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Development of an Optimized Short-span Steel Bridge Package

Lora B. Freeman

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Abstract

Development of an Optimized Short-span Steel Bridge Package

Lora B. Freeman

A recent study from the West Virginia Department of Transportation indicates that a number of existing bridges in West Virginia are structurally deficient or functionally obsolete. As there are not sufficient funds to replace or rehabilitate all of the insufficient structures a means of economically replacing the inadequate structures in a time efficient manner is necessary. One method of conserving time and resources is by employing standardized bridge plans. Therefore, the focus of this effort is on the development of a optimized short-span steel bridge package.

This study focused on developing optimized plans for two roadway cross-sections for spans between 40 feet and 120 feet in 5 ft. intervals. The girders designed in this effort were optimized based on weight and included members detailed at various cross-section depth to span length ratios and incorporated both homogeneous and hybrid configurations as well as rolled sections.

Additional optimization studies were performed to assess the feasibility of incorporating limited ranges of plate sizes which is a practice felt by steel bridge fabricators to offer significant economy. Also, design studies were performed for bridge systems constructed in the simply-supported for dead-load continuous for live-load condition. This system has the potential to offer construction economy due to the reduction of bolted field splices and potential elimination of erection crane requirements while maintaining similar girder height requirements.

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Chapter 1

Introduction

1.1 Background

A number of the existing bridges in West Virginia are structurally deficient or functionally obsolete. According to the West Virginia Bridge Data released by the Maintenance Division in July of 2003, 24.4% of all bridges in West Virginia with spans of 100 feet or less are functionally obsolete and 14.9% are structurally deficient. Unfortunately, there are not sufficient funds to replace and rehabilitate all of the insufficient structures. Therefore, developing a means of economically replacing the inadequate structures in a time efficient manner is necessary. The development of a standardized bridge package is one method of conserving time and resources.

Standardized plans for short-span bridges have proved beneficial in many types of structures. In the past, plans have been developed for concrete, timber, and steel superstructures, as well as plans for abutments, piers, and pier caps. The focus of this research is to develop a series of short-span bridge girders based on the AASHTO LRFD Specifications. These designs will include both homogeneous and hybrid plate girders as well as rolled beams.

1.2 Objectives

The focus of this research is to provide a design package of standardized short-span steel bridge girders to save time and resources during the construction of new structures and replacement of existing bridges. The standardized plans provide a series of girders for span lengths ranging from 40 to 120 ft. In the process of developing the design package three design studies were conducted: an optimized design study, a limited plate size design study, and a two-span design study that compares simple-span made continuous designs incorporating cover plates in the negative bending region to two-span continuous designs.

The optimized designs, based on girder weight, were completed for span lengths of 40 to 120 ft., in increments of 5 ft. The designs include plate girders with homogeneous and hybrid material configurations, as well as for rolled beams. In addition, sections for three span-to-depth ratios were developed, unless restricted by the minimum permitted web depth of 24 in. Also, unstiffened and partially stiffened web designs are included in this series of designs.

In addition to the optimized designs, a design series was developed based on a limited number of plate thicknesses and web depths. The primary objective of this study is to investigate the possibility of reducing expenses by purchasing certain plate thicknesses in bulk. In addition, the material necessary to fabricate a plate girder is readily available. This series includes designs for spans from 40 to 120 ft., in increments of 10 ft., and the plates were limited to the following:

- Web depths: 24”, 32”, 40”, and 48”
- Plate thicknesses: ½”, ¾”, 1”, 1–½”, 1–¾”, and 2”

Then, two-span designs with equal span configurations were completed by using the limited plate designs and applying cover plates in the negative bending region for span lengths from 80 ft. to 120 ft., in increments of 10 ft. The objective of this study is to investigate the economy of designs that are simply-supported for the non-composite dead load and continuous for live load and composite dead load by comparing these designs to designs which are continuous for both dead and live loads.

The final study assesses the AASHTO LRFD Specifications for hybrid HPS 100W steel I-girders. Both the Second and Third Editions of the Specifications restrict girders fabricated from steel with a nominal yield strength greater than 70 ksi to a maximum flexural capacity equal to the yield moment, while girders fabricated from lower grades of steel are permitted to reach their plastic moment (AASHTO 2001 and AASHTO 2003). Therefore, a parametric study assessing the ultimate flexural capacity of hybrid HPS 100W/ HPS 70W sections in negative bending was conducted to determine if these limitations can be removed. Three-dimensional non-linear finite element analysis was performed to determine the ultimate bending capacity for the series of hypothetical representative girders developed to span the range of feasible I-girder sections.

1.3 Organization of Thesis

This work contains eight chapters. The second chapter discusses common practices to economize steel-stringer bridges, in addition to standardized bridge packages and rapid construction techniques that are currently being employed.

The third chapter reviews the fundamentals of the Second and Third Editions of the AASHTO LRFD Bridge Design Specifications for the design of steel I-girder sections. This chapter presents design loads, lateral distribution factors, and the assessment of the resistance of composite steel I-girder sections.

Chapter four presents the parametric study focused on optimized short-span steel I-girder designs, along with observed trends. The optimized sections were designed for two cross-sections and three types of stringers: homogeneous plate girder, hybrid plate girder, and rolled beam. The fifth chapter discusses the limited plate size designs and presents a comparison of the designs to the optimized sections from the previous chapter. Chapter six contains a two-span design study which compares the simple-span made continuous designs and the continuous sections. The seventh chapter presents a comparison of the estimated flexural capacity of girders from the AASHTO LRFD specifications, neglecting the restriction based on the steel’s yield strength, and the ultimate negative bending capacity obtained from a non-linear finite element analysis study. The summary and conclusions of the studies are presented in chapter eight.

Chapter 2

Literature Review

2.1 Background

A number of the existing bridges are in need of repair or replacement, but sufficient funding is not available. As a result, the focus of the bridge industry is towards time saving techniques that result in a quality product that requires little maintenance and has a long service life. This can be achieved through developing standardized bridge designs and by employing rapid construction techniques.

Standardized bridge plans allow efficient, economical designs to be duplicated, while reducing the amount of time absorbed during the design process. Some of the advantages of standardized bridge plans are the reduced design and construction costs and the ability to implement improved details. Once the initial design process has been completed, the only cost associated with the design is the updating of details to reflect improvements in design practices. As a result, the standardized bridge plans enable the wide-range implementation of advanced, cost effective details (Holt and Medlock 2004).

In addition to saving resources during the design process, economy of the construction process is improved by the contractor's familiarity with the plans and the standardization of formwork (Holt and Medlock 2004). Savings can be realized because a precise cost estimate can be submitted due to the contractor's previous experience with the plans. In addition, the cast-in-place deck of similar designs requires the same formwork, which eliminates the cost associated with the purchase of custom forms for each project.

This chapter discusses some general steel I-girder bridge design guidelines, standardized bridge plans, and innovative rapid construction techniques currently being employed.

2.2 General Bridge Design Guidelines

The economy and practicality of a bridge design depends on more than just an optimum weight design; careless details can add significant cost to a structure without additional value. Therefore, this section presents an overview of common practices in the bridge industry that are felt to improve the economy of steel-stringer bridge designs.

2.2.1 Weight Optimization

As previously mentioned, weight optimization does not ensure an economical design. Some plate thicknesses may not be readily available to the fabricator; therefore, it is important to consult with fabricators to determine the most economical options (Steel Works 2004). By contacting fabricators in the area and becoming more familiar with common plate sizes, the cost-effectiveness of a bridge system can be improved, even though the design is not optimized based on weight.

2.2.2 Flange Transitions

Another important factor to consider is the cost of fabrication when considering flange transitions. For a flange transition from a thicker plate to a thinner plate to be economical between 800 to 1000 pounds of steel must be saved to offset fabrication costs (TxDOT 2000). Also, the plate should remain uniform for a minimum of 10 feet. An additional consideration that must be addressed when considering a flange transition is the number of plate sizes a particular design requires, including the connection plates and stiffeners. The plates are most economically purchased in widths of at least 48 inches; therefore, repeated plate thicknesses can reduce the material costs. As a result, a design that requires only a few different plate sizes may be more economical than a lighter design which requires a variety of plate thicknesses.

The designer must also consider the additional expenses associated with the fabrication of the flange transitions. Since material costs have remained constant and labor costs have steadily increased, the purchase of the additional steel may be more cost-effective than the expenses associated with the fabrication of the transition (Steel Works 2004).

Unlike flange transitions in thickness, flange transitions in width should not be considered because this will complicate the fabrication process and the construction of deck formwork, reducing the economical efficiency of the structure (TxDOT 2000).

2.2.3 Number of Girders Lines

Research has concluded that savings can be realized by the elimination of a girder line, when clearance is not an issue. For example, Clingenpeel and Barth (2003) conducted a parametric design study on a three-span continuous bridge system and concluded that cost savings of 13 percent was realized by selecting a 7-girder system instead of a 9-girder system. Another advantage to removing a girder line is the reduced number of field sections, cross-frames, and bearings that must be fabricated and placed.

However, the designer must keep in mind the minimum number of girders that should be used in a cross-section is four in order to maintain traffic flow during deck replacement, and a practical maximum girder spacing is 10 feet. Even though a girder spacing larger than 10 feet is possible, special formwork considerations may be required, decreasing the economy of the design (AISI 1996).

2.2.4 Optional Deck Forming

Since each fabricator and contractor has different manufacturing and construction practices, another technique to improve the economy of a design is to provide optional details in the plans whenever possible. For example, several of the most economical alternatives for the cross-frame designs and deck forms should be included in the bridge design plans (Steel Works 2004). By allowing the fabricator and contractor the option of metal deck forms, precast concrete deck forms, and forms constructed from plywood, the most economical alternative will be available for construction.

2.2.5 Uncoated Weathering Steel

The type of steel specified has a significant impact on the economy of a bridge design. To preserve the cost-effectiveness of a design, the use of uncoated weathering steel should be specified in the plans due to the reduced initial costs, as well as reduced maintenance costs (AISI 1996). The reduction in the preliminary costs for weathering steel is a result eliminating the painting process, which has become increasingly costly in the recent past due to environmental concerns. Similarly, the life-cycle costs of a weathering steel bridge are smaller than a regular steel structure as a result of eliminating the expenses associated with the re-painting process.

Although the use of weathering steel is applicable in many locations, the designer should keep in mind that weathering steel does not perform properly in some environments, including extremely humid conditions and environments with corrosive chemicals, (TxDOT 2000). In addition, if painting is required, weathering steel should not be specified because of the increased material cost compared to regular steel.

2.2.6 High Performance Steel

Another material consideration is the application of high performance steels. A homogeneous HPS 70W steel girder results in lighter sections than a conventional 50 ksi design, but generally costs more than the 50 ksi design. In contrast, a hybrid material configuration with a HPS 70W tension flange and 50 ksi web and compression flange in the positive bending region and HPS 70W flanges and a 50 ksi web in the negative bending region offers an economical option for steel girders over the conventional homogeneous 50 ksi designs (Clingenpeel 2001).

In addition to the increased cost of high performance steel, other parameters that limit the economy of high strength steel designs are the design limit states that depend on the geometric properties of the girder rather than the steel strength, such as the live-load deflection limit and the fatigue limit state. For designs which satisfy the strength limit state, but fail deflection or fatigue, the only means to satisfy these limit states is to increase the section. Since the advantage of the high strength steel is the reduction in the required steel, typically the economy of these designs is affected by the previously mentioned limit states.

In the past, designs generally satisfied the Live Load Deflection Criteria, but with the introduction of the high strength steels into the bridge market, designs were being controlled by this limit state.

As mentioned previously, the fatigue limit state also significantly affects the economy of a high performance steel design, but this can be controlled to an extent by avoiding details with low fatigue resistance. Nevertheless, a study by Homma and Sause (1995) determined for the bridge system studied designs composed of a steel with a yield strength higher than 76 ksi would result in the same optimized section due to the Category C fatigue limits.

2.2.7 Substructure Design

Both the superstructure and substructure should be considered when determining the final bridge design because the type and location of the substructure can have a significant effect on the initial and life-cycle costs of a bridge (AISI 1996). Optimum span configurations in which the bending moments are balanced may require an expensive substructure; therefore the cost of the superstructure and the substructure must be considered when conducting a weight optimization study.

2.2.8 Expansion Joints

Significant construction and maintenance expenses are associated with expansion joints, which eventually leak water and deicing chemicals that accelerate the corrosion of the steel girders. With the development of integral abutments to allow for the thermal expansion of the superstructure, jointless decks have been developed. Not only is the economy of the design improved by employing a jointless deck, integral abutments also reduce the cost of materials and labor compared to regular abutments (Romano 2004). Therefore, an integral abutment with a jointless deck system should be used whenever possible to ensure low-maintenance of a structure.

2.2.9 Constructibility

In many situations, the engineer does not give enough consideration to the constructibility of the design. This can result in structures that are difficult or even impossible to build. Therefore, it is imperative the strength and stability of the design are investigated during each deck casting sequence, and adequate lateral bracing for applicable construction conditions is provided. To economically satisfy these requirements the designer should avoid narrow compression flanges because the structure may require an excessive number of cross-frames or supplemental rigging during construction, which significantly increases the cost of the system (AISI 1996). The flange width should be greater than 60 times the span length (TxDOT 2000).

In addition to the flange width, another consideration which must be addressed is the minimum plate thickness required. Excessive cupping of the flange during the welding process can be avoided by restricting the minimum flange plate thickness to ¾” (TxDOT 2000).

2.2.10 Inspectibility

Bridges are required to be inspected at least every two years; hence, the specifications mandate the designer create a bridge system in which the inspection is not difficult (AISI 1996). For many bridge systems, the inspector can adequately perform an inspection from a rigging truck, but more complicated structures may require special details, such as inspector walkways. In addition, when designing box girders, the designer should ensure the section is deep enough to comfortably accommodate the inspector, and that proper inspection access to the interior of the box is available.

2.3 Summary of Standardized Bridge Plans

Standardized bridge packages have been gaining popularity in the recent past, and a variety of organizations have funded the development of such plans. Therefore, this section discusses some of the standardized plans that are currently being implemented.

2.3.1 TxDOT Bridge Standards

Since ninety percent of the bridges in Texas are 120 feet or shorter, the Texas Department of Transportation has developed an extensive package of standardized bridge plans for short-span bridges with superstructures comprised of either concrete or steel (Holt and Medlock 2004). The concrete designs encompass five roadway widths, four skew angles, and six different types of bridges, while there are three roadway widths and three skew angles for both rolled beam and plate girder designs. In addition to the superstructure designs, a variety of miscellaneous standards, such as prestressed concrete piling and bridge approach slabs, are included in the package.

The concrete standardized bridge plans developed for the Texas Department of Transportation include designs using I-beams, box beams, slab beams, double-T beams, cast-in-place culverts, and precast box culverts (TxDOT 2004). The concrete bridges can be adjusted for skews of up to forty-five degrees, and the available roadway widths include 24, 28, 30, 38, and 44 feet, but most of the standardized bridges that are built have roadway widths of 24, 28, or 30 feet (Holt and Medlock 2004). The majority of the designs are based on Load and Resistance Factor Design (LRFD), and efforts are underway to have all of the concrete designs in accordance with the LRFD standards.

The steel beam superstructure designs are available in roadway widths of 24 ft., 28 ft., and 30 ft., along with skew angles up to 30 degrees (TxDOT 2004). The span lengths range from 30 ft. to 120 ft., in 5 ft. increments, and details are provided to construct two and three span systems. The standard drawings include eight rolled beam depths, and optional plate girders for each rolled section. In addition, all of the steel designs are conducted in accordance with the AASHTO LRFD Bridge Design Specifications.

2.3.2 AISI Short Span Steel Bridge Plans and Software

The American Iron and Steel Institute has developed a set of standardized short-span steel bridge plans along with design-aid software, which enables the user to customize designs to accommodate specific locations (AISI 1998). Rubeiz and Snyder (1996) report the designs included in the plans were discussed with fabricators and selected on the basis of simplicity, fatigue resistance, and economy. The bridge plans, which include more than 1,100 designs, help to serve as a guide to designers, but generally must be modified to meet the site conditions since the designs are for level horizontal grades and tangent crossings.

The package contains designs ranging from 20 ft. to 120 ft. in 5 ft. increments, and offer five roadway widths: 24, 28, 34, 40, and 44 feet (AISI 1998). The stringers are either plate girders (stiffened or unstiffened) or rolled beams (with or without cover plates). In addition, designs are presented for decks composed of normal and light weight concrete with both composite and noncomposite beams. All of the sections are currently homogeneous 50 ksi steel, HPS 70W is being developed (Rubeiz and Snyder 1996).

The package also includes plans for components such as elastomeric bearings and integral abutments. The designs included in the package are based on the Strength Design Method (Load Factor Design) of the AASHTO Standard Specifications for Highway Bridges, 16th Edition, including the 1997 Interim Specifications (AISI 1998).

2.3.3 Standardized Bridge Systems

An effort to compile the standardized bridge systems and components from the Highway Departments of various states across the country into a computer-aided tool has been completed by University of Alabama (Gopu 2004). All of the standardized designs, ranging from abutments to piles, have been compiled into a database that was developed using Microsoft Access and Microsoft Visual Basics. With a variety of standardized plans in one location, the developed computer tool is a valuable resource for bridge design.

2.4 Innovative Ideas for Rapid Construction

Along with standardized bridge plans, rapid construction techniques are being developed for efficient construction of new bridges as well as replacement of existing bridges. The benefits of rapid construction include improved work zone safety, the reduction in traffic congestion, less construction related impact on the environment, an increase in over-all structural quality, and lower construction costs (Ralls and Tang 2003). The construction time can be reduced by utilizing prefabricated elements or by constructing the entire bridge system off-site and then transporting the structure to the final location. The following sections provide a brief description of some innovative ideas that are currently being explored and implemented in the bridge industry to reduce construction time and increase the overall quality of the system.

2.4.1 Precast Concrete Deck Systems

Full and partial depth prestressed precast concrete panels have been developed to reduce construction time and increase work zone safety. The partial depth panels act as the stay-in-place deck forms. Once the forms are in place, the cast-in-place concrete is cast on top of the panels. By using a full depth prefabricated concrete deck, the entire process of erecting formwork and pouring the concrete has been eliminated, which significantly reduces construction time (Kuennen 2000). Another advantage of the prefabricated panels is the increased quality control over the product since the panels are manufactured in a factory where quality control is easily monitored. Composite action is achieved through the use of shears studs implemented in discreet pockets that are in turn grouted (Sprinkel 1985).

Another advantage of the prestressed deck panels over the cast-in-place deck is the elimination of shrinkage cracks, which reduce the life of the structure because de-icing chemicals and water penetrate the concrete (Kuennen 2000). To ensure a long service life it is important to provide a low permeability overlay and adequate cover of the reinforcing steel. In addition, the ends of the edge panels are covered with a small overhang to conceal the prestressing strands from the environment. A leveling bolt system may be employed to adjust final panel elevation.

In contrast to using a precast deck panel, a technique used in Germany involves placing a partial-depth concrete deck on steel or concrete beams before erection (FHWA

2004). This process eliminates the time consuming process of constructing formwork for the deck pour on site by placing beams with the partial-depth deck such that the edges of the slab meet. This method reduces time, and also increases the safety of the work site by eliminating the possibility of objects falling between the beams.

2.4.3 Precast Trapezoidal Beams

Badie et. al discuss the development of trapezoidal precast, pretensioned beams that can span up to 100 ft. and cover a larger surface area with fewer members. The beams have larger span-to-depth ratios enabling their use in low clearance applications. The top flanges of the trapezoidal beams extend past the web of the section to minimize the effect of differential rotation and to decrease the number of beams required in the bridge system. Three different connections were developed to join adjacent beams; two of which can only be employed with the closed box beams.

Traditional box beam bridges have been reported to have longitudinal reflective cracks, which allow water and deicing agents to penetrate the cracks causing spalling of the concrete. A transverse post tensioning system has been proposed to control the longitudinal reflective cracks, however, it is felt that this would significantly increase the costs of fabrication (Badie 1999).

The proposed box beams are relatively light compared to other box beams. Therefore, when heavy-lifting equipment is not available, the purposed box beams are an economical option (Badie 1999). In addition, the trapezoidal box beam bridges were designed to employ a cast-in-place topping, which will provide a smooth riding surface for the bridge. Another advantage of the proposed beams is the aesthetically-pleasing appearance due to the continuity of their form.

2.4.4 Fiber Reinforced Polymer Elements

Fiber reinforced polymer (FRP) elements have only recently been accepted for bridge applications. The light weight of the FRP makes it an attractive option for bridge deck replacement. In the past, timber decks have been placed on steel girders for short-span bridges, but as the bridges aged, it became apparent the timber decks accelerated the corrosion of the steel girders by retaining moisture and allowing water to seep through the deck. Since existing girder designs detailed for timber decks may not have sufficient capacity for a concrete deck; use of a lighter material such as FRP presents an attractive alternative, (NCHRP 2004).

The disadvantages of FRP deck panels are the lack of standard specifications, appropriate design methods, and long-term performance evaluation, (NCHRP 2004). With time, these will be developed through extensive research and field testing. In addition, even though the use of FRP can reduce the overall life cycle costs of a structure, there is a significant increase in the initial costs. Fortunately, as the fabrication process becomes more standardized, the cost of the FRP deck panels will decrease. Eventually the FRP deck system will become an economical option for typical bridge systems.

2.4.5 Prefabricated Bridge Systems

Another option to reduce construction time is to construct the entire bridge off-site and move the system into place. This method improves the safety of the construction site and eliminates traffic congestion during most of the construction process. A variety of techniques have been developed to move the structures, including: self propelled modular trailers, floating the bridges into place using a barge, vertically lifting the bridge, and numerous other processes (FHWA 2004).

2.5 Summary

Since the majority of the bridges are considered short-span bridges, an economic interest in developing rapid replacement and rehabilitation plans has emerged. This section has reviewed some basic bridge design techniques to maximize the economy of a design, discussed standardized bridge packages, and detailed some techniques for rapid construction. The focus of this research is on developing a standardized short-span steel bridge package by studying the general trends in short-span bridge design to develop an economical series of sections.

Chapter 3

Fundamental Steel Bridge Design Aspects of the AASHTO LRFD Bridge Design Specifications

3.1 Introduction

The American Association of State Highway Transportation Officials (AASHTO) has produced guidelines for bridge design which provide information about design loads, lateral distribution of live loads, force effects, and member strength and serviceability limitations (AASHTO 2001). This section details the Load and Resistance Factor Design Specifications (LRFD). The Second Edition of the AASHTO LRFD Bridge Design Code was released in 1998, followed by interims each year after until 2003. The Third Edition of the AASHTO LRFD Bridge Design Code was released in 2003, wherein comprehensive changes have been incorporated with respect to steel I-girder capacity (AASHTO 2003). The main goal of the revisions incorporated in the Third Edition of the Specifications was to organize and streamline the equations, with hopes of integrating and unify horizontally-curved girder design into Section 6.10 in the near future. The following sections detail the method for designing steel I-sections for both the Second and Third Editions of the AASHTO Specifications.

3.2 Design Loads

The I-girder sections are designed to carry a combination of factored dead loads, design vehicular live loads, and estimated construction loads. The dead load includes the self weight of the structure, as well as any loads associated with a future wearing surfaces, utility loads, and planned widenings. The live-load accounts for the static and dynamic forces exerted by the design vehicles and lane load.

3.2.1 Types of Design Loads

3.2.1.1 Dead Loads

The dead loads consist of a combination of noncomposite dead loads (DC1), composite dead loads (DC2), and the dead load of the non-integral wearing surface (DW). DC1 is applied to the steel section only and consist of the dead load applied before the concrete deck has reached 75% of its compressive strength, and includes the dead load of the steel girders, concrete deck, haunch, stay-in-place deck forms, and miscellaneous steel to account for the cross-frames and other details. DC2 is composed of the dead loads applied after the deck becomes composite. This includes the barriers, sidewalks, and railing. DW is the dead weight of the future wearing surface and utilities.

Composite section refers to the steel beam and concrete deck when acting as a single unit. The strain diagram of a composite section with complete interaction (i.e. no slip between the interfaces of the steel and concrete sections) varies linearly. The complete interaction between the materials is accomplished by the use of shear studs, which transfer the horizontal forces from the deck to the steel section. The long term dead loads (DC2) are applied to the long term composite section which accounts for the creep and shrinkage of the concrete. This is calculated by using three times the modular ratio instead of just the modular ratio.

3.2.1.2 Design Vehicular Loads

The live-load of the bridge is carried by the short-term composite section. The design live-load termed HL-93 is a combination of the design truck or tandem combined with the design lane load. The design truck, see Figure 3.1, is composed of a front axle load of eight kips followed by two axles with loads of 32 kips. The front spacing of the axles is 14 feet, while the back axles are spaced between 14 feet and 30 feet apart, wherever produces the largest extreme force effects, and the transverse spacing of the wheels is six feet. The design tandem, as stated in Article 3.6.1.2.3, has double axles with 25 kip loads spaced at four feet with the transverse spacing of the wheels at six feet.

The design lane load, as described in Article 3.6.1.2.4, is a uniformly distributed load of 0.64 kips per linear foot, and the width of the design lane load is 10 feet. The load is not necessarily continuous, but rather depends on which sequence of loading produces the maximum force effect.

3.2.1.3 Construction Loads

An analysis of the bridge system during each stage of construction must be investigated. Therefore, the bending moment and shear forces in the structure during each casting sequence must be calculated and checked against the resistance of the system. In addition, the loads applied to the overhang brackets induce flange lateral bending stresses in the compression flange of the girder. Typical construction loads include the following: deck overhang, overhang deck forms, screed rails, railing, walkway, and finishing machine. Generally, half of the overhang weight is applied to the overhang bracket, and the other half is assumed to be carried by the girder. In addition, the finishing machine load is considered to be the weight of the engine, operator, and half of the finishing machine truss weight.

3.2.2 Limit State Design Loads

Various limit states are incorporated within the specifications that require the evaluation of member strength or serviceability at various load levels. Brief descriptions of the loadings for each limit state are discussed in the following sections.

3.2.2.1 Loading for Strength Limit State

During the evaluation of the strength limit state, the structure is subjected to the HL-93 loading, which consists of the following:

- a design truck or design tandem
- lane load.

3.2.2.2 Loading for Service Limit State

The HL-93 loading, previously discussed, is applied to evaluate the permanent deflections and the web requirement. The Live-load Deflection Criteria requires the evaluation of two loadings, which include:

- The design truck
- 25% of the design truck plus the design lane load

The controlling load case, which is the load case with the largest deflection, is utilized in the deflection check.

3.2.2.3 Loading for Fatigue Limit State

As stated in Article 3.6.1.4.1, the fatigue loading is consists of a single design truck with a constant rear axle spacing of 30 feet. This loading is meant to correspond to the truck that induces the loading that causes the majority of the fatigue damage on bridges.

3.3 Live-Load Distribution Factors

The live-load lateral distribution factor is applied to the vehicular and lane live-loads to determine the portion of the load that is carried by a single girder. Approximate equations or refined methods of analysis can be employed to determine the lateral distribution factors, but this research focuses on the use of approximate equations to determine the factors. The approximate equations are dependent on the type and geometry of the structure, as well as the location of the girder (i.e. interior or exterior). In order for the equations to be applicable, a variety of parameters, such as girder spacing and span length, must be within the ranges specified in the Specifications.

3.3.1 Interior Girder Distribution Factors

For an interior girder, the live-load distribution factor equations for moment and shear can be determined from Specification Tables 4.6.2.2.2b-1 and 4.6.2.2.3a-1, respectively. For example, the distribution factor for the moment of an interior girder with a single lane loaded is the following:

$$DF_{moment} = 0.06 + \left(\frac{S}{14}\right)^{0.4}\left(\frac{S}{L}\right)^{0.3}\left(\frac{K_g}{12.0\,L\,t_s^{\,3}}\right)^{0.1} \qquad \text{(Tb. 4.6.2.2.2b-1)}$$

where S = girder spacing, ft.

L = span length, ft.

K_g = longitudinal stiffness parameter

t_s = depth of concrete slab, in.

These approximate equations have the following range of applicability:

- $3.5 \leq S \leq 16.0$
- $4.5 \leq t_s \leq 12.0$
- $20 \leq L \leq 240$
- $N_b \leq 4$

where N_b = number of beams, stringers, or girders

For preliminary designs, the term containing K_g can be assumed 1.0, since the geometry of the girder is not known at this time.

3.3.2 Exterior Girder Distribution Factors

For an exterior girder, the live-load distribution factors for moment and shear can be determined from Specification Tables 4.6.2.2.2d-1 and 4.6.2.2.3b-1, respectively. From Table 4.6.2.2.2d-1, the exterior girder distribution factor for moment with a single lane loaded is calculated using the lever rule. The lever rule assumes that the deck is simply supported with hinges located at the interior girder locations. Multiple presence factors, discussed in Section 3.4.2, are be applied to distribution factors calculated using the lever rule. In order to obtain the distribution factor for two or more lanes loaded, the single lane distribution factor must be multiplied by the following correction factor:

$$e = 0.77 + \frac{d_e}{9.1} \qquad \text{(Tb. 4.6.2.2.2d-1)}$$

where d_e = the distance between the web of the exterior beam and the interior edge of curb or traffic barrier, ft.

The special analysis, in which the cross-section is assumed to deflect and rotate as a rigid cross-section, should also be considered for slab-on-steel stringer bridges with diaphragms or cross-frames. The procedure for determining the distribution factor from the special analysis outlined in Article C4.6.2.2.2d is as seen below:

$$R = \frac{N_L}{N_b} + \frac{X_{ext} \sum^{N_L} e}{\sum^{N_b} x^2} \qquad \text{(Eq. 3.1)}$$

where R = reaction on exterior beam in terms of lanes

N_L = number of loaded lanes under consideration

e = eccentricity of a design truck or a design lane load from the center of gravity of the pattern of girders (ft.)

x = horizontal distance from the center of gravity of the pattern of girders to each girder (ft.)

X_{ext} = horizontal distance from the center of gravity of the pattern of girders to the exterior girder (ft.)

N_b = number of beams or girders

Like the lever rule, the multiple presence factor must be applied to the value calculated from the above equation to determine the distribution factor.

3.3.3 Fatigue Distribution Factors

The fatigue distribution factor, as described in Article 3.6.1.4.3b, is the distribution factor for one traffic lane loaded, which must be calculated for both shear and moment. When using an approximate distribution factor equation from the tables, the multiple presence factor must be divided from the resulting distribution factor as stated in Article 3.6.1.1.2 of the specifications.

3.3.4 Live-Load Deflection Distribution Factor

According to Article 2.5.2.6.2, when calculating the maximum deflection of a structure, all of the design lanes should be loaded and all the girders are assumed to deflect equally. Therefore, the distribution factor for live-load deflection is equivalent to the number of lanes divided by the number of girders. The dynamic load allowance is applied to the design truck portion of Load Combination Service I, and the multiple presence factor must also be applied.

$$DF = m\frac{N_L}{N_B}$$

where m = multiple presence factor

3.4 Other Force Effects

3.4.1 Dynamic Load Allowance

The dynamic load allowance, as described in Article 3.6.2, accounts for the dynamic force effect produced by the moving vehicle load, and is 15 % for the fatigue loading and 33% for all other limit states, as shown in Table 3.3. Only the vehicular portion of the live load, not the pedestrian loads or design lane loads, is subjected to the dynamic load allowance.

3.4.2 Multiple Presence

The probability of more than one lane being loaded at any given time is taken into account by the multiple presence factor, which is found in Table 3.2. The multiple presence factor is not to be applied when checking the fatigue limit state, in which one design truck is used, nor when the distribution factors are calculated from the tables in Section 4.6.2.2.2 as multiple presence factors have already been incorporated into the equations. Therefore, the multiple presence factors are applied when the distribution factors are computed from the lever rule, the special analysis, or refined analysis methods.

3.4.3 Effective Width

The effective width is the width at which the longitudinal stresses can be assumed to be uniform, even though the actual stress distribution is variable. The actual and assumed stress distribution of the concrete slab can be seen in Fig. 3.2. When integrated across the effective width, the resulting force is the same as for the non-uniform stress distribution. The effective width is dependent on a several of parameters including: the girder spacing, the span length, slab thickness, web thickness, top flange width, and the location of the girder (interior or exterior). According to Article 4.6.2.6.1, for an interior girder the effective width is the minimum of the following:

- One-quarter of the effective span length,
- 12.0 times the average thickness of the slab, plus the greater of web thickness or one-half the width of the top flange of the girder, or
- The average spacing of adjacent beams

For an exterior girder, the effective width is one half of the effective width of the adjacent interior beam plus the minimum of the following:

- One-eighth of the effective span length,
- 6.0 times the average thickness of the slab, plus the greater of half the web thickness or one-quarter of the width of the top flange of the girder, or
- The width of the overhang

3.4.4 Load Modifier

The load modifier accounts for the ductility η_D, redundancy η_R, and operational importance η_I of the structure; all of which affect the margin of safety of the structure, as discussed in Article C1.3.2.1 of the specifications. The factors pertaining to ductility and redundancy are directly related to the strength of the structure, and the operational importance factor addresses the consequence of the bridge being out of service. Guidelines for appropriate factors for the strength limit state are shown in Table 3.4; the factors for all other limit states are to be taken as 1.00. The load modifier η_i, which is the product of the ductility, redundancy, and operational importance factors, has to be larger than 0.95, which is stated in Article 1.3.2.1 of the specifications. The ultimate load is the product of the load modifier and the factored load.

3.5 Load Combinations

The AASHTO LRFD Bridge Design Specifications define a variety of load combinations to assess different failure service and strength limit states for the structure. The total factored force effect in the LRFD format adopted by AASHTO is:

$$Q = \sum \eta_i \gamma_i Q_i \qquad \text{(Eq. 3.2)}$$

where η_i = load modifier specified in Article 1.3.2

Q_i = force effects from loads specified herein

γ_i = load factors specified in Tables 3.4.1-1 and 3.4.1-2

Load combinations and load factors can be found in Tables 3.4.1-1 and 3.4.1-2 of the specifications. The following is a brief description of the load combinations.

3.5.1 Strength Limit States

The strength limit states assess the strength and stability of the structure. The following are the strength limit states as described in the Second Edition of the specifications:

Strength I - Basic load combination relating to the normal vehicular use of the bridge without wind.

Strength II - Load combination relating to the use of the bridge by Owner-specified special design vehicles, evaluation permit vehicles, or both without wind.

Strength III - Load combination relating to the bridge exposed to wind velocity exceeding 55 MPH.

Strength IV - Load combination relating to very high dead load to live load force effect ratios.

Strength V - Load combination relating to normal vehicular use of the bridge with wind of 55 MPH velocity.

Article 3.4.2 of the specifications discusses the appropriate load factors to apply when assessing constructibility. The article states that the construction load factor for the weight of the structure and appurtenances is not to be taken less than 1.25. The load factor for construction loads, equipment, and dynamic effects is not to be taken less than 1.5, unless stated otherwise by the owner, and the wind load factor is to be at least 1.25. The load factor for any other loads not previously discussed is to be taken as 1.00.

3.5.2 Service Limit States

The service limit states control the stresses and deflections of the bridge to ensure proper performance during its service life. The permanent deflections check, which limits the yielding of the section to control the rideablility of the structure, are controlled by the Service II load combination, which applies a factor of 1.3 to the live-load and 1.0 to all other loads. The Live-load Deflection check is optional and is covered in Article 2.5.2.6.2 of the specifications. This deflection check is at the Service I load level, which applies a load factor of 1.0 to all load types.

3.5.3 Fatigue Limit State

The fatigue limit state controls fatigue cracking by limiting the stresses induced by the fatigue loading. The fatigue load combination is given in Table 3.4.1-1 of the specifications, which states a load factor of 0.75 is applied to the fatigue truck.

3.6 Fundamental Limit States

The design of composite steel I-sections is covered by Chapter 6 of the AASHTO LRFD Bridge Design Specifications. To properly evaluate the safety of a steel bridge girder, a variety of limits must be satisfied, and the governing equation each limit state must satisfy is as follows:

$$Q = \sum \eta_i \, \gamma_i \, Q_i \leq \phi \, R_n = R_r \qquad \text{(Eq. 3.3)}$$

where Q = force effects

η_i = load modifier

γ_i = load factor

ϕ = resistance factor

R_n = nominal resistance

R_r = factored resistance

As previously discussed, there are three basic limit states which must be evaluated: strength, service, and fatigue limit states. The following sections detail the process that must be followed for both the Second and Third Edition of the specifications to evaluate each of the limit state.

3.7 Summary of the Second Edition of the AASHTO LRFD Specifications

3.7.1 Strength Limit State

As this research focuses on simply supported members, the following subsections present a summary of the flexural capacity for members subjected to positive bending. A more comprehensive overview of the strength requirements including thoses for hogging moment sections may be found in the AASHTO Bridge Design Specifications.

3.7.1.1 Positive Flexural Capacity

The Second Edition of the AASHTO LRFD Bridge Design Specifications classifies the sections as either compact or noncompact based on the section properties and geometric proportions. A compact section must satisfy the following requirements from Article 6.10.4.1.1:

- Specified minimum yield strength does not exceed 70 ksi,
- The girder has a constant depth,
- The section does not have a longitudinal stiffener or holes in the tension flange, and
- The following equation must be satisfied

$$\frac{2\,D_{cp}}{t_w} \leq 3.76\sqrt{\frac{E}{F_{yc}}} \qquad \text{(Eq. 3.4)}$$

where D_{cp} = depth of the web in compression at the plastic moment (in.)

F_{yc} = specified minimum yield strength of the compression flange (ksi)

Note that a composite section in positive flexure automatically satisfies the compression-flange slenderness and compression-flange bracing requirements. Below describes the governing equations to determine the flexural resistance of the girder based on the classification of compact or noncompact.

Compact Sections

If the section is compact, then the flexural capacity of the girder is determined using Article 6.10.4.2.2. If the distance from the top of the concrete slab to the plastic neutral axis, which is D_p, is less than or equal to D’, the section is able to reach M_p, see Equation 6.10.4.2.2a-1of the specifications. D’ defined as the depth at which the composite section reaches its theoretical plastic moment capacity, Mp, when the maximum strain in the concrete slab is at the theoretical crushing strain. The Second Edition of the specifications defines a procedure for determining D’ in Article 6.10.4.2.2b of the specifications and is shown below.

$$D' = \beta \frac{(d + t_s + t_h)}{7.5} \qquad \text{(Eq. 3.5)}$$

where β = 0.9 for F_y = 36 ksi

= 0.7 for F_y = 50 ksi or 70 ksi

d = depth of the steel section (in.)

t_h = thickness of the concrete haunch about the top flange (in.)

t_s = thickness of concrete slab (in.)

If D_p is greater than D’ but less than 5.0D’, the section has a nominal flexural capacity that is defined by the following equation:

$$M_n = \frac{5\,M_p - 0.85\,M_y}{4} + \frac{0.85\,M_y - M_p}{4}\left(\frac{D_p}{D'}\right) \qquad \text{(Eq. 3.6)}$$

where M_y = moment capacity at first yield of the short-term composite positive moment section (k-in)

The ductility of the section must be evaluated to prevent the crushing of the concrete deck, governed by Article 6.10.4.2.2b. This limit applies to compact composite sections in which the moment due to the factored loads results in a flange stress that exceeds the yield strength either flange times the hybrid factor. The ratio of D_p to D’ must be less than or equal to 5.

Otherwise, the flexural capacity of the section can be approximated using Eq. 3.7, but the capacity must be less than the plastic moment and the capacity computed from Eq. 3.6.:

$$M_n = 1.3\,R_h\,M_y \qquad \text{(Eq. 3.7)}$$

where R_h = hybrid factor specified in Article 6.10.4.3.1

The hybrid factor accounts for the nonlinear stress distribution due to the yielding of the lower strength steel in the web of hybrid girders and is discussed in Article 6.10.4.3.1 of the specifications. The hybrid factor is equal to 1.0 for homogeneous sections and for sections in which the stress in both the top and bottom flanges do not exceed the yield strength of the web. For composite hybrid sections, the hybrid factor is determined using the following equation:

$$R_h = 1 - \left[\frac{\beta\,\psi\,(1-\rho)^2\,(3-\psi+\rho\,\psi)}{6+\beta\,\psi\,(3-\psi)} \right] \qquad \text{(Eq. 3.8)}$$

where ρ = F_{yw}/F_{yb}

β = A_w/A_{fb}

ψ = d_n/d

d_n = distance from the outer fiber of the bottom flange to the neutral axis of the transformed short-term composite section (in.)

d = depth of the steel section (in.)

F_{yb} = specified minimum yield strength of the bottom flange (ksi)

F_{yw} = specified minimum yield strength of the web (ksi)

A_w = area of the web (in.^{2})

A_{fb} = bottom flange area (in.^{2})

Noncompact Sections

The nominal flexural capacity of a noncompact section is defined by Article 6.10.4.2.4 in terms of stress. Below are the equations that define the flexural stress depending on the minimum specified nominal yield strength of the flange:

For the compression flange:

$$F_n = R_b\ R_h\ F_{yc} \qquad \text{(Eq. 3.9)}$$

For the tension flange:

$$F_n = R_b\ R_h\ F_{yt} \qquad \text{(Eq. 3.10)}$$

where R_b = load-shedding factor specified in Article 6.10.4.3.2

F_{yc} = specified minimum yield strength of the compression flange (ksi)

F_{yt} = specified minimum yield strength of the tension flange (ksi)

3.7.1.2 Shear

The shear resistance of the steel section is defined in Article 6.10.7 and depends on whether the web is stiffened or unstiffened. Defined in Article 6.10.7.2, the nominal shear resistance of a section without transverse or longitudinal stiffeners is as follows:

$$V_n = C\ V_p \qquad \text{(Eq. 3.11)}$$

and $$V_p = 0.58\ F_{yw}\ D\ t_w \qquad \text{(Eq. 3.12)}$$

where V_p = plastic shear force (kip)

C = ratio of shear buckling stress to the shear yield strength as specified in Article 6.10.7.3.3a, with the shear buckling coefficient, k, taken equal to 5.0

F_{yw} = specified minimum yield strength of the web (ksi)

D = web depth (in.)

t_w = thickness of web (in.)

The coefficient C can be determined by following the method outlined in Article 6.10.7.3.3a, which is shown below:

If $\frac{D}{t_w} \leq 1.10\sqrt{\frac{E\,k}{F_{yw}}}$, then

$$C = 1.0 \qquad \text{(Eq. 3.13)}$$

If $1.10\sqrt{\frac{E\,k}{F_{yw}}} \leq \frac{D}{t_w} \leq 1.38\sqrt{\frac{E\,k}{F_{yw}}}$, then

$$C = \frac{1.10}{\frac{D}{t_w}}\sqrt{\frac{E\,k}{F_{yw}}} \qquad \text{(Eq. 3.14)}$$

If $\frac{D}{t_w} > 1.38\sqrt{\frac{E\,k}{F_{yw}}}$, then

$$C = \frac{1.52}{\left(\frac{D}{t_w}\right)^2}\left(\frac{E\,k}{F_{yw}}\right) \qquad \text{(Eq. 3.15)}$$

where k = shear buckling coefficient

= 5.0 for unstiffened webs

3.7.1.3 Constructibility

As discussed in Article 6.10.3.2, the structure must have sufficient strength and stability during all stages of construction. This is accomplished by evaluating the shear and flexural capacity of the noncomposite section under factored construction loads during each pour sequence. The following sections describe the evaluation of flexure, shear, and web bend-buckling for the noncomposite section in order to assess constructibility using the Second Edition of the Specifications.

Flexure

The flexural strength must be investigated to ensure the noncomposite section has sufficient capacity to resist loads experienced during each critical construction stage. Refer to the flowchart in Figure C6.10.4-1 of the specifications for the method to determine the flexural strength of a noncomposite section.

Shear

The shear resistance of the noncomposite section during constructibility is determined from Article 6.10.3.2.3, and limits the member to the shear buckling or shear yield force. Therefore, the section can not rely on tension field action under factored dead load alone. If the design has an unstiffened web or has a hybrid material configuration this check does not have to be performed since the shear resistance is already limited to the shear buckling or shear yield force.

Web Bend-Buckling

As outlined in Article 6.10.3.2.2, the Second Edition of the specifications limits the stress in the web to the web bend-buckling stress to the theoretical elastic bend-buckling stress of the web with the following equation:

$$f_{cw} \leq \frac{0.9\,E\,\alpha\,k}{\left(\frac{D}{t_w}\right)^2} \leq F_{yw} \qquad \text{(Eq. 3.16)}$$

where f_{cw} = maximum compressive flexural stress in the web (ksi)

α = 1.25 for webs without longitudinal stiffeners

k = 9.0 $(D/D_c)^2$ for webs without longitudinal stiffeners

D_c = depth of the web in compression in the elastic range (in.)

3.7.2 Serviceability

The bridge structure must satisfy a variety of serviceability checks including: permanent deformations, live-load deflections, and a web requirement that ensures the web does not excessively deflect. The following sections describe each of the checks in detail.

3.7.2.1 Permanent Deformations

Limiting the Permanent deformation limitations are intended to prevent unsatisfactory deflections that might affect the rideability of the structure. Article 6.10.5.2 controls permanent deflections by limiting the flange stresses, shown in the following equation:

For both flanges of composite sections:

$$f_f \leq 0.95\, F_{yf} \qquad \text{(Eq. 3.17)}$$

where f_f = elastic flange stress caused by the factored loading (ksi)

F_{yf} = specified minimum yield strength of the flange (ksi)

3.7.2.2 Live-Load Deflection Criteria

The Live-load Deflection Criteria is discussed in Article 2.5.2.6.2 of the specifications and is an optional check for steel I-girder bridges. The designer must determine the maximum deflection in the structure based on load combinations discussed in Section 3.5.2. If a refined analysis is not conducted, the results of the line girder analysis must be multiplied by the appropriate lateral distribution factor to determine the estimated live-load deflection. The limit is dependent on the expected pedestrian traffic; if pedestrian traffic is permitted the deflection is limited to L/1000, otherwise the deflection is limited to L/800.

3.7.2.3 Web Requirements

The web requirements that must be checked under the Service II limit state limits the shear resistance using Eq. 3.16, discussed previously. The depth of web in compression in the elastic range is to correspond to the Service II load combination.

3.7.3 Fatigue and Fracture Limit State

The fatigue limit state imposes restrictions on the stress levels under service level conditions to prevent crack growth during the design life of the bridge. There are two main types of fatigue problems that must be checked, load-induced fatigue and distortion induced fatigue.

3.7.3.1 Distortion-Induced Fatigue

Distortion-induced fatigue is discussed in Article 6.6.1.3 of the Second Edition. To prevent distortion-induced fatigue, both the tension and compression flanges of the girder are to be welded to all transverse connection plate details in order to provide load paths sufficient to transmit forces.

In addition the web of the section is subject to a special requirement to limit out-of-plane flexing. When evaluating the special fatigue requirement for the webs, the live-load flexural stress and shear stress calculated from the fatigue load must be taken as twice that calculated using the fatigue load combination in Table 3.4.1-1 of the specifications. The procedure to investigate out-of-plane flexing of the web is discussed below and covered by Article 6.10.6, which limits both flexural stress and shear stress.

Flexure

The maximum web buckling stresses in the web is limited to the following:

If $\frac{2\,D_c}{t_w} \leq 5.70\sqrt{\frac{E}{F_{yw}}}$, then

$$f_{cf} \leq Fyw \qquad \text{(Eq. 3.21)}$$

otherwise,

$$f_{cf} \leq 32.5\,E\left(\frac{t_w}{2\,D_c}\right)^2 \qquad \text{(Eq. 3.22)}$$

where f_{cf} = maximum compressive elastic flexural stress in the compression flange due to the unfactored permanent load and the fatigue loading as specified in Article 6.10.6.2; taken as being indicative of the maximum flexural stress in the web (ksi)

F_{yw} = specified minimum yield strength of the web (ksi)

D_c = depth of the web in compression in the elastic range (in.)

Shear

The shear force in the web at the fatigue limit state is also limited to control distortion by satisfying the following equation:

$$v_{cf} \leq 0.58\, C\, F_{yw} \qquad \text{(Eq. 3.23)}$$

where v_{cf} = maximum elastic shear stress in the web due to the unfactored permanent load and the fatigue loading as specified in Article 6.10.6.2 (ksi)

C = ratio of the shear buckling stress to the shear yield strength as specified in Article 6.10.7.3.3a

F_{yw} = specified minimum yield strength of the web (ksi)

As stated in the Commentary at C6.10.6.4 of the specifications, the previous shear check does not have to be performed for unstiffened webs and webs of hybrid sections since they are already limited to either the shear yielding or the shear buckling force at the strength limit state.

3.7.3.2 Load-Induced Fatigue

To check for potential load-induced fatigue problems, the fatigue detail category must be determined from Tables 6.6.1.2.3-1 and 6.6.1.2.3-2 in Article 6.6.1.2.3 of the specifications. The detail with the least fatigue resistance employed in typical bridge systems is the welded connection of the cross-frame to the web of the girder, which falls under a fatigue category C'. The nominal fatigue resistance of structural details is obtained from the following equation:

$$(\Delta F)_n = \left(\frac{A}{N}\right)^{\frac{1}{3}} \geq \frac{1}{2}(\Delta F)_{TH} \qquad \text{(Eq. 3.18)}$$

and $$N = (365)(75)n(ADTT)_{SL} \qquad \text{(Eq. 3.19)}$$

where A = constant from Table 6.6.1.2.5-1 (ksi^3)

n = number of stress range cycles per truck passage taken from Table 6.6.1.2.5-2

$(ADTT)_{SL}$ = single-lane ADTT as specified in Article 3.6.1.4

$(\Delta F)_{TH}$ = constant-amplitude fatigue threshold taken from Table 6.6.1.2.5-3 (ksi)

The right side of Eq. 3.18 results in the stress at which the detail has an infinite fatigue life. The governing equation to limit load-induced fatigue is as follows:

$$\gamma(\Delta f) \leq (\Delta F)_n \qquad \text{(Eq. 3.20)}$$

where γ = load factor specified in Table 3.4.1-1 for the fatigue load combination

(Δf) = force effect, live load stress range due to the passage of the fatigue load as specified in Article 3.6.1.4 (ksi)

$(\Delta F)_n$ = nominal fatigue resistance as specified in Article 6.6.1.2.5 (ksi)

3.7.3.3 Fracture

To prevent fracture, the material for main components subjected to tension due to the Strength I load combination are to meet the Charpy V-notch fracture toughness requirements for the appropriate temperature zone, see Article 6.6.2. In addition, any member that is fracture critical should be indicated as such in the plans. In this case more stringent requirements are placed on material testing.

3.7.4 Section Proportion Limits

Along with the general limit states, there are also geometric proportion limitations the girders must satisfy, which are discussed in Article 6.10.2. The following sections describe the geometric restrictions imposed by the Second Edition of the AASHTO LRFD, where general, web, and flange proportions are addressed.

3.7.4.1 General Proportions

The ratio of I_{yc} to I_y locates the shear center of the section, and if the ratio is outside the limits, then the lateral torsional buckling formulas are not valid. The general proportions limit is as follows:

$$0.1 \leq \frac{I_{yc}}{I_y} \leq 0.9 \qquad \text{(Eq. 3.24)}$$

where I_y = moment of inertia of the steel section about the vertical axis in the plane of the web (in.^{4})

I_{yc} = moment of inertia of the compression flange of the steel section about the vertical axis in the plane of the web (in.^{4})

3.7.4.2 Web Slenderness

Article 6.10.2.2 limits the web slenderness to values at which fatigue due to excessive lateral web deflections does not need to be considered. Therefore, webs without longitudinal stiffeners are to satisfy the following requirement:

$$\frac{2\,D_c}{t_w} \leq 6.77\sqrt{\frac{E}{f_c}} \leq 200 \qquad \text{(Eq. 3.25)}$$

where f_c = stress in the compression flange due to the factored loading under investigation (ksi)

3.7.4.3 Flange Proportions

The compression flange proportional limit is incorperated to ensure the flange adequately restrains the web from bend buckling, and is as follows:

$$b_f \geq 0.3\,D_c \qquad \text{(Eq. 3.26)}$$

The tension flange slenderness limit ensures the flange will not distort excessively when welded to the web, and is as follows:

$$\frac{b_t}{2\,t_t} \leq 12.0 \qquad \text{(Eq. 3.27)}$$

3.8 Summary of the Third Edition of the AASHTO LRFD Specifications

The primary goals of the development of the 3rd Edition of the AASHTO Specifications was to move towards providing a set of unified specifications for both straight and horizontally-curved steel I-girders and to simplify the underlying design formulations for steel members. The result is a set of specifications that include both vertical bending and lateral flange bending. Straight I-girders experience flange lateral bending as a result of wind loads and torsion, which can be caused by significant skew, loading from overhang brackets, and staggered cross-frames.

Along with the previously mentioned changes in the specifications, a variety of other improvements have been made. General section proportion limits have been simplified to make the initial designs easier to develop. The provisions for compact and nearly compact sections have been updated and moved to Appendix A - Flexural Resistance – Composite Sections in Negative Flexure and Noncomposite Sections with Compact or Noncompact Webs, since sections satisfying the requirements are less common. Simplified and improved specifications for incorporating moment redistribution are provided in the Appendix B – Moment Redistribution from Interior-Pier Sections in Continuous-Span Bridges. Flow-charts to guide the design of steel I-girders are provided in the Appendix C – Basic Steps for Steel Bridge Superstructures, and procedures for determining fundamental values, such as the plastic moment and yield moment, are included in Appendix D – Fundamental Calculations for Flexural Members.

3.8.1 Strength Limit State

As previously discussed, the study is focused on simple-span bridges, therefore only the positive bending flexural capacity will be briefly described in the following section.

3.8.1.1 Positive Flexural Capacity

The positive flexural resistance of a composite section in accordance with the Third Edition of the AASHTO LRFD is governed by Section 6.10.7, and, like the Second Edition, is dependent on the girder classification as either compact or noncompact sections. Regardless of the girder classification, the section must satisfy the ductility requirement set forth in Article 6.10.7.3, which states the following:

$$D_p \leq 0.42\ D_t \qquad \text{(Eq. 3.28)}$$

where D_p = distance from the top of the concrete deck to the neutral axis of the composite section at the plastic moment (in.)

D_t = total depth of the composite section (in.)

The following sections describe the procedure involved in determining the positive flexural resistance of a composite section for compact and noncompact sections.

Compact Sections

As stated in Article 6.10.7.1.1 of the specifications, compact sections must satisfy the following criteria:

- $F_{yf} \leq 70$ ksi ,

- $\frac{D}{t_w} \leq 150$, and
- $\frac{2D_{cp}}{t_w} \leq 3.76\sqrt{\frac{E}{F_{yc}}}$.

If the section is deemed compact, the following equation must be satisfied:

$$M_u + \frac{1}{3} f_\ell S_{xt} \leq \phi_f \, M_n \qquad \text{(Eq. 3.29)}$$

where M_u = bending moment about the major axis of the cross-section determined as specified in Article 6.10.1.6 (k-in)

f_ℓ = flange lateral bending stress (ksi)

S_{xt} = elastic section modulus about the major axis of the section to the tension flange taken as M_{yt}/F_{yt} (in^3)

ϕ_f = 1.0, resistance factor for flexure

M_n = nominal flexural resistance of the section (k-in)

For composite sections in their final condition, lateral bending is not considered since the compression flange is continuously supported by the concrete deck.

As stated in Article 6.10.7.1.2, if the distance from the top of the concrete deck to the neutral axis of the composite section at plastic moment, D_p, is less than one tenth of the total depth of the composite section, D_t, then the nominal flexural resistance of the section is equal to the plastic moment of the section. Sections that do not satisfy the previous criteria are limited to the resistance calculated from Eq. 3-30, which limits the nominal resistance to prevent premature crushing of the concrete deck and ensures sufficient ductility.

$$M_n = M_p \left(1.07 - 0.7 \frac{D_p}{D_t}\right) \qquad \text{(Eq. 3.30)}$$

Noncompact Sections

Noncompact sections are limited to the moment at first yield, and must satisfy the following inequalities:

Compression flange: $f_{bu} \leq \phi_f F_{nc}$ (Eq. 3.31)

Tension flange: $f_{bu} + \frac{1}{3} f_\ell \leq \phi_f F_{nt}$ (Eq. 3.32)

where f_{bu} = flange stress calculated without consideration of flange lateral bending determined as specified in Article 6.10.1.6 (ksi)

F_{nc} = nominal flexural resistance of the compression flange determined as specified in Article 6.10.7.2.2 (ksi)

F_{nt} = nominal flexural resistance of the tension flange determined as specified in Article 6.10.7.2.2 (ksi)

The nominal flexural resistance of a noncompact section is calculated for each flange. The compression flange nominal flexural strength is computed from the following equation:

$$F_{nc} = R_b \ R_h \ F_{yc} \qquad \text{(Eq. 3.33)}$$

where R_b = web load-shedding factor determined as specified in Article 6.10.1.10.2

R_h = hybrid factor determined as specified in Article 6.10.1.10.1

The hybrid factor is 1.0 for homogeneous sections and sections with higher strength steel in the web than in both flanges. Otherwise, the hybrid factor can be determined using the following equations:

$$R_h = \frac{12 + \beta \left(3 \rho - \rho^3\right)}{12 + 2 \beta} \qquad \text{(Eq. 3.34)}$$

and $$\beta = \frac{2 D_n \ t_w}{A_{fn}} \qquad \text{(Eq. 3.35)}$$

where ρ = minimum of F_{yw}/f_n and 1.0

A_{fn} = sum of the flange area on the side of the neutral axis corresponding to D_n (in.^{2})

D_n = larger of the distances from the elastic neutral axis of the cross-section to the inside face of either flange (in.)

f_n = for sections where yielding occurs first in the flange on the side of the neutral axis corresponding to D_n, the largest of the specified minimum yield strengths of each component included in the calculation of A_{fn} (ksi). Otherwise the largest of the elastic stresses in the flange on the side if the neutral axis corresponding to D_n at first yield on the opposite side of the neutral axis

The load-shedding factor R_b is taken as 1.0 if the section is composite, in positive flexure, and the web satisfies the requirement of Article 6.10.2.1.1; while checking constructibility; or the following is satisfied:

$$\frac{2\,D_c}{t_w} \leq \lambda_{rw} \qquad \text{(Eq. 3.36)}$$

where λ_{rw} = limiting slenderness ratio for a noncompact web

$$= 5.7\sqrt{\frac{E}{F_{yc}}} \qquad \text{(Eq. 3.37)}$$

Otherwise R_b is calculated using the following equation:

$$R_b = 1 - \left(\frac{a_{wc}}{1200 + 300\,a_{wc}}\right)\left(\frac{2\,D_c}{t_w} - \lambda_{rw}\right) \leq 1.0 \qquad \text{(Eq. 3.38)}$$

where a_{wc} = ratio of two times the web area in compression to the area of the compression flange

$$= \frac{2\,D_c\;t_w}{b_{fc}\;t_{fc}} \qquad \text{(Eq. 3.39)}$$

f_{DC1} = compression flange stress in the section under consideration, calculated without consideration of flange lateral bending and caused by the factored permanent load applied before the concrete deck has hardened or is made composite (ksi)

D_c = depth of web in compression in elastic range (in.)

3.8.1.2 Shear

The shear resistance of a section is discussed in Article 6.10.9 of the Third Edition of the AASHTO LRFD. For unstiffened webs, the nominal shear resistance is controlled by either elastic shear-yielding or shear-buckling and is calculated from the following equation:

$$V_n = V_{cr} = C\,V_p \qquad \text{(Eq. 3.40)}$$

and $$V_p = 0.58\,F_{yw}\;D\,t_w \qquad \text{(Eq. 3.41)}$$

where V_n = nominal shear resistance (kip)

V_{cr} = shear buckling resistance (kip)

V_p = plastic shear force (kip)

C = ratio of the shear buckling resistance to the shear yield strength determined as specified in Article 6.10.9.3.2, with the shear buckling coefficient, k, taken equal to 5.0

F_{yw} = minimum yield strength of the web (ksi)

D = depth of the web (in.)

t_w = thickness of web (in.)

The coefficient C can be determined by following the method outlined in Article 6.10.9.3.2, and is as follows:

If $\frac{D}{t_w} \leq 1.12\sqrt{\frac{E\,k}{F_{yw}}}$, then

$$C = 1.0 \qquad \text{(Eq. 3.42)}$$

If $1.12\sqrt{\frac{E\,k}{F_{yw}}} \leq \frac{D}{t_w} \leq 1.40\sqrt{\frac{E\,k}{F_{yw}}}$, then

$$C = \frac{1.12}{\frac{D}{t_w}}\sqrt{\frac{E\,k}{F_{yw}}} \qquad \text{(Eq. 3.43)}$$

If $\frac{D}{t_w} > 1.40\sqrt{\frac{E\,k}{F_{yw}}}$, then

$$C = \frac{1.57}{\left(\frac{D}{t_w}\right)^2}\left(\frac{E\,k}{F_{yw}}\right) \qquad \text{(Eq. 3.44)}$$

where k = shear buckling coefficient

= 5.0 for unstiffened webs

3.8.1.3 Constructibility

To satisfy the constructibility check for the Third Edition, the section must meet requirements for flange nominal yielding, flexural resistance, and web bend buckling. The Third Edition of the specifications require the consideration of the flange lateral bending stresses, f_ℓ, which typically result from overhang bracket forces and wind loads during construction. While the compression flange is discretely braced during each critical construction stage, the following limits must be satisfied:

Check flange nominal yielding:

$$f_{bu} + f_\ell \leq \phi_f \; R_h \; F_{yc} \qquad \text{(Eq. 3.45)}$$

Check flexural resistance:

$$f_{bu} + \frac{1}{3} f_\ell \leq \phi_f \; F_{nc} \qquad \text{(Eq. 3.46)}$$

$$f_\ell \leq 0.6 \, F_{yt} \qquad \text{(Eq. 3.47)}$$

while $R_b = 1.0$

Check web bend buckling:

$$f_{bu} \leq \phi_f \; F_{crw} \qquad \text{(Eq. 3.48)}$$

where ϕ_f = resistance factor for flexure specified in Article 6.5.4.2

f_{bu} = flange stress calculated without consideration of flange lateral bending determined as specified in Article 6.10.1.6 (ksi)

f_{ℓ} = flange lateral bending stress determined as specified in Article 6.10.1.6 (ksi)

F_{crw} = nominal elastic bend-buckling resistance determined as specified in Article 6.10.1.9 (ksi)

$$= \frac{0.9\ E\ k}{\left(\frac{D}{t_w}\right)^2} \qquad \text{(Eq. 3.49)}$$

k = bend-buckling coefficient

$$= \frac{9}{\left(D_c\ /\ D\right)^2} \qquad \text{(Eq. 3.50)}$$

F_{nc} = nominal flexural resistance of the flange (ksi)

R_h = hybrid factor specified in Article 6.10.1.10.1

To ensure that the maximum stress in the compression flange does not surpass the minimum specified yield strength of the flange, Equation 3.45 must be satisfied. Equation 3.46 prevents lateral torsional and flange local buckling of the compression flange. If the web is compact or noncompact, Equation 3.48 does not need to be checked.

As stated in Article 6.10.3.2.2, the following flange nominal yielding requirement must be satisfied for a discretely braced tension flange:

$$f_{bu} + f_\ell \leq \phi_f \; R_h \; F_{yt} \qquad \text{(Eq. 3.51)}$$

where F_{yt} = minimum specified yield strength of the tension flange (ksi)

3.8.2 Serviceability

3.8.2.1 Permanent Deformations

Similar to the Second Edition of the specifications, Article 6.10.4.2.2 limits the stresses the flanges can experience, except the lateral bending stresses are included for the bottom flange. Below is a summary of the equations:

For the top flange of composite sections:

$$f_f \leq 0.95 \, R_h \; F_{yf} \qquad \text{(Eq. 3.52)}$$

For the bottom flange of composite sections:

$$f_f + \frac{f_\ell}{2} \leq 0.95 \, R_h \; F_{yf} \qquad \text{(Eq. 3.53)}$$

where f_f = flange stress in the section under consideration due to the Service II loads calculated without consideration of flange lateral bending (ksi)

f_ℓ = flange lateral bending stress in the section under consideration due to the Service II loads determined as specified in Article 6.10.1.6 (ksi)

R_h = hybrid factor determined as specified in Article 6.10.1.10.1

3.8.2.2 Live-Load Deflection Criteria

The Live-load Deflection Criteria remains the same for the Third Edition as it was in the Second Edition. Section 3.7.2.2 provides a discussion about the limit state.

3.8.2.3 Web Requirements

Article 6.10.4.2.2 of the Third Edition states that sections must satisfy Eq. 3.54 unless the section is composite, in positive flexure, and the ratio of D/t_w is less than or equal to 150.

$$f_c \leq F_{crw} \qquad \text{(Eq. 3.54)}$$

where f_c = compression-flange stress in the section under consideration due to the Service II loads calculated without consideration of flange lateral bending (ksi)

3.8.3 Fatigue and Fracture Limit State

3.8.3.1 Distortion-Induced Fatigue

Distortion-induced Fatigue is controlled in the same manner in the Third Edition of the specifications as the Second Edition. Transverse connection plates must be welded or bolted to both the tension and compression flanges of the section and the web must satisfy special requirements.

The web must satisfy the special fatigue requirement to ensure the web does not excessively elastically flex, to eliminate the possibility of a fatigue crack initiating. Article 6.10.5.3.2 of the Third Edition limits transversely stiffened webs to the following:

$$V \leq V_{cr} \qquad \text{(Eq. 3.55)}$$

where V = shear in the web in the section under consideration due to the unfactored permanent load plus the factored fatigue load (kip)

V_{cr} = shear buckling resistance determined from Equation 6.10.9.2-1 (kip)

3.8.3.2 Load-Induced Fatigue

The Third Edition requirements for the fatigue resistance of a detail are the same as the Second Edition requirements. The procedure for the load-induced fatigue check was previously discussed in Section 3.7.3.2.

3.8.4 Cross-section Proportion Limits

The Third Edition of the AASHTO LRFD sets proportion limits for the web, flanges, and general geometry for a variety of reasons, including: prevention of excess weld distortion, allows for easier proportioning of the web, and prevention of difficulties handling during construction. The cross-section proportion limits are addressed in Article 6.10.2 of the Third Edition.

3.8.4.1 Web Proportions

To prevent the design of girders that are difficult to handle during the construction stage, webs without longitudinal stiffeners are limited to the following:

$$\frac{D}{t_w} \leq 150 \qquad \text{(Eq. 3.56)}$$

3.8.4.2 Flange Proportions

The various flange proportion limits, as described in Article 6.10.2.2 of the specifications, are as follows:

- $\frac{b_f}{2\,t_f} \leq 12.0$ (Eq. 3.57)
- $b_f \geq D/6$ (Eq. 3.58)
- $t_f \geq 1.1\,t_w$ (Eq. 3.59)
- $0.1 \leq \frac{I_{yc}}{I_{yt}} \leq 10$ (Eq. 3.60)

where I_{yc} = moment of inertia of the compression flange of the steel section about the vertical axis in the plane of the web (in.^{4})

I_{yt} = moment of inertia of the tension flange of the steel section about the vertical axis in the plane of the web (in.^{4})

Each of the previous flange restrictions has significantly different functions. The flange slenderness is limited to 12.0 to ensure that the flange will not excessively distort during the process of welding the flange to the web. Equation 3.58 limits the cross-section aspect ratio to 6 to assure that the section can develop post buckling shear resistance due to tension-field action, which is discussed in C6.10.2.2 of the specifications. The flange is required to be at least 10 % thicker than the web, see Eq. 3.58, to ensure the flange provides restraint against web shear buckling. Like the web proportion restriction, limiting the ratio of I_{yc} to I_{yt} prevents the section from being difficult to handle during construction.

3.9 Additional Considerations

This chapter has described the design of steel I-girders considering the strength, service, and fatigue limit states, as well as the general proportions limits for both the Second and Third Editions of the specifications. To complete a superstructure design many other details need to be addressed including: shear studs, transverse and bearing stiffeners, bearings, cross frame details, and deck design. These topics are outside of the scope of this work and are not covered in this effort.

Table 3.1 Code Equation Legend

Thesis Equation	AASHTO Equation	AASHTO LRFD Edition
3.1	C4.6.2.2.2d-1	2nd
3.2	3.4.1-1	2nd
3.3	1.3.2.1-1	2nd
3.4	6.10.4.1.2-1	2nd
3.5	6.10.4.2.2a-2	2nd
3.6	6.10.4.2.2a-3	2nd
3.7	6.10.4.3.1b-1	2nd
3.8	6.10.4.2.4-1	2nd
3.9	6.10.4.2.4b-1	2nd
3.10	6.10.7.2-1	2nd
3.11	6.10.7.2-2	2nd
3.12	6.10.7.3.3a-5	2nd
3.13	6.10.7.3.3a-6	2nd
3.14	6.10.7.3.3a-7	2nd
3.15	6.10.3.2.2-1	2nd
3.16	6.10.5.2-1	2nd
3.17	6.6.1.2.5-1	2nd
3.18	6.6.1.2.5-2	2nd
3.19	6.6.1.2.2-1	2nd
3.20	6.10.3.2.2-1	2nd
3.21	6.10.6.3-1	2nd
3.22	6.10.6.3-2	2nd
3.23	6.10.6.4-1	2nd
3.24	6.10.2.1-1	2nd
3.25	6.10.2.2-1	2nd
3.26	6.10.2.3-1	2nd
3.27	6.10.2.3-2	2nd
3.28	6.10.7.3-1	3rd
3.29	6.10.7.1.1-2	3rd
3.30	6.10.7.1.2-2	3rd
3.31	6.10.7.2.1-1	3rd
3.32	6.10.7.2.1-2	3rd
3.33	6.10.7.2.2-1	3rd
3.34	6.10.1.10.1-1	3rd
3.35	6.10.1.10.1-2	3rd
3.36	6.10.1.10.2-2	3rd
3.37	6.10.1.10.2-4	3rd
3.38	6.10.1.10.2-3	3rd
3.39	6.10.1.10.2-5	3rd
3.40	6.10.9.2-1	3rd
3.41	6.10.9.2-2	3rd
3.42	6.10.9.3.2-4	3rd
3.43	6.10.9.3.2-5	3rd
3.44	6.10.9.3.2-6	3rd
3.45	6.10.3.2.1-1	3rd
3.46	6.10.3.2.1-2	3rd
3.47	6.10.1.6-1	3rd
3.48	6.10.3.2.1-3	3rd
3.49	6.10.1.9.1-1	3rd
3.50	6.10.1.9.1-2	3rd

Table 3.1 (cont'd) Code Equation Legend

Thesis Equation	**AASHTO Equation**	**AASHTO LRFD Edition**
3.51	6.10.3.2.2-1	3rd
3.52	6.10.4.2.2-1	3rd
3.53	6.10.4.2.2-2	3rd
3.54	6.10.4.2.2-4	3rd
3.55	6.10.5.3.2-1	3rd
3.56	6.10.2.1.1-1	3rd
3.57	6.10.2.2-1	3rd
3.58	6.10.2.2-2	3rd
3.59	6.10.2.2-3	3rd
3.60	6.10.2.2-4	3rd

Table 3.2 Multiple Presence Factors

Number of Loaded Lanes	Multiple Presence Factors "m"
1	1.20
2	1.00
3	0.85
>3	0.65

Table 3.3 Dynamic Load Allowance, IM

Component	IM
Deck Joints – All Limit States	75%
All Other Components	
• Fatigue and Fracture Limit State	15%
• All Other Limit States	33%

Table 3.4 Load Modifiers

Ductility	
Nonductile components and connections	$\eta_D \geq 1.05$
Conventional designs and details	$\eta_D = 1.00$
Components and details with more ductility than required	$\eta_D \geq 0.95$
Redundancy	
Nonredundant members	$\eta_R \geq 1.05$
Conventional levels of redundancy	$\eta_R = 1.00$
Exceptional levels of redundancy	$\eta_R \geq 0.95$
Operational Importance	
Important bridges	$\eta_I \geq 1.05$
Typical bridges	$\eta_I = 1.00$
Relatively less important bridges	$\eta_I \geq 0.95$

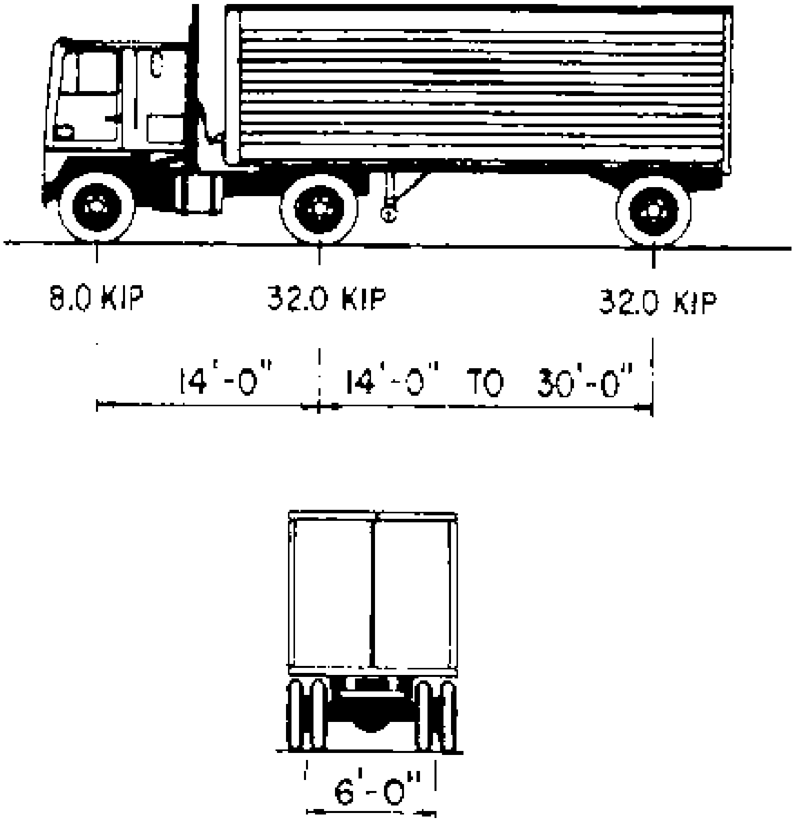

Figure 3.1 Design Truck (AASHTO 2001)

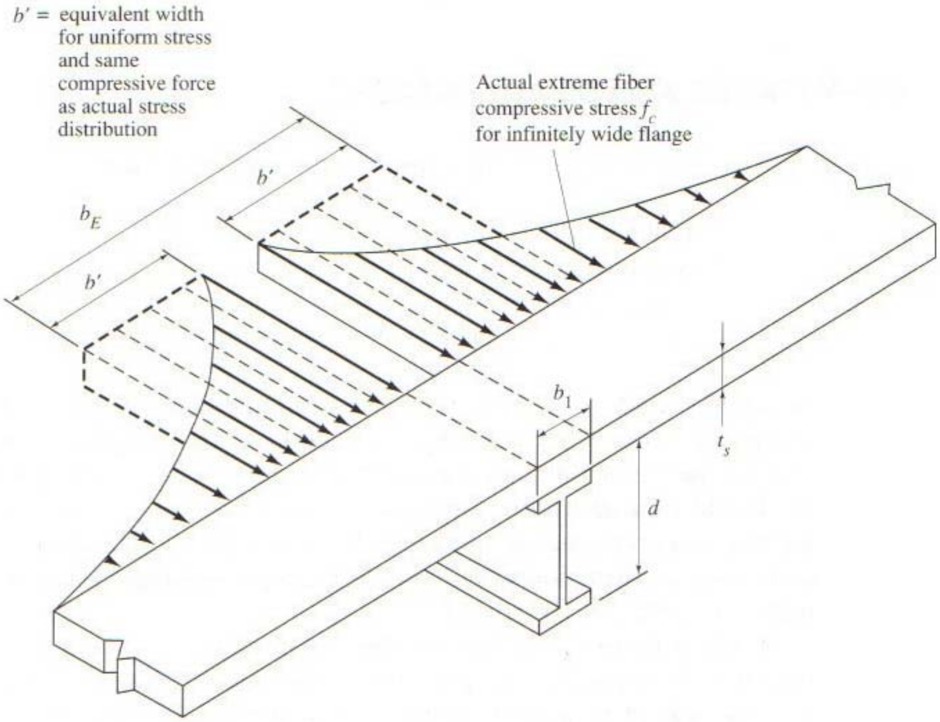

Figure 3.2 Actual and Equivalent Stress Distribution Over Flange Width (Salmon and Johnson 1996)

Chapter 4

Optimized Short-Span Steel Bridge Girder Design Study

4.1 Introduction

The purpose of this study is to design optimized simply-supported short-span steel girders for two 2-lane cross-sections, varying the following parameters: girder configuration (hybrid and homogenous plate girders and rolled beam), stiffened and unstiffened webs, girder location (interior and exterior), and span length. The homogeneous girders and the rolled beams are comprised of 50-ksi steel, while the hybrid configuration has a HPS 70W tension flange and 50 ksi web and compression flange. The designs are conducted in accordance with the 2nd Edition of the AASHTO LRFD Bridge Design Specifications (AASHTO 2001)

Since previous research (Clingenpeel 2001 and Homma & Sause 1995) has concluded that the Live-load Deflection Criteria influences the economy of girders manufactured from HPS steel, the effect of the criteria on short-span steel I-girder design is investigated. In addition to the standard AASHTO live-load deflection check, a live-load deflection check specified by the WVDOH, which uses the entire superstructure including the concrete barriers, is also studied. Finally, designs were developed in accordance with the 3rd Edition of the Specifications to investigate the influence of the 3rd Edition of the specifications on steel I-girder design.

4.2 Design Assumptions

Short-span steel I-girders were designed to meet both the Second and Third Editions of the AASHTO LRFD Bridge Specifications (AASHTO 2001 and AASHTO 2004). A typical girder elevation is shown in Fig. 4.1, where L is the span length, C denotes the cross-frame spacing, and X, Y, and Z indicate the transverse stiffener spacing. Girders were designed for two 2-lane cross-sections: a 28 ft. cross-section with four girders spaced at 8 ½ ft. and a 34 ft. cross-section with four girders spaced at 10 ft., which are depicted in Figures 4.2 and 4.3, respectively. Shear studs are assumed to be provided to achieve full composite action between the steel girder and the concrete slab.

The following parameters were varied for each cross-section:

- Girder type: homogeneous 50 ksi girder plate girder, hybrid plate girder (70 ksi tension flange and 50 ksi compression flange and web), and 50-ksi rolled beam
- Girder locations: interior and exterior
- Span-to-depth ratios: 20, 25, and 30
- Web: stiffened and unstiffened
- Span lengths: 40 ft. to 120 ft. in increments of 5 feet.

When calculating the span-to-depth ratios, the depth, D, is taken as the entire depth of the superstructure, which includes the concrete slab, steel section, and haunch. The haunch is considered to be the distance between the bottom of the concrete slab and the bottom of the top flange. The stiffened web designs were developed using the "partially stiffened web approach," which involves reducing the unstiffened web thickness by 1/16" to 1/8", depending on the layout of the required transverse stiffeners.

The parameters that remain constant for each design include:

- Stay-in-place deck forms = 15 psf
- Future wearing surface = 25 psf
- Concrete barriers = 305 lb/ft.
- Increase steel in weight to account for miscellaneous details = 5%
- Compressive strength of Concrete = 4.0 ksi
- Concrete Unit weight = 150 pcf
- Steel Unit weight = 490 pcf
- Modular ratio = 8.0
- Haunch = 2 in.
- Constant flange width
- Uniform web plate
- Construction loads:

Overhang deck forms:	40 lbs/ft.
Screed rail:	85 lbs/ft.
Railing:	25 lbs/ft.
Walkway:	125 lbs/ft.
Finishing Machine:	3000 lbs.

The available flange plate thicknesses are taken in increments of 1/8 in., and the web plates are taken in increments of 1/16 in. The plate widths are taken in increments of two inches. Minimum plate restrictions were imposed to ensure ease of fabrication and reduce problems associated with flange distortion due to welding. The minimum permitted flange side was 12 in. wide and ¾ in. thick. The minimum web plate was limited to 24” x 7/16”. In order to offset the cost of fabrication, flange transitions were included at 20% of the span length from the supports, refer to Fig. 4.1, if the transition would save a minimum of 800 lbs. of steel.

4.3 Design Approach

Each girder design began by selecting the web depth based on the span-to-depth ratio. For this study, three ratios were selected: 20, 25, and 30. Due to the previously mentioned minimum plate restrictions, only one design, which has a span-to-depth ratio less than 20, was developed for the shorter span lengths. Once the target depth of the superstructure was calculated from the span-to-depth ratio, the web depth was determined by subtracting the slab thickness, haunch, and bottom flange thickness from the depth of the superstructure. Finally, the web depths were rounded to the nearest even number to obtain web plates in increments of 2 inches.

After the web depth was chosen, a preliminary flange width was selected such that the ratio of web depth to flange width was between 3.0 and 4.0, if possible. Since restrictions were placed on the plate sizes, some of the sections were unable to have an aspect ratio within the targeted range. The flange width and web thickness were initially taken as the minimum allowed based on the plate restrictions. The cross-frame spacing was selected based on the span length, and was limited to a practical maximum of 30 feet.

For designs based on the 2nd Edition of the LRFD Specifications, the capacity of the preliminary section was checked using the software program Steel Bridge, by Bridgesoft (2003). A series of hand-calculations were performed to verify the accuracy of the software results. To design sections that satisfy the 3rd Edition of the LRFD, a series of spreadsheets were developed to compute section capacities, and the moment and shear envelopes were developed from the commercial software program ConSys 2000 (1998). First the unstiffened web thickness required to resist the shear loading was determined. If the design was partially stiffened, the unstiffened web thickness was reduced by 1/16" to 1/8". Then the compression and tension flange thicknesses were selected.

If the design section failed to meet one of the limit states or if the section was overly conservative, the dimensions of the member were adjusted and re-evaluated to ensure the requirements were satisfied. Generally, the designs were controlled by the permanent deflections criteria of the Service limit state. Therefore, the girders were initially selected to meet the permanent deformations; then, the remaining limit states were evaluated which is standard practice for positive bending sections.

To evaluate the effect of the Live-load Deflection Criteria on girder weight, the sections were designed to satisfy the strength and service limit states, but were initially permitted to violate the optional live-load deflection criteria. Then, the girders would be revised until the optimum section was obtained. If the optimized girder did not satisfy the deflection limit, a separate girder was developed to meet the criteria. An additional check was performed using the WVDOH Live-load Deflection procedures for the girders that failed the deflection criteria. The WVDOH criteria requires the same loading and deflection limit as the AASHTO deflection limit, but the moment of inertia of the girder is determined by dividing the moment of inertia of the entire superstructure, which includes the girders, deck, parapets, and sidewalks, by the number of girders in the cross-section.

4.4 Design Summary and Observations

This section describes the observations that were made during the optimized parametric bridge design study. The girders discussed in this section include interior girders were designed to meet the 2nd Edition of the Specifications, unless stated otherwise. A summary of the interior girder designs for the 28-ft. cross-section are included in Tbs. 4.1 and 4.2. An entire list of girder designs is contained in Appendix A.

4.4.1 Influence of Material Configuration

Figures 4.3 through 4.8 show the weight versus span-to-depth ratio for both the hybrid and homogeneous designs with span lengths of 120 ft., 100 ft., 80 ft., 60 ft., and 40 ft., where the weight corresponds to a single girder. The designs that meet all limit states except the live-load deflection criteria are plotted as a single open data point. From the figures, the hybrid material configuration results in a lighter design than the homogeneous configuration for the longer spans in this study. For example, at a span length of 120 ft., which is the maximum span length in the study, the weight savings between the homogeneous and hybrid optimized designs is 1.22 tons, a difference of 10.3 percent.

As the span length decreases, the hybrid and homogeneous designs approach the same weight until both of the configurations yield the same section due to plate size restrictions. This is the case for designs with a span length less than 55 ft. for the 28 ft. cross-section, and less than 50 ft. for the 34 ft. cross-section.

A cost analysis was performed for the sections based on the fabrication cost of \$0.61/lb. for 50 ksi steel and \$0.75/lbs. for HPS 70W steel (Clingenpeel 2001). Figures 4.9 through 4.13 show the relationship between the span-to-depth ratio and girder cost. From the graphs, savings can be realized by selecting the hybrid design over the homogeneous design for the longer span lengths. For example, there is a 4.0 percent difference between the hybrid and homogeneous designs with a span length of 120 ft. and a span-to-depth ratio of 25. As expected, for the shorter span lengths the price of the hybrid designs is higher than the price for the homogeneous designs partially because the sections are restricted by minimum plate sizes. In conclusion, the hybrid configuration should not be selected for girders with span lengths less than 55 ft.

4.4.2 Optimum Span-to-depth Ratio

The span-to-depth ratio has a significant impact on design economy. In general, designs with the highest span-to-depth ratios were found to have the highest weights. For example, the design with a span length of 80 ft. that has the largest span-to-depth ratio of 26.4 weighs 20.9 percent more than the section with a span-to-depth ratio of 19.4.

Another observation to note is that the optimum span-to-depth ratio was found to increase with increasing span length. For example, the optimum span-to-depth ratio for a span length of 120 ft. is approximately 24.0, while the lightest section with a span length of 80 ft. has a span-to-depth ratio of 19.4, which is the smallest span-to-depth ratio designed for that span length.

4.4.3 Interior & Exterior Girder Design

During the initial design process, girders were developed to satisfy the interior girder and the exterior girder locations and Figs. 4.14 through 4.18 depict the weight versus span-to-depth ratio for both girder designs. In general, the exterior girders required more steel than the interior girder designs, except for several specific cases. For example, from Fig. 4.15 it can be observed that the interior girder weighs more than the exterior section for the designs with a span-to-depth ratio of approximately 24.0. This is the result of the exterior girder saving enough steel to economically use a flange transition, while the interior girder design is uniform in cross-section for the entire span of the bridge.

The most influential difference between the interior and exterior girder design is the fatigue distribution factors. In some instances the fatigue distribution factor for the exterior girder based on the lever rule was as much as 42.6 percent greater than the interior girder distribution factor for fatigue; therefore, many of the exterior girder designs were controlled by fatigue. Since the fatigue limit state is based on geometry and not the strength of the steel, the hybrid designs required more steel to satisfy the fatigue requirements for load-induced fatigue.

In contrast, the bending moment distribution factor for the exterior girder was only slightly higher than the interior girder distribution factor. For instance, the maximum difference between the bending moment distribution factors was 10.8% for a span length of 120 ft. and decreased to 1.54% for the design with a 40 ft. span.

4.4.4 Influence of a Partially Stiffened Web

As previously mentioned, designs were completed for unstiffened and partially stiffened webs. Figures 4.19 and 4.20 depict the typical trends between the two types of designs. There is an overall average weight difference of 3.1 percent between the unstiffened and partially stiffened web designs. In general, the most significant weight savings by using a partially stiffened web is realized for the smaller span-to-depth ratios, with an average weight savings of 5.8 percent.

The only stiffened web designs which do not weigh less than the unstiffened web designs have a span-to-depth ratio of approximately 30. These sections must be significantly increased to meet the flexural requirements under the strength limit state as a result of the thinner web.

4.4.5 Weight Comparison of Rolled Beams

Rolled beams were found to be more economical as span length decreased until a span length of 50 ft. at which the rolled section is lighter than the plate girder designs. A series of graphs showing the relationship between the section weight and the span-to-depth ratio are in Figs. 4.21 through 4.25. Due to the limited depth at which a rolled section is manufactured, the longer spans require significantly heavier sections than the plate girder options. The largest span-to-depth ratio in the study was 31.2, which is for a rolled section with a span length of 120 ft. Differences in steel and fabrication costs for rolled beams versus plate girders may lead to a broader range of economy with rolled beams.

4.4.6 Influence of Span-to-Depth Ratio on Live-load Deflection Criteria

Figures 4.26 through 4.29 are graphs of the maximum deflection versus span-to-depth ratio. The black dashed line in the figures represents the live-load deflection limit of L/800. From the figures it can be observed that the majority of the designs which fail the live-load deflection criteria have larger span-to-depth ratios. Since the deflection criteria is a function of the moment of inertia of the section, it is reasonable to expect that designs with shallower depths fail the criteria more frequently than sections that have larger web depths. It is also noteworthy that none of the designs that initially failed the deflection criteria have a span-to-depth ratio less than 24.0.

In addition to failing the limit state more frequently, designs with a span-to-depth ratio of approximately 30 also require more steel to satisfy the deflection criteria. In fact, the larger span-to-depth ratios require approximately 34.1 percent more steel to satisfy the live-load deflection criteria than the design with the smaller span-to-depth ratio.

Only nine of the 44 designs that failed the deflection limit of L/800 are at the optimum span-to-depth ratios. In addition, the redesigned optimum sections that satisfy the limit are on average only 3.94 percent heavier than the sections that fail the criteria. This amounts to an average difference of 491 pounds.

4.4.7 Influence of Material Configuration on Live-load Deflection Criteria

Of the sections that fail to meet the live-load deflection criteria, the hybrid sections fail the deflection limit more frequently than the homogeneous material configurations. Including both cross-sections, a total of 44 designs initially failed the Live-load deflection criteria; 40 of these designs have hybrid material configurations.

For those sections not meeting the live-load deflection limit, the hybrid designs require more steel to meet the criteria than the girders with a homogeneous material configuration. For the designs where both the homogeneous and hybrid designs initially failed the deflection limit for the 28 ft. cross-section, the hybrid design required an average of 75.4 percent more steel than the homogeneous designs to satisfy the deflection criteria.

In addition, all nine of the designs with optimized web depths which failed the deflection limit had a hybrid material configuration. Therefore, the live-load deflection criteria can have a negative impact on the economy of hybrid girder designs.

4.4.8 Influence of WVDOH Live-load Deflection Criteria

When performing the WVDOH live-load deflection check, a number of the sections that failed the AASHTO deflection procedure were able to satisfy the WVDOH limit. During the optimized design study, 36 designs failed the AASHTO deflection criteria, but 12 of the section satisfied the WVDOH deflection check. The general trend between the two live-load deflection criteria is apparent from Fig. 4.30, which represents the interior girder designs for the 28-ft. cross-section. Six of the 23 girders that initially failed the AASHTO deflection limit were able to meet the WVDOH deflection criteria. It is interesting to note that all four of the homogeneous designs which failed the AASHTO deflection criteria were able to satisfy the WVDOH limit. This is expected since the homogeneous girders generally do not significantly fail the live-load deflection criteria.

The difference between the WVDOH and AASHTO deflection criteria is more significant for the shorter span lengths. From Fig. 4.31, the WVDOH deflection criteria produces deflections up to 22 percent smaller than the AASHTO live-load deflection procedure for the shortest span length that failed the criteria, which is 60 ft. The WVDOH criteria only reduced the deflection of the 120 ft. span by approximately 9 percent. This trend should be anticipated since the girders become larger as the span length increases, but the geometry of the barriers remains the same.

4.4.9 Influence of Third Edition of the Specifications

Figures 4.32 through 4.36 represent the typical results from comparing the designs from the 2nd and 3rd Editions of the LRFD Specifications, neglecting constructibility. With the exception of a few cases, designs conducted according to the

3rd Edition of the specifications were found to result in the same optimized section as the 2nd Edition. This can be attributed to the fact that most of the designs were controlled by permanent deformations. The 3rd Edition includes flange lateral bending stresses in the permanent deformation limit state, but since the structure is checked while in its final condition, the lateral stresses are negligible. Therefore, the permanent deflection check is the same for both editions of the AASHTO Specifications. Some of the 3rd Edition designs required smaller sections than the 2nd Edition designs to meet the flexural capacity requirements, but these designs generally failed the Live-load deflection criteria. This is due to the fact that the sections with a larger span-to-depth ratio are controlled by the flexural capacity and girders with a smaller span-to-depth ratio are controlled by permanent deformations.

4.4.10 Weight Comparison with Other Standardized Bridge Plans

The weight of the girder designs developed in this study for interior girders are compared to the weight of the designs from AISI Short-span Steel Bridges (AISI, 1998) and TxDOT Standardized Bridge Plans (TxDOT, 2004). The optimized girder designs for the three span-to-depth ratios along with designs from the other standardized bridge plans are shown in Fig. 4.37 based on weight and the span length. As can be seen from the figure, many of the designs developed from this study weigh less than the designs from both of the other design packages. For example, the optimum homogeneous unstiffened plate girder designs developed during this study were an average of 9.1

percent lighter than the AISI designs and 15.0 percent ligher than the lightest TxDot designs .

The TxDOT package results in lighter sections for span lengths between 55 ft. and 75 ft. These designs are similar to the rolled sections selected for the same span length in the design package. In contrast, the TxDOT designs typically have higher span-to-depth ratios for the longer span lengths, and therefore, generally require more steel.

The designs completed in this study are comparable to the designs specified in the AISI Short-span Steel Bridge Designs Manual which are in accordance with the LFD Bridge Specifications. The AISI bridge package does not include designs with hybrid material configurations; therefore, the comparisons are for the homogeneous designs. The main difference between the design packages is the range of superstructure depths. For example, the AISI designs have a span-to-depth ratio between 15.5 and 21.3, while the optimized designs developed from this study have span-to-depth ratios from 18.6 to 28.6. Since this study targeted three span-to-depth ratios, generally the designs with a larger span-to-depth ratio weigh more than the AISI designs, but the designs with the smaller span-to-depth ratios are comparable to the AISI package, and in many instances require less steel.

Table 4.1 Homogeneous 50-ksi Plate Girder Designs with Unstiffened Webs for 28-ft. Cross-section

Span Length (ft.)	L/D	b_{tf} (in.)	t_{tf} (in.)	D_w (in.)	t_w (in.)	b_{bf} (in.)	t_{bf} (in.)	b_{bf} (in.)	t_{bf} (in.)	Cross Frame Spacing (ft.)	WGT. (tons)
40	13.6	12	0.750	24	0.4375	-	-	12	0.750	20.00	1.94
45	15.3	12	0.750	24	0.4375	-	-	12	0.750	22.50	2.18
50	17.0	12	0.750	24	0.4375	-	-	12	0.750	25.00	2.42
55	18.6	12	0.750	24	0.4375	-	-	12	1.000	27.50	2.95
60	19.2	12	0.750	26	0.4375	-	-	12	1.000	20.00	3.30
60	20.2	12	0.750	24	0.4375	-	-	12	1.125	20.00	3.37
65	19.7	12	0.750	28	0.4375	-	-	12	1.125	21.66	3.84
65	21.9	12	0.750	24	0.4375	-	-	14	1.125	21.66	3.90
70	19.3	12	0.750	32	0.4375	-	-	12	1.125	23.33	4.35
70	23.4	12	0.750	24	0.4375	-	-	14	1.375	23.33	4.62
75	19.8	12	0.750	34	0.4375	-	-	14	1.000	25.00	4.83
75	23.7	12	0.750	26	0.4375	-	-	14	1.500	25.00	5.28
75	24.7	12	0.750	24	0.4375	-	-	12	2.000	28.33	5.55
80	19.3	12	0.750	38	0.4375	-	-	12	1.125	26.67	5.33
80	23.9	12	0.750	28	0.4375	-	-	12	1.750	26.67	5.75
80	26.4	12	0.750	24	0.4375	-	-	16	1.875	26.67	6.74
85	19.7	12	0.875	40	0.4375	-	-	12	1.250	28.33	6.22
85	24.2	14	0.750	30	0.4375	-	-	16	1.625	28.33	7.18
85	27.8	14	0.875	24	0.4375	16	1.125	16	2.250	28.33	7.46
85	28.0	14	0.875	24	0.4375	-	-	16	1.875	28.33	7.63
90	19.5	14	0.750	44	0.5000	-	-	14	1.000	30.00	7.12
90	24.5	14	0.875	32	0.4375	-	-	14	1.625	30.00	7.50
90	28.1	14	0.875	26	0.4375	18	1.000	18	2.000	30.00	8.03
90	28.2	14	0.875	26	0.4375	18	1.000	18	1.750	30.00	7.61
95	19.7	12	0.750	46	0.5000	-	-	12	1.250	23.75	7.60
95	23.7	14	0.750	36	0.4375	-	-	14	1.625	23.75	7.92
95	28.1	16	0.750	28	0.4375	18	1.000	18	2.000	23.75	8.57
95	28.2	14	0.875	28	0.4375	18	1.000	18	1.875	23.75	8.52

Table 4.1 (cont'd) Homogeneous 50-ksi Plate Girder Designs with Unstiffened Webs for 28-ft. Cross-section

Span Length (ft.)	L/D	b_{tf} (in.)	t_{tf} (in.)	D_w (in.)	t_w (in.)	b_{bf} (in.)	t_{bf} (in.)	b_{bf} (in.)	t_{bf} (in.)	Cross Frame Spacing (ft.)	WGT. (tons)
100	19.5	14	0.750	50	0.5000	-	-	14	1.125	25.00	8.72
100	23.9	12	0.875	38	0.4375	-	-	14	1.625	25.00	8.49
100	28.2	14	1.000	30	0.4375	16	1.125	16	2.125	25.00	9.31
100	28.3	14	1.000	30	0.4375	16	1.125	16	1.875	25.00	8.90
105	19.8	14	0.750	52	0.5000	-	-	14	1.125	26.25	9.33
105	24.2	14	0.750	40	0.5000	-	-	16	1.500	26.25	9.74
105	28.4	14	1.000	32	0.4375	18	1.000	18	1.875	26.25	9.91
110	19.5	14	0.750	56	0.5625	-	-	14	1.125	27.50	10.81
110	24.3	14	0.750	42	0.5000	14	1.000	14	1.875	27.50	9.89
110	28.3	14	0.750	34	0.4375	18	1.125	18	2.125	27.50	10.56
115	19.9	16	0.750	58	0.5625	-	-	16	1.000	28.75	11.86
115	24.4	14	0.875	44	0.5000	14	1.000	14	2.000	28.75	11.08
115	28.5	14	1.125	36	0.5000	18	1.000	18	1.875	28.75	11.97
120	19.6	16	0.750	62	0.5625	-	-	16	1.000	30.00	12.84
120	24.0	16	0.875	48	0.5000	16	0.875	16	1.500	30.00	11.84
120	28.6	14	1.125	38	0.5000	18	1.125	18	1.875	30.00	12.88

Table 4.2 Hybrid Plate Girder Designs with Unstiffened Webs for 28-ft. Cross-section

Span Length (ft.)	L/D	b_{tf} (in.)	t_{tf} (in.)	D_w (in.)	t_w (in.)	b_{bf} (in.)	t_{bf} (in.)	b_{bf} (in.)	t_{bf} (in.)	Cross Frame Spacing (ft.)	WGT. (tons)
40	13.6	12	0.750	24	0.4375	-	-	12	0.750	20.00	1.94
45	15.3	12	0.750	24	0.4375	-	-	12	0.750	22.50	2.18
50	17.0	12	0.750	24	0.4375	-	-	12	0.750	25.00	2.42
55	18.7	12	0.750	24	0.4375	-	-	12	0.750	27.50	2.67
60	19.3	12	0.750	26	0.4375	-	-	12	0.750	20.00	3.00
60	20.3	12	0.750	24	0.4375	-	-	12	1.000	20.00	3.22
60	20.4	12	0.750	24	0.4375	-	-	12	0.750	20.00	2.91
65	19.8	12	0.750	28	0.4375	-	-	12	0.875	21.67	3.51
65	19.9	12	0.750	28	0.4375	-	-	12	0.750	21.67	3.35
65	22.0	12	0.750	24	0.4375	-	-	14	1.000	21.67	3.70
65	22.0	12	0.750	24	0.4375	-	-	12	0.875	21.67	3.32
70	19.4	12	0.750	32	0.4375	-	-	12	0.750	23.33	3.81
70	23.4	12	0.750	24	0.4375	-	-	14	1.375	23.33	4.62
70	23.7	12	0.750	24	0.4375	-	-	12	1.000	23.33	3.75
75	19.9	12	0.750	34	0.4375	-	-	12	0.750	25.00	4.19
75	23.6	12	0.750	26	0.4375	-	-	12	1.625	25.00	5.09
75	24.1	12	0.875	26	0.4375	-	-	14	0.875	25.00	4.35
75	24.7	12	0.750	24	0.4375	-	-	12	2.000	25.00	5.55
75	25.4	12	0.875	24	0.4375	-	-	14	1.000	25.00	4.47
80	19.4	12	0.750	38	0.4375	-	-	12	1.000	26.67	5.12
80	23.9	12	0.750	28	0.4375	-	-	12	1.625	26.67	5.55
80	24.2	12	0.875	28	0.4375	-	-	12	1.250	26.67	5.14
80	26.3	12	0.750	24	0.4375	-	-	14	2.000	26.67	6.47
80	26.8	12	0.875	24	0.4375	-	-	12	1.375	26.67	5.10
85	19.8	12	1.000	40	0.4375	-	-	12	1.000	28.33	6.00
85	24.3	14	0.750	30	0.4375	-	-	14	1.500	28.33	6.45
85	24.6	14	0.875	30	0.4375	-	-	14	1.000	28.33	5.69
85	27.8	14	0.750	24	0.4375	16	0.750	16	2.250	28.33	6.85
85	28.5	14	0.875	24	0.4375	-	-	16	1.250	28.33	6.18

Table 4.2 (cont'd) Hybrid Plate Girder Designs with Unstiffened Webs for 28-ft. Cross-section

Span Length (ft.)	L/D	b_{tf} (in.)	t_{tf} (in.)	D_w (in.)	t_w (in.)	b_{bf} (in.)	t_{bf} (in.)	b_{bf} (in.)	t_{bf} (in.)	Cross Frame Spacing (ft.)	WGT. (tons)
90	19.5	12	0.750	44	0.4375	-	-	12	0.750	30.00	5.70
90	24.3	12	0.750	32	0.4375	12	0.750	12	1.875	30.00	6.14
90	24.7	12	0.750	32	0.4375	-	-	12	1.250	30.00	5.82
90	27.9	14	0.750	26	0.4375	18	0.875	18	2.250	30.00	8.04
90	28.6	14	0.875	26	0.4375	-	-	16	1.250	30.00	6.68
95	19.9	12	0.750	46	0.5000	-	-	12	0.875	23.75	6.87
95	23.7	12	0.750	36	0.4375	-	-	12	1.625	23.75	7.15
95	23.9	12	0.875	36	0.4375	-	-	12	1.125	23.75	6.42
95	28.0	12	1.000	28	0.4375	16	1.000	16	2.250	23.75	8.45
95	28.7	12	1.125	28	0.4375	-	-	16	1.250	23.75	7.39
100	19.6	14	0.750	50	0.5000	-	-	14	0.750	25.00	7.83
100	24.0	12	0.875	38	0.4375	-	-	12	1.500	25.00	7.68
100	24.1	12	0.875	38	0.4375	-	-	12	1.250	25.00	7.17
100	28.2	12	1.000	30	0.4375	16	1.125	16	2.125	25.00	8.97
100	28.6	12	1.125	30	0.4375	-	-	14	1.500	25.00	8.10
105	19.9	14	0.750	52	0.5000	-	-	14	0.750	26.25	8.40
105	24.3	14	0.750	40	0.5000	-	-	14	1.250	26.25	8.58
105	24.5	14	0.750	40	0.5000	-	-	14	1.000	26.25	7.95
105	28.4	14	0.875	32	0.4375	18	1.000	18	1.875	26.25	9.59
105	28.8	14	1.000	32	0.4375	-	-	18	1.250	26.25	9.02
110	19.6	14	0.750	56	0.5625	-	-	14	0.750	27.50	9.83
110	24.5	14	0.750	42	0.5000	-	-	14	1.375	27.50	9.50
110	28.2	14	0.875	34	0.4375	16	1.000	16	2.250	27.50	10.32
110	28.6	16	0.875	34	0.4375	16	0.875	16	1.625	27.50	9.37
115	19.9	14	0.750	58	0.5625	-	-	14	0.875	28.75	10.83
115	24.7	14	0.875	44	0.5000	-	-	14	1.375	28.75	10.47
115	28.4	14	0.875	36	0.5000	16	1.000	16	2.125	28.75	11.16
120	19.7	16	0.750	62	0.5625	-	-	16	0.750	30.00	12.02
120	24.2	16	0.750	48	0.5000	-	-	16	1.000	30.00	10.62
120	28.4	14	0.875	38	0.5000	14	1.250	14	2.250	30.00	11.67
120	28.5	16	1.000	38	0.5000	14	1.000	14	2.000	30.00	11.31

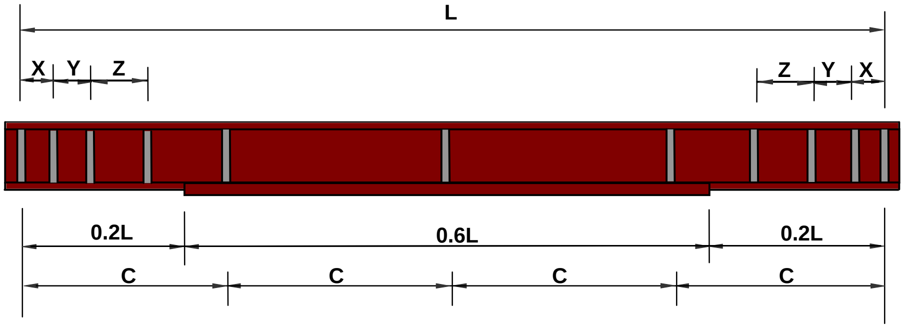

Figure 4.1 Typical Girder Elevation

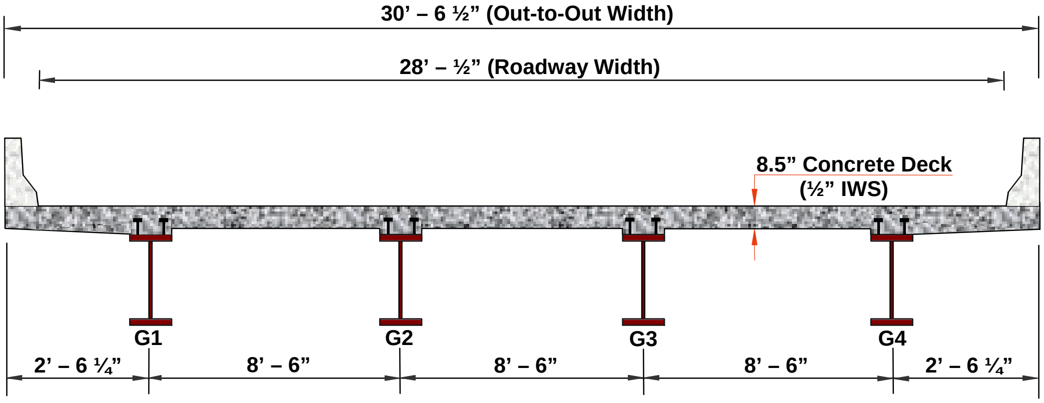

Figure 4.2 Bridge Cross-section with 28-ft. Clear Roadway Width

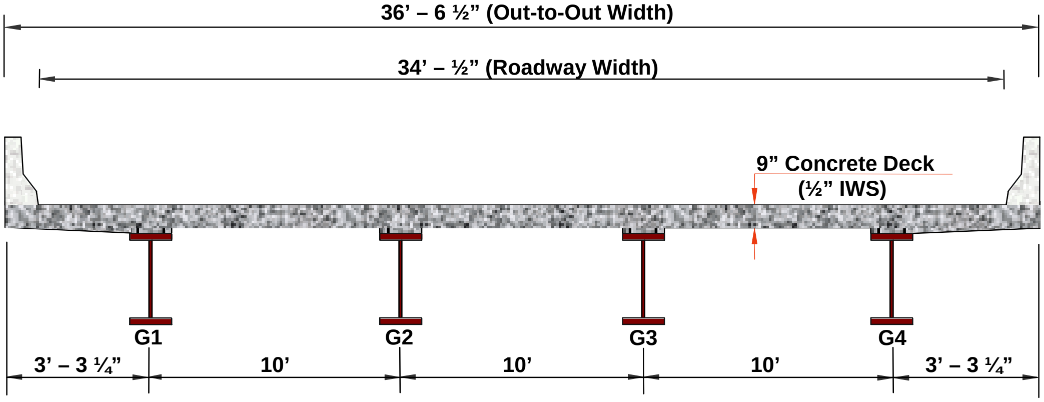

Figure 4.3 Bridge Cross-section with 34-ft. Clear Roadway Width

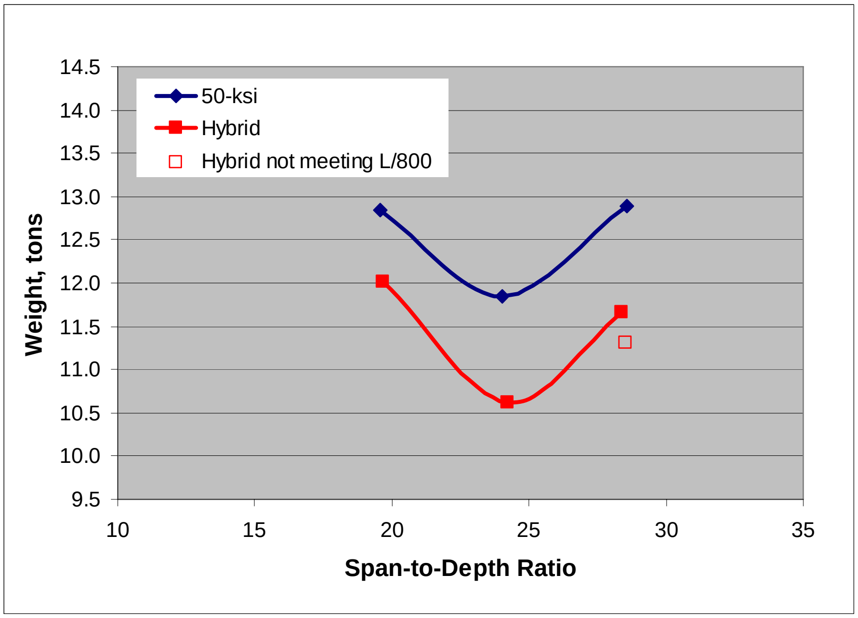

Figure 4.4 120 ft. with 28 ft. Cross-section System

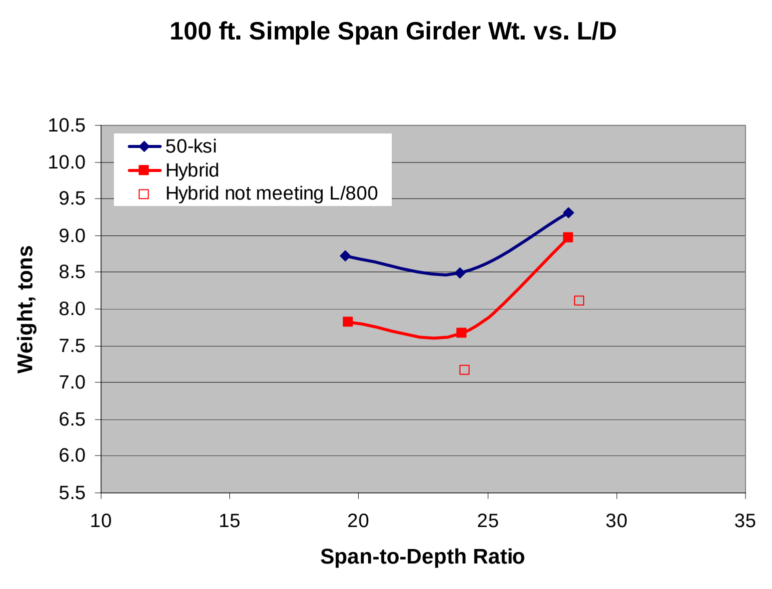

Figure 4.5 100 ft. with 28 ft. Cross-section System

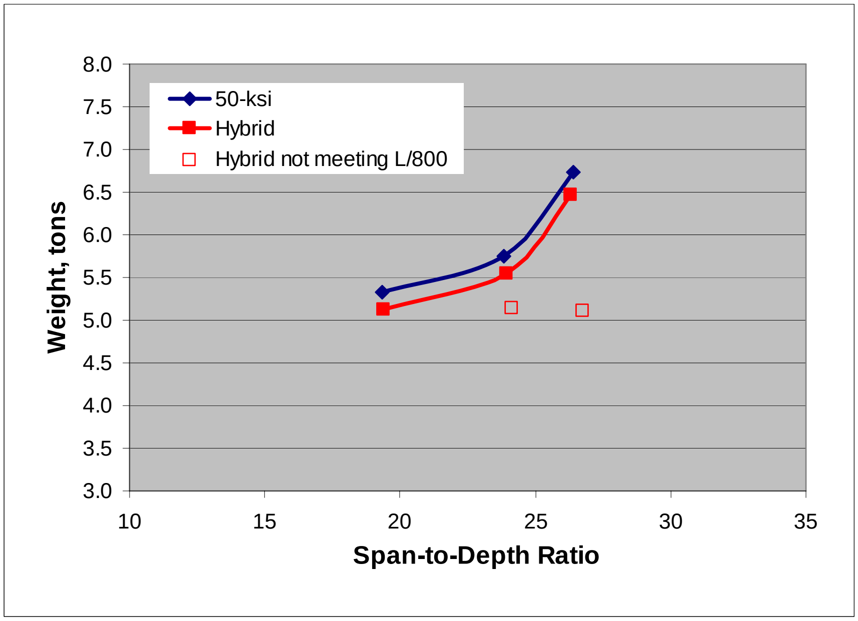

Figure 4.6 80 ft. with 28 ft. Cross-section System

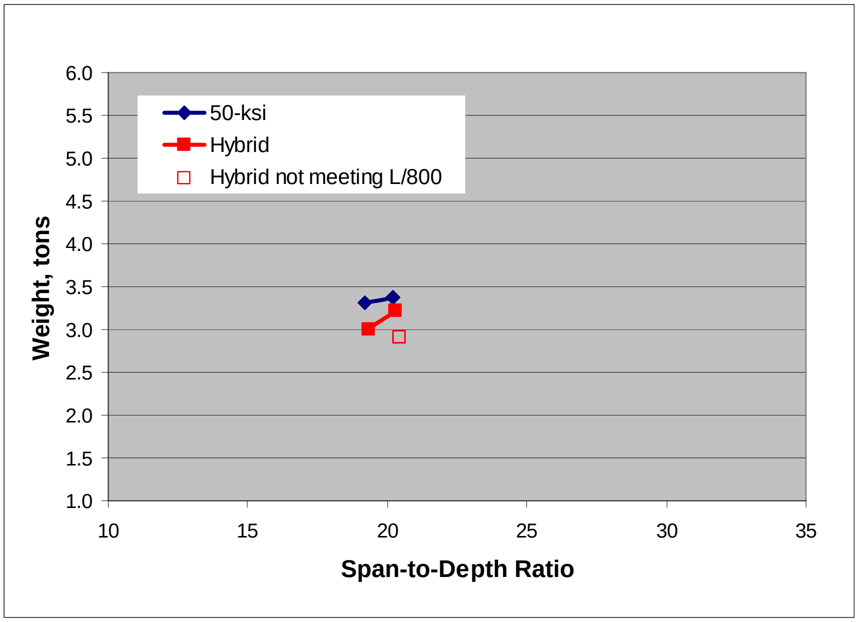

Figure 4.7 60 ft. with 28 ft. Cross-section System

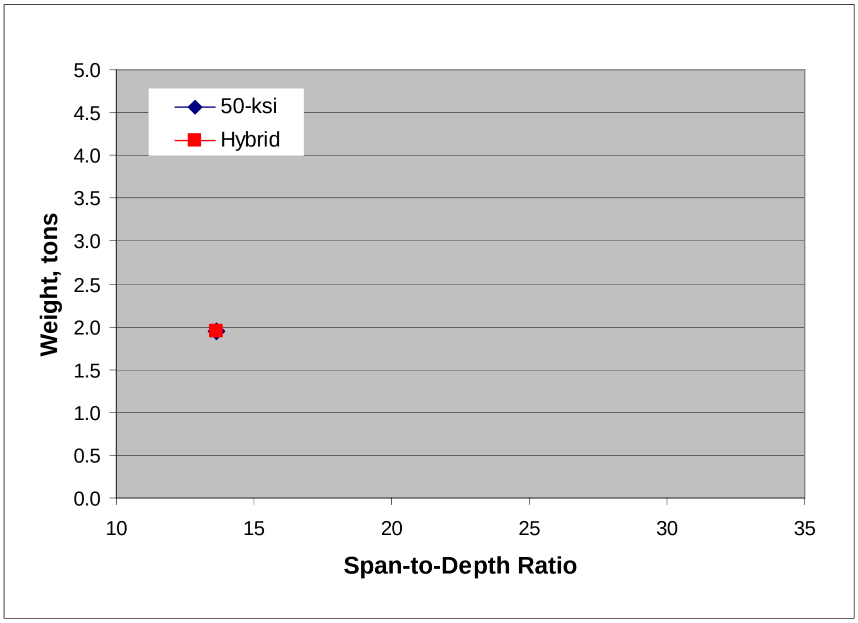

Figure 4.8 40 ft. with 28 ft. Cross-section System

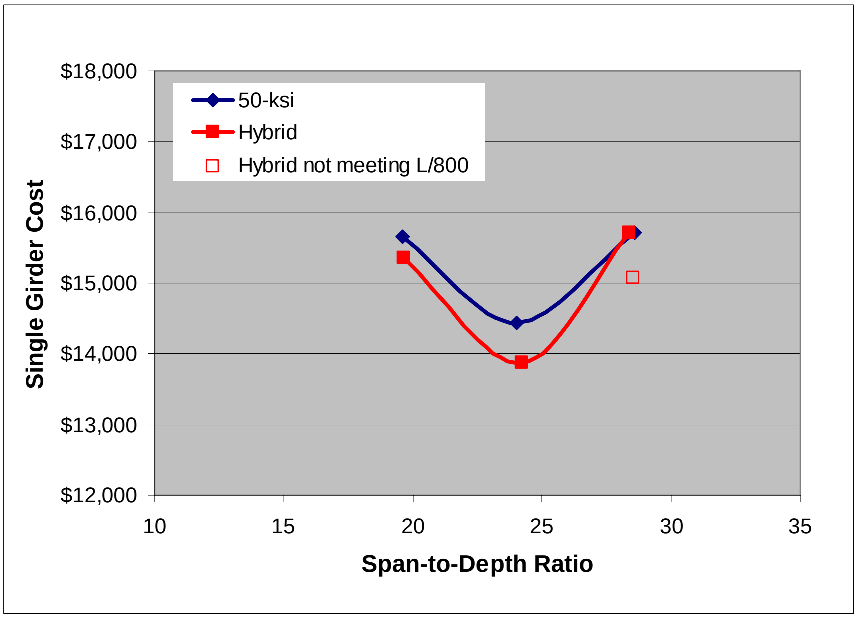

Figure 4.9 Girder Cost for 120 ft. with 28 ft. Cross-section

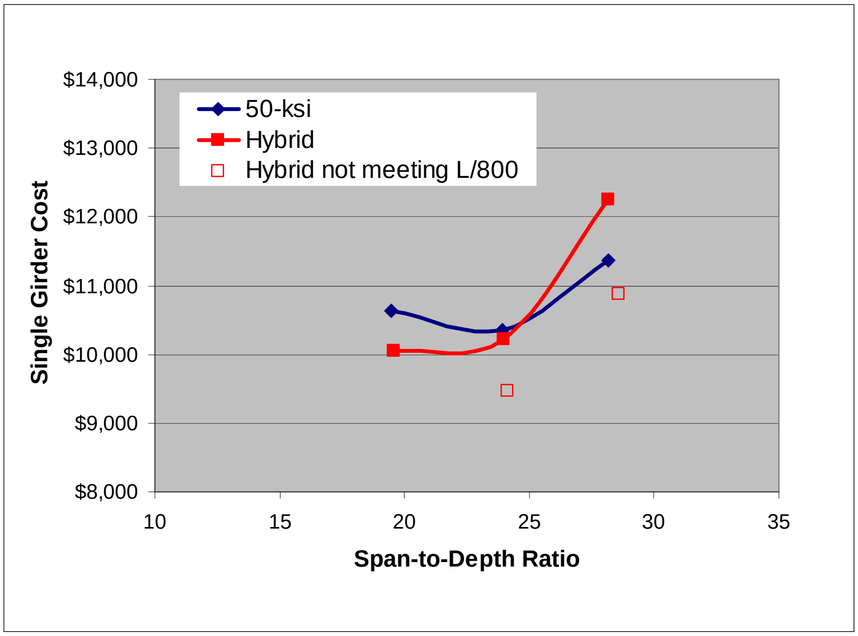

Figure 4.10 Girder Cost for 100 ft. with 28 ft. Cross-section

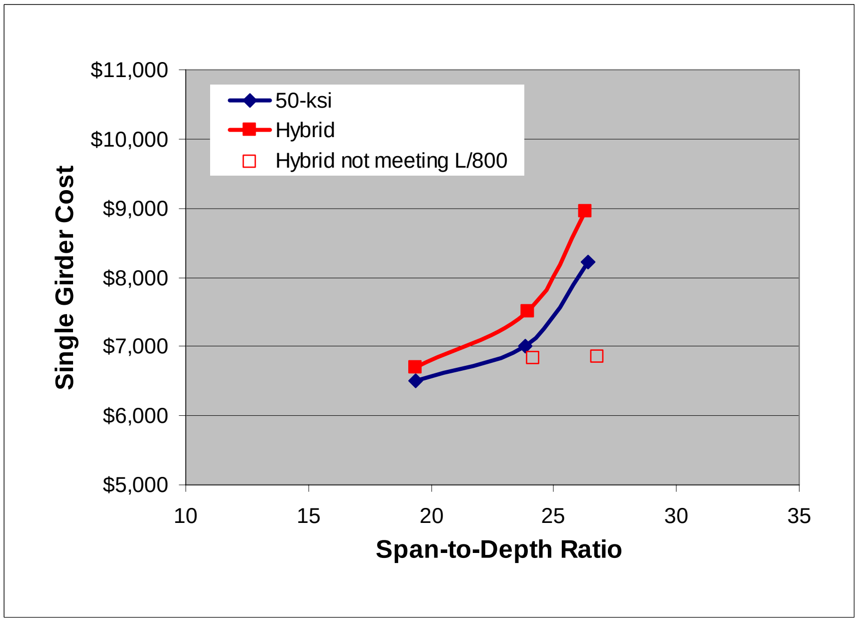

Figure 4.11 Girder Cost for 80 ft. with 28 ft. Cross-section

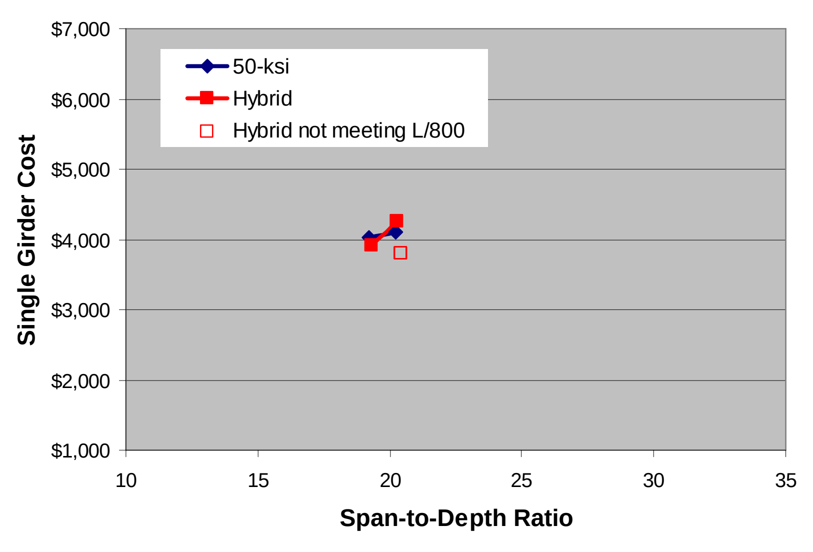

Figure 4.12 Girder Cost for 60 ft. with 28 ft. Cross-section

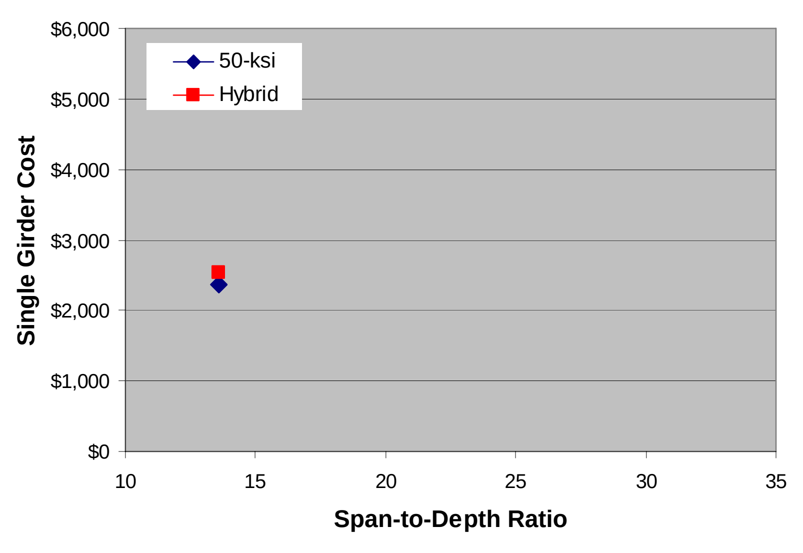

Figure 4.13 Girder Cost for 40 ft. with 28 ft. Cross-section

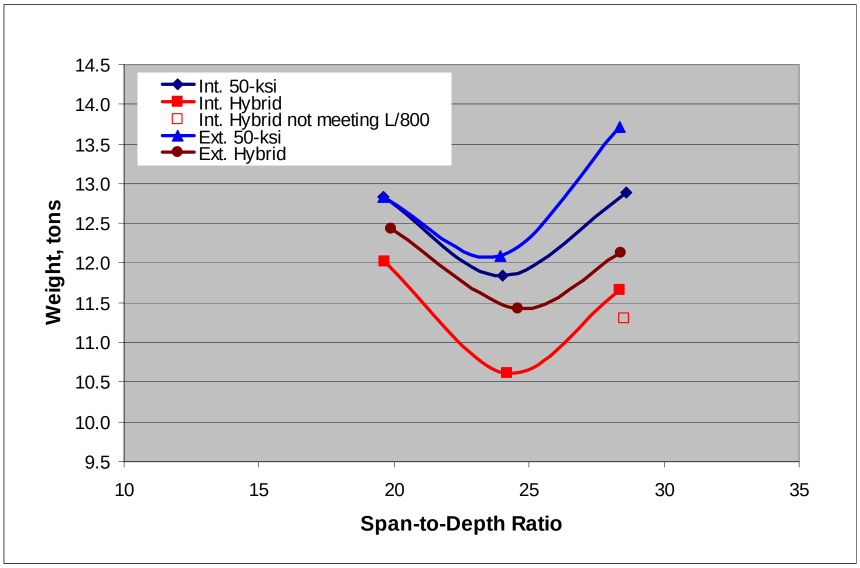

Figure 4.14 Interior and Exterior Girder Weights for 120 ft. Span with 28 ft. Cross-section System

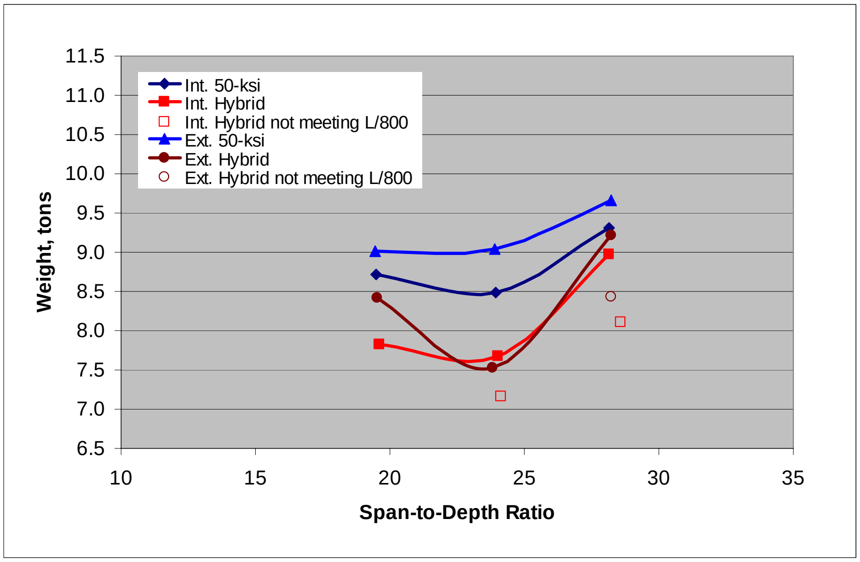

Figure 4.15 Interior and Exterior Girder Weights for 100 ft. Span with 28 ft. Cross-section System

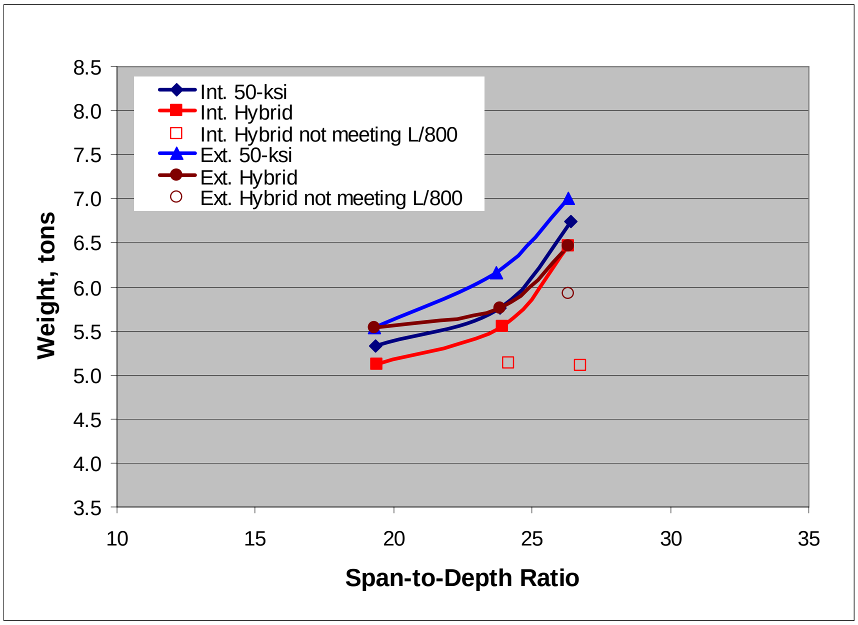

Figure 4.16 Interior and Exterior Girder Weights for 80 ft. Span with 28 ft. Cross-section System

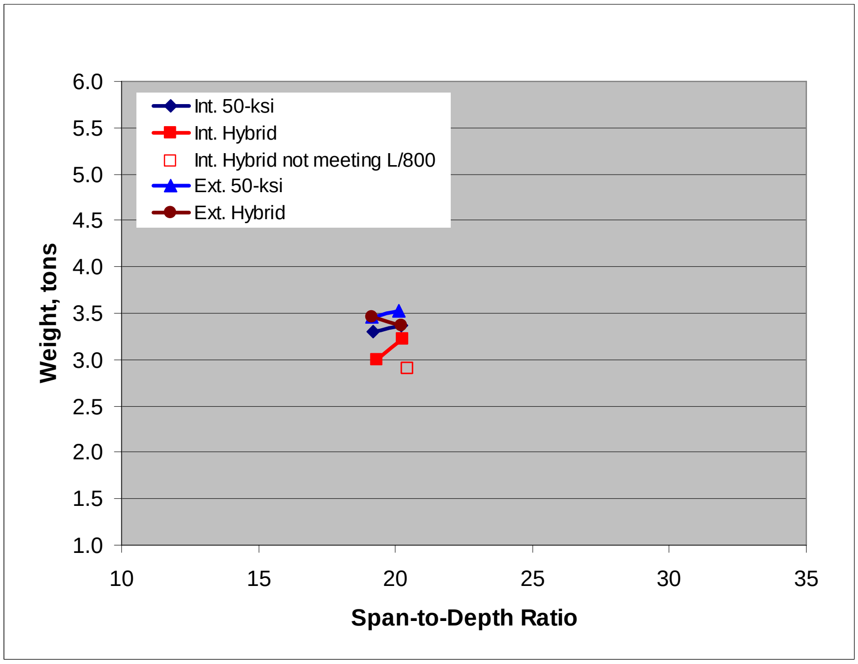

Figure 4.17 Interior and Exterior Girder Weights for 60 ft. Span with 28 ft. Cross-section System

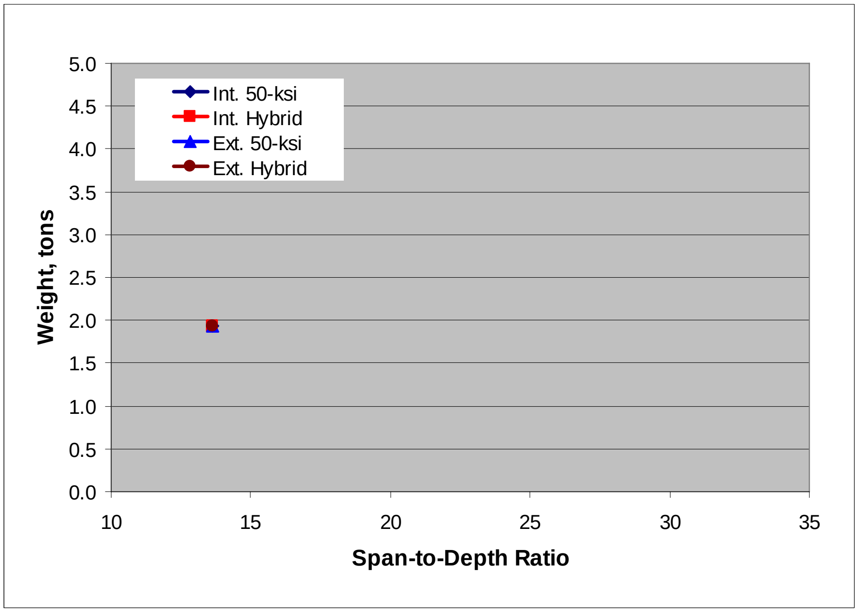

Figure 4.18 Interior and Exterior Girder Weights for 40 ft. Span with 28 ft. Cross-section System

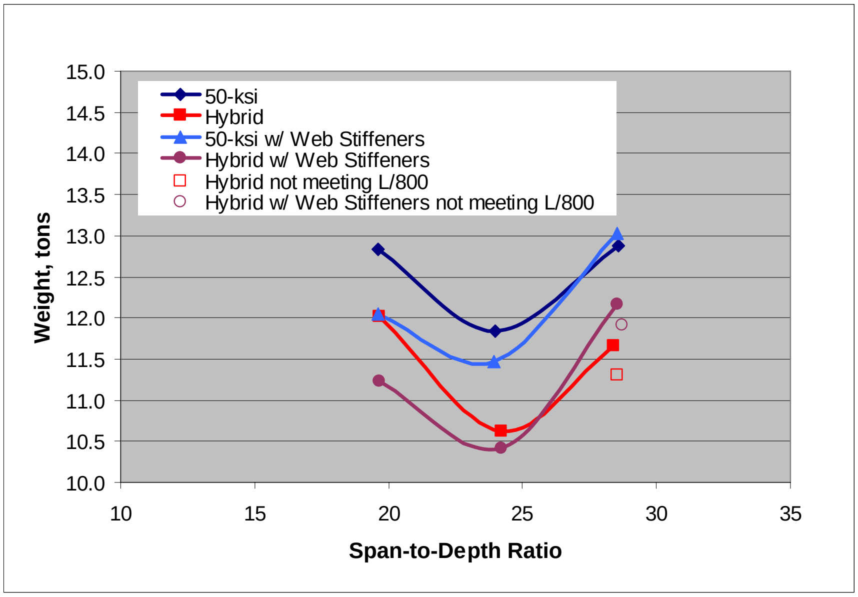

Figure 4.19 Partially Stiffened Web for 120 ft. Span with 28 ft. Cross-section System

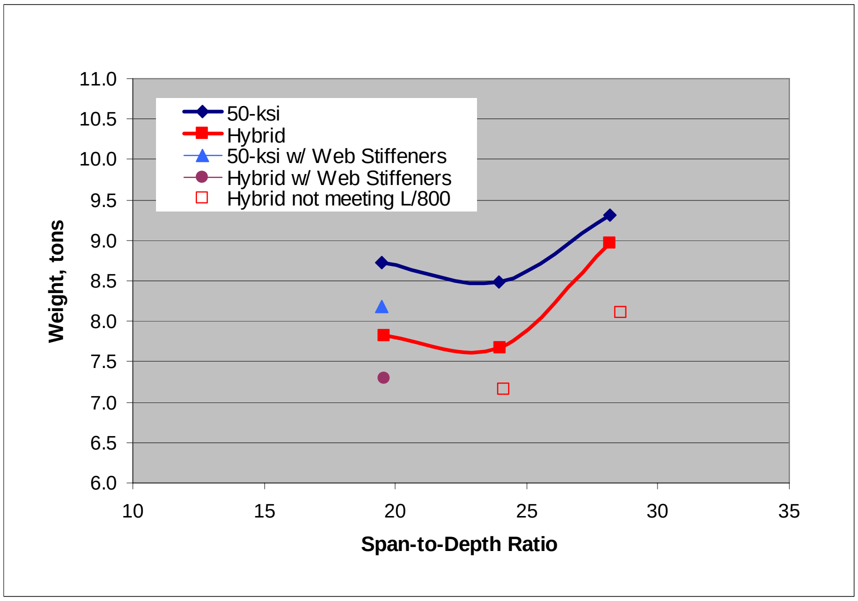

Figure 4.20 Partially Stiffened Web for 100 ft. Span with 28 ft. Cross-section System

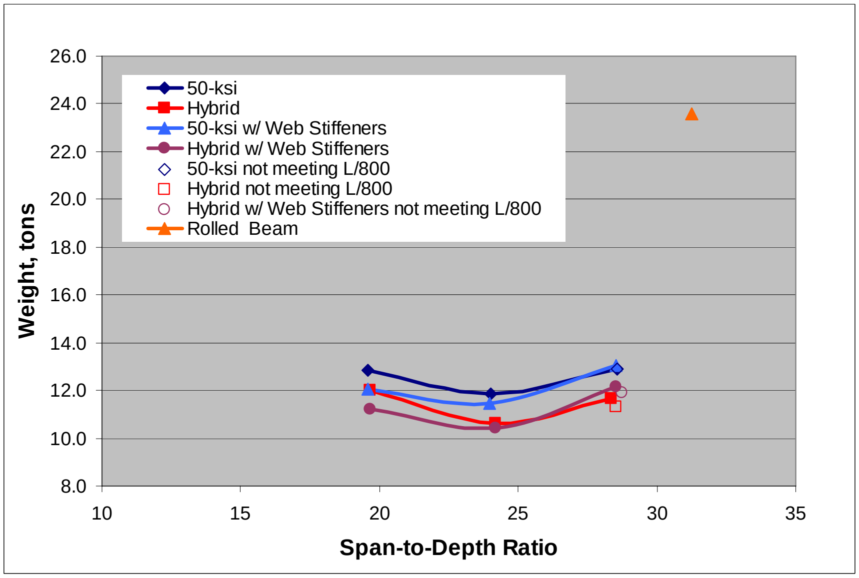

Figure 4.21 Weight Comparisons of Rolled Beam Designs for 120 ft. span and 28-ft. Cross-section

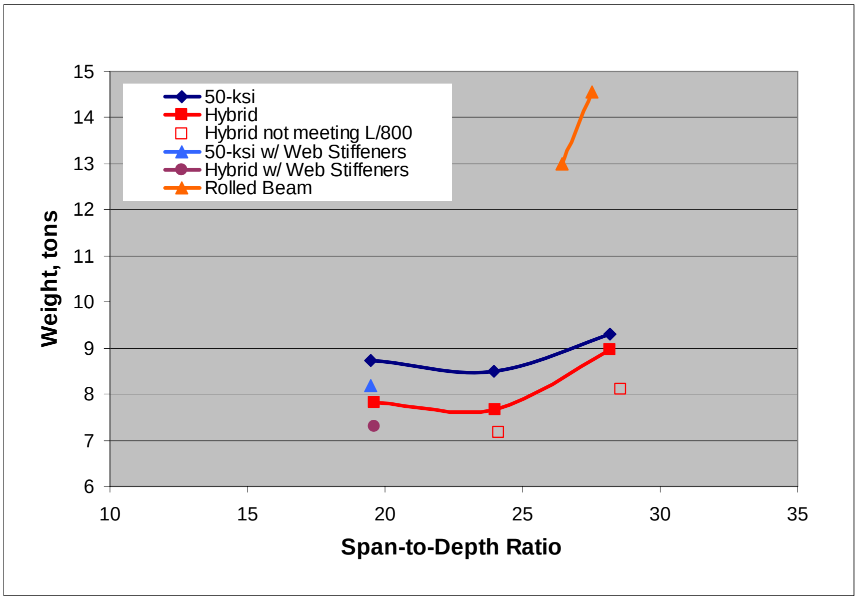

Figure 4.22 Weight Comparisons of Rolled Beam Designs for 100 ft. span and 28-ft. Cross-section

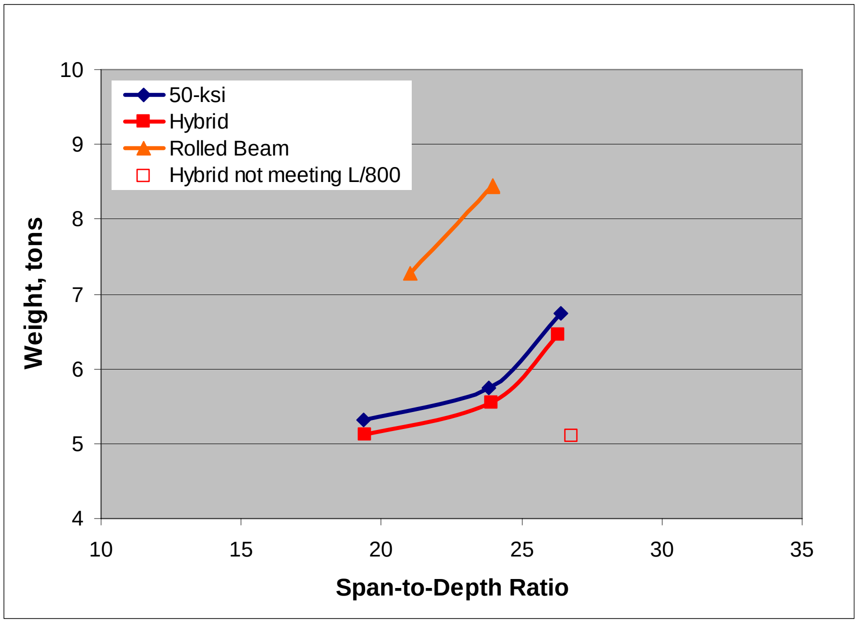

Figure 4.23 Weight Comparisons of Rolled Beam Designs for 80 ft. span and 28-ft. Cross-section

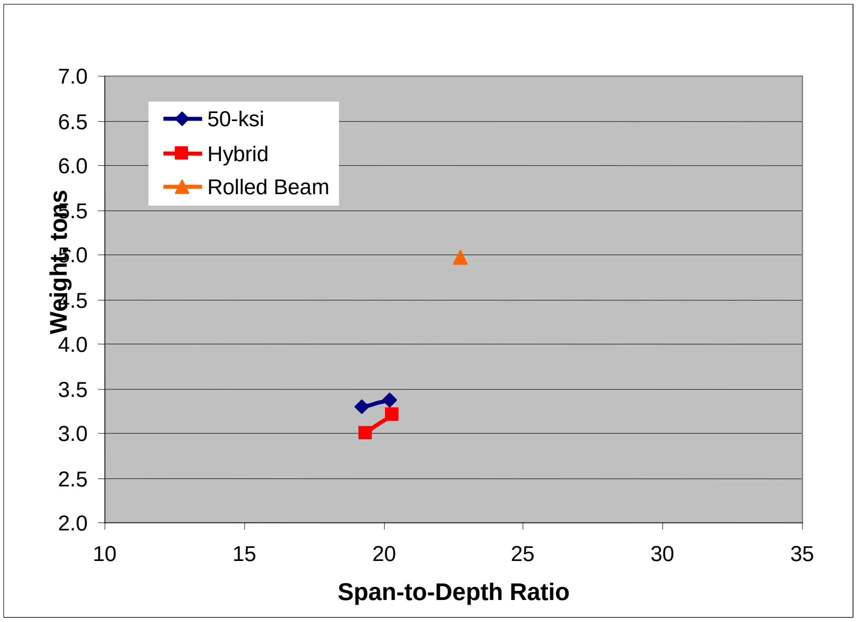

Figure 4.24 Weight Comparisons of Rolled Beam Designs for 60 ft. span and 28-ft. Cross-section

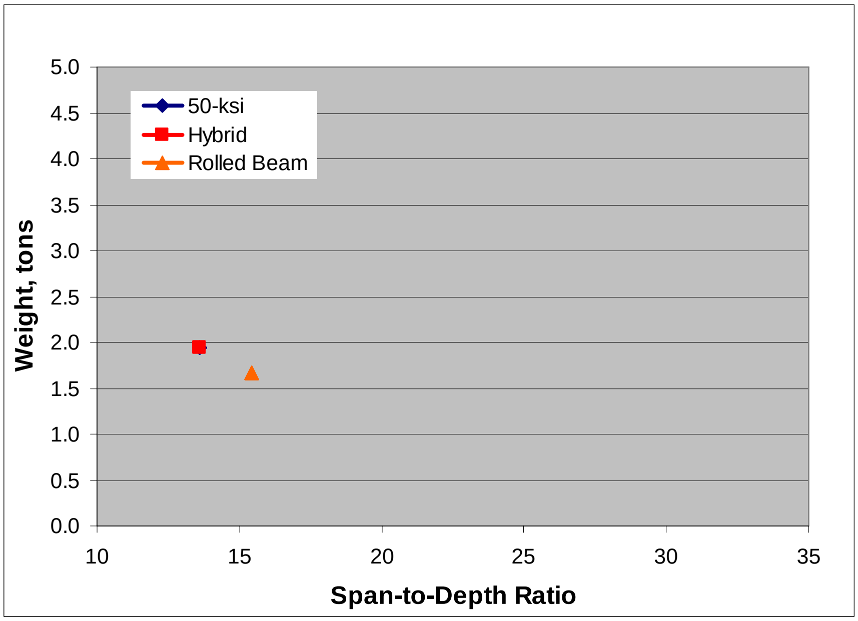

Figure 4.25 Weight Comparisons of Rolled Beam Designs for 40 ft. span and 28-ft. Cross-section

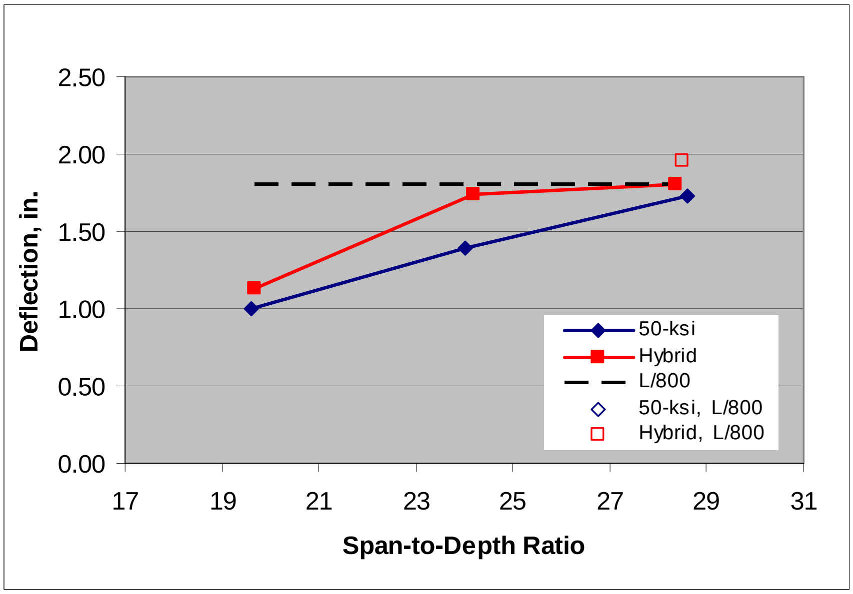

Figure 4.26 120 ft. with 28 ft. Cross-section System Deflection

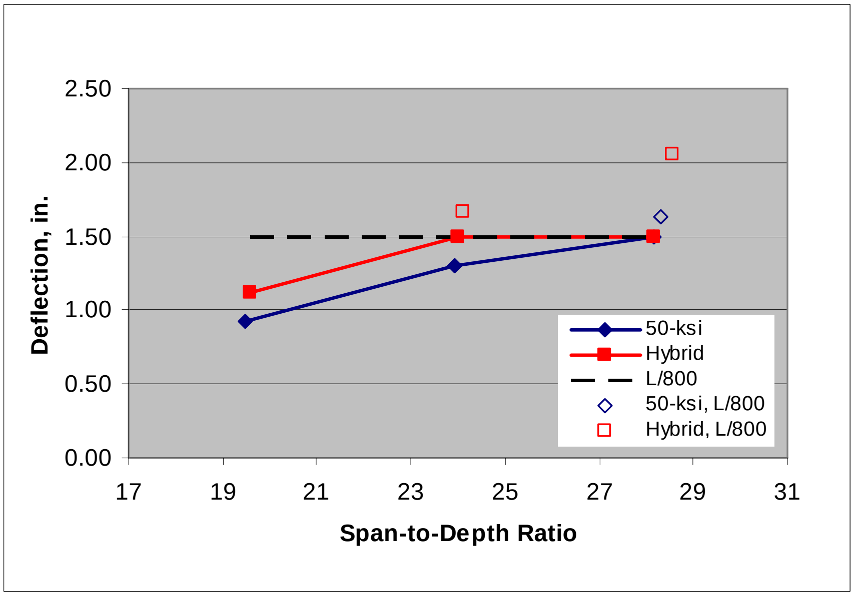

Figure 4.27 100 ft. with 28 ft. Cross-section System Deflection

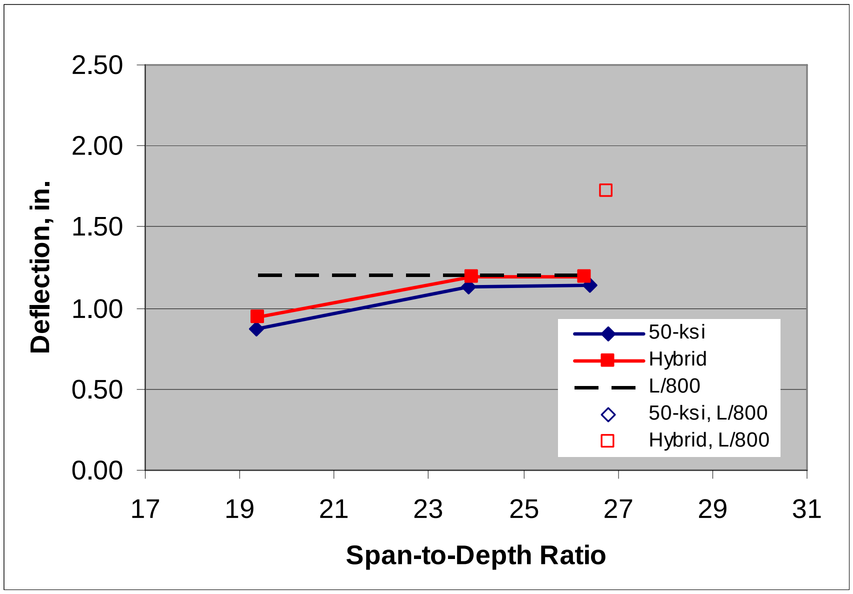

Figure 4.28 80 ft. with 28 ft. Cross-section System Deflection

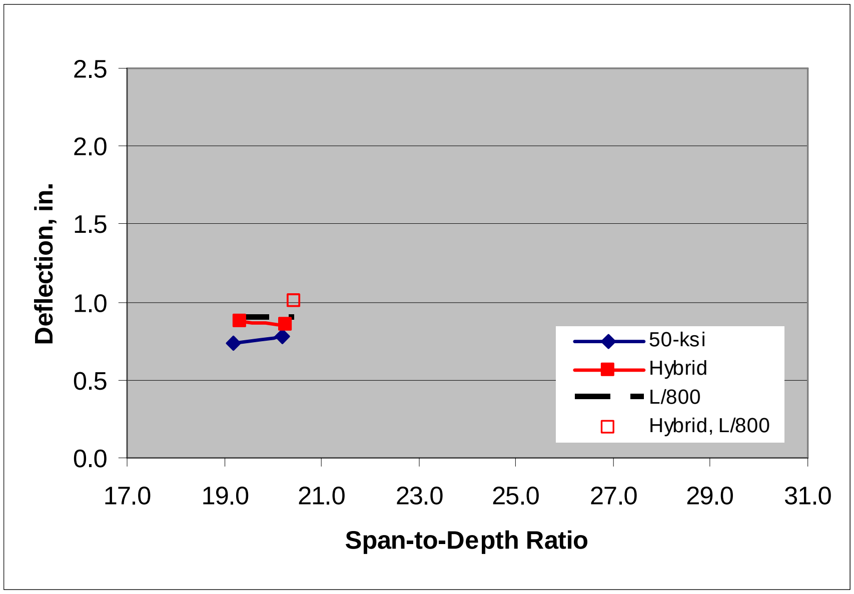

Figure 4.29 60 ft. with 28 ft. Cross-section System Deflection

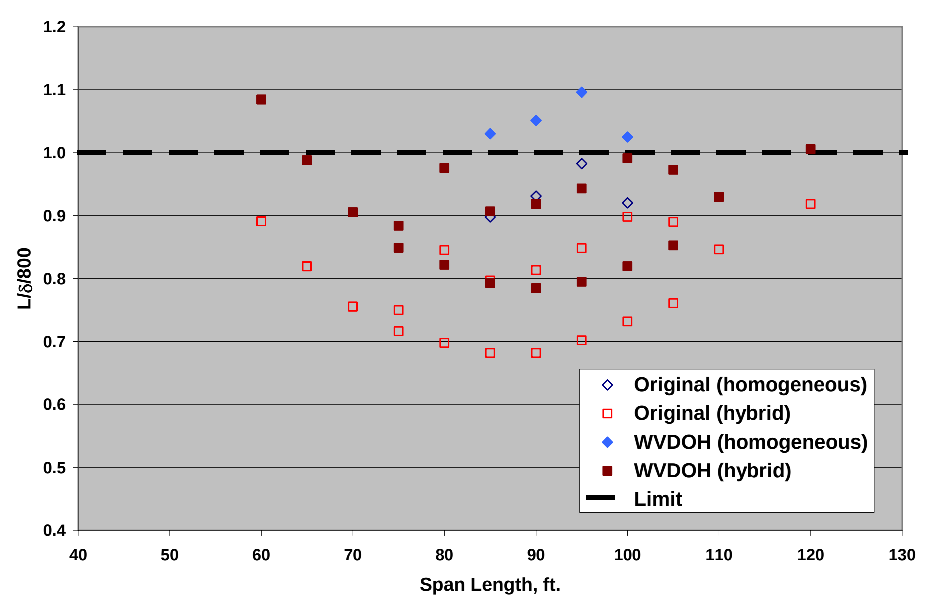

Figure 4.30 Comparison of Live-load Deflection Check for 28-ft. Cross-section

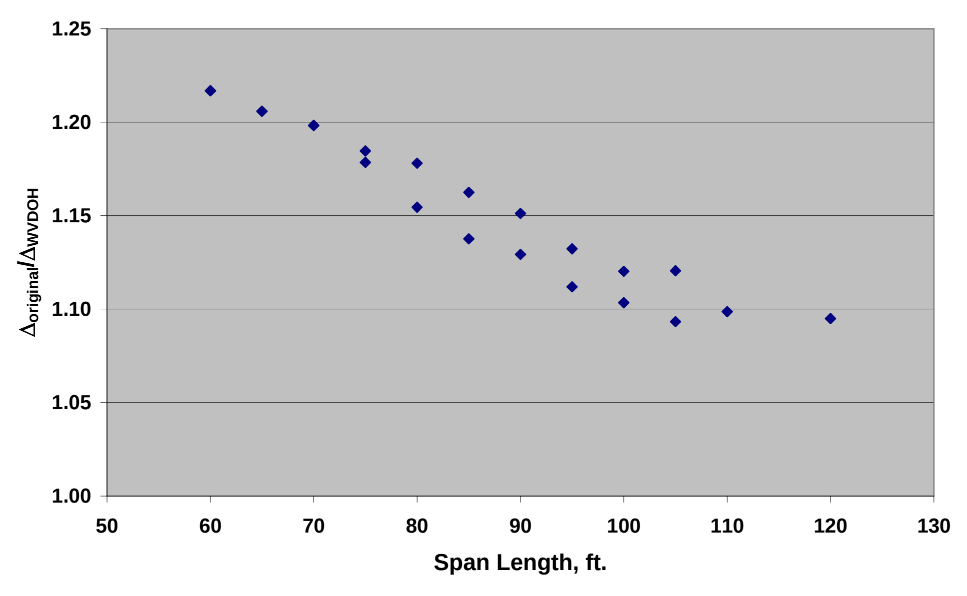

Figure 4.31 WVDOH Live-load Deflection

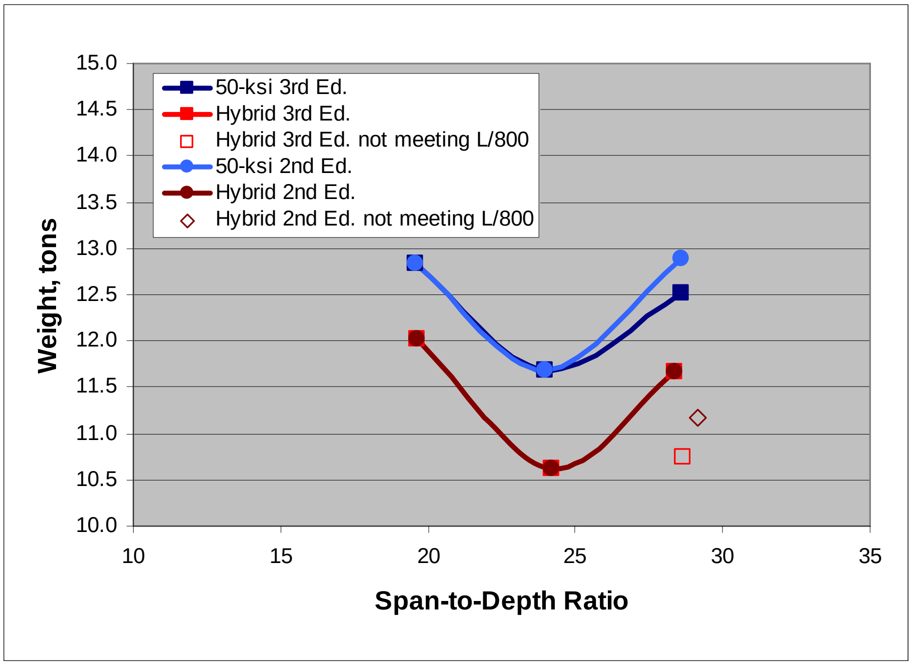

Figure 4.32 Comparison of 2^{nd} and 3^{rd} Editions for 120 ft. Span and 28-ft. Cross-section

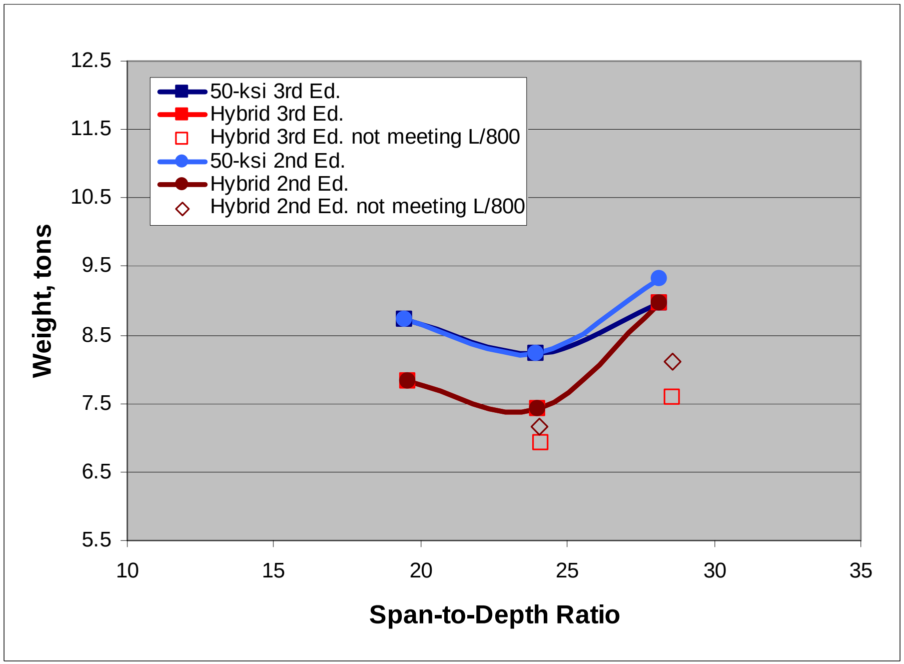

Figure 4.33 Comparison of 2^{nd} and 3^{rd} Editions for 100 ft. Span and 28-ft. Cross-section

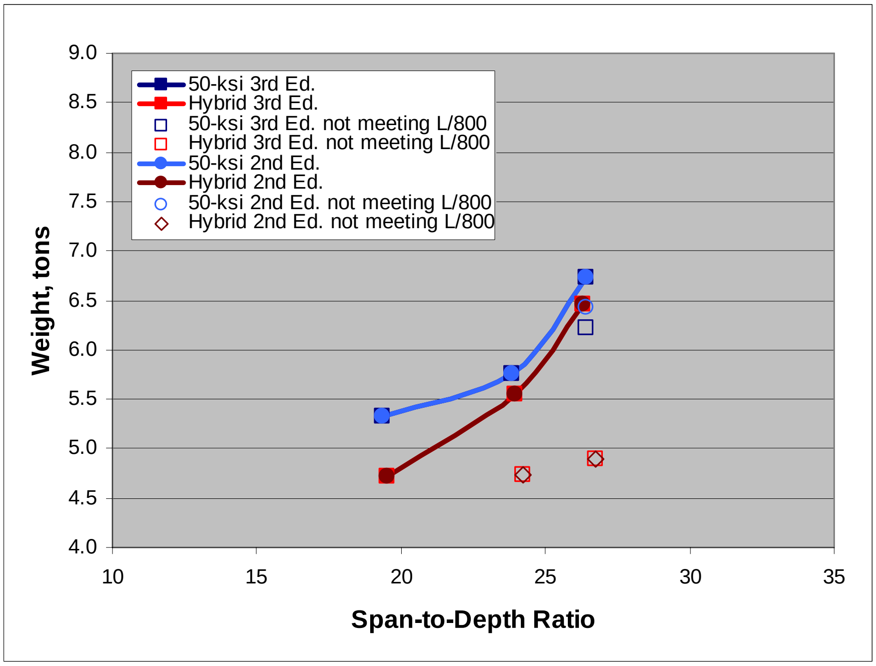

Figure 4.34 Comparison of 2nd and 3rd Editions for 80 ft. Span and 28-ft. Cross-section

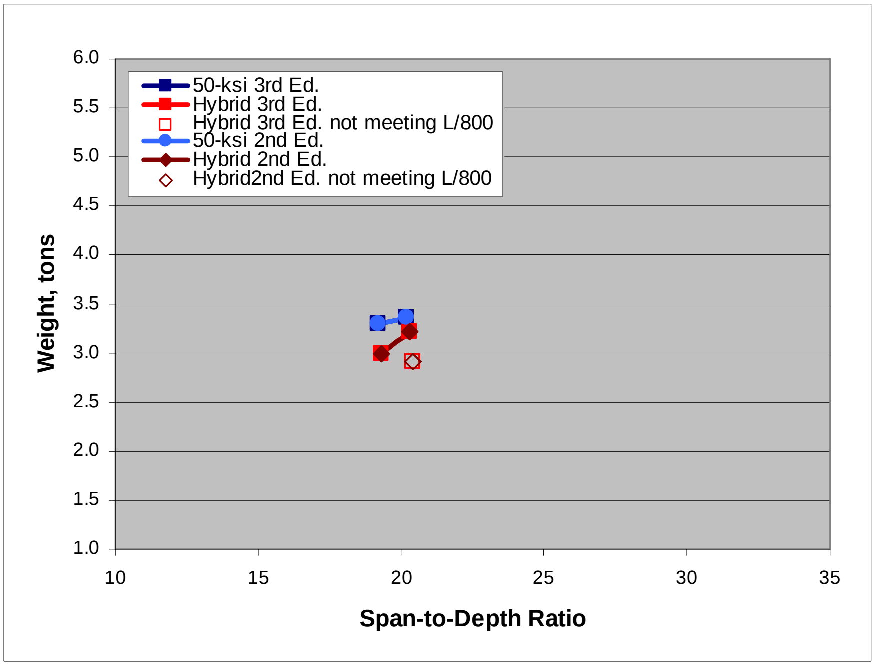

Figure 4.35 Comparison of 2nd and 3rd Editions for 60 ft. Span and 28-ft. Cross-section

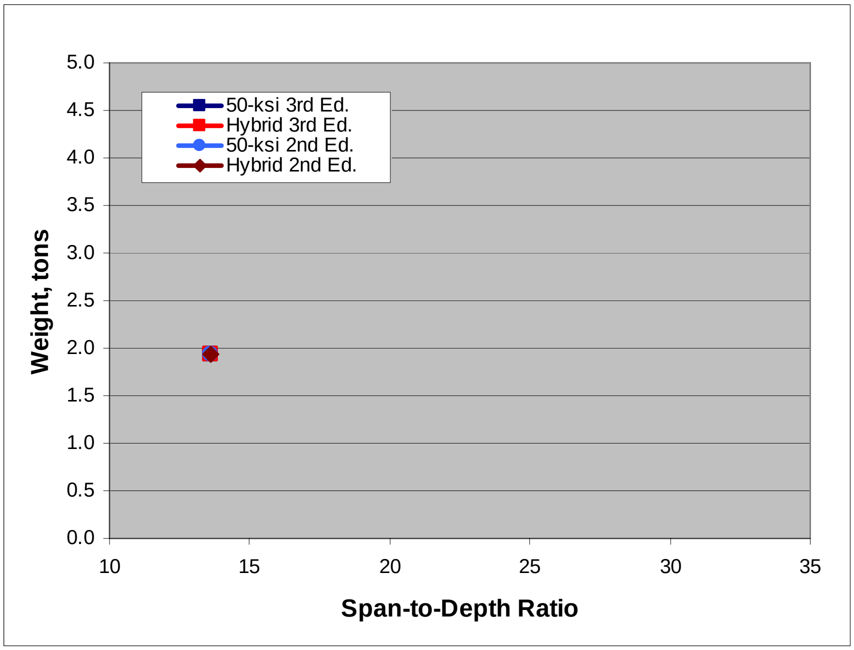

Figure 4.36 Comparison of 2nd and 3rd Editions for 40 ft. Span and 28-ft. Cross-section

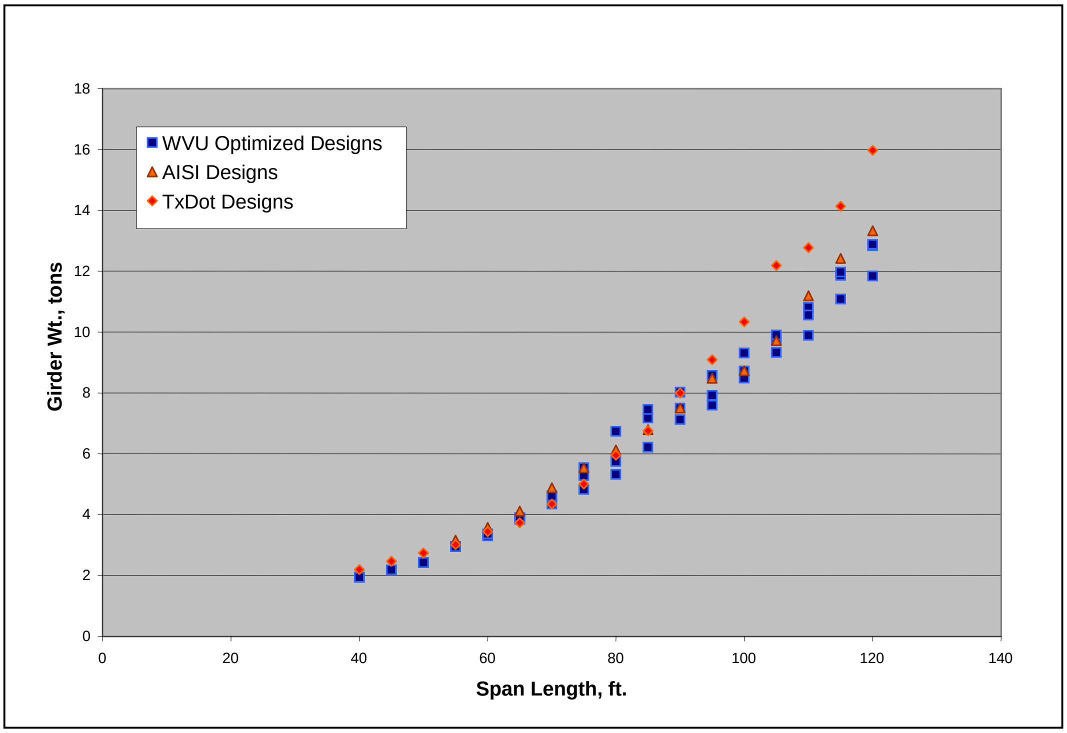

Figure 4.37 Weight Comparisons of Homogeneous Girder Designs for 28-ft. Cross-section

Chapter 5

Short-span Limited Plate Size Design Study

5.1 Introduction

This chapter discusses the design of short-span steel I-girders based on a limited number of available plate sizes for the purpose of investigating the economical impact of stock piling certain plate sizes. Since plates are more economical if purchased in widths of at least 48”, designs that require only a couple plate thicknesses reduce the cost of the design. By limiting the number of plate thicknesses used in by the design package and eliminating flange transitions, savings may be realized even though the sections require more steel than the optimized designs.

5.2 Assumptions and Plate Sizes

Composite steel I-girder designs consisting of a limited number of plate sizes were completed for two cross-sections, see Figs. 4.2 and 4.3, with span lengths from 40 ft. to 120 ft., in increments of 10 ft. Both a homogeneous 50 ksi plate girder and a hybrid plate girder with a 70 ksi tension flange and 50 ksi web and compression flange were developed. The typical girder elevation, see Fig. 5.1, is similar to the girder elevation for the optimized girder design study except the flange transitions are omitted. This study was focused on unstiffened web designs, but as discussed in the following section, a number of the sections must be stiffened to avoid unrealistically thick web plates. The available plate thicknesses were limited to the more common thicknesses of ½”, ¾”, 1”, 1 ½”, 1 ¾”, and 2”, and the web depths selected for the study include 24, 32, 40, or 48 in. Since the optimized plate girder design study found the web depth to have a significant impact on the economy of a design, these values of web depth were selected based on the optimum span-to-depth ratios from the optimized girder study. Similar to the optimized design study, the span-to-depth ratios are calculated using the entire superstructure depth, which includes the slab thickness, the haunch, web depth, and the thickness of the bottom flange. Due to the limited number of web depths, designs were completed for only one span-to-depth ratio that was the closest to the optimum, except for the designs with a 100 ft. span length, where two designs were developed since two of the web depths were near the optimum span-to-depth ratio.

The dead loads and parameters that remain constant are identical to those employed for the optimized plate designs, which are discussed in Section 4.2. A similar procedure to the one discussed in Section 4.3 for designs in accordance with the 2nd Edition of the Specifications was followed to develop the limited plate designs. This procedure involves determining the appropriate web depth based on the span-to-depth ratio. The span-to-depth ratios were calculated for each of the available web depths, and the depths with span-to-depth ratios near the optimized ratio were selected. The preliminary flange width was selected such that D_{bfc}, the ratio of the web depth to compression flange width, was between 3.0 and 4.0. The plate thicknesses were taken as the minimum permitted. The design capacity of the initial section was calculated using the software program Steel Bridge, by Bridgesoft (2003). The unstiffened web thickness was determined, and then the flanges were sized accordingly. Once the initial cross-section was developed, the capacity of the girder was checked, and any necessary revisions to the steel cross-section were made. The iterative process was continued until the lightest section comprised of the available plates was obtained.

The girders developed during this study satisfy the strength, fatigue, and service limit states of the 2nd Edition of the AASHTO LRFD Bridge Specifications (AASHTO 2001). The designs were permitted to fail the Live-load Deflection Criteria, but designs with the same web depth were developed to satisfy the limit.

Similar to the optimized design study discussed in Chapter 4, plate restrictions were employed which limited the flange to a minimum 12” x ¾” plate.

5.3 Designs and Results

A summary of the limited plate designs for the 28-ft. and 34-ft. cross-sections are presented in Tables 5.1 and 5.2, in which the weight refers to the weight of a single girder. Note that all of the designs have unstiffened webs, except four of the sections which required web plates thicker than ½”. These designs include: the homogeneous and hybrid designs for the 34 ft. cross-section with span lengths of 110 ft. and 120 ft. To satisfy the plate restrictions, the designs with span lengths of 110 ft. and 120 ft. would either require transverse stiffeners with the ½” web or would have an unstiffened web thickness of ¾”.

The following sections discuss observations of general trends from the limited plate sizes design study.

5.3.1 Weight Comparison

The limited plate designs are not significantly heavier than the optimized design, as can be observed from Fig. 5.2, which plots the weight of the girder versus the span length. The maximum percent difference between the lightest optimized design and the limited plate design is 17.0 percent, with an average of 8.6 percent. In general, the limited plate designs weigh approximately the same as the heaviest optimized design, see Figs. 5.3 through 5.6. As the span length decreases, the limited plate designs approach the lightest optimized sections because the shorter span lengths are generally controlled by the minimum plate restrictions. For example, the weight difference between the optimized design and the limited plate design with a 120 ft. span length and a homogeneous material configuration is 14.7 percent, while the weight difference between the designs with a 40 ft. span is 4.9 percent.

5.3.2 Influence of Material Configuration

In general, the limited plate size sections are closer to the weight of the optimized designs for the hybrid designs than for the homogeneous. The hybrid limited plate size designs on average weigh 7.0 percent more than the lightest optimized design for a given span length, while the homogeneous designs are approximately 10.3 percent heavier than the optimized designs. This is the result of the hybrid material configuration typically requiring a tension flange thickness less than or equal to 1 inch, and the homogeneous designs requiring a tension flange thicker than 1 inch. The plates are available in thicknesses of ½”, ¾”, 1”, 1 ½”, 1 ¾”, and 2”. Therefore, if the design requires a plate slightly thicker than 1”, the next plate thickness available is 1 ½”; this adds significantly more weight.

5.3.3 Influence of Live-load Deflection

Figures 5.8 through 5.12 show the relationship between the live-load deflection and the span-to-depth ratio for both the limited plate designs and the optimized designs. In general, the limited plate size designs are more likely to satisfy the deflection limit than the optimized designs due to the increased section required to develop a girder composed of the available plates. Of the limited plate girder designs, only one design with a hybrid material configuration, which has a span length of 80 ft. and a 28 ft. roadway width, failed to satisfy the live-load deflection criteria of L/800; this design is indicated by the shaded portion in Table 5.1.

Table 5.1 Limited Plate Size Designs for 28-ft. Cross-section

	Span Length (ft.)	L/D	b_{tf} (in.)	t_{tf} (in.)	D (in.)	t_w (in.)	b_{bf} (in.)	t_{bf} (in.)	Cross Frame Spacing (ft.)	Weight (tons)
	L								C	
50-ksi	40	13.6	12	0.75	24	0.5000	12	0.75	20.00	2.04
	50	17.0	12	0.75	24	0.5000	12	0.75	25.00	2.55
	60	20.0	12	0.75	24	0.5000	12	1.50	20.00	3.98
	70	19.3	12	0.75	32	0.5000	14	1.00	23.33	4.64
	80	21.8	12	0.75	32	0.5000	14	1.50	26.67	6.26
	90	20.8	14	0.75	40	0.5000	14	1.50	30.00	7.89
	100	20.2	14	0.75	48	0.5000	16	1.00	25.00	8.59
	100	23.0	12	0.75	40	0.5000	14	1.75	25.00	9.10
	110	22.0	14	1.00	48	0.5000	14	1.50	27.50	11.04
	120	23.9	16	1.00	48	0.5000	16	1.75	30.00	13.88
Hybrid	40	13.6	12	0.75	24	0.5000	12	0.75	20.00	2.04
	50	17.0	12	0.75	24	0.5000	12	0.75	25.00	2.55
	60	20.3	12	0.75	24	0.5000	12	1.00	20.00	3.37
	70	19.4	12	0.75	32	0.5000	12	0.75	23.33	4.05
	80	22.1	12	1.00	32	0.5000	14	1.00	26.67	5.72
	80	22.1	12	1.00	32	0.5000	12	1.00	26.67	5.44
	90	21.0	14	0.75	40	0.5000	14	1.00	30.00	6.81
	100	20.3	14	0.75	48	0.5000	14	0.75	25.00	7.66
	100	23.1	12	1.00	40	0.5000	12	1.50	25.00	8.51
	110	22.2	14	0.75	48	0.5000	14	1.00	27.50	9.08
	120	24.2	16	1.00	48	0.5000	16	1.00	30.00	11.43

Table 5.2 Limited Plate Size Designs for 34-ft. Cross-section

	Span Length (ft.)	L/D	b_{tf} (in.)	t_{tf} (in.)	D (in.)	t_w (in.)	b_{bf} (in.)	t_{bf} (in.)	Cross Frame Spacing (ft.)	Weight (tons)
	L								C	
50-ksi	40	13.6	12	0.75	24	0.5000	12	0.75	20.00	2.04
	50	16.9	12	0.75	24	0.5000	12	1.00	25.00	2.81
	60	20.0	12	0.75	24	0.5000	12	1.50	20.00	3.98
	70	19.1	12	0.75	32	0.5000	12	1.50	23.33	5.12
	80	21.7	12	1.00	32	0.5000	14	1.75	26.67	7.15
	90	20.6	14	1.00	40	0.5000	14	2.00	30.00	9.49
	100	20.0	14	0.75	48	0.5000	14	1.50	25.00	9.44
	100	22.9	12	1.00	40	0.5000	14	2.00	25.00	10.21
	110	21.8	14	0.75	48	0.5625	14	2.00	27.50	12.26
	120	23.8	16	1.00	48	0.5625	16	2.00	30.00	15.31
Hybrid	40	13.6	12	0.75	24	0.5000	12	0.75	20.00	2.04
	50	17.0	12	0.75	24	0.5000	12	0.75	25.00	2.55
	60	20.3	12	0.75	24	0.5000	12	1.00	20.00	3.37
	70	19.3	12	0.75	32	0.5000	12	1.00	23.33	4.41
	80	22.1	12	1.00	32	0.5000	14	1.00	26.67	5.72
	90	21.0	14	1.00	40	0.5000	14	1.00	30.00	7.35
	100	20.2	14	0.75	48	0.5000	14	1.00	25.00	8.25
	100	23.1	12	1.00	40	0.5000	12	1.50	25.00	8.51
	110	22.0	14	1.00	48	0.5625	14	1.50	27.50	11.60
	120	24.0	16	1.00	48	0.5625	16	1.50	30.00	13.68

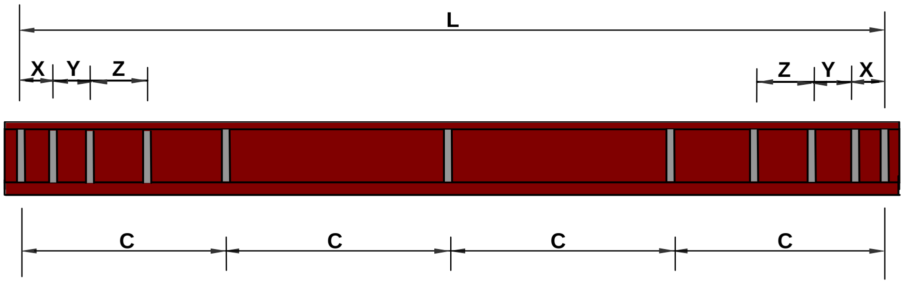

Figure 5.1 Typical Girder Elevation

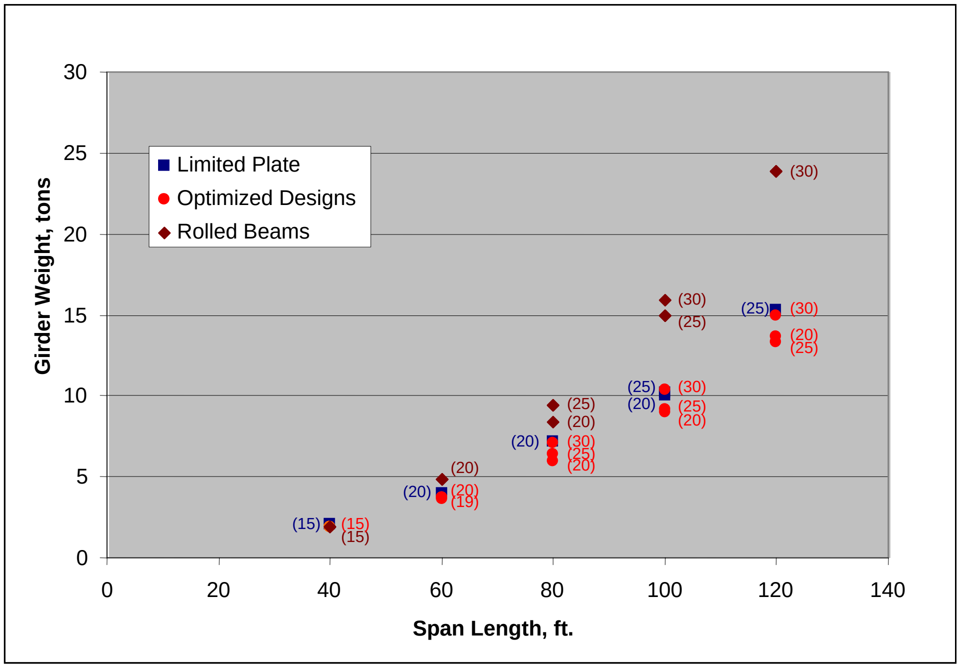

Figure 5.2 Weight Comparisons of Limited Plate Designs and Optimized Designs for Homogeneous 50-ksi Girders with 28 ft. Cross-section

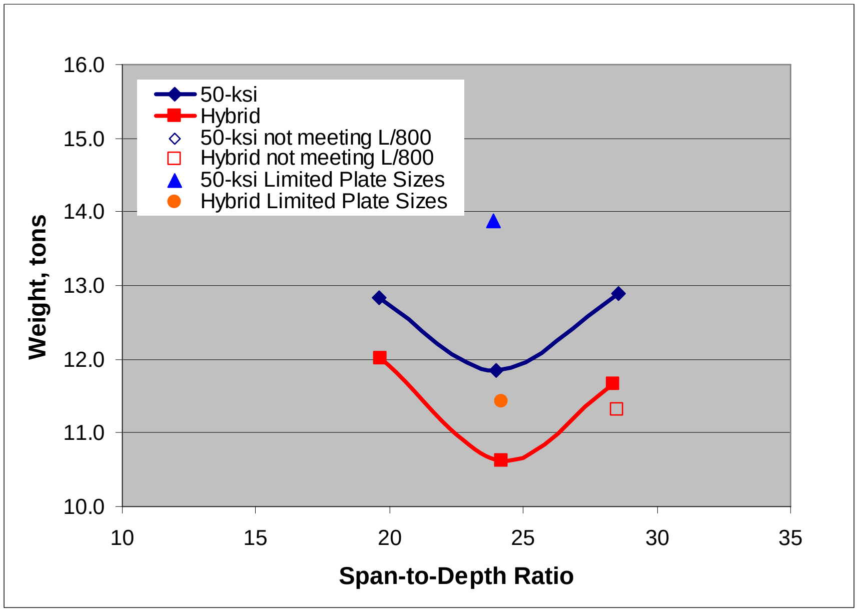

Figure 5.3 Limited Plate Designs for 120 ft. with 28 ft. Cross-section System

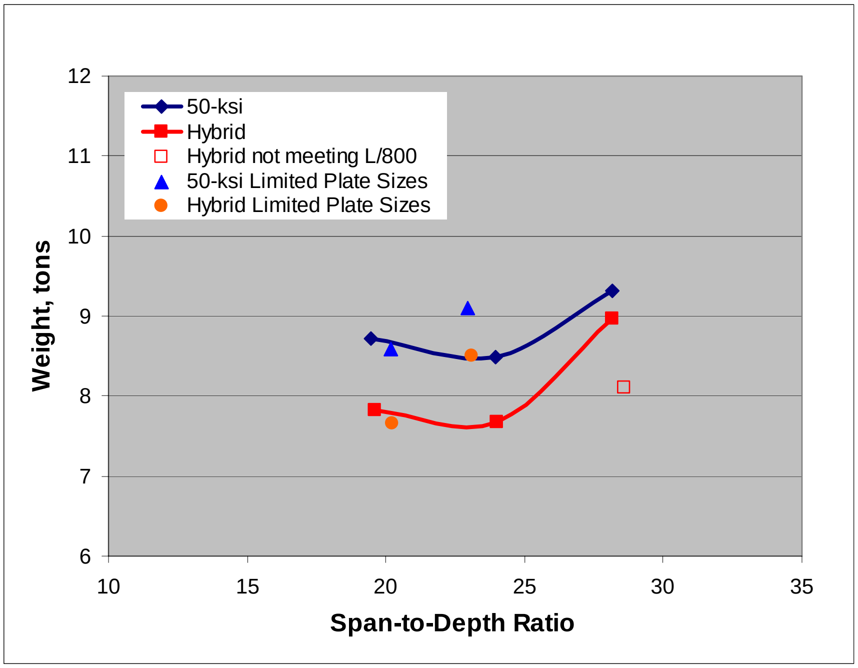

Figure 5.4 Limited Plate Designs for 100 ft. with 28 ft. Cross-section System

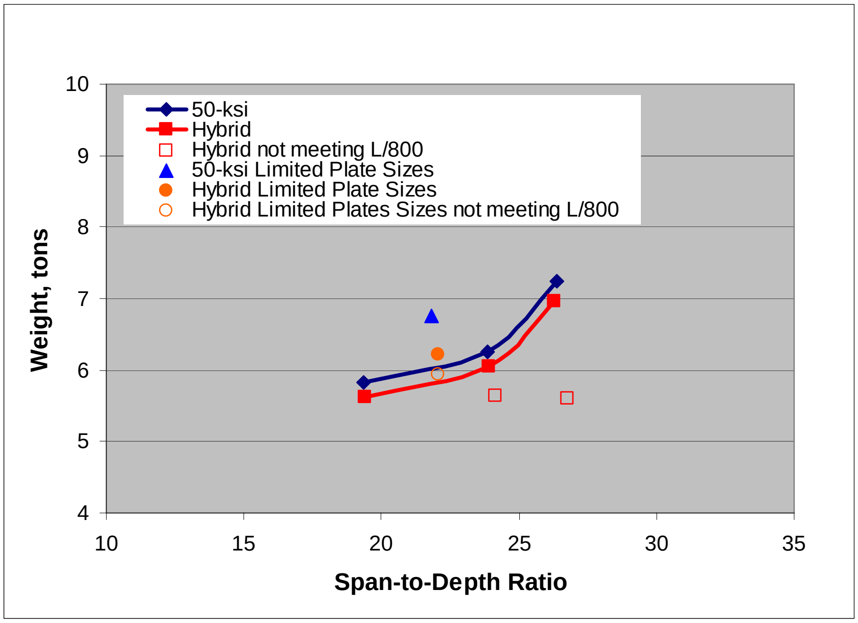

Figure 5.5 Limited Plate Designs for 80 ft. with 28 ft. Cross-section System

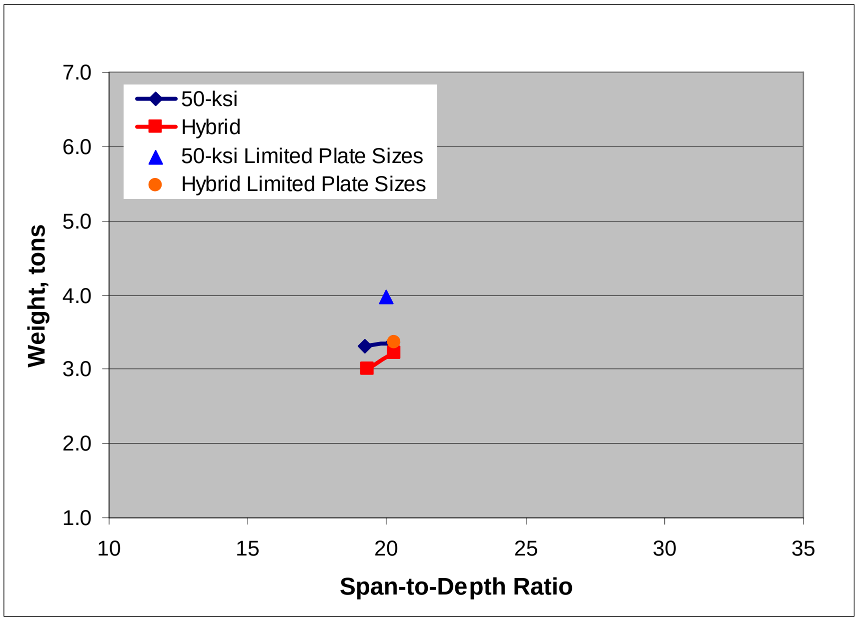

Figure 5.6 Limited Plate Designs for 60 ft. with 28 ft. Cross-section System

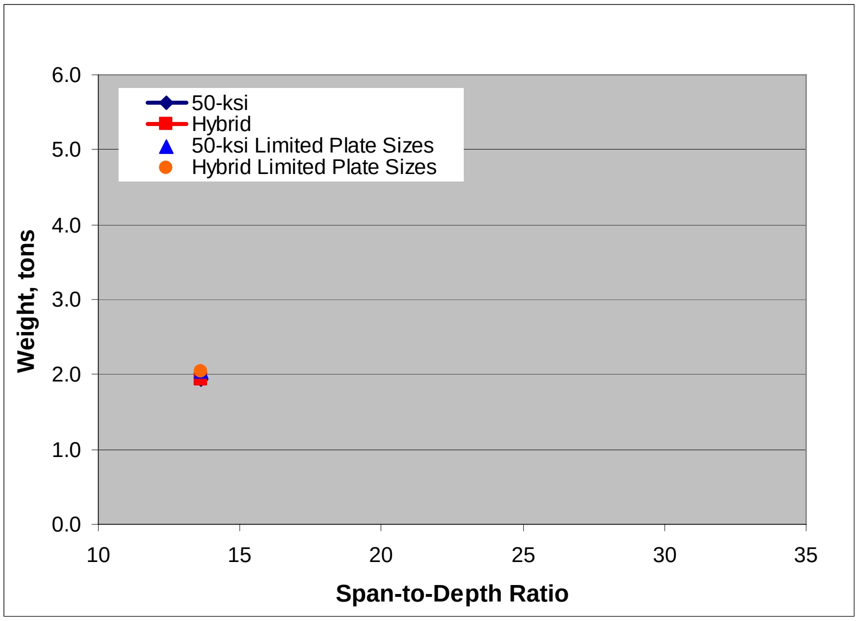

Figure 5.7 Limited Plate Designs for 40 ft. with 28 ft. Cross-section System

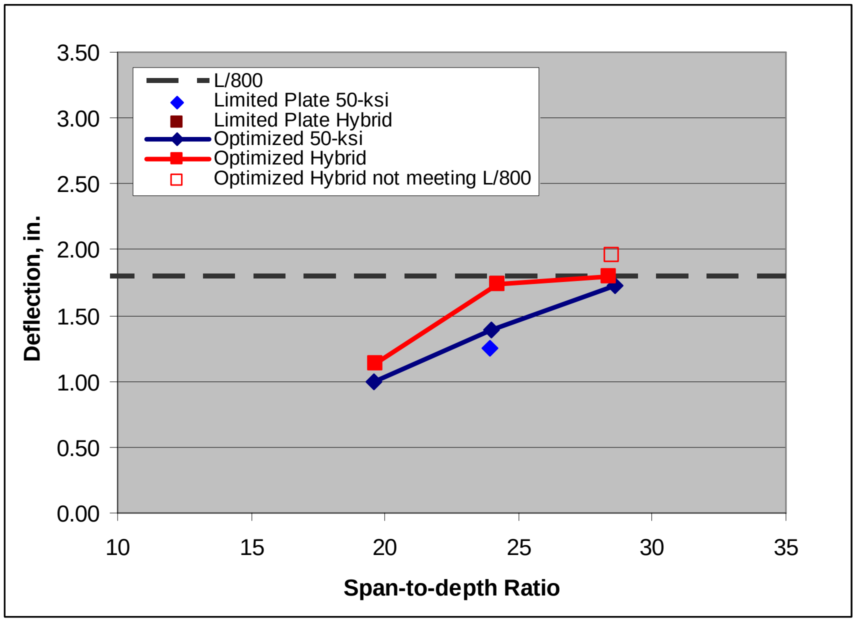

Figure 5.8 Limited Plate Design Deflection for 120 ft. with 28 ft. Cross-section System

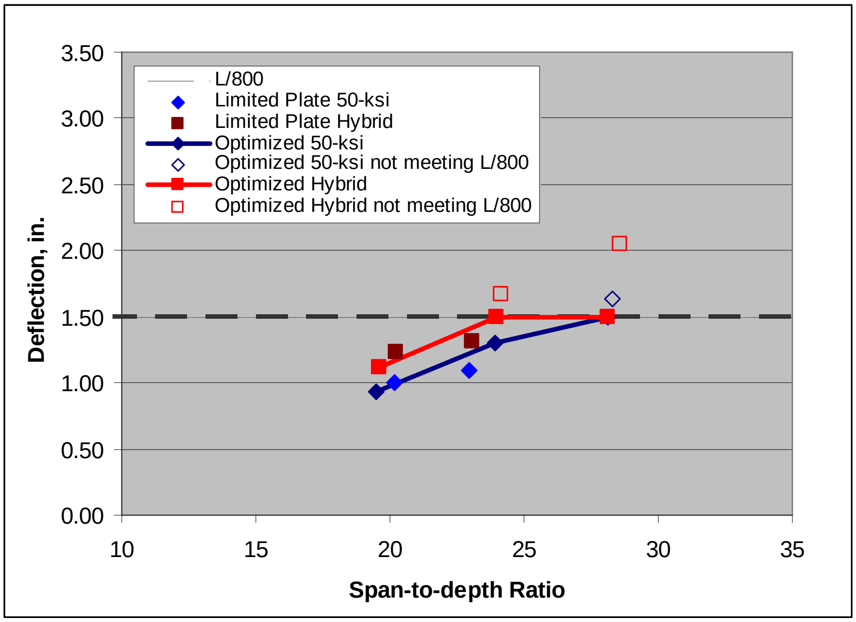

Figure 5.9 Limited Plate Design Deflection for 100 ft. with 28 ft. Cross-section System

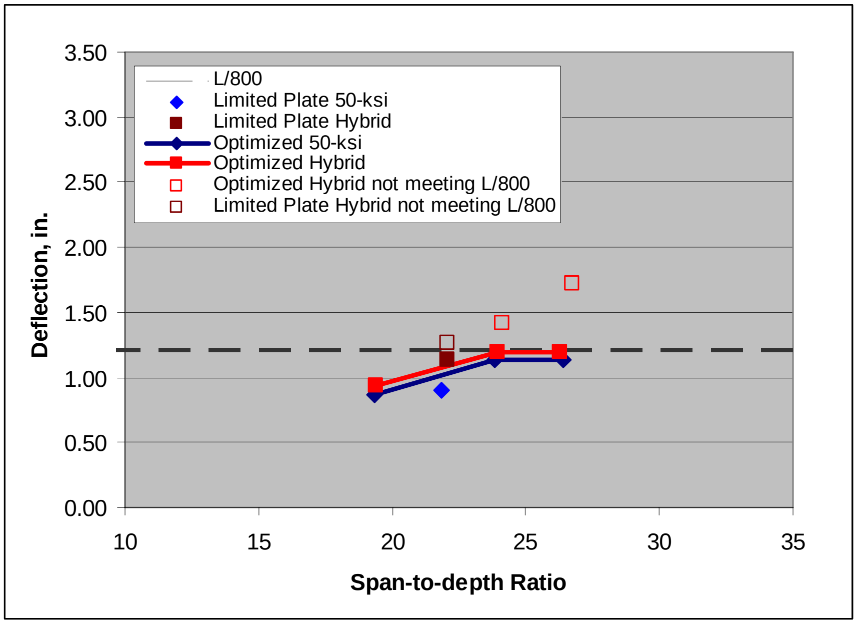

Figure 5.10 Limited Plate Design Deflection for 80 ft. with 28 ft. Cross-section System

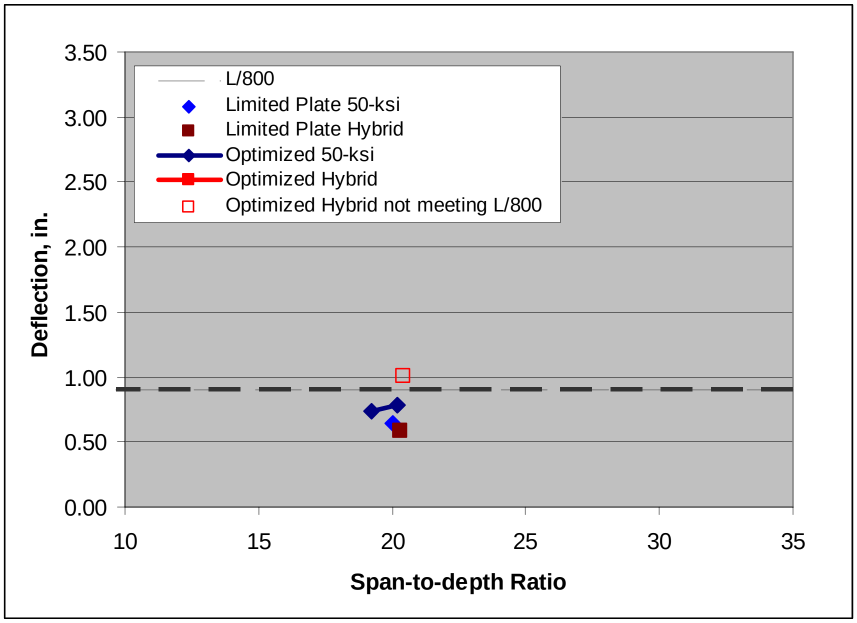

Figure 5.11 Limited Plate Design Deflection for 60 ft. with 28 ft. Cross-section System

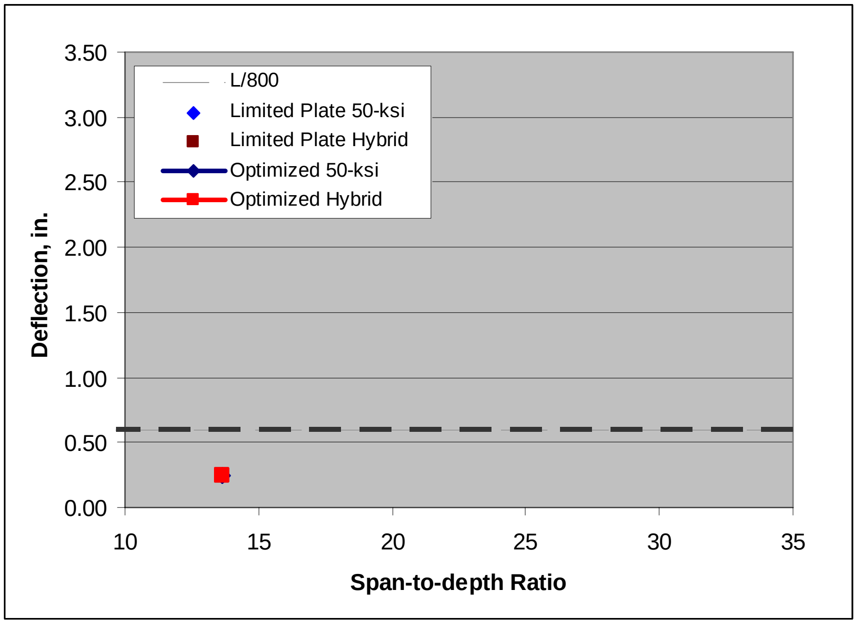

Figure 5.12 Limited Plate Design Deflection for 40 ft. with 28 ft. Cross-section System

Chapter 6

Two-span Bridge Designed Simply-Supported for Dead Load and Continuous for Live Load

6.1 Introduction

This study investigates the feasibility of a two-span bridge system that acts simply-supported for DC_1 dead loads (girder self weight, slab weight, haunch weight, stay-in-place deck forms, and weight of miscellaneous steel) and continuous for live loads and DC_2 (parapet weight). The initial bridge consists of two simply-supported girders; for this design study, the sections designed for the limited plate study were employed. An integral reinforced concrete pier diaphragm is used to make the system continuous, and cover plates are connected to the tension and compression flanges of the girder to develop the capacity required to resist the negative bending moment. Details of the pier section from the Dupont Access Road Bridge (TDOT 2002) are shown in Figure 6.1. Details of the kicker plate and the top cover plate from the same bridge are included in Figs. 6.2 and 6.3.

The simple-span made continuous design has many advantages over the typical continuous span design. For instance, the elimination of the field splice reduces the traffic disruption and facilitates construction. In addition, the simple-span made continuous configuration has a reduced negative flexural moment, but an increased positive flexural moment. This condition allows for a smaller differential between the negative bending section and the positive bending section; in some instances, a constant cross-section can be used throughout the structure, which reduces the fabrication costs. Furthermore, the system allows for greater tolerance while the girders are being placed. Despite the advantages the designer must restrict the simple-span made continuous designs to spans in which the girder can be shipped as one piece, which is typically a maximum of 150 feet.

In addition to the designs for the simple-span made continuous bridge system, optimized two-span continuous designs were also developed as a benchmark to assess the economy of the simple-span made continuous bridge systems.

6.2 Design Assumptions & Procedures

Since the simple-span made continuous designs are based on the limited plate designs, systems were completed for the homogeneous and hybrid plate girders for both the 28 ft. and 34 ft. cross-sections. The two-span systems have equal span lengths ranging from 80 ft. to 120 ft., in increments of 10 ft. During the design of the simple-span made continuous sections, the non-composite dead loads (DC1) are assumed to act on the simply-supported girders, but once the concrete deck gains strength, the system behaves as a continuous system. Therefore, the remaining dead loads and the live loads are assumed to be carried by the continuous two-span system. The loading employed in this design study were similar to the loads from Section 4.2 of the optimized design study.

As previously mentioned, cover plates are applied to the negative bending region to develop the necessary bending capacity. The bottom flange cover plate is welded to the flange, but the top flange cover plate, which is in tension, is bolted to avoid fatigue issues. The cover plates were restricted to the plate sizes employed for the limited plate design study, and a minimum plate length of 7'-6" was imposed on the designs.

The cover plates were selected in accordance with the 2nd Edition of the Specifications. This was accomplished by obtaining the moment and shear envelopes using the line girder analysis software ConSys 2000 and developing a series of spreadsheets to determine the capacity of the sections (1998).

For the two-span continuous designs, the section was assumed to act compositely in the positive bending region, while a composite section consisting of the steel section and reinforcing were used in the negative bending region. Flange transitions were incorporated variable distances from the pier, depending on the length necessary to optimize the design and satisfy the limits. The commercial software Steel Bridge, by Bridge Soft was used to develop the continuous girder designs.

The influence of the Live-load deflection criteria was investigated for both types of systems, but the limit was not found to influence the designs.

6.3 Designs and Results

The cover plates and extension lengths necessary to satisfy the requirements of the specifications are given in Table 6.1. As shown in the table, many of the cover plates are at the minimum length, and all are at the minimum thickness of ½”. The continuous girder designs are listed in Table 6.2, where the positive bending section is shaded and the negative bending section is not.

In general the simple-span made continuous designs weigh slightly more than the continuous span designs, see Figs. 6.4 and 6.5, which depict the girder weight for one span versus the span length. The average weight increase for the simple-span made continuous system over the continuous system is 6.4 percent. The benefits of the simple-span made continuous designs are apparent for the longer spans with a 34 ft. cross-section. This cross-section has a larger girder spacing than the 28 ft. cross-section, which increases the load demand placed on each girder. As a result of using the simple-span made continuous configuration, the large negative moment at the pier due to the dead load is eliminated, which allows a lighter section than the typical continuous design.

As previously mentioned, the live-load deflection of both the continuous and the simple-span made continuous designs were checked against the limit of L/800. All of the sections were able to satisfy the criteria without requiring the additional steel.

Table 6.1 Cover Plate Sizes and Extension Lengths for Simple-span Made Continuous Designs

			Top Cover Plate			Bottom Cover Plate		
		Span Length (ft.)	Plate Width (in.)	Plate Thickness (in.)	Plate Length (ft.)	Plate Width (in.)	Plate Thickness (in.)	Plate Length (ft.)
28 ft. Cross-section	50-ksi	80	12	0.5	7.5	14	0.5	7.5
		90	14	0.5	7.5	14	0.5	7.5
		100	14	0.5	7.5	16	0.5	7.5
		100	12	0.5	7.5	14	0.5	7.5
		110	14	0.5	7.5	14	0.5	7.5
		120	16	0.5	7.5	16	0.5	7.5
	Hybrid	80	12	0.5	7.5	12	0.5	7.5
		90	14	0.5	7.5	14	0.5	7.5
		100	14	0.5	7.5	14	0.5	7.5
		100	12	0.5	7.5	12	0.5	7.5
		110	14	0.5	7.5	14	0.5	7.5
		120	16	0.5	7.5	16	0.5	7.5
34 ft. Cross-section	50-ksi	80	12	0.5	7.5	14	0.5	7.5
		90	14	0.5	7.5	14	0.5	7.5
		100	14	0.5	7.5	14	0.5	7.5
		100	12	0.5	7.5	14	0.5	7.5
		110	14	0.5	7.5	14	0.5	7.5
		120	16	0.5	7.5	16	0.5	7.5
	Hybrid	80	12	0.5	7.5	14	0.5	7.5
		90	14	0.5	7.5	14	0.5	7.5
		100	14	0.5	7.5	14	0.5	7.5
		100	12	0.5	7.5	12	0.5	7.5
		110	14	0.5	7.5	14	0.5	7.5
		120	16	0.5	7.5	16	0.5	7.5

Table 6.2 Two-span Continuous Design Summary for 28 ft. Cross-section

	Span Length (ft.)	L/D	b_{tf} (in.)	t_{tf} (in.)	D_w (in.)	t_w (in.)	b_{bf} (in.)	t_{bf} (in.)	Length (ft.)	WGT. (tons)
Homogeneous Configuration	80	22.2	12	0.750	32	0.5000	14	0.750	70	5.17
			12	1.375	32	0.5000	14	1.625	10	
	90	21.0	14	0.750	40	0.5000	14	0.875	80	6.81
			14	1.125	40	0.5000	14	1.625	10	
	100	20.3	14	0.750	48	0.5000	16	0.750	90	8.23
			14	1.375	48	0.5000	16	1.375	10	
	100	23.4	14	0.875	40	0.5000	16	0.875	85	8.63
			14	1.875	40	0.5000	16	1.875	15	
	110	22.2	14	0.750	48	0.5000	14	1.125	98	9.87
			14	1.625	48	0.5000	14	1.875	12	
	120	24.2	16	1.000	48	0.5000	18	1.125	110	12.70
			16	1.750	48	0.5000	18	1.750	10	
Hybrid Configuration	80	22.2	12	0.75	32	0.5000	14	0.750	73	5.03
			12	1.375	32	0.5000	14	1.375	7	
	90	21.0	14	0.750	40	0.5000	14	0.8750	82	6.78
			14	1.375	40	0.5000	14	1.500	8	
	100	20.3	14	0.750	48	0.5000	14	0.750	90	7.92
			14	1.250	48	0.5000	14	1.375	10	
	100	23.4	14	0.875	40	0.5000	14	0.875	90	7.99
			14	1.750	40	0.5000	14	1.750	10	
	110	22.2	14	0.875	48	0.5000	14	1.000	100	9.73
			14	1.625	48	0.5000	14	1.625	10	
	120	24.2	16	1.000	48	0.5000	16	1.000	109	11.88
			16	1.750	48	0.5000	16	1.750	11	

Note: Shaded region indicates positive bending section and unshaded region indicates the negative bending region.

Table 6.3 Two-span Continuous Design Summary for 34 ft. Cross-section

	Span Length (ft.)	L/D	b_{tf} (in.)	t_{tf} (in.)	D_w (in.)	t_w (in.)	b_{bf} (in.)	t_{bf} (in.)	Length (ft.)	WGT. (tons)
Homogeneous Configuration	80	22.2	14	1.000	32	0.5000	16	1.500	70	7.80
			14	1.750	32	0.5000	16	2.500	10	
	90	21.0	16	0.875	40	0.5000	18	1.000	84	8.16
			16	1.500	40	0.5000	18	1.500	6	
	100	20.3	14	0.750	48	0.5000	16	1.375	90	10.06
			14	1.625	48	0.5000	16	2.250	10	
	100	23.4	16	1.000	40	0.5000	18	1.625	90	11.53
			16	1.875	40	0.5000	18	2.250	10	
	110	22.2	16	1.000	48	0.5625	16	1.125	100	11.86
			16	1.750	48	0.5625	16	2.000	10	
	120	24.2	18	1.000	48	0.5625	18	2.000	105	17.40
			18	1.875	48	0.5625	18	3.000	15	
Hybrid Configuration	80	22.2	14	1.000	32	0.5000	16	1.500	70	7.63
			14	1.750	32	0.5000	16	1.875	10	
	90	21.0	14	1.000	40	0.5000	14	1.125	82	7.88
			14	1.625	40	0.5000	14	1.875	8	
	100	20.3	14	0.750	48	0.5000	16	1.375	90	9.92
			14	1.625	48	0.5000	16	1.750	10	
	100	23.4	14	1.250	40	0.5000	16	1.625	90	11.15
			14	2.125	40	0.5000	16	2.125	10	
	110	22.2	16	1.000	48	0.5625	16	1.000	101	11.47
			16	1.875	48	0.5625	16	1.875	9	
	120	24.2	18	1.000	48	0.5625	18	1.625	105	15.96
			18	2.000	48	0.5625	18	2.375	15	

Note: Shaded region indicates positive bending section and unshaded region indicates the negative bending region.

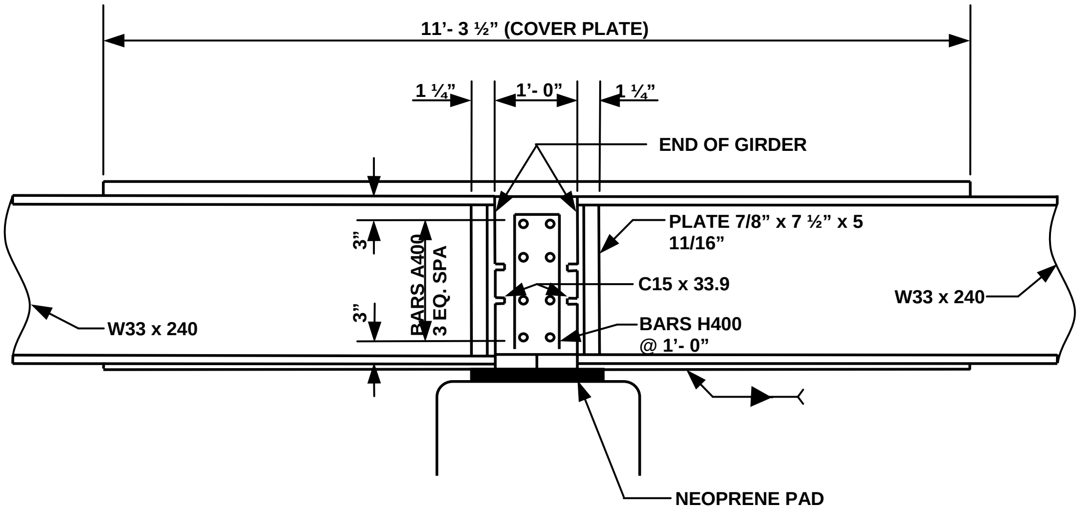

Figure 6.1 Pier Elevation for Dupont Access Road (TDOT 2002)

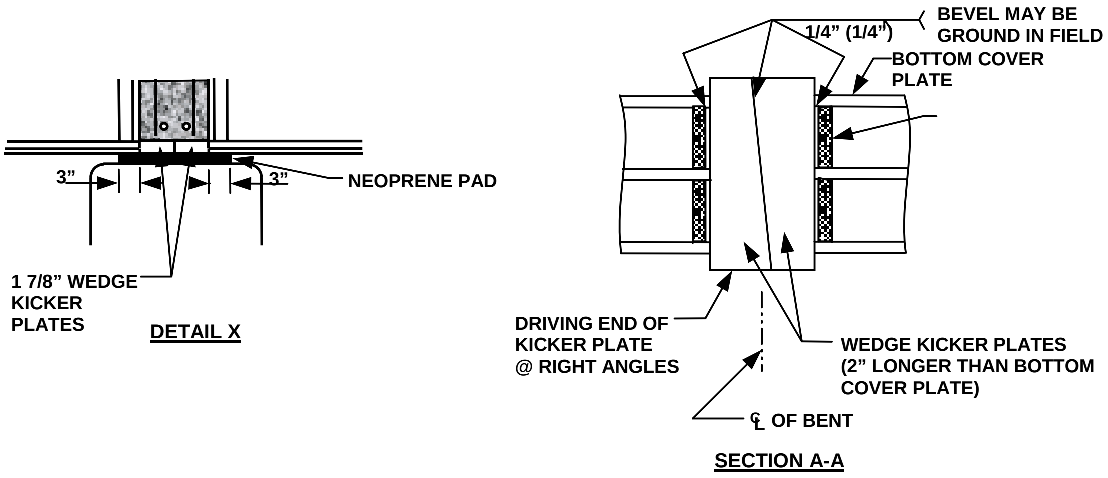

Figure 6.2 Wedge Kicker Plate Details for Dupont Access Road (TDOT 2002)

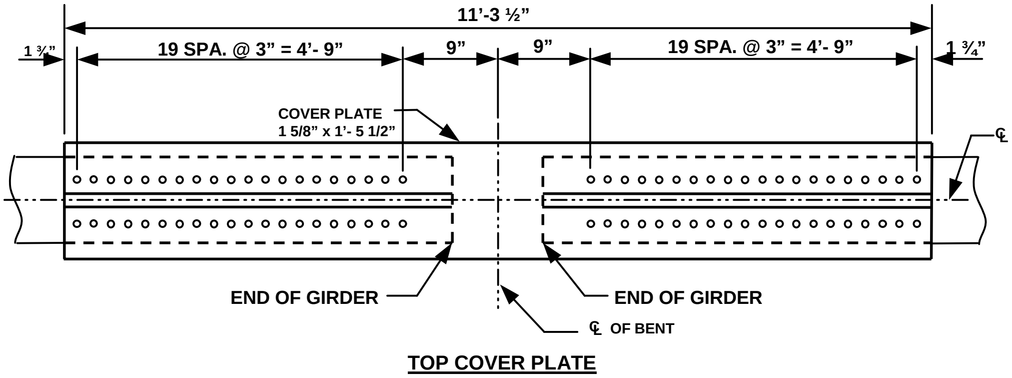

Figure 6.3 Top Cover Plate Details for Dupont Access Road (TDOT 2002)

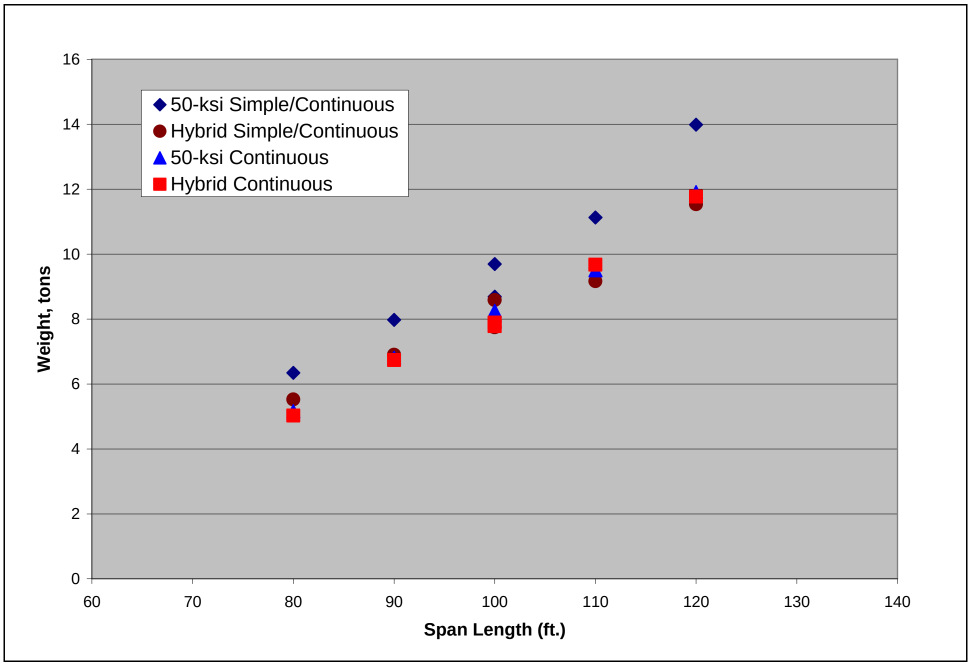

Figure 6.4 Weight Comparison of Two-span Designs for 28 ft. Cross-section

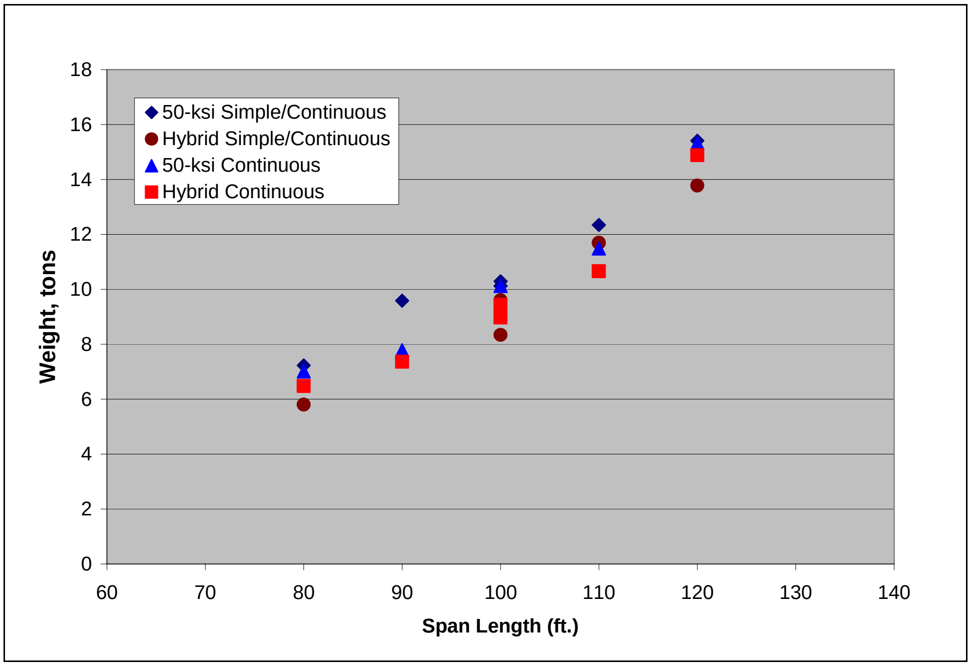

Figure 6.5 Weight Comparison of Two-span Designs for 34 ft. Cross-section

Chapter 7

Summary and Concluding Remarks

7.1 Introduction

The primary focus of this research was to develop a series of standardized bridge girder designs for short-span steel stringer bridge systems. Three designs studies were performed and a detailed discussion about the observations with regard to weight, live-load deflection, and performance was presented.

A literature review of the basic steel bridge design guidelines along with an overview of standardized bridge packages and methods of rapid construction that are currently employed in the bridge industry was presented in Chapter 2. The fundamental design aspects of both the 2nd and 3rd Editions of the AASHTO LRFD Bridge Design Specifications were provided in Chapter 3. Among the topics discussed in that section are flexural capacity, shear capacity, constructibility, fatigue design, geometric proportions, and structural analysis techniques.

A series of parametric design studies were conducted which varied span length, material configuration, and span-to-depth ratios for two bridge cross-sections. Designs were completed for 50 ksi rolled beams and plate girders with 50 ksi homogeneous configurations and 50/70 hybrid configurations. Additionally, the optimized design study investigated unstiffened webs and partially stiffened webs.

7.2 Scope of Work

In this research, three studies were conducted on short-span bridge design. An optimized design study based on span lengths between 40 ft. and 120 ft. was conducted. Sections were designed for homogeneous 50 ksi plate girders, hybrid HPS 70W/50 ksi plate girders, and 50 ksi rolled beams. Designs were completed for two cross-sections: a 28 ft. cross-section with two design lanes and four girders spaced at 8’-6” and a 34 ft. cross-section with two design lanes and four girders spaced at 10’-0”. The designs were optimized based on weight and checked against the live-load deflection limit of L/800. Observations about the material configuration, span-to-depth ratio, girder location, and live-load deflection limit were discussed.

A study focusing on girder designs based on a limited number of available plate sizes was also presented. The sections were limited to four web depths and six plate thicknesses to investigate the economical impact of fabricators stock piling plates. The span lengths range from 40 ft. to 120 ft., and two material configurations were employed: a homogeneous 50 ksi configuration and a hybrid HPS 70W/50 ksi configuration. A discussion on the comparison between the optimized designs and the limited plate designs was provided.

A design study based on two-span bridge systems was also conducted, which presents a weight comparison between simple-span made continuous designs and continuous girder designs. In addition, a detailed discussion with regards to the simple-span made continuous bridge systems was presented.

7.3 Summary of Results

Several observations were noted from the extensive design studies. This section presents a brief overview of the key findings previously discussed.

For the optimized designs, the economy of the hybrid material configuration is dependent on the span length and span-to-depth ratio. For instance, the weight savings between the design with the hybrid material configuration and the homogeneous configuration decreases as the span length decreases, until the both configurations result in the same design. In addition, the hybrid designs with smaller span-to-depth ratios are generally more economical than the homogeneous design for the longer span lengths.

For the range of span-to-depth ratios employed in this study, the design with the largest span-to-depth ratio weighed the most. In addition, the designs with the larger span-to-depth ratios were more likely to fail the live-load deflection limit of L/800.

The results of the optimized, short-span girder designs indicate the exterior girder load-induced fatigue limit results in a severe weight increase of the section. As a result, the plate girders with a hybrid material configuration required a significant amount of steel in order to satisfy the fatigue limit under when designing the exterior girder.

With the exception of the shorter span lengths that were restricted to the minimum plate sizes, the rolled sections weighed more than the plate girders. Additionally, for the longer spans, the rolled beams are significantly heavier than the plate girder designs due to the limited depth at which a rolled section can be produced.

The 3rd Edition of the Specifications results in a similar design as the 2nd Edition of the Specifications. Differences were found only in sections that were controlled by the flexural capacity since the limit state that frequently controls the designs, the permanent deformations, is essentially the same for both editions.

The study based on the limited plate designs resulted in sections that did not require significantly more steel than the optimized designs. In conclusion, the limited plate designs may be more economical than the optimized designs if the plates are purchased in large quantities.

The two-span bridge study concluded that the simple-span made continuous designs are not considerably heavier than the continuous span designs and offer a variety of advantages during construction.

7.4 Concluding Remarks

From the result of this study, the hybrid material configuration can be more economical than homogeneous designs for the longer span lengths in this study. However, the hybrid material configuration does not offer any economical advantages for the shorter span lengths due to the minimum plate restrictions. In addition, rolled sections have been demonstrated to be economical for the shortest of the span lengths considered, but are found to be much heavier than plate girders in longer span ranges.

The limited plate size designs were comparable in weight to the weight-optimized designs, but could offer a savings as a result of reduced material costs. Therefore, the limited plate sizes designs can be an economical option when fabricator stock piling plates is an option.

The results of the two-span bridge study indicate that even though the simple-span made continuous designs are generally heavier than the continuous designs, they can save significant cost due to the facilitation of construction.

The result of this research on short-span steel bridge girders will be key to the development of a standardized bridge package for the West Virginia Division of Highways. Once completed, the design package will facilitate the design process and conserve resources. As previously mentioned, a significant portion of the bridges are in need of repair or replacement. The goal of the standardized bridge package is to provide a means to efficiently replace the structures inadequate bridge systems. To extend the applicability of the design package, future work should be focused on incorporating additional bridge cross-sections and skewed bridge design.

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Appendix

Tables of Designs

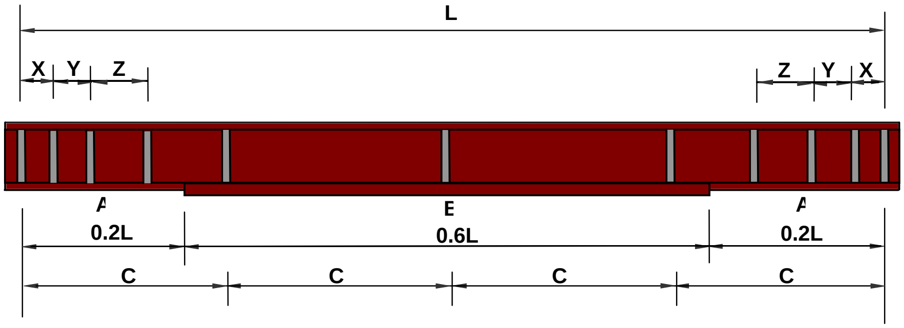

Figure A.1 Typical Girder Elevation

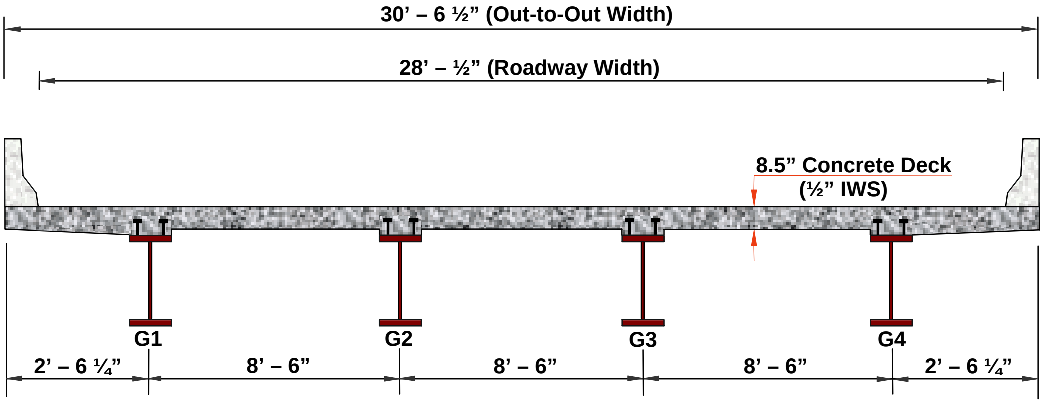

Figure A.2 Bridge Cross-section with 28-ft. Clear Roadway Width

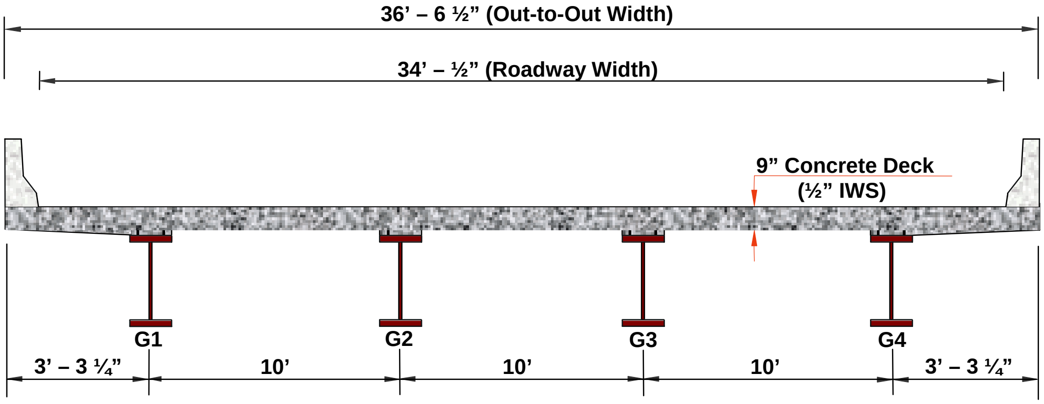

Figure A.3 Bridge Cross-section with 34-ft. Clear Roadway Width

Table A.1 Optimized Interior Girder Designs for 28-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
40	13.6	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.67	0.25	0.60
45	15.3	12 x 3/4	24 x 7/16	-	-	12 x 3/4	45	22.50	2.18	Min. Plate	0.81	0.39	0.68
50	17.0	12 x 3/4	24 x 7/16	-	-	12 x 3/4	50	25.00	2.42	Min. Plate	0.96	0.55	0.75
55	18.6	12 x 3/4	24 x 7/16	-	-	12 x 1	55	27.50	2.95	Service	0.93	0.64	0.83
60	19.2	12 x 3/4	26 x 7/16	-	-	12 x 1	60	20.00	3.30	Service	0.99	0.74	0.90
60	20.2	12 x 3/4	24 x 7/16	-	-	12 x 1-1/8	60	20.00	3.37	Service	0.99	0.78	0.90
65	19.7	12 x 3/4	28 x 7/16	-	-	12 x 1-1/8	65	21.66	3.84	Service	0.97	0.78	0.98
65	21.9	12 x 3/4	24 x 7/16	-	-	14 x 1-1/8	65	21.66	3.90	Service	1.00	0.92	0.98
70	19.3	12 x 3/4	32 x 7/16	-	-	12 x 1-1/8	70	23.33	4.35	Service	0.96	0.79	1.05
70	23.4	12 x 3/4	24 x 7/16	-	-	14 x 1-3/8	70	23.33	4.62	Service	0.98	1.02	1.05
75	19.8	12 x 3/4	34 x 7/16	-	-	14 x 1	75	25.00	4.83	Service	0.99	0.86	1.13
75	23.7	12 x 3/4	26 x 7/16	-	-	14 x 1-1/2	75	25.00	5.28	Service	0.95	1.05	1.13
75	24.9	12 x 3/4	24 x 7/16	-	-	16 x 1-5/8	75	25.00	5.81	Service	0.97	1.13	1.13
80	19.3	12 x 3/4	38 x 7/16	-	-	12 x 1-1/8	80	26.67	5.33	Service	1.00	0.87	1.20
80	23.9	12 x 3/4	28 x 7/16	-	-	12 x 1-3/4	80	26.67	5.75	Service	0.99	1.13	1.20
80	26.4	12 x 3/4	24 x 7/16	-	-	16 x 1-7/8	80	26.67	6.74	Service	0.98	1.14	1.20
85	19.7	12 x 7/8	40 x 7/16	-	-	12 x 1-1/4	85	28.33	6.22	Constr.	0.98	0.91	1.28
85	24.2	14 x 3/4	30 x 7/16	-	-	16 x 1-5/8	85	28.33	7.18	Service	0.96	1.18	1.28
85	27.8	14 x 7/8	24 x 7/16	16 x 1-1/8	17	16 x 2-1/4	51	28.33	7.46	Service	0.93	1.26	1.28
90	19.5	14 x 3/4	44 x 1/2	-	-	14 x 1	90	30.00	7.12	Service	0.98	0.91	1.35
90	24.5	14 x 7/8	32 x 7/16	-	-	14 x 1-5/8	90	30.00	7.50	Service	0.99	1.26	1.35
90	28.1	14 x 7/8	26 x 7/16	18 x 1	18	18 x 2	54	30.00	8.03	Service	0.95	1.33	1.35
95	19.7	12 x 3/4	46 x 1/2	-	-	12 x 1-1/4	95	23.75	7.60	Service	0.99	0.96	1.43
95	23.7	14 x 3/4	36 x 7/16	-	-	14 x 1-1/8	95	23.75	7.92	Service	0.98	1.22	1.43
95	28.1	16 x 3/4	28 x 7/16	18 x 1	19	18 x 2	57	23.75	8.57	Service	0.98	1.40	1.43
100	19.5	14 x 3/4	50 x 1/2	-	-	14 x 1-1/8	100	25.00	8.72	Service	0.95	0.93	1.50
100	23.9	12 x 7/8	38 x 7/16	-	-	14 x 1-5/8	100	25.00	8.49	Service	1.00	1.30	1.50
100	28.2	14 x 1	30 x 7/16	16 x 1-1/8	20	16 x 2-1/8	60	25.00	9.31	Strength	0.96	1.50	1.50
105	19.8	14 x 3/4	52 x 1/2	-	-	14 x 1-1/8	105	26.25	9.33	Service	0.98	1.00	1.58
105	24.2	14 x 3/4	40 x 1/2	-	-	16 x 1-1/2	105	26.25	9.74	Service	0.97	1.30	1.58
105	28.4	14 x 1	32 x 7/16	18 x 1	21	18 x 1-7/8	63	26.25	9.91	Strength	1.00	1.58	1.58
110	19.5	14 x 3/4	56 x 9/16	-	-	14 x 1-1/8	110	27.50	10.81	Service	0.95	0.96	1.65
110	24.3	14 x 3/4	42 x 1/2	14 x 1	22	14 x 1-7/8	66	27.50	9.89	Service	0.95	1.30	1.65
110	28.3	14 x 3/4	34 x 7/16	18-1/8	22	18 x 2-1/8	66	27.50	10.56	Strength	0.98	1.51	1.65
115	19.9	16 x 3/4	58 x 9/16	-	-	16 x 1	115	28.75	11.86	Service	0.96	1.01	1.73
115	24.4	14 x 7/8	44 x 1/2	14 x 1	23	14 x 2	69	28.75	11.08	Service	0.97	1.31	1.73
115	28.5	14 x 1-1/8	36 x 1/2	18 x 1	23	18 x 1-7/8	69	28.75	11.97	Service	1.00	1.68	1.73
120	19.6	16 x 3/4	62 x 9/16	-	-	16 x 1	120	30.00	12.84	Strength	0.96	1.00	1.80
120	24.0	16 x 7/8	48 x 1/2	16 x 7/8	24	16 x 1-1/2	72	30.00	11.84	Service	1.00	1.39	1.80
120	28.6	14 x 1-1/8	38 x 1/2	18 x 1-1/8	24	18 x 1-7/8	72	30.00	12.88	Strength	1.00	1.73	1.80

Table A.2 Optimized Interior Girder Designs Failing the L/800 Deflection Limit for 28-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
85	28.0	14 x 7/8	24 x 7/16	-	-	16 x 1-7/8	85	28.33	7.63	Strength	0.95	1.42	1.28
90	28.2	14 x 7/8	26 x 7/16	18 x 1	18	18 x 1-3/4	54	30.00	7.61	Strength	0.95	1.45	1.35
95	28.2	14 x 7/8	28 x 7/16	18 x 1	19	18 x 1-7/8	57	23.75	8.52	Strength	0.98	1.45	1.43
100	28.3	14 x 1	30 x 7/16	16 x 1/8	20	16 x 1-7/8	60	25.00	8.90	Strength	1.00	1.63	1.50

Table A.3 Optimized Interior Girder Designs with Partially Stiffened Web for 28-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Stiffener Spacing			Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length		X	Y	Z					
ft		in.	in.	in.	ft.	in.	ft.	ft.	ft.	ft.	ft.	tons			in.	in.
90	19.4	12 x 1	44 x 7/16	-	-	12 x 1-1/4	90	30.00	5			7.08	Constr.	1.00	0.92	1.35
95	19.7	12 x 3/4	46 x 7/16	-	-	12 x 1-3/8	95	23.75	5	9		7.37	Constr.	0.97	0.94	1.43
100	19.5	14 x 3/4	50 x 7/16	-	-	14 x 1-1/8	100	25.00	6	8		8.19	Service	0.97	0.96	1.50
105	19.8	14 x 3/4	52 x 7/16	-	-	14 x 1-1/4	105	26.25	6	10		9.07	Constr.	0.98	0.97	1.58
105	24.2	14 x 7/8	40 x 7/16	-	-	16 x1-1/2	105	26.25	5			9.60	Constr.	1.00	1.33	1.58
110	19.5	14 x 3/4	56 x 7/16	-	-	14 x 1-1/8	110	27.50	7	10		9.50	Service	1.00	1.02	1.65
110	24.3	14 x 1	42 x 7/16	-	-	14 x 1-3/4	110	27.50	5	10		10.64	Service	0.99	1.38	1.65
115	19.9	16 x 3/4	58 x 1/2	-	-	16 x 1	115	28.75	6	6		11.15	Service	0.99	1.04	1.73
115	24.4	14 x 1-1/8	44 x 7/16	-	-	14 x 2	115	28.75	5.5	11		11.37	Service	0.98	1.33	1.73
115	28.5	14 x 1-1/8	36 x 7/16	18 x 1-1/8	23	18 x 1-7/8	69	28.75	4.5			11.71	Strength	1.00	1.69	1.73
120	19.6	16 x 3/4	62 x 1/2	-	-	16 x 1	120	30.00	7	10		12.05	Service	0.99	1.04	1.80
120	24.0	16 x 7/8	48 x 7/16	16 x 7/8	24	16 x 1-5/8	72	30.00	6	12		11.47	Constr.	0.97	1.36	1.80
120	28.5	14 x 1-1/4	38 x 7/16	18 x 1-1/8	24	18 x 2	72	30.00	4.5	9		13.03	Strength	0.99	1.68	1.80

Table A.4 Optimized Interior Girder Designs for 28-ft. Cross-section with a Hybrid Material Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A) Plate	Bottom Flange (A) Length	Bottom Flange (B) Plate	Bottom Flange (B) Length	Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
40	13.6	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.62	0.25	0.60
45	15.3	12 x 3/4	24 x 7/16	-	-	12 x 3/4	45	22.50	2.18	Min. Plate	0.58	0.58	0.68
50	17.0	12 x 3/4	24 x 7/16	-	-	12 x 3/4	50	25.00	2.42	Min. Plate	0.68	0.55	0.75
55	18.7	12 x 3/4	24 x 7/16	-	-	12 x 3/4	55	27.50	2.67	Min. Plate	0.80	0.76	0.83
60	19.3	12 x 3/4	26 x 7/16	-	-	12 x 3/4	60	20.00	3.00	Service	0.85	0.88	0.90
60	20.3	12 x 3/4	24 x 7/16	-	-	12 x 1	60	20.00	3.22	Service	0.76	0.85	0.90
65	19.8	12 x 3/4	28 x 7/16	-	-	12 x 7/8	65	21.66	3.51	Service	0.84	0.92	0.98
65	22.0	12 x 3/4	24 x 7/16	-	-	14 x 1	65	21.66	3.70	Strength	0.78	0.98	0.98
70	19.4	12 x 3/4	32 x 7/16	-	-	12 x 3/4	70	23.33	3.81	Service	0.88	1.00	1.05
70	23.4	12 x 3/4	24 x 7/16	-	-	14 x 1-3/8	70	23.33	4.62	Constr.	0.75	1.02	1.05
75	19.9	12 x 3/4	34 x 7/16	-	-	12 x 3/4	75	25.00	4.19	Service	0.93	1.11	1.13
75	23.7	12 x 3/4	26 x 7/16	-	-	14 x 1-1/2	75	25.00	5.09	Constr.	0.79	1.05	1.13
75	24.8	12 x 3/4	24 x 7/16	-	-	14 x 1-3/4	75	25.00	5.55	Constr.	0.85	1.07	1.13
80	19.4	12 x 3/4	38 x 7/16	-	-	12 x 1	80	26.67	5.12	Constr.	0.99	0.94	1.20
80	23.9	12 x 3/4	28 x 7/16	-	-	12 x 1-5/8	80	26.67	5.55	Constr.	0.94	1.19	1.20
80	26.3	12 x 3/4	24 x 7/16	-	-	14 x 2	80	26.67	6.47	Constr.	0.86	1.19	1.20
85	19.8	12 x 1	40 x 7/16	-	-	12 x 1	85	28.33	6.00	Constr.	0.90	1.03	1.28
85	24.3	14 x 3/4	30 x 7/16	-	-	14 x 1-1/2	85	28.33	6.45	Constr.	0.82	1.26	1.28
85	27.8	14 x 3/4	24 x 7/16	16 x 3/4	17	16 x 2-1/4	51	28.33	6.85	Strength	0.99	1.28	1.28
90	19.5	12 x 3/4	44 x 1/2	-	-	12 x 3/4	90	30.00	5.70	Service	0.94	1.18	1.35
90	24.3	12 x 3/4	32 x 7/16	12 x 3/4	18	12 x 1-7/8	54	30.00	6.14	Service	0.81	1.30	1.35
90	27.9	14 x 3/4	26 x 7/16	18 x 7/8	18	18 x 2-1/4	54	30.00	8.04	Strength	0.99	1.25	1.35
95	19.9	12 x 3/4	46 x 1/2	-	-	12 x 7/8	95	23.75	6.87	Constr.	1.0	1.14	1.43
95	23.7	12 x 3/4	36 x 7/16	-	-	12 x 1-5/8	95	23.75	7.15	Constr.	1.00	1.36	1.43
95	28.0	12 x 1	28 x 7/16	16 x 1	19	16 x 2-1/4	57	23.75	8.45	Constr.	0.93	1.40	1.43
100	19.6	14 x 3/4	50 x 1/2	-	-	14 x 3/4	100	25.00	7.83	Service	0.85	1.12	1.50
100	24.0	12 x 7/8	38 x 7/16	-	-	12 x 1-1/2	100	25.00	7.68	Constr.	0.94	1.50	1.50
100	28.2	12 x 1	30 x 7/16	16 x 1-1/8	20	16 x 2-1/8	60	25.00	8.97	Constr.	0.95	1.50	1.50
105	19.9	14 x 3/4	52 x 1/2	-	-	14 x 3/4	105	26.25	8.40	Constr.	0.88	1.20	1.58
105	24.3	14 x 3/4	40 x 1/2	-	-	14 x 1-1/4	105	26.25	8.58	Constr.	0.89	1.57	1.58
105	28.4	14 x 7/8	32 x 7/16	18 x 1	21	18 x 1-7/8	63	26.25	9.59	Constr.	0.97	1.58	1.58
110	19.6	14 x 3/4	56 x 9/16	-	-	14 x 3/4	110	27.50	9.83	Constr.	0.99	1.14	1.65
110	24.5	14 x 3/4	42 x 1/2	-	-	14 x 1-3/8	110	27.50	9.50	Constr.	1.00	1.57	1.65
110	28.2	14 x 7/8	34 x 7/16	16 x 7/8	22	16 x 2-1/4	66	27.50	10.32	Constr.	0.90	1.60	1.65
115	19.9	14 x 3/4	58 x 9/16	-	-	14 x 7/8	115	28.75	10.83	Constr.	0.98	1.13	1.73
115	24.7	14 x 7/8	44 x 1/2	-	-	14 x 1-3/8	115	28.75	10.47	Constr.	1.00	1.64	1.73
115	28.4	14 x 7/8	36 x 1/2	16 x 1	23	16 x 2-1/8	69	28.75	11.16	Constr.	0.98	1.68	1.73
120	19.7	16 x 3/4	62 x 9/16	-	-	16 x 3/4	120	30.00	12.02	Constr.	0.88	1.13	1.80
120	24.2	16 x 3/4	48 x 1/2	-	-	16 x 1	120	30.00	10.62	Constr.	0.94	1.74	1.80
120	28.4	14 x 7/8	38 x 1/2	14 x 1-1/4	24	14 x 2-1/4	72	30.00	11.67	Constr.	1.00	1.80	1.80

Table A.5 Optimized Interior Girder Designs Failing the L/800 Deflection Limit for 28-ft. Cross-section with a Hybrid Material Configuration in Accordance with 2^{nd} Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
60	20.4	12 x 3/4	24 x 7/16	-	-	12 x 3/4	60	20.00	2.91	Min. Plate	0.92	1.01	0.90
65	19.9	12 x 3/4	28 x 7/16	-	-	12 x 3/4	65	21.66	3.35	Service	0.90	1.00	0.98
65	22.0	12 x 3/4	24 x 7/16	-	-	12 x 7/8	65	21.66	3.32	Service	0.94	1.19	0.98
70	23.7	12 x 3/4	24 x 7/16	-	-	12 x 1	70	23.33	3.75	Service	0.97	1.39	1.05
75	24.1	12 x 7/8	26 x 7/16	-	-	14 x 7/8	75	25.00	4.35	Service	0.98	1.50	1.13
75	25.4	12 x 7/8	24 x 7/16	-	-	14 x 1	75	25.00	4.47	Service	0.98	1.57	1.13
80	24.2	12 x 7/8	28 x 7/16	-	-	12 x 1-1/4	80	26.67	5.14	Service	0.96	1.42	1.20
80	26.8	12 x 7/8	24 x 7/16	-	-	12 x 1-3/8	80	26.67	5.10	Strength	0.99	1.72	1.20
85	24.6	14 x 7/8	30 x 7/16	-	-	14 x 1	85	28.33	5.69	Strength	0.97	1.60	1.28
85	28.5	14 x 7/8	24 x 7/16	-	-	16 x 1-1/4	85	28.33	6.18	Strength	0.98	1.87	1.28
90	24.7	12 x 3/4	32 x 7/16	-	-	12 x 1-1/4	90	30.00	5.82	Strength	0.95	1.66	1.35
90	28.6	14 x 7/8	26 x 7/16	-	-	16 x 1-1/4	90	30.00	6.68	Strength	0.97	1.98	1.35
95	23.9	12 x 7/8	36 x 7/16	-	-	12 x 1-1/8	95	23.75	6.42	Constr.	0.99	1.68	1.43
95	28.7	12 x 1-1/8	28 x 7/16	-	-	16 x 1-1/4	95	23.75	7.39	Strength	1.00	2.03	1.43
100	24.1	12 x 7/8	38 x 7/16	-	-	12 x 1-1/4	100	25.00	7.17	Constr.	1.00	1.67	1.50
100	28.6	12 x 1-1/8	30 x 7/16	-	-	14 x 1-1/2	100	25.00	8.10	Strength	0.98	2.05	1.50
105	24.5	14 x 3/4	40 x 1/2	-	-	14 x 1	105	26.25	7.95	Strength	0.99	1.77	1.58
105	28.8	14 x 1	32 x 7/16	-	-	18 x 1-1/4	105	26.25	9.02	Strength	0.98	2.07	1.58
110	28.6	16 x 7/8	34 x 7/16	16 x 7/8	22	16 x 1-5/8	66	27.50	9.37	Strength	0.99	1.95	1.65
120	28.5	14 x 1	38 x 1/2	14 x 1	24	14 x 2	72	30.00	11.31	Strength	0.98	1.96	1.80

Table A.6 Optimized Interior Girder Designs with Partially Stiffened Web for 28-ft. Cross-section with Hybrid Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Stiffener Spacing			Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length		X	Y	Z					
ft		in.	in.	in.	ft.	in.	ft.	ft.	ft.	ft.	ft.	tons			in.	in.
90	19.5	14 x 3/4	44 x 7/16	-	-	14 x 3/4	90	30.00	5.5			6.16	Constr.	0.95	1.10	1.35
95	19.9	12 x 3/4	46 x 7/16	-	-	12 x 7/8	95	23.75	5	10		6.40	Constr.	1.00	1.19	1.43
100	19.6	14 x 3/4	50 x 7/16	-	-	14 x 3/4	100	25.00	6.25	6.25		7.29	Strength	0.88	1.17	1.50
105	19.9	14 x 3/4	52 x 7/16	-	-	14 x 3/4	105	26.25	6	8		7.82	Service	0.86	1.26	1.58
105	24.3	14 x 3/4	40 x 7/16	-	-	14 x 1-3/8	105	26.25	5			8.44	Constr.	0.91	1.53	1.58
110	19.6	14 x 3/4	56 x 7/16	-	-	14 x 3/4	110	27.50	6	6	7	8.52	Constr.	0.99	1.24	1.65
110	24.5	14 x 7/8	42 x 7/16	-	-	14 x 1-3/8	110	27.50	5	7		9.33	Constr.	0.98	1.61	1.65
115	19.9	14 x 7/8	58 x 7/16	-	-	14 x 7/8	115	28.75	6	6	7	9.76	Constr.	0.97	1.23	1.73
115	24.7	14 x 1	44 x 7/16	-	-	14 x 1-3/8	115	28.75	5.5	9		10.27	Constr.	1.00	1.67	1.73
115	28.4	14 x 1	36 x 7/16	16 x 1	23	16 x 2-1/8	69	28.75	4.5			11.06	Constr.	0.92	1.70	1.73
120	19.7	16 x 3/4	62 x 1/2	-	-	16 x 3/4	120	30.00	5	10		11.23	Constr.	0.88	1.18	1.80
120	24.2	16 x 7/8	48 x 7/16	-	-	16 x 1	120	30.00	6	6	7	10.41	Constr.	0.98	1.78	1.80
120	28.5	14 x 1-1/8	38 x 7/16	16 x 1-1/4	24	16 x 2	72	30.00	4.5	9		12.16	Strength	0.96	1.80	1.80

Table A.7 Optimized Interior Girder Designs Failing the L/800 Deflection Limit with Partially Stiffened Web for 28-ft. Cross-section with Hybrid Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Stiffener Spacing			Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length		X	Y	Z					
ft		in.	in.	in.	ft.	in.	ft.	ft.	ft.	ft.	ft.	tons			in.	in.
105	24.4	14 x 3/4	40 x 7/16	-	-	14 x 1-1/8	105	26.25	5			7.82	Strength	0.96	1.72	1.58
110	24.6	14 x 7/8	42 x 7/16	-	-	14 x 1-1/8	110	27.50	5	7		8.68	Strength	0.96	1.79	1.65
115	24.8	14 x 1	44 x 7/16	-	-	14 x 1-1/8	115	28.75	5.5	9		9.59	Strength	0.99	1.87	1.73
115	28.5	14 x 1	36 x 7/16	16 x 1	23	16 x 1-7/8	69	28.75	4.5			10.59	Constr.	0.97	1.84	1.73
120	28.7	14 x 1-1/8	62 x 1/2	-	-	16 x 1-5/8	120	30.00	5	10		11.92	Strength	0.98	2.05	1.80

Table A.8 Interior Rolled Beams for 28-ft. Cross-section in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Section	Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
ft.			ft.	tons			in.	in.
40	15.5	W21 X 83	20.00	1.66	Service	0.91	0.38	0.60
45	18.4	W21 X 93	22.50	2.09	Service	1.00	0.53	0.68
50	16.4	W27 X 94	25.00	2.35	Service	1.00	0.53	0.75
50	19.3	W21 X 111	25.00	2.78	Service	0.98	0.65	0.75
55	16.7	W30 X 108	27.50	2.97	Service	0.97	0.57	0.83
55	17.9	W27 X 114	27.50	3.14	Service	0.98	0.62	0.83
60	22.8	W21 X 166	20.00	4.98	Service	0.92	0.85	0.90
65	17.2	W36 X 135	21.66	4.39	Service	0.92	0.61	0.98
65	21.1	W27 X 146	21.66	4.75	Service	0.98	0.86	0.98
65	22.8	W24 X 162	21.66	5.27	Service	0.98	0.93	0.98
70	17.5	W 40 X 149	23.33	5.22	Service	0.91	0.64	1.05
70	19.6	W33 X 152	23.33	5.32	Service	0.96	0.78	1.05
70	24.3	W24 X 192	23.33	6.72	Service	0.96	1.04	1.05
75	18.7	W40 X 167	25.00	6.26	Service	0.89	0.72	1.13
75	20.9	W33 X 169	25.00	6.34	Service	0.97	0.89	1.13
80	21.0	W36 X 182	26.67	7.28	Service	0.96	0.92	1.20
80	24.0	W30 X 211	26.67	8.45	Service	0.92	1.05	1.20
85	21.1	W40 X 183	28.33	7.78	Service	0.98	0.97	1.28
85	23.8	W33 X 201	28.33	8.54	Service	0.99	1.13	1.28
90	22.4	W40 X 199	30.00	8.96	Service	0.98	1.08	1.35
90	23.9	W36 X 230	30.00	10.35	Service	0.92	1.10	1.35
95	23.6	W40 X 215	23.75	10.21	Service	0.98	1.18	1.43
95	25.3	W36 X 230	23.75	10.93	Service	1.00	1.31	1.43
100	26.5	W36 X 260	25.00	13.00	Service	0.98	1.38	1.50
100	27.5	W33 X 291	25.00	14.55	Strength	0.94	1.39	1.50
105	24.1	W44 X 262	26.25	13.76	Service	0.92	1.18	1.58
105	25.8	W40 X 278	26.25	14.60	Service	0.99	1.36	1.58
110	25.2	W44 X 262	27.50	14.41	Service	0.99	1.36	1.65
110	27.1	W40 X 297	27.50	16.34	Service	0.96	1.45	1.65
115	26.3	W44 X 290	28.75	16.68	Service	0.98	1.44	1.73
115	30.1	W36 X 359	28.75	20.64	Strength	0.95	1.65	1.73
120	31.2	W36 X 393	30.00	23.58	Strength	0.95	1.75	1.80

Table A.9 Optimized Interior Girder Designs for 34-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
40	13.4	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.76	0.24	0.60
45	15.1	12 x 3/4	24 x 7/16	-	-	12 x 3/4	45	22.50	2.18	Min. Plate	0.91	0.37	0.68
50	16.7	12 x 3/4	24 x 7/16	-	-	12 x 7/8	50	25.00	2.55	Service	0.98	0.48	0.75
55	18.3	12 x 3/4	24 x 7/16	-	-	12 x 1-1/8	55	27.50	3.09	Service	0.97	0.56	0.83
60	18.8	12 x 3/4	26 x 7/16	-	-	12 x 1-1/4	60	20.00	3.61	Service	0.97	0.61	0.90
60	19.8	12 x 3/4	24 x 7/16	-	-	12 x 1-3/8	60	20.00	3.68	Service	0.97	0.65	0.90
65	19.3	12 x 3/4	28 x 7/16	-	-	12 x 1-3/8	65	21.66	4.17	Service	0.96	0.66	0.98
65	21.3	12 x 3/4	24 x 7/16	-	-	12 x 1-5/8	65	21.66	4.31	Service	0.98	0.75	0.98
70	18.9	12 x 3/4	32 x 7/16	-	-	12 x 1-3/8	70	23.33	4.70	Service	0.96	0.66	1.05
70	22.9	12 x 3/4	24 x 7/16	-	-	14 x 1-5/8	70	23.33	5.03	Service	0.98	0.86	1.05
75	19.4	12 x 3/4	34 x 7/16	-	-	12 x 1-1/2	75	25.00	5.34	Service	0.95	0.70	1.13
75	23.2	12 x 3/4	26 x 7/16	-	-	14 x 1-3/4	75	25.00	5.73	Service	0.97	0.90	1.13
75	24.4	12 x 7/8	24 x 7/16	-	-	14 x 1-7/8	75	25.00	6.03	Service	0.98	0.97	1.13
80	19.1	12 x 7/8	38 x 7/16	-	-	12 x 1-3/8	80	26.67	5.94	Service	0.99	0.74	1.20
80	23.6	12 x 7/8	28 x 7/16	-	-	14 x 1-3/4	80	26.67	6.43	Service	1.00	0.97	1.20
80	25.9	12 x 1	24 x 7/16	-	-	14 x 2-1/8	80	26.67	7.11	Strength	1.00	1.08	1.20
85	19.4	12 x 1	40 x 1/2	-	-	12 x 1-1/2	85	28.33	7.23	Constr.	0.98	0.77	1.28
85	23.8	12 x 1	30 x 7/16	-	-	14 x 1-7/8	85	28.33	7.43	Service	0.97	1.03	1.28
85	27.5	12 x 1-1/4	24 x 7/16	16 x 1-1/4	17	16 x 2-1/8	51	28.33	7.79	Strength	0.97	1.23	1.28
90	19.1	12 x 1-1/8	44 x 1/2	-	-	12 x 1-5/8	90	30.00	8.42	Constr.	0.99	0.73	1.35
90	24.1	12 x 1-1/4	32 x 7/16	-	-	14 x 1-7/8	90	30.00	8.46	Service	1.00	1.09	1.35
90	27.8	14 x 1-1/8	26 x 7/16	-	-	18 x 1-7/8	90	30.00	9.32	Strength	1.00	1.30	1.35
95	19.5	12 x 3/4	46 x 1/2	-	-	12 x 1-1/2	95	23.75	8.08	Service	1.00	0.84	1.43
95	23.2	12 x 3/4	36 x 1/2	-	-	14 x 1-7/8	95	23.75	8.61	Service	0.99	1.04	1.43
95	27.8	14 x 1-1/4	28 x 7/16	18 x 1-1/8	19	18 x 2	57	23.75	9.61	Strength	0.98	1.31	1.43
100	19.2	14 x 3/4	50 x 1/2	-	-	14 x 1-3/8	100	25.00	9.32	Strength	0.99	0.81	1.50
100	23.5	12 x 7/8	38 x 1/2	14 x 1-1/8	20	14 x 2	60	25.00	8.95	Service	0.97	1.07	1.50
100	27.7	14 x 1-1/4	30 x 7/16	16 x 1-3/8	20	16 x 2-1/4	60	25.00	10.38	Strength	1.00	1.36	1.50
105	19.6	14 x 3/4	52 x 9/16	-	-	14 x 1-3/8	105	26.25	10.54	Constr.	1.00	0.84	1.58
105	23.8	14 x 3/4	40 x 1/2	14 x 1-1/8	21	14 x 2	63	26.25	9.58	Service	1.00	1.13	1.58
105	27.8	14 x 1-1/4	32 x 7/16	18 x 1-1/4	21	18 x 2-3/8	63	26.25	11.82	Strength	0.98	1.27	1.58
110	21.1	14 x 7/8	56 x 9/16	-	-	14 x 1-5/8	110	27.50	11.81	Service	0.97	0.96	1.65
110	24.1	14 x 7/8	42 x 1/2	16 x 1	22	16 x 1-7/8	66	27.50	10.79	Service	0.97	1.15	1.65
110	28.0	14 x 1-3/8	34 x 1/2	18-1/4	22	18 x 2-1/8	66	27.50	12.76	Strength	1.00	1.40	1.65
115	19.6	16 x 3/4	58 x 9/16	-	-	16 x 1-1/4	115	28.75	12.64	Service	0.96	0.87	1.73
115	24.3	14 x 1	44 x 1/2	16 x 1	23	16 x 1-7/8	69	28.75	11.82	Service	0.99	1.21	1.73
115	28.0	14 x 1-3/8	36 x 1/2	18 x 1-1/4	23	18 x 2-1/4	69	28.75	13.80	Strength	0.99	1.41	1.73
120	19.4	16 x 3/4	62 x 9/16	16 x 3/4	24	16 x 1-3/8	72	30.00	13.25	Constr.	1.00	0.83	1.80
120	23.7	16 x 3/4	48 x 9/16	16 x 1	24	16 x 1-7/8	72	30.00	12.94	Constr.	0.97	1.15	1.80
120	28.0	14 x 1-3/8	38 x 1/2	18 x 1-1/4	24	18 x 2-3/8	72	30.00	14.88	Strength	0.99	1.41	1.80

Table A.10 Optimized Interior Girder Designs with Partially Stiffened Web for 34-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Stiffener Spacing			Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length		X	Y	Z					
ft		in.	in.	in.	ft.	in.	ft.	ft.	ft.	ft.	ft.	tons			in.	in.
85	19.4	12 x 1	40 x 7/16	-	-	12 x 1-1/2	85	28.33	5			6.87	Service	0.98	0.79	1.28
90	19.2	14 x 1	44 x 7/16	-	-	14 x 1-1/4	90	30.00	5.5	10		7.77	Service	0.98	0.80	1.35
95	19.4	12 x 1	46 x 7/16	-	-	12 x 1-5/8	95	23.75	5.75	8		8.34	Service	0.96	0.82	1.43
95	23.3	12 x 7/8	36 x 7/16	-	-	14 x 1-7/8	95	23.75	4			8.49	Service	0.99	1.06	1.43
100	19.2	14 x 3/4	50 x 7/16	-	-	14 x 1-3/8	100	25.00	5	10		9.32	Strength	0.97	0.83	1.50
100	23.5	12 x 1-1/8	38 x 7/16	14 x 1-1/8	20	14 x 2	60	25.00	4	8		9.06	Strength	0.98	1.08	1.50
105	19.6	14 x 7/8	52 x 1/2	-	-	14 x 1-3/8	105	26.25	6			10.27	Service	0.98	0.86	1.58
105	23.8	14 x 1-1/8	40 x 7/16	-	-	14 x 2	105	26.25	5	10		10.94	Service	0.99	1.14	1.58
110	19.3	14 x 1-1/8	56 x 1/2	-	-	14 x 1-3/8	110	27.50	7	9		11.14	Constr.	0.98	0.86	1.65
110	23.9	14 x 1-1/4	42 x 7/16	16 x 1-1/4	22	16 x 2-1/8	66	27.50	5	7	7	12.03	Strength	0.98	1.06	1.65
110	27.9	14 x 1-3/8	34 x 7/16	18-1-1/4	22	18 x 2-1/4	66	27.50	4	4		12.62	Strength	0.98	1.37	1.65
115	19.6	16 x 7/8	58 x 1/2	-	-	16 x 1-1/4	115	28.75	7	8		12.33	Service	0.98	0.89	1.73
115	24.2	16 x 1-1/4	44 x 7/16	16 x 1-1/4	23	16 x 2-1/8	69	28.75	5	8	8	13.24	Strength	1.00	1.12	1.73
115	27.8	16 x 1-1/2	36 x 7/16	18 x 1-1/2	23	18 x 2-5/8	69	28.75	5	9		15.44	Strength	0.99	1.27	1.73
120	19.4	16 x 7/8	62 x 1/2	-	-	16 x 1-1/4	120	30.00	7.75	7.75		13.27	Service	1.00	0.89	1.80
120	23.7	16 x 1-1/8	48 x 1/2	16 x 1	24	16 x 1-7/8	72	30.00	6			13.56	Service	0.97	1.16	1.80
120	28.1	16 x 1-5/8	38 x 7/16	18 x 1-1/4	24	18 x 2-1/4	72	30.00	4.75	4.75	8	15.50	Strength	0.99	1.47	1.80

Table A.11 Optimized Interior Girder Designs for 34-ft. Cross-section with a Hybrid Material Configuration in Accordance with 2^{nd} Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
40	13.4	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.66	0.24	0.60
45	15.1	12 x 3/4	24 x 7/16	-	-	12 x 3/4	45	22.50	2.18	Min. Plate	0.65	0.37	0.68
50	16.8	12 x 3/4	24 x 7/16	-	-	12 x 3/4	50	25.00	2.42	Min. Plate	0.77	0.53	0.75
55	18.5	12 x 3/4	24 x 7/16	-	-	12 x 3/4	55	27.50	2.67	Min. Plate	0.90	0.72	0.83
60	19.1	12 x 3/4	26 x 7/16	-	-	12 x 3/4	60	20.00	3.00	Service	0.96	0.84	0.90
60	20.1	12 x 3/4	24 x 7/16	-	-	12 x 7/8	60	20.00	3.06	Service	0.94	0.88	0.90
65	19.6	12 x 3/4	28 x 7/16	-	-	12 x 7/8	65	21.66	3.51	Service	0.93	0.88	0.98
65	21.6	12 x 3/4	24 x 7/16	-	-	12 x 1-1/8	65	21.66	3.65	Service	0.90	0.97	0.98
70	19.2	12 x 3/4	32 x 7/16	-	-	12 x 3/4	70	23.33	3.81	Service	1.00	0.96	1.05
70	23.0	12 x 3/4	24 x 7/16	-	-	12 x 1-1/2	70	23.33	4.47	Constr.	0.91	1.01	1.05
75	19.5	12 x 3/4	34 x 7/16	-	-	12 x 1-1/8	75	25.00	4.77	Constr.	0.99	0.84	1.13
75	23.5	12 x 7/8	26 x 7/16	-	-	14 x 1-3/8	75	25.00	5.25	Constr.	0.89	1.06	1.13
75	24.6	12 x 7/8	24 x 7/16	-	-	14 x 1-5/8	75	25.00	5.58	Constr.	0.92	1.07	1.13
80	19.2	12 x 1	38 x 7/16	-	-	12 x 1	80	26.67	5.53	Strength	0.98	0.90	1.20
80	23.7	12 x 1	28 x 7/16	-	-	12 x 1-1/2	80	26.67	5.75	Constr.	0.94	1.20	1.20
80	25.9	12 x 1	24 x 7/16	-	-	12 x 2-1/8	80	26.67	6.53	Constr.	0.94	1.20	1.20
85	19.6	12 x 1-1/8	40 x 1/2	-	-	12 x 1-1/8	85	28.33	6.80	Constr.	0.95	0.89	1.28
85	24.1	12 x 1-1/8	30 x 7/16	-	-	14 x 1-3/8	85	28.33	6.85	Constr.	0.93	1.24	1.28
85	27.6	12 x 1-1/8	24 x 7/16	-	-	16 x 2	85	28.33	8.32	Constr.	0.90	1.28	1.28
90	19.1	12 x 1-1/8	44 x 1/2	-	-	12 x 1-5/8	90	30.00	8.42	Constr.	0.99	0.73	1.35
90	24.3	12 x 1-3/8	32 x 7/16	-	-	14 x 1-3/8	90	30.00	7.62	Constr.	1.00	1.33	1.35
90	27.8	14 x 1-3/8	26 x 7/16	18 x 1-1/8	18	18 x 1-7/8	54	30.00	8.49	Constr.	0.89	1.64	1.35
95	19.7	12 x 7/8	46 x 1/2	-	-	12 x 7/8	95	23.75	7.11	Service	0.97	1.10	1.43
95	23.7	14 x 3/4	36 x 1/2	-	-	14 x 1-1/8	95	23.75	7.15	Service	0.99	1.43	1.43
95	27.8	14 x 1-1/8	28 x 7/16	16 x 1-1/4	19	16 x 2	57	23.75	8.79	Strength	0.94	1.42	1.43
100	19.4	14 x 3/4	50 x 1/2	-	-	14 x 3/4	100	25.00	7.83	Strength	0.98	1.08	1.50
100	23.8	12 x 1	38 x 1/2	-	-	12 x 1-1/2	100	25.00	8.34	Service	1.00	1.40	1.50
100	27.7	14 x 1-1/8	30 x 7/16	14 x 1-1/4	20	14 x 2-1/4	60	25.00	9.32	Strength	1.00	1.50	1.50
105	19.6	14 x 3/4	52 x 9/16	-	-	14 x 1-3/8	105	26.25	10.54	Constr.	1.00	0.84	1.58
105	24.1	14 x 7/8	40 x 1/2	-	-	14 x 1-1/4	105	26.25	8.89	Strength	0.98	1.50	1.58
105	28.0	14 x 1-1/4	32 x 7/16	16 x 1-1/8	21	16 x 2	63	26.25	10.34	Strength	0.93	1.55	1.58
110	19.4	14 x 7/8	56 x 9/16	-	-	14 x 7/8	110	27.50	10.48	Constr.	0.90	1.03	1.65
110	24.3	14 x 1	42 x 1/2	-	-	14 x 1-1/4	110	27.50	9.83	Constr.	0.99	1.57	1.65
110	28.1	14 x 1-1/4	34 x 1/2	16 x 1-1/4	22	16 x 2	66	27.50	11.55	Strength	0.95	1.58	1.65
115	19.8	16 x 3/4	58 x 9/16	-	-	16 x 3/4	115	28.75	11.08	Constr.	0.94	1.10	1.73
115	24.5	14 x 1-1/8	44 x 1/2	-	-	14 x 1-3/8	115	28.75	11.15	Strength	0.97	1.55	1.73
115	28.4	14 x 1-3/8	36 x 1/2	-	-	18 x 1-5/8	115	28.75	13.01	Strength	0.97	1.73	1.73
120	19.5	16 x 7/8	62 x 9/16	-	-	16 x 7/8	120	30.00	12.84	Strength	0.96	1.02	1.80
120	24.0	16 x 7/8	48 x 9/16	-	-	16 x 1-1/8	120	30.00	12.05	Constr.	0.96	1.52	1.80
120	28.1	14 x 1-3/8	38 x 1/2	14 x 1	24	14 x 2-1/4	72	30.00	12.81	Strength	0.95	1.74	1.80

Table A.12 Optimized Interior Girder Designs Failing the L/800 Deflection Limit for 34-ft. Cross-section with a Hybrid Material Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
65	21.7	12 x 3/4	24 x 7/16	-	-	12 x 1	65	21.66	3.48	Service	0.98	1.05	0.98
70	23.2	12 x 3/4	24 x 7/16	-	-	12 x 1-1/4	70	23.33	4.11	Service	0.95	1.15	1.05
75	23.6	12 x 7/8	26 x 7/16	-	-	14 x 1-1/8	75	25.00	4.80	Constr.	0.99	1.22	1.13
75	24.8	12 x 7/8	24 x 7/16	-	-	14 x 1-1/4	75	25.00	4.91	Constr.	0.98	1.29	1.13
80	23.9	12 x 1-1/8	28 x 7/16	-	-	12 x 1-1/4	80	26.67	5.55	Constr.	1.00	1.36	1.20
80	26.2	12 x 1-1/8	24 x 7/16	-	-	12 x 1-5/8	80	26.67	5.92	Strength	0.99	1.46	1.20
85	24.1	12 x 1-1/4	30 x 7/16	-	-	14 x 1-1/4	85	28.33	6.60	Constr.	0.96	1.32	1.28
85	27.8	12 x 1-1/4	24 x 7/16	-	-	14 x 1-3/4	85	28.33	7.23	Strength	0.94	1.54	1.28
90	28.1	14 x 1-1/8	26 x 7/16	-	-	16 x 1-1/2	90	30.00	7.83	Strength	0.97	1.64	1.35
95	28.1	12 x 1-3/8	28 x 7/16	-	-	16 x 1-1/2	95	23.75	8.53	Strength	0.99	1.72	1.43
100	28.1	14 x 1-1/4	30 x 7/16	-	-	14 x 1-3/4	100	25.00	9.38	Strength	1.00	1.76	1.50
105	28.1	14 x 1-1/4	32 x 7/16	-	-	16 x 1-7/8	105	26.25	10.99	Strength	0.97	1.61	1.58
110	28.3	14 x 1-3/8	34 x 1/2	-	-	16 x 1-5/8	110	27.50	11.65	Strength	1.00	1.79	1.65

Table A.13 Optimized Interior Girder Designs with Partially Stiffened Web for 34-ft. Cross-section with Hybrid Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Stiffener Spacing			Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length		X	Y	Z					
ft		in.	in.	in.	ft.	in.	ft.	ft.	ft.	ft.	ft.	tons			in.	in.
85	19.7	14 x 3/4	40 x 7/16	-	-	14 x 3/4	85	28.33	5			5.57	Constr.	0.99	1.07	1.28
90	19.3	14 x 7/8	44 x 7/16	-	-	14 x 7/8	90	30.00	5.5	9		6.70	Constr.	0.97	0.97	1.35
95	19.7	12 x 7/8	46 x 7/16	-	-	12 x 1	95	23.75	5.5	7		6.89	Service	0.94	1.07	1.43
95	23.6	12 x 7/8	36 x 7/16	-	-	14 x 1-3/8	95	23.75	4.5			7.35	Constr.	0.99	1.30	1.43
100	19.4	14 x 3/4	50 x 7/16	-	-	14 x 3/4	100	25.00	5	6	6	7.29	Service	1.00	1.13	1.50
100	23.8	12 x 1	38 x 7/16	-	-	12 x 1-1/2	100	25.00	4.5	9		7.93	Constr.	1.00	1.43	1.50
105	19.8	14 x 3/4	52 x 1/2	-	-	14 x 3/4	105	26.25	6			8.40	Service	0.99	1.16	1.58
105	24.1	14 x 7/8	40 x 7/16	-	-	14 x 1-3/8	105	26.25	5	8		8.75	Strength	0.96	1.46	1.58
110	19.4	14 x 7/8	56 x 1/2	-	-	14 x 7/8	110	27.50	7	7		9.83	Service	0.90	1.07	1.65
110	24.3	14 x 1	42 x 7/16	-	-	14 x 1-3/8	110	27.50	5	6	6	9.66	Strength	0.96	1.53	1.65
110	28.1	14 x 1-1/4	34 x 7/16	-	-	16 x 2	110	27.50	4	4		12.05	Strength	0.98	1.60	1.65
115	19.8	16 x 3/4	58 x 1/2	-	-	16 x 3/4	115	28.75	7	10		10.37	Service	0.94	1.15	1.73
115	24.5	14 x 1-1/8	44 x 7/16	-	-	14 x 1-3/8	115	28.75	5	6	8	10.61	Strength	0.99	1.60	1.73
115	28.3	14 x 1-3/8	36 x 7/16	-	-	18 x 1-3/4	115	28.75	4.5	8		13.01	Strength	0.96	1.67	1.73
120	19.5	16 x 7/8	62 x 1/2	-	-	16 x 7/8	120	30.00	7.75	10		12.05	Constr.	0.90	1.06	1.80
120	24.0	16 x 7/8	48 x 1/2	-	-	16 x 1-1/8	120	30.00	6			11.43	Service	0.98	1.56	1.80
120	28.1	16 x 1-3/8	38 x 7/16	14 x 1-3/8	24	14 x 2-1/4	72	30.00	4.5	7	7	12.76	Service	0.98	1.73	1.80

Table A.14 Optimized Interior Girder Designs Failing the L/800 Deflection Limit with Partially Stiffened Web for 34-ft. Cross-section with Hybrid Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Stiffener Spacing			Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length		X	Y	Z					
ft		in.	in.	in.	ft.	in.	ft.	ft.	ft.	ft.	ft.	tons			in.	in.
115	28.4	14 x 1-3/8	36 x 7/16	-	-	18 x 1-5/8	115	28.75	4.5	8		12.57	Strength	1.00	1.76	1.73

Table A.15 Interior Rolled Beams for 34-ft. Cross-section in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Section	Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
ft.			ft.	tons			in.	in.
40	15.2	W21 X 93	20.00	1.86	Service	0.93	0.33	0.60
45	18.7	W18 X 119	22.50	2.68	Service	0.96	0.49	0.68
50	20.6	W18 X 143	25.00	3.58	Service	0.98	0.61	0.75
55	19.1	W24 X 146	27.50	4.02	Service	0.93	0.56	0.83
55	20.5	W21 X 166	27.50	4.57	Service	0.90	0.60	0.83
60	22.4	W24 X 162	20.00	4.86	Service	0.97	0.68	0.90
65	18.0	W30 X 152	21.66	4.94	Service	0.96	0.59	0.98
65	22.3	W24 X 192	21.66	6.24	Service	0.96	0.77	0.98
70	18.3	W 36 X 160	23.33	5.60	Service	0.99	0.64	1.05
70	20.8	W30 X 173	23.33	6.06	Service	1.00	0.77	1.05
70	23.8	W24 X 229	23.33	8.02	Service	0.93	0.86	1.05
75	18.5	W40 X 183	25.00	6.86	Service	0.92	0.63	1.13
75	22.2	W30 X 211	25.00	7.91	Service	0.94	0.82	1.13
75	23.7	W27 X 217	25.00	8.14	Service	0.99	0.93	1.13
80	20.7	W36 X 210	26.67	8.40	Service	0.96	0.78	1.20
80	23.5	W30 X 235	26.67	9.40	Service	0.95	0.92	1.20
85	20.8	W40 X 211	28.33	8.97	Service	0.99	0.83	1.28
85	23.3	W33 X 241	28.33	10.24	Service	0.95	0.93	1.28
85	26.6	W27 X 281	28.33	11.94	Strength	0.99	1.12	1.28
90	22.0	W40 X 235	30.00	10.58	Service	0.99	0.92	1.35
90	24.6	W33 X 263	30.00	11.84	Service	0.96	1.03	1.35
90	27.9	W27 X 336	30.00	15.12	Strength	0.95	1.17	1.35
95	23.1	W40 X 264	23.75	12.54	Service	0.99	0.99	1.43
95	25.9	W36 X 291	23.75	13.82	Service	0.97	1.13	1.43
100	26.1	W36 X 300	25.00	15.00	Service	0.98	1.17	1.50
100	27.1	W33 X 318	25.00	15.90	Service	0.98	1.23	1.50
105	25.4	W40 X 327	26.25	17.17	Service	0.98	1.14	1.58
105	27.2	W36 X 328	26.25	17.22	Service	0.98	1.27	1.58
105	28.3	W33 X 354	26.25	18.59	Service	0.98	1.32	1.58
110	25.2	W40 X 362	27.50	19.91	Service	0.93	1.18	1.65
110	27.1	W36 X 359	27.50	19.75	Strength	0.99	1.37	1.65
115	27.9	W40 X 372	28.75	21.39	Service	0.98	1.34	1.73
120	28.9	W40 X 397	30.00	23.82	Service	0.99	1.45	1.80

Table A.16 Optimized Exterior Girder Designs for 28-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
40	13.6	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.79	0.25	0.60
45	15.3	12 x 3/4	24 x 7/16	-	-	12 x 3/4	45	22.50	2.18	Min. Plate	0.90	0.39	0.68
50	17.0	12 x 3/4	24 x 7/16	-	-	12 x 7/8	50	25.00	2.55	Fatigue	0.92	0.50	0.75
55	18.6	12 x 3/4	24 x 7/16	-	-	12 x 1	55	27.50	2.95	Service	0.97	0.64	0.83
60	19.1	12 x 3/4	26 x 7/16	-	-	12 x 1-1/8	60	20.00	3.46	Service	0.96	0.69	0.90
60	20.1	12 x 3/4	24 x 7/16	-	-	12 x 1-1/4	60	20.00	3.52	Service	0.96	0.73	0.90
65	19.6	12 x 3/4	28 x 7/16	-	-	12 x 1-1/4	65	21.66	4.01	Service	0.95	0.73	0.98
65	21.7	12 x 3/4	24 x 7/16	-	-	12 x 1-1/2	65	21.66	4.15	Service	0.97	0.84	0.98
70	19.3	12 x 3/4	32 x 7/16	-	-	14 x 1	70	23.33	4.41	Service	0.98	0.79	1.05
70	23.2	12 x 3/4	24 x 7/16	-	-	12 x 1-3/4	70	23.33	4.82	Service	0.98	0.95	1.05
75	19.7	12 x 3/4	34 x 7/16	-	-	14 x 1-1/8	75	25.00	5.06	Service	0.96	0.80	1.13
75	23.5	12 x 3/4	26 x 7/16	-	-	12 x 1-7/8	75	25.00	5.47	Service	0.97	0.99	1.13
75	24.7	12 x 3/4	24 x 7/16	-	-	12 x 2	75	25.00	5.55	Service	0.99	1.07	1.13
80	19.3	12 x 3/4	38 x 7/16	-	-	12 x 1-1/4	80	26.67	5.53	Service	0.99	0.82	1.20
80	23.7	12 x 3/4	28 x 7/16	-	-	12 x 2	80	26.67	6.16	Service	0.96	1.02	1.20
80	26.3	12 x 3/4	24 x 7/16	-	-	16 x 2	80	26.67	7.01	Strength	1.00	1.09	1.20
85	19.7	12 x 7/8	40 x 7/16	-	-	12 x 1-3/8	85	28.33	6.44	Service	0.96	0.87	1.28
85	24.0	12 x 7/8	30 x 7/16	-	-	12 x 2	85	28.33	6.89	Service	0.99	1.14	1.28
85	27.8	14 x 7/8	24 x 7/16	16 x 1-1/4	17	16 x 2-1/8	51	28.33	7.40	Strength	0.95	1.28	1.28
90	19.4	14 x 3/4	44 x 1/2	-	-	14 x 1-1/8	90	30.00	7.39	Service	0.96	0.86	1.35
90	24.4	14 x 3/4	32 x 7/16	-	-	14 x 1-3/4	90	30.00	7.50	Service	1.00	1.21	1.35
90	27.9	12 x 1	26 x 7/16	16 x 1-1/4	18	16 x 2-1/4	54	30.00	8.11	Strength	0.99	1.31	1.35
95	19.7	12 x 3/4	46 x 1/2	-	-	12 x 1-1/4	95	23.75	7.60	Service	0.98	0.96	1.43
95	23.6	12 x 3/4	36 x 7/16	-	-	14 x 1-3/4	95	23.75	7.96	Service	0.97	1.16	1.43
95	28.1	12 x 1-1/8	28 x 7/16	16 x 1-1/4	19	16 x 2-1/8	57	23.75	8.75	Strength	0.99	1.43	1.43
100	19.4	14 x 3/4	50 x 1/2	-	-	14 x 1-1/4	100	25.00	9.02	Strength	0.93	0.88	1.50
100	23.9	12 x 1	38 x 7/16	-	-	14 x 1-3/4	100	25.00	9.04	Service	1.00	1.23	1.50
100	28.2	14 x 1	30 x 7/16	18 x 1-1/8	20	18 x 2	60	25.00	9.67	Strength	0.99	1.44	1.50
105	19.8	14 x 3/4	52 x 1/2	-	-	14 x 1-1/4	105	26.25	9.65	Service	0.96	0.94	1.58
105	24.1	12 x 7/8	40 x 1/2	14 x 1	21	14 x 1-7/8	63	26.25	9.26	Service	0.98	1.23	1.58
105	28.2	14 x 1	32 x 7/16	18 x 1-1/8	21	18 x 2-1/4	63	26.25	10.79	Strength	0.98	1.40	1.58
110	19.5	14 x 3/4	56 x 9/16	-	-	14 x 1-1/8	110	27.50	10.81	Service	0.96	0.94	1.65
110	24.3	14 x 3/4	42 x 1/2	-	-	14 x 1-7/8	110	27.50	10.81	Service	1.00	1.29	1.65
110	28.3	14 x 1-1/8	34 x 7/16	18-1-1/8	22	18 x 2-1/8	66	27.50	11.54	Service	0.99	1.50	1.65
115	19.8	16 x 3/4	58 x 9/16	-	-	16 x 1-1/8	115	28.75	12.25	Service	0.94	0.96	1.73
115	24.4	14 x 7/8	44 x 1/2	14 x 1-1/8	23	14 x 2	69	28.75	11.22	Service	0.97	1.31	1.73
115	28.4	14 x 1-1/8	36 x 1/2	18 x 1-1/8	23	18 x 2-1/8	69	28.75	12.68	Strength	1.00	1.51	1.73
120	19.6	16 x 3/4	62 x 9/16	-	-	16 x 1	120	30.00	12.84	Service	0.96	1.00	1.80
120	24.0	16 x 7/8	48 x 1/2	16 x 7/8	24	16 x 1-5/8	72	30.00	12.09	Service	1.00	1.33	1.80
120	28.4	14 x 1-1/8	38 x 1/2	18 x 1-1/8	24	18 x 2-1/4	72	30.00	13.71	Service	0.98	1.55	1.80

Table A.17 Optimized Exterior Girder Designs Failing the L/800 Deflection Limit for 28-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
85	27.9	14 x 7/8	24 x 7/16	16 x 1-1/8	17	16 x 2	51	28.33	7.11	Strength	0.98	1.36	1.28

Table A.18 Optimized Exterior Girder Designs with Partially Stiffened Web for 28-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Stiffener Spacing			Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length		X	Y	Z					
ft		in.	in.	in.	ft.	in.	ft.	ft.	ft.	ft.	ft.	tons			in.	in.
90	19.4	14 x 7/8	44 x 7/16	-	-	14 x 1-1/8	90	30.00	5			7.24	Service	0.98	0.89	1.35
95	19.7	12 x 3/4	46 x 7/16	-	-	12 x 1-3/8	95	23.75	5	9		7.34	Service	1.00	0.94	1.43
100	19.4	14 x 3/4	50 x 7/16	-	-	14 x 1-1/4	100	25.00	6	8		8.49	Strength	0.96	0.93	1.50
105	19.8	14 x 3/4	52 x 7/16	-	-	14 x 1-1/4	105	26.25	6	10		9.07	Service	0.99	1.03	1.58
105	24.1	14 x 7/8	40 x 7/16	14 x 1	21	14 x 1-7/8	63	26.25	5	10		9.13	Service	1.00	1.25	1.58
110	19.5	14 x 3/4	56 x 1/2	-	-	14 x 1-1/4	110	27.50	7	10		10.48	Service	0.96	0.94	1.65
110	24.3	16 x 3/4	42 x 7/16	16 x 1	22	16 x 1-3/4	66	27.50	5	10		10.03	Constr.	0.97	1.27	1.65
115	19.8	16 x 3/4	58 x 1/2	-	-	16 x 1-1/8	115	28.75	6	6		11.54	Service	0.97	1.05	1.73
115	24.5	16 x 7/8	44 x 7/16	16 x 1	23	16 x 1-3/4	69	28.75	5.5	11		11.04	Strength	0.98	1.33	1.73
120	19.6	16 x 3/4	62 x 1/2	-	-	16 x 1-1/8	120	30.00	7	10		12.45	Service	0.97	0.98	1.80
120	23.9	16 x 7/8	48 x 7/16	16 x 1	24	16 x 1-3/4	72	30.00	6	12		11.88	Constr.	0.98	1.29	1.80
120	28.4	14 x 1-3/8	38 x 7/16	18 x 1-1/4	24	18 x 2-1/8	72	30.00	4.5	9		13.85	Strength	1.00	1.60	1.80

Table A.19 Optimized Exterior Girder Designs for 28-ft. Cross-section with Hybrid Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
40	13.6	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.79	0.25	0.60
45	15.3	12 x 3/4	24 x 7/16	-	-	12 x 3/4	45	22.50	2.18	Min. Plate	0.90	0.39	0.68
50	17.0	12 x 3/4	24 x 7/16	-	-	12 x 7/8	50	25.00	2.55	Fatigue	0.92	0.50	0.75
55	18.6	12 x 3/4	24 x 7/16	-	-	12 x 1	55	27.50	2.95	Fatigue	0.94	0.64	0.83
60	19.1	12 x 3/4	26 x 7/16	-	-	12 x 1-1/8	60	20.00	3.46	Fatigue	0.94	0.74	0.90
60	20.2	12 x 3/4	24 x 7/16	-	-	12 x 1-1/8	60	20.00	3.37	Fatigue	1.00	0.78	0.90
65	19.7	12 x 3/4	28 x 7/16	-	-	12 x 1-1/8	65	21.66	3.84	Fatigue	1.00	0.78	0.98
65	21.7	12 x 3/4	24 x 7/16	-	-	12 x 1-3/8	65	21.66	3.98	Fatigue	0.98	0.95	0.98
70	19.3	12 x 3/4	32 x 7/16	-	-	12 x 1-1/8	70	23.33	4.35	Fatigue	1.00	0.73	1.05
70	23.3	12 x 3/4	24 x 7/16	-	-	12 x 1-5/8	70	23.33	4.64	Fatigue	0.97	1.00	1.05
75	19.7	12 x 3/4	34 x 7/16	-	-	12 x 1-1/4	75	25.00	4.96	Fatigue	0.97	0.82	1.13
75	23.6	12 x 3/4	26 x 7/16	-	-	12 x 1-5/8	75	25.00	5.09	Fatigue	1.00	1.09	1.13
75	24.7	12 x 3/4	24 x 7/16	-	-	12 x 2	75	25.00	5.55	Fatigue	0.90	1.07	1.13
80	19.3	12 x 3/4	38 x 7/16	-	-	12 x 1-1/4	80	26.67	5.53	Fatigue	0.95	0.82	1.20
80	23.9	12 x 3/4	28 x 7/16	-	-	12 x 3/4	80	26.67	5.75	Fatigue	0.98	1.13	1.20
80	26.3	12 x 3/4	24 x 7/16	-	-	14 x 2	80	26.67	6.47	Constr.	0.96	1.19	1.20
85	19.7	12 x 7/8	40 x 7/16	-	-	12 x 1-1/4	85	28.33	6.22	Fatigue	1.00	0.92	1.28
85	24.1	12 x 1	30 x 7/16	-	-	12 x 1-3/4	85	28.33	6.67	Fatigue	1.00	1.26	1.28
85	27.8	14 x 7/8	24 x 7/16	16 x 7/8	17	16 x 2-1/4	51	28.33	7.22	Strength	0.88	1.28	1.28
90	19.5	14 x 3/4	44 x 1/2	-	-	14 x 1	90	30.00	7.12	Fatigue	0.98	0.91	1.35
90	24.5	14 x 3/4	32 x 7/16	-	-	14 x 1-5/8	90	30.00	7.24	Fatigue	0.97	1.29	1.35
90	27.8	12 x 1	26 x 7/16	16 x 1-1/8	18	16 x 2-3/8	54	30.00	8.17	Constr.	0.90	1.28	1.35
95	19.7	12 x 3/4	46 x 1/2	-	-	12 x 1-1/4	95	23.75	7.60	Constr.	0.95	0.96	1.43
95	23.6	12 x 3/4	36 x 7/16	-	-	12 x 1-3/4	95	23.75	7.39	Fatigue	0.99	1.30	1.43
95	28.0	12 x 1	28 x 7/16	16 x 1	19	16 x 2-1/4	57	23.75	8.45	Strength	0.93	1.40	1.43
100	19.5	14 x 3/4	50 x 1/2	-	-	14 x 1	100	25.00	8.42	Fatigue	0.98	0.98	1.50
100	23.8	12 x 7/8	38 x 7/16	12 x 3/4	20	12 x 1-7/8	60	25.00	7.52	Strength	0.98	1.31	1.50
100	28.2	14 x 7/8	30 x 7/16	18 x 1	20	18 x 2	60	25.00	9.22	Constr.	0.96	1.46	1.50
105	19.8	14 x 3/4	52 x 1/2	-	-	14 x 1	105	26.25	9.02	Fatigue	0.99	1.06	1.58
105	24.2	14 x 3/4	40 x 1/2	-	-	14 x 1-1/2	105	26.25	9.20	Fatigue	1.00	1.41	1.58
105	28.2	14 x 1	32 x 7/16	16 x 1-1/8	21	16 x 2-1/8	63	26.25	9.93	Strength	0.89	1.56	1.58
110	19.6	14 x 3/4	56 x 9/16	-	-	14 x 7/8	110	27.50	10.15	Fatigue	1.00	1.07	1.65
110	24.6	14 x 3/4	42 x 1/2	14 x 3/4	22	14 x 1-5/8	66	27.50	9.24	Fatigue	0.99	1.43	1.65
110	28.4	14 x 7/8	34 x 7/16	16 x 1	22	16 x 2-1/4	66	27.50	10.32	Strength	0.99	1.58	1.65
115	19.9	16 x 3/4	58 x 9/16	-	-	14 x 7/8	115	28.75	10.83	Fatigue	0.96	1.14	1.73
115	24.6	14 x 7/8	44 x 1/2	14 x 3/4	23	14 x 1-5/8	69	28.75	10.19	Fatigue	0.97	1.50	1.73
115	28.4	14 x 1	36 x 1/2	16 x 1-1/8	23	16 x 2-1/8	69	28.75	11.66	Strength	0.92	1.67	1.73
120	19.6	16 x 3/4	62 x 9/16	-	-	16 x 7/8	120	30.00	12.43	Constr.	0.96	1.07	1.80
120	24.1	16 x 7/8	48 x 1/2	16 x 3/4	24	16 x 1-3/8	72	30.00	11.43	Fatigue	0.96	1.46	1.80
120	28.5	14 x 1	38 x 1/2	16 x 1-1/8	24	16 x 2	72	30.00	12.13	Strength	0.99	1.79	1.80

Table A.20 Optimized Exterior Girder Designs Failing the L/800 Deflection Limit for 28-ft. Cross-section with Hybrid Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
75	24.8	12 x 3/4	24 x 7/16	-	-	12 x 1-3/4	75	25.00	5.17	Fatigue	1.00	1.18	1.13
80	26.3	12 x 3/4	24 x 7/16	-	-	12 x 2	80	26.67	5.92	Fatigue	0.99	1.32	1.20
85	27.9	14 x 7/8	24 x 7/16	14 x 7/8	17	14 x 2	51	28.33	6.43	Fatigue	0.95	1.51	1.28
90	28.1	12 x 1	26 x 7/16	-	-	16 x 1-7/8	90	30.00	8.17	Strength	0.96	1.49	1.35
95	28.1	12 x 1	28 x 7/16	16 x 1-1/8	19	16 x 2	57	23.75	8.19	Strength	0.99	1.50	1.43
100	28.2	14 x 1	30 x 7/16	14 x 1	20	14 x 2	60	25.00	8.43	Fatigue	0.99	1.72	1.50
105	28.4	14 x 1	32 x 7/16	16 x 1-1/8	21	16 x 1-7/8	63	26.25	9.50	Strength	0.95	1.69	1.58
110	28.3	14 x 1	34 x 7/16	14 x 1	22	14 x 2-1/8	66	27.50	9.79	Strength	0.99	1.79	1.65
115	28.5	14 x 1	36 x 1/2	16 x 1-1/8	23	16 x 2	69	28.75	10.99	Strength	0.99	1.75	1.73

Table A.21 Optimized Exterior Girder Designs with Partially Stiffened Web for 28-ft. Cross-section with Hybrid Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Stiffener Spacing			Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length		X	Y	Z					
ft		in.	in.	in.	ft.	in.	ft.	ft.	ft.	ft.	ft.	tons			in.	in.
90	19.4	14 x 7/8	44 x 7/16	-	-	14 x 1-1/8	90	30.00	5.5			7.24	Fatigue	0.94	0.89	1.35
95	19.7	12 x 3/4	46 x 7/16	-	-	12 x 1-1/4	95	23.75	5	10		7.13	Fatigue	0.99	0.99	1.43
100	19.5	14 x 3/4	50 x 7/16	-	-	14 x 1-1/8	100	25.00	6.25	6.25		8.19	Strength	0.95	0.96	1.50
105	19.9	14 x 3/4	52 x 7/16	-	-	14 x 1-1/8	105	26.25	6	8		8.75	Constr.	0.98	1.03	1.58
105	24.6	14 x 7/8	40 x 7/16	14 x 3/4	21	14 x 1-5/8	63	26.25	5			8.50	Fatigue	0.97	1.39	1.58
110	19.6	14 x 3/4	56 x 1/2	-	-	14 x 1	110	27.50	6	6	7	9.83	Fatigue	0.97	1.05	1.65
110	24.4	14 x 1	42 x 7/16	-	-	14 x 1-5/8	110	27.50	5	7		10.32	Constr.	0.98	1.44	1.65
115	19.9	16 x 3/4	58 x 1/2	-	-	16 x 7/8	115	28.75	6	6	7	10.76	Fatigue	0.98	1.11	1.73
115	24.6	14 x 1-1/8	44 x 7/16	-	-	14 x 1-5/8	115	28.75	5.5	9		11.30	Fatigue	1.00	1.50	1.73
120	19.6	16 x 3/4	62 x 1/2	-	-	16 x 7/8	120	30.00	5	10		11.64	Constr.	0.97	1.11	1.80
120	24.1	16 x 7/8	48 x 7/16	-	-	16 x 1-3/8	120	30.00	6	6		11.64	Constr.	0.98	1.49	1.80
120	28.5	14 x 1-1/8	38 x 7/16	16 x 1-1/4	24	16 x 2	72	30.00	4.5	9		12.16	Constr.	1.00	1.80	1.80

Table A.22 Exterior Rolled Beams for 28-ft. Cross-section in Accordance with 2nd Edition of Specifications

Span Length (L) ft.	L/D	Section	Lateral Brace Spacing (C) ft.	Wt. tons	Controlling Limit State	PR	Defl. in.	L/800 in.
40	15.4	W21 X 93	20.00	1.86	Fatigue	0.93	0.27	0.60
45	18.7	W21 X 101	22.50	2.27	Fatigue	0.96	0.42	0.68
50	19.2	W21 X 122	25.00	3.05	Service	0.93	0.60	0.75
55	21.7	W21 X 147	27.50	4.04	Service	0.93	0.71	0.83
60	21.1	W24 X 146	20.00	4.38	Service	0.98	0.79	0.90
60	22.9	W21 X 166	20.00	4.98	Service	0.96	0.85	0.90
65	21.1	W27 X 161	21.66	5.23	Service	0.94	0.79	0.98
65	22.8	W24 X 176	21.66	5.72	Service	0.95	0.87	0.98
70	21.1	W 30 X 173	23.33	6.06	Service	0.92	0.81	1.05
70	22.6	W27 X 178	23.33	6.23	Service	0.98	0.93	1.05
75	20.9	W33 X 201	25.00	7.54	Service	0.84	0.77	1.13
75	24.1	W27 X 217	25.00	8.14	Strength	0.92	0.98	1.13
80	21.0	W36 X 182	26.67	7.28	Service	1.00	0.92	1.20
80	24.0	W30 X 211	26.67	8.44	Strength	0.96	1.05	1.20
85	21.0	W40 X 199	28.33	8.45	Service	0.93	0.87	1.28
85	25.4	W30 X 235	28.33	9.99	Strength	0.98	1.16	1.28
90	22.3	W40 X 211	30.00	9.49	Service	1.00	1.04	1.35
90	24.9	W33 X 241	30.00	10.85	Service	0.97	1.17	1.35
90	26.7	W30 X 261	30.00	11.75	Strength	0.99	1.28	1.35
95	23.4	W40 X 235	23.75	11.16	Service	1.00	1.13	1.43
95	25.2	W36 X 245	23.75	11.69	Service	1.00	1.24	1.43
95	28.0	W30 X 292	23.75	13.87	Strength	0.99	1.39	1.43
100	24.6	W40 X 264	25.00	13.20	Service	0.99	1.22	1.50
100	26.4	W36 X 280	25.00	14.00	Strength	0.96	1.30	1.50
100	29.4	W30 X 326	25.00	16.30	Strength	1.00	1.49	1.50
105	27.7	W36 X 300	26.25	15.75	Service	0.99	1.43	1.58
105	28.2	W33 X 318	26.25	16.70	Strength	1.00	1.51	1.58
110	28.9	W36 X 328	27.50	18.04	Strength	1.00	1.54	1.65
110	30.1	W33 X 354	27.50	19.47	Strength	0.99	1.60	1.65
115	30.1	W36 X 359	28.75	20.64	Strength	1.00	1.65	1.73
120	29.4	W40 X 372	30.00	22.32	Service	0.98	1.61	1.80

Table A.23 Optimized Exterior Girder Designs for 34-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 2^{nd} Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
40	13.4	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.96	0.24	0.60
45	15.1	12 x 3/4	24 x 7/16	-	-	12 x 7/8	45	22.50	2.30	Fatigue	0.99	0.34	0.68
50	16.6	12 x 3/4	24 x 7/16	-	-	12 x 1-1/8	50	25.00	2.81	Fatigue	0.93	0.41	0.75
55	18.2	12 x 3/4	24 x 7/16	-	-	12 x 1-1/4	55	27.50	3.23	Service	0.98	0.52	0.83
60	18.8	12 x 3/4	26 x 7/16	-	-	12 x 1-3/8	60	20.00	3.76	Service	0.99	0.57	0.90
60	19.7	12 x 3/4	24 x 7/16	-	-	12 x 1-1/2	60	20.00	3.83	Service	1.00	0.62	0.90
65	19.2	12 x 3/4	28 x 7/16	-	-	12 x 1-5/8	65	21.66	4.51	Service	0.93	0.59	0.98
65	21.2	12 x 3/4	24 x 7/16	-	-	12 x 1-7/8	65	21.66	4.64	Service	0.97	0.68	0.98
70	18.9	12 x 3/4	32 x 7/16	-	-	12 x 1-1/2	70	23.33	4.88	Service	0.98	0.63	1.05
70	22.8	12 x 3/4	24 x 7/16	-	-	14 x 1-7/8	70	23.33	5.45	Service	0.97	0.78	1.05
75	19.3	12 x 3/4	34 x 7/16	-	-	12 x 1-5/8	75	25.00	5.53	Service	0.98	0.66	1.13
75	23.1	12 x 3/4	26 x 7/16	-	-	14 x 2	75	25.00	6.17	Service	0.96	0.81	1.13
75	24.2	12 x 7/8	24 x 7/16	-	-	14 x 2-1/8	75	25.00	6.48	Strength	0.98	0.88	1.13
80	19.0	12 x 3/4	38 x 7/16	-	-	12 x 1-5/8	80	26.67	6.14	Constr.	1.00	0.67	1.20
80	23.4	12 x 7/8	28 x 7/16	-	-	14 x 2	80	26.67	6.91	Service	0.99	0.88	1.20
80	25.9	12 x 1-1/8	24 x 7/16	-	-	16 x 2-1/8	80	26.67	7.89	Strength	0.99	0.99	1.20
85	19.4	12 x 1	40 x 1/2	-	-	12 x 1-5/8	85	28.33	7.45	Service	0.99	0.73	1.28
85	23.7	12 x 7/8	30 x 7/16	-	-	14 x 2-1/8	85	28.33	7.72	Service	0.98	0.93	1.28
85	27.2	12 x 1-1/4	24 x 7/16	16 x 1-1/2	17	16 x 2-1/2	51	28.33	8.55	Strength	1.00	1.09	1.28
90	19.1	12 x 1-1/8	44 x 1/2	-	-	12 x 1-5/8	90	30.00	8.42	Constr.	0.99	0.73	1.35
90	23.9	12 x 1-1//4	32 x 7/16	14 x 1-1/4	18	14 x 2-1/4	54	30.00	8.41	Service	1.00	1.01	1.35
90	27.3	14 x 1-1/8	26 x 7/16	18 x 1-1/4	18	18 x 2-5/8	54	30.00	9.87	Service	1.00	1.04	1.35
95	19.4	12 x 7/8	46 x 1/2	-	-	12 x 1-3/4	95	23.75	8.81	Service	0.99	0.77	1.43
95	23.2	12 x 3/4	36 x 1/2	-	-	14 x 2-1/8	95	23.75	9.17	Strength	0.99	0.96	1.43
95	27.5	14 x 1-1/4	28 x 7/16	18 x 1-3/8	19	18 x 2-1/2	57	23.75	10.77	Strength	0.97	1.12	1.43
100	19.2	14 x 3/4	50 x 1/2	-	-	14 x 1-1/2	100	25.00	9.61	Strength	0.97	0.77	1.50
100	23.4	12 x 3/4	38 x 1/2	14 x 1-1/4	20	14 x 2-1/4	60	25.00	9.17	Service	1.00	0.99	1.50
100	27.4	14 x 1-3/8	30 x 7/16	16 x 1-1/2	20	16 x 2-3/4	60	25.00	11.63	Strength	1.00	1.18	1.50
105	19.5	14 x 3/4	52 x 9/16	-	-	14 x 1-1/2	105	26.25	10.85	Service	0.99	0.81	1.58
105	23.6	12 x 7/8	40 x 1/2	14 x 1-3/8	21	14 x 2-3/8	63	26.25	10.39	Strength	0.97	1.01	1.58
105	27.5	14 x 1-1/4	32 x 7/16	18 x 1-3/8	21	18 x 2-7/8	63	26.25	12.94	Strength	0.99	1.12	1.58
110	19.3	14 x 7/8	56 x 9/16	-	-	14 x 1-1/2	110	27.50	12.12	Service	0.98	0.80	1.65
110	23.9	14 x 1	42 x 1/2	16 x 1-1/8	22	16 x 2-1/8	66	27.50	11.72	Service	1.00	1.06	1.65
110	27.8	14 x 1-3/8	34 x 1/2	18-1-3/8	22	18 x 2-1/2	66	27.50	13.69	Strength	1.00	1.26	1.65
115	19.6	16 x 3/4	58 x 9/16	-	-	16 x 1-3/8	115	28.75	13.04	Service	0.99	0.83	1.73
115	24.2	16 x 1	44 x 1/2	16 x 1-1/4	23	16 x 2-1/8	69	28.75	12.99	Strength	0.98	1.10	1.73
115	27.7	14 x 1-3/8	36 x 1/2	18 x 1-3/8	23	18 x 2-3/4	69	28.75	15.04	Strength	1.00	1.24	1.73
120	19.4	16 x 3/4	62 x 9/16	16 x 3/4	24	16 x 1-3/8	72	30.00	13.25	Constr.	1.00	0.83	1.80
120	23.7	16 x 7/8	48 x 9/16	18 x 1	24	16 x 1-7/8	72	30.00	13.98	Service	0.97	1.07	1.80
120	27.8	14 x 1-3/8	38 x 1/2	18 x 1-1/2	24	18 x 2-7/8	72	30.00	16.35	Strngth	0.99	1.24	1.80

Table A.24 Optimized Exterior Girder Designs with Partially Stiffened Web for 34-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Stiffener Spacing			Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length		X	Y	Z					
ft		in.	in.	in.	ft.	in.	ft.	ft.	ft.	ft.	ft.	tons			in.	in.
85	19.3	12 x 1	40 x 7/16	-	-	12 x 1-3/4	85	28.33	5			7.30	Service	0.96	0.72	1.28
90	19.1	12 x 1-1/4	44 x 7/16	-	-	12 x 1-5/8	90	30.00	5.5	10		8.23	Service	0.99	0.74	1.35
95	19.4	12 x 1	46 x 7/16	-	-	12 x 1-3/4	95	23.75	5.75	8		8.59	Service	1.00	0.78	1.43
95	23.2	12 x 1	36 x 7/16			14 x 2-1/8	95	23.75	4			9.29	Service	0.99	0.97	1.43
100	19.2	14 x 3/4	50 x 7/16	-	-	14 x 1-1/2	100	25.00	5	10		9.08	Service	1.00	0.78	1.50
100	23.6	12 x 1-1/4	38 x 7/16	16 x 1-1/8	20	16 x 1-7/8	60	25.00	4	8		9.67	Service	1.00	1.00	1.50
105	19.5	14 x 1	52 x 1/2	-	-	14 x 1-1/2	105	26.25	6			10.90	Service	1.00	0.82	1.58
105	23.7	14 x 1-1/8	40 x 7/16	14 x 1-3/8	21	14 x 2-1/4	63	26.25	5	10		10.69	Service	1.00	1.05	1.58
110	19.3	14 x 7/8	56 x 1/2	-	-	14 x 1-1/2	110	27.50	7	9		11.46	Service	1.00	0.82	1.65
110	23.9	16 x 1	42 x 7/16	16 x 1-1/4	22	16 x 2-1/8	66	27.50	5	7	7	11.75	Service	0.97	1.06	1.65
110	27.7	14 x 1-3/8	34 x 7/16	18 x 1-3/8	22	18 x 2-5/8	66	27.50	4	4		13.55	Strength	1.00	1.24	1.65
115	19.6	16 x 37/8	58 x 1/2	-	-	16 x 1-3/8	115	28.75	7	8		12.72	Service	1.00	0.85	1.73
115	24.2	16 x 1	44 x 7/16	16 x 1-1/4	23	16 x 2-1/8	69	28.75	5	8	8	12.45	Strength	1.00	1.12	1.73
115	27.8	16 x 1-3/8	36 x 7/16	18 x 1-1/2	23	18 x 2-5/8	69	28.75	5	9		15.05	Strength	0.99	1.23	1.73
120	19.4	16 x 7/8	62 x 1/2	-	-	16 x 1-3/8	120	30.00	7.75	7.75		13.68	Service	1.00	0.85	1.80
120	23.6	16 x 1-1/4	48 x 1/2	16 x 1-1/8	24	16 x 2	72	30.00	6			14.37	Service	1.00	1.11	1.80
120	27.8	16 x 1-1/2	38 x 7/16	18 x 1-1/2	24	18 x 2-3/4	72	30.00	4.75	4.75	8	16.56	Strength	0.97	1.28	1.80

Table A.25 Optimized Exterior Girder Designs for 34-ft. Cross-section with Hybrid Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
40	13.4	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.96	0.24	0.60
45	15.1	12 x 3/4	24 x 7/16	-	-	12 x 7/8	45	22.50	2.30	Fatigue	0.99	0.34	0.68
50	16.6	12 x 3/4	24 x 7/16	-	-	12 x 1-1/8	50	25.00	2.81	Fatigue	0.93	0.41	0.75
55	18.2	12 x 3/4	24 x 7/16	-	-	12 x 1-1/4	55	27.50	3.23	Fatigue	0.97	0.52	0.83
60	18.8	12 x 3/4	26 x 7/16	-	-	12 x 1-3/8	60	20.00	3.76	Fatigue	0.99	0.57	0.90
60	19.7	12 x 3/4	24 x 7/16	-	-	12 x 1-1/2	60	20.00	3.83	Fatigue	0.98	0.62	0.90
65	19.3	12 x 3/4	28 x 7/16	-	-	12 x 1-1/2	65	21.66	4.34	Fatigue	0.99	0.62	0.98
65	21.2	12 x 3/4	24 x 7/16	-	-	12 x 1-3/4	65	21.66	4.48	Fatigue	0.98	0.71	0.98
70	18.9	12 x 3/4	32 x 7/16	-	-	12 x 1-1/2	70	23.33	4.88	Fatigue	0.99	0.63	1.05
70	22.7	12 x 3/4	24 x 7/16	-	-	12 x 2	70	23.33	5.18	Fatigue	0.99	0.82	1.05
75	19.3	12 x 3/4	34 x 7/16	-	-	12 x 1-5/8	75	25.00	5.53	Fatigue	0.98	0.66	1.13
75	23.2	12 x 3/4	26 x 7/16	-	-	14 x 1-7/8	75	25.00	5.95	Fatigue	0.98	0.85	1.13
75	24.3	12 x 3/4	24 x 7/16	-	-	14 x 2	75	25.00	6.25	Fatigue	0.97	0.92	1.13
80	19.0	12 x 3/4	38 x 7/16	-	-	12 x 1-5/8	80	26.67	6.14	Constr.	1.00	0.67	1.20
80	23.5	12 x 7/8	28 x 7/16	-	-	14 x 1-7/8	80	26.67	6.67	Fatigue	1.00	0.93	1.20
80	25.9	12 x 1	24 x 7/16	-	-	16 x 2	80	26.67	7.42	Strength	0.96	1.03	1.20
85	19.3	12 x 7/8	40 x 1/2	-	-	12 x 1-7/8	85	28.33	7.66	Constr.	0.97	0.69	1.28
85	23.7	12 x 7/8	30 x 7/16	14 x 1	17	14 x 2	51	28.33	6.66	Fatigue	0.98	0.99	1.28
85	27.5	12 x 1-1/4	24 x 7/16	16 x 1-1/4	17	16 x 2-1/8	51	28.33	7.79	Fatigue	0.98	1.23	1.28
90	19.1	12 x 1-1/8	44 x 1/2	-	-	12 x 1-5/8	90	30.00	8.42	Constr.	0.99	0.74	1.35
90	24.0	12 x 1-1/4	32 x 7/16	14 x 1	18	14 x 2	54	30.00	7.87	Fatigue	1.00	1.06	1.35
90	27.7	14 x 1-1/8	26 x 7/16	18 x 1	18	18 x 2	54	30.00	8.56	Fatigue	0.97	1.26	1.35
95	19.4	12 x 3/4	46 x 1/2	-	-	12 x 1-5/8	95	23.75	8.32	Fatigue	0.99	0.81	1.43
95	23.3	12 x 3/4	36 x 1/2	14 x 7/8	19	14 x 1-7/8	57	23.75	7.70	Fatigue	1.00	1.06	1.43
95	27.6	12 x 1-3/8	28 x 7/16	16 x 1-1/8	19	16 x 2-1/4	57	23.75	9.30	Fatigue	0.97	1.32	1.43
100	19.2	14 x 3/4	50 x 1/2	-	-	14 x 1-3/8	100	25.00	9.32	Fatigue	0.96	0.81	1.50
100	23.5	14 x 3/4	38 x 1/2	14 x 7/8	20	14 x 2	60	25.00	8.71	Fatigue	0.97	1.07	1.50
100	27.7	14 x 1-1/4	30 x 7/16	16 x 1-1/8	20	16 x 2-1/4	60	25.00	10.11	Fatigue	0.98	1.38	1.50
105	19.6	14 x 3/4	52 x 9/16	-	-	14 x 1-3/8	105	26.25	10.54	Constr.	1.00	0.84	1.58
105	23.7	12 x 1	40 x 1/2	14 x 1	21	14 x 2-1/8	63	26.25	9.91	Fatigue	0.96	1.10	1.58
105	27.8	14 x 1-1/4	32 x 7/16	16 x 1-1/8	21	16 x 2-1/4	63	26.25	10.77	Strength	0.99	1.44	1.58
110	19.3	14 x 7/8	56 x 9/16	-	-	14 x 1-3/8	110	27.50	11.79	Fatigue	0.95	0.84	1.65
110	23.9	14 x 7/8	42 x 1/2	14 x 7/8	22	14 x 2-1/8	66	27.50	10.48	Fatigue	0.98	1.14	1.65
110	27.9	14 x 1-1/4	34 x 1/2	16 x 1-1/8	22	16 x 2-3/8	66	27.50	12.07	Strength	0.97	1.43	1.65
115	19.7	16 x 3/4	58 x 9/16	-	-	16 x 1-1/8	115	28.75	12.25	Fatigue	1.00	0.92	1.73
115	24.3	14 x 1	44 x 1/2	16 x 1-1/8	23	16 x 1-7/8	69	28.75	11.97	Fatigue	0.99	1.20	1.73
115	28.0	14 x 1-1/4	36 x 1/2	18 x 1	23	18 x 2-1/4	69	28.75	13.11	Strength	0.98	1.43	1.73
120	19.4	16 x 3/4	62 x 9/16	-	-	16 x 1-1/8	120	30.00	13.25	Fatigue	0.98	0.91	1.80
120	23.7	16 x 3/4	48 x 9/16	16 x 1	24	16 x 1-3/4	72	30.00	12.70	Constr.	1.00	1.19	1.80
120	28.2	14 x 1-3/8	38 x 1/2	18 x 1	24	18 x 2-1/8	72	30.00	13.97	Strength	0.98	1.54	1.80

Table A.26 Optimized Exterior Girder Designs with Partially Stiffened Web for 34-ft. Cross-section with Hybrid Girder Configuration in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Stiffener Spacing			Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length		X	Y	Z					
ft		in.	in.	in.	ft.	in.	ft.	ft.	ft.	ft.	ft.	tons			in.	in.
85	19.3	12 x 1	40 x 7/16	-	-	12 x 1-3/4	85	28.33	5			7.30	Fatigue	0.95	0.73	1.28
90	19.2	14 x 1	44 x 7/16	-	-	14 x 1-3/8	90	30.00	5.5	9		8.04	Fatigue	1.00	0.76	1.35
95	19.4	12 x 1	46 x 7/16	-	-	12 x 1-3/4	95	23.75	5.5	7		8.59	Fatigue	0.98	0.80	1.43
95	23.3	12 x 7/8	36 x 7/16	14 x 7/8	19	14 x 2	57	23.75	4.5			7.75	Fatigue	0.97	1.04	1.43
100	19.2	14 x 3/4	50 x 7/16	-	-	14 x 1-1/2	100	25.00	6	6	6	9.08	Fatigue	0.97	0.79	1.50
100	23.5	14 x 1	38 x 7/16	14 x 7/8	20	14 x 2	60	25.00	4.5	9		8.90	Fatigue	0.94	1.10	1.50
105	19.6	14 x 7/8	52 x 1/2	-	-	14 x 1-3/8	105	26.25	6			10.27	Fatigue	1.00	0.87	1.58
105	23.8	12 x 1-3/8	40 x 7/16	14 x 1	21	14 x 2	63	26.25	5	8		10.08	Fatigue	1.00	1.16	1.58
110	19.3	16 x 3/4	56 x 1/2	-	-	16 x 1-1/4	110	27.50	7	7		11.23	Constr.	0.96	0.84	1.65
110	24.2	16 x 1	42 x 7/16	18 x 3/4	22	18 x 1-5/8	66	27.50	5	6	6	10.73	Fatigue	1.00	1.19	1.65
110	27.9	14 x 1-1/4	34 x 7/16	16 x 1-1/8	22	16 x 2-3/8	66	27.50	4	4		11.67	Strength	1.00	1.44	1.65
115	19.6	16 x 3/4	58 x 1/2	-	-	16 x 1-1/4	115	28.75	7	10		11.94	Fatigue	1.00	0.90	1.73
115	24.2	16 x 1	44 x 7/16	16 x 1	23	16 x 2	69	28.75	5	6	8	11.91	Fatigue	0.98	1.18	1.73
115	28.0	16 x 1-1/8	36 x 7/16	18 x 1	23	18 x 2-1/4	69	28.75	4.5	8		12.77	Strength	0.99	1.45	1.73
120	19.4	16 x 7/8	62 x 1/2	-	-	16 x 1-1/4	120	30.00	7.75	10		13.27	Strength	0.97	0.89	1.80
120	23.7	14 x 1-1/4	48 x 1/2	16 x 3/4	24	16 x 1-3/4	72	30.00	6			12.88	Fatigue	1.00	1.23	1.80
120	28.2	14 x 1-3/8	38 x 7/16	18 x 1	24	18 x 2-1/8	72	30.00	4.5	7	7	13.48	Strength	1.00	1.56	1.80

Table A.27 Exterior Rolled Beams for 34-ft. Cross-section in Accordance with 2nd Edition of Specifications

Span Length (L)	L/D	Section	Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
ft.			ft.	tons			in.	in.
40	15.2	W21 X 111	20.00	2.22	Fatigue	0.93	0.28	0.60
45	17.0	W21 X 132	22.50	2.97	Fatigue	0.92	0.37	0.68
50	18.8	W21 X 147	25.00	3.68	Service	0.93	0.49	0.75
55	20.8	W21 X 166	27.50	4.57	Service	0.97	0.60	0.83
60	20.7	W24 X 176	20.00	5.28	Service	0.98	0.64	0.90
65	20.7	W27 X 194	21.66	6.31	Service	0.93	0.65	0.98
70	19.3	W 33 X 200	23.33	7.04	Fatigue	0.89	0.59	1.05
70	22.2	W27 X 217	23.33	7.60	Service	0.95	0.75	1.05
75	20.6	W33 X 221	25.00	8.29	Service	0.90	0.68	1.13
75	22.1	W30 X 235	25.00	8.81	Service	0.92	0.75	1.13
80	19.6	W40 X 211	26.67	8.44	Service	0.96	0.69	1.20
80	23.4	W30 X 261	26.67	10.44	Strength	0.94	0.84	1.20
85	20.8	W40 X 235	28.33	9.99	Service	0.97	0.77	1.28
85	24.8	W30 X 292	28.33	12.41	Strength	0.96	0.93	1.28
90	21.9	W40 X 264	30.00	11.88	Service	0.98	0.84	1.35
90	24.5	W33 X 291	30.00	13.10	Strength	0.96	0.95	1.35
90	26.1	W30 X 326	30.00	14.67	Strength	0.97	1.02	1.35
95	24.8	W36 X 300	23.75	14.25	Service	0.97	1.00	1.43
95	25.7	W33 X 318	23.75	15.11	Strength	0.98	1.05	1.43
100	25.9	W36 X 328	25.00	16.40	Strength	0.99	1.09	1.50
100	27.0	W33 X 354	25.00	17.70	Strength	0.98	1.14	1.50
105	27.2	W36 X 359	26.25	18.85	Strength	1.00	1.19	1.58
110	28.3	W36 X 393	27.50	21.62	Strength	1.00	1.27	1.65
115	27.6	W40 X 431	28.75	22.63	Service	0.94	1.20	1.73
120	28.6	W40 X 503	30.00	30.18	Service	0.89	1.20	1.80

Table A.28 Optimized Interior Girder Designs for 28-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 2nd Edition of Specifications Neglecting Constructibility

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR
				Plate	Length	Plate	Length				
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons		
40	13.6	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.67
45	15.3	12 x 3/4	24 x 7/16	-	-	12 x 3/4	45	22.50	2.18	Min. Plate	0.81
50	17.0	12 x 3/4	24 x 7/16	-	-	12 x 3/4	50	25.00	2.42	Min. Plate	0.96
55	18.6	12 x 3/4	24 x 7/16	-	-	12 x 1	55	27.50	2.95	Service	0.93
60	19.2	12 x 3/4	26 x 7/16	-	-	12 x 1	60	20.00	3.30	Service	0.99
60	20.2	12 x 3/4	24 x 7/16	-	-	12 x 1-1/8	60	20.00	3.37	Service	0.99
65	19.7	12 x 3/4	28 x 7/16	-	-	12 x 1-1/8	65	21.66	3.84	Service	0.97
65	21.9	12 x 3/4	24 x 7/16	-	-	14 x 1-1/8	65	21.66	3.90	Service	1.00
70	19.3	12 x 3/4	32 x 7/16	-	-	12 x 1-1/8	70	23.33	4.35	Service	0.96
70	23.4	12 x 3/4	24 x 7/16	-	-	14 x 1-3/8	70	23.33	4.62	Service	0.98
75	19.8	12 x 3/4	34 x 7/16	-	-	14 x 1	75	25.00	4.83	Service	0.99
75	23.7	12 x 3/4	26 x 7/16	-	-	14 x 1-1/2	75	25.00	5.28	Service	0.95
75	24.8	12 x 3/4	24 x 7/16	-	-	14 x 1-3/4	75	25.00	5.61	Service	0.93
80	19.3	12 x 3/4	38 x 7/16	-	-	12 x 1-1/8	80	26.67	5.33	Service	1.00
80	23.9	12 x 3/4	28 x 7/16	-	-	12 x 1-3/4	80	26.67	5.75	Service	1.00
80	26.4	12 x 3/4	24 x 7/16	-	-	16 x 1-7/8	80	26.67	6.74	Strength	0.98
85	19.7	12 x 3/4	40 x 7/16	-	-	12 x 1-1/4	85	28.33	6.00	Service	0.98
85	24.2	14 x 3/4	30 x 7/16	-	-	14 x 1-5/8	85	28.33	6.71	Service	0.99
85	27.9	14 x 7/8	24 x 7/16	18 x 1	17	18 x 2	51	28.33	7.46	Service	0.93
90	19.5	14 x 3/4	44 x 1/2	-	-	14 x 1	90	30.00	7.12	Service	0.98
90	24.5	14 x 3/4	32 x 7/16	-	-	14 x 1-5/8	90	30.00	7.24	Service	0.99
90	28.0	14 x 7/8	26 x 7/16	18 x 1	18	18 x 2-1/8	54	30.00	8.23	Service	0.95
95	19.7	12 x 3/4	46 x 1/2	-	-	12 x 1-1/4	95	23.75	7.60	Service	0.99
95	23.7	14 x 3/4	36 x 7/16	-	-	14 x 1-5/8	95	23.75	7.92	Service	0.98
95	28.1	14 x 7/8	28 x 7/16	18 x 1	19	18 x 2	57	23.75	8.57	Strength	0.98
100	19.5	14 x 3/4	50 x 1/2	-	-	14 x 1-1/4	100	25.00	8.72	Service	0.95
100	23.9	12 x 3/4	38 x 7/16	-	-	14 x 1-5/8	100	25.00	8.23	Service	1.00
100	28.2	14 x 1	30 x 7/16	16 x 1-1/8	20	16 x 2-1/8	60	25.00	9.31	Strength	0.96
105	19.8	14 x 3/4	52 x 1/2	-	-	14 x 1-1/8	105	26.25	9.33	Service	0.98
105	24.2	14 x 3/4	40 x 1/2	-	-	16 x 1-1/2	105	26.25	9.74	Service	0.97
105	28.3	14 x 1	32 x 7/16	18 x 1	21	18 x 2	63	26.25	10.15	Strength	0.99
110	19.5	14 x 3/4	56 x 9/16	-	-	14 x 1-1/8	110	27.50	10.81	Service	0.95
110	24.3	14 x 3/4	42 x 1/2	14 x 1	22	14 x 1-7/8	66	27.50	9.89	Service	0.95
110	28.3	14 x 1	34 x 7/16	18-1-1/8	22	18 x 2-1/8	66	27.50	11.22	Strength	0.98
115	19.9	16 x 3/4	58 x 9/16	-	-	16 x 1	115	28.75	11.86	Service	0.96
115	24.4	14 x 7/8	44 x 1/2	14 x 1-1/8	23	14 x 2	69	28.75	10.88	Service	0.98
115	28.5	14 x 1-1/8	36 x 1/2	18 x 1	23	18 x 1-7/8	69	28.75	11.97	Service	1.00
120	19.6	16 x 3/4	62 x 9/16	-	-	16 x 1	120	30.00	12.84	Strength	0.96
120	24.0	16 x 3/4	48 x 1/2	16 x 7/8	24	16 x 1-5/8	72	30.00	11.68	Service	0.95
120	28.6	14 x 1-1/8	38 x 1/2	18 x 1-1/8	24	18 x 1-7/8	72	30.00	12.88	Strength	1.00

Table A.29 Optimized Interior Girder Designs Failing the L/800 Deflection Limit for 28-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 2nd Edition of Specifications Neglecting Constructibility

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
75	25.1	12 x 3/4	24 x 7/16	-	-	16 x 1-3/8	75	25.00	5.30	Service	0.99	1.17	1.13
80	26.4	12 x 7/8	24 x 7/16	-	-	14 x 1-7/8	80	26.67	6.43	Service	0.97	1.26	1.20
85	28.1	14 x 1	24 x 7/16	-	-	16 x 1-3/4	85	28.33	7.59	Service	0.93	1.51	1.28
95	28.2	16 x 3/4	28 x 7/16	18 x 1	19	18 x 1-7/8	57	23.75	8.36	Strength	1.00	1.48	1.43
105	28.5	14 x 1	32 x 7/16	18 x 1	21	18 x 1-3/4	63	26.25	9.66	Strength	1.00	1.67	1.58

Table A.30 Optimized Interior Girder Designs for 28-ft. Cross-section with Hybrid Girder Configuration in Accordance with 2nd Edition of Specifications Neglecting Constructibility

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR
				Plate	Length	Plate	Length				
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons		
40	13.6	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.62
45	15.3	12 x 3/4	24 x 7/16	-	-	12 x 3/4	45	22.50	2.18	Min. Plate	0.58
50	17.0	12 x 3/4	24 x 7/16	-	-	12 x 3/4	50	25.00	2.42	Min. Plate	0.74
55	18.7	12 x 3/4	24 x 7/16	-	-	12 x 3/4	55	27.50	2.67	Min. Plate	0.80
60	19.3	12 x 3/4	26 x 7/16	-	-	12 x 3/4	60	20.00	3.00	Service	0.88
60	20.3	12 x 3/4	24 x 7/16	-	-	12 x 1	60	20.00	3.22	Service	0.76
65	19.8	12 x 3/4	28 x 7/16	-	-	12 x 7/8	65	21.66	3.51	Service	0.92
65	21.8	12 x 3/4	24 x 7/16	-	-	12 x 1-1/4	65	21.66	3.82	Service	0.95
70	19.4	12 x 3/4	32 x 7/16	-	-	12 x 3/4	70	23.33	3.81	Service	0.88
70	23.4	12 x 3/4	24 x 7/16	-	-	14 x 1-3/8	70	23.33	4.62	Service	0.97
75	19.9	12 x 3/4	34 x 7/16	-	-	12 x 3/4	75	25.00	4.19	Service	0.93
75	23.8	12 x 3/4	26 x 7/16	-	-	14 x 1-3/8	75	25.00	5.06	Strength	0.76
75	24.8	12 x 3/4	24 x 7/16	-	-	14 x 1-3/4	75	25.00	5.61	Service	0.77
80	19.5	12 x 3/4	38 x 7/16	-	-	12 x 3/4	80	26.67	4.71	Service	0.95
80	23.9	12 x 3/4	28 x 7/16	-	-	12 x 1-5/8	80	26.67	5.55	Strength	0.77
80	26.3	12 x 3/4	24 x 7/16	-	-	14 x 2	80	26.67	6.47	Service	0.88
85	19.9	12 x 3/4	40 x 7/16	-	-	12 x 3/4	85	28.33	5.13	Service	0.95
85	24.3	14 x 3/4	30 x 7/16	-	-	14 x 1-1/2	85	28.33	6.45	Service	0.78
85	27.9	14 x 7/8	24 x 7/16	18 x 1	17	18 x 2	51	28.33	7.46	Service	0.83
90	19.5	12 x 3/4	44 x 1/2	-	-	12 x 3/4	90	30.00	6.13	Service	0.90
90	24.3	12 x 3/4	32 x 7/16	12 x 3/4	18	12 x 1-7/8	54	30.00	6.14	Service	0.84
90	27.9	14 x 3/4	26 x 7/16	18 x 7/8	18	18 x 2-1/4	54	30.00	8.04	Strength	0.99
95	19.9	12 x 3/4	46 x 1/2	-	-	12 x 3/4	95	23.75	6.63	Service	0.93
95	23.7	12 x 3/4	36 x 7/16	-	-	12 x 1-5/8	95	23.75	7.15	Service	0.79
95	28.1	14 x 7/8	28 x 7/16	18 x 1	19	18 x 2	57	23.75	8.61	Service	0.88
100	19.6	14 x 3/4	50 x 1/2	-	-	14 x 3/4	100	25.00	7.83	Service	0.85
100	24.0	12 x 3/4	38 x 7/16	-	-	12 x 1-1/2	100	25.00	7.42	Strength	0.85
100	28.2	12 x 1	30 x 7/16	16 x 1-1/8	20	16 x 2-1/8	60	25.00	8.97	Strength	0.95
105	19.9	14 x 3/4	52 x 1/2	-	-	14 x 3/4	105	26.25	8.40	Service	0.87
105	24.3	14 x 3/4	40 x 1/2	-	-	14 x 1-1/4	105	26.25	9.83	Strength	0.87
105	28.3	14 x 1	32 x 7/16	18 x 3/4	21	18 x 2	63	26.25	9.83	Service	0.94
110	19.6	14 x 3/4	56 x 9/16	-	-	14 x 3/4	110	27.50	9.83	Service	0.83
110	24.5	12 x 3/4	42 x 1/2	-	-	14 x 1-3/8	110	27.50	9.22	Service	0.89
110	28.2	14 x 1	34 x 7/16	16 x 7/8	22	16 x 2-1/4	66	27.50	10.49	Service	0.89
115	19.9	14 x 3/4	58 x 9/16	-	-	14 x 3/4	115	28.75	10.49	Service	0.86
115	24.7	14 x 3/4	44 x 1/2	-	-	14 x 1-3/8	115	28.75	10.13	Strength	0.87
115	28.4	14 x 7/8	36 x 1/2	16 x 1	23	16 x 2-1/8	69	28.75	10.72	Service	0.94
120	19.7	16 x 3/4	62 x 9/16	-	-	16 x 3/4	120	30.00	12.02	Service	0.79
120	24.2	16 x 3/4	48 x 1/2	-	-	16 x 1	120	30.00	10.62	Strength	0.93
120	28.4	14 x 7/8	38 x 1/2	14 x 1-1/4	24	14 x 2-1/4	72	30.00	11.67	Strength	0.99

Table A.31 Optimized Interior Girder Designs Failing the L/800 Deflection Limit for 28-ft. Cross-section with Hybrid Girder Configuration in Accordance with 2nd Edition of Specifications Neglecting Constructibility

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
60	20.4	12 x 3/4	24 x 7/16	-	-	12 x 3/4	60	20.00	2.91	Service	0.95	1.02	0.90
65	19.9	12 x 3/4	28 x 7/16	-	-	12 x 3/4	65	21.67	3.35	Service	0.90	1.00	0.98
65	22.0	12 x 3/4	24 x 7/16	-	-	12 x 7/8	65	21.67	3.32	Service	0.94	1.15	0.98
75	23.9	12 x 3/4	26 x 7/16	-	-	12 x 1-1/8	75	25.00	4.32	Service	0.93	1.40	1.13
75	25.4	12 x 3/4	24 x 7/16	-	-	14 x 1	75	25.00	4.27	Strength	0.97	1.57	1.13
80	24.2	12 x 3/4	28 x 7/16	-	-	12 x 1-1/8	80	26.67	4.73	Service	0.96	1.53	1.20
80	26.8	12 x 3/4	24 x 7/16	-	-	12 x 1-3/8	80	26.67	4.90	Service	0.97	1.74	1.20
85	24.6	14 x 3/4	30 x 7/16	-	-	14 x 1	85	28.33	5.44	Strength	0.97	1.61	1.28
85	28.5	14 x 7/8	24 x 7/16	-	-	16 x 1-1/4	85	28.33	6.18	Strength	0.98	1.87	1.28
90	24.7	12 x 3/4	32 x 7/16	-	-	12 x 1-1/4	90	30.00	5.82	Strength	0.95	1.68	1.35
90	28.6	14 x 7/8	26 x 7/16	-	-	16 x 1-1/4	90	30.00	6.68	Strength	0.97	2.00	1.35
95	23.9	12 x 3/4	36 x 7/16	-	-	12 x 1-1/8	95	23.75	6.18	Service	0.99	1.84	1.43
95	28.7	14 x 1	28 x 7/16	-	-	16 x 1-1/4	95	23.75	7.48	Strength	1.00	2.07	1.43
100	24.1	12 x 3/4	38 x 7/16	-	-	12 x 1-3/8	100	25.00	7.17	Strength	0.97	1.61	1.50
100	28.6	12 x 1-1/8	30 x 7/16	-	-	14 x 1-1/2	100	25.00	8.10	Strength	0.99	2.12	1.50
105	24.5	14 x 3/4	40 x 1/2	-	-	14 x 1	105	26.25	7.95	Strength	0.99	1.77	1.58
105	28.7	14 x 1	32 x 7/16	18 x 3/4	21	18 x 1-3/8	63	26.25	8.62	Strength	0.97	1.95	1.58
110	24.6	12 x 3/4	42 x 1/2	-	-	14 x 1-1/8	110	27.50	8.56	Strength	0.96	1.78	1.65
110	28.5	14 x 1	34 x 7/16	16 x 3/4	22	16 x 1-3/4	66	27.50	9.45	Strength	0.95	1.91	1.65
115	24.8	14 x 3/4	44 x 1/2	-	-	14 x 1-1/8	115	28.75	9.44	Service	0.97	1.84	1.73
115	28.7	14 x 1	36 x 7/16	-	-	16 x 1-5/8	115	28.75	10.91	Strength	1.00	1.97	1.73
120	29.2	14 x 1	38 x 1/2	14 x 7/8	24	14 x 2	72	30.00	11.17	Strength	0.97	2.00	1.80

Table A.32 Optimized Interior Girder Designs for 34-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 2nd Edition of Specifications Neglecting Constructibility

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR
				Plate	Length	Plate	Length				
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons		
40	13.4	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.75
45	15.1	12 x 3/4	24 x 7/16	-	-	12 x 3/4	45	22.50	2.18	Min. Plate	0.91
50	16.7	12 x 3/4	24 x 7/16	-	-	12 x 7/8	50	25.00	2.55	Service	0.98
55	18.3	12 x 3/4	24 x 7/16	-	-	12 x 1-1/8	55	27.50	3.09	Service	0.97
60	18.8	12 x 3/4	26 x 7/16	-	-	12 x 1-1/4	60	20.00	3.61	Service	0.97
60	19.8	12 x 3/4	24 x 7/16	-	-	12 x 1-3/8	60	20.00	3.68	Service	0.97
65	19.3	12 x 3/4	28 x 7/16	-	-	12 x 1-3/8	65	21.66	4.17	Service	0.96
65	21.3	12 x 3/4	24 x 7/16	-	-	12 x 1-5/8	65	21.66	4.31	Service	0.98
70	18.9	12 x 3/4	32 x 7/16	-	-	12 x 1-3/8	70	23.33	4.70	Service	0.96
70	22.9	12 x 3/4	24 x 7/16	-	-	14 x 1-5/8	70	23.33	5.03	Service	0.98
75	19.4	12 x 3/4	34 x 7/16	-	-	12 x 1-1/2	75	25.00	5.34	Service	0.95
75	23.2	12 x 3/4	26 x 7/16	-	-	14 x 1-3/4	75	25.00	5.73	Service	0.97
75	24.4	12 x 7/8	24 x 7/16	-	-	14 x 1-7/8	75	25.00	6.03	Service	0.98
80	19.1	12 x 3/4	38 x 7/16	-	-	12 x 1-3/8	80	26.67	5.73	Service	1.00
80	23.6	12 x 3/4	28 x 7/16	-	-	14 x 1-3/4	80	26.67	6.23	Service	1.00
80	25.9	12 x 1	24 x 7/16	-	-	14 x 2-1/8	80	26.67	7.11	Service	1.00
85	19.4	12 x 3/4	40 x 1/2	-	-	12 x 1-1/2	85	28.33	6.80	Service	0.97
85	23.8	12 x 7/8	30 x 7/16	-	-	14 x 1-7/8	85	28.33	7.21	Service	0.98
85	27.5	12 x 1-1/4	24 x 7/16	16 x 1-1/4	17	16 x 2-1/8	51	28.33	7.79	Strength	0.97
90	19.1	12 x 3/4	44 x 1/2	-	-	12 x 1-1/2	90	30.00	7.50	Service	0.96
90	24.0	12 x 7/8	32 x 7/16	-	-	14 x 2	90	30.00	8.04	Service	0.97
90	27.8	14 x 1-1/8	26 x 7/16	18 x 1-1/8	18	18 x 1-7/8	54	30.00	8.49	Strength	0.99
95	19.5	12 x 3/4	46 x 1/2	-	-	12 x 1-1/2	95	23.75	8.08	Service	1.00
95	23.3	12 x 3/4	36 x 1/2	-	-	14 x 1-7/8	95	23.75	8.61	Service	0.99
95	27.8	14 x 1-1/4	28 x 7/16	18 x 1-1/8	19	18 x 2	57	23.75	9.61	Strength	0.98
100	19.2	14 x 3/4	50 x 1/2	-	-	14 x 1-3/8	100	25.00	9.32	Service	0.95
100	23.5	12 x 3/4	38 x 1/2	14 x 1-1/8	20	14 x 2	60	25.00	8.69	Service	0.98
100	27.9	14 x 1-1/4	30 x 7/16	18 x 1-1/8	20	18 x 2	60	25.00	10.26	Strength	1.00
105	19.6	14 x 3/4	52 x 9/16	-	-	14 x 1-3/8	105	26.25	10.54	Service	0.97
105	23.8	14 x 3/4	40 x 1/2	14 x 1-1/8	21	14 x 2	63	26.25	9.58	Service	0.99
105	27.8	14 x 1-1/4	32 x 7/16	18 x 1-1/4	21	18 x 2-1/4	63	26.25	11.58	Strength	1.00
110	19.3	14 x 3/4	56 x 9/16	-	-	14 x 1-3/8	110	27.50	11.46	Service	0.96
110	24.1	12 x 7/8	42 x 1/2	16 x 1	22	16 x 1-7/8	66	27.50	10.46	Service	0.99
110	28.0	14 x 1-3/8	34 x 1/2	18-1-1/4	22	18 x 2-1/8	66	27.50	12.76	Strength	1.00
115	19.6	16 x 3/4	58 x 9/16	-	-	16 x 1-1/4	115	28.75	12.64	Service	0.97
115	24.3	14 x 3/4	44 x 1/2	16 x 1-1/8	23	16 x 1-7/8	69	28.75	11.29	Service	1.00
115	28.0	16 x 1-1/4	36 x 1/2	18 x 1-1/4	23	18 x 2-1/4	69	28.75	13.95	Strength	0.98
120	19.4	16 x 3/4	62 x 9/16	-	-	16 x 1-1/4	120	30.00	13.65	Service	0.96
120	23.7	16 x 3/4	48 x 9/16	16 x 1	24	16 x 1-7/8	72	30.00	12.94	Service	0.97
120	28.1	14 x 1-3/8	38 x 1/2	18 x 1-1/4	24	18 x 2-1/4	72	30.00	14.61	Strength	0.99

Table A.33 Optimized Interior Girder Designs for 34-ft. Cross-section with Hybrid Girder Configuration in Accordance with 2nd Edition of Specifications Neglecting Constructibility

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR
				Plate	Length	Plate	Length				
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons		
40	13.4	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.66
45	15.1	12 x 3/4	24 x 7/16	-	-	12 x 3/4	45	22.50	2.18	Min. Plate	0.65
50	16.8	12 x 3/4	24 x 7/16	-	-	12 x 3/4	50	25.00	2.42	Min. Plate	0.79
55	18.5	12 x 3/4	24 x 7/16	-	-	12 x 3/4	55	27.50	2.67	Min. Plate	0.90
60	19.1	12 x 3/4	26 x 7/16	-	-	12 x 3/4	60	20.00	3.00	Service	0.99
60	20.1	12 x 3/4	24 x 7/16	-	-	12 x 7/8	60	20.00	3.06	Service	0.94
65	19.6	12 x 3/4	28 x 7/16	-	-	12 x 7/8	65	21.66	3.51	Service	0.93
65	21.6	12 x 3/4	24 x 7/16	-	-	12 x 1-1/8	65	21.66	3.65	Service	0.90
70	19.1	12 x 3/4	32 x 7/16	-	-	12 x 7/8	70	23.33	3.99	Service	1.00
70	22.9	12 x 3/4	24 x 7/16	-	-	12 x 1-5/8	70	23.33	4.64	Strength	0.80
75	19.6	12 x 3/4	34 x 7/16	-	-	12 x 7/8	75	25.00	4.39	Service	0.96
75	23.5	12 x 3/4	26 x 7/16	-	-	14 x 1-3/8	75	25.00	5.06	Strength	0.84
75	24.6	12 x 3/4	24 x 7/16	-	-	14 x 1-5/8	75	25.00	5.58	Service	0.82
80	19.2	12 x 3/4	38 x 7/16	-	-	12 x 7/8	80	26.67	4.92	Service	0.95
80	23.7	12 x 7/8	28 x 7/16	-	-	12 x 1-1/2	80	26.67	5.55	Service	0.90
80	25.9	12 x 1	24 x 7/16	-	-	12 x 2-1/8	80	26.67	6.53	Strength	0.86
85	19.7	14x 3/4	40 x 1/2	-	-	14 x 3/4	85	28.33	5.93	Service	0.95
85	23.9	12x 7/8	30 x 7/16	-	-	12 x 1-5/8	85	28.33	6.24	Strength	0.89
85	27.5	14 x 1-1/8	24 x 7/16	16 x 1-1/8	17	16 x 2-1/8	51	28.33	7.79	Service	0.80
90	19.3	12 x 3/4	44 x 1/2	-	-	12 x 7/8	90	30.00	6.35	Service	0.95
90	24.3	12 x 7/8	32 x 7/16	-	-	14 x 1-1/2	90	30.00	6.97	Strength	0.94
90	27.8	14 x 1-1/8	26 x 7/16	18 x 1-1/8	18	18 x 1-7/8	54	30.00	8.49	Strength	0.86
95	19.7	12 x 3/4	46 x 1/2	-	-	12 x 7/8	95	23.75	6.87	Service	0.98
95	23.6	14x 3/4	36 x 1/2	-	-	14 x 1-1/4	95	23.75	7.44	Service	0.93
95	27.8	14 x 1-1/8	28 x 7/16	16 x 1-1/8	19	16 x 2	57	23.75	8.79	Strength	0.94
100	19.4	14 x 3/4	50 x 1/2	-	-	14 x 7/8	100	25.00	8.12	Service	0.96
100	23.8	12 x 1	38 x 1/2	-	-	12 x 1-3/8	100	25.00	8.08	Service	0.98
100	27.9	14 x 1-1/4	30 x 7/16	16 x 1-1/8	20	16 x 2	60	25.00	9.70	Strength	0.87
105	19.8	14 x 3/4	52 x 9/16	-	-	14 x 3/4	105	26.25	8.98	Service	0.96
105	24.1	14 x 7/8	40 x 1/2	-	-	14 x 1-1/4	105	26.25	8.89	Strength	0.98
105	28.0	16 x 1-1/8	32 x 7/16	16 x 1-1/8	21	16 x 2	63	26.25	10.43	Strength	0.90
110	19.5	14 x 3/4	56 x 9/16	-	-	14 x 3/4	110	27.50	9.83	Service	0.95
110	24.2	14 x 3/4	42 x 1/2	-	-	14 x 1-1/2	110	27.50	9.83	Strength	0.97
110	28.1	14 x 1-1/4	34 x 1/2	16 x 1	22	16 x 2	66	27.50	11.25	Strength	0.95
115	19.8	16 x 3/4	58 x 9/16	-	-	16 x 3/4	115	28.75	11.08	Service	0.91
115	24.5	14 x 7/8	44 x 1/2	-	-	14 x 1-3/8	115	28.75	10.47	Strength	1.00
115	28.3	16 x 1-1/4	36 x 1/2	18 x 1	23	18 x 1-3/4	69	28.75	12.54	Strength	0.91
120	19.5	16 x 3/4	62 x 9/16	-	-	16 x 3/4	120	30.00	12.02	Service	0.90
120	24.0	16 x 3/4	48 x 9/16	-	-	16 x 1-1/8	120	30.00	11.64	Strength	0.97
120	28.2	14 x 1-3/8	38 x 1/2	14 x 1	24	14 x 2-1/8	72	30.00	12.60	Strength	0.98

Table A.34 Optimized Interior Girder Designs Failing the L/800 Deflection Limit for 34-ft. Cross-section with Hybrid Girder Configuration in Accordance with 2nd Edition of Specifications Neglecting Constructibility

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
65	21.7	12 x 3/4	24 x 7/16	-	-	12 x 1	65	21.67	3.48	Service	0.98	1.06	0.98
70	23.2	12 x 3/4	24 x 7/16	-	-	12 x 1-1/4	70	23.33	4.11	Service	0.95	1.16	1.05
75	23.6	12 x 3/4	26 x 7/16	-	-	14 x 1-1/8	75	25.00	4.61	Service	0.95	1.23	1.13
75	24.8	12 x 7/8	24 x 7/16	-	-	14 x 1-1/4	75	25.00	4.91	Strength	0.95	1.30	1.13
80	23.8	12 x 7/8	28 x 7/16	-	-	12 x 1-3/8	80	26.67	5.34	Service	0.95	1.29	1.20
80	26.2	12 x 1-1/8	24 x 7/16	-	-	12 x 1-5/8	80	26.67	5.92	Strength	0.99	1.48	1.20
85	24.1	12 x 7/8	30 x 7/16	-	-	12 x 1-3/8	85	28.33	5.80	Service	0.98	1.42	1.28
85	27.8	14 x 1-1/8	24 x 7/16	-	-	14 x 1-3/4	85	28.33	7.34	Strength	0.94	1.56	1.28
90	24.3	12 x 7/8	32 x 7/16	-	-	14 x 1-3/8	90	30.00	6.70	Strength	1.00	1.38	1.35
90	28.1	14 x 1-1/8	26 x 7/16	-	-	16 x 1-1/2	90	30.00	7.83	Service	1.00	1.70	1.35
95	23.7	14 x 3/4	36 x 1/2	-	-	14 x 1-1/8	95	23.75	7.15	Service	0.99	1.45	1.43
95	28.0	14 x 1-1/8	28 x 7/16	-	-	14 x 1-3/4	95	23.75	8.49	Strength	1.00	1.72	1.43
100	28.1	14 x 1-1/4	30 x 7/16	-	-	14 x 1-3/4	100	25.00	9.38	Strength	1.00	1.79	1.50
105	28.2	16 x 1-1/8	32 x 7/16	-	-	16 x 1-3/4	105	26.25	10.72	Strength	0.96	1.71	1.58
110	28.2	14 x 1-1/4	34 x 1/2	16 x 7/8	22	16 x 1-7/8	66	27.50	10.87	Strength	0.98	1.71	1.65
115	28.5	16 x 1-1/4	36 x 1/2	-	-	18 x 1-1/2	115	28.75	12.72	Strength	0.99	1.86	1.73

Table A.35 Optimized Interior Girder Designs for 28-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 3rd Edition of Specifications Neglecting Constructibility

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR
				Plate	Length	Plate	Length				
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons		
40	13.6	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.67
45	15.3	12 x 3/4	24 x 7/16	-	-	12 x 3/4	45	22.50	2.18	Min. Plate	0.81
50	17.0	12 x 3/4	24 x 7/16	-	-	12 x 3/4	50	25.00	2.42	Min. Plate	0.96
55	18.6	12 x 3/4	24 x 7/16	-	-	12 x 1	55	27.50	2.95	Service	0.93
60	19.2	12 x 3/4	26 x 7/16	-	-	12 x 1	60	20.00	3.30	Service	0.99
60	20.2	12 x 3/4	24 x 7/16	-	-	12 x 1-1/8	60	20.00	3.37	Service	0.99
65	19.7	12 x 3/4	28 x 7/16	-	-	12 x 1-1/8	65	21.66	3.84	Service	0.97
65	21.9	12 x 3/4	24 x 7/16	-	-	14 x 1-1/8	65	21.66	3.90	Service	1.00
70	19.3	12 x 3/4	32 x 7/16	-	-	12 x 1-1/8	70	23.33	4.35	Service	0.96
70	23.4	12 x 3/4	24 x 7/16	-	-	14 x 1-3/8	70	23.33	4.62	Service	0.98
75	19.8	12 x 3/4	34 x 7/16	-	-	14 x 1	75	25.00	4.83	Service	0.99
75	23.7	12 x 3/4	26 x 7/16	-	-	14 x 1-1/2	75	25.00	5.28	Service	0.95
75	24.8	12 x 3/4	24 x 7/16	-	-	14 x 1-3/4	75	25.00	5.61	Service	0.93
80	19.3	12 x 3/4	38 x 7/16	-	-	12 x 1-1/8	80	26.67	5.33	Service	1.00
80	23.9	12 x 3/4	28 x 7/16	-	-	12 x 1-3/4	80	26.67	5.75	Service	1.00
80	26.4	12 x 3/4	24 x 7/16	-	-	16 x 1-7/8	80	26.67	6.74	Strength	0.98
85	19.7	12 x 3/4	40 x 7/16	-	-	12 x 1-1/4	85	28.33	6.00	Service	0.98
85	24.2	14 x 3/4	30 x 7/16	-	-	14 x 1-5/8	85	28.33	6.71	Service	0.96
85	27.9	14 x 7/8	24 x 7/16	18 x 1	17	18 x 2	51	28.33	7.46	Strength	0.85
90	19.5	14 x 3/4	44 x 1/2	-	-	14 x 1	90	30.00	7.12	Strength	0.98
90	24.5	14 x 3/4	32 x 7/16	-	-	14 x 1-5/8	90	30.00	7.24	Service	1.00
90	28.0	14 x 7/8	26 x 7/16	18 x 1	18	18 x 2-1/8	54	30.00	7.97	Service	0.95
95	19.7	12 x 3/4	46 x 1/2	-	-	12 x 1-1/4	95	23.75	7.60	Service	0.99
95	23.7	14 x 3/4	36 x 7/16	-	-	14 x 1-5/8	95	23.75	7.92	Service	0.99
95	28.1	14 x 7/8	28 x 7/16	18 x 1	19	18 x 2	57	23.75	8.61	Service	0.99
100	19.5	14 x 3/4	50 x 1/2	-	-	14 x 1-1/4	100	25.00	8.72	Service	0.95
100	23.9	12 x 3/4	38 x 7/16	-	-	14 x 1-5/8	100	25.00	8.23	Service	1.00
100	28.2	12 x 1	30 x 7/16	16 x 1-1/8	20	16 x 2-1/8	60	25.00	8.97	Service	0.98
105	19.8	14 x 3/4	52 x 1/2	-	-	14 x 1-1/8	105	26.25	9.33	Service	0.98
105	24.2	14 x 3/4	40 x 1/2	-	-	16 x 1-1/2	105	26.25	9.74	Service	0.96
105	28.3	14 x 7/8	32 x 7/16	18 x 1	21	18 x 2	63	26.25	9.83	Service	0.99
110	19.5	14 x 3/4	56 x 9/16	-	-	14 x 1-1/8	110	27.50	10.15	Service	0.99
110	24.3	14 x 3/4	42 x 1/2	14 x 1	22	14 x 1-7/8	66	27.50	9.89	Service	0.95
110	28.3	14 x 7/8	34 x 7/16	18-1-1/8	22	18 x 1-7/8	66	27.50	10.38	Service	0.97
115	19.9	16 x 3/4	58 x 9/16	-	-	16 x 1	115	28.75	11.86	Service	0.96
115	24.4	14 x 3/4	44 x 1/2	14 x 1	23	14 x 1-7/8	69	28.75	10.54	Service	0.97
115	28.5	14 x 1	36 x 1/2	18 x 1-1/8	23	18 x 1-7/8	69	28.75	11.81	Service	0.97
120	19.6	16 x 3/4	62 x 9/16	-	-	16 x 1	120	30.00	12.84	Service	0.96
120	24.0	16 x 3/4	48 x 1/2	16 x 7/8	24	16 x 1-5/8	72	30.00	11.68	Service	0.95
120	28.6	14 x 1	38 x 1/2	18 x 1-1/8	24	18 x 1-7/8	72	30.00	12.53	Service	0.98

Table A.36 Optimized Interior Girder Designs Failing the L/800 Deflection Limit for 28-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 3rd Edition of Specifications Neglecting Constructibility

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
75	25.1	12 x 3/4	24 x 7/16	-	-	16 x 1-3/8	75	25.00	5.30	Service	0.99	1.17	1.13
80	26.4	12 x 3/4	24 x 7/16	-	-	14 x 1-7/8	80	26.67	6.23	Service	0.97	1.26	1.20
85	28.1	14 x 7/8	24 x 7/16	-	-	16 x 1-3/4	85	28.33	7.34	Service	0.99	1.50	1.28
90	28.2	14 x 3/4	26 x 7/16	18 x 1	18	18 x 1-3/4	54	30.00	7.35	Service	0.95	1.47	1.35
95	28.3	14 x 7/8	28 x 7/16	18 x 1	19	18 x 1-3/4	57	23.75	8.18	Strength	0.96	1.54	1.43
100	28.2	14 x 3/4	30 x 7/16	16 x 1-1/8	20	16 x 2	60	25.00	8.51	Service	1.00	1.59	1.50
105	28.5	14 x 7/8	32 x 7/16	18 x 1	21	18 x 1-3/4	63	26.25	9.35	Service	1.00	1.68	1.58

Table A.37 Optimized Interior Girder Designs for 28-ft. Cross-section with Hybrid Girder Configuration in Accordance with 3rd Edition of Specifications Neglecting Constructibility

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR
				Plate	Length	Plate	Length				
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons		
40	13.6	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.62
45	15.3	12 x 3/4	24 x 7/16	-	-	12 x 3/4	45	22.50	2.18	Min. Plate	0.68
50	17.0	12 x 3/4	24 x 7/16	-	-	12 x 3/4	50	25.00	2.42	Min. Plate	0.74
55	18.7	12 x 3/4	24 x 7/16	-	-	12 x 3/4	55	27.50	2.67	Min. Plate	0.87
60	19.3	12 x 3/4	26 x 7/16	-	-	12 x 3/4	60	20.00	3.00	Service	0.88
60	20.3	12 x 3/4	24 x 7/16	-	-	12 x 1	60	20.00	3.22	Service	0.76
65	19.8	12 x 3/4	28 x 7/16	-	-	12 x 7/8	65	21.66	3.51	Service	0.81
65	21.8	12 x 3/4	24 x 7/16	-	-	12 x 1-1/4	65	21.66	3.82	Service	0.73
70	19.4	12 x 3/4	32 x 7/16	-	-	12 x 3/4	70	23.33	3.81	Service	0.92
70	23.4	12 x 3/4	24 x 7/16	-	-	14 x 1-3/8	70	23.33	4.62	Service	0.97
75	19.9	12 x 3/4	34 x 7/16	-	-	12 x 3/4	75	25.00	4.19	Service	0.93
75	23.8	12 x 3/4	26 x 7/16	-	-	14 x 1-3/8	75	25.00	5.06	Strength	0.72
75	24.8	12 x 3/4	24 x 7/16	-	-	14 x 1-3/4	75	25.00	5.61	Service	0.73
80	19.5	12 x 3/4	38 x 7/16	-	-	12 x 3/4	80	26.67	4.71	Service	0.95
80	23.9	12 x 3/4	28 x 7/16	-	-	12 x 1-5/8	80	26.67	5.55	Strength	0.76
80	26.3	12 x 3/4	24 x 7/16	-	-	14 x 2	80	26.67	6.47	Service	0.88
85	19.9	12 x 3/4	40 x 7/16	-	-	12 x 3/4	85	28.33	5.13	Service	0.96
85	24.1	12 x 3/4	30 x 7/16	-	-	12 x 1-3/4	85	28.33	6.24	Service	0.74
85	27.9	14 x 7/8	24 x 7/16	18 x 1	17	18 x 2	51	28.33	7.46	Service	0.78
90	19.5	12 x 3/4	44 x 1/2	-	-	12 x 3/4	90	30.00	6.13	Service	0.95
90	24.3	12 x 3/4	32 x 7/16	12 x 3/4	18	12 x 1-7/8	54	30.00	6.14	Service	0.92
90	28.0	14 x 3/4	26 x 7/16	18 x 1	18	18 x 2-1/4	54	30.00	7.97	Service	0.96
95	19.9	12 x 3/4	46 x 1/2	-	-	12 x 3/4	95	23.75	6.63	Service	0.94
95	23.7	12 x 3/4	36 x 7/16	-	-	12 x 1-5/8	95	23.75	7.15	Service	0.81
95	28.1	12 x 1	28 x 7/16	18 x 1	19	18 x 2	57	23.75	8.57	Service	0.85
100	19.6	14 x 3/4	50 x 1/2	-	-	14 x 3/4	100	25.00	7.83	Service	0.89
100	24.0	12 x 3/4	38 x 7/16	-	-	12 x 1-1/2	100	25.00	7.42	Strength	0.95
100	28.2	12 x 1	30 x 7/16	16 x 1-1/8	20	16 x 2-1/8	60	25.00	8.97	Service	0.93
105	19.9	14 x 3/4	52 x 1/2	-	-	14 x 3/4	105	26.25	8.40	Service	0.88
105	24.3	14 x 3/4	40 x 1/2	-	-	14 x 1-1/4	105	26.25	9.58	Service	0.85
105	28.3	14 x 3/4	32 x 7/16	18 x 1	21	18 x 2	63	26.25	9.52	Service	0.97
110	19.6	14 x 3/4	56 x 9/16	-	-	14 x 3/4	110	27.50	9.17	Service	0.99
110	24.5	12 x 3/4	42 x 1/2	-	-	14 x 1-3/8	110	27.50	9.22	Service	0.89
110	28.2	14 x 7/8	34 x 7/16	16 x 7/8	22	16 x 2-1/4	66	27.50	10.17	Service	0.97
115	19.9	14 x 3/4	58 x 9/16	-	-	14 x 3/4	115	28.75	10.49	Service	0.91
115	24.7	14 x 3/4	44 x 1/2	-	-	14 x 1-3/8	115	28.75	10.13	Strength	0.84
115	28.4	14 x 7/8	36 x 1/2	16 x 1	23	16 x 2-1/8	69	28.75	10.72	Service	0.92
120	19.7	16 x 3/4	62 x 9/16	-	-	16 x 3/4	120	30.00	12.02	Service	0.84
120	24.2	16 x 3/4	48 x 1/2	-	-	16 x 1	120	30.00	10.62	Strength	0.94
120	28.4	14 x 7/8	38 x 1/2	14 x 1-1/4	24	14 x 2-1/4	72	30.00	11.67	Service	1.00

Table A.38 Optimized Interior Girder Designs Failing the L/800 Deflection Limit for 28-ft. Cross-section with Hybrid Girder Configuration in Accordance with 3rd Edition of Specifications Neglecting Constructibility

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
60	20.4	12 x 3/4	24 x 7/16	-	-	12 x 3/4	60	20.00	2.91	Service	0.95	1.02	0.90
65	19.9	12 x 3/4	28 x 7/16	-	-	12 x 3/4	65	21.67	3.35	Service	0.90	1.15	0.98
65	22.0	12 x 3/4	24 x 7/16	-	-	12 x 7/8	65	21.67	3.32	Service	0.94	1.05	0.98
75	24.1	12 x 3/4	26 x 7/16	-	-	14 x 7/8	75	25.00	4.16	Service	0.98	1.73	1.13
75	25.4	12 x 3/4	24 x 7/16	-	-	14 x 1	75	25.00	4.27	Service	0.96	1.59	1.13
80	24.2	12 x 3/4	28 x 7/16	-	-	12 x 1-1/8	80	26.67	4.73	Service	0.96	1.53	1.20
80	26.8	12 x 3/4	24 x 7/16	-	-	12 x 1-3/8	80	26.67	4.90	Service	0.97	1.34	1.20
85	24.6	12 x 3/4	30 x 7/16	-	-	12 x 1-1/8	85	28.33	5.15	Service	0.98	1.67	1.28
85	28.5	12 x 7/8	24 x 7/16	-	-	14 x 1-1/4	85	28.33	5.57	Service	0.99	2.08	1.28
90	24.7	12 x 3/4	32 x 7/16	-	-	12 x 1-1/4	90	30.00	5.82	Service	0.95	1.68	1.35
90	28.6	14 x 7/8	26 x 7/16	-	-	16 x 1-1/4	90	30.00	6.41	Strength	0.96	2.00	1.35
95	23.9	12 x 3/4	36 x 7/16	-	-	12 x 1-1/8	95	23.75	6.18	Service	0.98	1.70	1.43
95	28.6	12 x 1	28 x 7/16	-	-	14 x 1-3/4	95	23.75	7.03	Strength	0.97	2.13	1.43
100	24.1	12 x 3/4	38 x 7/16	-	-	12 x 1-1/4	100	25.00	6.91	Service	0.96	1.70	1.50
100	28.6	12 x 7/8	30 x 7/16	-	-	14 x 1-1/2	100	25.00	7.59	Service	0.99	2.10	1.50
105	24.5	14 x 3/4	40 x 1/2	-	-	14 x 1	105	26.25	7.95	Service	0.98	1.80	1.58
105	28.7	14 x 1	32 x 7/16	-	-	16 x 1-3/8	105	26.25	8.93	Strength	0.95	2.13	1.58
110	24.6	12 x 3/4	42 x 1/2	-	-	14 x 1-1/8	110	27.50	8.56	Service	0.95	1.78	1.65
110	28.5	14 x 7/8	34 x 7/16	16 x 3/4	22	16 x 1-1/2	66	27.50	8.67	Service	0.97	2.10	1.65
115	24.8	14 x 3/4	44 x 1/2	-	-	14 x 1-1/4	115	28.75	9.78	Service	0.96	1.76	1.73
115	28.8	14 x 7/8	36 x 7/16	-	-	16 x 1-3/8	115	28.75	10.78	Strength	0.96	2.26	1.73
120	28.7	14 x 1	38 x 1/2	14 x 7/8	24	14 x 1-3/4	72	30.00	10.74	Service	0.96	2.17	1.80

Table A.39 Optimized Interior Girder Designs for 34-ft. Cross-section with Homogeneous Girder Configuration in Accordance with 3rd Edition of Specifications Neglecting Constructibility

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR
				Plate	Length	Plate	Length				
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons		
40	13.4	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.75
45	15.1	12 x 3/4	24 x 7/16	-	-	12 x 3/4	45	22.50	2.18	Min. Plate	0.91
50	16.7	12 x 3/4	24 x 7/16	-	-	12 x 7/8	50	25.00	2.55	Service	0.98
55	18.3	12 x 3/4	24 x 7/16	-	-	12 x 1-1/8	55	27.50	3.09	Service	0.97
60	18.8	12 x 3/4	26 x 7/16	-	-	12 x 1-1/4	60	20.00	3.61	Service	0.97
60	19.8	12 x 3/4	24 x 7/16	-	-	12 x 1-3/8	60	20.00	3.68	Service	0.97
65	19.3	12 x 3/4	28 x 7/16	-	-	12 x 1-3/8	65	21.66	4.17	Service	0.96
65	21.3	12 x 3/4	24 x 7/16	-	-	12 x 1-5/8	65	21.66	4.31	Service	0.98
70	18.9	12 x 3/4	32 x 7/16	-	-	12 x 1-3/8	70	23.33	4.70	Service	0.96
70	22.9	12 x 3/4	24 x 7/16	-	-	14 x 1-5/8	70	23.33	5.03	Service	0.98
75	19.4	12 x 3/4	34 x 7/16	-	-	12 x 1-1/2	75	25.00	5.34	Service	0.95
75	23.2	12 x 3/4	26 x 7/16	-	-	14 x 1-3/4	75	25.00	5.73	Service	0.97
75	24.4	12 x 7/8	24 x 7/16	-	-	14 x 1-7/8	75	25.00	5.84	Service	0.99
80	19.1	12 x 3/4	38 x 7/16	-	-	12 x 1-3/8	80	26.67	5.73	Service	1.00
80	23.6	12 x 3/4	28 x 7/16	-	-	14 x 1-3/4	80	26.67	6.23	Service	1.00
80	25.9	12 x 7/8	24 x 7/16	-	-	14 x 2-1/8	80	26.67	6.91	Service	0.99
85	19.4	12 x 3/4	40 x 1/2	-	-	12 x 1-1/2	85	28.33	6.80	Service	0.97
85	23.8	12 x 7/8	30 x 7/16	-	-	14 x 1-7/8	85	28.33	7.21	Service	0.98
85	27.5	12 x 1	24 x 7/16	16 x 1-1/4	17	16 x 2-1/8	51	28.33	7.36	Service	0.97
90	19.1	12 x 3/4	44 x 1/2	-	-	12 x 1-1/2	90	30.00	7.50	Service	0.96
90	24.0	12 x 3/4	32 x 7/16	-	-	14 x 2	90	30.00	7.81	Service	0.98
90	27.8	14 x 1	26 x 7/16	18 x 1-1/8	18	18 x 1-7/8	54	30.00	8.23	Service	0.99
95	19.5	12 x 3/4	46 x 1/2	-	-	12 x 1-1/2	95	23.75	8.08	Service	0.97
95	23.3	12 x 3/4	36 x 1/2	-	-	14 x 1-7/8	95	23.75	8.61	Service	0.95
95	27.9	14 x 7/8	28 x 7/16	18 x 1-1/8	19	18 x 1-7/8	57	23.75	8.54	Service	0.98
100	19.2	14 x 3/4	50 x 1/2	-	-	14 x 1-3/8	100	25.00	9.32	Service	0.95
100	23.5	12 x 3/4	38 x 1/2	14 x 1-1/8	20	14 x 2	60	25.00	8.69	Service	0.98
100	27.9	14 x 1	30 x 7/16	18 x 1-1/4	20	18 x 2	60	25.00	9.82	Strength	0.99
105	19.6	14 x 3/4	52 x 9/16	-	-	14 x 1-3/8	105	26.25	10.54	Service	0.97
105	23.8	14 x 3/4	40 x 1/2	14 x 1-1/8	21	14 x 2	63	26.25	9.58	Service	0.95
105	28.1	14 x 3/4	32 x 7/16	16 x 1-1/8	21	16 x 1-7/8	63	26.25	8.88	Service	0.99
110	19.3	14 x 3/4	56 x 9/16	-	-	14 x 1-3/8	110	27.50	11.46	Service	0.96
110	24.1	12 x 7/8	42 x 1/2	16 x 1	22	16 x 1-7/8	66	27.50	10.46	Service	0.97
110	28.0	14 x 1-1/8	34 x 1/2	18-1-1/4	22	18 x 2-1/8	66	27.50	12.11	Service	0.98
115	19.6	16 x 3/4	58 x 9/16	-	-	16 x 1-1/4	115	28.75	12.64	Service	0.97
115	24.3	14 x 3/4	44 x 1/2	16 x 1-1/8	23	16 x 1-7/8	69	28.75	11.29	Service	0.98
115	28.1	16 x 7/8	36 x 1/2	18 x 1-1/4	23	18 x 2-1/8	69	28.75	12.51	Service	0.99
120	19.4	16 x 3/4	62 x 9/16	-	-	16 x 1-1/4	120	30.00	13.65	Service	0.96
120	23.7	16 x 3/4	48 x 9/16	16 x 1	24	16 x 1-7/8	72	30.00	12.94	Service	0.97
120	28.1	14 x 1-1/4	38 x 1/2	18 x 1-1/4	24	18 x 2-1/4	72	30.00	14.25	Service	0.99

Table A.40 Optimized Interior Girder Designs for 34-ft. Cross-section with Hybrid Girder Configuration in Accordance with 3rd Edition of Specifications Neglecting Constructibility

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR
				Plate	Length	Plate	Length				
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons		
40	13.4	12 x 3/4	24 x 7/16	-	-	12 x 3/4	40	20.00	1.94	Min. Plate	0.66
45	15.1	12 x 3/4	24 x 7/16	-	-	12 x 3/4	45	22.50	2.18	Min. Plate	0.72
50	16.8	12 x 3/4	24 x 7/16	-	-	12 x 3/4	50	25.00	2.42	Min. Plate	0.79
55	18.5	12 x 3/4	24 x 7/16	-	-	12 x 3/4	55	27.50	2.67	Min. Plate	0.93
60	19.1	12 x 3/4	26 x 7/16	-	-	12 x 3/4	60	20.00	3.00	Service	0.99
60	20.1	12 x 3/4	24 x 7/16	-	-	12 x 7/8	60	20.00	3.06	Service	0.94
65	19.6	12 x 3/4	28 x 7/16	-	-	12 x 7/8	65	21.66	3.51	Service	0.96
65	21.6	12 x 3/4	24 x 7/16	-	-	12 x 1-1/8	65	21.66	3.65	Service	0.93
70	19.1	12 x 3/4	32 x 7/16	-	-	12 x 7/8	70	23.33	3.99	Service	0.91
70	22.9	12 x 3/4	24 x 7/16	-	-	12 x 1-5/8	70	23.33	4.64	Service	0.84
75	19.6	12 x 3/4	34 x 7/16	-	-	12 x 7/8	75	25.00	4.39	Service	1.00
75	23.5	12 x 3/4	26 x 7/16	-	-	14 x 1-3/8	75	25.00	5.06	Service	0.85
75	24.6	12 x 3/4	24 x 7/16	-	-	14 x 1-5/8	75	25.00	5.39	Service	0.92
80	19.2	12 x 3/4	38 x 7/16	-	-	12 x 7/8	80	26.67	4.92	Service	0.95
80	23.7	12 x 3/4	28 x 7/16	-	-	12 x 1-1/2	80	26.67	5.34	Service	0.90
80	25.9	12 x 7/8	24 x 7/16	-	-	12 x 2-1/8	80	26.67	6.33	Service	0.93
85	19.7	14x 3/4	40 x 1/2	-	-	14 x 3/4	85	28.33	5.93	Service	0.97
85	23.9	12x 3/4	30 x 7/16	-	-	12 x 1-5/8	85	28.33	6.02	Service	0.88
85	27.5	14 x 7/8	24 x 7/16	16 x 1	17	16 x 2-1/8	51	28.33	7.17	Service	0.91
90	19.3	12 x 3/4	44 x 1/2	-	-	12 x 7/8	90	30.00	6.35	Service	0.95
90	24.3	12 x 3/4	32 x 7/16	-	-	14 x 1-1/2	90	30.00	6.74	Service	0.97
90	27.8	14 x 7/8	26 x 7/16	-	-	18 x 1-7/8	90	30.00	8.79	Service	0.98
95	19.7	12 x 3/4	46 x 1/2	-	-	12 x 7/8	95	23.75	6.87	Service	0.98
95	23.6	14x 3/4	36 x 1/2	-	-	14 x 1-1/4	95	23.75	7.44	Service	0.93
95	27.9	14 x 7/8	28 x 7/16	18 x 1-1/8	19	18 x 1-7/8	57	23.75	8.54	Service	0.98
100	19.4	14 x 3/4	50 x 1/2	-	-	14 x 7/8	100	25.00	8.12	Service	0.95
100	23.8	12 x 7/8	38 x 1/2	-	-	12 x 1-3/8	100	25.00	7.83	Service	0.99
100	27.9	14 x 1	30 x 7/16	16 x 1-1/8	20	16 x 2	60	25.00	9.11	Strength	0.98
105	19.8	14 x 3/4	52 x 9/16	-	-	14 x 3/4	105	26.25	8.98	Service	0.98
105	24.1	14 x 7/8	40 x 1/2	-	-	14 x 1-1/4	105	26.25	8.89	Service	1.00
105	28.0	16 x 1	32 x 7/16	16 x 1-1/8	21	16 x 2	63	26.25	10.08	Service	0.92
110	19.5	14 x 3/4	56 x 9/16	-	-	14 x 3/4	110	27.50	9.83	Service	1.00
110	24.2	14 x 3/4	42 x 1/2	-	-	14 x 1-1/2	110	27.50	9.83	Service	0.96
110	28.1	14 x 1-1/8	34 x 1/2	16 x 1	22	16 x 2	66	27.50	10.92	Service	0.95
115	19.8	16 x 3/4	58 x 9/16	-	-	16 x 3/4	115	28.75	11.08	Service	0.96
115	24.5	14 x 7/8	44 x 1/2	-	-	14 x 1-3/8	115	28.75	10.47	Service	0.99
115	28.3	16 x 1	36 x 1/2	18 x 7/8	23	18 x 1-3/4	69	28.75	11.58	Service	0.97
120	19.5	16 x 3/4	62 x 9/16	-	-	16 x 3/4	120	30.00	12.02	Service	0.95
120	24.0	16 x 3/4	48 x 9/16	-	-	16 x 1-1/8	120	30.00	11.64	Service	0.97
120	28.1	14 x 1-1/4	38 x 1/2	14 x 1	24	14 x 2-1/4	72	30.00	12.45	Service	1.00

Table A.41 Optimized Interior Girder Designs Failing the L/800 Deflection Limit for 34-ft. Cross-section with Hybrid Girder Configuration in Accordance with 3rd Edition of Specifications Neglecting Constructibility

Span Length (L)	L/D	Top Flange	Web	Bottom Flange (A)		Bottom Flange (B)		Lateral Brace Spacing (C)	Wt.	Controlling Limit State	PR	Defl.	L/800
				Plate	Length	Plate	Length						
ft		in.	in.	in.	ft.	in.	ft.	ft.	tons			in.	in.
65	21.7	12 x 3/4	24 x 7/16	-	-	12 x 1	65	21.67	3.48	Service	1.00	1.06	0.98
70	23.2	12 x 3/4	24 x 7/16	-	-	12 x 1-1/4	70	23.33	4.11	Service	0.95	1.16	1.05
75	23.6	12 x 3/4	26 x 7/16	-	-	14 x 1-1/8	75	25.00	4.61	Service	0.97	1.23	1.13
75	24.8	12 x 3/4	24 x 7/16	-	-	14 x 1-1/4	75	25.00	4.72	Service	0.96	1.30	1.13
80	23.8	12 x 3/4	28 x 7/16	-	-	12 x 1-3/8	80	26.67	5.14	Service	0.95	1.29	1.20
80	26.2	12 x 7/8	24 x 7/16	-	-	12 x 1-5/8	80	26.67	5.51	Service	0.97	1.48	1.20
85	24.1	12 x 3/4	30 x 7/16	-	-	12 x 1-3/8	85	28.33	5.59	Service	0.99	1.42	1.28
85	27.9	14 x 7/8	24 x 7/16	-	-	14 x 1-1/2	85	28.33	6.33	Service	0.99	1.74	1.28
90	24.3	12 x 3/4	32 x 7/16	-	-	14 x 1-3/8	90	30.00	6.47	Service	0.97	1.38	1.35
90	28.1	14 x 7/8	26 x 7/16	-	-	16 x 1-1/2	90	30.00	7.29	Service	0.99	1.69	1.35
95	23.7	14 x 3/4	36 x 1/2	-	-	14 x 1-1/8	95	23.75	7.15	Service	1.00	1.45	1.43
95	28.1	14 x 1	28 x 7/16	-	-	14 x 1-5/8	95	23.75	7.92	Strength	0.98	1.82	1.43
100	28.1	14 x 1	30 x 7/16	-	-	14 x 1-3/4	100	25.00	8.78	Strength	0.99	1.79	1.50
105	28.2	16 x 1	32 x 7/16	-	-	16 x 1-5/8	105	26.25	10.00	Strength	0.98	1.81	1.58
110	28.2	14 x 1-1/8	34 x 1/2	16 x 7/8	22	16 x 1-3/4	66	27.50	10.32	Service	0.98	1.78	1.65
115	28.5	16 x 1	36 x 1/2	18 x 7/8	23	18 x 1-1/2	69	28.75	11.05	Strength	0.98	1.88	1.73
120	28.2	14 x 1-1/4	38 x 1/2	14 x 1	24	14 x 2-1/8	72	30.00	12.24	Service	1.00	1.83	1.80