional buckling trends for beams that lend to some general rules of thumb for selecting a shape that will yield before buckle. As expected, the lateral-torsional buckling capacity of the beams is greater for shorter lengths than longer lengths, for deeper beams than shallower beams, and for heavier beams than lighter beams. Mid-span and third-span bracing can substantially increase the lateral-torsional buckling capacity of the beam.

For lengths where the buckling stress is shown to be greater than 50 ksi, yielding, rather than elastic lateral-torsional buckling, would be the governing limit state. This means that by selecting a shape and length where the buckling stress is greater than 50 ksi, the shape would yield before elastically buckling. This is a typical design approach in moment frame design.

For beams without intermediate lateral bracing, the shape options are somewhat limited if yielding is to happen before lateral-torsional buckling. For longer lengths (around 40 feet), the selection is limited to two shapes: a W27X539 and a W18X311 to allow yielding before buckling. When selecting a shorter beam (around 20 ft), there are more options, but with no intermediate lateral bracing the options are limited to heavier shapes. If selecting a W36 shape or deeper, the shape ought to weigh more than 400 pounds per foot (weight of base shape before tapering). W30, W27, and W24 shapes will work if above 300 pounds per foot, as a general rule of thumb. W18s above 200 pounds per foot will probably provide the most cost-per-weight savings. W21s and W16s will not work at shorter lengths when there is no intermediate bracing. It is highly recommended that lateral bracing be used, especially for longer-length beams.

For beams with mid-span bracing, the options increase. For shorter lengths (20 ft), a W44 and W40 shape above 300 pounds per foot will work; shapes W36, through W24 above 200 pounds per foot will also work. With a W21, W18, or W16 shape, a beam as light as 100 pounds per foot will meet the design criteria. At longer lengths (40 ft), each shape is limited to the one or two heaviest shapes, but W44s, W33s, W21s, and W16s do not have a heavy enough shape that works.

For beams with third-span bracing, there are many options for shapes that will yield before buckling. If looking for a shorter beam (20 ft), a general rule of thumb is to select a beam heavier than 100 pounds per foot. This works for any depth of beam. For beams closer to 40 feet in length, the depth of the beam makes more of a difference on the weight of the beam. If using a W30 or deeper, the beam will need to weigh at least 200 pounds per foot. If using a W21 through W27 shape, 170 pounds per foot or heavier will work and a W18 shape can be as light as 120 pounds per foot. The advantage provided by intermediate bracing is almost necessary for beams longer in length.

Although it isn't apparent in the above plots, web local buckling occasionally occurred before lateral-torsional buckling. This occurred in deeper, heavier beams at shorter lengths. These buckling stresses are provided in Appendix C. When this occurred, there is a decrease in buckling stress at lower lengths, as shown in Figure 5-11. Figure 5-12 shows local web buckling that occurred before lateral-torsional buckling. Theoretically, the lateral-torsional buckling capacity of a shape increases as the length decreases.

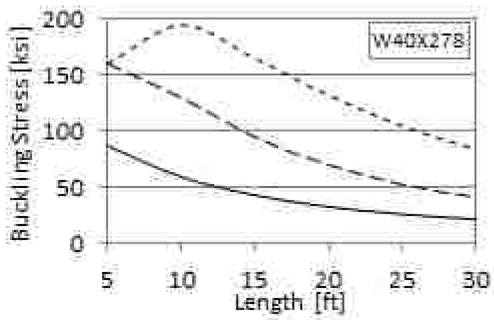

Figure 5-11: W40X278 with Local Buckling at Lower Lengths

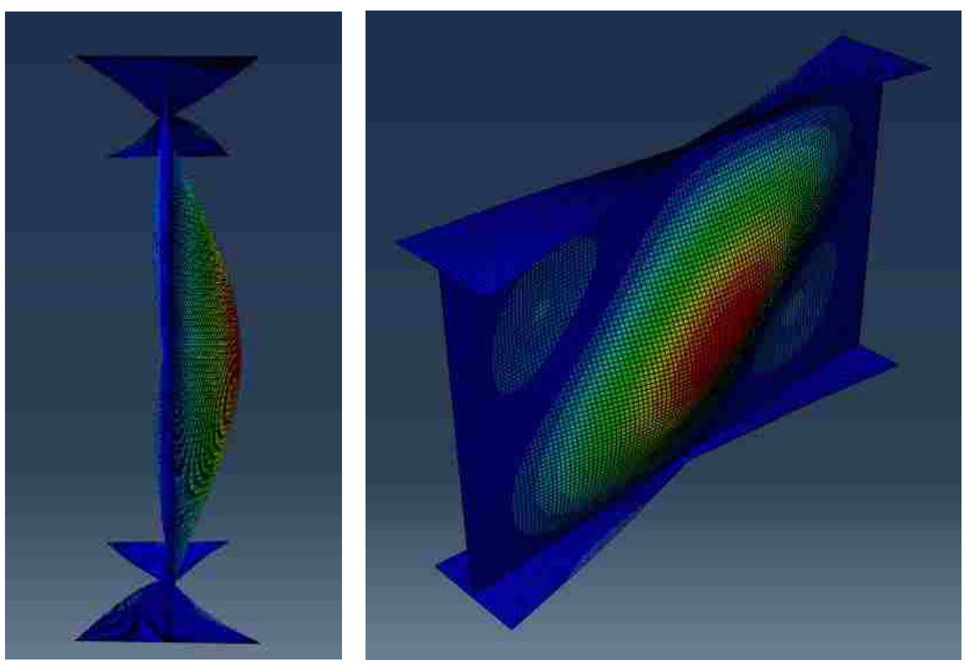

Figure 5-12: Cross Section (Left) and Global View (Right) of Web Local Buckling occurring in a 5-ft W40X278 Beam with Third-Span Bracing (deflections exaggerated)

5.1.2 Buckling Stress Plots for Tapered-Flange Columns

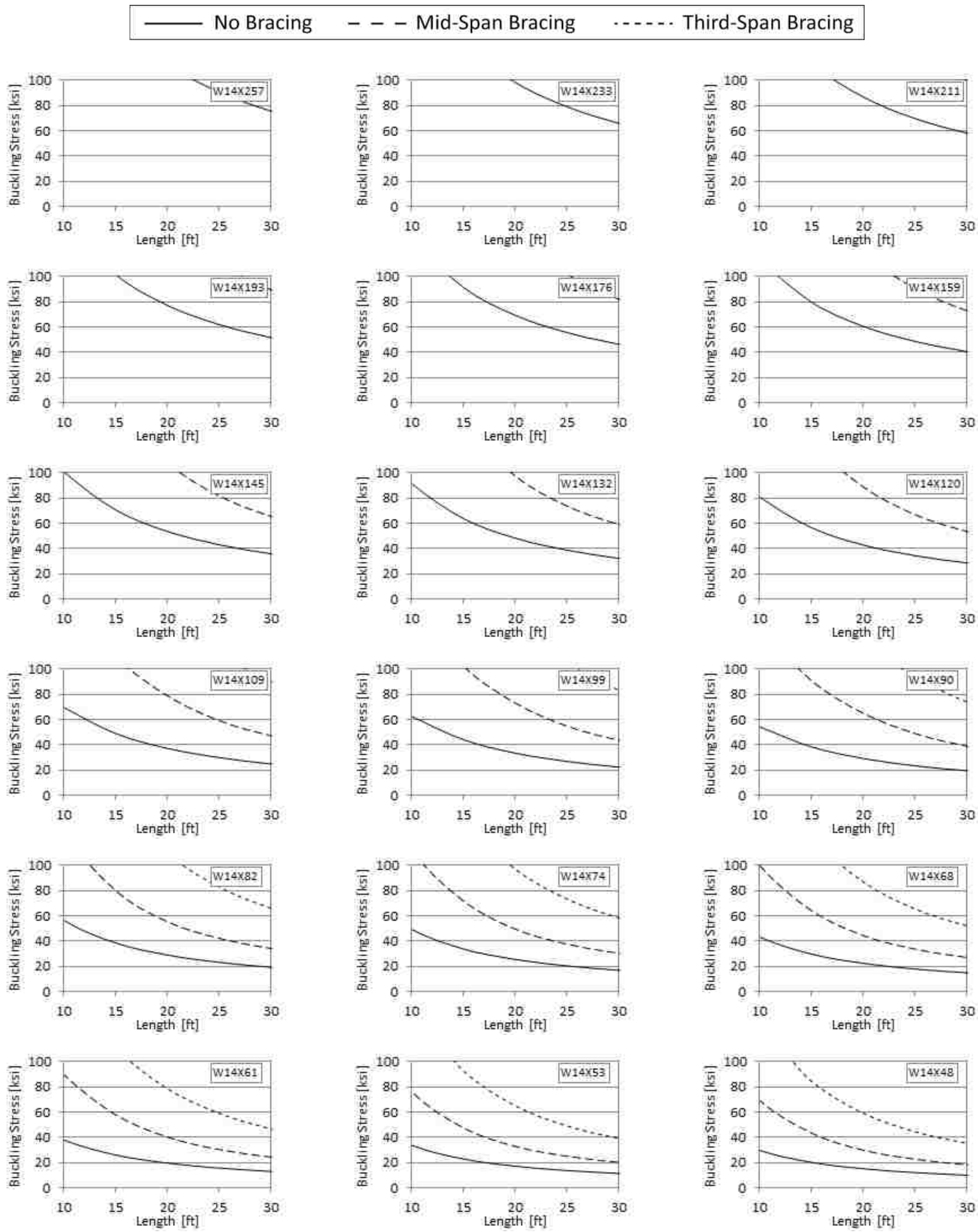

Figure 5-13: Buckling Stress Plot for W14X257 to W14X48 Columns

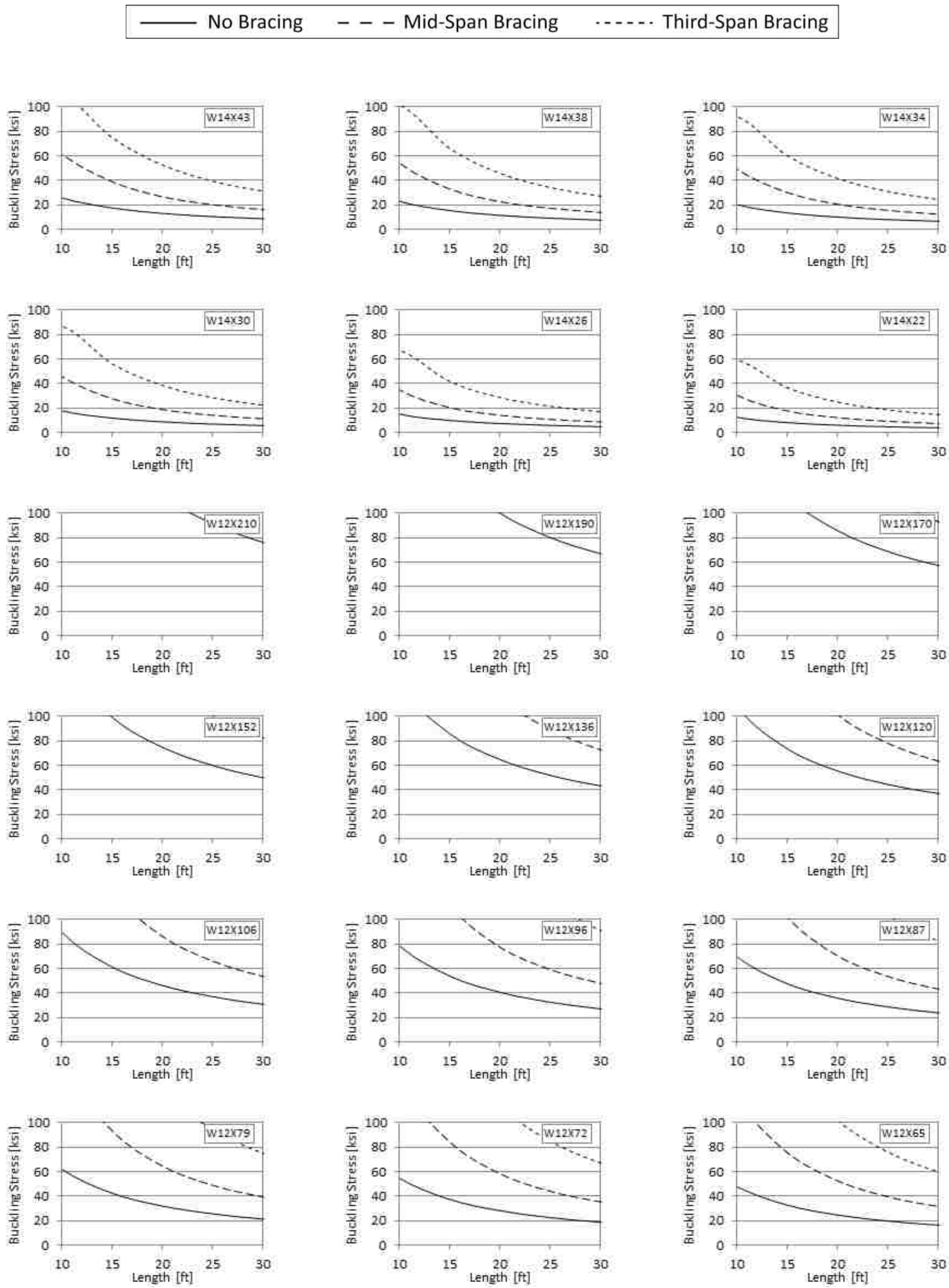

Figure 5-14: Buckling Stress Plot for W14X43 to W12X65 Columns

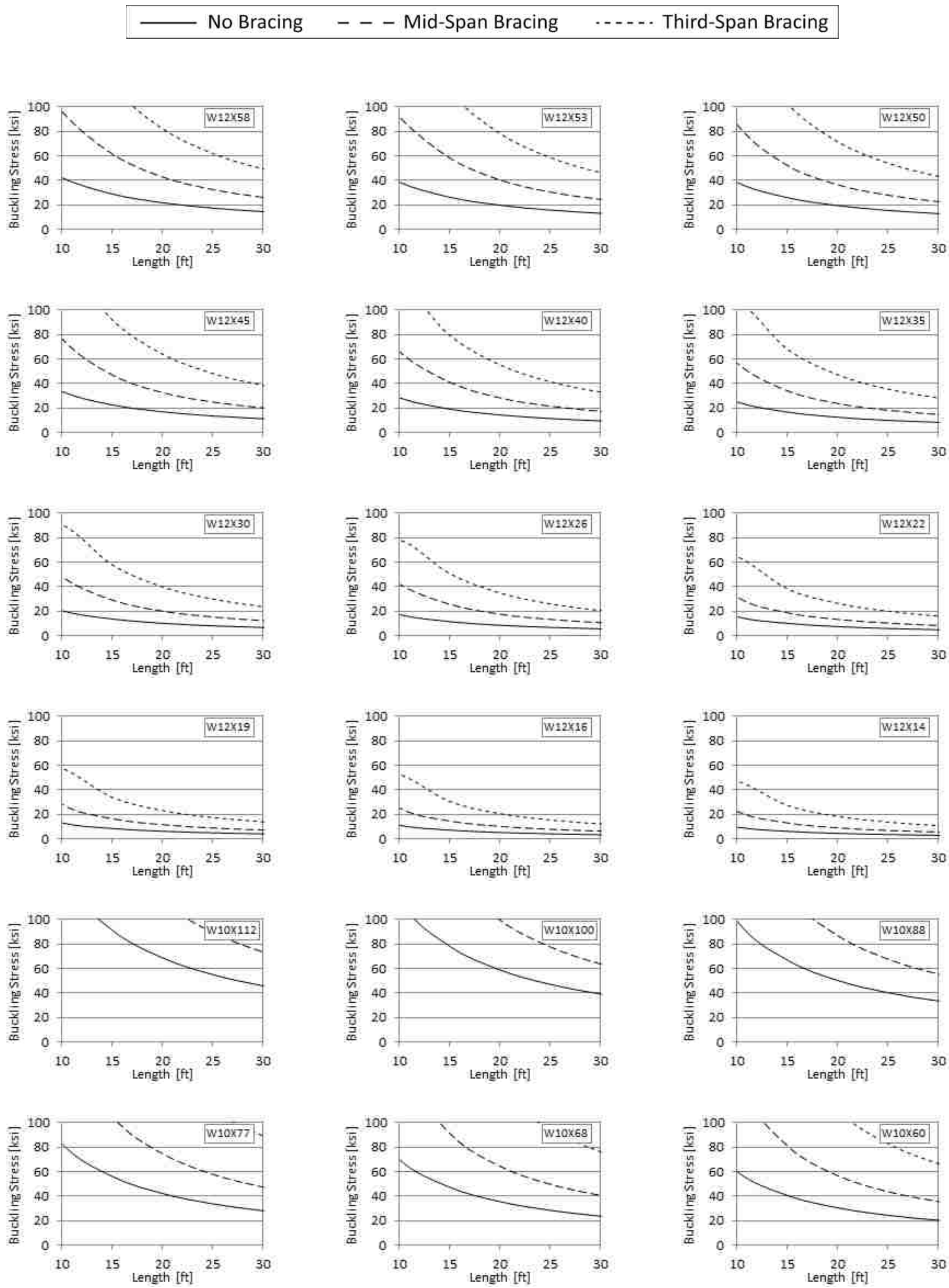

Figure 5-15: Buckling Stress Plot for W12X58 to W10X60 Columns

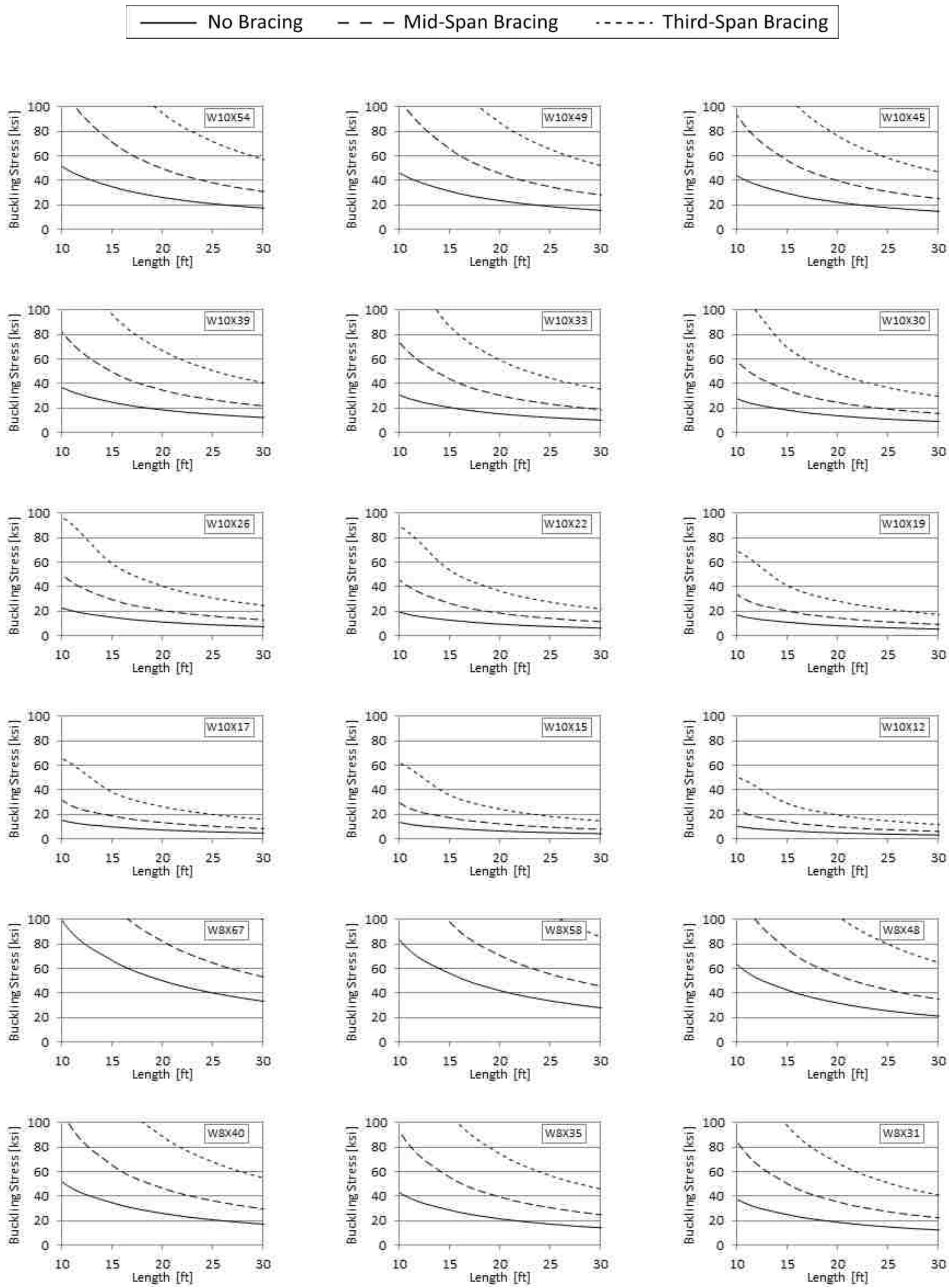

Figure 5-16: Buckling Stress Plot for W10X54 to W8X31 Columns

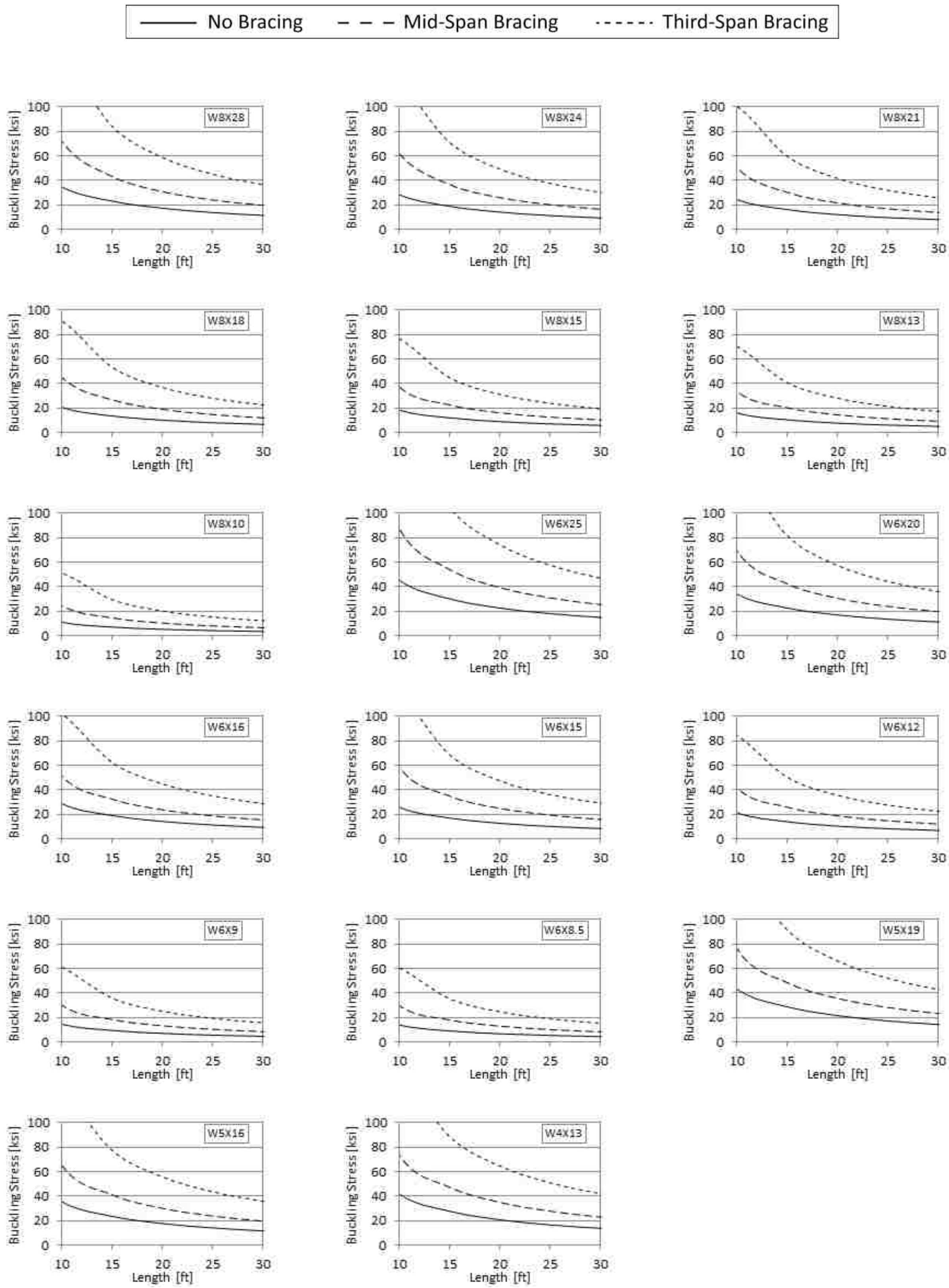

Figure 5-17: Buckling Stress Plot for W8X28 to W4X13 Columns

The plots reveal lateral-torsional buckling trends for columns that lend to some general rules of thumb for selecting a shape that will yield before buckling. While mid-span and third-span bracing can substantially increase the lateral-torsional buckling capacity of the column, it is uncommon to have intermediate bracing in a column. Accordingly, the rules of thumb suggested for columns are for columns with no intermediate lateral bracing. The rules described will result in columns that will yield prior to experiencing lateral-torsional buckling. When selecting a shorter column (around 10 ft) made of 50 ksi steel, choose a shallower column to reduce weight. For a W14, W12, W10, and W8, select a shape that is at least 90, 80, 60, or 50 pounds per foot, respectively. A W6 shape is not recommended, as its buckling capacity is less than a 50 ksi yield strength for any length over 10 feet. For columns closer to 30 feet in length, use a W14 that weighs at least 200 pounds per foot or a W12 that weighs at least 170 pounds per foot. Shapes W10 and lighter will likely buckle before yielding for lengths greater than 30 feet.

Overall, it appears that lateral-torsional buckling is not an insurmountable problem by any means when using tapered-flange beams and columns.

5.2 Buckling Stress Ratio Plots for Tapered-Flange to Straight-Flange Shapes

The ratio of the tapered-flange to straight-flange buckling stress was plotted for beams and columns. Each plot contains three lines: a solid line for the shape with no bracing, a long-dashed line for the shape with mid-span bracing, and a short-dashed line for the shape with third-span bracing. The results for each shape at every length analyzed are provided in Appendix C.

5.2.1 Buckling Stress Ratio Plots for Tapered-Flange to Straight-Flange Beams

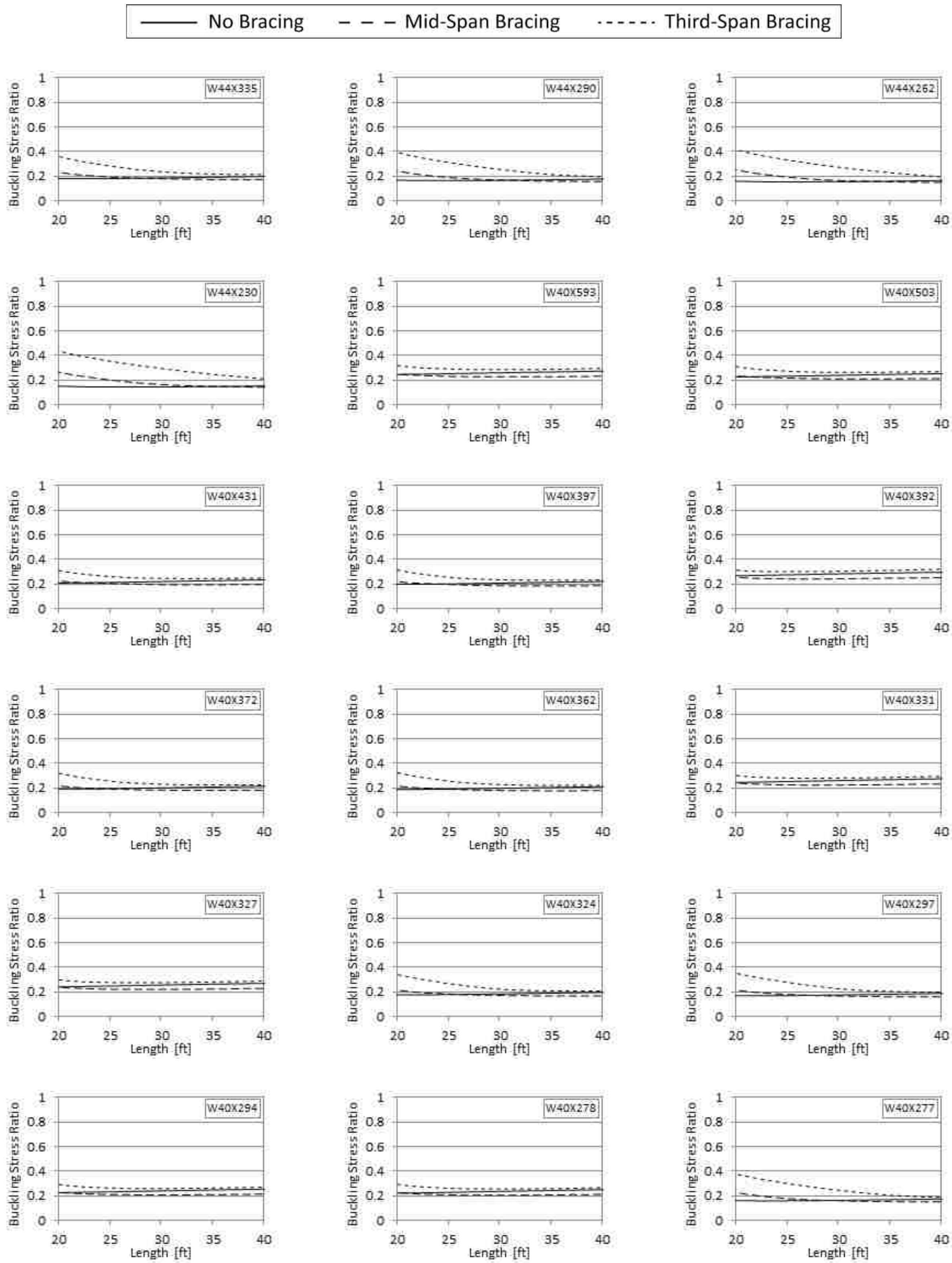

Figure 5-18: Buckling Stress Ratio Plot for W44X335 to W40X277 Beams

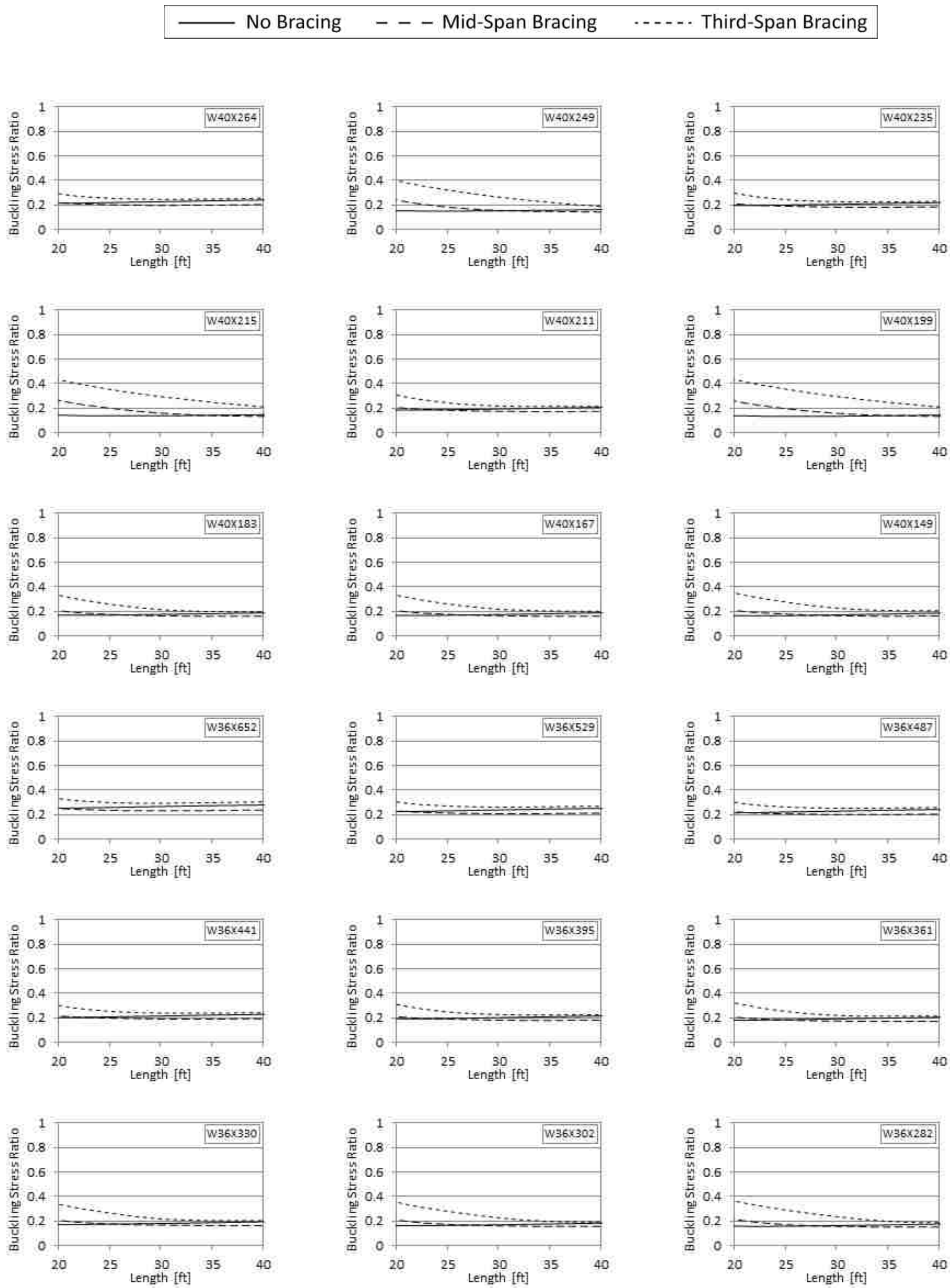

Figure 5-19: Buckling Stress Ratio Plot for W40X264 to W36X282 Beams

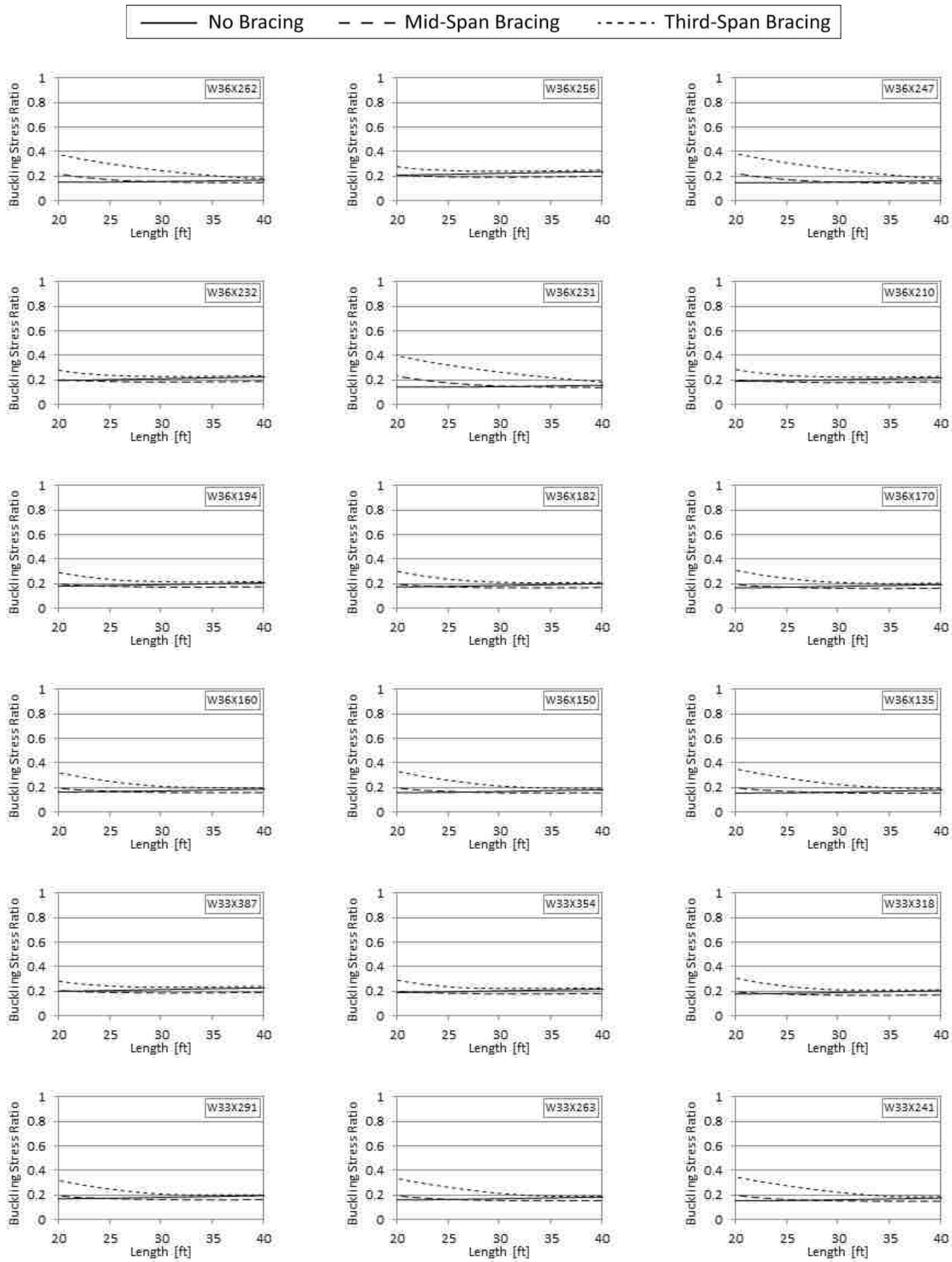

Figure 5-20: Buckling Stress Ratio Plot for W36X262 to W33X241 Beams

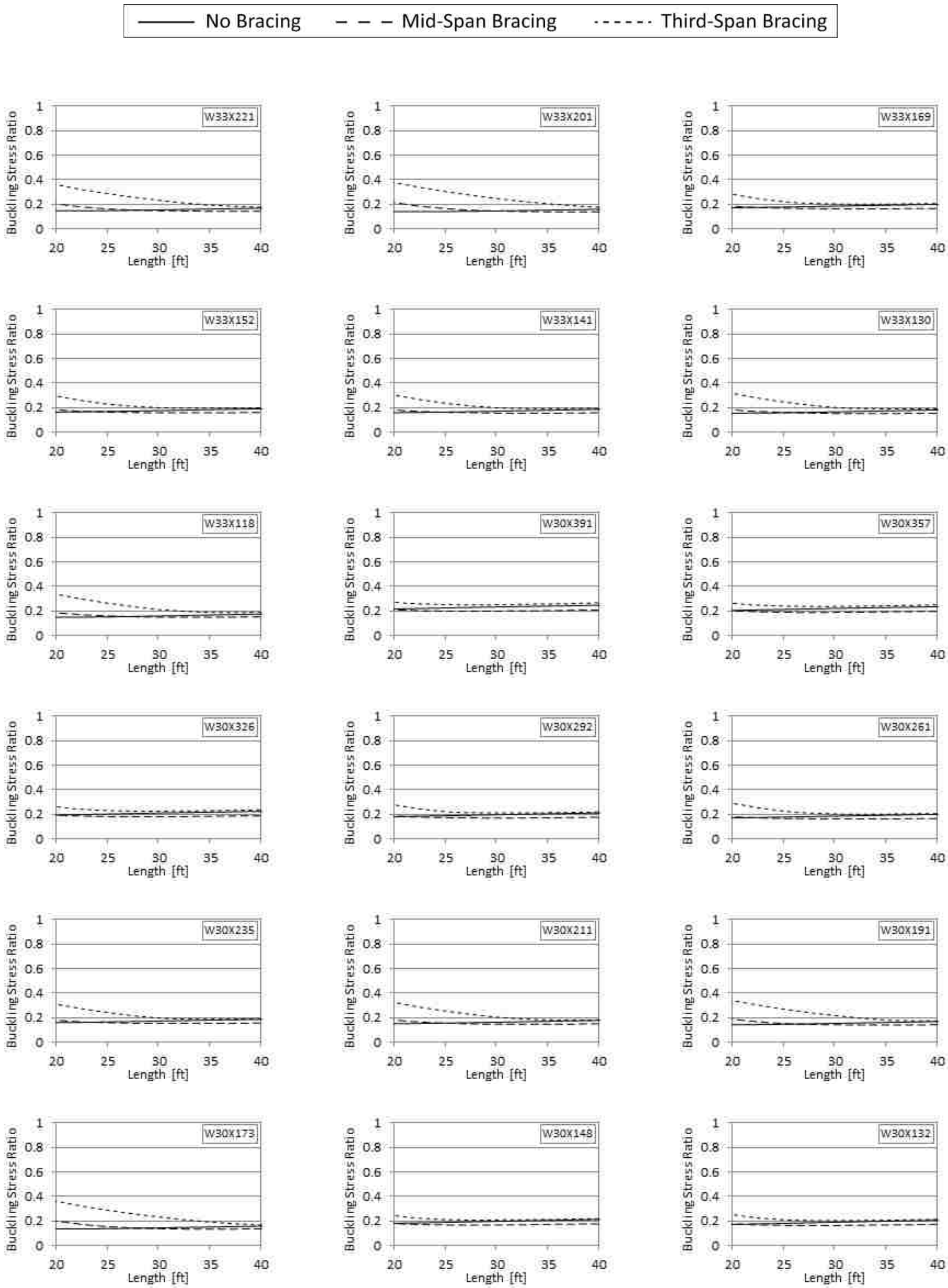

Figure 5-21: Buckling Stress Ratio Plot for W33X221 to W30X132 Beams

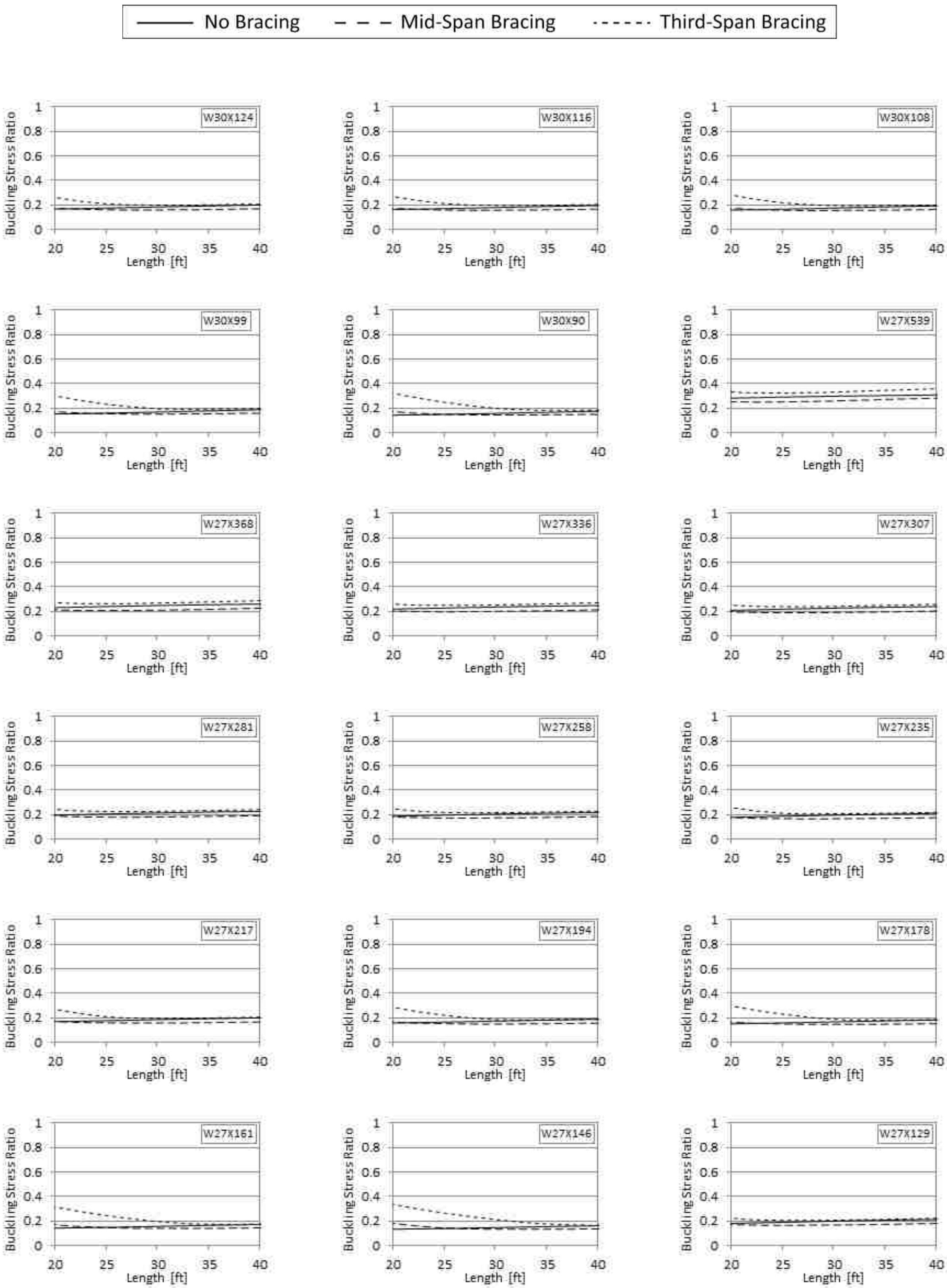

Figure 5-22: Buckling Stress Ratio Plot for W30X124 to W27X129 Beams

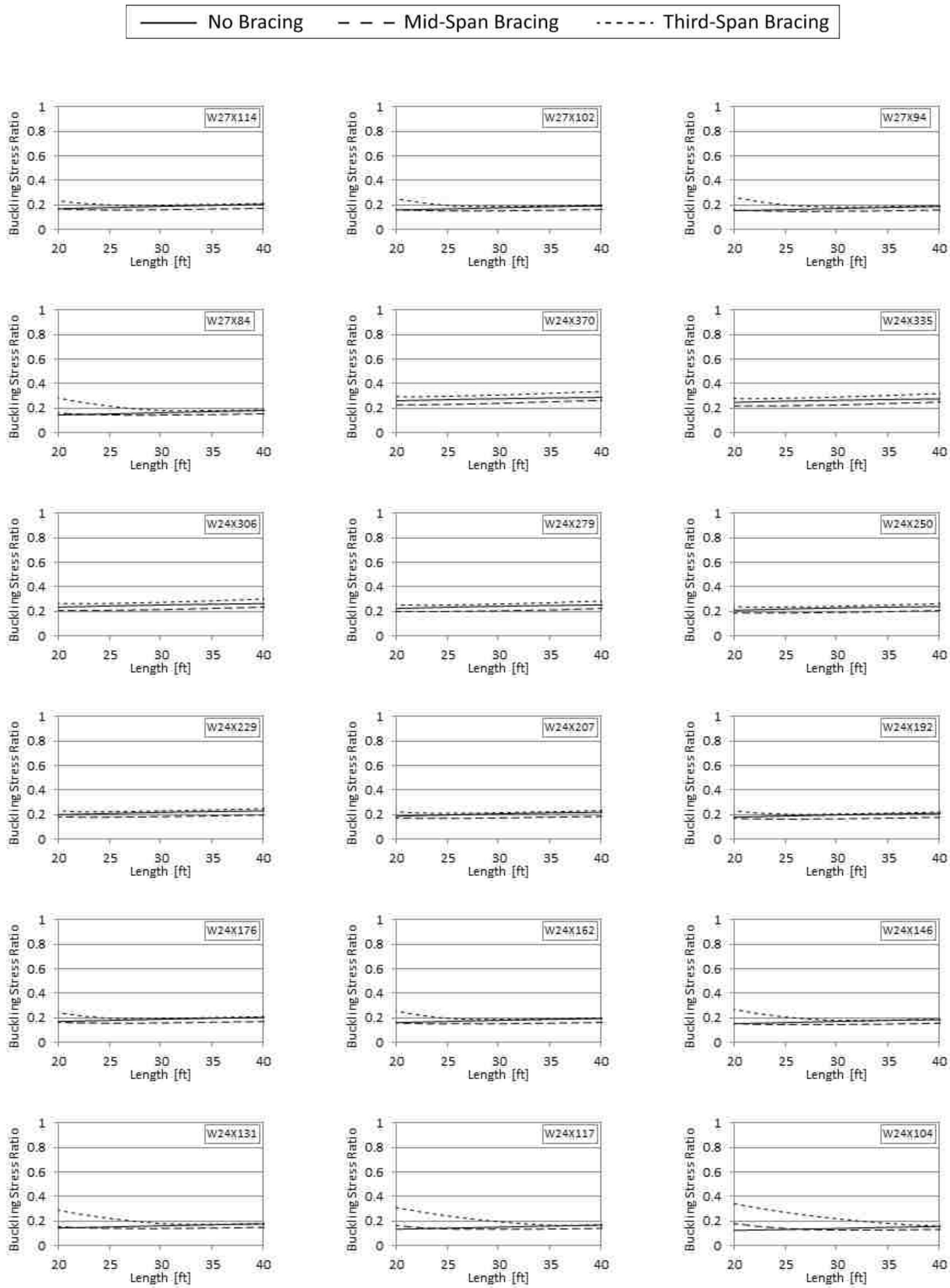

Figure 5-23: Buckling Stress Ratio Plot for W27X114 to W24X104 Beams

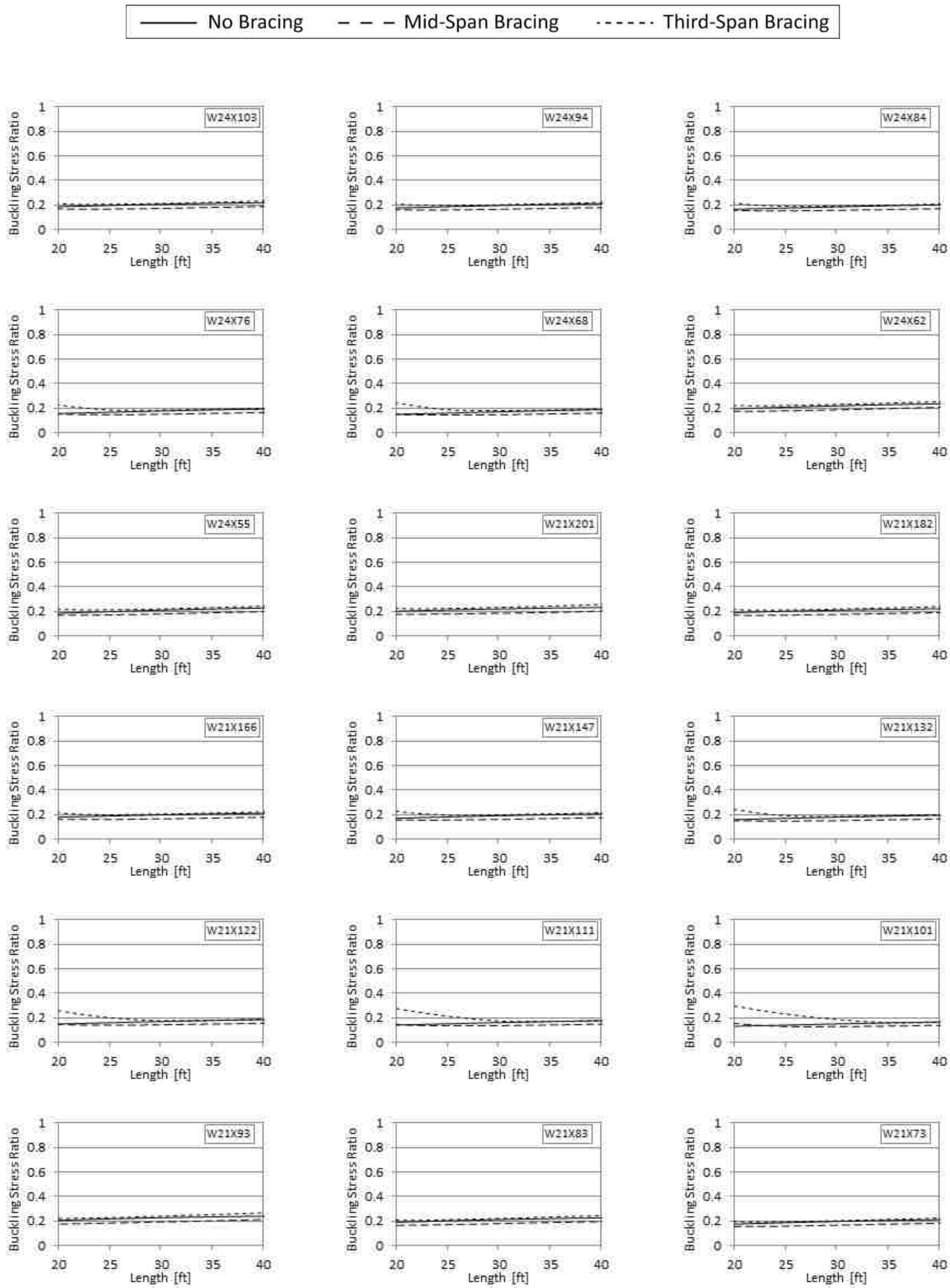

Figure 5-24: Buckling Stress Ratio Plot for W24X103 to W21X73 Beams

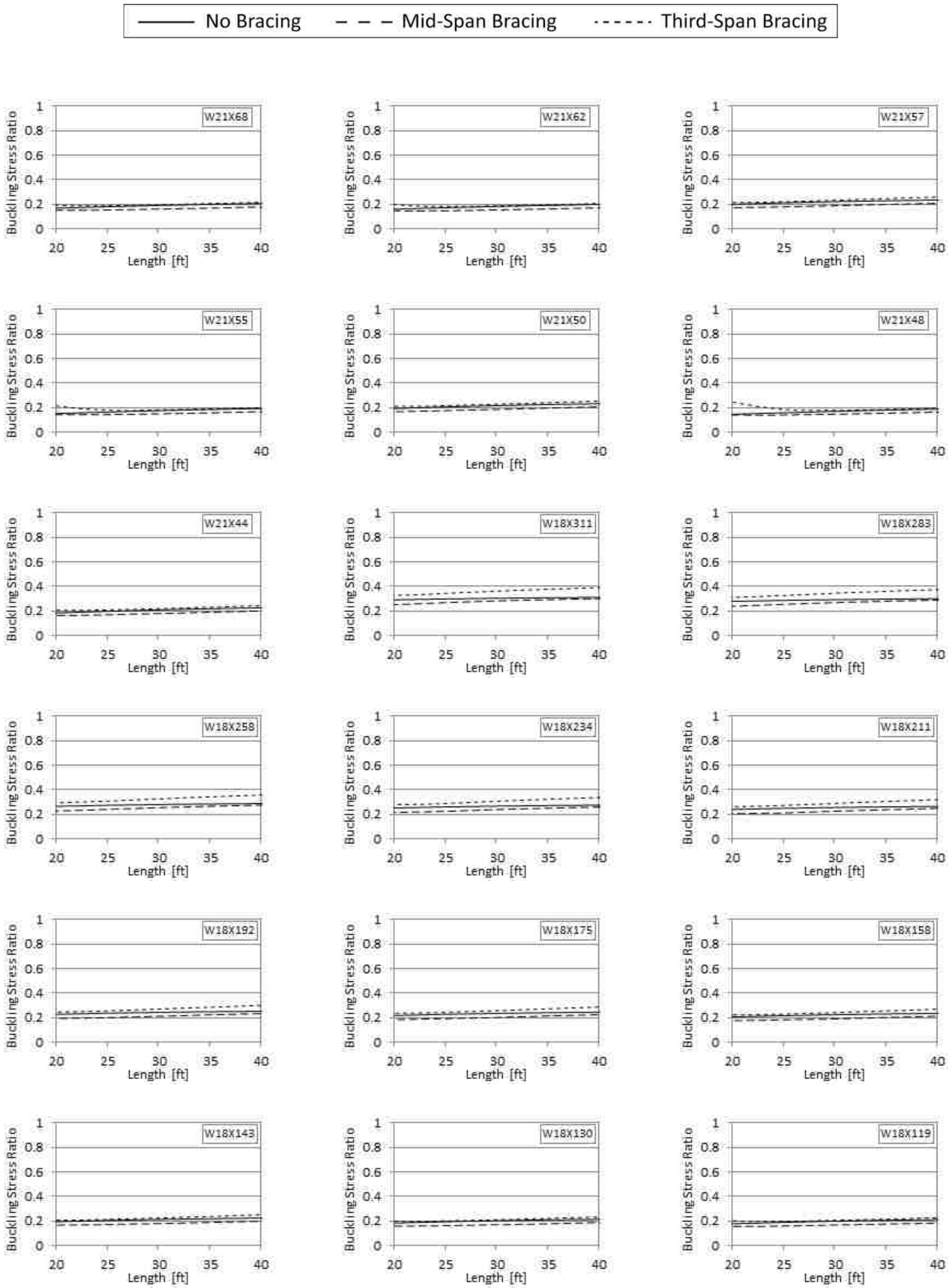

Figure 5-25: Buckling Stress Ratio Plot for W21X68 to W18X119 Beams

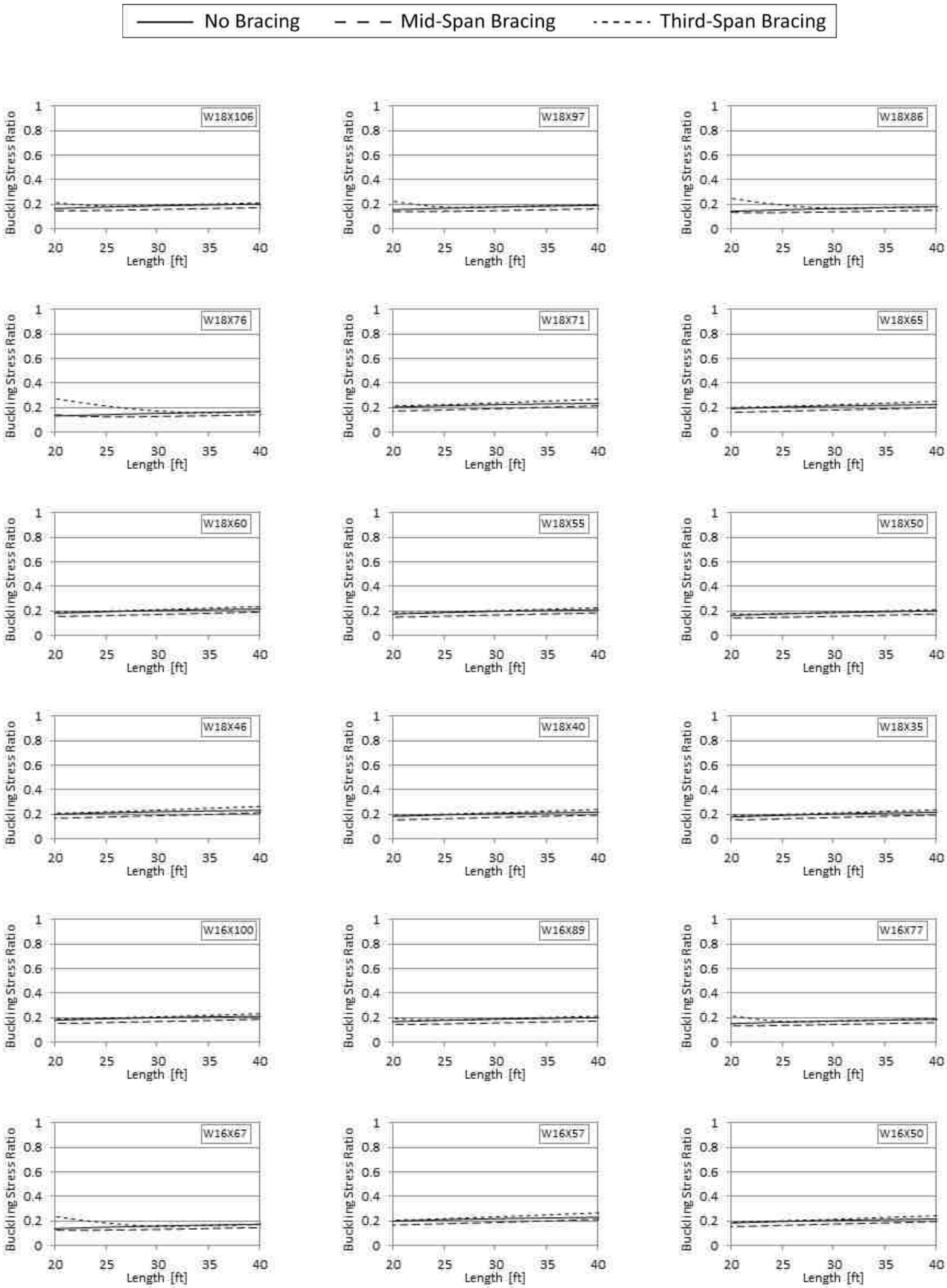

Figure 5-26: Buckling Stress Ratio Plot for W18X106 to W16X50 Beams

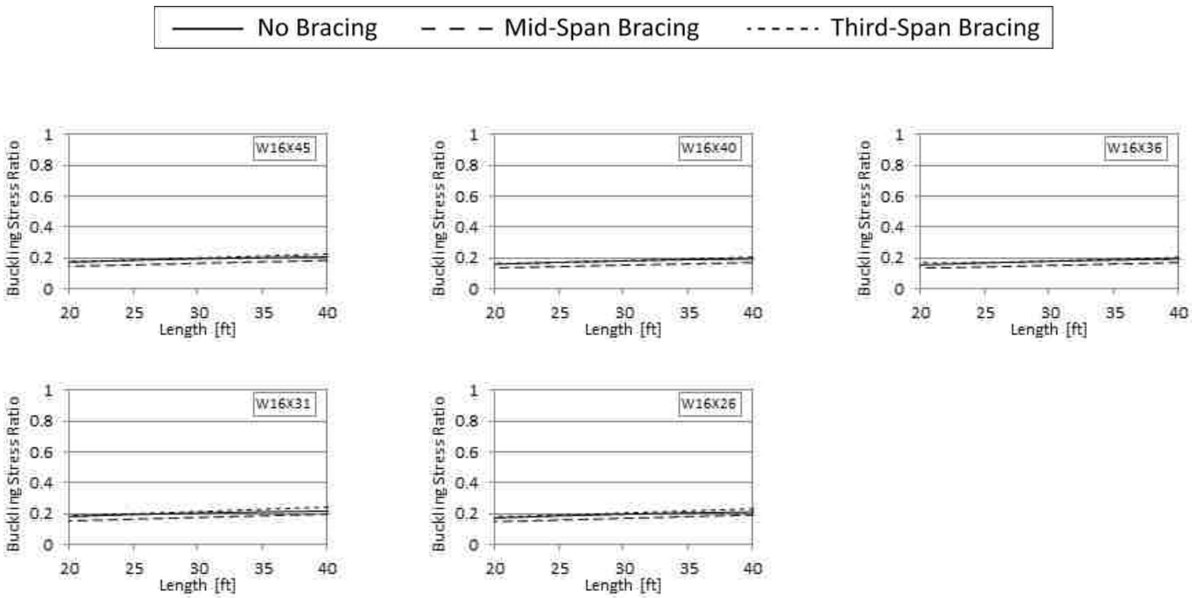

Figure 5-27: Buckling Stress Ratio Plot for W16X45 to W16X26 Beams

The plots above provide a convenient way to estimate the buckling stress in tapered-flange beams, directly from the results of straight-flange beams. It is apparent from the above plots that the tapered-flange beams have about 20% of the buckling capacity of the straight-flange beams. This is fairly consistent for each depth, weight, length, and bracing condition. The largest deviations from this value occurs for the W27X530 as well as some heavier W24s, W21s, and W18s, where the buckling capacity of the tapered-flange beam is closer to 30% of the straight-flange beam. Another notable exception is that in some cases, especially at shorter lengths and for heavier beams, the third-span bracing can increase the buckling capacity of the tapered-flange beam so that it is approximately 40% of the straight-flange beam buckling capacity. This is most notable in the W44s and mid-weight W33s. It is interesting to note that the mid-span bracing achieves slightly less of the buckling capacity of its straight-flange counterpart than the beams with no bracing do.

5.2.2 Buckling Stress Ratio Plots for Tapered-Flange to Straight-Flange Columns

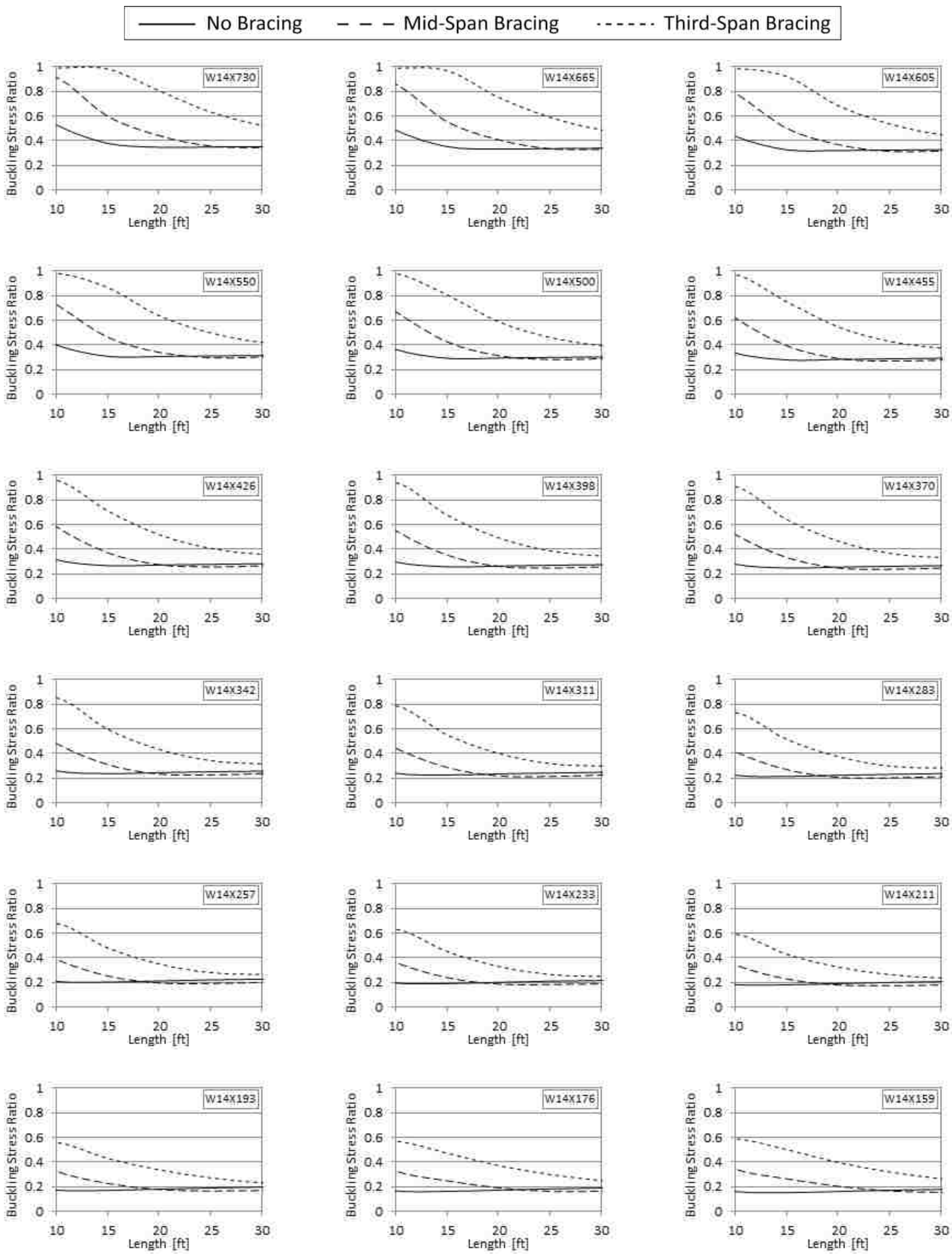

Figure 5-28: Buckling Stress Ratio Plot for W14X730 to W14X159 Columns

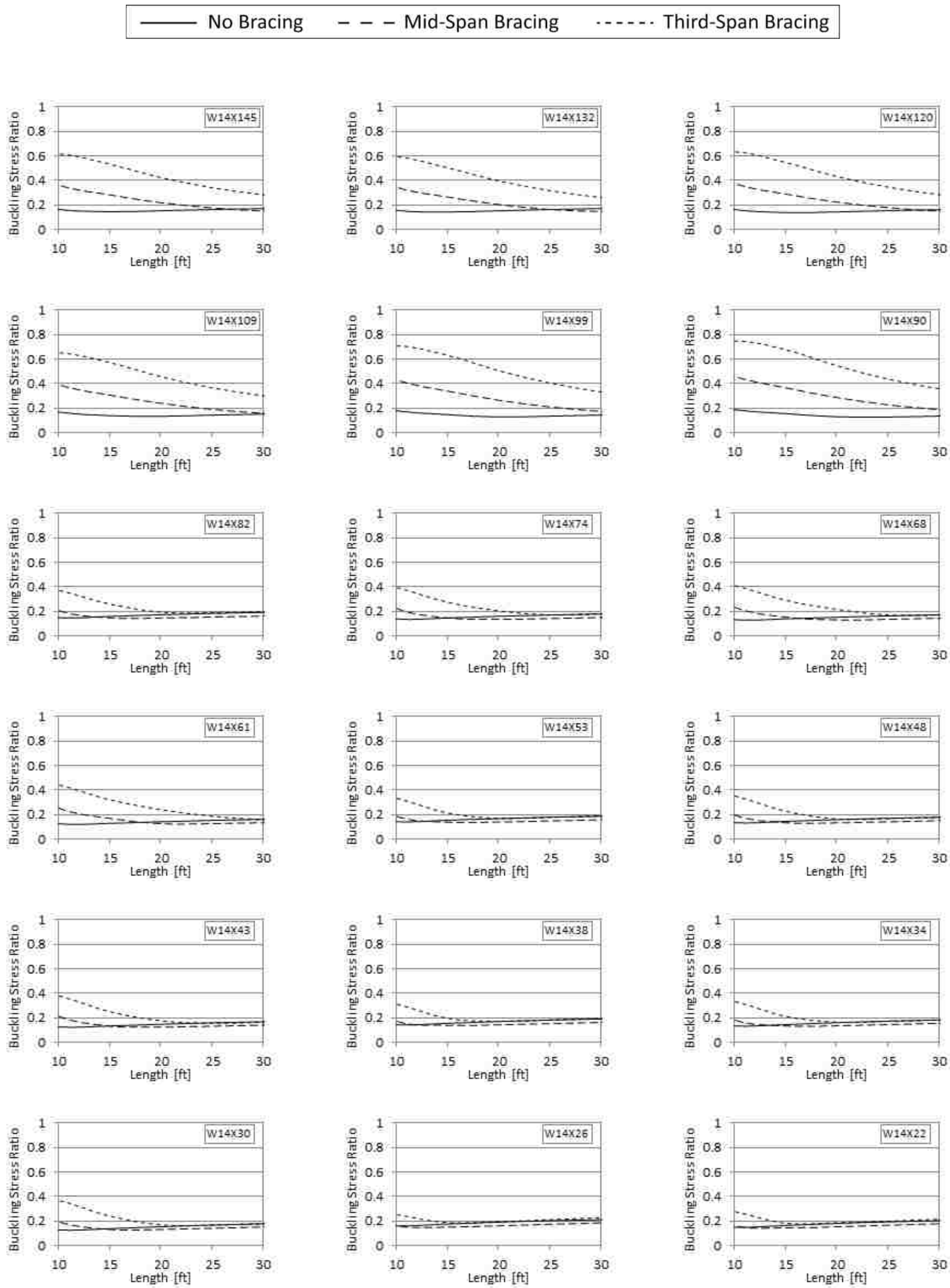

Figure 5-29: Buckling Stress Ratio Plot for W14X145 to W14X22 Columns

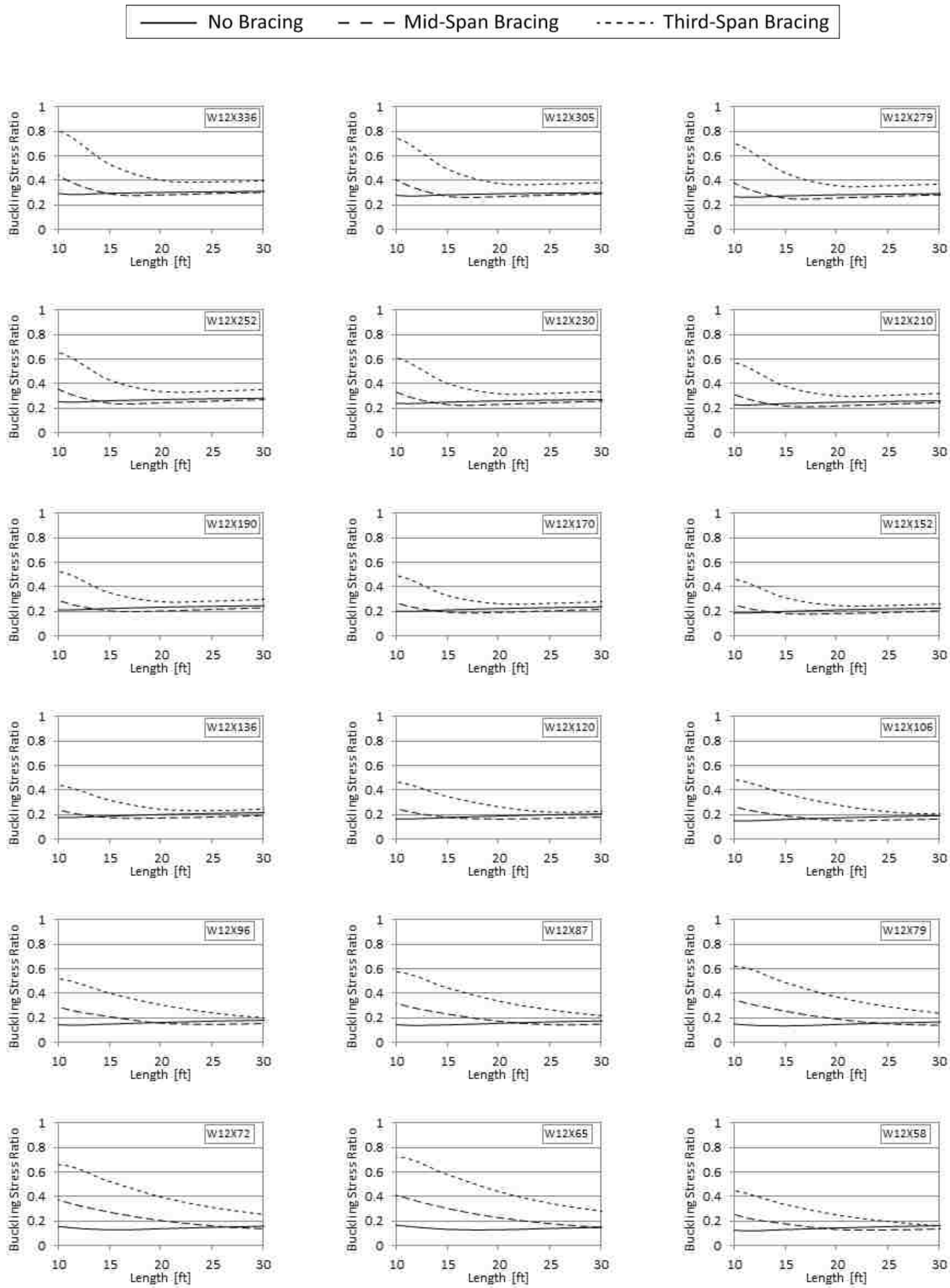

Figure 5-30: Buckling Stress Ratio Plot for W12X336 to W12X58 Columns

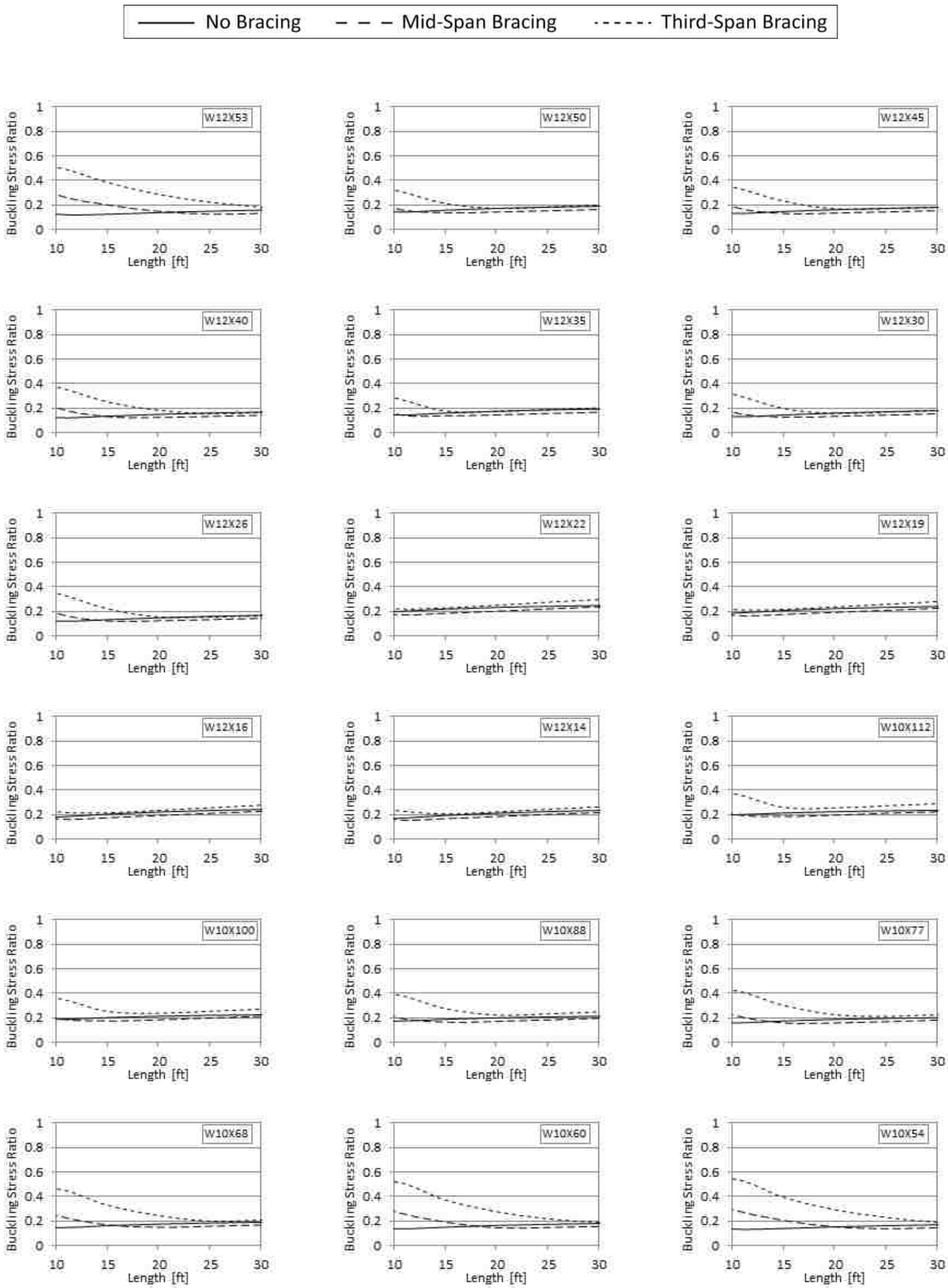

Figure 5-31: Buckling Stress Ratio Plot for W12X53 to W10X54 Columns

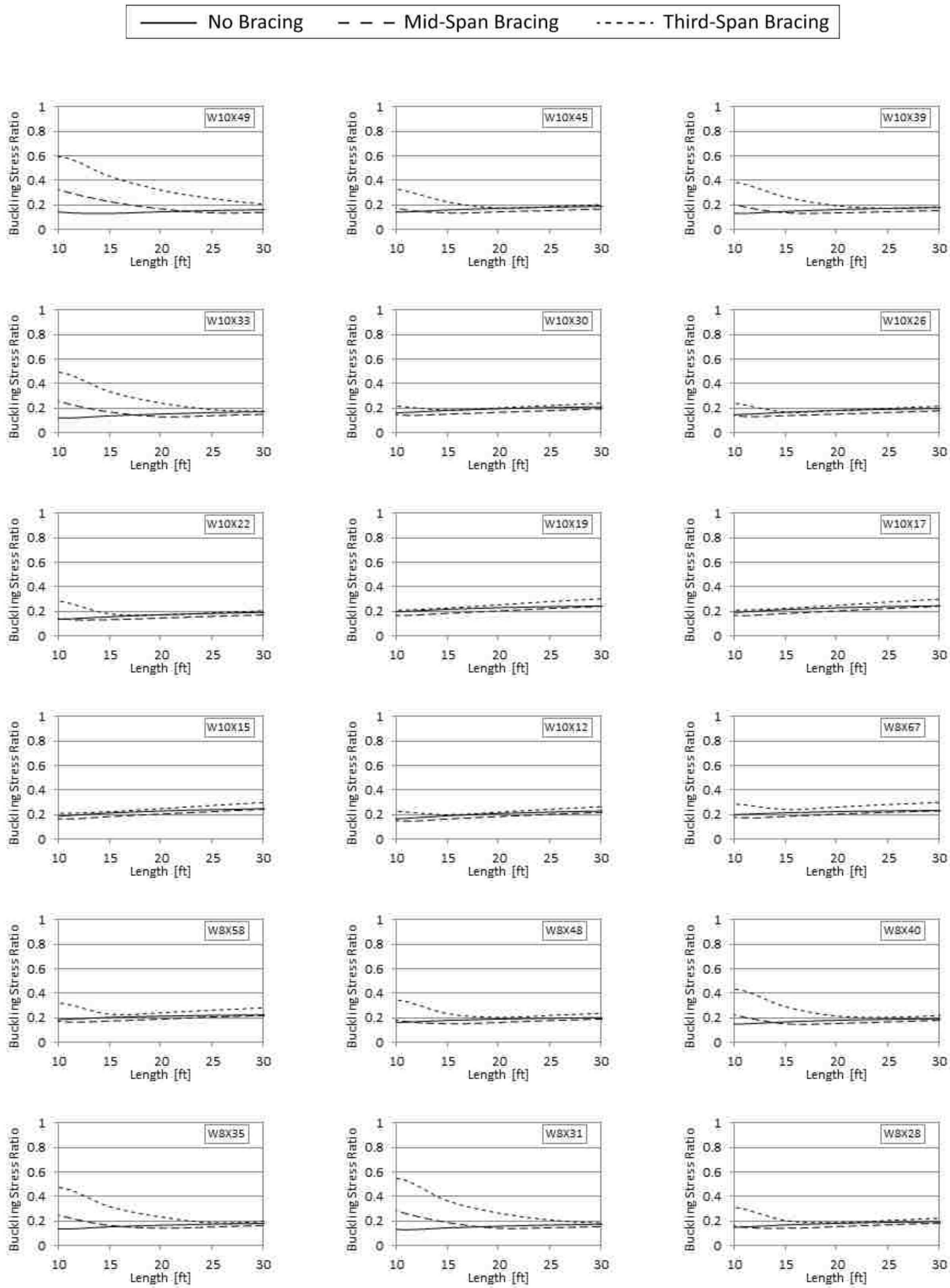

Figure 5-32: Buckling Stress Ratio Plot for W10X49 to W8X28 Columns

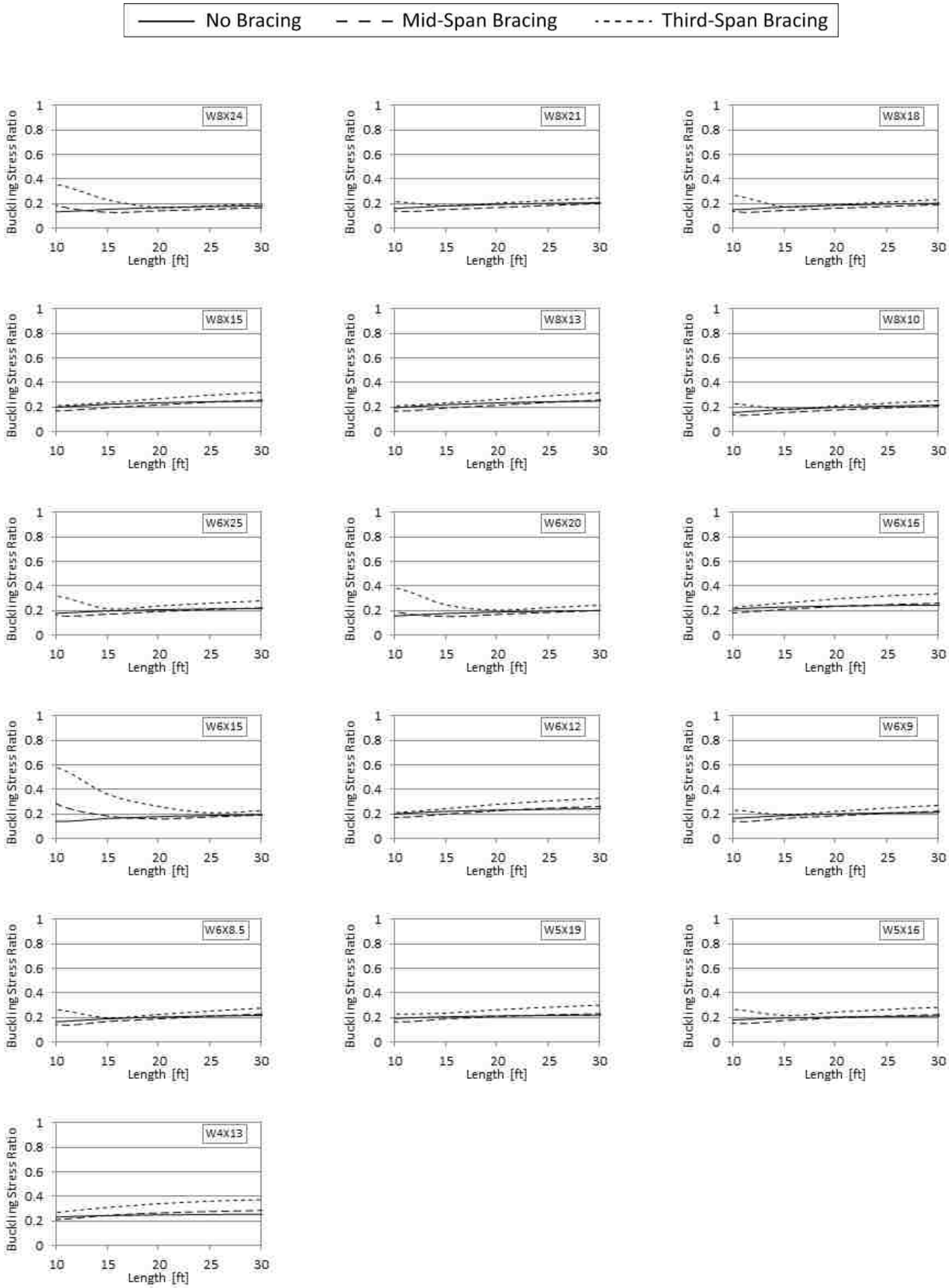

Figure 5-33: Buckling Stress Ratio Plot for W8X24 to W4X13 Columns

While the tapered-flange beam shapes fairly consistently have approximately 20% of the buckling capacity of the straight-flange beam shapes, some of the tapered-flange column shapes have almost as much buckling capacity as their counterpart straight-flange columns. The heavier W14 and W12 shapes have approximately 30% of their counterpart column's capacity for no bracing. The other bracing conditions have minimal practical application, since columns are not braced at mid-span. These, however, will be discussed for completeness. Ten-foot long W14 columns have as much as 90% of their counterpart columns with mid-span bracing and 100% with third-span bracing. For mid-weight W14 columns, 60% tapered-flange to straight-flange buckling capacity can still be reached at 10 feet. W12 shapes have up to 80% buckling capacity for shorter columns with third-span bracing. W10s, W8s, and shallower shapes have more consistent, 20% buckling capacity behavior.

6 SUMMARY AND CONCLUSION

Steel moment frames are a common lateral-force resisting system used in seismic design, but they are not a perfect lateral-force resisting system. They are easy to construct, can be bolted or welded together, and are architecturally versatile. They are typically constructed from standard, constant cross-section Wide-Flange shapes listed in the AISC Steel Construction Manual (2011). However, I-shapes with constant cross-section are inefficient for resisting non-uniform moments. The stress is not uniform along the length, leading to inefficiencies in energy absorption and stiffness.

Shapes with tapered-flanges are more efficient for use in moment frames. They are more uniformly stressed under a non-uniform moment, leading to better energy absorption and stiffness per pound of steel.

Lateral-torsional buckling is a failure mode that needs to be considered in moment frames, whether the shape's flanges are straight or tapered. Lateral bracing is typically provided at specified intervals to mitigate this problem. Closed-form solutions exist for straight-flange I-beams under moment gradient with intermediate bracing. Closed-form and finite element solutions also exist for many kinds of non-prismatic shapes under a non-uniform moment, but not for the conditions present in moment frame beams (linear moment gradient with intermediate lateral bracing).

The objective of this work was to use finite element methods to quantify the lateral-torsional buckling capacity of tapered-flange shapes used in moment frames.

To this end, finite element analysis was used to determine the lateral-torsional buckling capacities of different Wide-Flange shapes at several lengths with three different bracing conditions. Each W-Shape in the AISC Steel Construction Manual (2011) was modeled with shell elements in the finite element software Abaqus. Straight-flange and tapered-flange shapes were analyzed at 11 different lengths (1 ft and 5 ft to 50 ft in 5-foot increments) and three different intermediate lateral bracing conditions (no bracing, mid-span bracing, and third-span bracing). The flange taper decreases linearly from both ends of the beam length, reaching its smallest width (equal to the web width) at the center of the beam length. Applied equal moments at both ends of the beam and simply-supported boundary conditions created a non-uniform, linear moment gradient. The buckling moment was determined through a buckling analysis and was then converted to a buckling stress.

Plots were generated of the buckling stress versus the length for each shape at each bracing condition. Beams are generally deeper shapes (W44 through W16) with longer lengths (20 to 40 feet) and columns are generally shallower shapes (W14 through W4) with shorter lengths (10 to 30 feet). For shorter length beams at any bracing condition, it is not difficult to find a shape that will yield before undergoing lateral-torsional buckling. At longer lengths, it is still an easy task to find shapes with third-span bracing that will yield before buckling, but if intermediate bracing is not an option, then the shapes are limited to heavier shapes. For columns, the discussion mostly examined no intermediate bracing, since intermediate lateral bracing is uncommon in columns. This led to many options for shorter columns, but for longer columns the options are limited to heavier shapes.

Plots were also generated of the buckling stress ratio for tapered-flange to straight-flange beams and columns.

Based on the study, the following conclusions can be made:

1. Overall, it appears that lateral-torsional buckling of tapered-flange I-beams is not a problem that would prohibit wide-scale use of this configuration in moment frames.
2. Generally, for beams and columns, the tapered-flange buckling capacity is approximately 20% of the straight-flange buckling capacity. Thus, the tapered-flange capacity can be reasonably estimated by taking 20% of the buckling capacity of the shape's straight-flange counterpart.
3. Heavier W14s and W12s experience an increase in the tapered-flange over the straight-flange buckling capacity, particularly for third-span bracing.

REFERENCES

Abaqus (2010). *Standard User's Manual*, Dassault Systemes, Providence, RI.

American Institute of Steel Construction (2011). "Steel Construction Manual", 14^{th} Edition.

Al-Sadder, S. Z. (2004). Exact expressions for stability functions of a general non-prismatic beam–column member. *Journal of Constructional Steel Research*, *60*(11), 1561-1584.

ASCE. (2005). "Minimum design loads for buildings and other structures." ASCE/SEI 7-05 including Supplement No.1, Reston, VA.

Bradford, M. A., & Cuk, P. E. (1988). Elastic buckling of tapered monosymmetric I-beams. *Journal of Structural Engineering*, *114*(5), 977-996.

Chan, S. L. (1990). Buckling analysis of structures composed of tapered members. *Journal of Structural Engineering*, *116*(7), 1893-1906.

Chi, B., & Uang, C. M. (2002). Cyclic response and design recommendations of reduced beam section moment connections with deep columns. *Journal of Structural Engineering*, *128*(4), 464-473.

Christopoulos, C., Filiatrault, A., Uang, C. M., & Folz, B. (2002). Posttensioned energy dissipating connections for moment-resisting steel frames. Journal of Structural Engineering, 128(9), 1111-1120.

Eisenberger, M. (1991). Buckling loads for variable cross-section members with variable axial forces. *International Journal of Solids and Structures*, *27*(2), 135-143.

Erochko, J., Christopoulos, C., Tremblay, R., & Choi, H. (2010). Residual drift response of SMRFs and BRB frames in steel buildings designed according to ASCE 7-05. *Journal of Structural Engineering*, *137*(5), 589-599.

Gilton, C. S., & Uang, C. M. (2002). Cyclic response and design recommendations of weak-axis reduced beam section moment connections. *Journal of Structural Engineering*, *128*(4), 452-463.

Gupta, P., Wang, S. T., & Blandford, G. E. (1996). Lateral-torsional buckling of nonprismatic I-beams. *Journal of Structural Engineering*, *122*(7), 748-755.

Hamburger, R. O., Krawinkler, H., Malley, J. O., & Adan, S. M. (2009). Seismic Design of Steel Special Moment Frames: a guide for practicing engineers *NEHRP Seismic Design Technical Brief No.2*.

Hughes, T. J., & Liu, W. K. (1981). Nonlinear finite element analysis of shells: Part I. Three-dimensional shells. *Computer Methods in Applied Mechanics and Engineering*, *26*(3), 331-362.

Jones, S. L., Fry, G. T., & Engelhardt, M. D. (2002). Experimental evaluation of cyclically loaded reduced beam section moment connections. *Journal of Structural Engineering*, *128*(4), 441-451.

Kim, H. J., & Christopoulos, C. (2009). Seismic design procedure and seismic response of post-tensioned self-centering steel frames. Earthquake Engineering & Structural Dynamics, 38(3), 355-376.

Kim, T., Whittaker, A. S., Gilani, A. S. J., Bertero, V. V., & Takhirov, S. M. (2002). Cover-plate and flange-plate steel moment-resisting connections.*Journal of Structural Engineering*, *128*(4), 474-482.

Kitipornchai, S., Wang, C. M., & Trahair, N. S. (1986). Buckling of monosymmetric I-beams under moment gradient. *Journal of Structural Engineering*, *112*(4), 781-799.

Mohebkhah, A., & Chegeni, B. (2013). Flexural Capacity of Locally Buckled Steel I-Beams under Moment Gradient. *Open Construction and Building Technology Journal*, *7*, 244-250.

Nakashima, M., Roeder, C. W., & Maruoka, Y. (2000). Steel moment frames for earthquakes in United States and Japan. *Journal of Structural Engineering*, *126*(8), 861-868.

Pettinga, D., Christopoulos, C., Pampanin, S., & Priestley, N. (2007). Effectiveness of simple approaches in mitigating residual deformations in buildings. *Earthquake Engineering & Structural Dynamics*, *36*(12), 1763-1783.

Rajasekaran, S. (1994). Instability of tapered thin-walled beams of generic section. *Journal of engineering mechanics*, *120*(8), 1630-1640.

Ricles, J. M., Sause, R., Garlock, M. M., & Zhao, C. (2001). Posttensioned seismic-resistant connections for steel frames. Journal of Structural Engineering, 127(2), 113-121.

Roeder, C. W. (2002). Connection performance for seismic design of steel moment frames. *Journal of Structural Engineering*, *128*(4), 517-525.

Suryoatmono, B., & Ho, D. (2002). The moment–gradient factor in lateral–torsional buckling on wide flange steel sections. *Journal of Constructional Steel Research*, *58*(9), 1247-1264.

Yang, Y. B., & Yau, J. D. (1987). Stability of beams with tapered I-sections. *Journal of engineering mechanics*, *113*(9), 1337-1357.

Yun, S. Y., Hamburger, R. O., Cornell, C. A., & Foutch, D. A. (2002). Seismic performance evaluation for steel moment frames. *Journal of Structural Engineering, 128*(4), 534-545.

APPENDIX A. PYTHON SCRIPTS

Two Python scripts were written to create and analyze straight-flange and tapered-flange I-beams in Abaqus. Section A.1 contains the script for the creation and analysis of straight-flange shapes. Section A.2 contains the script for the creation and analysis of tapered-flange shapes. Both scripts have non-uniform moment loading.

A.1 Straight-Flange Python Script

```
#This script creates an Excel output database with buckling moment, buckling
stress, and beam properties. This is for NONTAPERED BEAMS.
#Required inputs: Desired lengths, bracing conditions, beams to be tested
(read automatically from the batch file).
#Outputs: Buckling load, buckling stress, various beam properties.

# Do not delete the following import lines
from abaqus import *
from abaqusConstants import *
import __main__

import section
import regionToolset
import displayGroupMdbToolset as dgm
import part
import material
import assembly
import step
import interaction
import load
import mesh
import job
import sketch
import visualization
import xyPlot
import displayGroupOdbToolset as dgo
import connectorBehavior
import csv
import datetime
```

```
today = datetime.date.today()

#User-defined parameters
MidPoints = False
ThirdPoints = False
NewFile = False

LMin = 60
LMax = 600
LInc = 60
L = LMin

#Databases to search through
ShapesDatabase = 'J:\Research\OldBucklingResearch\ShapesDatabaseNew.csv'
#Database for shape properties
BatchFile = 'J:\Research\OldBucklingResearch\BatchFile.csv' #File containing
the shapes to be analysed
FilePath = 'D:/AbaqusTemp/' #Location of output .dat files

#Output databases:
OutputFile =  'D:/AbaqusTemp/NotTaperedOutput' + str(today.month)+ "-" +
str(today.day) +  '.csv' #Write-to database
BackupOutputFile = 'D:/AbaqusTemp/NotTaperedOutput1-' + str(today.month)+ "-"
+ str(today.day) +  '.csv'

#Set this equal to true, if you want it to start a new output database for
you.
#WARNING: If you set this to True, and you already have a database under the
name found at OutputFile, IT WILL BE ERASED!!!
#(Talk to me if that happens to you.)
NewFile = False

BracingList = ['NoBracing', 'MidPoints', 'ThirdPoints']

# Defining functions: Beam creation and exporting needed data to a CSV file
def newBeamCreation(MidPoints, ThirdPoints):
      #LongName
      if MidPoints == True:
            LongName = PartName +"_" + str(int(L)) + "in_" +
"MidpointBracing_NotTapered"
      elif ThirdPoints == True:
            LongName = PartName +"_" + str(int(L)) + "in_" +
"ThirdpointBracing_NotTapered"
      else:
            LongName = PartName +"_" + str(int(L)) + "in_" +
"NoBracing_NotTapered"

      #Model creation
      mdb.Model(name=LongName, modelType=STANDARD_EXPLICIT)

      #Sketch the I-beam cross section.
      s1 = mdb.models[LongName].ConstrainedSketch(name='__profile__',
            sheetSize=bd)
      g, v, d, c = s1.geometry, s1.vertices, s1.dimensions, s1.constraints
      s1.setPrimaryObject(option=STANDALONE)
```

```
        s1.Line(point1=(bf/2, (bd-tf)/2), point2=(-bf/2, (bd-tf)/2))
        s1.HorizontalConstraint(entity=g[2], addUndoState=False)
        s1.Line(point1=(bf/2, -(bd-tf)/2), point2=(-bf/2, -(bd-tf)/2))
        s1.HorizontalConstraint(entity=g[3], addUndoState=False)
        s1.Line(point1=(0.0, (bd-tf)/2), point2=(0.0, -(bd-tf)/2))
        s1.VerticalConstraint(entity=g[4], addUndoState=False)
        p = mdb.models[LongName].Part(name=LongName, dimensionality=THREE_D,
              type=DEFORMABLE_BODY)
        p = mdb.models[LongName].parts[LongName]
        p.BaseShellExtrude(sketch=s1, depth=L)
        s1.unsetPrimaryObject()

        #Create Steel material
        mdb.models[LongName].Material(name='Steel')
        mdb.models[LongName].materials['Steel'].Elastic(table=((29000000.0,
0.3), ))

        #Create section properties
        mdb.models[LongName].HomogeneousShellSection(name='Web',
preIntegrate=OFF,
              material='Steel', thicknessType=UNIFORM, thickness=tw,
              thicknessField='', idealization=NO_IDEALIZATION,
              poissonDefinition=DEFAULT, thicknessModulus=None,
temperature=GRADIENT,
              useDensity=OFF, integrationRule=SIMPSON, numIntPts=5)
        mdb.models[LongName].HomogeneousShellSection(name='Flange',
preIntegrate=OFF,
              material='Steel', thicknessType=UNIFORM, thickness=tf,
              thicknessField='', idealization=NO_IDEALIZATION,
              poissonDefinition=DEFAULT, thicknessModulus=None,
temperature=GRADIENT,
              useDensity=OFF, integrationRule=SIMPSON, numIntPts=5)

        #Section assignments
        #Web
        p = mdb.models[LongName].parts[LongName]
        f = p.faces
        faces = f.getSequenceFromMask(mask=('[#10 ]', ), )
        region = regionToolset.Region(faces=faces)
        p = mdb.models[LongName].parts[LongName]
        p.SectionAssignment(region=region, sectionName='Web', offset=0.0,
              offsetType=MIDDLE_SURFACE, offsetField='',
              thicknessAssignment=FROM_SECTION)
        #Beam
        p = mdb.models[LongName].parts[LongName]
        f = p.faces
        faces = f.getSequenceFromMask(mask=('[#f ]', ), )
        region = regionToolset.Region(faces=faces)
        p = mdb.models[LongName].parts[LongName]
        p.SectionAssignment(region=region, sectionName='Flange', offset=0.0,
              offsetType=MIDDLE_SURFACE, offsetField='',
              thicknessAssignment=FROM_SECTION)

        #Create assembly
        a = mdb.models[LongName].rootAssembly
        a.DatumCsysByDefault(CARTESIAN)
        p = mdb.models[LongName].parts[LongName]
```

```
        a.Instance(name=LongName, part=p, dependent=ON)

        #Seeding
        p = mdb.models[LongName].parts[LongName]
        p.seedPart(size=0.5, deviationFactor=0.1)

        #Mesh part
        p = mdb.models[LongName].parts[LongName]
        p.generateMesh()

        #Create datums for midpoints
        p = mdb.models[LongName].parts[LongName]
        p.DatumPointByCoordinate(coords=(0.0, 0.0, 0.0))
        p = mdb.models[LongName].parts[LongName]
        p.DatumPointByCoordinate(coords=(0.0, 0.0, L))

        #Create sets:
        #LeftMid
        p = mdb.models[LongName].parts[LongName]
        n = p.nodes
        nodes=n.getByBoundingSphere((0.0,0.125,L) , 0.190)
        #A sphere of this radius may theoretically select two or even three
nodes on occasion, depending on the exact mesh generated by Abaqus.
        #However, it is believed that this will not affect the overall results
significantly.
        #Additionally, it is the smallest radius that has been attempted to
consistently select at least one node in every circumstance.
        p.Set(nodes=nodes, name='LeftMid')

        #BothMid
        p = mdb.models[LongName].parts[LongName]
        n = p.nodes
        nodes=n.getByBoundingSphere((0,0.125,L),0.190)+
n.getByBoundingSphere((0,0.125,0),0.190)
        p.Set(nodes=nodes, name='BothMid')

        #BothEnds
        p = mdb.models[LongName].parts[LongName]
        edges = p.edges.findAt(((0.0,0.0,L),)) +
p.edges.findAt(((0.0,0.0,0.0),)) + \
              p.edges.findAt(((bf/4,(bd-tf)/2,L),)) + p.edges.findAt(((-
bf/4,(bd-tf)/2,L),)) + \
              p.edges.findAt(((bf/4,(bd-tf)/2,0.0),)) + p.edges.findAt(((-
bf/4,(bd-tf)/2,0.0),)) + \
              p.edges.findAt(((bf/4,-(bd-tf)/2,0.0),)) + p.edges.findAt(((-
bf/4,-(bd-tf)/2,0.0),))+ \
              p.edges.findAt(((bf/4,-(bd-tf)/2,L),)) + p.edges.findAt(((-bf/4,-
(bd-tf)/2,L),))

        p.Set(edges=edges, name='BothEnds')

        #BothWeb
        p = mdb.models[LongName].parts[LongName]
        edges = p.edges.findAt(((0.0,0.0,L),)) +
p.edges.findAt(((0.0,0.0,0.0),))
        p.Set(edges=edges, name='BothWeb')
```

```
	#LeftWeb
	p = mdb.models[LongName].parts[LongName]
	edges = p.edges.findAt(((0.0,0.0,L),))
	p.Set(edges=edges, name='LeftWeb')

	#RightWeb
	p = mdb.models[LongName].parts[LongName]
	edges = p.edges.findAt(((0.0,0.0,0.0),))
	p.Set(edges=edges, name='RightWeb')

	#MidPoints, ThirdPoints
	if MidPoints == True:
		p = mdb.models[LongName].parts[LongName]
		n = p.nodes
		nodes=n.getByBoundingSphere((0.0,(bd-tf)/2,L/2) , 0.030) +
n.getByBoundingSphere((0.0,-(bd-tf)/2,L/2) , 0.030)
		p.Set(nodes=nodes, name='MidPoints')

	if ThirdPoints == True:
		p = mdb.models[LongName].parts[LongName]
		n = p.nodes
		nodes=n.getByBoundingSphere((0.0,(bd-tf)/2, L/3) , 0.240) +
n.getByBoundingSphere((0.0,-(bd-tf)/2, L/3) , 0.240) + \
			n.getByBoundingSphere((0.0,(bd-tf)/2, 2*L/3) , 0.240)  +
n.getByBoundingSphere((0.0,-(bd-tf)/2, 2*L/3) , 0.240)
		p.Set(nodes=nodes, name='ThirdPoints')

	#Create Boundary Conditions
	a = mdb.models[LongName].rootAssembly
	a.regenerate()
	a = mdb.models[LongName].rootAssembly
	region = a.instances[LongName].sets['BothWeb']
	mdb.models[LongName].DisplacementBC(name='BothWeb',
createStepName='Initial',
		region=region, u1=SET, u2=UNSET, u3=UNSET, ur1=UNSET, ur2=UNSET,
		ur3=UNSET, amplitude=UNSET, distributionType=UNIFORM,
fieldName='',
		localCsys=None)
	a = mdb.models[LongName].rootAssembly
	region = a.instances[LongName].sets['BothMid']
	mdb.models[LongName].DisplacementBC(name='BothMid',
createStepName='Initial',
		region=region, u1=UNSET, u2=SET, u3=UNSET, ur1=UNSET, ur2=UNSET,
		ur3=UNSET, amplitude=UNSET, distributionType=UNIFORM,
fieldName='',
		localCsys=None)
	a = mdb.models[LongName].rootAssembly
	region = a.instances[LongName].sets['LeftMid']
	mdb.models[LongName].DisplacementBC(name='LeftMid',
createStepName='Initial',
		region=region, u1=UNSET, u2=UNSET, u3=SET, ur1=UNSET, ur2=UNSET,
		ur3=UNSET, amplitude=UNSET, distributionType=UNIFORM,
fieldName='',
		localCsys=None)
	a = mdb.models[LongName].rootAssembly
	region = a.instances[LongName].sets['BothEnds']
	mdb.models[LongName].DisplacementBC(name='BothEnds',
```

```
createStepName='Initial',
            region=region, u1=UNSET, u2=UNSET, u3=UNSET, ur1=UNSET,
ur2=UNSET,
            ur3=SET, amplitude=UNSET, distributionType=UNIFORM, fieldName='',
            localCsys=None)

      #Midpoint, Thirdpoint boundary conditions
      if MidPoints == True:
            region = a.instances[LongName].sets['MidPoints']
            mdb.models[LongName].DisplacementBC(name='MidPoints',
createStepName='Initial',
                  region=region, u1=SET, u2=UNSET, u3=UNSET, ur1=UNSET,
ur2=UNSET,
                  ur3=UNSET, amplitude=UNSET, distributionType=UNIFORM,
fieldName='',
                  localCsys=None)

      if ThirdPoints == True:
            region = a.instances[LongName].sets['ThirdPoints']
            mdb.models[LongName].DisplacementBC(name='ThirdPoints',
createStepName='Initial',
                  region=region, u1=SET, u2=UNSET, u3=UNSET, ur1=UNSET,
ur2=UNSET,
                  ur3=UNSET, amplitude=UNSET, distributionType=UNIFORM,
fieldName='',
                  localCsys=None)

      #Creating reference point 1, LeftWeb constraint
      a = mdb.models[LongName].rootAssembly
      d11 = a.instances[LongName].datums
      a.ReferencePoint(point=d11[6])

      a = mdb.models[LongName].rootAssembly
      region4=a.instances[LongName].sets['LeftWeb']
      a = mdb.models[LongName].rootAssembly
      r1 = a.referencePoints
      refPoints1=(r1[4], )
      region1=regionToolset.Region(referencePoints=refPoints1)
      mdb.models[LongName].RigidBody(name='LeftWeb', refPointRegion=region1,
            tieRegion=region4)

      #Creating reference point 2, RightWeb constraint
      a = mdb.models[LongName].rootAssembly
      d1 = a.instances[LongName].datums
      a.ReferencePoint(point=d1[5])

      a = mdb.models[LongName].rootAssembly
      region4=a.instances[LongName].sets['RightWeb']
      a = mdb.models[LongName].rootAssembly
      r1 = a.referencePoints
      refPoints1=(r1[6], )
      region1=regionToolset.Region(referencePoints=refPoints1)
      mdb.models[LongName].RigidBody(name='RightWeb', refPointRegion=region1,
            tieRegion=region4)

      #Create buckling step.
      mdb.models[LongName].BuckleStep(name='Buckle', previous='Initial',
```

```
numEigen=1,
            vectors=6, maxIterations=1000)

      #Create Applied Moment Load
      a = mdb.models[LongName].rootAssembly
      region = a.instances[LongName].sets['BothMid']
      mdb.models[LongName].Moment(name='Load-1', createStepName='Buckle',
            region=region, cm1=1.0, distributionType=UNIFORM, field='',
            localCsys=None)

      #Create job
      mdb.Job(name=LongName, model=LongName, description='',
            type=ANALYSIS, atTime=None, waitMinutes=0, waitHours=0,
queue=None, memory=90,
        memoryUnits=PERCENTAGE, getMemoryFromAnalysis=True,
        explicitPrecision=SINGLE, nodalOutputPrecision=SINGLE, echoPrint=OFF,
        modelPrint=OFF, contactPrint=OFF, historyPrint=OFF,
userSubroutine='',
        scratch='', parallelizationMethodExplicit=DOMAIN, numDomains=4,
        activateLoadBalancing=False, multiprocessingMode=DEFAULT, numCpus=4)

      #Submit job
      mdb.jobs[LongName].submit(consistencyChecking=OFF)
      mdb.jobs[LongName].waitForCompletion()

      #Find eigenvalue
      with open(FilePath + LongName + '.dat') as f:
            f.seek(-407, 2)
            myString = f.readline()
            EigString = myString[13:]
            myEig = abs(float(EigString) / 12000)

      #Put eigenvalue in our output database
            with open(output, 'a') as file:
                  file.write(PartName + ',' + str(L/12) +',' + str(MidPoints)
+ ',' + str(ThirdPoints) + ',' + str(myEig) + \
                  ',' + str(myEig * 12 * bd /2 / Ix) + ',' + str(bA) + ',' +
str(bd) + ',' + str(bf) + ',' + str(tw)+ ',' + str(tf)+ ',' +
str(bfOverTwotf) + \
                  ',' + str(hOvertw)+ ',' + str(Ix)+ ',' + str(Zx)+ ',' +
str(Iy)+ ',' + str(Zy)+ ',' + str(J)+ ',' + str(Cw) + ',\n')

#Create a dictionary with part properties
myDict = {}
with open(ShapesDatabase) as csvfile:
      quoting = csv.QUOTE_NONNUMERIC
      reader = csv.reader(csvfile)
      for row in reader:
            myDict[row[0]] = row[3], row[4], row[6], row[8], \
                  row[11], row[16], row[17], row[18], row[19], \
                  row[22], row[23], row[26], row[27]

if NewFile == True:
      #Create new output file
      try:
            with open(OutputFile, 'w') as file:
                  file.write('Shape Name, Length [ft], Midspan Bracing?, \
```

```
                        Third Points Bracing?, Buckling Moment [k-ft],\
                        Buckling Stress
[ksi],A,d,bf,tw,tf,bf/2tf,h/tw,Ix,Zx,\
                        Iy,Zy,J,Cw,Graphing, \n')
      except IOError:
            with open(BackupOutputFile, 'w') as file:
                  file.write('Shape Name, Length [ft], Midspan Bracing?, \
                        Third Points Bracing?, Buckling Moment [k-ft],\
                        Buckling Stress
[ksi],A,d,bf,tw,tf,bf/2tf,h/tw,Ix,Zx,\
                        Iy,Zy,J,Cw,Graphing, \n')

#Loop across bracing conditions:
for condition in BracingList:
      if condition == 'NoBracing':
            MidPoints = False
            ThirdPoints = False
      if condition == 'MidPoints':
            MidPoints = True
            ThirdPoints = False
      if condition == 'ThirdPoints':
            MidPoints = False
            ThirdPoints = True

      #Loop across the batch file
      with open(BatchFile) as csvfile:
            quoting = csv.QUOTE_NONNUMERIC
            reader = csv.reader(csvfile)
            for row in reader:
                  #Short part name
                  PartName = str(row[0])

                  #Read beam properties from dictionary
                  bA = float(myDict[PartName][0])
                  bd = float(myDict[PartName][1])
                  bf = float(myDict[PartName][2])
                  tw = float(myDict[PartName][3])
                  tf = float(myDict[PartName][4])
                  bfOverTwotf = float(myDict[PartName][5])
                  hOvertw = float(myDict[PartName][6])
                  Ix = float(myDict[PartName][7])
                  Zx = float(myDict[PartName][8])
                  Iy = float(myDict[PartName][9])
                  Zy = float(myDict[PartName][10])
                  J = float(myDict[PartName][11])
                  Cw = float(myDict[PartName][12])

                  #Loop across the lengths
                  L = LMin
                  while L<= LMax:
                        newBeamCreation(MidPoints, ThirdPoints)

                        L += LInc
```

A.2 Tapered-Flange Python Script

```
#This script creates an Excel output database with buckling moment, buckling
stress, and beam properties.
#Required inputs: Desired lengths, bracing conditions, beams to be tested
(read automatically from the batch file).
#Outputs: Buckling load, buckling stress, various beam properties.

# Do not delete the following import lines
from abaqus import *
from abaqusConstants import *
import __main__

import section
import regionToolset
import displayGroupMdbToolset as dgm
import part
import material
import assembly
import step
import interaction
import load
import mesh
import job
import sketch
import visualization
import xyPlot
import displayGroupOdbToolset as dgo
import connectorBehavior

import csv
import datetime

today = datetime.date.today()

#User-defined parameters
MidPoints = False
ThirdPoints = False
NewFile = False

LMin = 60
LMax = 600
LInc = 60
L = LMin

#Databases to search through
ShapesDatabase = 'J:\Research\ShapesDatabaseNew.csv' #Database for shape
properties
BatchFile = 'J:\Research\BatchFile.csv' #File containing the shapes to be
analysed
FilePath = 'D:/AbaqusTemp/' #Location of output .dat files

#Output databases:
OutputFile =  'D:/AbaqusTemp/Output' + str(today.month)+ "-" + str(today.day)
+  '.csv' #Write-to database
BackupOutputFile = 'D:/AbaqusTemp/Output1-' + str(today.month)+ "-" +
```

```
str(today.day) +  '.csv'

# Defining functions: Beam creation; exporting needed data to a CSV file
def newBeamCreation():

      #Model creation
      mdb.Model(name=LongName, modelType=STANDARD_EXPLICIT)

      #Sketch the I-beam cross section.
      s1 = mdb.models[LongName].ConstrainedSketch(name='__profile__',
            sheetSize=bd)
      g, v, d, c = s1.geometry, s1.vertices, s1.dimensions, s1.constraints
      s1.setPrimaryObject(option=STANDALONE)
      s1.Line(point1=(bf/2, (bd-tf)/2), point2=(-bf/2, (bd-tf)/2))
      s1.HorizontalConstraint(entity=g[2], addUndoState=False)
      s1.Line(point1=(bf/2, -(bd-tf)/2), point2=(-bf/2, -(bd-tf)/2))
      s1.HorizontalConstraint(entity=g[3], addUndoState=False)
      s1.Line(point1=(0.0, (bd-tf)/2), point2=(0.0, -(bd-tf)/2))
      s1.VerticalConstraint(entity=g[4], addUndoState=False)
      p = mdb.models[LongName].Part(name=LongName, dimensionality=THREE_D,
            type=DEFORMABLE_BODY)
      p = mdb.models[LongName].parts[LongName]
      p.BaseShellExtrude(sketch=s1, depth=L)
      s1.unsetPrimaryObject()

      #Cut out the triangular sections to taper the beam.
      p = mdb.models[LongName].parts[LongName]
      del mdb.models[LongName].sketches['__profile__']
      p = mdb.models[LongName].parts[LongName]
      f, e = p.faces, p.edges
      t = p.MakeSketchTransform(sketchPlane=f[1], sketchUpEdge=e[6],
            sketchPlaneSide=SIDE1, sketchOrientation=RIGHT, origin=(0.0, (bd-
tf)/2,
            L/2))
      s = mdb.models[LongName].ConstrainedSketch(name='__profile__',
            sheetSize=L*2, gridSpacing=L/20, transform=t)
      g, v, d, c = s.geometry, s.vertices, s.dimensions, s.constraints
      s.setPrimaryObject(option=SUPERIMPOSE)
      p = mdb.models[LongName].parts[LongName]
      p.projectReferencesOntoSketch(sketch=s, filter=COPLANAR_EDGES)
      s.Line(point1=(0.0, -(tw/2)), point2=(L/2, -bf/2))
      s.Line(point1=(L/2, -bf/2), point2=(-L/2, -bf/2))
      s.HorizontalConstraint(entity=g[12], addUndoState=False)
      s.Line(point1=(-L/2, -bf/2), point2=(0.0, -(tw/2)))
      s.Line(point1=(0.0, (tw/2)), point2=(L/2, bf/2))
      s.Line(point1=(L/2, bf/2), point2=(-L/2, bf/2))
      s.HorizontalConstraint(entity=g[15], addUndoState=False)
      s.Line(point1=(-L/2, bf/2), point2=(0.0, (tw/2)))
      p = mdb.models[LongName].parts[LongName]
      f1, e1 = p.faces, p.edges
      p.CutExtrude(sketchPlane=f1[1], sketchUpEdge=e1[6],
sketchPlaneSide=SIDE1,
            sketchOrientation=RIGHT, sketch=s, flipExtrudeDirection=OFF)
      s.unsetPrimaryObject()
      del mdb.models[LongName].sketches['__profile__']

      #Create Steel material
```

```
	mdb.models[LongName].Material(name='Steel')
	mdb.models[LongName].materials['Steel'].Elastic(table=((29000000.0, 
0.3), ))

	#Create section properties
	mdb.models[LongName].HomogeneousShellSection(name='Web', 
preIntegrate=OFF, 
		material='Steel', thicknessType=UNIFORM, thickness=tw, 
		thicknessField='', idealization=NO_IDEALIZATION, 
		poissonDefinition=DEFAULT, thicknessModulus=None, 
temperature=GRADIENT, 
		useDensity=OFF, integrationRule=SIMPSON, numIntPts=5)
	mdb.models[LongName].HomogeneousShellSection(name='Flange', 
preIntegrate=OFF, 
		material='Steel', thicknessType=UNIFORM, thickness=tf, 
		thicknessField='', idealization=NO_IDEALIZATION, 
		poissonDefinition=DEFAULT, thicknessModulus=None, 
temperature=GRADIENT, 
		useDensity=OFF, integrationRule=SIMPSON, numIntPts=5)

	#Section assignments:
	#Web
	p = mdb.models[LongName].parts[LongName]
	f = p.faces
	faces = f.getSequenceFromMask(mask=('[#10 ]', ), )
	region = regionToolset.Region(faces=faces)
	p = mdb.models[LongName].parts[LongName]
	p.SectionAssignment(region=region, sectionName='Web', offset=0.0, 
		offsetType=MIDDLE_SURFACE, offsetField='', 
		thicknessAssignment=FROM_SECTION)
	#Beam
	p = mdb.models[LongName].parts[LongName]
	f = p.faces
	faces = f.getSequenceFromMask(mask=('[#f ]', ), )
	region = regionToolset.Region(faces=faces)
	p = mdb.models[LongName].parts[LongName]
	p.SectionAssignment(region=region, sectionName='Flange', offset=0.0, 
		offsetType=MIDDLE_SURFACE, offsetField='', 
		thicknessAssignment=FROM_SECTION)

	#Creating assembly
	a = mdb.models[LongName].rootAssembly
	a.DatumCsysByDefault(CARTESIAN)
	p = mdb.models[LongName].parts[LongName]
	a.Instance(name=LongName, part=p, dependent=ON)

	#Seeding
	p = mdb.models[LongName].parts[LongName]
	p.seedPart(size=0.5, deviationFactor=0.1)

	#Meshing part
	p = mdb.models[LongName].parts[LongName]
	p.generateMesh()

	#Creating datums for midpoints
	p = mdb.models[LongName].parts[LongName]
	p.DatumPointByCoordinate(coords=(0.0, 0.0, 0.0))
```

```
        p = mdb.models[LongName].parts[LongName]
        p.DatumPointByCoordinate(coords=(0.0, 0.0, L))

        #Creating sets:
        #LeftMid
        p = mdb.models[LongName].parts[LongName]
        n = p.nodes
        nodes=n.getByBoundingSphere((0.0,0.125,L) , 0.190)
        #A sphere of this radius may theoretically select two or even three
nodes on occasion, depending on the exact mesh generated by Abaqus.
        #However, it is believed that this will not affect the overall results
significantly.
        #Additionally, it is the smallest radius that has been attempted to
consistently select at least one node in every circumstance.
        p.Set(nodes=nodes, name='LeftMid')

        #BothMid
        p = mdb.models[LongName].parts[LongName]
        n = p.nodes
        nodes=n.getByBoundingSphere((0,0.125,L),0.190)+
n.getByBoundingSphere((0,0.125,0),0.190)
        p.Set(nodes=nodes, name='BothMid')

        #BothEnds
        p = mdb.models[LongName].parts[LongName]
        edges = p.edges.findAt(((0.0,0.0,L),)) +
p.edges.findAt(((0.0,0.0,0.0),)) + \
              p.edges.findAt(((bf/4,(bd-tf)/2,L),)) + p.edges.findAt(((-
bf/4,(bd-tf)/2,L),)) + \
              p.edges.findAt(((bf/4,(bd-tf)/2,0.0),)) + p.edges.findAt(((-
bf/4,(bd-tf)/2,0.0),)) + \
              p.edges.findAt(((bf/4,-(bd-tf)/2,0.0),)) + p.edges.findAt(((-
bf/4,-(bd-tf)/2,0.0),))+ \
              p.edges.findAt(((bf/4,-(bd-tf)/2,L),)) + p.edges.findAt(((-bf/4,-
(bd-tf)/2,L),))
        p.Set(edges=edges, name='BothEnds')

        #BothWeb
        p = mdb.models[LongName].parts[LongName]
        edges = p.edges.findAt(((0.0,0.0,L),)) +
p.edges.findAt(((0.0,0.0,0.0),))
        p.Set(edges=edges, name='BothWeb')

        #LeftWeb
        p = mdb.models[LongName].parts[LongName]
        edges = p.edges.findAt(((0.0,0.0,L),))
        p.Set(edges=edges, name='LeftWeb')

        #RightWeb
        p = mdb.models[LongName].parts[LongName]
        edges = p.edges.findAt(((0.0,0.0,0.0),))
        p.Set(edges=edges, name='RightWeb')

        #MidPoints, ThirdPoints
        if MidPoints == True:
              p = mdb.models[LongName].parts[LongName]
              n = p.nodes
```

```
            nodes=n.getByBoundingSphere((0.0,(bd-tf)/2,L/2) , 0.030) +
n.getByBoundingSphere((0.0,-(bd-tf)/2,L/2) , 0.030)
            p.Set(nodes=nodes, name='MidPoints')

      if ThirdPoints == True:
            p = mdb.models[LongName].parts[LongName]
            n = p.nodes
            nodes=n.getByBoundingSphere((0.0,(bd-tf)/2, L/3) , 0.240) +
n.getByBoundingSphere((0.0,-(bd-tf)/2, L/3) , 0.240) + \
                  n.getByBoundingSphere((0.0,(bd-tf)/2, 2*L/3) , 0.240)  +
n.getByBoundingSphere((0.0,-(bd-tf)/2, 2*L/3) , 0.240)
            p.Set(nodes=nodes, name='ThirdPoints')

      #Create Boundary Conditions
      a = mdb.models[LongName].rootAssembly
      a.regenerate()
      a = mdb.models[LongName].rootAssembly
      region = a.instances[LongName].sets['BothWeb']
      mdb.models[LongName].DisplacementBC(name='BothWeb',
createStepName='Initial',
            region=region, u1=SET, u2=UNSET, u3=UNSET, ur1=UNSET, ur2=UNSET,
            ur3=UNSET, amplitude=UNSET, distributionType=UNIFORM,
fieldName='',
            localCsys=None)
      a = mdb.models[LongName].rootAssembly
      region = a.instances[LongName].sets['BothMid']
      mdb.models[LongName].DisplacementBC(name='BothMid',
createStepName='Initial',
            region=region, u1=UNSET, u2=SET, u3=UNSET, ur1=UNSET, ur2=UNSET,
            ur3=UNSET, amplitude=UNSET, distributionType=UNIFORM,
fieldName='',
            localCsys=None)
      a = mdb.models[LongName].rootAssembly
      region = a.instances[LongName].sets['LeftMid']
      mdb.models[LongName].DisplacementBC(name='LeftMid',
createStepName='Initial',
            region=region, u1=UNSET, u2=UNSET, u3=SET, ur1=UNSET, ur2=UNSET,
            ur3=UNSET, amplitude=UNSET, distributionType=UNIFORM,
fieldName='',
            localCsys=None)
      a = mdb.models[LongName].rootAssembly
      region = a.instances[LongName].sets['BothEnds']
      mdb.models[LongName].DisplacementBC(name='BothEnds',
createStepName='Initial',
            region=region, u1=UNSET, u2=UNSET, u3=UNSET, ur1=UNSET,
ur2=UNSET,
            ur3=SET, amplitude=UNSET, distributionType=UNIFORM, fieldName='',
            localCsys=None)

      #Midpoint, Thirdpoint boundary conditions
      if MidPoints == True:
            region = a.instances[LongName].sets['MidPoints']
            mdb.models[LongName].DisplacementBC(name='MidPoints',
createStepName='Initial',
                  region=region, u1=SET, u2=UNSET, u3=UNSET, ur1=UNSET,
ur2=UNSET,
                  ur3=UNSET, amplitude=UNSET, distributionType=UNIFORM,
```

```
fieldName='',
                    localCsys=None)

      if ThirdPoints == True:
            region = a.instances[LongName].sets['ThirdPoints']
            mdb.models[LongName].DisplacementBC(name='ThirdPoints',
createStepName='Initial',
                    region=region, u1=SET, u2=UNSET, u3=UNSET, ur1=UNSET,
ur2=UNSET,
                    ur3=UNSET, amplitude=UNSET, distributionType=UNIFORM,
fieldName='',
                    localCsys=None)

      #Create reference point 1, LeftWeb constraint
      a = mdb.models[LongName].rootAssembly
      d11 = a.instances[LongName].datums
      a.ReferencePoint(point=d11[7])
      a = mdb.models[LongName].rootAssembly
      region4=a.instances[LongName].sets['LeftWeb']
      a = mdb.models[LongName].rootAssembly
      r1 = a.referencePoints
      refPoints1=(r1[4], )
      region1=regionToolset.Region(referencePoints=refPoints1)
      mdb.models[LongName].RigidBody(name='LeftWeb', refPointRegion=region1,
            tieRegion=region4)

      #Create reference point 2, RightWeb constraint
      a = mdb.models[LongName].rootAssembly
      d21 = a.instances[LongName].datums
      a.ReferencePoint(point=d21[6])
      a = mdb.models[LongName].rootAssembly
      d11 = a.instances[LongName].datums
      a.ReferencePoint(point=d11[6])

      a = mdb.models[LongName].rootAssembly
      region4=a.instances[LongName].sets['RightWeb']
      a = mdb.models[LongName].rootAssembly
      r1 = a.referencePoints
      refPoints1=(r1[7], )
      region1=regionToolset.Region(referencePoints=refPoints1)
      mdb.models[LongName].RigidBody(name='RightWeb', refPointRegion=region1,
            tieRegion=region4)

      #Create buckling step.
      mdb.models[LongName].BuckleStep(name='Buckle', previous='Initial',
numEigen=1,
            vectors=6, maxIterations=100)

      #Create applied moment load
      a = mdb.models[LongName].rootAssembly
      region = a.instances[LongName].sets['BothMid']
      mdb.models[LongName].Moment(name='Load-1', createStepName='Buckle',
            region=region, cm1=1.0, distributionType=UNIFORM, field='',
            localCsys=None)

      #Create job
      mdb.Job(name=LongName, model=LongName, description='',
```

```
            type=ANALYSIS, atTime=None, waitMinutes=0, waitHours=0,
queue=None, memory=90,
        memoryUnits=PERCENTAGE, getMemoryFromAnalysis=True,
        explicitPrecision=SINGLE, nodalOutputPrecision=SINGLE, echoPrint=OFF,
        modelPrint=OFF, contactPrint=OFF, historyPrint=OFF,
userSubroutine='',
        scratch='', parallelizationMethodExplicit=DOMAIN, numDomains=4,
        activateLoadBalancing=False, multiprocessingMode=DEFAULT, numCpus=4)
      #Submit job
      mdb.jobs[LongName].submit(consistencyChecking=OFF)
      mdb.jobs[LongName].waitForCompletion()

def Output(output):
      with open(FilePath + LongName + '.dat') as f:
            f.seek(-407, 2)
            myString = f.readline()
            EigString = myString[13:]
            myEig = abs(float(EigString) / 12000)

      #Put eigenvalue in our output database
            with open(output, 'a') as file:
                  file.write(PartName + ',' + str(L/12) +',' + str(MidPoints)
+ ',' + str(ThirdPoints) + ',' + str(myEig) + \
                  ',' + str(myEig * 12 * bd /2 / Ix) + ',' + str(bA) + ',' +
str(bd) + ',' + str(bf) + ',' + str(tw)+ ',' + str(tf)+ ',' +
str(bfOverTwotf) + \
                  ',' + str(hOvertw)+ ',' + str(Ix)+ ',' + str(Zx)+ ',' +
str(Iy)+ ',' + str(Zy)+ ',' + str(J)+ ',' + str(Cw) + ',\n')

#Create a dictionary with part properties
myDict = {}
with open(ShapesDatabase) as csvfile:
      quoting = csv.QUOTE_NONNUMERIC
      reader = csv.reader(csvfile)
      for row in reader:
            myDict[row[0]] = row[3], row[4], row[6], row[8], \
                  row[11], row[16], row[17], row[18], row[19], \
                  row[22], row[23], row[26], row[27]

if NewFile == True:
      #Create new output file
      try:
            with open(OutputFile, 'w') as file:
                  file.write('Shape Name, Length [ft], Midspan Bracing?, \
                        Third Points Bracing?, Buckling Moment [k-ft],\
                        Buckling Stress
[ksi],A,d,bf,tw,tf,bf/2tf,h/tw,Ix,Zx,\
                        Iy,Zy,J,Cw,Graphing, \n')
      except IOError:
            with open(BackupOutputFile, 'w') as file:
                  file.write('Shape Name, Length [ft], Midspan Bracing?, \
                        Third Points Bracing?, Buckling Moment [k-ft],\
                        Buckling Stress
[ksi],A,d,bf,tw,tf,bf/2tf,h/tw,Ix,Zx,\
                        Iy,Zy,J,Cw,Graphing, \n')

#Loop across the batch file
```

```
with open(BatchFile) as csvfile:
      quoting = csv.QUOTE_NONNUMERIC
      reader = csv.reader(csvfile)
      for row in reader:
            #Short part name
            PartName = str(row[0])

            #Read beam properties from dictionary
            bA = float(myDict[PartName][0])
            bd = float(myDict[PartName][1])
            bf = float(myDict[PartName][2])
            tw = float(myDict[PartName][3])
            tf = float(myDict[PartName][4])
            bfOverTwotf = float(myDict[PartName][5])
            hOvertw = float(myDict[PartName][6])
            Ix = float(myDict[PartName][7])
            Zx = float(myDict[PartName][8])
            Iy = float(myDict[PartName][9])
            Zy = float(myDict[PartName][10])
            J = float(myDict[PartName][11])
            Cw = float(myDict[PartName][12])

            #Loop across the lengths
            L = LMin
            while L<= LMax:
                  #Long part name
                  if MidPoints == True:
                        LongName = PartName +"_" + str(int(L)) + "in_" +
"MidpointBracing_Tapered"
                  elif ThirdPoints == True:
                        LongName = PartName +"_" + str(int(L)) + "in_" +
"ThirdpointBracing_Tapered"
                  else:
                        LongName = PartName +"_" + str(int(L)) + "in_" +
"NoBracing_Tapered"

                  newBeamCreation()
                  try:
                        Output(OutputFile)
                  except IOError:
                        Output(BackupOutputFile)

                  L += LInc
```

APPENDIX B. ABAQUS INPUT FILES

This appendix contains examples of Abaqus input files. Section B.1 contains the Abaqus input file for the circular column discussed in Section 3.2. Section B.2 contains the Abaqus input file for the plate column discussed in Section 3.3. Section B.3 contains the input file for a tapered-flange W21X68 beam.

B.1 Circular Column Input File

```
*Heading
** Job name: 1d-circ Model name: col-1d-circ
** Generated by: Abaqus/CAE 6.10-3
*Preprint, echo=NO, model=NO, history=NO, contact=NO
**
** PARTS
**
*Part, name=Part-1
*Node
      1,           0.,         12.5
      2,           0.,         11.5
      3,           0.,         10.5
      4,           0.,          9.5
      5,           0.,          8.5
      6,           0.,          7.5
      7,           0.,          6.5
      8,           0.,          5.5
      9,           0.,          4.5
     10,           0.,          3.5
     11,           0.,          2.5
     12,           0.,          1.5
     13,           0.,          0.5
     14,           0.,         -0.5
     15,           0.,         -1.5
     16,           0.,         -2.5
     17,           0.,         -3.5
     18,           0.,         -4.5
     19,           0.,         -5.5
     20,           0.,         -6.5
     21,           0.,         -7.5
     22,           0.,         -8.5
     23,           0.,         -9.5
     24,           0.,        -10.5
```

```
     25,           0.,         -11.5
     26,           0.,         -12.5
*Element, type=B21
 1,  1,  2
 2,  2,  3
 3,  3,  4
 4,  4,  5
 5,  5,  6
 6,  6,  7
 7,  7,  8
 8,  8,  9
 9,  9, 10
10, 10, 11
11, 11, 12
12, 12, 13
13, 13, 14
14, 14, 15
15, 15, 16
16, 16, 17
17, 17, 18
18, 18, 19
19, 19, 20
20, 20, 21
21, 21, 22
22, 22, 23
23, 23, 24
24, 24, 25
25, 25, 26
*Nset, nset= PickedSet3, internal, generate
  1,  26,   1
*Elset, elset= PickedSet3, internal, generate
  1,  25,   1
*Nset, nset= PickedSet4, internal, generate
  1,  26,   1
*Elset, elset= PickedSet4, internal, generate
  1,  25,   1
*Nset, nset=allnodes, generate
  1,  26,   1
** Section: Section-1  Profile: circ
*Beam Section, elset= PickedSet3, material=steel, temperature=GRADIENTS,
section=CIRC
0.5
0.,0.,-1.
*End Part
**
**
** ASSEMBLY
**
*Assembly, name=Assembly
**
*Instance, name=Part-1-1, part=Part-1
*End Instance
**
*Nset, nset= PickedSet4, internal, instance=Part-1-1
 1,
*Nset, nset= PickedSet5, internal, instance=Part-1-1
 26,
*Nset, nset= PickedSet6, internal, instance=Part-1-1
 1,
*End Assembly
**
** MATERIALS
**
*Material, name=steel
```

```
*Elastic
 2.9e+07, 0.3
**
** BOUNDARY CONDITIONS
**
** Name: bottom Type: Displacement/Rotation
*Boundary
 PickedSet5, 1, 1
 PickedSet5, 2, 2
** Name: top Type: Displacement/Rotation
*Boundary
 PickedSet4, 1, 1
** ----------------------------------------------------------------
**
** STEP: buckle
**
*Step, name=buckle, perturbation
*Buckle
1, , 2, 30
**
** BOUNDARY CONDITIONS
**
** Name: bottom Type: Displacement/Rotation
*Boundary, op=NEW, load case=1
 PickedSet5, 1, 1
 PickedSet5, 2, 2
*Boundary, op=NEW, load case=2
 PickedSet5, 1, 1
 PickedSet5, 2, 2
** Name: top Type: Displacement/Rotation
*Boundary, op=NEW, load case=1
 PickedSet4, 1, 1
*Boundary, op=NEW, load case=2
 PickedSet4, 1, 1
**
** LOADS
**
** Name: eul   Type: Concentrated force
*Cload
 PickedSet6, 2, -1.
**
** OUTPUT REQUESTS
**
*Restart, write, frequency=0
**
** FIELD OUTPUT: F-Output-1
**
*Output, field, variable=PRESELECT
*NODE FILE, MODE=1
U
*End Step
```

B.2 Plate Column Input File

```
Heading
** Job name: eul Model name: Model-1
** Generated by: Abaqus/CAE 6.10-3
*Preprint, echo=NO, model=NO, history=NO, contact=NO
**
** PARTS
**
*Part, name=Part-1
```

```
*Node
      1,           0.,           0.,           1.
      2,           0.,           1.,           1.
      3,           0.,           2.,           1.
      4,           0.,           3.,           1.
      5,           0.,           4.,           1.
      6,           0.,           5.,           1.
      7,           0.,           6.,           1.
      8,           0.,           7.,           1.
      9,           0.,           8.,           1.
     10,           0.,           9.,           1.
     11,           0.,          10.,           1.
     12,           0.,          11.,           1.
     13,           0.,          12.,           1.
     14,           0.,          13.,           1.
     15,           0.,          14.,           1.
     16,           0.,          15.,           1.
     17,           0.,          16.,           1.
     18,           0.,          17.,           1.
     19,           0.,          18.,           1.
     20,           0.,          19.,           1.
     21,           0.,          20.,           1.
     22,           0.,          21.,           1.
     23,           0.,          22.,           1.
     24,           0.,          23.,           1.
     25,           0.,          24.,           1.
     26,           0.,          25.,           1.
     27,           0.,           0.,           0.
     28,           0.,           1.,           0.
     29,           0.,           2.,           0.
     30,           0.,           3.,           0.
     31,           0.,           4.,           0.
     32,           0.,           5.,           0.
     33,           0.,           6.,           0.
     34,           0.,           7.,           0.
     35,           0.,           8.,           0.
     36,           0.,           9.,           0.
     37,           0.,          10.,           0.
     38,           0.,          11.,           0.
     39,           0.,          12.,           0.
     40,           0.,          13.,           0.
     41,           0.,          14.,           0.
     42,           0.,          15.,           0.
     43,           0.,          16.,           0.
     44,           0.,          17.,           0.
     45,           0.,          18.,           0.
     46,           0.,          19.,           0.
     47,           0.,          20.,           0.
     48,           0.,          21.,           0.
     49,           0.,          22.,           0.
     50,           0.,          23.,           0.
     51,           0.,          24.,           0.
     52,           0.,          25.,           0.
*Element, type=S4R
 1,  1,  2, 28, 27
 2,  2,  3, 29, 28
 3,  3,  4, 30, 29
 4,  4,  5, 31, 30
 5,  5,  6, 32, 31
 6,  6,  7, 33, 32
 7,  7,  8, 34, 33
 8,  8,  9, 35, 34
 9,  9, 10, 36, 35
10, 10, 11, 37, 36
```

```
11, 11, 12, 38, 37
12, 12, 13, 39, 38
13, 13, 14, 40, 39
14, 14, 15, 41, 40
15, 15, 16, 42, 41
16, 16, 17, 43, 42
17, 17, 18, 44, 43
18, 18, 19, 45, 44
19, 19, 20, 46, 45
20, 20, 21, 47, 46
21, 21, 22, 48, 47
22, 22, 23, 49, 48
23, 23, 24, 50, 49
24, 24, 25, 51, 50
25, 25, 26, 52, 51
*Nset, nset= PickedSet2, internal, generate
  1,  52,   1
*Elset, elset= PickedSet2, internal, generate
  1,  25,   1
*Nset, nset=top
 26, 52
*Nset, nset=bottom
  1, 27
*Nset, nset=allnodes, generate
  1,  52,   1
*Nset, nset=pos
  1, 52
*Nset, nset=neg
 26, 27
** Section: Section-1
*Shell Section, elset= PickedSet2, material=steel
0.25, 5
*End Part
**
**
** ASSEMBLY
**
*Assembly, name=Assembly
**
*Instance, name=Part-1-1, part=Part-1
*End Instance
**
*Nset, nset= PickedSet4, internal, instance=Part-1-1
 26,
*Nset, nset= PickedSet5, internal, instance=Part-1-1
 52,
*End Assembly
**
** MATERIALS
**
*Material, name=steel
*Elastic
 2.9e+07, 0.3
**
** BOUNDARY CONDITIONS
**
** Name: pin bottom Type: Displacement/Rotation
*Boundary
Part-1-1.bottom, 1, 1
Part-1-1.bottom, 2, 2
Part-1-1.bottom, 3, 3
Part-1-1.bottom, 4, 4
Part-1-1.bottom, 5, 5
** Name: top-bc Type: Displacement/Rotation
```

```
*Boundary
Part-1-1.top, 1, 1
Part-1-1.top, 3, 3
Part-1-1.top, 4, 4
Part-1-1.top, 5, 5
** ------------------------------------------------------------------
**
** STEP: buckle
**
*Step, name=buckle, perturbation
*Buckle
3, , 6, 30
**
** BOUNDARY CONDITIONS
**
** Name: pin bottom Type: Displacement/Rotation
*Boundary, op=NEW, load case=1
Part-1-1.bottom, 1, 1
Part-1-1.bottom, 2, 2
Part-1-1.bottom, 3, 3
Part-1-1.bottom, 4, 4
Part-1-1.bottom, 5, 5
*Boundary, op=NEW, load case=2
Part-1-1.bottom, 1, 1
Part-1-1.bottom, 2, 2
Part-1-1.bottom, 3, 3
Part-1-1.bottom, 4, 4
Part-1-1.bottom, 5, 5
** Name: top-bc Type: Displacement/Rotation
*Boundary, op=NEW, load case=1
Part-1-1.top, 1, 1
Part-1-1.top, 3, 3
Part-1-1.top, 4, 4
Part-1-1.top, 5, 5
*Boundary, op=NEW, load case=2
Part-1-1.top, 1, 1
Part-1-1.top, 3, 3
Part-1-1.top, 4, 4
Part-1-1.top, 5, 5
**
** LOADS
**
** Name: unit-eul   Type: Concentrated force
*Cload
Part-1-1.top, 2, -0.5
**
** OUTPUT REQUESTS
**
*Restart, write, frequency=0
**
** FIELD OUTPUT: F-Output-1
**
*Output, field, variable=PRESELECT
*NODE FILE, MODE=1
U
*End Step
```

B.3 Tapered-Flange Uniform-Moment W21X68 Beam Input File

```
*Heading
** Job name: W21X68 120in NoBracing Tapered Model name:
W21X68_120in_NoBracing_Tapered
```

```
** Generated by: Abaqus/CAE 6.11-1
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** Section: Web
*Shell Section, elset=_PickedSet3, material=Steel
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*Node
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*Nset, nset= PickedSet8, internal
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*Rigid Body, ref node= PickedSet5, tie
nset=W21X68 120in NoBracing Tapered.LeftWeb
** Constraint: RightWeb
*Rigid Body, ref node= PickedSet8, tie
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** Name: BothMid Type: Displacement/Rotation
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** Name: BothWeb Type: Displacement/Rotation
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** Name: LeftMid Type: Displacement/Rotation
*Boundary
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** BOUNDARY CONDITIONS
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** Name: BothEnds Type: Displacement/Rotation
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*Boundary, op=NEW, load case=2
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*Boundary, op=NEW, load case=2
W21X68 120in NoBracing Tapered.BothMid, 2, 2
** Name: BothWeb Type: Displacement/Rotation
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*Boundary, op=NEW, load case=2
W21X68 120in NoBracing Tapered.BothWeb, 1, 1
** Name: LeftMid Type: Displacement/Rotation
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*Boundary, op=NEW, load case=2
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*Output, field, variable=PRESELECT
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APPENDIX C. ANALYSIS RESULTS

The Abaqus results for all straight-flange and tapered-flange Wide-Flange shapes at all analyzed lengths for each bracing condition is contained here.

Table C-1: Straight-Flange and Tapered-Flange Buckling Stress for W-shape at Each Length for No Bracing, Mid-Span Bracing, and Third-Span Bracing

		No Bracing		Mid-Span Bracing		Third-Span Bracing	
Shape Name	Length [ft]	Straight Buckling Stress [ksi]	Tapered Buckling Stress [ksi]	Straight Buckling Stress [ksi]	Tapered Buckling Stress [ksi]	Straight Buckling Stress [ksi]	Tapered Buckling Stress [ksi]
W44X335	1	270.8	269.6	270.8	270.6	270.8	270.7
W44X335	5	136.5	69.9	136.5	121.4	137.2	128.3
W44X335	10	200.7	53.1	215.2	118.6	218.7	158.2
W44X335	15	216.5	42.4	297.2	97.7	308.7	154.2
W44X335	20	184.5	33.6	332.3	77.2	374.0	135.4
W44X335	25	150.4	27.3	316.0	61.4	405.5	115.0
W44X335	30	122.8	22.8	276.1	49.8	408.1	96.6
W44X335	35	101.8	19.5	234.1	40.4	372.6	81.3
W44X335	40	86.0	17.0	197.7	33.9	323.4	69.2
W44X335	45	73.9	15.1	168.0	29.1	277.1	59.6
W44X335	50	64.6	13.5	144.2	25.5	237.8	52.0

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W44X290	1	191.2	190.3	191.2	191.0	191.2	191.1
W44X290	5	94.3	49.3	94.3	84.8	94.6	88.7
W44X290	10	145.9	39.8	151.8	88.5	152.8	113.8
W44X290	15	176.8	33.2	216.0	76.4	218.0	116.0
W44X290	20	160.1	26.8	255.8	62.0	266.3	105.1
W44X290	25	134.2	22.0	264.4	50.2	292.3	91.4
W44X290	30	111.2	18.5	243.7	41.1	306.1	78.3
W44X290	35	92.8	15.9	212.7	34.0	311.5	66.8
W44X290	40	78.5	13.9	182.5	28.5	292.9	57.3
W44X290	45	67.5	12.3	156.5	24.4	257.6	49.6
W44X290	50	58.9	11.1	135.0	21.4	223.9	43.4
W44X262	1	161.7	160.9	161.7	161.7	161.7	161.6
W44X262	5	78.6	41.4	78.7	70.9	78.9	73.9
W44X262	10	123.2	33.9	127.1	76.1	127.7	96.2
W44X262	15	156.4	28.7	181.5	67.0	182.2	100.3
W44X262	20	146.4	23.4	217.2	55.1	222.2	92.2
W44X262	25	124.7	19.3	233.0	44.9	243.7	81.1
W44X262	30	104.1	16.2	224.4	37.0	255.4	70.0
W44X262	35	87.2	13.9	200.0	30.9	261.8	60.0
W44X262	40	73.8	12.2	173.5	25.8	263.4	51.6
W44X262	45	63.4	10.8	149.6	22.1	244.4	44.8
W44X262	50	55.2	9.7	129.4	19.3	215.1	39.2
W44X230	1	139.0	138.2	138.9	138.8	138.9	138.8
W44X230	5	66.5	35.1	66.5	60.0	66.6	62.2
W44X230	10	104.4	28.6	107.2	65.6	107.6	81.8
W44X230	15	136.2	24.3	152.6	58.6	153.6	86.9
W44X230	20	131.3	19.9	182.3	48.6	185.1	80.9
W44X230	25	113.5	16.4	197.7	39.8	201.9	71.7
W44X230	30	95.5	13.8	199.9	32.9	210.9	62.2
W44X230	35	80.2	11.9	184.1	27.5	216.0	53.5
W44X230	40	67.9	10.4	161.9	23.1	218.7	46.1
W44X230	45	58.2	9.2	140.5	19.7	218.7	40.0
W44X230	50	50.5	8.3	121.8	17.1	202.0	35.0
W40X593	1	626.9	624.0	627.1	626.8	627.1	626.7
W40X593	5	415.7	197.3	427.3	363.1	433.1	404.3
W40X593	10	518.7	143.3	663.1	305.1	699.2	449.7
W40X593	15	435.8	107.5	767.6	226.5	934.5	387.5
W40X593	20	337.4	83.1	682.5	169.8	975.9	312.7
W40X593	25	265.2	67.0	557.0	129.1	859.7	249.9
W40X593	30	215.0	55.9	449.9	102.0	709.3	202.2
W40X593	35	179.3	47.9	368.5	84.1	580.0	167.2
W40X593	40	153.3	41.8	307.9	71.5	479.4	141.4
W40X593	45	133.6	37.1	262.0	62.2	402.8	122.0
W40X593	50	118.2	33.4	223.2	55.1	342.1	107.1

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W40X503	1	512.3	509.6	512.5	512.3	512.4	512.2
W40X503	5	324.0	152.2	329.8	281.0	333.5	310.6
W40X503	10	430.1	113.2	523.5	244.5	543.9	354.1
W40X503	15	376.0	85.9	640.5	185.0	746.6	312.4
W40X503	20	294.5	66.7	594.7	139.7	823.6	256.4
W40X503	25	232.0	53.8	495.4	107.5	759.0	207.2
W40X503	30	187.6	44.9	403.2	84.7	640.0	168.7
W40X503	35	156.1	38.4	330.6	69.6	527.8	139.8
W40X503	40	132.9	33.6	275.7	59.1	437.3	118.2
W40X503	45	115.5	29.8	234.2	51.3	367.2	101.9
W40X503	50	102.0	26.8	202.3	45.3	312.9	89.3
W40X431	1	419.4	417.0	419.5	419.3	419.5	419.2
W40X431	5	256.0	119.4	258.6	221.0	261.0	242.4
W40X431	10	357.8	90.5	417.0	198.8	428.9	283.1
W40X431	15	326.4	69.4	533.8	153.2	597.9	255.4
W40X431	20	259.2	54.1	518.9	116.6	684.7	212.8
W40X431	25	204.8	43.7	442.9	90.9	665.4	173.9
W40X431	30	165.4	36.4	364.2	71.4	578.2	142.4
W40X431	35	137.1	31.2	299.6	58.5	483.2	118.2
W40X431	40	116.4	27.2	249.6	49.5	402.3	100.0
W40X431	45	100.8	24.2	211.4	42.8	338.1	86.1
W40X431	50	88.7	21.7	182.0	37.8	287.7	75.4
W40X397	1	354.6	352.4	354.6	354.5	354.6	354.4
W40X397	5	212.8	99.6	213.8	183.9	215.5	200.2
W40X397	10	311.0	77.9	349.6	171.2	356.9	239.5
W40X397	15	297.8	60.8	464.3	134.6	506.2	220.7
W40X397	20	240.8	47.6	470.9	103.5	590.5	186.6
W40X397	25	191.6	38.6	412.2	81.4	602.3	154.3
W40X397	30	155.1	32.2	343.4	64.3	540.7	127.2
W40X397	35	128.6	27.6	284.1	52.6	458.7	106.1
W40X397	40	109.0	24.1	237.3	44.4	384.6	89.9
W40X397	45	94.3	21.4	201.1	38.4	324.2	77.5
W40X397	50	82.9	19.2	173.0	33.9	276.2	67.9
W40X372	1	330.2	328.2	330.3	330.1	330.3	330.1
W40X372	5	196.8	91.7	197.3	169.7	198.8	184.3
W40X372	10	291.5	71.9	323.9	159.7	329.9	222.3
W40X372	15	283.6	56.2	434.3	126.3	467.8	206.5
W40X372	20	230.6	44.1	448.2	97.4	546.4	175.4
W40X372	25	183.7	35.7	396.9	76.6	568.2	145.4
W40X372	30	148.6	29.8	332.4	60.7	520.7	120.1
W40X372	35	123.0	25.6	275.6	49.6	445.7	100.2
W40X372	40	104.1	22.3	230.2	41.8	375.0	84.9
W40X372	45	89.9	19.8	194.8	36.1	316.5	73.2
W40X372	50	78.9	17.8	167.4	31.8	269.6	64.0

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W40X362	1	308.8	306.9	308.8	308.6	308.8	308.6
W40X362	5	182.6	85.4	182.8	157.7	184.0	170.8
W40X362	10	274.2	67.8	301.1	150.3	306.1	207.8
W40X362	15	272.2	53.4	408.4	119.8	433.4	194.4
W40X362	20	223.0	42.0	428.3	92.8	510.8	166.1
W40X362	25	178.4	34.1	383.4	73.1	539.1	138.3
W40X362	30	144.5	28.5	323.0	58.2	503.1	114.7
W40X362	35	119.7	24.4	268.6	47.5	433.7	95.8
W40X362	40	101.3	21.3	224.6	40.1	366.2	81.3
W40X362	45	87.4	18.9	190.3	34.6	309.6	70.1
W40X362	50	76.7	17.0	163.5	30.5	263.9	61.3
W40X324	1	253.4	251.9	253.4	253.3	253.4	253.3
W40X324	5	147.0	69.3	147.1	127.7	147.9	137.2
W40X324	10	229.5	56.6	244.7	126.2	247.6	171.2
W40X324	15	242.0	45.3	339.8	102.9	351.2	164.1
W40X324	20	203.2	35.9	374.4	80.7	415.5	142.4
W40X324	25	164.1	29.2	348.5	64.0	447.1	120.0
W40X324	30	133.4	24.5	299.5	51.5	450.3	100.3
W40X324	35	110.5	21.0	251.6	42.0	403.5	84.2
W40X324	40	93.4	18.4	211.4	35.4	345.7	71.6
W40X324	45	80.5	16.3	179.3	30.5	294.1	61.8
W40X324	50	70.5	14.6	153.9	26.8	251.5	54.0
W40X297	1	225.6	224.2	225.6	225.5	225.6	225.5
W40X297	5	129.5	61.1	129.6	112.6	130.3	120.6
W40X297	10	204.9	50.0	216.2	113.0	218.4	152.0
W40X297	15	221.8	40.3	301.6	92.9	309.2	147.4
W40X297	20	188.4	32.0	338.8	73.2	364.4	128.8
W40X297	25	152.9	26.0	323.2	58.1	391.9	109.0
W40X297	30	124.4	21.8	281.1	47.1	403.2	91.4
W40X297	35	102.9	18.7	237.4	38.3	377.8	76.8
W40X297	40	86.8	16.3	199.9	32.2	327.5	65.3
W40X297	45	74.6	14.5	169.6	27.7	279.9	56.3
W40X297	50	65.2	13.0	145.5	24.3	239.7	49.2
W40X277	1	174.4	173.3	174.4	174.3	174.4	174.2
W40X277	5	99.3	47.8	99.3	87.4	99.8	92.7
W40X277	10	163.7	41.6	167.8	92.8	169.1	121.2
W40X277	15	195.3	34.8	238.6	79.2	240.5	121.6
W40X277	20	174.0	28.1	279.8	63.8	287.1	108.8
W40X277	25	144.3	23.1	288.5	51.3	311.7	93.8
W40X277	30	118.7	19.4	262.1	42.0	324.5	79.8
W40X277	35	98.8	16.7	226.1	34.6	330.3	67.8
W40X277	40	83.6	14.6	192.7	29.1	311.1	58.0
W40X277	45	71.9	13.0	164.5	25.0	270.8	50.2
W40X277	50	62.8	11.7	141.7	21.9	233.9	44.0

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W40X249	1	145.0	144.1	145.0	144.9	144.9	144.9
W40X249	5	81.7	39.6	81.7	72.2	82.0	76.1
W40X249	10	136.3	35.1	138.4	79.1	139.3	101.5
W40X249	15	171.6	29.9	197.3	69.0	198.0	104.2
W40X249	20	158.6	24.3	233.0	56.3	236.3	94.7
W40X249	25	133.6	20.0	249.6	45.6	256.5	82.6
W40X249	30	110.7	16.9	240.7	37.5	267.2	70.8
W40X249	35	92.3	14.5	212.2	31.2	273.1	60.4
W40X249	40	78.1	12.7	182.6	26.1	275.4	51.9
W40X249	45	67.1	11.3	156.7	22.4	256.7	44.9
W40X249	50	58.5	10.2	135.1	19.6	224.3	39.4
W40X215	1	111.5	110.9	111.5	111.4	111.5	111.4
W40X215	5	62.1	30.5	62.1	55.3	62.3	57.8
W40X215	10	104.9	27.6	105.7	63.2	106.3	79.0
W40X215	15	140.0	24.1	150.4	56.8	150.8	83.9
W40X215	20	138.2	19.9	178.4	47.2	179.7	77.9
W40X215	25	119.7	16.5	193.2	38.7	194.9	69.1
W40X215	30	100.5	13.9	199.7	32.0	203.1	59.9
W40X215	35	84.3	12.0	191.4	26.9	207.7	51.5
W40X215	40	71.4	10.5	168.8	22.7	210.5	44.4
W40X215	45	61.2	9.3	146.4	19.4	212.0	38.6
W40X215	50	53.2	8.4	126.9	16.9	207.9	33.8
W40X199	1	123.1	122.3	123.1	123.0	123.1	123.0
W40X199	5	67.2	32.5	67.3	59.3	67.5	62.1
W40X199	10	111.2	27.6	113.2	65.7	113.6	83.4
W40X199	15	142.3	23.3	158.7	57.9	159.3	87.6
W40X199	20	135.4	18.9	183.7	47.5	185.4	80.6
W40X199	25	115.9	15.5	196.0	38.6	198.3	70.7
W40X199	30	96.6	13.0	200.2	31.7	205.0	60.7
W40X199	35	80.5	11.2	188.0	26.4	208.6	51.8
W40X199	40	67.8	9.8	164.6	22.1	210.7	44.3
W40X199	45	57.8	8.7	142.0	18.8	211.5	38.2
W40X199	50	50.0	7.8	122.6	16.4	203.4	33.4
W40X392	1	571.7	568.2	571.8	571.5	571.8	571.3
W40X392	5	331.4	154.1	349.0	283.9	355.7	326.4
W40X392	10	349.4	99.0	501.4	210.5	554.7	329.3
W40X392	15	265.3	70.0	511.4	147.0	684.4	262.4
W40X392	20	197.4	52.8	415.9	105.7	639.2	200.9
W40X392	25	152.6	42.0	323.7	78.5	516.0	155.2
W40X392	30	122.8	34.8	255.5	62.1	406.7	123.4
W40X392	35	102.2	29.6	207.0	51.3	325.2	101.2
W40X392	40	87.2	25.8	172.2	43.6	265.9	85.3
W40X392	45	75.9	22.9	143.7	38.0	221.1	73.4
W40X392	50	67.2	20.5	122.6	33.6	187.1	64.4

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W40X331	1	455.0	452.1	455.1	454.9	455.1	454.8
W40X331	5	257.1	118.2	266.8	218.1	271.1	248.7
W40X331	10	290.9	77.7	396.3	168.0	428.3	258.2
W40X331	15	227.8	55.4	430.1	119.4	549.0	211.4
W40X331	20	170.9	41.9	363.4	87.4	546.1	164.9
W40X331	25	132.0	33.3	287.0	64.7	458.2	128.7
W40X331	30	105.9	27.6	227.3	51.0	366.4	102.7
W40X331	35	87.7	23.5	183.9	41.9	294.3	84.2
W40X331	40	74.6	20.5	152.4	35.6	240.5	70.8
W40X331	45	64.8	18.1	129.1	30.9	200.6	60.9
W40X331	50	57.2	16.3	109.7	27.3	169.6	53.3
W40X327	1	421.0	418.3	421.1	420.8	421.1	420.7
W40X327	5	237.7	109.7	245.9	201.7	249.6	229.2
W40X327	10	276.9	73.5	370.1	157.8	397.0	240.2
W40X327	15	220.1	52.8	409.8	113.2	516.2	198.9
W40X327	20	166.0	40.0	350.7	83.4	523.0	156.3
W40X327	25	128.7	32.0	278.7	61.9	443.8	122.6
W40X327	30	103.4	26.5	221.4	48.8	356.7	98.1
W40X327	35	85.7	22.6	179.4	40.2	287.1	80.6
W40X327	40	72.9	19.7	148.8	34.1	235.0	67.9
W40X327	45	63.4	17.4	126.2	29.6	196.1	58.4
W40X327	50	55.9	15.6	107.3	26.2	165.9	51.2
W40X294	1	349.2	346.7	349.2	349.0	349.2	348.9
W40X294	5	195.1	90.0	200.0	165.2	202.6	186.2
W40X294	10	241.4	62.0	308.3	133.9	325.5	200.3
W40X294	15	198.7	45.1	358.9	97.8	434.4	169.7
W40X294	20	151.6	34.3	318.8	72.5	461.7	135.6
W40X294	25	117.8	27.4	257.8	54.4	407.6	107.5
W40X294	30	94.6	22.8	206.1	42.8	333.5	86.5
W40X294	35	78.3	19.4	167.3	35.2	270.3	71.2
W40X294	40	66.5	16.9	138.7	29.9	221.7	60.0
W40X294	45	57.7	15.0	117.3	25.9	184.9	51.6
W40X294	50	50.8	13.4	100.9	22.9	157.0	45.1
W40X278	1	342.4	340.1	342.4	342.2	342.4	342.2
W40X278	5	189.6	87.1	194.0	160.2	196.4	180.5
W40X278	10	234.7	59.4	298.5	130.0	314.9	194.8
W40X278	15	193.3	43.1	349.2	94.9	419.6	165.1
W40X278	20	147.4	32.8	312.0	70.3	448.5	132.0
W40X278	25	114.3	26.1	252.8	52.7	399.3	104.6
W40X278	30	91.6	21.7	202.2	41.4	328.2	84.0
W40X278	35	75.6	18.5	163.9	34.0	266.3	69.1
W40X278	40	64.1	16.1	135.6	28.8	218.4	58.1
W40X278	45	55.5	14.2	114.5	25.0	182.0	49.9
W40X278	50	48.9	12.8	98.4	22.0	154.3	43.6

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W40X264	1	296.8	294.8	296.8	296.7	296.8	296.7
W40X264	5	164.2	75.7	167.1	138.7	169.0	155.3
W40X264	10	212.2	52.9	261.5	115.6	273.2	170.7
W40X264	15	180.0	38.8	316.2	85.6	370.2	147.3
W40X264	20	138.6	29.6	290.4	63.9	407.3	119.1
W40X264	25	108.0	23.7	238.8	48.4	373.6	95.2
W40X264	30	86.6	19.7	192.2	38.0	311.7	76.9
W40X264	35	71.5	16.8	156.3	31.1	254.6	63.4
W40X264	40	60.6	14.6	129.4	26.3	209.4	53.4
W40X264	45	52.4	12.9	109.2	22.8	174.7	45.9
W40X264	50	46.1	11.6	93.8	20.1	148.1	40.1
W40X235	1	219.4	218.1	219.4	219.5	219.4	219.4
W40X235	5	121.5	56.7	122.4	103.2	123.4	113.5
W40X235	10	172.8	42.2	197.7	92.0	202.9	131.4
W40X235	15	159.3	32.0	257.8	70.7	283.8	118.0
W40X235	20	126.4	24.7	255.2	53.8	329.7	98.2
W40X235	25	99.7	19.9	219.0	41.8	329.1	80.2
W40X235	30	80.3	16.5	180.0	32.8	288.9	65.6
W40X235	35	66.4	14.1	147.7	26.8	241.4	54.5
W40X235	40	56.2	12.3	122.8	22.7	200.6	46.0
W40X235	45	48.5	10.9	103.7	19.6	168.1	39.6
W40X235	50	42.6	9.8	89.0	17.3	142.7	34.7
W40X211	1	183.3	182.1	183.3	183.2	183.3	183.1
W40X211	5	100.8	47.2	101.1	85.7	101.8	93.6
W40X211	10	148.4	35.8	164.7	78.7	168.1	110.8
W40X211	15	142.9	27.4	220.9	61.6	236.6	101.5
W40X211	20	115.2	21.3	227.8	47.2	277.7	85.6
W40X211	25	91.4	17.2	200.7	37.0	289.5	70.5
W40X211	30	73.7	14.3	167.1	29.1	265.3	58.0
W40X211	35	60.8	12.2	137.9	23.8	225.7	48.3
W40X211	40	51.4	10.6	114.8	20.1	189.0	40.8
W40X211	45	44.3	9.4	96.9	17.3	158.9	35.1
W40X211	50	38.8	8.5	83.1	15.2	135.0	30.7
W40X183	1	141.1	140.3	141.1	141.1	141.1	141.0
W40X183	5	76.6	36.3	76.7	65.6	77.1	70.8
W40X183	10	117.8	28.2	126.0	63.0	127.9	86.5
W40X183	15	121.8	21.9	173.9	50.6	180.4	81.9
W40X183	20	101.1	17.1	190.7	39.4	211.8	70.5
W40X183	25	81.2	13.8	176.6	31.1	226.5	58.9
W40X183	30	65.7	11.5	150.9	24.8	228.1	48.8
W40X183	35	54.1	9.8	126.1	20.1	204.8	40.8
W40X183	40	45.6	8.6	105.5	16.9	174.8	34.6
W40X183	45	39.1	7.6	89.1	14.6	148.2	29.7
W40X183	50	34.1	6.8	76.3	12.8	126.3	26.0

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W40X167	1	157.3	156.4	157.3	157.2	157.3	157.2
W40X167	5	83.3	38.7	83.3	70.6	83.8	76.6
W40X167	10	121.8	28.0	134.0	65.4	136.4	91.7
W40X167	15	119.2	21.2	179.3	51.3	189.0	85.4
W40X167	20	97.2	16.3	190.9	39.3	217.0	72.4
W40X167	25	77.3	13.1	173.3	30.7	228.2	59.6
W40X167	30	62.0	10.8	146.5	24.1	224.7	48.9
W40X167	35	50.8	9.2	121.5	19.6	198.9	40.5
W40X167	40	42.4	8.0	101.0	16.4	168.9	34.1
W40X167	45	36.2	7.1	84.9	14.1	142.6	29.2
W40X167	50	31.5	6.3	72.3	12.3	121.2	25.4
W40X149	1	166.8	165.6	166.8	166.6	166.8	166.6
W40X149	5	84.4	38.7	84.5	71.7	85.0	78.0
W40X149	10	117.5	26.4	132.1	64.3	134.8	91.9
W40X149	15	111.1	19.5	172.0	49.5	181.1	84.7
W40X149	20	90.1	14.9	180.1	37.6	201.5	70.9
W40X149	25	71.3	11.8	162.8	29.2	208.4	57.7
W40X149	30	56.8	9.7	137.1	22.6	206.5	46.9
W40X149	35	46.1	8.3	113.3	18.3	185.4	38.6
W40X149	40	38.3	7.2	93.8	15.3	157.8	32.3
W40X149	45	32.5	6.3	78.5	13.1	133.1	27.5
W40X149	50	28.1	5.6	66.6	11.4	112.9	23.8
W36X652	1	704.4	701.0	704.6	704.2	704.6	704.1
W36X652	5	529.2	241.0	549.2	457.0	558.6	517.4
W36X652	10	654.3	179.4	868.1	380.1	918.9	568.8
W36X652	15	536.0	134.4	960.4	279.1	1180.3	482.7
W36X652	20	412.1	103.9	830.3	208.4	1164.7	385.2
W36X652	25	323.6	83.8	670.2	157.3	1021.5	305.5
W36X652	30	262.7	70.0	539.4	124.8	839.7	246.6
W36X652	35	219.6	60.0	441.9	103.3	685.5	203.9
W36X652	40	188.2	52.5	370.0	88.1	566.9	172.7
W36X652	45	164.3	46.6	311.1	76.8	475.4	149.3
W36X652	50	145.7	41.9	266.1	68.1	403.9	131.3
W36X529	1	533.3	530.4	533.4	533.1	533.4	533.0
W36X529	5	377.3	168.8	386.2	322.6	391.4	361.9
W36X529	10	513.6	130.9	634.4	282.0	656.3	412.1
W36X529	15	442.7	99.7	765.1	212.4	901.0	360.8
W36X529	20	345.2	77.5	696.8	160.1	967.9	294.8
W36X529	25	271.5	62.7	575.4	122.8	877.8	237.4
W36X529	30	219.8	52.4	466.8	97.1	735.8	193.0
W36X529	35	183.1	44.9	382.6	80.1	605.5	160.1
W36X529	40	156.3	39.3	319.4	68.1	501.6	135.6
W36X529	45	136.0	34.9	271.7	59.2	421.5	117.1
W36X529	50	120.3	31.4	233.0	52.4	359.1	102.8

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W36X487	1	483.2	480.6	483.3	483.0	483.3	483.0
W36X487	5	336.1	149.4	342.7	286.4	346.9	320.4
W36X487	10	470.4	116.9	567.9	254.3	584.5	368.9
W36X487	15	412.7	89.4	702.2	193.0	809.6	326.2
W36X487	20	323.3	69.6	652.9	145.9	891.7	268.3
W36X487	25	254.4	56.3	544.3	112.5	826.7	217.0
W36X487	30	205.6	47.0	443.1	88.8	700.4	176.9
W36X487	35	170.9	40.3	363.3	73.1	579.0	146.7
W36X487	40	145.5	35.2	302.8	62.0	480.2	124.2
W36X487	45	126.5	31.3	257.1	53.9	403.3	107.2
W36X487	50	111.6	28.1	222.0	47.6	343.7	94.1
W36X441	1	417.8	415.4	417.9	417.7	417.9	417.7
W36X441	5	283.7	126.0	287.5	241.7	290.6	268.6
W36X441	10	415.8	100.9	482.4	221.3	492.9	316.1
W36X441	15	379.1	78.1	621.4	170.8	694.0	284.8
W36X441	20	300.9	61.0	600.8	130.0	787.2	237.4
W36X441	25	237.6	49.4	511.1	101.5	764.3	193.8
W36X441	30	192.0	41.3	419.8	79.9	662.9	158.8
W36X441	35	159.4	35.4	345.3	65.6	553.7	132.0
W36X441	40	135.5	31.0	287.9	55.6	461.2	111.9
W36X441	45	117.4	27.5	244.1	48.2	387.7	96.5
W36X441	50	103.5	24.7	210.3	42.6	330.3	84.6
W36X395	1	348.9	347.0	349.0	348.8	349.0	348.7
W36X395	5	232.2	103.0	234.2	197.9	236.4	218.2
W36X395	10	355.1	84.4	397.0	186.7	403.7	262.7
W36X395	15	337.8	66.2	529.0	146.5	567.3	241.1
W36X395	20	272.0	51.9	534.1	112.4	654.3	203.5
W36X395	25	215.8	42.1	465.1	88.3	675.6	167.7
W36X395	30	174.5	35.3	386.3	69.8	606.5	138.1
W36X395	35	144.6	30.2	319.0	57.2	513.6	115.2
W36X395	40	122.6	26.4	266.2	48.4	430.3	97.7
W36X395	45	106.1	23.5	225.5	41.9	362.5	84.3
W36X395	50	93.3	21.1	194.0	37.0	308.8	73.8
W36X361	1	304.0	302.3	304.0	303.9	304.0	303.8
W36X361	5	199.6	88.5	200.7	170.2	202.3	186.5
W36X361	10	314.1	73.7	342.2	164.4	347.0	228.6
W36X361	15	309.7	58.3	464.5	130.8	486.8	213.0
W36X361	20	252.6	45.9	487.1	101.0	562.3	181.6
W36X361	25	201.4	37.3	433.9	79.5	596.2	150.6
W36X361	30	162.9	31.2	364.2	63.3	565.5	124.6
W36X361	35	134.8	26.8	302.2	51.8	486.9	104.1
W36X361	40	114.1	23.4	252.5	43.7	410.6	88.3
W36X361	45	98.5	20.8	213.7	37.8	346.8	76.2
W36X361	50	86.5	18.7	183.6	33.3	295.6	66.7

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W36X330	1	258.1	256.7	258.1	258.0	258.1	258.0
W36X330	5	167.4	74.6	167.7	143.1	168.9	155.7
W36X330	10	271.8	63.6	287.7	142.6	291.2	195.2
W36X330	15	281.8	51.0	397.1	115.5	408.6	185.4
W36X330	20	234.5	40.4	435.8	90.1	473.5	160.1
W36X330	25	188.4	32.9	402.1	71.3	505.2	134.1
W36X330	30	152.8	27.6	343.0	57.3	513.5	111.7
W36X330	35	126.4	23.7	286.8	46.8	459.7	93.6
W36X330	40	106.8	20.7	240.4	39.5	392.1	79.6
W36X330	45	92.1	18.4	203.6	34.1	332.8	68.6
W36X330	50	80.7	16.5	174.8	30.0	284.2	60.1
W36X302	1	227.6	226.3	227.6	227.5	227.6	227.5
W36X302	5	146.4	65.2	146.4	125.3	147.3	135.6
W36X302	10	242.4	56.2	252.1	127.9	254.8	173.0
W36X302	15	261.5	45.6	349.1	105.1	356.1	167.1
W36X302	20	221.5	36.2	393.6	82.6	411.3	145.7
W36X302	25	179.2	29.5	378.6	65.5	438.6	122.9
W36X302	30	145.5	24.7	328.7	53.1	451.6	102.8
W36X302	35	120.2	21.2	277.1	43.3	437.8	86.3
W36X302	40	101.4	18.6	232.9	36.4	380.5	73.4
W36X302	45	87.2	16.5	197.4	31.3	325.0	63.3
W36X302	50	76.2	14.8	169.3	27.5	278.3	55.4
W36X282	1	203.0	201.6	203.0	202.8	203.0	202.8
W36X282	5	129.3	57.8	129.3	111.1	130.0	119.6
W36X282	10	217.0	50.4	223.1	115.4	225.3	154.6
W36X282	15	241.7	41.2	309.8	95.9	314.7	151.2
W36X282	20	207.9	32.9	353.5	75.9	363.5	132.9
W36X282	25	169.3	26.8	352.3	60.4	387.8	112.8
W36X282	30	137.8	22.5	311.4	49.1	399.9	94.7
W36X282	35	113.9	19.3	264.4	40.1	402.9	79.7
W36X282	40	96.0	16.9	223.0	33.6	363.3	67.8
W36X282	45	82.4	15.0	189.2	29.0	312.4	58.5
W36X282	50	71.9	13.5	162.3	25.4	268.2	51.1
W36X262	1	190.7	189.4	190.7	190.6	190.7	190.6
W36X262	5	119.9	53.6	119.9	103.1	120.5	110.6
W36X262	10	201.6	46.4	206.7	108.1	208.6	144.0
W36X262	15	228.7	38.0	285.9	90.4	289.8	142.2
W36X262	20	198.8	30.3	326.1	71.7	333.0	125.6
W36X262	25	162.6	24.7	333.2	57.1	354.2	106.9
W36X262	30	132.5	20.7	300.4	46.4	364.8	89.8
W36X262	35	109.4	17.8	256.8	38.0	369.7	75.6
W36X262	40	91.9	15.5	217.2	31.8	351.6	64.3
W36X262	45	78.7	13.8	184.4	27.3	305.4	55.4
W36X262	50	68.5	12.4	158.0	23.9	262.9	48.4

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W36X247	1	176.8	175.6	176.8	176.7	176.8	176.7
W36X247	5	110.4	49.4	110.4	95.0	110.9	101.8
W36X247	10	186.3	42.8	190.4	100.5	192.0	133.3
W36X247	15	214.8	35.1	262.8	84.5	265.9	132.5
W36X247	20	188.6	28.0	299.6	67.3	304.7	117.6
W36X247	25	155.0	22.9	310.8	53.6	323.5	100.3
W36X247	30	126.4	19.2	286.4	43.6	333.1	84.5
W36X247	35	104.3	16.4	246.4	35.7	337.8	71.2
W36X247	40	87.6	14.4	209.0	29.9	333.2	60.5
W36X247	45	74.9	12.7	177.5	25.7	294.2	52.1
W36X247	50	65.1	11.5	152.1	22.4	254.1	45.5
W36X231	1	162.5	161.3	162.5	162.3	162.5	162.3
W36X231	5	100.7	45.1	100.8	86.8	101.2	92.7
W36X231	10	170.9	39.2	173.8	93.1	175.2	122.5
W36X231	15	201.3	32.3	239.3	78.9	241.8	123.1
W36X231	20	179.5	25.9	272.5	63.1	276.0	110.0
W36X231	25	148.5	21.1	285.8	50.4	292.6	94.2
W36X231	30	121.5	17.7	273.0	41.1	301.0	79.5
W36X231	35	100.3	15.2	237.8	33.8	305.4	67.1
W36X231	40	84.1	13.3	202.6	28.2	307.8	57.1
W36X231	45	71.8	11.8	172.4	24.2	284.7	49.1
W36X231	50	62.2	10.6	147.8	21.1	247.5	42.8
W36X256	1	299.8	297.9	299.8	299.6	299.8	299.6
W36X256	5	183.8	79.7	188.1	152.0	190.5	172.5
W36X256	10	242.7	57.5	304.5	126.4	316.9	189.3
W36X256	15	202.0	42.1	363.4	92.9	430.3	161.3
W36X256	20	154.3	32.2	327.0	69.0	465.5	129.5
W36X256	25	119.7	25.8	265.6	52.0	418.6	103.0
W36X256	30	95.8	21.4	212.5	40.9	345.0	83.0
W36X256	35	79.2	18.3	172.2	33.6	280.2	68.4
W36X256	40	67.1	15.9	142.4	28.5	229.8	57.6
W36X256	45	58.1	14.1	120.2	24.8	191.5	49.6
W36X256	50	51.1	12.7	103.4	21.9	162.2	43.4
W36X232	1	253.1	251.6	253.2	253.2	253.2	253.2
W36X232	5	154.3	67.1	156.9	127.7	158.6	143.8
W36X232	10	213.9	49.4	257.6	109.6	265.7	161.6
W36X232	15	184.4	36.6	320.4	81.8	365.6	140.5
W36X232	20	142.5	28.1	299.4	61.2	408.5	114.3
W36X232	25	110.9	22.5	247.9	46.6	384.8	91.7
W36X232	30	88.8	18.7	199.9	36.6	324.5	74.2
W36X232	35	73.2	16.0	162.5	30.0	266.1	61.2
W36X232	40	61.9	13.9	134.3	25.4	219.0	51.6
W36X232	45	53.5	12.3	113.2	22.0	182.6	44.4
W36X232	50	47.0	11.1	97.1	19.4	154.6	38.8

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W36X210	1	247.6	245.5	247.6	247.4	247.6	247.4
W36X210	5	148.4	63.7	150.3	122.2	151.9	137.8
W36X210	10	203.4	45.7	244.7	104.6	252.3	154.7
W36X210	15	175.0	33.5	304.5	77.8	343.4	134.9
W36X210	20	135.2	25.5	287.4	58.0	382.7	109.6
W36X210	25	104.9	20.4	239.3	44.1	367.7	87.6
W36X210	30	83.5	16.9	193.2	34.5	314.4	70.6
W36X210	35	68.4	14.4	156.7	28.2	259.0	58.1
W36X210	40	57.6	12.5	129.1	23.8	213.3	48.8
W36X210	45	49.5	11.1	108.3	20.5	177.6	41.8
W36X210	50	43.3	9.9	92.5	18.1	150.1	36.5
W36X194	1	213.3	211.6	213.3	213.1	213.3	213.1
W36X194	5	127.5	55.0	128.5	105.2	129.7	117.7
W36X194	10	181.3	40.1	211.5	92.5	216.7	135.0
W36X194	15	161.3	29.7	270.6	69.8	297.3	119.7
W36X194	20	126.1	22.7	264.2	52.4	335.1	98.3
W36X194	25	98.3	18.2	224.3	40.2	335.6	79.2
W36X194	30	78.3	15.1	182.8	31.4	295.5	64.1
W36X194	35	64.1	12.9	148.8	25.6	246.4	52.8
W36X194	40	53.9	11.2	122.8	21.6	203.9	44.4
W36X194	45	46.2	9.9	103.0	18.6	170.2	38.1
W36X194	50	40.4	8.9	87.8	16.4	143.9	33.2
W36X182	1	194.5	192.8	194.5	194.3	194.5	194.3
W36X182	5	116.1	50.1	116.7	95.8	117.7	106.7
W36X182	10	168.5	36.9	192.9	85.7	197.0	124.1
W36X182	15	153.2	27.5	250.5	65.3	272.6	111.3
W36X182	20	120.9	21.1	250.5	49.2	305.3	92.0
W36X182	25	94.5	16.8	215.9	38.0	313.3	74.5
W36X182	30	75.3	14.0	177.2	29.6	284.3	60.5
W36X182	35	61.6	11.9	144.7	24.1	239.6	49.8
W36X182	40	51.7	10.4	119.4	20.3	199.2	41.9
W36X182	45	44.3	9.2	100.1	17.5	166.6	35.9
W36X182	50	38.6	8.2	85.3	15.4	140.8	31.3
W36X170	1	173.9	172.6	173.9	173.8	173.9	173.8
W36X170	5	103.2	44.7	103.4	85.3	104.2	94.5
W36X170	10	152.7	33.2	171.5	77.6	174.6	111.4
W36X170	15	142.4	24.9	225.8	59.7	240.4	101.2
W36X170	20	113.6	19.1	231.7	45.3	270.9	84.3
W36X170	25	89.2	15.3	203.2	35.2	282.1	68.6
W36X170	30	71.1	12.7	168.3	27.4	266.6	55.8
W36X170	35	58.1	10.8	138.0	22.3	228.1	46.1
W36X170	40	48.7	9.4	114.0	18.7	190.8	38.7
W36X170	45	41.6	8.3	95.6	16.1	159.9	33.2
W36X170	50	36.2	7.5	81.4	14.2	135.3	28.9

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W36X160	1	162.9	161.4	162.9	162.7	162.9	162.8
W36X160	5	96.1	41.6	96.1	79.5	96.8	87.7
W36X160	10	143.3	30.8	159.5	73.0	162.1	104.4
W36X160	15	135.6	23.2	210.8	56.4	222.3	95.5
W36X160	20	108.9	17.8	219.8	42.9	249.0	79.9
W36X160	25	85.7	14.2	195.5	33.3	259.9	65.2
W36X160	30	68.4	11.8	162.9	26.0	253.9	53.1
W36X160	35	55.8	10.0	133.9	21.1	221.0	43.8
W36X160	40	46.6	8.7	110.8	17.7	185.8	36.8
W36X160	45	39.7	7.7	92.8	15.3	156.0	31.5
W36X160	50	34.5	6.9	78.9	13.4	132.1	27.4
W36X150	1	156.5	155.0	156.5	156.3	156.5	156.3
W36X150	5	91.0	39.4	91.0	75.5	91.6	83.0
W36X150	10	135.8	29.0	150.5	69.7	152.6	99.4
W36X150	15	129.9	21.8	198.7	54.0	208.1	91.5
W36X150	20	104.9	16.7	209.6	41.1	231.5	76.8
W36X150	25	82.8	13.3	188.9	32.0	241.2	62.7
W36X150	30	66.0	11.0	158.4	25.0	240.9	51.0
W36X150	35	53.8	9.4	130.6	20.2	214.7	42.1
W36X150	40	44.8	8.2	108.0	17.0	181.6	35.3
W36X150	45	38.1	7.2	90.5	14.6	152.8	30.2
W36X150	50	33.0	6.5	76.8	12.8	129.5	26.2
W36X135	1	158.7	157.0	158.7	158.5	158.7	158.5
W36X135	5	89.0	38.2	89.0	74.0	89.6	81.5
W36X135	10	129.1	27.1	144.7	67.3	146.5	97.1
W36X135	15	122.1	20.1	187.1	51.7	194.0	89.2
W36X135	20	98.7	15.3	196.7	39.2	210.7	74.3
W36X135	25	77.7	12.2	179.0	30.3	216.7	60.3
W36X135	30	61.7	10.0	150.4	23.6	217.9	48.8
W36X135	35	50.0	8.5	123.9	19.0	202.6	40.1
W36X135	40	41.4	7.4	102.4	15.9	172.7	33.5
W36X135	45	35.1	6.5	85.5	13.6	145.5	28.6
W36X135	50	30.3	5.8	72.4	11.9	123.2	24.8
W33X387	1	390.5	387.1	390.6	390.2	390.6	390.3
W33X387	5	288.5	120.6	294.6	239.5	298.4	269.9
W33X387	10	424.4	97.7	507.1	214.5	518.2	312.9
W33X387	15	371.9	74.6	635.0	162.3	715.0	275.4
W33X387	20	290.0	58.0	592.2	122.3	797.6	225.9
W33X387	25	227.2	46.9	492.5	94.3	750.3	182.5
W33X387	30	183.0	39.2	399.5	74.4	635.2	148.5
W33X387	35	151.8	33.6	326.6	61.3	523.9	123.2
W33X387	40	129.0	29.4	271.5	52.1	433.5	104.4
W33X387	45	112.0	26.1	230.0	45.2	363.3	90.1
W33X387	50	98.8	23.5	198.3	40.0	309.1	79.1

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W33X354	1	341.7	338.3	341.7	341.4	341.8	341.5
W33X354	5	249.6	104.1	253.9	207.2	256.7	232.3
W33X354	10	380.6	85.7	440.2	189.9	448.2	274.1
W33X354	15	343.1	65.9	567.6	145.4	615.8	244.6
W33X354	20	270.0	51.4	547.4	110.1	695.1	202.4
W33X354	25	211.9	41.5	462.4	85.5	693.1	164.5
W33X354	30	170.5	34.7	377.6	67.4	599.8	134.3
W33X354	35	141.1	29.8	309.2	55.4	498.8	111.5
W33X354	40	119.7	26.0	257.0	47.0	414.0	94.5
W33X354	45	103.7	23.1	217.3	40.8	347.2	81.5
W33X354	50	91.3	20.8	187.0	36.0	295.1	71.5
W33X318	1	283.5	280.2	283.5	283.3	283.6	283.4
W33X318	5	204.6	85.7	207.2	170.6	209.2	189.5
W33X318	10	328.0	72.6	362.2	162.1	368.9	229.9
W33X318	15	310.9	56.7	483.1	126.6	505.0	209.5
W33X318	20	248.9	44.4	493.2	96.7	572.7	175.9
W33X318	25	196.5	36.0	428.7	75.8	601.7	144.4
W33X318	30	158.2	30.1	354.6	59.9	558.1	118.6
W33X318	35	130.7	25.8	291.9	49.1	472.3	98.8
W33X318	40	110.7	22.6	242.9	41.6	394.7	83.7
W33X318	45	95.6	20.1	205.3	36.0	331.8	72.2
W33X318	50	84.0	18.0	176.2	31.8	282.2	63.3
W33X291	1	246.9	243.8	246.9	246.6	246.9	246.7
W33X291	5	177.2	74.1	179.0	147.9	180.5	163.5
W33X291	10	291.4	63.6	314.1	143.5	318.8	201.5
W33X291	15	285.0	50.0	423.0	113.3	435.8	186.0
W33X291	20	230.8	39.2	448.6	87.0	494.0	157.4
W33X291	25	182.8	31.8	399.2	68.3	520.6	129.9
W33X291	30	147.2	26.6	333.4	54.3	515.9	107.1
W33X291	35	121.4	22.8	275.4	44.4	445.8	89.2
W33X291	40	102.5	20.0	229.3	37.5	374.9	75.6
W33X291	45	88.4	17.7	193.6	32.5	315.9	65.2
W33X291	50	77.5	15.9	166.0	28.6	268.7	57.1
W33X263	1	207.1	204.4	207.1	206.9	207.1	207.0
W33X263	5	147.3	61.9	148.4	123.5	149.5	135.6
W33X263	10	249.9	54.3	261.3	123.6	264.3	170.9
W33X263	15	257.0	43.2	355.2	99.3	361.7	160.9
W33X263	20	212.2	34.1	392.8	77.0	410.7	137.8
W33X263	25	169.4	27.7	366.6	60.7	433.8	114.8
W33X263	30	136.7	23.2	311.5	48.6	444.1	95.1
W33X263	35	112.6	19.9	259.3	39.7	416.7	79.5
W33X263	40	94.9	17.4	216.6	33.5	355.3	67.4
W33X263	45	81.6	15.5	182.9	28.9	300.9	58.1
W33X263	50	71.4	13.9	156.6	25.4	256.4	50.8

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W33X241	1	200.5	197.6	200.5	200.3	200.5	200.3
W33X241	5	140.9	58.6	141.4	117.5	142.4	129.1
W33X241	10	237.5	50.3	248.3	118.0	251.2	163.0
W33X241	15	246.0	39.9	333.6	94.9	339.3	154.5
W33X241	20	204.2	31.3	369.1	73.6	380.8	132.6
W33X241	25	163.1	25.4	354.1	57.8	400.0	110.4
W33X241	30	131.2	21.2	304.1	46.4	408.9	91.3
W33X241	35	107.7	18.2	253.9	37.7	401.9	76.1
W33X241	40	90.4	15.9	211.9	31.7	349.1	64.4
W33X241	45	77.4	14.1	178.6	27.3	296.6	55.3
W33X241	50	67.4	12.7	152.5	24.0	252.9	48.3
W33X221	1	179.5	176.7	179.6	179.3	179.6	179.4
W33X221	5	125.6	52.1	125.8	104.7	126.6	114.7
W33X221	10	213.6	44.8	221.0	106.7	223.3	146.4
W33X221	15	226.9	35.7	295.9	86.5	300.0	140.2
W33X221	20	190.7	28.1	328.6	67.4	335.3	121.1
W33X221	25	153.1	22.8	327.3	53.0	351.5	101.2
W33X221	30	123.3	19.0	286.8	42.7	359.2	83.9
W33X221	35	101.1	16.3	241.0	34.7	361.4	69.9
W33X221	40	84.6	14.2	201.6	29.1	331.2	59.1
W33X221	45	72.3	12.6	170.0	25.0	283.5	50.8
W33X221	50	62.8	11.4	145.0	21.9	242.2	44.3
W33X201	1	157.7	155.4	157.7	157.5	157.7	157.5
W33X201	5	108.9	45.2	108.9	91.0	109.5	99.1
W33X201	10	186.8	39.0	191.1	94.5	192.9	128.4
W33X201	15	205.0	31.3	254.9	77.5	257.7	124.9
W33X201	20	175.6	24.7	283.0	60.7	286.8	108.8
W33X201	25	142.2	20.0	290.8	47.9	299.9	91.4
W33X201	30	114.7	16.7	266.4	38.8	306.1	76.0
W33X201	35	94.0	14.3	226.5	31.5	308.9	63.4
W33X201	40	78.5	12.5	190.4	26.3	304.9	53.6
W33X201	45	66.9	11.1	160.7	22.6	268.5	46.0
W33X201	50	57.9	10.0	137.0	19.8	230.5	40.1
W33X169	1	165.0	162.7	165.0	164.8	165.0	164.8
W33X169	5	111.3	45.9	112.9	90.3	114.0	101.4
W33X169	10	170.1	35.7	194.5	81.0	197.9	118.0
W33X169	15	152.8	26.8	253.2	61.4	270.4	104.6
W33X169	20	119.5	20.6	249.3	46.2	303.9	86.0
W33X169	25	93.1	16.5	211.2	35.6	312.7	69.4
W33X169	30	74.3	13.8	171.7	27.9	278.0	56.3
W33X169	35	61.0	11.8	139.8	22.8	231.0	46.6
W33X169	40	51.4	10.2	115.4	19.3	190.9	39.3
W33X169	45	44.2	9.1	96.9	16.7	159.2	33.8
W33X169	50	38.7	8.2	82.8	14.7	134.6	29.5

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W33X152	1	158.6	156.2	158.6	158.4	158.6	158.4
W33X152	5	105.6	43.0	106.5	85.2	107.5	95.7
W33X152	10	160.3	32.7	182.4	76.8	185.5	111.9
W33X152	15	145.1	24.4	236.9	58.2	250.2	99.9
W33X152	20	113.9	18.7	238.0	43.8	278.0	82.2
W33X152	25	88.7	15.0	204.3	33.7	288.2	66.2
W33X152	30	70.5	12.4	166.9	26.3	268.3	53.6
W33X152	35	57.5	10.6	135.8	21.5	225.7	44.2
W33X152	40	48.2	9.2	111.9	18.1	187.2	37.2
W33X152	45	41.3	8.2	93.7	15.6	156.2	31.8
W33X152	50	36.0	7.3	79.7	13.7	131.8	27.8
W33X141	1	149.6	146.9	149.6	149.3	149.6	149.4
W33X141	5	98.5	39.8	99.0	79.3	99.9	89.2
W33X141	10	148.7	29.9	168.9	71.5	171.6	104.4
W33X141	15	135.1	22.2	218.6	54.2	229.4	93.4
W33X141	20	106.3	17.0	221.9	40.7	252.8	76.9
W33X141	25	82.8	13.5	192.0	31.4	261.9	61.9
W33X141	30	65.6	11.2	157.3	24.4	250.9	50.0
W33X141	35	53.4	9.6	128.1	19.9	213.2	41.1
W33X141	40	44.6	8.3	105.4	16.7	177.3	34.5
W33X141	45	38.1	7.4	88.1	14.4	148.0	29.5
W33X141	50	33.1	6.6	74.8	12.6	124.9	25.7
W33X130	1	145.5	143.0	145.5	145.2	145.5	145.3
W33X130	5	94.3	37.7	94.4	75.7	95.2	85.3
W33X130	10	140.6	27.8	159.7	68.2	162.0	99.9
W33X130	15	128.2	20.6	205.0	51.6	213.4	89.7
W33X130	20	101.3	15.7	210.4	38.8	232.5	73.7
W33X130	25	78.8	12.5	184.2	29.8	239.9	59.2
W33X130	30	62.3	10.3	151.5	23.2	236.8	47.8
W33X130	35	50.5	8.8	123.4	18.8	205.5	39.2
W33X130	40	42.0	7.6	101.5	15.8	171.5	32.8
W33X130	45	35.7	6.8	84.6	13.6	143.2	28.0
W33X130	50	31.0	6.0	71.7	11.9	120.8	24.3
W33X118	1	140.3	137.9	140.3	140.0	140.3	140.1
W33X118	5	88.4	35.3	88.5	71.4	89.2	80.3
W33X118	10	130.8	25.5	148.3	64.2	149.9	94.5
W33X118	15	120.3	18.8	187.7	48.7	192.9	85.2
W33X118	20	95.6	14.3	195.1	36.5	206.9	70.0
W33X118	25	74.5	11.3	174.6	28.1	211.8	56.2
W33X118	30	58.8	9.4	144.7	21.7	212.7	45.2
W33X118	35	47.4	7.9	118.1	17.6	195.4	37.0
W33X118	40	39.3	6.9	97.0	14.7	164.6	30.9
W33X118	45	33.3	6.1	80.8	12.7	137.8	26.3
W33X118	50	28.7	5.5	68.3	11.1	116.2	22.8

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W30X391	1	472.8	465.1	472.8	472.1	473.0	472.5
W30X391	5	403.1	155.8	419.0	319.7	427.7	373.5
W30X391	10	530.9	121.6	720.6	263.6	750.5	404.2
W30X391	15	422.4	89.8	789.1	190.1	977.2	336.0
W30X391	20	318.3	69.0	666.8	140.5	970.1	264.7
W30X391	25	246.8	55.6	528.5	105.4	824.3	208.4
W30X391	30	198.7	46.4	420.0	83.8	665.3	167.7
W30X391	35	165.3	39.8	341.0	69.4	537.3	138.6
W30X391	40	141.1	34.8	283.6	59.3	441.1	117.4
W30X391	45	122.9	30.9	239.0	51.7	368.6	101.6
W30X391	50	108.8	27.8	203.7	45.9	311.9	89.5
W30X357	1	405.7	398.6	405.7	405.1	405.9	405.5
W30X357	5	342.4	132.2	353.9	272.0	360.2	315.0
W30X357	10	477.5	105.7	620.3	230.9	639.0	349.3
W30X357	15	390.0	78.7	713.6	168.7	842.5	295.1
W30X357	20	296.0	60.7	620.3	125.2	886.5	235.2
W30X357	25	229.6	48.9	497.4	94.6	774.1	186.4
W30X357	30	184.6	40.9	396.7	75.1	631.9	150.4
W30X357	35	153.3	35.0	322.1	62.1	512.4	124.4
W30X357	40	130.6	30.6	267.4	53.0	420.9	105.4
W30X357	45	113.6	27.2	226.8	46.2	352.0	91.1
W30X357	50	100.4	24.5	193.3	40.9	298.2	80.2
W30X326	1	355.7	349.4	355.7	355.2	355.8	355.5
W30X326	5	297.8	114.7	306.4	236.9	311.3	272.4
W30X326	10	433.8	93.2	542.7	205.7	553.9	308.0
W30X326	15	362.6	69.8	649.2	151.9	730.4	263.6
W30X326	20	276.9	53.9	580.4	113.1	804.5	211.9
W30X326	25	214.8	43.5	470.7	86.0	728.9	168.8
W30X326	30	172.3	36.3	376.7	68.0	602.5	136.4
W30X326	35	142.7	31.1	305.8	56.2	490.7	112.9
W30X326	40	121.3	27.2	253.5	47.8	403.5	95.6
W30X326	45	105.3	24.2	214.5	41.6	337.1	82.6
W30X326	50	92.9	21.7	184.4	36.9	286.4	72.6
W30X292	1	292.8	286.5	292.9	292.3	292.9	292.5
W30X292	5	243.1	94.0	248.9	194.5	252.2	221.2
W30X292	10	377.3	78.7	445.5	175.3	450.7	258.0
W30X292	15	329.1	59.7	560.4	131.8	596.2	225.3
W30X292	20	254.6	46.3	528.1	98.8	659.2	183.7
W30X292	25	198.1	37.4	437.5	76.0	663.2	147.7
W30X292	30	158.8	31.3	353.1	60.0	564.8	119.9
W30X292	35	131.2	26.8	287.3	49.4	464.7	99.3
W30X292	40	111.2	23.4	238.0	42.0	383.4	84.1
W30X292	45	96.3	20.8	201.0	36.5	320.4	72.6
W30X292	50	84.8	18.7	172.8	32.3	271.9	63.8

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W30X261	1	254.0	248.5	254.0	253.6	254.1	253.8
W30X261	5	209.2	80.6	213.3	167.6	215.8	189.4
W30X261	10	335.4	68.1	382.7	154.4	386.2	225.1
W30X261	15	301.3	51.9	490.0	117.3	508.4	199.3
W30X261	20	235.1	40.3	484.0	88.3	561.4	163.8
W30X261	25	183.1	32.5	408.7	68.4	582.3	132.2
W30X261	30	146.4	27.2	332.2	53.8	529.5	107.5
W30X261	35	120.5	23.3	270.6	44.2	440.6	89.0
W30X261	40	101.8	20.4	223.8	37.5	364.8	75.3
W30X261	45	87.9	18.1	188.5	32.5	305.0	64.9
W30X261	50	77.2	16.3	161.6	28.7	258.5	56.9
W30X235	1	205.0	200.5	205.0	204.7	205.1	204.8
W30X235	5	168.2	65.5	171.0	136.1	172.5	152.0
W30X235	10	284.5	57.4	308.4	130.8	310.2	186.9
W30X235	15	271.9	44.5	402.8	101.5	410.0	169.3
W30X235	20	216.7	34.7	427.8	77.3	454.9	141.4
W30X235	25	170.0	28.1	377.4	60.4	474.7	115.4
W30X235	30	136.0	23.5	311.6	47.7	478.9	94.4
W30X235	35	111.8	20.2	255.5	39.1	415.8	78.4
W30X235	40	94.3	17.6	211.8	33.1	347.5	66.3
W30X235	45	81.2	15.7	178.3	28.7	291.5	57.2
W30X235	50	71.2	14.1	152.6	25.3	247.3	50.1
W30X211	1	188.1	183.8	188.1	187.7	188.1	187.9
W30X211	5	153.3	58.9	155.2	123.5	156.6	137.8
W30X211	10	259.7	50.9	279.1	119.6	280.6	170.6
W30X211	15	252.2	39.4	360.3	93.2	365.5	155.8
W30X211	20	202.2	30.7	388.1	70.9	401.8	130.5
W30X211	25	158.6	24.8	355.1	55.3	417.5	106.5
W30X211	30	126.5	20.7	295.8	43.7	423.9	87.0
W30X211	35	103.5	17.7	243.0	35.7	394.7	72.1
W30X211	40	86.9	15.5	201.1	30.1	332.8	60.8
W30X211	45	74.5	13.8	168.9	26.0	279.6	52.3
W30X211	50	65.0	12.4	144.0	22.9	237.0	45.7
W30X191	1	163.0	159.3	163.0	162.6	163.0	162.7
W30X191	5	131.7	50.7	133.0	106.6	134.0	118.1
W30X191	10	227.0	44.3	239.0	105.8	240.1	149.1
W30X191	15	230.2	34.5	308.3	83.5	311.7	138.4
W30X191	20	187.8	27.0	336.0	63.9	341.9	117.0
W30X191	25	148.3	21.8	327.2	50.0	355.1	96.2
W30X191	30	118.3	18.2	278.7	39.8	361.2	78.8
W30X191	35	96.6	15.6	230.6	32.4	360.5	65.3
W30X191	40	80.8	13.6	191.2	27.2	316.9	55.1
W30X191	45	69.1	12.1	160.5	23.5	267.9	47.3
W30X191	50	60.1	10.9	136.7	20.6	227.5	41.3

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W30X173	1	142.5	139.3	142.5	142.2	142.5	142.3
W30X173	5	114.9	44.2	115.7	93.3	116.5	102.8
W30X173	10	200.2	38.9	207.8	94.6	208.6	132.1
W30X173	15	211.5	30.6	266.4	75.6	268.6	124.6
W30X173	20	176.0	23.9	290.1	58.3	293.2	106.3
W30X173	25	139.9	19.3	295.2	45.6	303.7	87.8
W30X173	30	111.8	16.1	264.0	36.5	308.4	72.1
W30X173	35	91.1	13.8	220.7	29.7	310.1	59.8
W30X173	40	76.0	12.1	183.6	24.9	300.5	50.4
W30X173	45	64.7	10.7	154.2	21.4	258.4	43.2
W30X173	50	56.2	9.6	131.1	18.8	220.2	37.6
W30X148	1	175.2	171.2	175.2	174.8	175.2	174.9
W30X148	5	134.8	50.6	138.7	103.5	141.1	120.4
W30X148	10	189.0	37.7	241.5	85.6	247.5	131.1
W30X148	15	152.8	27.3	285.9	61.7	325.5	109.6
W30X148	20	114.6	20.8	252.1	45.4	352.8	86.6
W30X148	25	87.8	16.6	201.1	34.0	321.1	68.0
W30X148	30	69.7	13.8	158.9	26.8	261.5	54.5
W30X148	35	57.3	11.8	127.7	22.0	210.4	44.8
W30X148	40	48.4	10.3	104.9	18.7	171.4	37.8
W30X148	45	41.8	9.1	88.1	16.3	142.1	32.5
W30X148	50	36.7	8.2	75.5	14.4	119.9	28.5
W30X132	1	169.1	165.0	168.9	168.5	169.0	168.6
W30X132	5	127.9	46.8	130.8	97.3	132.7	113.8
W30X132	10	175.1	33.8	224.9	79.8	231.1	123.5
W30X132	15	141.0	24.2	265.5	57.2	297.6	103.1
W30X132	20	105.4	18.2	236.2	41.8	319.9	81.0
W30X132	25	80.3	14.5	188.8	31.1	299.7	63.3
W30X132	30	63.3	12.0	148.9	24.4	246.7	50.4
W30X132	35	51.6	10.3	119.1	20.0	198.8	41.2
W30X132	40	43.3	8.9	97.4	16.9	161.7	34.6
W30X132	45	37.2	7.9	81.3	14.7	133.7	29.7
W30X132	50	32.5	7.1	69.3	13.0	112.5	25.9
W30X124	1	156.9	153.1	156.7	156.2	156.7	156.3
W30X124	5	118.1	43.3	120.3	90.2	122.0	104.8
W30X124	10	165.1	31.3	207.4	75.0	212.4	115.4
W30X124	15	135.1	22.5	249.2	54.1	272.2	97.2
W30X124	20	101.7	17.0	227.1	39.7	293.1	76.8
W30X124	25	77.5	13.5	183.5	29.6	286.4	60.1
W30X124	30	61.0	11.2	145.2	23.2	240.4	47.9
W30X124	35	49.6	9.5	116.3	19.0	194.9	39.2
W30X124	40	41.5	8.3	95.0	16.0	158.8	32.8
W30X124	45	35.6	7.3	79.2	13.9	131.3	28.1
W30X124	50	31.1	6.6	67.4	12.2	110.4	24.5

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W30X116	1	152.2	148.7	152.2	151.7	152.2	151.8
W30X116	5	113.8	41.2	115.4	86.6	116.9	100.8
W30X116	10	157.9	29.5	197.9	72.0	202.4	111.2
W30X116	15	129.7	21.1	237.6	51.9	256.0	93.8
W30X116	20	97.7	15.9	219.0	38.0	273.8	74.0
W30X116	25	74.3	12.6	177.8	28.3	272.7	57.8
W30X116	30	58.3	10.4	140.8	22.1	233.2	46.0
W30X116	35	47.2	8.9	112.7	18.1	189.6	37.5
W30X116	40	39.4	7.7	91.8	15.2	154.6	31.4
W30X116	45	33.7	6.8	76.4	13.2	127.8	26.9
W30X116	50	29.3	6.1	64.8	11.6	107.3	23.4
W30X108	1	149.3	145.8	149.3	148.8	149.3	148.9
W30X108	5	109.9	39.3	110.8	83.5	112.3	97.4
W30X108	10	150.2	27.6	188.3	69.0	192.3	107.4
W30X108	15	123.7	19.7	224.7	49.7	238.3	90.6
W30X108	20	93.3	14.8	209.6	36.3	252.1	71.2
W30X108	25	70.8	11.7	171.1	27.0	254.0	55.5
W30X108	30	55.3	9.7	135.6	21.0	224.1	44.0
W30X108	35	44.6	8.2	108.4	17.1	183.2	35.8
W30X108	40	37.1	7.1	88.2	14.4	149.4	29.9
W30X108	45	31.6	6.3	73.2	12.5	123.4	25.5
W30X108	50	27.4	5.6	61.9	11.0	103.5	22.2
W30X99	1	144.9	141.6	144.9	144.4	145.0	144.5
W30X99	5	104.4	37.0	104.5	79.5	105.8	92.7
W30X99	10	141.6	25.7	175.8	65.8	178.9	102.7
W30X99	15	117.8	18.3	208.4	47.4	216.3	86.9
W30X99	20	89.3	13.7	199.5	34.6	225.9	68.3
W30X99	25	67.7	10.8	164.8	25.7	228.1	53.1
W30X99	30	52.7	8.9	131.1	20.0	214.4	42.1
W30X99	35	42.3	7.6	104.8	16.2	177.5	34.2
W30X99	40	35.1	6.6	85.1	13.7	145.2	28.5
W30X99	45	29.7	5.8	70.5	11.8	119.9	24.3
W30X99	50	25.7	5.2	59.5	10.3	100.4	21.1
W30X90	1	118.1	115.5	118.1	117.6	118.1	117.7
W30X90	5	85.5	30.7	85.5	65.8	86.5	75.9
W30X90	10	122.7	21.9	145.2	56.4	147.2	86.7
W30X90	15	106.3	15.7	174.1	41.4	177.5	75.0
W30X90	20	82.0	11.8	176.0	30.5	185.6	59.7
W30X90	25	62.6	9.3	151.6	22.9	187.9	46.9
W30X90	30	48.8	7.7	122.3	17.7	187.3	37.3
W30X90	35	39.2	6.5	98.3	14.4	165.7	30.3
W30X90	40	32.3	5.7	80.0	12.1	136.9	25.3
W30X90	45	27.4	5.0	66.3	10.4	113.5	21.5
W30X90	50	23.6	4.5	55.9	9.1	95.2	18.6

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W27X539	1	865.1	852.7	865.1	864.0	865.6	864.9
W27X539	5	871.4	330.0	960.2	673.6	1000.9	841.4
W27X539	10	839.8	232.4	1344.2	475.7	1464.6	786.5
W27X539	15	603.4	165.1	1165.0	322.6	1433.6	589.2
W27X539	20	445.6	125.7	888.5	225.2	1299.4	435.0
W27X539	25	347.3	101.0	680.2	171.3	1027.6	333.2
W27X539	30	282.7	84.2	533.0	138.1	804.4	266.5
W27X539	35	237.8	72.2	426.3	115.8	640.2	221.1
W27X539	40	205.0	63.1	353.0	99.7	525.2	188.6
W27X539	45	180.1	56.1	300.4	87.6	442.2	164.3
W27X539	50	160.5	50.5	261.1	78.1	380.4	145.7
W27X368	1	526.6	515.7	526.5	525.4	526.8	526.0
W27X368	5	512.3	183.2	542.1	383.5	554.1	466.0
W27X368	10	594.9	137.1	901.5	292.9	980.2	468.7
W27X368	15	443.0	98.8	869.1	203.4	1143.8	369.8
W27X368	20	327.0	75.4	686.7	145.5	1032.7	281.7
W27X368	25	252.6	60.6	528.8	109.6	827.3	218.0
W27X368	30	203.8	50.6	416.2	87.8	650.5	174.5
W27X368	35	170.1	43.3	337.7	73.1	520.5	144.3
W27X368	40	145.8	37.9	277.2	62.7	424.8	122.6
W27X368	45	127.4	33.7	232.6	54.9	353.4	106.4
W27X368	50	113.1	30.3	199.5	48.9	300.4	94.0
W27X336	1	454.2	444.7	454.4	453.3	454.6	453.8
W27X336	5	440.2	156.8	462.1	329.6	470.2	396.7
W27X336	10	543.2	120.1	793.2	258.6	840.8	408.8
W27X336	15	411.8	87.1	801.5	181.4	1035.8	327.6
W27X336	20	305.0	66.6	645.3	131.2	966.5	252.1
W27X336	25	235.3	53.6	500.0	98.6	785.7	196.1
W27X336	30	189.4	44.7	393.8	78.7	621.0	157.2
W27X336	35	157.8	38.3	318.9	65.5	497.3	129.9
W27X336	40	135.0	33.5	264.1	56.1	407.2	110.3
W27X336	45	117.8	29.8	220.8	49.1	338.0	95.7
W27X336	50	104.4	26.8	188.8	43.6	286.5	84.5
W27X307	1	399.7	391.3	400.0	399.1	400.2	399.6
W27X307	5	385.6	136.5	402.7	288.4	408.7	345.0
W27X307	10	494.9	105.6	702.8	230.0	734.7	361.0
W27X307	15	379.6	76.8	735.6	162.3	923.7	292.0
W27X307	20	281.5	58.8	600.8	118.0	897.0	226.1
W27X307	25	216.7	47.3	467.4	88.5	737.6	176.3
W27X307	30	174.0	39.4	368.0	70.5	585.1	141.3
W27X307	35	144.6	33.8	297.4	58.6	468.7	116.7
W27X307	40	123.5	29.5	246.9	50.1	383.2	99.0
W27X307	45	107.6	26.2	206.8	43.8	318.7	85.8
W27X307	50	95.3	23.6	176.3	38.9	269.6	75.6

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W27X281	1	341.4	334.2	341.8	341.1	341.9	341.3
W27X281	5	329.0	117.0	341.4	247.8	345.0	292.7
W27X281	10	453.3	93.2	609.1	204.5	623.2	315.9
W27X281	15	357.7	68.5	677.4	146.4	789.7	260.3
W27X281	20	267.1	52.5	570.7	107.8	832.7	204.1
W27X281	25	205.7	42.3	449.3	80.8	707.6	160.2
W27X281	30	164.9	35.3	354.9	64.3	567.9	128.8
W27X281	35	136.8	30.3	286.7	53.3	456.5	106.4
W27X281	40	116.5	26.5	237.6	45.6	373.4	90.2
W27X281	45	101.3	23.5	200.9	39.8	311.5	78.2
W27X281	50	89.6	21.1	170.7	35.3	263.0	68.8
W27X258	1	299.8	293.3	300.0	299.6	300.0	299.7
W27X258	5	287.6	102.1	297.3	217.3	299.8	254.9
W27X258	10	413.1	82.4	534.8	183.0	542.2	280.3
W27X258	15	332.3	60.8	617.9	132.1	687.3	233.6
W27X258	20	249.2	46.7	534.3	97.5	740.9	184.5
W27X258	25	191.7	37.6	424.3	73.4	666.4	145.3
W27X258	30	153.3	31.4	335.8	58.2	540.4	116.8
W27X258	35	126.8	26.9	271.1	48.2	435.7	96.5
W27X258	40	107.7	23.5	224.1	41.1	356.4	81.7
W27X258	45	93.5	20.9	189.4	35.9	296.9	70.7
W27X258	50	82.6	18.8	161.9	31.8	251.3	62.2
W27X235	1	268.2	262.4	268.4	268.1	268.4	268.1
W27X235	5	256.0	90.5	263.7	193.8	265.7	226.0
W27X235	10	378.9	73.4	475.8	165.7	480.1	252.3
W27X235	15	309.8	54.2	564.2	120.4	606.1	212.1
W27X235	20	233.1	41.6	501.9	88.8	653.6	168.4
W27X235	25	179.0	33.5	402.2	67.1	627.0	132.9
W27X235	30	142.7	27.9	318.9	53.1	515.5	106.8
W27X235	35	117.6	23.9	257.1	43.9	417.1	88.1
W27X235	40	99.7	20.9	212.0	37.3	341.2	74.5
W27X235	45	86.3	18.6	178.7	32.5	283.9	64.4
W27X235	50	76.0	16.7	153.5	28.8	240.4	56.6
W27X217	1	222.8	218.4	222.9	222.7	222.9	222.6
W27X217	5	214.0	76.3	219.8	163.5	220.6	188.6
W27X217	10	336.6	63.9	398.2	144.6	400.4	216.7
W27X217	15	285.9	47.8	491.2	106.7	508.6	185.4
W27X217	20	217.6	36.8	462.7	79.3	551.1	149.0
W27X217	25	167.6	29.7	377.7	60.5	564.8	118.5
W27X217	30	133.5	24.8	301.7	47.8	486.8	95.6
W27X217	35	109.9	21.2	243.7	39.4	397.2	79.0
W27X217	40	93.0	18.6	201.0	33.5	325.9	66.8
W27X217	45	80.4	16.5	169.2	29.2	271.3	57.7
W27X217	50	70.7	14.8	145.1	25.8	229.6	50.6

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W27X194	1	187.1	183.7	187.2	187.0	187.2	187.0
W27X194	5	179.2	64.1	183.4	138.0	183.9	157.5
W27X194	10	294.3	54.6	332.1	125.6	333.6	185.9
W27X194	15	260.3	41.1	415.3	94.0	423.0	161.7
W27X194	20	200.4	31.8	419.1	70.2	458.5	131.3
W27X194	25	154.6	25.6	351.5	54.0	473.0	105.0
W27X194	30	122.9	21.4	283.1	42.5	453.4	84.9
W27X194	35	100.8	18.3	229.2	34.9	375.9	70.1
W27X194	40	85.0	16.0	188.8	29.6	309.6	59.2
W27X194	45	73.2	14.2	158.5	25.7	257.9	51.0
W27X194	50	64.2	12.8	135.5	22.8	218.0	44.7
W27X178	1	186.7	183.2	186.8	186.5	186.8	186.5
W27X178	5	177.0	61.7	180.5	135.2	181.6	154.6
W27X178	10	285.2	51.1	324.3	122.2	325.8	182.2
W27X178	15	251.4	38.1	395.8	91.0	402.5	158.5
W27X178	20	193.2	29.3	403.8	67.6	430.6	128.2
W27X178	25	148.4	23.6	343.7	51.8	441.2	102.0
W27X178	30	117.2	19.6	277.1	40.6	435.7	82.0
W27X178	35	95.6	16.8	223.8	33.3	369.3	67.5
W27X178	40	80.1	14.7	183.6	28.1	304.7	56.8
W27X178	45	68.7	13.0	153.5	24.4	253.5	48.8
W27X178	50	60.1	11.7	130.7	21.5	213.8	42.6
W27X161	1	157.4	154.6	157.5	157.3	157.5	157.3
W27X161	5	148.9	52.3	151.5	114.8	152.2	130.0
W27X161	10	248.5	44.2	272.0	106.9	273.1	157.3
W27X161	15	229.8	33.3	333.7	80.8	337.5	139.2
W27X161	20	179.4	25.6	352.2	60.5	361.0	113.9
W27X161	25	138.5	20.6	319.4	46.8	370.2	91.2
W27X161	30	109.4	17.2	261.4	36.6	373.8	73.6
W27X161	35	88.9	14.7	212.1	29.9	348.0	60.5
W27X161	40	74.3	12.9	174.2	25.2	290.6	50.9
W27X161	45	63.6	11.4	145.5	21.8	242.5	43.7
W27X161	50	55.4	10.2	123.7	19.2	204.6	38.1
W27X146	1	135.3	132.9	135.3	135.1	135.3	135.1
W27X146	5	127.7	45.0	129.5	99.2	130.1	111.4
W27X146	10	217.9	38.7	232.2	95.2	232.9	138.2
W27X146	15	212.3	29.4	284.1	73.1	286.4	124.6
W27X146	20	169.0	22.7	302.1	55.1	305.6	103.1
W27X146	25	131.3	18.3	296.1	42.6	312.8	83.1
W27X146	30	103.7	15.2	249.9	33.6	315.2	67.2
W27X146	35	84.1	13.1	204.3	27.3	313.9	55.3
W27X146	40	70.1	11.4	168.0	23.0	280.6	46.5
W27X146	45	59.7	10.1	140.3	19.9	235.7	39.8
W27X146	50	51.9	9.1	119.0	17.5	199.2	34.7

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W27X129	1	167.1	164.0	167.1	166.9	167.1	166.9
W27X129	5	151.6	51.7	157.2	109.4	159.1	131.2
W27X129	10	200.1	37.7	275.7	86.0	284.5	136.2
W27X129	15	152.9	26.8	304.1	60.2	357.4	109.8
W27X129	20	112.1	20.3	252.4	43.5	374.3	84.4
W27X129	25	85.1	16.2	195.4	32.3	317.7	65.4
W27X129	30	67.4	13.5	152.2	25.6	251.1	52.0
W27X129	35	55.4	11.5	121.6	21.1	199.5	42.7
W27X129	40	46.9	10.0	99.8	18.0	161.6	36.1
W27X129	45	40.5	8.9	83.9	15.7	133.7	31.1
W27X129	50	35.7	8.0	71.9	13.9	112.8	27.3
W27X114	1	157.3	154.4	157.3	157.0	157.3	157.0
W27X114	5	140.5	46.9	144.6	101.3	147.0	121.1
W27X114	10	186.2	33.6	252.0	80.1	260.2	127.3
W27X114	15	143.7	23.8	283.9	56.1	318.8	103.1
W27X114	20	105.4	17.9	241.4	40.6	337.2	79.3
W27X114	25	79.5	14.2	188.2	29.9	304.6	61.2
W27X114	30	62.5	11.8	146.5	23.6	244.1	48.5
W27X114	35	51.0	10.1	116.5	19.4	194.3	39.7
W27X114	40	42.8	8.8	95.1	16.5	157.2	33.3
W27X114	45	36.8	7.8	79.4	14.3	129.6	28.6
W27X114	50	32.3	7.0	67.7	12.6	108.9	25.0
W27X102	1	130.6	128.3	130.6	130.4	130.6	130.4
W27X102	5	117.0	39.3	119.8	85.1	121.6	100.6
W27X102	10	163.8	28.7	210.7	69.4	214.8	108.9
W27X102	15	130.3	20.4	246.7	49.2	262.8	89.8
W27X102	20	96.5	15.4	220.1	35.8	279.3	69.7
W27X102	25	72.9	12.2	174.5	26.6	275.3	54.1
W27X102	30	57.1	10.1	136.7	20.8	227.9	42.9
W27X102	35	46.4	8.6	108.8	17.1	182.9	35.1
W27X102	40	38.9	7.5	88.6	14.5	148.2	29.4
W27X102	45	33.3	6.7	73.8	12.6	122.2	25.2
W27X102	50	29.1	6.0	62.8	11.1	102.6	22.0
W27X94	1	123.4	121.3	123.4	123.2	123.4	123.2
W27X94	5	109.6	36.4	111.7	79.8	113.7	94.1
W27X94	10	153.8	26.3	195.1	65.3	199.0	102.7
W27X94	15	123.6	18.7	228.9	46.4	239.2	85.0
W27X94	20	91.8	14.0	209.7	33.7	252.5	66.1
W27X94	25	69.2	11.2	167.7	25.0	254.7	51.2
W27X94	30	54.0	9.2	131.6	19.6	219.4	40.5
W27X94	35	43.7	7.9	104.7	16.0	177.0	33.0
W27X94	40	36.4	6.9	85.1	13.5	143.5	27.6
W27X94	45	31.1	6.1	70.7	11.7	118.3	23.7
W27X94	50	27.1	5.4	59.9	10.3	99.1	20.6

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W27X84	1	116.1	114.1	116.1	115.9	116.1	115.9
W27X84	5	101.0	33.1	102.3	73.8	103.8	86.8
W27X84	10	141.5	23.6	176.2	60.5	179.0	95.8
W27X84	15	115.3	16.7	204.7	43.2	209.8	79.6
W27X84	20	86.1	12.5	195.8	31.3	218.7	61.8
W27X84	25	64.8	9.9	159.1	23.2	221.1	47.8
W27X84	30	50.3	8.2	125.2	18.1	207.2	37.8
W27X84	35	40.4	7.0	99.5	14.7	169.2	30.7
W27X84	40	33.5	6.1	80.7	12.4	137.5	25.6
W27X84	45	28.5	5.4	66.8	10.7	113.3	21.9
W27X84	50	24.7	4.8	56.4	9.4	94.7	19.0
W24X370	1	681.5	670.8	682.1	680.8	682.2	681.1
W24X370	5	755.8	252.1	833.5	529.1	858.6	683.2
W24X370	10	700.1	174.4	1191.8	360.9	1381.9	610.8
W24X370	15	488.3	122.4	979.9	240.2	1343.0	447.3
W24X370	20	355.8	92.8	725.3	166.5	1104.7	326.8
W24X370	25	275.5	74.4	547.7	126.8	839.5	249.5
W24X370	30	223.6	62.1	426.5	102.4	649.0	199.5
W24X370	35	187.7	53.2	339.9	85.9	513.4	165.6
W24X370	40	161.7	46.5	280.8	74.0	419.6	141.4
W24X370	45	141.9	41.3	238.5	65.1	352.5	123.3
W24X370	50	126.4	37.2	207.0	58.1	302.7	109.4
W24X335	1	587.0	577.9	587.4	586.4	587.5	586.5
W24X335	5	654.2	214.5	711.7	453.1	728.9	580.4
W24X335	10	635.2	150.6	1070.3	315.0	1242.2	529.0
W24X335	15	445.7	106.0	901.0	211.0	1251.5	392.5
W24X335	20	324.3	80.4	671.0	146.6	1029.5	288.6
W24X335	25	250.5	64.5	506.4	111.5	784.3	220.6
W24X335	30	202.8	53.8	397.4	89.9	606.5	176.4
W24X335	35	170.0	46.1	315.6	75.3	480.0	146.3
W24X335	40	146.2	40.3	259.7	64.8	391.1	124.8
W24X335	45	128.2	35.8	219.8	56.9	327.4	108.7
W24X335	50	114.1	32.2	190.1	50.8	280.3	96.3
W24X306	1	506.5	499.6	506.8	506.0	506.9	506.1
W24X306	5	568.5	184.7	610.4	392.0	621.6	496.8
W24X306	10	585.2	132.2	965.1	279.2	1097.1	464.0
W24X306	15	414.9	93.5	841.0	188.3	1172.0	349.5
W24X306	20	301.8	71.0	632.9	131.7	975.2	259.1
W24X306	25	232.6	57.0	478.3	99.9	747.4	198.6
W24X306	30	187.9	47.5	374.6	80.4	578.4	158.8
W24X306	35	157.2	40.7	299.8	67.3	459.1	131.6
W24X306	40	135.0	35.6	245.7	57.9	372.9	112.1
W24X306	45	118.2	31.6	207.2	50.8	311.2	97.6
W24X306	50	105.1	28.4	178.7	45.3	265.6	86.5

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W24X279	1	444.8	439.2	445.0	444.3	445.1	444.5
W24X279	5	502.0	161.5	534.0	345.1	541.7	433.9
W24X279	10	541.6	117.1	873.5	250.4	968.1	413.0
W24X279	15	387.1	83.0	787.1	169.8	1087.5	314.6
W24X279	20	281.4	63.1	598.3	119.4	923.6	234.7
W24X279	25	216.3	50.6	452.7	90.3	713.2	180.2
W24X279	30	174.3	42.2	353.8	72.5	552.4	144.0
W24X279	35	145.5	36.1	285.3	60.6	439.4	119.2
W24X279	40	124.7	31.6	233.0	52.1	356.2	101.4
W24X279	45	109.0	28.1	195.8	45.7	296.4	88.2
W24X279	50	96.9	25.3	168.3	40.7	252.1	78.0
W24X250	1	368.1	363.2	368.2	367.5	368.2	367.7
W24X250	5	418.6	134.4	440.2	288.9	444.3	358.2
W24X250	10	488.5	100.2	751.8	216.6	800.2	351.9
W24X250	15	355.9	71.5	719.2	148.4	956.1	273.2
W24X250	20	259.2	54.4	557.9	105.4	857.9	206.0
W24X250	25	198.7	43.7	424.3	79.5	673.4	158.8
W24X250	30	159.7	36.4	331.4	63.7	523.8	127.0
W24X250	35	132.9	31.2	267.5	53.1	416.5	105.0
W24X250	40	113.7	27.3	219.7	45.6	338.8	89.3
W24X250	45	99.2	24.2	183.8	40.0	280.9	77.6
W24X250	50	88.0	21.8	157.3	35.6	238.2	68.6
W24X229	1	323.4	319.1	323.4	322.9	323.5	323.0
W24X229	5	368.2	117.8	384.9	254.8	387.5	313.3
W24X229	10	450.3	88.8	668.6	194.7	698.4	313.8
W24X229	15	332.0	63.5	668.4	134.2	838.0	246.3
W24X229	20	241.9	48.4	526.6	95.9	804.8	186.8
W24X229	25	185.0	38.8	402.0	72.1	641.1	144.2
W24X229	30	148.1	32.4	313.6	57.6	500.6	115.3
W24X229	35	123.0	27.7	252.4	48.0	397.9	95.2
W24X229	40	105.0	24.2	209.0	41.1	324.1	80.9
W24X229	45	91.5	21.5	174.2	36.0	268.4	70.2
W24X229	50	81.0	19.4	148.6	32.0	226.9	61.9
W24X207	1	272.3	268.3	272.3	271.8	272.4	271.9
W24X207	5	311.1	99.8	323.1	217.1	324.3	263.7
W24X207	10	407.1	76.9	570.3	170.8	585.9	271.7
W24X207	15	306.7	55.3	608.3	119.0	706.1	216.6
W24X207	20	224.3	42.2	492.2	85.9	735.0	165.9
W24X207	25	171.2	33.9	378.7	64.4	605.2	128.6
W24X207	30	136.6	28.3	295.7	51.3	476.4	102.8
W24X207	35	113.1	24.2	237.5	42.6	379.2	84.9
W24X207	40	96.3	21.2	196.2	36.5	308.5	72.0
W24X207	45	83.7	18.8	164.9	31.9	256.2	62.4
W24X207	50	74.1	16.9	140.2	28.3	216.0	55.0

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W24X192	1	240.5	236.9	240.6	240.1	240.6	240.2
W24X192	5	275.6	88.8	284.9	194.1	285.4	233.3
W24X192	10	380.7	69.8	506.5	156.5	516.3	246.2
W24X192	15	292.9	50.5	568.5	110.1	623.4	199.0
W24X192	20	215.2	38.5	473.6	80.2	659.8	153.6
W24X192	25	164.0	31.0	367.7	60.0	586.1	119.5
W24X192	30	130.6	25.8	287.6	47.7	465.9	95.6
W24X192	35	107.9	22.1	230.7	39.6	371.8	78.8
W24X192	40	91.6	19.3	190.2	33.8	302.5	66.8
W24X192	45	79.5	17.2	160.6	29.5	251.3	57.8
W24X192	50	70.2	15.4	136.6	26.2	211.9	50.9
W24X176	1	209.7	206.4	209.7	209.3	209.7	209.4
W24X176	5	241.6	77.7	249.0	171.0	249.0	204.0
W24X176	10	347.5	61.8	443.3	140.4	450.0	219.3
W24X176	15	272.2	44.8	514.3	99.5	542.2	179.0
W24X176	20	200.6	34.2	443.1	72.7	574.6	139.0
W24X176	25	152.7	27.5	346.9	54.4	549.5	108.3
W24X176	30	121.2	22.9	271.7	43.2	442.4	86.6
W24X176	35	99.8	19.6	217.7	35.8	353.9	71.4
W24X176	40	84.6	17.2	179.0	30.5	287.9	60.4
W24X176	45	73.3	15.3	150.7	26.6	238.8	52.2
W24X176	50	64.6	13.7	129.2	23.6	201.8	45.9
W24X162	1	191.0	187.9	191.0	190.6	191.0	190.7
W24X162	5	219.4	70.3	225.4	156.4	225.3	185.1
W24X162	10	326.5	56.3	400.2	130.8	405.0	203.1
W24X162	15	261.4	40.9	471.2	93.3	484.7	167.5
W24X162	20	193.5	31.3	428.0	68.2	512.5	130.8
W24X162	25	146.9	25.1	339.3	51.3	518.1	102.0
W24X162	30	116.2	20.9	266.4	40.5	435.1	81.5
W24X162	35	95.2	17.9	213.2	33.5	350.0	67.0
W24X162	40	80.4	15.7	174.8	28.5	284.8	56.6
W24X162	45	69.4	13.9	146.6	24.8	236.0	48.8
W24X162	50	61.0	12.5	125.5	22.0	199.1	42.9
W24X146	1	167.8	165.1	167.8	167.6	167.8	167.6
W24X146	5	192.8	61.3	197.6	137.9	197.4	162.1
W24X146	10	294.4	49.2	348.8	117.1	352.2	181.0
W24X146	15	240.7	35.8	410.5	84.0	417.8	150.6
W24X146	20	179.0	27.3	394.6	61.4	440.1	118.1
W24X146	25	135.6	21.9	318.0	46.3	447.3	92.2
W24X146	30	106.8	18.3	250.4	36.5	408.5	73.5
W24X146	35	87.1	15.6	200.2	30.0	331.4	60.4
W24X146	40	73.3	13.7	163.7	25.5	269.9	50.8
W24X146	45	63.1	12.1	136.8	22.2	223.4	43.8
W24X146	50	55.3	10.9	116.7	19.6	188.1	38.4

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W24X131	1	153.6	151.1	153.6	153.4	153.6	153.4
W24X131	5	174.4	54.8	178.3	125.3	178.3	146.4
W24X131	10	270.0	43.8	311.1	107.7	313.7	166.3
W24X131	15	226.2	31.9	361.3	77.7	365.8	139.6
W24X131	20	169.2	24.3	364.0	56.8	381.1	109.8
W24X131	25	127.9	19.5	304.3	42.9	384.4	85.7
W24X131	30	100.2	16.2	240.9	33.6	378.6	68.2
W24X131	35	81.3	13.8	192.4	27.6	320.7	55.8
W24X131	40	68.0	12.1	156.9	23.4	262.1	46.9
W24X131	45	58.2	10.7	130.7	20.3	216.7	40.3
W24X131	50	50.9	9.6	111.0	17.9	182.1	35.2
W24X117	1	130.9	128.4	130.9	130.5	130.9	130.5
W24X117	5	147.9	46.5	150.8	107.4	150.8	124.2
W24X117	10	235.7	37.6	261.5	94.5	263.1	144.7
W24X117	15	206.0	27.5	301.3	69.1	303.8	123.4
W24X117	20	156.1	21.0	309.5	50.7	314.4	97.8
W24X117	25	118.3	16.8	281.5	38.4	315.4	76.6
W24X117	30	92.4	14.0	226.1	30.1	312.9	61.0
W24X117	35	74.6	11.9	181.1	24.6	298.9	49.8
W24X117	40	62.1	10.4	147.5	20.8	248.4	41.8
W24X117	45	53.0	9.2	122.6	18.0	205.8	35.8
W24X117	50	46.1	8.3	103.8	15.8	172.8	31.2
W24X104	1	111.9	109.9	111.9	111.5	111.9	111.6
W24X104	5	126.0	39.7	128.1	92.6	128.1	105.9
W24X104	10	205.2	32.6	220.2	84.0	221.2	127.2
W24X104	15	190.1	24.0	250.5	62.3	252.0	110.4
W24X104	20	146.9	18.3	256.1	46.0	257.9	88.4
W24X104	25	111.8	14.7	251.8	35.1	256.4	69.6
W24X104	30	87.2	12.2	216.0	27.4	252.9	55.5
W24X104	35	70.1	10.4	174.2	22.3	249.1	45.3
W24X104	40	58.1	9.1	142.0	18.8	238.1	37.9
W24X104	45	49.3	8.1	117.8	16.2	199.8	32.4
W24X104	50	42.7	7.2	99.5	14.3	167.9	28.2
W24X103	1	157.1	154.4	157.1	156.6	157.1	156.7
W24X103	5	169.8	51.5	177.8	111.8	179.6	140.3
W24X103	10	195.4	35.4	302.5	81.0	320.3	134.2
W24X103	15	139.4	24.6	296.8	54.6	380.5	102.5
W24X103	20	99.6	18.5	228.4	38.2	361.4	76.2
W24X103	25	75.0	14.7	171.1	28.5	281.9	58.0
W24X103	30	59.4	12.2	131.6	22.7	216.5	46.0
W24X103	35	48.9	10.4	104.7	18.8	170.0	37.8
W24X103	40	41.5	9.1	86.0	16.1	137.2	31.9
W24X103	45	36.0	8.1	72.3	14.1	113.4	27.6
W24X103	50	31.7	7.2	61.2	12.5	95.2	24.3

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W24X94	1	142.3	139.7	142.3	141.8	142.3	141.9
W24X94	5	153.7	46.2	159.9	101.9	161.5	126.7
W24X94	10	183.3	31.9	273.9	75.0	285.9	123.9
W24X94	15	132.5	22.1	280.6	50.8	337.3	95.5
W24X94	20	94.7	16.6	220.5	35.6	340.4	71.2
W24X94	25	71.0	13.2	166.0	26.5	274.3	54.2
W24X94	30	55.9	11.0	127.5	21.0	212.0	42.9
W24X94	35	45.8	9.4	101.1	17.4	166.6	35.1
W24X94	40	38.7	8.2	82.6	14.8	134.1	29.6
W24X94	45	33.4	7.2	69.3	12.9	110.6	25.5
W24X94	50	29.4	6.5	59.2	11.5	93.0	22.4
W24X84	1	122.6	120.3	122.6	122.1	122.6	122.2
W24X84	5	132.3	39.7	136.8	88.5	138.1	108.9
W24X84	10	165.3	27.6	235.6	66.6	242.8	109.3
W24X84	15	121.9	19.2	253.6	45.4	284.5	85.4
W24X84	20	87.5	14.4	205.5	32.1	296.3	64.0
W24X84	25	65.4	11.5	156.1	23.8	257.4	48.7
W24X84	30	51.2	9.5	120.0	18.8	201.2	38.5
W24X84	35	41.7	8.1	94.9	15.5	158.4	31.4
W24X84	40	35.1	7.1	77.2	13.2	127.4	26.4
W24X84	45	30.2	6.2	64.5	11.5	104.8	22.7
W24X84	50	26.5	5.6	55.0	10.2	88.0	19.9
W24X76	1	112.4	110.1	112.4	112.0	112.4	112.0
W24X76	5	120.3	35.7	123.9	80.8	125.3	99.0
W24X76	10	152.6	24.7	211.9	61.3	217.1	100.8
W24X76	15	114.0	17.2	233.2	41.9	250.8	79.1
W24X76	20	81.9	12.8	194.0	29.7	260.9	59.3
W24X76	25	60.9	10.2	148.3	21.9	242.9	45.1
W24X76	30	47.5	8.4	114.0	17.2	192.2	35.5
W24X76	35	38.5	7.2	89.9	14.2	151.6	28.9
W24X76	40	32.2	6.3	72.9	12.0	121.9	24.3
W24X76	45	27.6	5.5	60.6	10.5	100.0	20.8
W24X76	50	24.2	5.0	51.5	9.2	83.8	18.2
W24X68	1	106.9	104.6	106.9	106.4	106.9	106.5
W24X68	5	111.8	32.6	114.8	75.5	116.5	92.4
W24X68	10	141.3	22.3	192.6	57.2	196.3	94.8
W24X68	15	106.5	15.4	212.4	39.1	221.2	74.3
W24X68	20	76.5	11.4	182.8	27.6	227.7	55.6
W24X68	25	56.6	9.1	140.5	20.2	224.4	42.1
W24X68	30	43.8	7.5	108.0	15.9	182.9	33.0
W24X68	35	35.3	6.4	84.9	13.0	144.6	26.8
W24X68	40	29.4	5.5	68.6	11.0	116.1	22.4
W24X68	45	25.1	4.9	56.8	9.6	95.1	19.2
W24X68	50	21.9	4.4	48.0	8.4	79.4	16.8

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	 Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	 Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	 Tapered Buckling Stress [ksi]
W24X62	1	139.7	136.2	139.7	139.0	139.7	139.1
W24X62	5	130.5	36.6	140.6	82.9	145.9	110.1
W24X62	10	116.0	21.6	209.0	52.7	234.6	94.2
W24X62	15	77.6	14.3	178.2	33.5	254.7	66.5
W24X62	20	53.6	10.5	128.7	22.5	211.1	47.0
W24X62	25	39.6	8.2	93.5	16.7	157.2	34.9
W24X62	30	30.9	6.8	70.6	13.2	118.2	27.3
W24X62	35	25.2	5.8	55.5	11.0	91.7	22.2
W24X62	40	21.2	5.0	45.2	9.3	73.3	18.6
W24X62	45	18.3	4.4	37.8	8.1	60.2	16.0
W24X62	50	16.1	4.0	32.1	7.2	50.4	14.0
W24X55	1	124.0	121.1	124.0	123.4	124.0	123.5
W24X55	5	114.2	32.0	121.7	73.4	126.3	96.7
W24X55	10	105.3	18.9	184.2	47.4	200.8	84.6
W24X55	15	71.5	12.5	163.6	30.4	220.0	60.2
W24X55	20	49.4	9.2	120.3	20.3	194.9	42.7
W24X55	25	36.3	7.2	87.7	15.0	147.9	31.7
W24X55	30	28.1	5.9	66.1	11.9	111.7	24.7
W24X55	35	22.8	5.0	51.8	9.8	86.6	20.0
W24X55	40	19.1	4.3	41.9	8.3	69.1	16.8
W24X55	45	16.4	3.8	34.9	7.3	56.6	14.4
W24X55	50	14.4	3.4	29.7	6.4	47.4	12.6
W21X201	1	319.9	309.4	320.0	318.9	320.0	318.7
W21X201	5	446.1	128.1	465.8	280.8	468.0	358.0
W21X201	10	486.1	92.7	779.3	201.9	815.2	336.1
W21X201	15	342.4	65.4	710.4	135.6	927.3	253.5
W21X201	20	246.1	49.6	535.6	95.1	830.3	187.8
W21X201	25	187.7	39.8	401.9	72.0	639.4	143.8
W21X201	30	150.6	33.2	312.1	57.8	492.9	114.9
W21X201	35	125.3	28.4	251.3	48.4	390.3	95.1
W21X201	40	107.2	24.9	205.3	41.6	316.1	81.0
W21X201	45	93.6	22.1	171.9	36.5	262.1	70.5
W21X201	50	83.1	19.9	147.3	32.5	222.3	62.4
W21X182	1	273.4	264.6	273.5	272.5	273.5	272.4
W21X182	5	384.6	110.3	398.3	243.7	399.4	307.4
W21X182	10	445.3	81.1	677.7	179.2	696.1	295.5
W21X182	15	317.8	57.3	657.2	121.2	797.3	225.7
W21X182	20	228.4	43.5	503.9	85.5	775.9	168.2
W21X182	25	173.6	34.9	379.3	64.5	607.2	129.0
W21X182	30	138.7	29.1	294.0	51.7	469.7	102.9
W21X182	35	115.1	24.9	235.9	43.1	371.6	85.1
W21X182	40	98.3	21.8	194.3	37.0	301.6	72.3
W21X182	45	85.6	19.4	162.0	32.4	249.4	62.9
W21X182	50	75.9	17.4	138.3	28.9	210.8	55.6

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W21X166	1	225.3	218.1	225.3	224.5	225.3	224.5
W21X166	5	319.3	93.0	328.0	205.9	328.3	255.7
W21X166	10	403.2	70.4	566.8	156.7	575.8	254.2
W21X166	15	294.7	50.1	598.0	107.3	666.0	197.7
W21X166	20	212.7	38.1	472.1	76.5	692.5	149.0
W21X166	25	161.4	30.6	358.2	57.6	574.7	114.6
W21X166	30	128.7	25.5	277.9	46.0	447.8	91.5
W21X166	35	106.5	21.9	222.6	38.4	354.7	75.6
W21X166	40	90.7	19.1	183.7	32.9	287.9	64.2
W21X166	45	78.9	17.0	153.7	28.8	238.4	55.8
W21X166	50	69.8	15.3	130.8	25.6	201.0	49.3
W21X147	1	229.3	220.8	229.3	228.1	229.3	228.3
W21X147	5	318.4	87.9	328.2	202.8	328.7	253.1
W21X147	10	386.4	63.9	545.0	151.4	554.0	250.1
W21X147	15	279.7	44.9	571.6	102.3	617.0	192.7
W21X147	20	199.4	33.9	457.8	72.3	626.8	143.5
W21X147	25	149.5	27.1	346.0	53.9	556.8	109.3
W21X147	30	117.9	22.6	266.3	42.9	436.4	86.6
W21X147	35	96.8	19.3	211.5	35.5	344.6	71.1
W21X147	40	81.9	16.9	173.2	30.4	278.3	60.0
W21X147	45	70.9	15.0	145.5	26.5	230.1	51.9
W21X147	50	62.5	13.5	124.0	23.5	193.5	45.6
W21X132	1	189.5	182.6	189.5	188.5	189.6	188.6
W21X132	5	266.8	74.1	273.4	172.2	273.4	212.0
W21X132	10	347.6	55.1	455.1	132.4	460.3	216.0
W21X132	15	258.3	38.9	497.5	90.5	512.9	169.1
W21X132	20	185.0	29.5	425.4	64.5	521.7	127.0
W21X132	25	138.5	23.6	325.5	48.0	507.4	97.0
W21X132	30	108.8	19.6	251.0	38.0	413.3	76.8
W21X132	35	89.0	16.8	199.1	31.5	327.6	62.9
W21X132	40	75.1	14.7	162.5	26.8	264.6	53.1
W21X132	45	64.8	13.0	136.1	23.4	218.4	45.8
W21X132	50	57.0	11.7	116.4	20.8	183.9	40.3
W21X122	1	163.1	157.3	163.2	162.3	163.2	162.4
W21X122	5	229.8	64.7	234.7	151.1	234.4	183.4
W21X122	10	319.2	49.2	391.5	119.7	395.0	192.7
W21X122	15	244.8	35.0	433.9	82.8	440.7	153.4
W21X122	20	176.8	26.5	402.4	59.7	448.3	116.3
W21X122	25	132.2	21.2	314.2	44.3	443.5	89.2
W21X122	30	103.5	17.7	243.4	35.0	399.7	70.6
W21X122	35	84.4	15.1	192.9	28.9	319.9	57.8
W21X122	40	70.9	13.2	157.2	24.6	258.7	48.7
W21X122	45	61.1	11.7	131.3	21.4	213.3	42.0
W21X122	50	53.6	10.5	112.0	19.0	179.3	36.8

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W21X111	1	138.9	133.8	138.9	138.1	138.9	138.2
W21X111	5	196.6	55.7	200.2	131.0	199.8	157.3
W21X111	10	286.2	43.1	333.3	106.4	335.6	169.6
W21X111	15	226.8	30.8	369.8	74.4	373.4	136.9
W21X111	20	165.0	23.3	364.3	53.7	379.0	104.5
W21X111	25	123.3	18.7	295.9	40.0	374.9	80.3
W21X111	30	96.3	15.6	230.3	31.6	364.8	63.6
W21X111	35	78.2	13.3	182.6	26.0	304.4	52.0
W21X111	40	65.5	11.6	148.5	22.1	246.7	43.7
W21X111	45	56.2	10.3	123.7	19.2	203.4	37.6
W21X111	50	49.2	9.3	105.2	17.0	170.7	33.0
W21X101	1	115.7	111.6	115.7	115.0	115.7	115.1
W21X101	5	164.1	47.4	166.6	111.9	166.1	132.1
W21X101	10	253.1	37.9	279.3	94.4	279.8	148.0
W21X101	15	212.9	27.3	310.4	67.2	312.4	122.1
W21X101	20	157.2	20.8	314.0	48.8	317.6	94.5
W21X101	25	117.8	16.6	282.5	36.7	314.6	73.0
W21X101	30	91.8	13.8	223.1	28.8	309.6	57.9
W21X101	35	74.3	11.8	177.4	23.7	293.8	47.3
W21X101	40	62.0	10.3	144.1	20.1	241.4	39.7
W21X101	45	53.0	9.2	119.8	17.4	199.3	34.1
W21X101	50	46.3	8.2	101.6	15.4	167.2	29.9
W21X93	1	209.9	201.6	209.9	208.5	209.9	208.7
W21X93	5	258.3	66.5	282.4	150.2	288.1	204.4
W21X93	10	218.9	40.8	411.1	94.2	479.9	168.4
W21X93	15	142.9	27.4	324.7	59.5	493.2	117.4
W21X93	20	99.4	20.4	228.3	40.5	374.8	83.1
W21X93	25	74.5	16.2	165.6	30.5	272.4	62.3
W21X93	30	59.2	13.5	126.2	24.4	204.4	49.1
W21X93	35	48.9	11.5	100.4	20.4	159.3	40.4
W21X93	40	41.6	10.0	81.9	17.5	128.0	34.2
W21X93	45	36.2	8.9	68.2	15.3	105.4	29.6
W21X93	50	32.1	8.0	58.2	13.6	88.9	26.1
W21X83	1	166.4	159.9	166.4	165.3	166.4	165.5
W21X83	5	212.5	54.8	226.7	124.3	229.8	165.7
W21X83	10	197.5	34.5	352.1	81.1	387.3	142.6
W21X83	15	131.4	23.4	297.8	52.4	426.5	101.8
W21X83	20	91.5	17.4	213.8	35.5	349.9	72.7
W21X83	25	68.4	13.8	155.7	26.6	258.4	54.6
W21X83	30	54.0	11.5	118.4	21.3	194.4	43.0
W21X83	35	44.5	9.8	93.9	17.7	151.3	35.3
W21X83	40	37.8	8.5	77.0	15.2	121.7	29.9
W21X83	45	32.8	7.6	64.1	13.3	100.0	25.8
W21X83	50	28.9	6.8	54.4	11.8	84.0	22.8

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W21X73	1	131.0	126.0	131.0	130.1	131.0	130.3
W21X73	5	171.9	44.7	180.2	102.1	181.8	133.2
W21X73	10	176.3	29.0	292.6	69.4	307.1	120.0
W21X73	15	120.2	19.7	269.6	45.3	344.5	87.6
W21X73	20	83.9	14.7	199.0	31.0	321.2	63.2
W21X73	25	62.4	11.7	145.9	23.2	243.6	47.5
W21X73	30	49.1	9.7	110.8	18.4	184.3	37.4
W21X73	35	40.2	8.3	87.5	15.3	143.5	30.7
W21X73	40	34.0	7.2	71.5	13.1	115.1	25.9
W21X73	45	29.4	6.4	60.0	11.4	94.8	22.4
W21X73	50	25.9	5.7	50.8	10.2	79.4	19.7
W21X68	1	119.2	114.6	119.2	118.3	119.2	118.4
W21X68	5	156.6	40.7	163.4	93.8	164.7	121.4
W21X68	10	166.1	26.6	266.6	64.5	276.4	111.2
W21X68	15	114.4	18.1	255.4	42.3	309.3	81.8
W21X68	20	79.8	13.5	191.2	29.0	303.9	59.2
W21X68	25	59.2	10.7	140.5	21.6	235.3	44.5
W21X68	30	46.4	8.9	106.6	17.2	178.6	35.0
W21X68	35	37.9	7.6	84.0	14.2	139.0	28.6
W21X68	40	32.0	6.6	68.4	12.2	111.3	24.1
W21X68	45	27.6	5.8	57.2	10.6	91.5	20.8
W21X68	50	24.3	5.2	48.8	9.4	76.8	18.3
W21X62	1	106.4	102.8	106.4	105.6	106.4	105.7
W21X62	5	139.2	36.2	144.5	84.4	145.5	108.2
W21X62	10	153.9	23.8	235.7	59.0	241.7	101.4
W21X62	15	107.6	16.2	237.5	38.9	268.7	75.3
W21X62	20	75.2	12.0	181.9	26.8	273.8	54.6
W21X62	25	55.5	9.6	134.4	19.9	225.2	41.0
W21X62	30	43.2	7.9	101.9	15.7	172.1	32.2
W21X62	35	35.2	6.7	80.0	13.0	134.0	26.3
W21X62	40	29.5	5.9	64.9	11.1	107.2	22.1
W21X62	45	25.4	5.2	54.1	9.7	87.9	19.0
W21X62	50	22.3	4.7	46.1	8.6	73.6	16.7
W21X55	1	100.7	97.1	100.7	99.9	100.7	99.9
W21X55	5	128.3	32.7	133.2	78.5	134.2	100.5
W21X55	10	142.4	21.2	210.8	54.8	214.5	95.1
W21X55	15	100.3	14.3	218.4	36.1	232.3	70.5
W21X55	20	69.8	10.6	171.8	24.7	235.6	50.9
W21X55	25	51.2	8.4	127.2	18.3	212.8	38.0
W21X55	30	39.6	7.0	96.1	14.4	163.9	29.7
W21X55	35	31.9	5.9	75.2	11.9	127.6	24.2
W21X55	40	26.7	5.2	60.6	10.1	101.8	20.3
W21X55	45	22.9	4.6	50.3	8.8	83.2	17.4
W21X55	50	20.0	4.1	42.7	7.8	69.5	15.2

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W21X48	1	95.5	91.6	95.6	94.7	95.6	94.7
W21X48	5	116.8	29.2	121.5	72.3	122.4	93.0
W21X48	10	128.8	18.6	182.2	50.2	183.9	88.2
W21X48	15	91.3	12.5	188.3	32.9	191.2	65.0
W21X48	20	63.3	9.2	157.7	22.4	190.0	46.6
W21X48	25	46.0	7.3	117.0	16.5	186.8	34.7
W21X48	30	35.3	6.0	88.2	13.0	151.4	27.0
W21X48	35	28.3	5.1	68.7	10.7	117.9	21.9
W21X48	40	23.5	4.4	55.2	9.0	93.9	18.3
W21X48	45	20.0	3.9	45.5	7.8	76.5	15.7
W21X48	50	17.4	3.5	38.4	6.9	63.7	13.7
W21X57	1	126.5	121.4	126.5	125.5	126.6	125.6
W21X57	5	149.6	38.0	164.1	85.5	168.1	117.3
W21X57	10	123.2	22.4	236.1	52.5	276.1	94.9
W21X57	15	79.8	14.9	184.5	32.6	283.0	65.2
W21X57	20	55.1	11.0	128.7	22.1	213.6	45.8
W21X57	25	41.0	8.7	92.8	16.6	154.3	34.2
W21X57	30	32.4	7.2	70.3	13.3	115.2	26.9
W21X57	35	26.7	6.1	55.7	11.1	89.4	22.0
W21X57	40	22.6	5.3	45.6	9.5	71.8	18.6
W21X57	45	19.6	4.7	37.8	8.3	58.9	16.1
W21X57	50	17.3	4.2	32.2	7.4	49.5	14.2
W21X50	1	121.1	116.1	121.1	120.0	121.1	120.2
W21X50	5	137.9	34.2	152.0	79.5	156.0	109.8
W21X50	10	112.2	19.7	216.2	48.2	247.3	88.5
W21X50	15	72.3	13.0	170.5	29.7	255.9	60.2
W21X50	20	49.4	9.5	118.8	20.0	198.0	41.9
W21X50	25	36.4	7.5	85.1	15.0	143.3	31.1
W21X50	30	28.5	6.2	64.1	11.9	106.7	24.3
W21X50	35	23.3	5.3	50.4	9.9	82.4	19.9
W21X50	40	19.7	4.6	41.1	8.5	65.9	16.7
W21X50	45	17.0	4.1	34.3	7.4	54.1	14.4
W21X50	50	15.0	3.6	29.0	6.6	45.3	12.7
W21X44	1	109.7	105.2	109.7	108.7	109.7	108.8
W21X44	5	122.1	30.1	133.5	71.4	136.7	98.2
W21X44	10	102.4	17.3	192.5	43.7	211.0	80.5
W21X44	15	66.6	11.3	157.8	27.0	222.2	54.9
W21X44	20	45.3	8.3	111.1	18.1	184.5	38.2
W21X44	25	33.1	6.5	79.6	13.5	135.1	28.2
W21X44	30	25.7	5.4	59.7	10.7	100.6	22.0
W21X44	35	20.9	4.6	46.7	8.9	77.6	17.9
W21X44	40	17.6	4.0	37.8	7.6	61.8	15.1
W21X44	45	15.1	3.5	31.6	6.6	50.6	13.0
W21X44	50	13.3	3.1	26.8	5.9	42.4	11.4

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W18X311	1	837.3	810.8	837.9	835.3	837.7	833.9
W18X311	5	1153.8	347.8	1455.1	718.1	1519.0	1030.9
W18X311	10	802.7	216.6	1452.4	421.1	1623.8	757.5
W18X311	15	531.1	148.7	1037.2	259.6	1471.0	501.4
W18X311	20	386.4	112.3	731.2	184.4	1087.1	356.1
W18X311	25	301.7	90.0	532.2	143.1	792.5	272.8
W18X311	30	247.0	75.1	414.0	117.0	609.0	220.5
W18X311	35	209.0	64.4	337.7	99.0	489.8	185.1
W18X311	40	181.1	56.3	284.9	85.8	408.1	159.6
W18X311	45	159.8	50.1	246.4	75.8	349.2	140.3
W18X311	50	143.0	45.0	217.1	67.8	305.0	125.2
W18X283	1	751.7	725.1	752.2	749.6	752.0	748.1
W18X283	5	1063.6	308.5	1316.7	644.1	1362.5	919.4
W18X283	10	751.2	193.0	1382.0	380.9	1582.9	686.1
W18X283	15	495.3	132.4	984.6	235.5	1417.8	457.4
W18X283	20	358.9	100.0	695.1	166.7	1041.4	324.8
W18X283	25	279.4	80.1	506.2	129.0	759.5	248.3
W18X283	30	228.2	66.8	391.5	105.3	580.7	200.3
W18X283	35	192.8	57.3	317.6	89.0	464.8	167.8
W18X283	40	166.9	50.1	266.9	77.1	385.5	144.5
W18X283	45	147.1	44.5	230.0	68.1	328.6	126.9
W18X283	50	131.5	40.1	202.2	60.9	286.0	113.2
W18X258	1	653.5	629.0	653.8	651.6	653.6	650.2
W18X258	5	963.0	269.7	1158.6	567.0	1188.4	802.1
W18X258	10	699.9	170.7	1296.5	340.5	1514.1	611.2
W18X258	15	461.5	117.3	929.8	211.9	1351.5	412.2
W18X258	20	333.5	88.6	656.1	149.6	993.2	293.4
W18X258	25	259.0	71.0	480.9	115.6	726.0	224.1
W18X258	30	211.2	59.2	370.0	94.2	552.9	180.6
W18X258	35	178.2	50.7	298.9	79.6	440.7	151.2
W18X258	40	154.0	44.4	250.2	68.9	364.1	130.0
W18X258	45	135.7	39.4	215.0	60.8	309.3	114.1
W18X258	50	121.2	35.5	188.5	54.4	268.4	101.7
W18X234	1	554.6	533.5	554.8	552.9	554.7	551.8
W18X234	5	857.0	232.4	995.4	491.7	1013.7	687.4
W18X234	10	648.9	149.5	1202.4	301.3	1423.2	537.2
W18X234	15	428.9	103.1	874.4	189.2	1278.6	367.4
W18X234	20	309.1	77.9	617.9	133.2	944.7	262.5
W18X234	25	239.5	62.4	456.6	102.7	693.4	200.6
W18X234	30	194.9	52.0	349.5	83.7	526.2	161.5
W18X234	35	164.2	44.6	281.1	70.6	417.8	135.1
W18X234	40	141.8	39.0	234.4	61.1	343.8	116.1
W18X234	45	124.8	34.7	200.7	53.9	291.0	101.8
W18X234	50	111.4	31.2	175.5	48.2	251.7	90.7

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W18X211	1	481.0	460.2	481.1	479.5	481.1	478.6
W18X211	5	767.1	201.8	868.2	431.9	881.1	599.0
W18X211	10	598.8	130.8	1112.3	268.0	1323.0	476.3
W18X211	15	395.3	90.1	819.3	169.2	1205.1	328.7
W18X211	20	283.6	68.1	578.8	118.7	894.5	235.1
W18X211	25	218.9	54.6	430.4	91.3	656.8	179.3
W18X211	30	177.7	45.5	328.1	74.2	498.2	144.1
W18X211	35	149.4	39.0	262.4	62.5	393.6	120.3
W18X211	40	128.8	34.1	217.7	54.1	322.4	103.2
W18X211	45	113.2	30.3	185.7	47.6	271.7	90.4
W18X211	50	101.0	27.2	161.8	42.6	234.2	80.5
W18X192	1	404.6	386.6	404.6	403.3	404.6	402.5
W18X192	5	670.8	173.2	734.0	372.8	742.8	510.3
W18X192	10	553.4	114.3	1016.9	236.9	1183.4	416.7
W18X192	15	367.2	79.0	768.5	151.3	1129.7	291.9
W18X192	20	262.8	59.7	545.6	105.8	849.9	209.8
W18X192	25	202.2	47.9	404.9	81.2	625.3	160.1
W18X192	30	163.8	39.9	311.0	65.9	475.5	128.5
W18X192	35	137.4	34.2	247.5	55.5	374.4	107.2
W18X192	40	118.3	29.9	204.5	47.9	305.4	91.9
W18X192	45	103.9	26.6	173.7	42.2	256.4	80.4
W18X192	50	92.6	23.9	150.9	37.7	220.2	71.6
W18X175	1	358.2	342.2	358.2	356.9	358.2	356.3
W18X175	5	607.5	153.1	655.4	333.7	662.8	454.9
W18X175	10	512.1	101.0	939.1	213.4	1062.3	375.0
W18X175	15	339.0	69.7	719.9	136.6	1060.3	263.7
W18X175	20	241.4	52.7	511.1	95.1	802.6	189.4
W18X175	25	184.9	42.2	377.7	72.8	590.3	144.2
W18X175	30	149.3	35.2	291.8	58.9	449.4	115.5
W18X175	35	125.0	30.1	231.1	49.6	352.4	96.1
W18X175	40	107.4	26.3	190.1	42.8	286.4	82.3
W18X175	45	94.2	23.4	160.9	37.7	239.5	72.0
W18X175	50	83.9	21.0	139.3	33.6	205.0	63.9
W18X158	1	305.0	291.3	305.0	303.9	305.0	303.4
W18X158	5	531.0	131.9	560.0	290.4	565.8	391.7
W18X158	10	471.2	88.1	845.7	189.2	911.9	330.0
W18X158	15	313.4	60.9	672.0	122.4	975.8	234.7
W18X158	20	222.3	46.0	480.1	84.8	758.2	169.0
W18X158	25	169.6	36.8	354.1	64.7	560.0	128.6
W18X158	30	136.4	30.7	274.2	52.3	426.1	102.8
W18X158	35	113.9	26.3	217.4	43.9	334.3	85.4
W18X158	40	97.7	23.0	177.9	37.9	270.6	73.0
W18X158	45	85.6	20.4	149.9	33.3	225.4	63.8
W18X158	50	76.1	18.4	129.3	29.7	192.2	56.6

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W18X143	1	250.8	239.5	250.8	249.9	250.8	249.6
W18X143	5	449.1	111.9	461.7	247.3	466.2	328.2
W18X143	10	432.4	76.6	734.4	166.2	759.3	285.6
W18X143	15	291.3	53.2	624.9	109.1	834.4	206.7
W18X143	20	206.5	40.2	452.6	75.6	715.3	149.9
W18X143	25	157.0	32.2	334.3	57.5	533.5	114.2
W18X143	30	125.9	26.9	258.2	46.4	406.3	91.3
W18X143	35	104.9	23.0	206.4	38.9	319.7	75.8
W18X143	40	89.8	20.1	168.2	33.5	258.0	64.7
W18X143	45	78.5	17.9	141.2	29.4	214.1	56.4
W18X143	50	69.7	16.1	121.2	26.3	181.9	50.1
W18X130	1	217.1	207.2	217.1	216.3	217.2	216.1
W18X130	5	393.9	98.1	399.4	219.5	403.3	287.4
W18X130	10	405.8	68.3	644.3	151.1	655.9	257.0
W18X130	15	276.6	47.5	593.5	99.6	723.0	188.4
W18X130	20	195.6	36.0	436.5	69.3	686.3	137.3
W18X130	25	148.0	28.8	322.7	52.5	519.7	104.5
W18X130	30	118.2	24.0	248.4	42.3	396.3	83.4
W18X130	35	98.2	20.6	199.0	35.4	311.8	69.0
W18X130	40	83.8	18.0	162.5	30.4	251.6	58.8
W18X130	45	73.1	16.0	135.8	26.7	208.1	51.3
W18X130	50	64.8	14.4	116.1	23.8	176.1	45.4
W18X119	1	222.6	211.7	222.6	221.7	222.7	221.4
W18X119	5	395.4	94.0	405.4	218.4	408.7	288.0
W18X119	10	393.3	63.5	623.9	147.6	635.5	255.4
W18X119	15	265.1	43.8	579.1	96.1	678.1	185.1
W18X119	20	185.2	33.0	426.2	66.3	656.3	133.4
W18X119	25	138.8	26.3	312.9	50.0	509.4	100.7
W18X119	30	110.1	21.9	239.1	40.0	387.7	79.8
W18X119	35	90.9	18.8	190.2	33.4	303.6	65.8
W18X119	40	77.3	16.4	156.5	28.7	245.1	55.8
W18X119	45	67.2	14.5	130.1	25.1	201.8	48.5
W18X119	50	59.5	13.1	110.7	22.4	170.0	42.8
W18X106	1	185.2	175.8	185.2	184.3	185.2	184.1
W18X106	5	334.2	79.1	338.8	186.6	341.6	243.1
W18X106	10	355.0	54.1	518.7	128.9	525.1	221.4
W18X106	15	242.9	37.4	519.0	84.4	554.8	162.4
W18X106	20	169.4	28.1	396.1	58.5	545.9	117.4
W18X106	25	126.2	22.5	291.9	43.9	475.9	88.6
W18X106	30	99.5	18.7	222.4	35.1	365.0	70.0
W18X106	35	81.8	16.0	176.1	29.2	285.6	57.6
W18X106	40	69.3	14.0	144.2	25.0	229.9	48.8
W18X106	45	60.1	12.4	121.0	21.9	189.6	42.3
W18X106	50	53.1	11.2	102.5	19.5	159.2	37.3

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W18X97	1	151.8	144.2	151.8	151.1	151.8	151.0
W18X97	5	277.6	67.2	278.5	158.7	280.9	203.2
W18X97	10	322.5	47.3	433.2	113.5	436.9	191.7
W18X97	15	226.4	32.9	455.5	75.2	467.4	143.3
W18X97	20	158.6	24.8	371.8	52.6	465.6	104.6
W18X97	25	117.9	19.8	276.6	39.3	443.2	79.0
W18X97	30	92.7	16.5	211.0	31.4	348.3	62.5
W18X97	35	75.9	14.1	166.8	26.1	273.2	51.3
W18X97	40	64.2	12.3	136.2	22.3	219.7	43.4
W18X97	45	55.6	10.9	114.3	19.5	181.2	37.6
W18X97	50	49.0	9.8	97.3	17.3	152.1	33.1
W18X86	1	125.0	118.7	125.0	124.4	125.0	124.3
W18X86	5	229.4	56.4	229.4	135.1	231.0	170.0
W18X86	10	290.7	40.7	354.5	100.0	356.7	166.7
W18X86	15	211.6	28.4	374.4	67.0	378.0	126.9
W18X86	20	148.8	21.4	347.1	47.3	373.2	93.4
W18X86	25	110.2	17.1	264.4	35.2	363.4	70.6
W18X86	30	86.1	14.2	202.0	27.9	334.1	55.7
W18X86	35	70.1	12.2	159.3	23.2	264.3	45.6
W18X86	40	59.0	10.6	129.5	19.8	212.5	38.5
W18X86	45	50.9	9.4	108.1	17.3	174.8	33.3
W18X86	50	44.7	8.5	92.3	15.3	146.8	29.2
W18X76	1	99.4	94.4	99.4	99.0	99.5	98.9
W18X76	5	183.1	46.1	183.1	111.6	184.1	137.8
W18X76	10	251.4	34.2	283.3	85.7	283.8	140.7
W18X76	15	192.9	24.0	298.4	58.3	300.0	109.4
W18X76	20	136.9	18.1	292.4	41.6	295.6	81.2
W18X76	25	101.1	14.5	246.4	30.8	287.9	61.6
W18X76	30	78.6	12.0	189.4	24.4	281.0	48.5
W18X76	35	63.7	10.3	149.1	20.1	249.6	39.6
W18X76	40	53.3	9.0	120.8	17.2	201.2	33.4
W18X76	45	45.8	8.0	100.5	14.9	165.3	28.7
W18X76	50	40.1	7.2	85.4	13.2	138.5	25.2
W18X71	1	180.1	170.0	180.1	179.2	180.1	179.0
W18X71	5	275.8	62.1	310.3	142.3	315.8	202.0
W18X71	10	206.2	36.7	414.7	83.9	496.3	154.4
W18X71	15	130.0	24.5	299.8	51.3	473.5	103.3
W18X71	20	89.8	18.3	204.2	35.2	337.0	72.1
W18X71	25	67.5	14.5	146.9	26.7	240.0	54.0
W18X71	30	53.8	12.1	111.9	21.5	179.0	42.8
W18X71	35	44.6	10.3	88.9	18.0	139.2	35.3
W18X71	40	38.1	9.0	72.1	15.5	111.6	30.1
W18X71	45	33.2	8.0	60.3	13.6	92.2	26.2
W18X71	50	29.4	7.2	51.7	12.2	78.1	23.1

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W18X65	1	148.5	139.9	148.5	147.7	148.5	147.6
W18X65	5	238.2	53.5	258.9	122.8	262.4	171.2
W18X65	10	191.4	32.3	371.4	74.7	415.8	135.7
W18X65	15	122.1	21.7	282.4	46.4	433.3	92.4
W18X65	20	84.3	16.2	194.7	31.8	321.9	64.9
W18X65	25	63.1	12.9	140.1	24.0	230.9	48.6
W18X65	30	50.1	10.7	106.5	19.3	172.3	38.5
W18X65	35	41.5	9.1	84.7	16.2	134.0	31.8
W18X65	40	35.3	8.0	68.9	13.9	107.4	27.0
W18X65	45	30.8	7.1	57.4	12.2	88.4	23.5
W18X65	50	27.2	6.3	49.0	10.9	74.6	20.7
W18X60	1	125.5	118.3	125.5	124.8	125.5	124.7
W18X60	5	209.2	46.8	222.3	107.9	224.9	148.5
W18X60	10	178.0	28.7	332.7	67.2	355.7	120.9
W18X60	15	114.7	19.3	265.7	42.2	384.4	83.4
W18X60	20	79.1	14.4	185.1	28.8	306.2	58.8
W18X60	25	59.0	11.5	133.3	21.7	221.3	44.1
W18X60	30	46.7	9.5	101.1	17.5	165.1	34.8
W18X60	35	38.5	8.1	80.1	14.6	128.3	28.7
W18X60	40	32.8	7.1	65.6	12.5	102.9	24.4
W18X60	45	28.5	6.3	54.5	11.0	84.5	21.2
W18X60	50	25.2	5.6	46.3	9.8	71.2	18.7
W18X55	1	114.7	108.0	114.7	114.0	114.7	114.0
W18X55	5	190.9	42.4	201.4	99.2	203.5	135.7
W18X55	10	167.6	26.0	303.9	62.4	317.9	112.3
W18X55	15	108.5	17.5	253.1	39.4	343.5	77.8
W18X55	20	74.5	13.0	177.6	26.8	293.8	54.8
W18X55	25	55.3	10.4	127.7	20.1	213.8	41.0
W18X55	30	43.5	8.6	96.5	16.1	159.5	32.3
W18X55	35	35.8	7.3	76.2	13.4	123.6	26.5
W18X55	40	30.3	6.4	62.3	11.5	99.1	22.5
W18X55	45	26.3	5.7	51.9	10.1	81.3	19.5
W18X55	50	23.2	5.1	44.0	9.0	68.2	17.2
W18X50	1	96.2	90.5	96.2	95.6	96.2	95.5
W18X50	5	163.2	36.5	169.2	86.2	170.7	115.9
W18X50	10	154.7	22.8	259.8	55.8	265.9	99.3
W18X50	15	101.8	15.4	236.2	35.7	288.0	69.9
W18X50	20	69.9	11.5	169.2	24.2	276.1	49.5
W18X50	25	51.6	9.1	122.1	18.1	205.6	37.0
W18X50	30	40.4	7.5	92.0	14.5	153.9	29.1
W18X50	35	33.1	6.4	72.4	12.0	119.1	23.9
W18X50	40	28.0	5.6	59.0	10.3	95.2	20.2
W18X50	45	24.2	5.0	49.4	9.0	78.3	17.5
W18X50	50	21.3	4.5	41.8	8.0	65.5	15.4

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W18X46	1	113.7	106.9	113.7	112.9	113.7	112.8
W18X46	5	169.0	37.7	191.7	85.5	195.6	122.7
W18X46	10	123.0	21.5	252.5	49.5	306.5	91.7
W18X46	15	76.9	14.3	179.4	29.9	287.5	60.6
W18X46	20	52.9	10.6	121.3	20.5	201.8	42.1
W18X46	25	39.6	8.4	86.8	15.6	142.8	31.5
W18X46	30	31.4	6.9	65.9	12.5	106.1	24.9
W18X46	35	26.0	5.9	52.4	10.5	82.4	20.5
W18X46	40	22.2	5.2	42.4	9.0	65.9	17.5
W18X46	45	19.3	4.6	35.4	7.9	54.4	15.2
W18X46	50	17.1	4.1	30.3	7.1	45.9	13.4
W18X40	1	87.9	82.7	87.9	87.3	87.9	87.2
W18X40	5	138.2	30.6	150.4	70.0	152.5	98.3
W18X40	10	109.8	17.8	215.8	42.0	238.9	77.0
W18X40	15	69.6	11.8	164.0	25.8	251.1	51.8
W18X40	20	47.7	8.8	112.4	17.6	187.9	36.2
W18X40	25	35.4	6.9	80.4	13.3	134.2	27.0
W18X40	30	28.0	5.7	60.7	10.7	99.6	21.3
W18X40	35	23.0	4.9	48.1	8.9	77.2	17.5
W18X40	40	19.5	4.3	39.3	7.6	61.8	14.9
W18X40	45	17.0	3.8	32.6	6.7	50.7	12.9
W18X40	50	15.0	3.4	27.7	6.0	42.6	11.4
W18X35	1	89.2	83.4	89.2	88.0	89.2	88.1
W18X35	5	130.2	27.9	144.5	67.0	146.4	95.5
W18X35	10	100.8	15.8	200.0	39.4	216.8	73.8
W18X35	15	63.3	10.4	152.8	23.8	225.9	48.8
W18X35	20	42.7	7.6	104.2	16.1	175.4	33.7
W18X35	25	31.3	6.0	73.9	12.1	125.2	24.9
W18X35	30	24.5	5.0	55.3	9.7	92.5	19.5
W18X35	35	20.0	4.2	43.4	8.0	71.2	16.0
W18X35	40	16.9	3.7	35.3	6.9	56.8	13.5
W18X35	45	14.6	3.3	29.5	6.0	46.6	11.7
W18X35	50	12.9	2.9	24.9	5.4	39.0	10.3
W16X100	1	198.5	178.9	198.5	197.2	198.6	197.2
W16X100	5	414.7	91.1	427.4	209.7	430.1	285.7
W16X100	10	373.4	59.2	627.1	134.2	638.3	237.5
W16X100	15	243.5	40.5	542.3	86.0	672.5	166.3
W16X100	20	169.3	30.5	384.9	59.2	612.7	118.4
W16X100	25	127.4	24.4	280.1	44.9	454.2	89.4
W16X100	30	101.4	20.3	214.1	36.2	342.8	71.1
W16X100	35	84.1	17.4	170.9	30.3	268.3	58.9
W16X100	40	71.8	15.2	139.1	26.1	215.6	50.2
W16X100	45	62.6	13.5	116.1	22.9	178.1	43.7
W16X100	50	55.5	12.1	99.3	20.4	150.6	38.8

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W16X89	1	164.3	147.6	164.3	163.2	164.4	163.2
W16X89	5	349.9	77.3	354.1	180.7	355.8	242.0
W16X89	10	345.5	51.3	520.7	119.3	526.0	208.5
W16X89	15	229.0	35.2	503.7	77.1	551.1	148.4
W16X89	20	158.7	26.5	368.5	53.1	540.7	106.1
W16X89	25	118.6	21.2	268.7	40.1	439.1	80.0
W16X89	30	93.9	17.6	204.5	32.2	332.6	63.4
W16X89	35	77.5	15.1	162.4	26.9	259.8	52.4
W16X89	40	65.9	13.2	133.5	23.1	209.3	44.5
W16X89	45	57.3	11.7	110.9	20.3	172.2	38.7
W16X89	50	50.7	10.5	94.3	18.1	144.9	34.3
W16X77	1	124.3	111.6	124.3	123.4	124.3	123.4
W16X77	5	270.4	61.1	270.9	144.7	271.9	189.8
W16X77	10	301.4	41.7	400.6	99.4	401.4	170.8
W16X77	15	205.4	28.8	412.8	64.9	419.8	124.1
W16X77	20	142.3	21.7	335.6	45.1	413.1	89.3
W16X77	25	105.6	17.3	246.6	33.9	271.9	67.2
W16X77	30	83.1	14.4	187.3	27.1	401.4	53.2
W16X77	35	68.2	12.3	148.0	22.6	419.8	43.8
W16X77	40	57.7	10.8	120.9	19.4	413.1	37.1
W16X77	45	50.0	9.6	101.6	17.0	395.1	32.2
W16X77	50	44.1	8.6	86.0	15.1	308.7	28.5
W16X67	1	94.3	85.1	94.3	93.7	94.4	93.7
W16X67	5	207.2	48.6	207.0	116.2	207.6	148.9
W16X67	10	261.1	34.3	307.3	83.4	307.8	140.6
W16X67	15	186.1	23.8	321.2	55.2	323.2	104.6
W16X67	20	129.5	17.9	303.0	38.8	318.7	76.0
W16X67	25	95.6	14.4	228.9	29.0	310.8	57.3
W16X67	30	74.7	11.9	174.1	23.1	288.0	45.2
W16X67	35	61.0	10.2	137.0	19.2	226.8	37.1
W16X67	40	51.4	8.9	111.5	16.4	182.0	31.4
W16X67	45	44.4	7.9	93.2	14.4	149.7	27.2
W16X67	50	39.0	7.1	79.6	12.8	125.8	24.0
W16X57	1	153.0	135.4	153.0	151.7	153.0	151.7
W16X57	5	273.8	56.2	316.3	129.7	321.6	189.3
W16X57	10	190.0	32.4	396.6	73.5	474.2	137.5
W16X57	15	117.4	21.6	272.6	44.3	437.9	89.6
W16X57	20	80.9	16.1	182.7	30.6	301.7	62.3
W16X57	25	60.9	12.8	130.9	23.3	212.8	46.8
W16X57	30	48.6	10.6	99.8	18.9	158.3	37.2
W16X57	35	40.4	9.1	78.8	15.8	122.8	30.8
W16X57	40	34.5	7.9	64.1	13.7	98.6	26.3
W16X57	45	30.1	7.0	53.8	12.0	81.7	22.9
W16X57	50	26.8	6.3	46.2	10.7	69.3	20.3

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W16X50	1	121.9	108.5	121.9	120.8	121.9	120.8
W16X50	5	230.0	46.7	252.7	108.9	256.3	155.7
W16X50	10	173.3	27.4	347.0	63.9	378.1	118.1
W16X50	15	108.1	18.3	254.2	39.0	392.7	78.3
W16X50	20	74.1	13.7	172.1	26.8	286.3	54.6
W16X50	25	55.3	10.9	123.0	20.3	203.1	40.9
W16X50	30	43.9	9.0	93.2	16.4	150.8	32.4
W16X50	35	36.3	7.7	74.1	13.7	117.1	26.8
W16X50	40	31.0	6.7	60.1	11.8	93.7	22.8
W16X50	45	27.0	6.0	50.1	10.4	77.1	19.8
W16X50	50	23.9	5.4	42.8	9.3	65.1	17.6
W16X45	1	101.5	90.4	101.5	100.5	101.5	100.5
W16X45	5	199.0	40.0	212.4	94.5	214.7	133.3
W16X45	10	159.6	23.8	302.6	56.7	314.5	104.1
W16X45	15	100.4	15.9	237.7	35.0	333.7	69.8
W16X45	20	68.5	11.9	162.5	23.9	271.0	48.7
W16X45	25	50.8	9.4	115.9	18.1	193.6	36.4
W16X45	30	40.1	7.8	87.5	14.5	143.6	28.8
W16X45	35	33.1	6.7	69.2	12.1	111.2	23.7
W16X45	40	28.1	5.8	56.6	10.4	89.0	20.1
W16X45	45	24.4	5.2	47.0	9.2	73.0	17.5
W16X45	50	21.6	4.6	39.9	8.2	61.4	15.5
W16X40	1	79.3	71.3	79.3	78.6	79.3	78.6
W16X40	5	162.4	33.1	167.3	78.6	168.6	108.3
W16X40	10	145.0	20.2	244.8	49.1	248.5	88.7
W16X40	15	93.1	13.6	219.4	31.0	265.3	60.8
W16X40	20	63.4	10.1	153.5	21.0	253.2	42.6
W16X40	25	46.8	8.1	109.8	15.8	185.0	31.8
W16X40	30	36.7	6.7	82.6	12.7	137.6	25.1
W16X40	35	30.1	5.7	65.0	10.6	106.3	20.7
W16X40	40	25.5	5.0	53.1	9.1	85.0	17.5
W16X40	45	22.1	4.4	44.3	8.0	69.8	15.2
W16X40	50	19.5	4.0	37.5	7.1	58.4	13.4
W16X36	1	81.9	72.9	81.9	81.1	82.0	81.1
W16X36	5	157.7	31.0	165.0	77.1	166.7	107.5
W16X36	10	137.5	18.5	227.9	47.4	230.7	87.2
W16X36	15	87.6	12.3	209.8	29.5	239.5	59.0
W16X36	20	59.0	9.1	146.9	19.9	236.2	40.9
W16X36	25	43.1	7.2	104.4	14.9	177.9	30.3
W16X36	30	33.5	6.0	78.0	11.9	131.9	23.8
W16X36	35	27.3	5.1	60.9	9.9	101.5	19.5
W16X36	40	23.0	4.5	49.4	8.5	80.8	16.5
W16X36	45	19.8	4.0	41.2	7.4	66.1	14.2
W16X36	50	17.4	3.5	35.1	6.6	55.3	12.5

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W16X31	1	79.9	71.7	79.9	79.0	79.9	79.0
W16X31	5	140.1	27.8	159.1	65.4	161.6	95.8
W16X31	10	99.2	15.5	207.9	37.0	233.5	69.7
W16X31	15	60.9	10.2	146.3	22.1	233.5	45.1
W16X31	20	41.2	7.5	97.6	15.1	164.3	31.1
W16X31	25	30.6	6.0	69.1	11.5	115.4	23.1
W16X31	30	24.1	4.9	52.1	9.2	85.2	18.3
W16X31	35	19.9	4.2	41.2	7.7	65.8	15.1
W16X31	40	16.9	3.7	33.5	6.6	52.6	12.8
W16X31	45	14.7	3.3	27.8	5.8	43.2	11.1
W16X31	50	13.0	2.9	23.7	5.2	36.3	9.8
W16X26	1	73.2	65.5	73.2	72.2	73.2	72.3
W16X26	5	122.3	23.6	138.6	58.2	140.2	85.9
W16X26	10	88.4	13.0	180.9	32.9	190.6	62.8
W16X26	15	54.0	8.5	133.1	19.5	195.9	40.3
W16X26	20	36.1	6.2	88.8	13.2	150.9	27.5
W16X26	25	26.4	4.9	62.4	9.9	106.1	20.3
W16X26	30	20.6	4.1	46.5	8.0	78.0	16.0
W16X26	35	16.8	3.5	36.4	6.6	59.9	13.1
W16X26	40	14.2	3.0	29.6	5.7	47.7	11.1
W16X26	45	12.3	2.7	24.7	5.0	39.0	9.6
W16X26	50	10.8	2.4	20.9	4.4	32.6	8.4
W14X730	1	1536.5	1541.7	1571.5	1549.0	1595.8	1565.2
W14X730	5	1506.8	1192.4	1526.3	1502.9	1547.1	1513.6
W14X730	10	1481.9	785.0	1493.2	1368.4	1502.2	1486.7
W14X730	15	1446.8	548.4	1480.5	888.1	1486.9	1460.7
W14X730	20	1202.9	417.8	1469.3	648.2	1478.4	1190.6
W14X730	25	963.2	336.6	1429.7	510.3	1471.0	931.8
W14X730	30	799.5	281.6	1220.5	420.9	1458.3	763.9
W14X730	35	682.7	241.9	1026.4	358.3	1387.2	647.5
W14X730	40	595.6	212.0	883.6	311.9	1211.9	562.2
W14X730	45	528.2	188.7	775.6	276.2	1061.4	497.0
W14X730	50	474.5	169.9	691.3	247.9	942.7	444.8
W14X665	1	1515.1	1519.5	1550.2	1524.7	1574.6	1537.2
W14X665	5	1477.9	1078.0	1499.4	1473.3	1521.1	1486.4
W14X665	10	1451.7	706.4	1465.4	1261.1	1474.8	1458.0
W14X665	15	1399.8	492.8	1451.9	806.4	1459.0	1413.5
W14X665	20	1125.7	375.1	1438.9	587.0	1450.0	1091.0
W14X665	25	898.5	302.1	1377.9	461.5	1441.5	851.2
W14X665	30	744.7	252.7	1150.9	380.3	1424.1	696.7
W14X665	35	635.3	217.0	964.2	323.6	1320.1	589.9
W14X665	40	553.8	190.2	828.1	281.6	1141.5	511.8
W14X665	45	490.9	169.2	725.6	249.3	996.8	452.2
W14X665	50	440.8	152.4	645.8	223.6	883.6	405.1

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W14X605	1	1470.2	1434.2	1473.8	1466.2	1473.2	1462.3
W14X605	5	1465.7	963.4	1489.4	1458.4	1511.3	1476.4
W14X605	10	1437.2	628.2	1455.0	1143.4	1464.8	1445.5
W14X605	15	1340.6	437.5	1440.5	723.5	1448.6	1334.6
W14X605	20	1039.6	332.8	1423.5	525.2	1438.8	986.4
W14X605	25	826.9	267.9	1311.4	412.3	1428.1	767.4
W14X605	30	684.3	224.0	1071.3	339.5	1396.3	627.2
W14X605	35	583.1	192.4	893.7	288.6	1238.6	530.5
W14X605	40	508.0	168.6	765.6	251.1	1061.2	459.9
W14X605	45	450.0	150.0	669.6	222.2	923.8	406.1
W14X605	50	403.9	135.0	595.1	199.3	817.2	363.7
W14X550	1	1337.9	1298.7	1341.1	1334.7	1340.4	1330.8
W14X550	5	1422.7	854.2	1448.9	1409.7	1471.6	1434.9
W14X550	10	1391.6	556.7	1413.5	1031.1	1423.8	1401.2
W14X550	15	1258.3	387.4	1398.2	648.0	1407.0	1219.3
W14X550	20	961.7	294.6	1377.6	469.2	1396.5	889.9
W14X550	25	763.0	237.1	1235.9	367.8	1384.1	691.0
W14X550	30	630.4	198.2	1000.4	302.6	1338.1	563.9
W14X550	35	536.7	170.2	831.6	257.1	1160.9	476.5
W14X550	40	467.1	149.1	710.5	223.5	990.0	412.8
W14X550	45	413.6	132.6	620.1	197.8	859.5	364.3
W14X550	50	371.1	119.4	550.3	177.3	758.7	326.1
W14X500	1	1235.0	1193.5	1237.7	1232.0	1237.1	1228.7
W14X500	5	1401.6	766.0	1431.1	1374.3	1455.1	1415.7
W14X500	10	1365.6	497.9	1394.1	936.6	1405.1	1376.8
W14X500	15	1184.6	346.1	1377.4	587.1	1387.4	1118.9
W14X500	20	894.4	262.9	1350.7	423.7	1375.8	810.9
W14X500	25	707.5	211.5	1173.0	331.5	1360.3	628.0
W14X500	30	583.5	176.8	941.3	272.4	1290.0	511.6
W14X500	35	496.1	151.8	779.1	231.3	1096.3	431.7
W14X500	40	431.4	132.9	663.5	201.0	930.3	373.6
W14X500	45	381.7	118.2	577.8	177.8	805.1	329.4
W14X500	50	342.2	106.5	511.7	159.3	708.9	294.7
W14X455	1	1130.5	1088.9	1132.7	1127.6	1132.3	1124.6
W14X455	5	1367.2	684.7	1399.9	1308.9	1424.7	1382.5
W14X455	10	1325.5	443.7	1361.7	845.7	1373.1	1335.8
W14X455	15	1104.8	307.9	1343.6	529.7	1354.7	1018.6
W14X455	20	827.1	233.8	1309.7	381.1	1342.2	734.9
W14X455	25	652.3	188.0	1104.9	297.6	1323.1	567.9
W14X455	30	537.1	157.1	880.5	244.3	1227.3	461.8
W14X455	35	456.1	134.8	725.9	207.3	1028.7	389.2
W14X455	40	396.2	118.1	616.4	180.0	869.3	336.5
W14X455	45	350.3	105.0	535.4	159.2	750.1	296.6
W14X455	50	313.9	94.6	473.3	142.7	658.8	265.2

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W14X426	1	1029.5	982.3	1031.2	1025.9	1031.0	1023.3
W14X426	5	1341.9	623.6	1377.7	1232.5	1403.6	1357.2
W14X426	10	1296.2	407.9	1338.4	781.5	1350.3	1298.0
W14X426	15	1060.3	283.5	1319.4	491.6	1331.3	948.1
W14X426	20	791.3	215.3	1281.9	353.1	1318.1	684.0
W14X426	25	623.2	173.2	1070.3	275.5	1297.1	528.3
W14X426	30	512.5	144.7	850.0	226.0	1192.3	429.5
W14X426	35	434.9	124.2	698.9	191.7	994.8	361.8
W14X426	40	377.6	108.8	592.2	166.4	838.7	312.7
W14X426	45	333.7	96.7	513.6	147.1	722.2	275.5
W14X426	50	299.0	87.1	453.4	131.8	633.3	246.3
W14X398	1	956.7	900.6	958.2	953.2	958.1	951.1
W14X398	5	1314.6	573.4	1352.9	1157.3	1379.4	1329.0
W14X398	10	1263.5	375.0	1312.8	725.9	1325.1	1249.2
W14X398	15	1008.9	260.4	1293.1	456.9	1305.6	884.6
W14X398	20	749.4	197.7	1250.2	327.4	1291.8	636.9
W14X398	25	588.9	159.0	1028.6	255.1	1268.2	491.3
W14X398	30	483.7	132.8	813.4	209.0	1150.0	398.8
W14X398	35	410.0	114.0	666.7	177.2	953.9	335.7
W14X398	40	355.7	99.8	563.5	153.8	801.9	289.9
W14X398	45	314.2	88.8	487.7	135.9	688.9	255.3
W14X398	50	281.3	79.9	429.9	121.7	602.9	228.1
W14X370	1	881.1	816.7	882.2	877.5	882.3	875.7
W14X370	5	1283.7	522.9	1324.9	1074.1	1352.0	1295.1
W14X370	10	1225.6	342.1	1284.1	669.8	1296.7	1180.1
W14X370	15	954.9	237.4	1263.4	421.9	1276.8	819.5
W14X370	20	705.9	180.2	1214.2	301.5	1262.2	589.0
W14X370	25	553.4	144.8	984.7	234.5	1235.3	453.6
W14X370	30	453.8	121.0	775.2	192.0	1104.4	367.7
W14X370	35	384.2	103.8	633.3	162.6	911.0	309.2
W14X370	40	333.1	90.9	533.8	141.1	763.6	266.8
W14X370	45	294.0	80.8	460.9	124.6	654.3	234.8
W14X370	50	263.1	72.8	405.5	111.6	571.4	209.7
W14X342	1	793.8	721.4	794.7	790.0	794.9	788.8
W14X342	5	1261.3	469.9	1305.5	980.0	1333.4	1259.9
W14X342	10	1190.9	308.6	1264.8	611.0	1278.1	1090.1
W14X342	15	900.3	214.1	1242.1	385.9	1257.6	750.6
W14X342	20	662.3	162.5	1180.5	275.0	1241.7	539.0
W14X342	25	517.8	130.6	941.0	213.6	1209.0	414.5
W14X342	30	423.9	109.1	737.3	174.7	1059.0	335.6
W14X342	35	358.5	93.6	600.1	147.8	868.4	281.9
W14X342	40	310.5	81.9	504.2	128.2	725.4	243.1
W14X342	45	273.8	72.9	434.3	113.2	619.9	213.8
W14X342	50	244.9	65.6	381.2	101.4	540.1	190.8

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W14X311	1	703.2	627.5	703.8	699.1	704.1	698.4
W14X311	5	1221.0	413.0	1267.9	875.0	1297.8	1178.8
W14X311	10	1134.9	272.0	1227.5	546.6	1242.0	979.3
W14X311	15	834.0	188.7	1202.6	346.1	1220.8	673.6
W14X311	20	609.8	143.1	1123.0	245.8	1203.6	483.1
W14X311	25	475.2	115.0	885.8	190.4	1163.9	370.8
W14X311	30	388.1	96.0	690.3	155.5	1000.0	299.8
W14X311	35	327.6	82.4	559.3	131.5	815.3	251.4
W14X311	40	283.4	72.1	468.2	114.0	678.4	216.6
W14X311	45	249.7	64.1	401.9	100.6	577.8	190.3
W14X311	50	223.1	57.7	351.9	90.0	501.9	169.8
W14X283	1	616.1	539.3	616.5	612.0	617.0	611.7
W14X283	5	1174.4	363.4	1221.9	780.4	1252.7	1065.3
W14X283	10	1077.6	241.0	1183.6	491.3	1199.0	878.9
W14X283	15	779.5	167.3	1157.3	312.5	1177.4	607.0
W14X283	20	567.3	126.9	1067.5	221.1	1159.5	435.3
W14X283	25	440.5	101.9	842.8	170.9	1116.6	333.6
W14X283	30	358.9	85.1	653.9	139.4	952.3	269.3
W14X283	35	302.4	73.0	527.6	117.8	773.9	225.5
W14X283	40	261.3	63.9	439.9	102.0	641.9	194.1
W14X283	45	229.9	56.8	376.4	90.0	545.0	170.4
W14X283	50	205.3	51.1	328.6	80.5	471.9	151.9
W14X257	1	542.5	468.4	542.8	538.6	543.2	538.6
W14X257	5	1138.0	320.4	1183.6	698.1	1213.8	952.1
W14X257	10	1027.9	214.3	1150.3	444.4	1166.5	791.8
W14X257	15	732.7	148.8	1122.0	284.3	1144.6	550.3
W14X257	20	530.4	112.8	1020.8	200.2	1125.4	394.6
W14X257	25	410.2	90.6	801.3	154.4	1078.5	301.8
W14X257	30	333.2	75.6	624.6	125.6	914.0	243.1
W14X257	35	280.2	64.9	501.6	106.0	740.8	203.3
W14X257	40	241.6	56.8	416.4	91.7	612.4	174.7
W14X257	45	212.4	50.5	354.9	80.9	518.1	153.2
W14X257	50	189.5	45.4	308.8	72.3	447.1	136.5
W14X233	1	460.5	388.5	460.7	456.9	461.1	457.1
W14X233	5	1071.6	276.3	1104.9	609.3	1127.0	825.9
W14X233	10	957.7	186.8	1084.7	393.1	1100.8	695.8
W14X233	15	677.9	129.8	1056.0	253.3	1078.9	487.3
W14X233	20	488.7	98.4	953.2	177.8	1058.3	349.7
W14X233	25	376.4	79.0	747.4	136.7	1008.4	267.1
W14X233	30	304.9	66.0	587.4	111.0	859.9	214.8
W14X233	35	255.9	56.6	469.9	93.6	697.4	179.3
W14X233	40	220.3	49.5	388.5	80.9	575.3	153.9
W14X233	45	193.4	44.0	329.9	71.3	485.2	134.9
W14X233	50	172.4	39.6	286.1	63.7	417.5	120.1

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W14X211	1	403.5	336.6	403.6	400.0	404.0	400.4
W14X211	5	1017.2	242.2	1027.1	543.0	1035.4	731.6
W14X211	10	901.4	164.8	1036.9	354.3	1052.1	624.2
W14X211	15	632.9	114.5	1002.7	229.6	1024.8	439.6
W14X211	20	453.8	86.8	893.3	160.3	970.1	315.3
W14X211	25	347.9	69.7	703.7	122.8	910.8	240.2
W14X211	30	280.8	58.2	555.1	99.6	811.2	192.7
W14X211	35	235.0	49.9	444.7	83.8	663.1	160.6
W14X211	40	201.9	43.7	366.1	72.4	546.0	137.6
W14X211	45	177.0	38.8	309.6	63.7	459.2	120.4
W14X211	50	157.5	34.9	267.5	56.9	393.8	107.1
W14X193	1	340.6	280.5	340.7	337.5	341.0	337.9
W14X193	5	886.2	210.4	894.0	474.6	896.3	631.2
W14X193	10	845.7	146.0	971.9	317.1	983.0	551.4
W14X193	15	596.1	101.8	911.7	207.4	915.5	393.7
W14X193	20	426.7	77.2	817.5	144.9	839.0	283.4
W14X193	25	326.0	62.0	667.2	110.7	790.5	215.9
W14X193	30	262.2	51.7	527.0	89.6	745.2	172.9
W14X193	35	219.0	44.4	425.5	75.3	634.9	143.9
W14X193	40	187.8	38.8	349.1	65.0	523.3	123.2
W14X193	45	164.4	34.5	294.3	57.2	439.3	107.7
W14X193	50	146.1	31.1	253.5	51.0	375.8	95.7
W14X176	1	307.8	251.5	307.8	304.7	308.2	305.2
W14X176	5	813.3	188.9	810.2	434.7	812.3	575.6
W14X176	10	792.6	131.4	890.3	292.7	891.8	508.3
W14X176	15	562.8	91.5	770.1	191.1	769.8	363.9
W14X176	20	401.7	69.4	699.0	133.6	701.9	261.5
W14X176	25	305.4	55.7	625.4	101.7	661.9	198.5
W14X176	30	244.7	46.4	500.9	82.1	633.2	158.5
W14X176	35	203.7	39.8	406.3	68.9	596.4	131.6
W14X176	40	174.3	34.8	334.0	59.3	502.3	112.4
W14X176	45	152.3	31.0	280.4	52.2	421.4	98.1
W14X176	50	135.2	27.9	240.7	46.6	359.7	87.1
W14X159	1	253.8	205.0	253.8	251.2	254.1	251.6
W14X159	5	677.7	160.6	672.0	373.0	673.7	486.2
W14X159	10	709.6	114.4	750.6	258.5	750.7	442.3
W14X159	15	523.7	79.9	640.9	169.9	641.0	321.7
W14X159	20	375.0	60.6	585.4	119.5	584.1	232.2
W14X159	25	284.0	48.7	545.7	90.6	550.7	176.2
W14X159	30	226.6	40.6	471.0	73.0	528.9	140.5
W14X159	35	188.0	34.8	382.7	61.1	510.9	116.4
W14X159	40	160.4	30.5	317.7	52.6	475.4	99.2
W14X159	45	139.9	27.1	265.8	46.2	401.6	86.5
W14X159	50	124.0	24.4	227.3	41.2	342.3	76.7

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W14X145	1	215.3	174.9	215.3	213.1	215.6	213.5
W14X145	5	568.3	139.3	572.6	326.6	574.0	421.0
W14X145	10	616.7	100.9	635.0	231.4	635.0	391.6
W14X145	15	484.3	70.6	540.3	152.9	540.3	288.3
W14X145	20	350.5	53.6	492.4	108.0	492.4	208.8
W14X145	25	264.7	43.0	463.5	81.7	464.1	158.3
W14X145	30	210.4	35.9	433.9	65.6	446.4	125.9
W14X145	35	174.0	30.8	360.4	54.8	432.4	104.1
W14X145	40	148.1	26.9	299.3	47.1	420.0	88.6
W14X145	45	128.9	23.9	252.1	41.4	381.2	77.1
W14X145	50	114.1	21.5	214.9	36.9	325.4	68.3
W14X132	1	205.8	167.2	205.8	203.6	206.0	203.9
W14X132	5	540.3	128.8	545.6	303.6	546.9	395.1
W14X132	10	585.1	91.4	607.9	211.4	608.1	361.0
W14X132	15	445.4	63.8	522.2	138.8	522.3	263.0
W14X132	20	316.8	48.3	477.5	97.6	478.0	189.5
W14X132	25	238.1	38.8	450.1	73.7	451.7	143.3
W14X132	30	188.9	32.3	402.4	59.2	435.4	113.9
W14X132	35	156.1	27.7	325.7	49.5	421.8	94.2
W14X132	40	132.8	24.2	269.4	42.6	404.7	80.1
W14X132	45	115.5	21.5	226.3	37.3	345.6	69.7
W14X132	50	102.2	19.4	192.7	33.3	293.4	61.7
W14X120	1	174.4	140.2	174.4	172.5	174.6	172.8
W14X120	5	460.4	111.8	464.2	266.7	465.2	342.5
W14X120	10	496.3	80.9	506.6	190.4	506.7	321.5
W14X120	15	408.8	56.6	433.6	125.8	433.7	237.4
W14X120	20	298.6	42.9	396.5	88.9	396.7	171.7
W14X120	25	223.9	34.4	374.6	66.9	374.8	129.7
W14X120	30	176.9	28.7	358.0	53.6	361.4	102.9
W14X120	35	145.6	24.6	309.4	44.7	350.5	84.8
W14X120	40	123.5	21.5	255.9	38.4	341.8	72.0
W14X120	45	107.1	19.1	216.2	33.6	328.0	62.6
W14X120	50	94.6	17.2	184.2	29.9	281.9	55.3
W14X109	1	137.1	111.1	137.1	135.6	137.2	135.8
W14X109	5	367.5	93.1	369.6	222.1	370.3	279.6
W14X109	10	412.3	69.7	418.0	164.8	418.2	272.7
W14X109	15	352.2	49.0	358.9	110.4	359.0	205.8
W14X109	20	277.2	37.2	328.4	78.9	328.5	150.2
W14X109	25	208.1	29.9	310.3	59.2	310.4	113.8
W14X109	30	163.9	24.9	298.2	47.3	298.4	90.1
W14X109	35	134.4	21.4	284.6	39.4	290.6	74.2
W14X109	40	113.7	18.7	240.0	33.7	283.9	62.9
W14X109	45	98.4	16.6	202.5	29.5	278.3	54.6
W14X109	50	86.7	14.9	174.1	26.3	265.6	48.2

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W14X99	1	120.9	97.8	120.9	119.6	121.0	119.8
W14X99	5	322.0	82.2	323.7	199.8	324.2	248.5
W14X99	10	348.6	62.6	352.0	151.6	352.1	249.1
W14X99	15	298.6	44.1	301.0	102.3	301.0	190.3
W14X99	20	260.6	33.5	275.3	73.2	275.4	139.5
W14X99	25	198.3	26.9	260.1	54.9	260.2	105.5
W14X99	30	155.5	22.4	250.0	43.7	250.1	83.3
W14X99	35	127.0	19.2	242.6	36.3	243.5	68.3
W14X99	40	107.0	16.8	229.5	31.0	238.0	57.8
W14X99	45	92.3	14.9	194.7	27.1	233.4	50.0
W14X99	50	81.1	13.4	167.0	24.1	229.4	44.1
W14X90	1	99.7	81.1	99.7	98.7	99.8	98.9
W14X90	5	267.8	69.8	268.9	171.1	269.4	209.9
W14X90	10	287.8	54.3	289.9	133.4	289.9	216.7
W14X90	15	246.7	38.4	247.8	91.0	247.8	168.1
W14X90	20	224.3	29.2	226.7	65.1	226.8	124.0
W14X90	25	183.4	23.4	215.5	49.0	214.3	93.8
W14X90	30	143.7	19.6	206.0	38.9	206.0	74.0
W14X90	35	116.9	16.8	200.1	32.2	200.1	60.5
W14X90	40	98.1	14.7	195.5	27.5	196.2	51.1
W14X90	45	84.4	13.0	181.2	24.0	192.4	44.1
W14X90	50	74.0	11.7	155.6	21.3	189.1	38.8
W14X82	1	177.8	142.4	177.8	175.5	177.9	175.9
W14X82	5	452.0	90.7	471.3	210.6	473.1	296.1
W14X82	10	383.0	56.7	612.3	127.7	618.0	231.1
W14X82	15	242.3	38.6	540.9	80.1	599.5	156.0
W14X82	20	167.3	29.0	378.6	55.4	566.2	109.8
W14X82	25	125.8	23.2	273.7	42.3	440.7	82.9
W14X82	30	100.4	19.3	209.1	34.2	331.9	66.1
W14X82	35	83.4	16.6	166.6	28.7	259.4	54.9
W14X82	40	71.3	14.5	135.3	24.8	208.5	47.0
W14X82	45	62.3	12.9	113.3	21.8	172.6	41.0
W14X82	50	55.2	11.6	97.1	19.5	146.3	36.4
W14X74	1	136.6	110.6	136.6	135.0	136.7	135.3
W14X74	5	358.5	76.1	366.2	175.9	367.2	240.4
W14X74	10	355.7	49.3	495.4	111.9	498.1	197.6
W14X74	15	230.4	33.8	485.9	71.8	496.9	136.9
W14X74	20	159.0	25.5	364.6	49.5	475.6	97.1
W14X74	25	119.0	20.4	264.8	37.7	426.9	73.4
W14X74	30	94.6	17.0	201.8	30.4	324.3	58.5
W14X74	35	78.3	14.5	160.7	25.5	253.6	48.5
W14X74	40	66.8	12.7	131.2	22.0	204.0	41.4
W14X74	45	58.2	11.3	109.4	19.3	168.3	36.1
W14X74	50	51.6	10.1	93.4	17.2	142.1	32.0

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W14X68	1	116.9	94.3	116.9	115.4	117.0	115.7
W14X68	5	309.9	66.3	315.4	155.0	316.3	210.1
W14X68	10	325.9	43.4	423.5	100.1	425.4	175.7
W14X68	15	213.1	29.7	416.5	64.3	420.3	122.6
W14X68	20	146.6	22.4	340.2	44.5	401.2	87.0
W14X68	25	109.3	17.9	247.5	33.7	384.3	65.5
W14X68	30	86.5	14.9	188.1	27.1	304.9	52.1
W14X68	35	71.4	12.8	149.3	22.7	238.2	43.1
W14X68	40	60.7	11.2	122.6	19.6	191.9	36.8
W14X68	45	52.8	9.9	101.9	17.2	157.9	32.0
W14X68	50	46.7	8.9	86.7	15.3	133.0	28.4
W14X61	1	97.3	79.1	97.3	96.1	97.4	96.3
W14X61	5	258.6	56.8	262.0	134.7	262.6	179.4
W14X61	10	299.1	37.9	349.7	89.8	351.1	155.8
W14X61	15	201.6	26.1	341.5	58.0	342.9	110.4
W14X61	20	138.4	19.7	318.4	40.3	326.3	78.6
W14X61	25	102.5	15.7	238.5	30.4	314.2	59.1
W14X61	30	80.6	13.1	180.8	24.4	294.6	46.8
W14X61	35	66.2	11.2	142.8	20.4	231.6	38.6
W14X61	40	56.1	9.8	116.8	17.5	186.2	32.8
W14X61	45	48.6	8.7	97.9	15.4	153.4	28.5
W14X61	50	42.9	7.8	82.9	13.7	128.7	25.3
W14X53	1	110.9	89.3	110.9	109.3	111.0	109.6
W14X53	5	285.3	55.5	297.3	127.8	298.3	180.6
W14X53	10	237.4	33.8	408.2	76.4	412.8	138.7
W14X53	15	148.6	22.9	343.2	47.6	432.8	92.8
W14X53	20	102.1	17.2	234.5	32.9	383.8	65.1
W14X53	25	76.6	13.7	168.2	25.1	275.2	49.1
W14X53	30	61.0	11.4	128.0	20.3	205.2	39.2
W14X53	35	50.6	9.8	101.9	17.1	159.7	32.5
W14X53	40	43.2	8.5	82.6	14.7	127.9	27.8
W14X53	45	37.7	7.6	69.0	13.0	105.6	24.3
W14X53	50	33.4	6.8	59.1	11.6	89.4	21.6
W14X48	1	95.9	77.6	95.9	94.4	95.9	94.7
W14X48	5	248.2	48.6	256.1	113.8	256.8	159.2
W14X48	10	221.7	29.9	349.8	69.3	352.6	125.2
W14X48	15	139.6	20.3	323.9	43.5	368.2	84.4
W14X48	20	95.4	15.2	224.1	29.9	360.5	59.2
W14X48	25	71.1	12.1	160.5	22.7	265.4	44.5
W14X48	30	56.3	10.1	121.5	18.3	197.8	35.4
W14X48	35	46.5	8.6	96.3	15.4	153.5	29.3
W14X48	40	39.6	7.5	78.6	13.3	123.0	25.0
W14X48	45	34.5	6.7	65.4	11.6	101.2	21.8
W14X48	50	30.5	6.0	55.7	10.4	85.2	19.3

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W14X43	1	78.1	63.8	78.1	77.0	78.2	77.2
W14X43	5	204.1	41.1	208.5	97.4	209.0	133.9
W14X43	10	203.2	25.8	284.9	61.2	286.3	109.4
W14X43	15	130.1	17.5	290.6	38.9	298.5	74.9
W14X43	20	88.6	13.1	212.6	26.7	297.8	52.6
W14X43	25	65.5	10.5	152.4	20.2	254.0	39.4
W14X43	30	51.6	8.7	114.8	16.2	189.9	31.2
W14X43	35	42.4	7.4	90.6	13.6	147.0	25.8
W14X43	40	36.0	6.5	74.1	11.7	117.8	21.9
W14X43	45	31.2	5.8	61.7	10.2	96.7	19.1
W14X43	50	27.6	5.2	52.3	9.1	81.1	16.9
W14X38	1	94.0	77.2	94.0	92.5	94.1	92.8
W14X38	5	217.1	39.8	235.4	94.7	236.4	137.5
W14X38	10	161.9	23.0	313.8	54.4	322.3	101.4
W14X38	15	99.2	15.4	237.3	33.0	336.3	66.1
W14X38	20	67.4	11.5	158.9	22.7	265.7	45.8
W14X38	25	50.2	9.1	112.8	17.3	187.4	34.3
W14X38	30	39.7	7.6	85.2	13.9	138.6	27.2
W14X38	35	32.8	6.5	67.5	11.7	107.3	22.5
W14X38	40	28.0	5.7	54.8	10.1	85.8	19.2
W14X38	45	24.3	5.0	45.6	8.9	70.5	16.7
W14X38	50	21.5	4.5	38.9	7.9	59.4	14.8
W14X34	1	82.2	67.7	82.2	80.8	82.3	81.0
W14X34	5	191.0	34.7	203.6	84.6	204.3	121.8
W14X34	10	150.5	20.2	269.2	49.3	272.9	91.9
W14X34	15	92.7	13.5	224.1	30.1	283.0	60.2
W14X34	20	62.5	10.1	151.2	20.6	253.2	41.6
W14X34	25	46.1	8.0	107.0	15.6	180.0	31.0
W14X34	30	36.3	6.6	80.3	12.5	132.9	24.5
W14X34	35	29.8	5.7	63.2	10.5	102.5	20.2
W14X34	40	25.3	4.9	51.7	9.0	82.0	17.2
W14X34	45	22.0	4.4	42.9	7.9	67.1	14.9
W14X34	50	19.4	3.9	36.4	7.1	56.3	13.2
W14X30	1	79.8	65.0	79.8	78.3	79.8	78.5
W14X30	5	177.2	31.1	189.9	79.4	191.0	115.7
W14X30	10	139.6	17.8	232.8	45.9	234.7	86.8
W14X30	15	85.4	11.8	209.4	27.7	233.2	56.1
W14X30	20	56.8	8.8	141.7	18.8	226.5	38.5
W14X30	25	41.5	7.0	99.6	14.1	169.7	28.5
W14X30	30	32.3	5.8	74.1	11.3	124.8	22.4
W14X30	35	26.4	4.9	58.0	9.5	95.8	18.4
W14X30	40	22.3	4.3	47.1	8.1	76.2	15.6
W14X30	45	19.3	3.8	39.4	7.1	62.5	13.5
W14X30	50	17.0	3.4	33.3	6.3	52.2	11.9

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W14X26	1	81.4	67.6	81.4	79.8	81.5	80.1
W14X26	5	155.4	28.4	194.2	66.5	197.3	102.5
W14X26	10	94.7	15.2	212.3	35.0	264.4	67.2
W14X26	15	56.5	10.0	134.4	20.4	223.1	41.8
W14X26	20	38.4	7.4	87.6	14.2	146.4	28.7
W14X26	25	28.7	5.8	62.1	10.8	101.6	21.5
W14X26	30	22.9	4.8	47.1	8.8	75.0	17.1
W14X26	35	19.0	4.1	37.1	7.4	57.9	14.2
W14X26	40	16.2	3.6	30.1	6.4	46.4	12.1
W14X26	45	14.1	3.2	25.2	5.6	38.4	10.6
W14X26	50	12.5	2.9	21.7	5.0	32.5	9.4
W14X22	1	71.9	59.1	71.9	70.4	71.9	70.6
W14X22	5	134.4	23.7	164.5	58.1	167.2	90.0
W14X22	10	84.1	12.5	188.1	30.5	212.6	59.4
W14X22	15	49.6	8.2	122.1	17.7	201.1	36.7
W14X22	20	33.2	6.0	79.1	12.2	134.4	24.9
W14X22	25	24.5	4.8	55.5	9.2	92.9	18.5
W14X22	30	19.3	3.9	41.6	7.5	68.1	14.7
W14X22	35	15.9	3.4	32.9	6.2	52.5	12.1
W14X22	40	13.5	2.9	26.7	5.4	41.8	10.3
W14X22	45	11.7	2.6	22.1	4.7	34.3	8.9
W14X22	50	10.4	2.3	18.9	4.2	28.9	7.9
W12X336	1	1240.1	1100.0	1242.3	1231.6	1243.4	1231.4
W12X336	5	1594.6	665.4	1644.0	1296.1	1669.3	1616.7
W12X336	10	1346.3	396.1	1593.6	703.3	1610.6	1300.2
W12X336	15	917.3	271.2	1509.8	440.4	1581.5	842.1
W12X336	20	677.6	205.1	1134.5	320.3	1508.3	605.4
W12X336	25	535.1	164.7	857.8	251.9	1216.2	471.2
W12X336	30	441.7	137.5	686.0	207.6	967.4	386.0
W12X336	35	376.1	118.0	571.2	176.7	798.2	327.1
W12X336	40	327.5	103.3	489.5	153.8	678.5	284.0
W12X336	45	290.1	91.9	428.5	136.2	590.0	251.0
W12X336	50	260.4	82.7	381.2	122.2	522.0	225.0
W12X305	1	1112.4	959.3	1114.0	1103.3	1115.5	1104.2
W12X305	5	1543.1	587.0	1601.2	1162.0	1627.6	1561.5
W12X305	10	1250.8	348.9	1548.3	628.9	1567.0	1171.5
W12X305	15	842.3	238.7	1443.6	392.0	1535.2	755.4
W12X305	20	620.0	180.4	1058.9	284.4	1440.9	541.8
W12X305	25	488.5	144.8	795.4	223.4	1136.4	420.9
W12X305	30	402.8	120.9	633.2	184.0	898.7	344.3
W12X305	35	342.6	103.7	525.5	156.5	738.5	291.5
W12X305	40	298.1	90.8	449.2	136.2	625.8	252.9
W12X305	45	263.9	80.7	392.5	120.5	542.8	223.5
W12X305	50	236.8	72.7	348.6	108.1	479.3	200.2

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W12X279	1	1056.2	892.0	1057.6	1046.7	1059.3	1048.2
W12X279	5	1529.6	537.7	1597.0	1088.0	1626.0	1539.3
W12X279	10	1187.2	317.1	1540.8	584.8	1562.6	1098.2
W12X279	15	789.1	216.3	1411.7	361.9	1527.4	703.4
W12X279	20	577.9	163.3	1013.6	261.5	1407.0	502.0
W12X279	25	454.0	131.0	755.4	204.9	1089.0	388.6
W12X279	30	373.6	109.3	597.8	168.6	855.5	317.0
W12X279	35	317.3	93.8	493.8	143.3	699.4	267.9
W12X279	40	275.8	82.1	420.7	124.6	590.1	232.2
W12X279	45	244.0	73.0	366.5	110.3	510.1	204.9
W12X279	50	218.8	65.7	324.9	98.9	449.2	183.5
W12X252	1	935.4	764.4	936.4	925.4	938.3	928.0
W12X252	5	1462.8	473.4	1537.5	972.4	1567.8	1435.7
W12X252	10	1104.0	279.2	1480.2	524.6	1504.2	987.5
W12X252	15	728.1	190.4	1334.7	323.0	1467.6	631.9
W12X252	20	531.1	143.7	953.9	232.8	1337.1	450.1
W12X252	25	416.3	115.2	706.4	182.2	1025.5	347.7
W12X252	30	341.9	96.1	556.2	149.7	801.6	283.2
W12X252	35	290.1	82.4	457.6	127.2	652.4	239.1
W12X252	40	251.9	72.2	388.6	110.6	548.5	207.0
W12X252	45	222.7	64.2	337.8	97.8	472.7	182.6
W12X252	50	199.6	57.7	298.8	87.7	415.2	163.4
W12X230	1	839.5	673.9	840.2	829.5	842.0	832.4
W12X230	5	1420.5	423.4	1505.1	881.9	1537.7	1325.1
W12X230	10	1042.1	250.3	1446.2	479.9	1473.2	901.9
W12X230	15	682.3	170.6	1279.8	293.8	1434.5	577.7
W12X230	20	495.6	128.7	912.9	211.2	1291.6	410.5
W12X230	25	387.4	103.2	671.8	164.9	982.2	316.5
W12X230	30	317.7	86.1	526.0	135.4	763.8	257.4
W12X230	35	269.2	73.8	431.0	114.9	618.9	217.0
W12X230	40	233.5	64.6	364.7	99.9	518.3	187.7
W12X230	45	206.3	57.4	316.2	88.3	445.2	165.5
W12X230	50	184.7	51.7	279.2	79.2	390.0	148.0
W12X210	1	734.1	577.7	734.6	724.4	736.4	727.8
W12X210	5	1351.6	373.6	1441.8	786.9	1475.2	1185.1
W12X210	10	973.8	221.6	1383.9	432.6	1412.7	809.8
W12X210	15	634.0	151.0	1209.8	263.7	1373.7	519.9
W12X210	20	458.8	114.0	865.0	189.0	1229.7	369.0
W12X210	25	357.7	91.4	633.1	147.5	931.1	284.1
W12X210	30	292.8	76.2	493.4	121.0	721.1	230.8
W12X210	35	247.8	65.3	402.6	102.6	582.0	194.4
W12X210	40	214.8	57.2	339.7	89.1	485.7	168.1
W12X210	45	189.6	50.8	293.7	78.8	415.9	148.1
W12X210	50	169.7	45.7	258.8	70.6	363.4	132.4

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W12X190	1	617.6	470.9	617.9	608.6	619.4	611.7
W12X190	5	1279.6	323.7	1375.5	687.4	1409.0	1026.1
W12X190	10	910.6	194.2	1322.0	383.5	1352.2	714.9
W12X190	15	590.7	132.6	1145.5	234.9	1313.3	462.6
W12X190	20	425.7	100.0	824.5	167.9	1175.3	328.4
W12X190	25	331.0	80.2	600.5	130.7	888.5	252.5
W12X190	30	270.4	66.9	465.4	107.1	685.3	204.9
W12X190	35	228.5	57.4	378.0	90.8	550.7	172.5
W12X190	40	197.9	50.2	317.7	78.8	457.7	149.0
W12X190	45	174.5	44.6	273.9	69.6	390.6	131.2
W12X190	50	156.1	40.1	240.7	62.4	340.3	117.3
W12X170	1	527.3	393.4	527.4	518.8	528.8	521.9
W12X170	5	1190.4	277.4	1285.9	599.5	1315.5	890.6
W12X170	10	832.9	166.7	1240.1	335.9	1270.4	626.9
W12X170	15	536.2	113.7	1061.7	206.0	1232.0	406.2
W12X170	20	384.0	85.8	759.6	146.6	1095.3	287.7
W12X170	25	297.4	68.7	556.6	113.9	828.9	220.6
W12X170	30	242.3	57.3	428.6	93.2	636.5	178.6
W12X170	35	204.3	49.1	346.1	78.9	508.9	150.0
W12X170	40	176.7	43.0	289.5	68.4	420.9	129.5
W12X170	45	155.6	38.2	248.6	60.4	357.7	113.9
W12X170	50	139.1	34.4	217.8	54.1	310.4	101.7
W12X152	1	456.1	337.5	456.2	448.3	457.4	451.2
W12X152	5	1119.3	241.3	1208.2	530.9	1226.9	783.1
W12X152	10	775.6	145.5	1179.1	299.9	1208.1	559.2
W12X152	15	496.0	99.2	1000.4	184.2	1167.0	363.3
W12X152	20	352.8	74.8	713.8	130.5	1034.4	256.6
W12X152	25	272.0	60.0	526.9	101.1	789.0	196.1
W12X152	30	220.9	50.0	403.0	82.5	603.7	158.4
W12X152	35	185.9	42.8	323.5	69.8	480.3	132.8
W12X152	40	160.4	37.5	269.2	60.5	395.3	114.5
W12X152	45	141.1	33.3	230.1	53.4	334.4	100.6
W12X152	50	126.0	30.0	200.8	47.8	289.0	89.8
W12X136	1	394.9	285.6	394.9	387.5	395.9	390.1
W12X136	5	1033.5	208.8	1104.5	469.1	1108.5	687.8
W12X136	10	717.8	126.2	1108.5	266.7	1126.8	497.3
W12X136	15	455.9	86.0	929.2	164.0	1018.7	323.6
W12X136	20	321.9	64.8	666.6	115.6	930.2	227.8
W12X136	25	246.8	51.9	492.9	89.2	743.6	173.5
W12X136	30	199.7	43.3	377.0	72.8	569.2	139.7
W12X136	35	167.6	37.1	300.7	61.5	450.9	116.9
W12X136	40	144.4	32.4	248.8	53.2	369.3	100.6
W12X136	45	126.8	28.8	211.7	47.0	310.9	88.3
W12X136	50	113.1	25.9	184.0	42.0	267.5	78.7

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W12X120	1	332.5	240.6	332.5	325.8	333.3	328.0
W12X120	5	904.1	177.9	947.5	407.5	948.5	592.3
W12X120	10	658.6	108.1	933.8	234.5	934.0	435.9
W12X120	15	417.3	73.6	805.7	144.7	818.4	284.8
W12X120	20	292.4	55.5	618.7	101.4	757.9	199.9
W12X120	25	222.9	44.4	456.5	78.0	686.8	151.7
W12X120	30	179.6	37.0	352.0	63.5	534.9	121.8
W12X120	35	150.3	31.7	279.1	53.5	422.3	101.7
W12X120	40	129.2	27.7	229.6	46.3	344.4	87.3
W12X120	45	113.3	24.6	194.4	40.8	288.5	76.5
W12X120	50	100.8	22.2	168.2	36.5	247.2	68.2
W12X106	1	246.4	178.4	246.5	241.5	246.9	243.1
W12X106	5	703.2	143.2	722.3	328.8	723.7	465.0
W12X106	10	593.1	89.6	737.5	197.2	738.4	358.8
W12X106	15	381.0	61.3	646.0	123.7	647.1	239.5
W12X106	20	265.7	46.2	565.4	86.2	602.1	168.7
W12X106	25	201.3	37.0	422.7	66.1	571.0	127.8
W12X106	30	161.5	30.8	326.9	53.6	500.0	102.4
W12X106	35	134.6	26.4	260.1	45.2	396.7	85.3
W12X106	40	115.4	23.1	212.7	39.0	322.3	73.1
W12X106	45	101.0	20.5	179.1	34.4	268.9	64.0
W12X106	50	89.8	18.5	154.3	30.7	229.4	57.0
W12X96	1	202.7	146.4	202.7	198.6	203.1	199.8
W12X96	5	588.5	123.3	599.9	285.8	600.5	397.5
W12X96	10	545.3	78.6	608.2	176.0	608.9	316.4
W12X96	15	358.9	53.9	532.0	111.7	532.5	213.9
W12X96	20	249.4	40.6	490.5	77.5	493.4	150.8
W12X96	25	188.0	32.5	402.1	59.2	471.4	114.0
W12X96	30	150.1	27.1	310.8	47.9	452.1	91.1
W12X96	35	124.8	23.2	249.5	40.3	381.9	75.8
W12X96	40	106.7	20.3	203.2	34.8	310.1	64.9
W12X96	45	93.2	18.1	170.3	30.6	257.9	56.7
W12X96	50	82.7	16.2	146.1	27.3	219.3	50.4
W12X87	1	185.5	132.7	185.5	181.6	185.8	182.7
W12X87	5	530.5	109.8	541.2	261.4	541.7	363.9
W12X87	10	483.4	69.6	505.5	161.2	505.6	291.1
W12X87	15	332.3	47.6	440.2	102.1	440.6	196.1
W12X87	20	229.6	35.9	407.4	70.4	408.2	137.6
W12X87	25	171.9	28.7	372.0	53.6	389.8	103.5
W12X87	30	136.6	23.9	289.5	43.3	375.9	82.4
W12X87	35	113.2	20.5	231.6	36.3	355.4	68.4
W12X87	40	96.5	17.9	189.9	31.3	291.8	58.4
W12X87	45	84.1	15.9	158.5	27.5	242.1	50.9
W12X87	50	74.6	14.3	135.4	24.6	205.1	45.2

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W12X79	1	158.2	113.6	158.2	154.8	158.4	155.6
W12X79	5	452.8	96.1	460.2	232.2	460.7	318.6
W12X79	10	414.0	62.0	421.7	146.9	422.0	262.8
W12X79	15	315.4	42.4	367.0	93.4	367.3	179.3
W12X79	20	218.2	32.0	339.7	64.6	340.2	125.8
W12X79	25	162.5	25.6	323.1	48.9	324.1	94.4
W12X79	30	128.4	21.3	278.4	39.4	313.3	74.9
W12X79	35	105.9	18.3	222.4	33.0	305.0	62.0
W12X79	40	90.1	16.0	183.1	28.4	283.2	52.8
W12X79	45	78.3	14.2	152.9	24.9	235.6	46.0
W12X79	50	69.3	12.7	130.1	22.3	199.1	40.7
W12X72	1	134.5	96.9	134.5	131.6	134.7	132.3
W12X72	5	385.3	83.5	390.7	204.2	391.1	276.7
W12X72	10	350.3	54.5	354.3	132.1	354.5	234.2
W12X72	15	290.4	37.4	308.6	84.2	308.6	161.5
W12X72	20	203.7	28.2	285.6	58.4	286.0	113.5
W12X72	25	150.9	22.5	272.2	44.1	272.4	84.9
W12X72	30	118.7	18.8	258.4	35.4	263.5	67.2
W12X72	35	97.5	16.1	209.3	29.6	256.7	55.4
W12X72	40	82.6	14.1	171.8	25.4	251.3	47.1
W12X72	45	71.7	12.5	144.7	22.3	224.1	41.0
W12X72	50	63.3	11.2	122.6	19.9	189.1	36.3
W12X65	1	111.5	80.3	111.5	109.1	111.7	109.6
W12X65	5	321.0	71.6	324.6	177.5	324.9	237.2
W12X65	10	284.7	47.6	286.6	117.9	286.7	207.0
W12X65	15	246.6	32.7	249.3	75.6	249.3	144.6
W12X65	20	190.5	24.6	230.8	52.6	230.8	101.8
W12X65	25	140.7	19.7	219.9	39.5	220.0	76.0
W12X65	30	110.1	16.4	212.4	31.6	212.7	59.9
W12X65	35	90.1	14.1	197.1	26.4	207.1	49.3
W12X65	40	76.1	12.3	162.0	22.7	203.4	41.8
W12X65	45	65.8	10.9	136.0	19.9	199.8	36.3
W12X65	50	57.9	9.8	116.4	17.7	180.5	32.1
W12X58	1	101.1	74.3	101.1	99.1	101.2	99.6
W12X58	5	305.5	65.3	308.9	151.5	309.3	206.5
W12X58	10	335.1	42.2	375.7	96.3	376.7	169.4
W12X58	15	220.7	28.9	347.2	61.7	347.8	116.4
W12X58	20	151.3	21.8	325.3	42.8	327.4	82.2
W12X58	25	112.7	17.4	253.7	32.6	314.4	62.0
W12X58	30	89.2	14.5	193.2	26.3	302.8	49.4
W12X58	35	73.7	12.4	153.5	22.0	243.3	40.9
W12X58	40	62.7	10.9	126.0	19.0	196.4	35.0
W12X58	45	54.6	9.7	104.7	16.7	161.8	30.5
W12X58	50	48.3	8.7	89.2	14.9	136.4	27.1

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W12X53	1	98.4	71.9	98.4	96.3	98.5	96.7
W12X53	5	289.8	60.3	293.8	145.0	294.2	198.5
W12X53	10	307.0	38.5	321.6	91.9	322.2	163.4
W12X53	15	210.7	26.3	290.6	58.4	290.9	111.6
W12X53	20	143.3	19.8	272.6	40.4	273.0	78.3
W12X53	25	105.9	15.8	244.1	30.6	262.0	58.6
W12X53	30	83.3	13.2	185.6	24.6	254.4	46.5
W12X53	35	68.4	11.3	146.7	20.6	235.4	38.4
W12X53	40	58.0	9.9	120.0	17.7	190.2	32.7
W12X53	45	50.3	8.7	100.4	15.5	156.7	28.5
W12X53	50	44.5	7.9	85.1	13.9	131.7	25.2
W12X50	1	132.6	95.3	132.6	129.3	132.7	130.2
W12X50	5	372.3	65.9	396.7	153.1	397.8	225.0
W12X50	10	270.9	38.5	486.8	85.7	492.7	159.5
W12X50	15	164.8	26.0	381.2	52.3	483.6	102.7
W12X50	20	113.2	19.5	255.0	36.5	414.9	71.6
W12X50	25	85.3	15.6	182.5	28.0	294.6	54.1
W12X50	30	68.2	12.9	139.3	22.7	219.7	43.3
W12X50	35	56.8	11.1	109.8	19.1	170.4	36.1
W12X50	40	48.6	9.7	89.5	16.6	137.1	31.0
W12X50	45	42.5	8.6	75.2	14.6	113.8	27.1
W12X50	50	37.8	7.7	64.7	13.0	96.7	24.1
W12X45	1	110.4	80.1	110.4	107.7	110.5	108.4
W12X45	5	316.1	56.8	330.0	133.8	330.8	193.9
W12X45	10	252.3	33.6	404.3	76.7	407.2	141.7
W12X45	15	154.2	22.6	358.6	47.1	396.7	92.1
W12X45	20	105.1	17.0	242.8	32.7	378.3	64.1
W12X45	25	78.6	13.6	173.2	25.0	283.2	48.2
W12X45	30	62.5	11.3	131.4	20.2	210.8	38.5
W12X45	35	51.9	9.7	104.5	17.0	163.7	32.0
W12X45	40	44.3	8.4	84.7	14.7	131.1	27.4
W12X45	45	38.6	7.5	70.8	12.9	108.3	23.9
W12X45	50	34.3	6.7	60.6	11.5	91.6	21.3
W12X40	1	84.8	62.1	84.8	82.8	84.9	83.3
W12X40	5	250.8	47.0	256.6	111.3	257.3	157.8
W12X40	10	229.3	28.4	319.1	66.0	320.5	120.2
W12X40	15	142.0	19.2	309.9	41.1	313.8	79.3
W12X40	20	96.3	14.4	227.3	28.4	301.4	55.3
W12X40	25	71.6	11.5	162.1	21.6	267.0	41.5
W12X40	30	56.6	9.6	122.4	17.5	199.2	33.0
W12X40	35	46.8	8.2	97.0	14.7	154.6	27.4
W12X40	40	39.8	7.2	79.1	12.6	123.8	23.4
W12X40	45	34.7	6.4	65.8	11.1	101.8	20.4
W12X40	50	30.7	5.7	56.1	9.9	85.8	18.1

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W12X35	1	100.6	75.4	100.6	98.1	100.7	98.7
W12X35	5	259.8	44.4	287.5	104.2	289.7	155.9
W12X35	10	174.1	25.1	360.7	56.9	374.4	107.3
W12X35	15	104.8	16.8	247.6	34.2	383.6	68.1
W12X35	20	71.6	12.5	163.1	23.8	270.6	47.2
W12X35	25	53.8	10.0	116.0	18.2	189.2	35.5
W12X35	30	42.9	8.3	88.3	14.8	140.2	28.4
W12X35	35	35.7	7.1	69.6	12.4	108.5	23.6
W12X35	40	30.5	6.2	56.6	10.8	87.0	20.2
W12X35	45	26.7	5.5	47.5	9.5	72.1	17.7
W12X35	50	23.7	5.0	40.8	8.5	61.2	15.8
W12X30	1	77.5	58.7	77.5	75.6	77.6	76.0
W12X30	5	209.1	35.7	221.6	85.7	222.8	126.1
W12X30	10	155.9	20.4	281.4	48.2	284.3	90.3
W12X30	15	94.1	13.6	227.0	29.2	292.5	57.8
W12X30	20	63.6	10.2	150.6	20.1	252.1	39.9
W12X30	25	47.3	8.1	106.5	15.3	177.2	29.9
W12X30	30	37.4	6.7	80.3	12.4	130.7	23.8
W12X30	35	30.9	5.8	63.6	10.4	101.1	19.7
W12X30	40	26.3	5.0	51.6	9.0	80.7	16.8
W12X30	45	22.9	4.5	43.0	7.9	66.4	14.7
W12X30	50	20.3	4.0	36.7	7.1	55.9	13.0
W12X26	1	62.2	48.1	62.2	60.6	62.3	60.9
W12X26	5	170.3	29.8	177.1	72.7	177.5	105.2
W12X26	10	142.2	17.2	222.6	42.1	223.8	78.3
W12X26	15	86.7	11.5	209.6	25.7	228.6	50.7
W12X26	20	58.1	8.6	141.8	17.6	225.6	34.9
W12X26	25	42.7	6.8	100.0	13.3	168.8	26.0
W12X26	30	33.6	5.7	74.8	10.7	124.4	20.6
W12X26	35	27.6	4.8	58.8	9.0	95.8	17.0
W12X26	40	23.4	4.2	48.1	7.7	76.5	14.5
W12X26	45	20.3	3.7	39.9	6.8	62.6	12.6
W12X26	50	17.9	3.4	33.9	6.1	52.5	11.2
W12X22	1	116.9	85.7	116.9	112.1	117.0	113.5
W12X22	5	161.9	31.1	273.2	71.3	303.7	121.6
W12X22	10	78.2	15.5	181.1	31.8	293.3	64.7
W12X22	15	46.2	10.1	101.9	18.9	167.8	38.3
W12X22	20	32.1	7.5	66.2	13.3	105.4	26.4
W12X22	25	24.5	5.9	46.9	10.3	72.9	20.0
W12X22	30	19.8	4.9	35.5	8.4	54.2	16.1
W12X22	35	16.6	4.2	28.4	7.1	42.6	13.5
W12X22	40	14.3	3.7	23.6	6.2	34.8	11.6
W12X22	45	12.5	3.2	20.2	5.5	29.4	10.2
W12X22	50	11.2	2.9	17.6	4.9	25.3	9.1

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W12X19	1	102.1	75.3	102.1	97.9	102.2	99.1
W12X19	5	144.1	26.5	236.4	63.0	256.3	107.6
W12X19	10	70.5	13.1	166.9	28.2	267.0	57.7
W12X19	15	40.9	8.5	93.9	16.5	157.1	34.0
W12X19	20	28.1	6.3	60.2	11.6	98.2	23.2
W12X19	25	21.2	4.9	43.0	9.0	67.8	17.5
W12X19	30	17.0	4.1	32.2	7.3	49.9	14.0
W12X19	35	14.2	3.5	25.5	6.2	38.8	11.7
W12X19	40	12.2	3.0	21.0	5.3	31.5	10.0
W12X19	45	10.7	2.7	17.8	4.7	26.3	8.7
W12X19	50	9.5	2.4	15.4	4.2	22.6	7.8
W12X16	1	101.5	73.3	101.5	97.1	101.6	98.2
W12X16	5	128.7	23.2	214.1	58.0	228.1	101.8
W12X16	10	62.1	11.2	150.9	25.3	237.1	52.8
W12X16	15	35.2	7.2	83.9	14.7	142.1	30.6
W12X16	20	23.7	5.3	53.0	10.3	88.2	20.7
W12X16	25	17.8	4.2	37.4	7.9	60.3	15.5
W12X16	30	14.2	3.4	28.1	6.4	44.3	12.3
W12X16	35	11.8	2.9	22.1	5.4	34.2	10.2
W12X16	40	10.0	2.5	18.0	4.7	27.5	8.7
W12X16	45	8.8	2.2	15.1	4.1	22.8	7.6
W12X16	50	7.8	2.0	13.0	3.7	19.4	6.7
W12X14	1	87.3	63.2	87.3	83.5	87.4	84.4
W12X14	5	115.4	20.1	182.7	51.3	189.1	89.9
W12X14	10	57.0	9.7	139.5	22.6	200.9	47.3
W12X14	15	32.0	6.2	78.2	13.1	133.3	27.4
W12X14	20	21.4	4.5	49.2	9.1	82.9	18.5
W12X14	25	15.9	3.6	34.4	7.0	56.4	13.7
W12X14	30	12.6	2.9	25.9	5.6	41.4	10.9
W12X14	35	10.4	2.5	20.3	4.7	31.8	9.0
W12X14	40	8.9	2.2	16.5	4.1	25.4	7.7
W12X14	45	7.7	1.9	13.8	3.6	21.0	6.7
W12X14	50	6.8	1.7	11.8	3.2	17.8	5.9
W10X112	1	512.3	321.8	512.5	493.7	515.3	503.6
W10X112	5	1165.8	240.3	1359.8	512.7	1386.5	816.3
W10X112	10	680.6	135.2	1251.6	260.6	1336.8	499.7
W10X112	15	427.3	91.4	857.4	159.2	1206.4	312.8
W10X112	20	306.5	68.8	583.5	114.5	869.5	221.9
W10X112	25	238.3	55.1	422.9	89.5	628.8	171.3
W10X112	30	194.8	45.9	328.5	73.6	482.4	139.6
W10X112	35	164.8	39.3	267.7	62.5	387.9	117.8
W10X112	40	142.8	34.4	225.7	54.3	323.1	102.0
W10X112	45	126.0	30.6	195.1	48.0	276.5	90.0
W10X112	50	112.8	27.5	171.9	43.1	241.4	80.6

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W10X100	1	431.5	266.2	431.6	414.7	433.8	423.1
W10X100	5	1062.4	205.4	1231.7	445.8	1244.7	704.2
W10X100	10	620.7	115.8	1144.4	229.0	1207.9	436.6
W10X100	15	386.6	78.3	790.9	139.0	1080.0	273.1
W10X100	20	275.7	58.9	542.3	99.6	810.2	193.1
W10X100	25	213.5	47.1	390.2	77.7	584.7	148.7
W10X100	30	174.1	39.3	301.0	63.8	446.1	120.9
W10X100	35	147.0	33.6	243.9	54.1	356.8	101.9
W10X100	40	127.2	29.4	204.7	47.0	295.8	88.2
W10X100	45	112.1	26.2	176.3	41.6	252.0	77.7
W10X100	50	100.3	23.5	154.9	37.3	219.3	69.5
W10X88	1	355.2	216.1	355.2	340.9	356.9	347.5
W10X88	5	960.0	174.7	1064.6	386.7	1066.4	603.0
W10X88	10	574.0	99.0	973.4	201.7	976.5	382.2
W10X88	15	354.7	66.9	738.1	122.0	867.8	239.3
W10X88	20	251.1	50.3	506.7	87.0	756.4	168.5
W10X88	25	193.5	40.3	367.8	67.7	554.9	129.3
W10X88	30	157.3	33.5	281.4	55.5	421.4	104.8
W10X88	35	132.4	28.7	226.4	47.0	335.0	88.2
W10X88	40	114.4	25.1	188.9	40.8	276.1	76.2
W10X88	45	100.7	22.3	161.9	36.1	233.9	67.1
W10X88	50	90.0	20.1	141.6	32.3	202.6	60.0
W10X77	1	283.4	171.8	283.4	272.0	284.6	276.9
W10X77	5	821.4	145.4	870.3	327.6	871.1	502.4
W10X77	10	523.8	83.1	769.7	173.7	770.5	327.7
W10X77	15	321.7	56.2	661.9	105.4	683.2	206.0
W10X77	20	225.7	42.2	468.5	74.8	637.8	144.5
W10X77	25	172.9	33.8	343.4	58.0	520.9	110.4
W10X77	30	140.0	28.2	260.7	47.4	394.5	89.3
W10X77	35	117.5	24.1	208.1	40.1	311.7	74.9
W10X77	40	101.3	21.1	172.4	34.8	255.3	64.6
W10X77	45	89.0	18.7	147.0	30.7	215.1	56.9
W10X77	50	79.4	16.9	128.0	27.5	185.3	50.8
W10X68	1	228.8	138.4	228.8	219.6	229.6	223.3
W10X68	5	680.4	121.7	706.9	278.8	707.5	421.9
W10X68	10	475.1	70.1	608.6	150.2	609.0	282.1
W10X68	15	291.3	47.4	538.0	91.4	539.8	177.9
W10X68	20	202.7	35.6	430.6	64.5	506.4	124.3
W10X68	25	154.3	28.5	314.9	49.8	473.6	94.6
W10X68	30	124.3	23.7	240.8	40.7	367.4	76.3
W10X68	35	104.1	20.3	190.9	34.4	289.1	63.9
W10X68	40	89.5	17.8	157.3	29.8	235.5	55.0
W10X68	45	78.5	15.8	133.3	26.3	197.4	48.3
W10X68	50	70.0	14.2	115.5	23.5	169.2	43.1

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W10X60	1	188.1	113.5	188.1	180.4	188.7	183.2
W10X60	5	561.0	103.6	576.4	242.3	577.0	361.7
W10X60	10	433.6	60.1	477.1	132.9	477.2	248.6
W10X60	15	269.8	40.6	422.1	81.2	422.4	157.4
W10X60	20	186.1	30.5	389.5	56.9	395.3	109.5
W10X60	25	140.7	24.4	295.4	43.8	378.7	82.9
W10X60	30	112.8	20.3	227.5	35.6	348.1	66.6
W10X60	35	94.1	17.4	179.9	30.1	274.9	55.6
W10X60	40	80.7	15.2	147.2	26.0	223.0	47.8
W10X60	45	70.6	13.5	124.0	23.0	185.9	41.9
W10X60	50	62.8	12.2	106.9	20.5	158.6	37.4
W10X54	1	146.1	89.2	146.1	140.3	146.4	142.2
W10X54	5	450.2	86.9	458.9	203.6	459.3	297.1
W10X54	10	378.5	51.4	390.4	115.4	390.7	212.9
W10X54	15	249.3	34.8	346.0	71.2	346.2	136.6
W10X54	20	171.1	26.2	323.5	49.7	324.1	94.9
W10X54	25	128.5	20.9	275.6	38.1	310.7	71.7
W10X54	30	102.6	17.4	211.9	31.0	301.6	57.4
W10X54	35	85.3	14.9	168.9	26.1	259.6	47.9
W10X54	40	73.0	13.0	137.5	22.5	210.2	41.1
W10X54	45	63.7	11.6	115.3	19.9	174.6	36.0
W10X54	50	56.6	10.4	99.0	17.8	148.4	32.0
W10X49	1	126.0	77.3	126.0	121.1	126.3	122.5
W10X49	5	386.7	77.2	392.9	183.5	393.2	264.6
W10X49	10	323.1	46.1	326.9	106.0	326.9	194.5
W10X49	15	237.1	31.2	289.4	65.8	289.5	125.6
W10X49	20	162.1	23.5	270.8	45.6	271.0	87.1
W10X49	25	121.0	18.8	257.1	34.9	259.8	65.5
W10X49	30	96.1	15.6	203.3	28.3	252.6	52.3
W10X49	35	79.6	13.4	162.3	23.8	245.2	43.5
W10X49	40	67.9	11.7	132.5	20.5	203.9	37.2
W10X49	45	59.2	10.4	110.6	18.1	169.0	32.5
W10X49	50	52.5	9.3	94.5	16.1	143.2	28.9
W10X45	1	152.8	92.8	152.8	146.1	153.2	148.5
W10X45	5	469.6	77.6	497.2	176.2	497.8	268.6
W10X45	10	307.4	43.9	524.6	93.1	527.7	174.6
W10X45	15	184.5	29.5	414.5	56.4	484.9	109.3
W10X45	20	127.8	22.2	275.6	39.8	436.6	76.4
W10X45	25	97.2	17.7	198.9	30.8	311.8	58.3
W10X45	30	78.3	14.7	150.8	25.2	232.6	47.0
W10X45	35	65.6	12.6	119.4	21.3	181.7	39.5
W10X45	40	56.4	11.0	98.3	18.5	147.6	34.0
W10X45	45	49.5	9.8	83.4	16.3	123.5	29.9
W10X45	50	44.1	8.8	72.3	14.6	105.9	26.7

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W10X39	1	130.4	79.2	130.4	124.4	130.7	126.4
W10X39	5	395.8	65.4	412.6	154.5	413.1	234.7
W10X39	10	281.1	36.9	398.7	82.1	399.7	154.8
W10X39	15	167.1	24.8	361.4	49.6	364.2	96.5
W10X39	20	114.2	18.6	256.2	34.7	344.9	66.9
W10X39	25	86.0	14.8	183.1	26.8	292.9	50.6
W10X39	30	68.8	12.3	139.8	21.8	219.1	40.7
W10X39	35	57.3	10.6	110.0	18.4	169.9	34.0
W10X39	40	49.1	9.2	89.8	15.9	137.0	29.2
W10X39	45	43.0	8.2	75.5	14.0	113.8	25.6
W10X39	50	38.2	7.4	65.1	12.6	96.9	22.8
W10X33	1	121.0	72.7	121.0	114.7	121.2	116.5
W10X33	5	329.8	55.3	339.8	139.9	340.6	215.4
W10X33	10	252.9	30.7	285.3	73.5	285.5	141.2
W10X33	15	149.2	20.5	258.3	43.8	258.4	86.7
W10X33	20	100.1	15.3	233.9	30.4	244.8	59.3
W10X33	25	74.4	12.2	166.4	23.3	235.8	44.5
W10X33	30	59.0	10.2	125.6	18.9	202.2	35.4
W10X33	35	48.8	8.7	99.7	15.9	157.1	29.5
W10X33	40	41.6	7.6	80.8	13.7	125.6	25.2
W10X33	45	36.3	6.8	67.4	12.1	103.5	22.0
W10X33	50	32.1	6.1	57.6	10.8	87.4	19.6
W10X30	1	143.8	91.9	143.8	136.7	144.1	139.2
W10X30	5	328.1	52.3	442.1	121.6	447.9	198.4
W10X30	10	170.7	27.7	392.0	58.6	522.5	114.7
W10X30	15	100.9	18.4	228.1	34.8	375.2	69.5
W10X30	20	70.0	13.7	148.2	24.7	238.8	48.3
W10X30	25	53.4	11.0	106.1	19.1	165.9	36.8
W10X30	30	43.1	9.1	80.0	15.6	122.9	29.7
W10X30	35	36.1	7.8	63.6	13.2	96.2	24.9
W10X30	40	31.1	6.8	52.7	11.5	78.4	21.5
W10X30	45	27.3	6.1	44.9	10.2	65.8	18.9
W10X30	50	24.4	5.4	39.0	9.1	56.6	16.9
W10X26	1	109.6	70.9	109.6	104.2	109.8	105.9
W10X26	5	280.2	42.5	339.8	100.9	342.5	161.5
W10X26	10	153.8	22.7	351.8	50.1	398.6	96.7
W10X26	15	90.1	15.1	210.4	29.5	347.5	58.7
W10X26	20	61.9	11.3	135.9	20.8	223.1	40.6
W10X26	25	46.8	9.0	97.0	16.1	154.6	30.8
W10X26	30	37.6	7.5	73.2	13.1	114.1	24.8
W10X26	35	31.4	6.4	57.8	11.1	88.6	20.7
W10X26	40	27.0	5.6	47.4	9.6	71.7	17.8
W10X26	45	23.6	4.9	40.1	8.5	59.8	15.7
W10X26	50	21.0	4.4	34.7	7.6	51.1	14.0

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W10X22	1	102.8	65.7	102.8	97.3	102.9	98.7
W10X22	5	252.8	36.7	295.9	92.6	298.2	150.1
W10X22	10	141.4	19.3	306.6	45.5	311.9	89.4
W10X22	15	81.2	12.7	197.9	26.5	296.0	53.5
W10X22	20	54.7	9.5	126.3	18.5	211.9	36.6
W10X22	25	40.9	7.5	88.8	14.2	145.7	27.5
W10X22	30	32.5	6.3	67.2	11.5	107.2	22.0
W10X22	35	27.0	5.4	52.8	9.7	82.6	18.3
W10X22	40	23.1	4.7	42.9	8.4	66.2	15.7
W10X22	45	20.2	4.2	36.0	7.4	54.7	13.7
W10X22	50	17.9	3.7	30.9	6.6	46.4	12.2
W10X19	1	141.5	87.5	141.6	131.4	141.9	135.2
W10X19	5	191.8	34.2	359.7	79.4	409.5	141.6
W10X19	10	86.2	16.9	200.3	33.8	330.1	69.3
W10X19	15	50.8	11.1	109.8	20.3	179.2	40.9
W10X19	20	35.6	8.2	71.3	14.5	111.9	28.4
W10X19	25	27.3	6.5	50.3	11.3	77.3	21.7
W10X19	30	22.1	5.4	38.4	9.3	57.9	17.5
W10X19	35	18.6	4.6	31.0	7.9	45.8	14.7
W10X19	40	16.1	4.0	25.9	6.8	37.7	12.7
W10X19	45	14.1	3.6	22.2	6.0	32.0	11.2
W10X19	50	12.6	3.2	19.5	5.4	27.8	10.0
W10X17	1	142.6	87.2	142.7	131.9	143.1	135.8
W10X17	5	179.6	31.2	340.1	75.7	380.9	137.8
W10X17	10	79.1	15.1	189.3	31.6	313.6	65.8
W10X17	15	45.8	9.9	102.3	18.8	169.7	38.2
W10X17	20	31.7	7.3	65.7	13.4	105.0	26.3
W10X17	25	24.1	5.8	46.4	10.4	72.2	20.0
W10X17	30	19.5	4.8	35.1	8.5	53.6	16.1
W10X17	35	16.3	4.1	28.0	7.2	42.1	13.5
W10X17	40	14.1	3.6	23.3	6.2	34.4	11.6
W10X17	45	12.3	3.2	19.9	5.5	29.0	10.2
W10X17	50	11.0	2.8	17.3	4.9	25.0	9.1
W10X15	1	143.6	86.7	143.7	132.7	144.0	136.8
W10X15	5	167.4	28.5	316.0	72.0	338.5	133.8
W10X15	10	72.4	13.6	177.6	29.5	294.1	62.2
W10X15	15	41.2	8.8	94.7	17.5	159.2	35.7
W10X15	20	28.2	6.5	60.1	12.4	97.8	24.4
W10X15	25	21.3	5.1	42.6	9.6	67.0	18.4
W10X15	30	17.1	4.3	31.9	7.8	49.3	14.8
W10X15	35	14.3	3.6	25.3	6.6	38.5	12.3
W10X15	40	12.3	3.2	20.9	5.7	31.2	10.6
W10X15	45	10.8	2.8	17.7	5.1	26.2	9.2
W10X15	50	9.6	2.5	15.4	4.5	22.5	8.2

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W10X12	1	101.9	63.0	101.9	94.6	102.1	97.0
W10X12	5	139.8	21.7	225.6	57.1	228.3	104.6
W10X12	10	62.8	10.4	157.8	23.9	220.7	50.5
W10X12	15	35.0	6.7	84.7	14.0	145.0	28.9
W10X12	20	23.5	4.9	53.0	9.8	88.7	19.6
W10X12	25	17.6	3.9	37.2	7.6	60.3	14.7
W10X12	30	14.0	3.2	28.0	6.1	44.2	11.7
W10X12	35	11.6	2.7	21.9	5.2	34.1	9.7
W10X12	40	9.9	2.4	17.9	4.5	27.4	8.3
W10X12	45	8.7	2.1	15.0	4.0	22.7	7.3
W10X12	50	7.7	1.9	12.9	3.5	19.3	6.5
W8X67	1	519.7	264.9	520.0	479.6	525.1	503.9
W8X67	5	995.9	186.7	1363.8	396.3	1386.1	681.3
W8X67	10	497.4	99.4	1013.8	182.9	1249.1	359.5
W8X67	15	308.8	66.7	610.2	113.3	911.0	220.7
W8X67	20	222.2	50.1	401.9	82.3	601.0	157.4
W8X67	25	173.4	40.1	293.8	64.6	432.7	122.4
W8X67	30	142.2	33.4	230.4	53.3	333.9	100.2
W8X67	35	120.5	28.6	189.4	45.3	270.5	84.9
W8X67	40	104.6	25.0	160.8	39.5	227.0	73.8
W8X67	45	92.5	22.2	139.8	35.0	195.5	65.2
W8X67	50	82.8	20.0	123.7	31.4	171.7	58.5
W8X58	1	443.4	222.7	443.6	407.6	447.5	427.6
W8X58	5	903.6	157.6	1191.9	346.2	1193.6	593.4
W8X58	10	448.9	83.7	916.0	159.6	975.8	314.3
W8X58	15	274.9	56.1	560.0	98.0	833.3	191.4
W8X58	20	196.3	42.1	370.8	70.8	560.1	135.7
W8X58	25	152.4	33.6	267.9	55.5	399.8	105.0
W8X58	30	124.6	28.0	208.1	45.7	305.7	85.8
W8X58	35	105.4	24.0	169.8	38.9	245.7	72.5
W8X58	40	91.3	21.0	143.3	33.8	204.8	62.9
W8X58	45	80.6	18.7	124.0	29.9	175.3	55.6
W8X58	50	72.2	16.8	109.4	26.8	153.3	49.8
W8X48	1	275.4	143.2	275.5	255.2	277.2	264.9
W8X48	5	734.8	117.1	825.8	257.9	826.5	421.9
W8X48	10	391.0	63.3	684.9	124.8	687.0	238.9
W8X48	15	236.9	42.5	497.6	75.9	622.9	146.4
W8X48	20	167.6	31.9	334.3	54.6	507.8	103.4
W8X48	25	129.4	25.5	239.0	42.7	361.5	79.8
W8X48	30	105.3	21.2	183.5	35.1	273.8	65.1
W8X48	35	88.8	18.2	148.3	29.8	218.0	54.9
W8X48	40	76.8	15.9	124.2	25.9	180.2	47.6
W8X48	45	67.7	14.1	106.9	22.9	153.2	42.0
W8X48	50	60.5	12.7	93.8	20.5	133.1	37.6

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W8X40	1	247.6	122.3	247.6	227.3	249.1	236.4
W8X40	5	599.0	97.0	623.7	228.6	624.3	378.2
W8X40	10	348.4	51.8	483.6	109.3	484.2	211.5
W8X40	15	206.8	34.7	431.1	65.4	436.8	127.3
W8X40	20	144.0	26.0	301.0	46.6	412.3	88.8
W8X40	25	110.1	20.8	217.3	36.3	333.4	68.0
W8X40	30	89.1	17.3	164.6	29.7	250.2	55.1
W8X40	35	74.8	14.8	131.4	25.2	197.1	46.4
W8X40	40	64.5	12.9	108.9	21.9	161.2	40.0
W8X40	45	56.7	11.5	92.9	19.4	135.8	35.3
W8X40	50	50.6	10.3	81.0	17.3	117.1	31.5
W8X35	1	183.9	92.1	183.9	169.5	184.7	175.2
W8X35	5	469.1	79.5	479.7	189.3	480.0	305.1
W8X35	10	316.2	42.9	373.6	93.2	373.8	178.1
W8X35	15	187.3	28.8	336.9	55.6	337.2	107.5
W8X35	20	129.3	21.6	277.5	39.4	319.5	74.7
W8X35	25	98.2	17.2	200.7	30.6	304.4	56.9
W8X35	30	79.1	14.3	152.3	25.0	233.8	46.0
W8X35	35	66.2	12.3	120.7	21.2	183.2	38.6
W8X35	40	56.9	10.7	99.4	18.4	149.0	33.3
W8X35	45	49.9	9.5	84.3	16.2	124.8	29.3
W8X35	50	44.5	8.6	73.1	14.5	107.0	26.2
W8X31	1	163.0	81.5	163.0	149.9	163.7	154.7
W8X31	5	379.8	69.5	384.7	171.8	384.9	276.8
W8X31	10	285.3	37.4	295.9	84.6	295.9	162.8
W8X31	15	173.1	25.0	266.9	50.3	266.7	97.6
W8X31	20	118.2	18.7	250.5	35.4	253.0	67.2
W8X31	25	89.1	15.0	187.8	27.4	243.8	51.0
W8X31	30	71.4	12.5	143.8	22.3	222.2	41.0
W8X31	35	59.5	10.7	113.1	18.9	173.6	34.3
W8X31	40	51.0	9.3	92.5	16.4	140.4	29.5
W8X31	45	44.7	8.3	77.9	14.5	116.9	25.9
W8X31	50	39.7	7.4	67.2	12.9	99.7	23.1
W8X28	1	185.5	91.8	185.5	169.0	186.4	175.8
W8X28	5	462.5	65.9	524.3	154.9	526.6	260.6
W8X28	10	232.7	34.6	446.4	72.0	448.1	140.3
W8X28	15	136.5	23.1	304.8	43.2	411.3	84.1
W8X28	20	95.0	17.3	198.5	30.9	314.9	58.8
W8X28	25	72.7	13.8	141.8	24.1	219.7	45.1
W8X28	30	58.8	11.5	107.3	19.7	163.7	36.6
W8X28	35	49.4	9.8	85.8	16.7	128.6	30.8
W8X28	40	42.6	8.6	71.2	14.5	105.2	26.6
W8X28	45	37.4	7.6	60.8	12.9	88.7	23.4
W8X28	50	33.4	6.9	53.1	11.5	76.5	21.0

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W8X24	1	139.8	70.4	139.8	127.8	140.3	132.2
W8X24	5	373.8	53.6	393.2	129.1	394.5	212.8
W8X24	10	211.4	28.4	333.3	61.7	333.8	118.7
W8X24	15	122.4	18.9	281.7	36.6	306.6	71.0
W8X24	20	84.1	14.1	182.8	26.0	289.4	49.2
W8X24	25	63.8	11.3	130.8	20.2	206.2	37.5
W8X24	30	51.4	9.4	98.7	16.5	152.7	30.3
W8X24	35	43.0	8.0	78.1	14.0	119.0	25.5
W8X24	40	37.0	7.0	64.3	12.1	96.5	22.0
W8X24	45	32.4	6.2	54.5	10.7	80.8	19.3
W8X24	50	28.9	5.6	47.3	9.6	69.2	17.3
W8X21	1	163.1	84.9	163.1	147.4	163.8	153.8
W8X21	5	332.3	47.8	475.1	113.4	480.5	197.8
W8X21	10	152.5	24.4	359.0	50.3	460.7	100.4
W8X21	15	89.1	16.2	198.5	30.3	325.9	59.6
W8X21	20	62.1	12.1	128.5	21.7	204.3	41.6
W8X21	25	47.6	9.6	91.0	16.9	141.1	31.9
W8X21	30	38.5	8.0	69.1	13.9	105.1	25.9
W8X21	35	32.4	6.9	55.3	11.8	82.7	21.8
W8X21	40	27.9	6.0	46.1	10.2	67.8	18.9
W8X21	45	24.5	5.3	39.4	9.0	57.2	16.6
W8X21	50	21.9	4.8	34.4	8.1	49.4	14.8
W8X18	1	149.5	76.8	149.6	134.6	150.1	140.3
W8X18	5	300.9	40.8	380.1	102.9	382.7	181.8
W8X18	10	138.0	20.6	327.6	45.0	337.2	91.0
W8X18	15	78.8	13.6	183.7	26.7	304.6	53.3
W8X18	20	54.1	10.1	116.9	19.0	190.9	36.8
W8X18	25	41.0	8.1	83.4	14.8	131.4	28.0
W8X18	30	33.0	6.7	62.5	12.1	96.8	22.6
W8X18	35	27.6	5.7	49.5	10.2	75.4	19.0
W8X18	40	23.7	5.0	40.8	8.9	61.2	16.4
W8X18	45	20.8	4.4	34.7	7.9	51.2	14.4
W8X18	50	18.6	4.0	30.1	7.0	43.9	12.8
W8X15	1	220.7	106.5	220.8	192.0	222.4	205.9
W8X15	5	226.4	38.0	475.8	92.3	527.3	177.7
W8X15	10	92.1	18.4	217.0	37.0	362.9	76.7
W8X15	15	54.0	12.0	115.6	22.5	187.9	44.8
W8X15	20	37.8	8.9	74.2	16.2	116.1	31.2
W8X15	25	29.1	7.1	52.6	12.7	80.4	23.9
W8X15	30	23.6	5.9	40.4	10.4	60.4	19.4
W8X15	35	19.9	5.0	32.6	8.8	48.0	16.3
W8X15	40	17.2	4.4	27.4	7.7	39.6	14.1
W8X15	45	15.1	3.9	23.6	6.8	33.7	12.4
W8X15	50	13.5	3.5	20.7	6.1	29.3	11.1

Table C-1 Continued

Shape Name	Length [ft]	No Bracing: Straight Buckling Stress [ksi]	No Bracing: Tapered Buckling Stress [ksi]	Mid-Span Bracing: Straight Buckling Stress [ksi]	Mid-Span Bracing: Tapered Buckling Stress [ksi]	Third-Span Bracing: Straight Buckling Stress [ksi]	Third-Span Bracing: Tapered Buckling Stress [ksi]
W8X13	1	210.6	100.4	210.8	183.8	212.2	197.3
W8X13	5	207.5	33.4	402.8	85.1	409.3	166.5
W8X13	10	82.5	16.0	200.5	33.6	336.7	70.4
W8X13	15	47.4	10.4	105.1	20.3	173.9	40.6
W8X13	20	32.9	7.7	67.4	14.5	106.9	28.1
W8X13	25	25.1	6.1	47.3	11.3	73.3	21.4
W8X13	30	20.3	5.1	35.9	9.3	54.6	17.3
W8X13	35	17.1	4.3	28.8	7.9	43.0	14.5
W8X13	40	14.7	3.8	24.0	6.8	35.2	12.5
W8X13	45	12.9	3.4	20.6	6.1	29.8	11.0
W8X13	50	11.5	3.0	18.0	5.4	25.8	9.8
W8X10	1	112.8	57.5	112.8	99.7	113.2	104.8
W8X10	5	167.4	22.7	246.1	60.2	247.2	112.8
W8X10	10	70.2	10.9	177.5	24.6	223.1	51.2
W8X10	15	39.2	7.1	93.2	14.6	158.9	29.4
W8X10	20	26.6	5.3	58.5	10.3	96.7	20.2
W8X10	25	20.0	4.2	41.4	8.0	66.0	15.3
W8X10	30	16.1	3.5	31.0	6.6	48.4	12.3
W8X10	35	13.4	3.0	24.4	5.5	37.5	10.3
W8X10	40	11.5	2.6	20.1	4.8	30.3	8.8
W8X10	45	10.1	2.3	17.0	4.2	25.3	7.8
W8X10	50	8.9	2.1	14.7	3.8	21.6	6.9
W6X25	1	428.4	165.9	429.4	356.0	435.4	392.4
W6X25	5	586.7	89.6	681.0	207.2	681.7	390.1
W6X25	10	254.3	45.4	537.0	87.5	547.1	174.4
W6X25	15	152.9	30.2	314.8	54.1	483.7	104.5
W6X25	20	108.8	22.6	204.4	39.3	312.0	74.2
W6X25	25	84.4	18.1	147.3	30.9	220.6	57.6
W6X25	30	69.0	15.0	114.5	25.5	168.2	47.1
W6X25	35	58.4	12.9	93.4	21.7	135.1	39.9
W6X25	40	50.6	11.3	78.9	18.9	112.6	34.6
W6X25	45	44.6	10.0	68.3	16.7	96.5	30.6
W6X25	50	40.0	9.0	60.3	15.0	84.4	27.4
W6X20	1	299.5	117.5	299.8	251.6	302.9	273.0
W6X20	5	437.9	67.4	446.3	164.1	446.6	304.1
W6X20	10	218.2	34.1	358.2	69.5	358.5	138.1
W6X20	15	128.1	22.7	277.6	42.4	329.9	81.7
W6X20	20	89.9	16.9	181.8	30.6	281.8	57.4
W6X20	25	69.1	13.5	128.8	24.0	196.9	44.3
W6X20	30	56.2	11.3	98.4	19.7	148.0	36.1
W6X20	35	47.3	9.6	79.3	16.8	117.3	30.5
W6X20	40	40.9	8.4	66.3	14.6	96.6	26.4
W6X20	45	36.0	7.5	57.0	12.9	82.0	23.3
W6X20	50	32.2	6.7	49.9	11.6	71.1	20.9

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W6X15	1	272.8	101.7	272.9	228.6	275.6	249.5
W6X15	5	255.6	51.8	255.7	143.0	255.9	273.1
W6X15	10	182.7	25.8	204.9	58.4	205.0	119.0
W6X15	15	103.8	17.1	188.7	34.9	188.9	68.6
W6X15	20	71.0	12.7	154.3	24.9	180.8	47.5
W6X15	25	53.8	10.2	110.2	19.4	172.5	36.2
W6X15	30	43.3	8.4	82.9	16.0	128.3	29.3
W6X15	35	36.2	7.2	65.6	13.5	99.9	24.6
W6X15	40	31.1	6.3	54.0	11.8	81.1	21.2
W6X15	45	27.3	5.6	45.8	10.4	67.8	18.7
W6X15	50	24.3	5.0	39.7	9.3	58.1	16.7
W6X16	1	383.2	145.0	390.3	303.1	396.9	348.4
W6X16	5	323.6	58.0	711.3	124.2	893.9	240.4
W6X16	10	135.2	28.8	285.0	51.6	454.7	102.3
W6X16	15	83.3	19.1	154.8	32.5	237.4	62.4
W6X16	20	60.1	14.2	102.0	23.8	151.7	44.9
W6X16	25	47.0	11.4	75.5	18.8	109.7	35.1
W6X16	30	38.6	9.5	60.0	15.6	85.4	28.9
W6X16	35	32.8	8.1	49.8	13.3	69.9	24.5
W6X16	40	28.5	7.1	42.6	11.6	59.2	21.3
W6X16	45	25.2	6.3	37.2	10.3	51.4	18.9
W6X16	50	22.6	5.7	33.1	9.2	45.4	16.9
W6X12	1	354.6	125.7	355.0	275.0	361.0	319.1
W6X12	5	272.4	43.8	514.6	104.5	517.9	209.2
W6X12	10	106.4	21.3	242.5	41.7	400.6	84.7
W6X12	15	63.4	14.1	130.0	25.9	205.8	50.3
W6X12	20	45.0	10.5	83.1	18.9	127.5	35.6
W6X12	25	34.9	8.3	59.9	14.8	89.7	27.6
W6X12	30	28.5	6.9	46.6	12.2	68.4	22.5
W6X12	35	24.1	5.9	38.1	10.4	55.0	19.0
W6X12	40	20.9	5.2	32.3	9.1	45.9	16.5
W6X12	45	18.4	4.6	28.0	8.0	39.4	14.6
W6X12	50	16.5	4.1	24.7	7.2	34.5	13.1
W6X9	1	200.7	75.0	200.7	160.1	202.8	179.3
W6X9	5	226.4	29.7	303.8	75.4	304.0	147.7
W6X9	10	87.6	14.5	212.9	30.1	261.6	61.2
W6X9	15	50.5	9.5	111.3	18.4	183.6	35.8
W6X9	20	35.2	7.1	71.6	13.3	112.9	25.1
W6X9	25	27.0	5.6	50.3	10.4	77.6	19.4
W6X9	30	21.9	4.7	38.3	8.6	57.9	15.8
W6X9	35	18.4	4.0	30.8	7.3	45.8	13.3
W6X9	40	15.9	3.5	25.8	6.3	37.6	11.5
W6X9	45	14.0	3.1	22.1	5.6	31.9	10.1
W6X9	50	12.5	2.8	19.4	5.0	27.6	9.1

Table C-1 Continued

Shape Name	Length [ft]	No Bracing Straight Buckling Stress [ksi]	No Bracing Tapered Buckling Stress [ksi]	Mid-Span Bracing Straight Buckling Stress [ksi]	Mid-Span Bracing Tapered Buckling Stress [ksi]	Third-Span Bracing Straight Buckling Stress [ksi]	Third-Span Bracing Tapered Buckling Stress [ksi]
W6X8.5	1	210.8	76.7	210.9	168.1	213.2	189.6
W6X8.5	5	220.7	28.7	572.5	75.1	265.7	149.2
W6X8.5	10	83.9	13.9	420.1	29.6	227.4	60.6
W6X8.5	15	48.0	9.1	233.8	18.0	178.2	35.3
W6X8.5	20	33.3	6.8	152.4	13.0	109.2	24.7
W6X8.5	25	25.4	5.4	111.9	10.2	74.9	19.0
W6X8.5	30	20.6	4.5	88.2	8.4	55.7	15.4
W6X8.5	35	17.3	3.8	72.8	7.1	43.8	13.0
W6X8.5	40	14.9	3.4	62.0	6.2	35.9	11.2
W6X8.5	45	13.1	3.0	54.0	5.5	30.4	9.9
W6X8.5	50	11.7	2.7	47.9	4.9	26.2	8.8
W5X19	1	539.7	180.2	550.2	404.9	547.1	463.6
W5X19	5	525.8	85.8	824.9	179.1	787.8	341.3
W5X19	10	224.9	43.3	347.5	76.4	650.0	147.8
W5X19	15	139.7	28.8	192.5	48.5	386.9	91.4
W5X19	20	101.3	21.6	131.6	35.6	251.1	66.2
W5X19	25	79.4	17.2	99.9	28.2	182.9	52.1
W5X19	30	65.4	14.4	80.7	23.3	143.2	43.0
W5X19	35	55.6	12.3	67.7	19.9	117.6	36.6
W5X19	40	48.4	10.8	58.4	17.4	99.8	31.9
W5X19	45	42.8	9.6	51.4	15.4	86.7	28.2
W5X19	50	38.4	8.6	45.9	13.8	76.7	25.4
W5X16	1	460.9	150.9	468.7	346.6	466.3	393.8
W5X16	5	470.6	70.8	572.5	155.3	573.1	298.5
W5X16	10	197.0	35.5	420.1	65.3	474.4	126.9
W5X16	15	120.5	23.6	233.8	41.2	357.3	77.5
W5X16	20	86.6	17.7	152.4	30.1	228.6	55.8
W5X16	25	67.7	14.1	111.9	23.8	164.1	43.7
W5X16	30	55.5	11.8	88.2	19.7	126.9	36.0
W5X16	35	47.1	10.1	72.8	16.8	103.2	30.6
W5X16	40	40.9	8.8	62.0	14.6	86.9	26.6
W5X16	45	36.2	7.8	54.0	13.0	75.1	23.6
W5X16	50	32.4	7.0	47.9	11.7	66.1	21.2
W4X13	1	1161.9	281.3	1222.4	687.9	1221.4	902.0
W4X13	5	422.4	84.3	824.9	167.7	835.8	343.1
W4X13	10	180.1	41.8	347.5	73.5	529.3	141.9
W4X13	15	113.6	27.7	192.5	47.3	285.0	88.6
W4X13	20	83.0	20.8	131.6	35.0	189.2	64.6
W4X13	25	65.4	16.6	99.9	27.8	140.8	50.9
W4X13	30	54.0	13.8	80.7	23.1	112.1	42.1
W4X13	35	46.1	11.8	67.7	19.7	93.2	35.9
W4X13	40	40.1	10.4	58.4	17.2	79.8	31.3
W4X13	45	35.6	9.2	51.4	15.3	69.9	27.7
W4X13	50	31.9	8.3	45.9	13.7	62.2	24.9