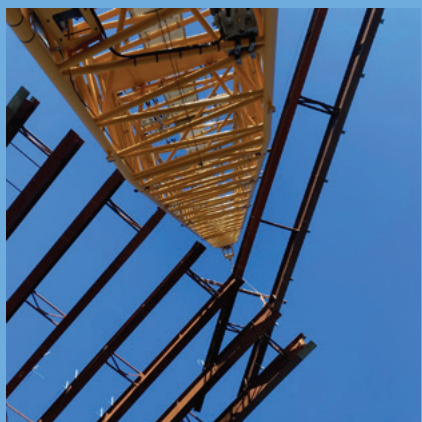




Steel Bridge Erection Guide Specification S10.1–2023



AMERICAN ASSOCIATION
OF STATE HIGHWAY AND
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AASHTO



AASHTO/NSBA STEEL BRIDGE COLLABORATION

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Preface

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It is intended that Owners adopt and implement Collaboration documents in their entirety to facilitate the achievement of standardization. It is understood, however, that local statutes or preferences may prevent full adoption of the document. In such cases Owners should adopt these documents with the exceptions they feel are necessary.

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SECTION 1: GENERAL

1.1—DEFINITIONS

1.1.1—Steel Bridge Erection

Steel bridge erection is the process of transporting, handling, and assembling steel bridge components to result in a bridge structure that meets all the geometric and structural requirements of the Contract Documents.

C1.1.1

Steel erection is complete when all field connections are completed to the final design condition and falsework or temporary bracing is or can be removed. Erection should proceed in a safe, methodical fashion ensuring all performance criteria are satisfied.

1.1.2—Erector

In this document, “Erector” refers to the entity that is responsible for the erection of the structural steel.

1.1.3—Contractor

The Contractor is responsible for proper completion of all tasks required by the Contract. Subcontractors, including Fabricators, Erectors, and field painters, may be used by the Contractor, but the Contractor retains responsibility for all material, operations, and the final product. The Contractor may permit direct subcontractor interaction with the Owner to expedite the project, but subcontractors shall inform the Contractor of any proposed modifications to contract requirements accepted by the Owner.

1.1.4—Design Engineer

In this document, “Design Engineer” refers to the licensed professional who is responsible for sealing the Contract Plans. Sealing indicates that a licensed professional has performed or supervised the analysis, design, and document preparation for the structure and has knowledge of the load-carrying structural system.

1.1.5—Erection Engineer

In this document, “Erection Engineer” refers to the licensed professional who is responsible for developing, evaluating, and specifying the Contractor’s specific procedures and plans for erecting the structural steel of the bridge.

1.1.6—Fabricator

In this document, “Fabricator” refers to the facility(-ies) performing such shop activities as cutting, welding, drilling, punching, cleaning, and painting of structural steel. “Fabricator” also includes any agents of the Fabricator, such as subcontracted Fabricators. In some cases, the Fabricator is subcontracted by the Contractor.

1.1.7—Inspection

The examination by the Owner, Contractor, Erector, or Fabricator of processes and products to verify conformance with the Contract requirements.

1.1.8—Owner

In this document, “Owner” refers to the entity paying the Contractor to fulfill the terms of the Contract. The Owner also encompasses the following: those preparing the Contract Documents, including those responsible for the structure’s adequate design; and those authorized to represent the Owner during construction, commonly called the “Engineer” and the “Inspector.” The Engineer and Inspector may be employees either of the Owner or of professional firms contracted for the work.

1.1.9—Plans

In this document, if not otherwise noted or modified by adjectives, the term “Plans” refers to the engineering drawings prepared by the Design Engineer. The terms “Design Plans” and “Contract Plans” are identical in meaning to the generic term “Plans.”

1.1.10—Erection Plans

In this document, the term “Erection Plans” refers specifically to the engineering drawings prepared by the Erection Engineer describing and specifying the erection (i.e., the field-installation and member-placement) of the structural steel. In this document, the term “Erection Plans” may also refer in a more general context to the combination of engineering drawings and Erection Procedures describing and specifying the erection (i.e., the field-installation and member-placement) of the structural steel.

C1.1.9

The term “Plans” can refer to many documents, but typically refers to the engineering drawings prepared by the Design Engineer unless modified by at least one descriptive adjective to denote different meaning (e.g., “Erection Plans” refers to the engineering drawings prepared by the Erection Engineer). When not otherwise clear, the term “Plans” should be interpreted (in this document) as referring to the plans prepared by the Design Engineer, which can also be denoted as the “Design Plans” or the “Contract Plans.”

C1.1.10

The intent of these definitions is not to create requirements for separating information shown on the Erection Plans from information presented in the Erection Procedures; the two documents are intended to be complementary. The required information can be shown in either the Erection Plans or the Erection Procedures as is appropriate for clear presentation, efficiency, and simplicity; the key is that all required information is presented in either one or the other.

1.1.11—Erection Procedures

In this document, the term “Erection Procedures” refers to the documents which describe the specific sequence, methods, equipment, and other directives which the Contractor is to follow in erecting the structural steel. The terms “Erection Plans” and “Erection Procedures” are not synonymous, but the Erection Plans and Erection Procedures shall be fully integrated with each other and shall together describe and specify all aspects of how the structural steel is to be erected, including, but not limited to, sequence of erection, methods or techniques to be used, equipment to be used, materials to be used, along with any temporary works or other devices necessary. Items identified as required by these specifications and not addressed in the Erection Plans shall be addressed in the Erection Procedures.

1.1.12—Erection Engineering Calculations

In this document, the term “Erection Engineering Calculations” refers to any engineering calculations associated with the substantiation of the Erection Plans and Erection Procedures.

1.1.13—Contract Documents

In this document, the term “Contract Documents” refers to the documents that define the responsibilities of the parties that are involved in bidding, fabricating, and erecting structural steel (and other elements of the project). These documents normally include the design drawings, the specifications, and the contract.

1.2—ERECTOR QUALIFICATIONS

Structural steel shall be erected by a qualified, competent Erector. The Owner shall specify qualifications for the steel Erector based on the complexity of the project.

C1.1.11

The Erection Procedures should be presented in some written format (i.e., verbal directives are not sufficient to constitute Erection Procedures). The Erection Procedures can include reference to standard operating procedures of the Contractor (to avoid unnecessary repetition or excessive documentation), but in such a case, the standard operating procedures should be written, and should be available for review by the Owner.

C1.2

A “qualified, competent Erector” has knowledge, training, and experience, and has demonstrated the technical proficiency and ability to complete the work specified. The Erector should be able to resolve common problems associated with the complexity of work proposed. American Institute of Steel Construction (AISC) credentials such as Certified Erector, or other similar industry-based qualifications, should be considered based on the requirements for such certifications and the complexity of the bridge. Certification alone may not be sufficient evidence of qualification for complex or monumental bridge structure types, such as suspension, cable-stayed, tied arch, cantilever truss, or movable bridges.

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SECTION 2: ERECTION ENGINEERING

2.1—GENERAL

2.1.1—Required Erection Plans and Procedures and Erection Engineering Calculations

The Contractor shall submit Erection Plans and Erection Procedures to the Owner for each bridge structural unit identified on the Contract Plans and specifications. In the Contract Documents language, “an erection plan is required” or similar invokes a requirement for submittal of Erection Plans and Procedures and the associated Erection Engineering Calculations as described in this Guide Specification.

The Contractor shall submit Erection Engineering Calculations to the Owner for each bridge structural unit identified on the Contract Plans and specifications. In the Contract Documents language, “Erection engineering calculations are required” or similar invokes a requirement for submittal of Erection Plans and Procedures and the associated Erection Engineering Calculations as described in this Guide Specification.

Unless otherwise specified in the Contract Documents, if the submittal of Erection Plans and Procedures (with or without Erection Engineering Calculations) is required, the Owner shall be allowed a minimum of 15 working days to review the submittal, after which the Contractor may assume the submittal has been approved by the Owner, unless the Owner provides written notification that the submittal was not approved.

2.1.2—Erection Plans and Procedures Overview

The Erection Plans and Procedures shall be prepared by a licensed professional engineer licensed in the state(s) or jurisdiction(s) in which the subject bridge is being built. The Erection Plans and Procedures submittal shall address all requirements for erection of the structural steel into the final designed configuration. Any and all written review comments provided by the Owner shall be addressed to the Owner’s satisfaction prior to the start of erection. As a minimum, the Erection Plans and Procedures shall include consideration of all items described in Article 2.2.

C2.1.1

Formal submittal and review of Erection Plans and Procedures and Erection Engineering Calculations may not be warranted for all bridges. Owners may choose to forgo requiring formal submittal and review of Erection Plans and Procedures and Erection Engineering Calculations where the additional cost and time is not justified. For simpler structures where the risk associated with problems is minimal, the Owner may choose to rely upon the Contractor’s expertise to erect the bridge without requiring a formal submittal. For example, for a shorter, rural, simple-span creek crossing bridge, formal submittal and review of Erection Plans and Procedures and associated Erection Engineering Calculations may not be warranted.

Note that, as explained in Articles 1.1.9, 1.1.10, and 1.1.11, the term “Erection Plan” encompasses both engineering drawings (defined specifically as Erection Plans) and any associated Erection Procedures documents.

C2.1.2

The qualifications of the Erection Engineer preparing the Erection Plans and Procedures and the Erection Engineering Calculations should be evidenced by knowledge, training, and experience in steel erection, and having demonstrated the ability to resolve problems related to steel bridge erection. Many states also require that erection procedures and temporary falsework design be prepared by a professional engineer licensed or registered in that state. Some states may specifically require licensure or registration as a Structural Engineer (SE); in such cases, the specification language should be revised as appropriate.

The submission date(s) and review period(s) should be established and agreed to by the Owner and the Contractor as soon as possible after the Contract award, and should be established such that sufficient time is allotted for development of the erection submittal by the Erection Engineer and for review by the Owner. Erectors are encouraged to attend prebid and preconstruction meetings to help understand the complexities associated with the steel erection well in advance. Projects that involve complex erection or multi-agency reviews can be expected to require additional time for review of the submitted Erection Plans and Procedures. In these cases, the established submission dates and review periods should reflect the need for appropriate reviews by all involved parties. In some cases, particularly for bridges with complex erection schemes, it may be appropriate to establish one or more interim submittals including an early submittal of preliminary Erection Plans and Procedures that illustrate the proposed erection sequence and reflect any fabrication changes required to accommodate the proposed erection sequence.

2.1.3—Erection Engineering Calculations Submittal

Erection Engineering Calculations to substantiate the structural adequacy and stability of the erected structure and any associated temporary works, temporary components, or both, do not need to be included in the Erection Plans and Procedures submittal, unless otherwise specifically required on the Contract Plans or in special provisions. However, the Owner reserves the right to request the submittal of Erection Engineering Calculations for review and approval at any time. If requested, such calculations shall be submitted within 14 calendar days of request by the Owner.

In the absence of Erection Engineering Calculation submittal requirements, the Contractor may provide calculations in any format of their own choosing, including without limitation electronic analysis files, spreadsheets, copies of hand calculations, etc. The Contractor shall provide reading software for any electronic analysis files prepared using analysis software not otherwise already owned and used by the Owner or freely available to the Owner.

C2.1.3

Complex or signature structures should have specific requirements noted in the Contract Documents. Complex erection projects may require input from the Design Engineer in addition to the original design calculations such that the Contractor can confirm constructability of the structure during various erection stages. The Owner should ensure that the Design Engineer is available to consult with the Contractor in these cases. Further, it is beneficial for the Owner to discuss with the Contractor particular issues or concerns with the Erection Plans and Procedures to secure an explanation.

When calculations are required, it is beneficial for the Owner to specify their preferred format for submittal. Printed (or PDF) reports of output are common; if the Owner would like actual data files, this should be explicit in the Contract Documents.

A checklist listing all items discussed below is provided in Appendix A as an aid for engineers preparing or reviewing erection submittals.

2.2—ERECTION PLANS AND PROCEDURES

2.2.1—Plan of Work Area

The Erection Plans shall include:

- a) a plan of the work area showing the proposed bridge,
- b) the permanent support structures (piers and abutments),
- c) roads,
- d) railroad tracks,
- e) waterways (including location and dimensions of any navigational channel(s) and any navigational clearances to be respected during construction),
- f) overhead and underground utilities,
- g) structures and conditions that may limit access (consideration of clearance requirements over roadways or railroads),
- h) staging or material storage areas,
- i) right-of-way and property lines,
- j) information, plans, etc. regarding maintenance of traffic requirements, lane or road closures, restrictions, durations, etc. necessary to protect public safety for all erection operations over or adjacent to live traffic, and
- k) any other information that may be pertinent to the steel erection.

Unless otherwise clearly allowed by the Owner's standard specifications or unless otherwise clearly allowed in the Contract Documents, erection of structural steel over live traffic shall not be permitted.

2.2.2—Erection Sequence

The Erection Plans and Procedures shall indicate the erection sequence for all primary members (including indication of any attached secondary members), noting the use of temporary support conditions, such as (but not limited to) holding crane positions, temporary supports, and falsework. The erection sequence shall be shown in an illustrative plan view of the bridge for each erection stage, highlighting the structural components to be erected, their weights and center of gravity locations, lifting crane locations for primary member picks, and any temporary support conditions that are necessary during that particular stage. The illustrative plan view shall be accompanied with a written narrative of the procedure to be followed by the steel

C2.2.1

The plan of work area drawing should provide a general overview of the area where the bridge is to be erected, preferably drawn to scale. It allows all involved to see site conditions, access routes and staging areas, utilities, roadways, existing structures, and other possible site constraints, and better understand why certain procedures or details are being specified.

Example Erection Plans can be found in Appendix D.

C2.2.2

The erection sequence should indicate specific structural components to be erected at a given stage, such as (but not limited to) the girders, cross-frames, and lateral bracing. The erection sequence should also indicate lifting crane positions, as well as any temporary support conditions necessarily to facilitate a certain erection stage, such as (but not limited to) temporary supports, holding crane positions, tie-down stability provisions, and blocking of the bearings. The erection sequence drawings should provide instructions for construction of the bridge and should be written, and followed, as mandatory directives.

Erector, which shall state items such as structural components to be erected, use of temporary supports, use of temporary bracing, hold cranes, etc. Member reference marks, when reflected on the Erection Plans and Procedures, should be the same as used on shop detail drawings.

2.2.3—Delivery Location

The Erection Plans and Procedures shall indicate the delivery location and orientation of all primary members.

2.2.4—Crane Information

The Erection Plans and Procedures shall show the location of each crane to be used for each primary member pick (see Article 2.2.2), the crane type, crane pick radius, the crane support methods (crane mats, barges, work trestles, etc.), and the means of attachment to the girders being lifted or supported.

The erection submittal shall include capacity charts or tables that address, and demonstrate the adequacy of, each crane configuration, boom length, counterweight configuration, outrigger configuration, and pick weight required to do the proposed work. The Erection Plans and Procedures shall also indicate any potential above- or below-ground obstructions or restrictions to crane operations (existing structures, utilities, etc.). When cranes are required to be placed on or near new or existing structures (bridges, abutments, retaining walls, culverts, etc.), the structure shall be evaluated to ensure it has adequate capacity to withstand crane loading.

In the event that the submitted cranes are not available at the time of construction, the Contractor can propose alternate cranes, subject to review and approval by the Owner. The submittal package for alternate cranes shall include capacity charts or tables that address, and demonstrate the adequacy of, each crane configuration, boom length, counterweight configuration, outrigger configuration, and pick weight required to do the proposed work, but resubmittal of the full Erection Plans and Procedures and the Erection Engineering Calculations package is not required.

C2.2.3

The maximum crane lift radius is often controlled by the material delivery location, hence the need to indicate the delivery location on the Erection Plans and Procedures. Correct girder segment orientation at the delivery location is important since the ability to rotate long segments under the crane boom may be restricted.

C2.2.4

The erection submittal should include adequate documentation of any items needed to support cranes. For example, if a work trestle is used to support a crane, the erection submittal should include plans for the work trestle. Likewise, if the steel erection takes place on a navigable waterway, the configuration of the barges, loading sequence, and stability provisions (tie-downs, supports, etc.) should be provided in the Erection Plans and Procedures.

Communication between the Contractor and the Erection Engineer is vital to ensure the cranes assumed by the Erection Engineer are available to the Contractor. Providing the crane types, pick radii, pick weight, boom lengths, possible obstructions, etc. in the erection submittal will help to prevent crane failures, overloads, and interferences during the steel erection process in the field. Owners should recognize that it is not uncommon for Contractors to need to substitute alternate cranes at the time of construction, due to lack of availability of the originally proposed cranes, mechanical problems, etc. The Owner and the Contractor should agree to procedures and review times for alternate crane submittals as part of their establishment of dates and review periods for erection submittals. Typically, crane submittals are relatively simple to review, so it is generally appropriate to establish relatively short review periods to allow the Contractor reasonable flexibility in managing their equipment needs.

Any plans associated with crane supports (crane mats, barges, work trestles, etc.) shall also be included. When applicable, Manufacturers' certification documents or catalog cuts for pre-engineered devices or equipment may be used to meet this requirement; these items shall be included with the Erection Plans and Procedures and shall be subject to review and approval by the Owner. Calculations for crane supports (crane mats, barges, work trestles, etc.) do not need to be included in the Erection Plans and Procedures and calculations submittal, unless otherwise specifically required on the plans or in special provisions, but the Owner reserves the right to request their submittal for review and approval at any time. If requested, such calculations shall be submitted within 14 calendar days of request by the Owner.

2.2.5—Primary Member Crane Pick Information

The Erection Plans and Procedures shall include the lifting weight of the primary member picks, including all rigging and pre-attached elements (such as cross-frames or splice plates). The Erection Plans and Procedures shall also include the approximate center of gravity locations for the primary member picks of non-symmetric girders and assemblies.

2.2.6—Lifting Devices and Special Procedures

The Erection Plans and Procedures shall include the details, weight, capacity, and arrangement of all rigging (beam clamps, lifting lugs, etc.) and all lifting devices (such as spreader and lifting beams) required for lifting primary members. The Erection Plans and Procedures shall also specify details for rigging or lifting devices bolted or welded to permanent members, including the method and time (shop or field) of attachment and capacity, as well as methods, time, and responsibility for removal.

C2.2.5

The lifting weights and the approximate centers of gravity for each pick will provide the steel Erector with necessary information to safely lift various components. The centers of gravity provided on the plans should be taken as approximate locations, as these are typically calculated assuming nominal material sizes and approximations of minor items such as bolted connections, etc. The actual center of gravity locations should reasonably match these approximate locations and will aid the steel Erector in determining the proper lifting location in the field.

C2.2.6

Assumptions regarding the weight of rigging, spreader beams, etc., should be included in the Erection Plans and Procedures. Explicitly indicating all details related to rigging and spreader or lifting beams will help to ensure that the appropriate devices are being properly used in the field. Special considerations may be required for lifting attachments, including additional bolt holes or welding to the top girder flange. Some proprietary beam clamps apply clamping forces to secure the clamp to the girder. Effects of clamping forces on the girder flange should be considered to ensure there will be no damage or effect on the in-service performance of the girders.

As necessary, the Erection Plans and Procedures shall provide special lifting/handling procedures for any primary member with potential stability or slenderness issues.

2.2.7—Bolting Requirements

The Erection Plans and Procedures shall indicate the bolting requirements for field splices and cross-frame (or diaphragm) connections for each stage.

Refer to Article 6.7 for minimum bolting requirements during erection.

2.2.8—Bearing Blocking and Tie-Down Details

The Erection Plans and Procedures shall indicate blocking details, tie-down details, or both for the bridge bearings, and associated force demands, as necessary.

Slender beams, traditionally defined as those having a length-to-flange-width ratio (L/b) greater than 85, are prone to lateral-torsional buckling and require particular attention during lifting/handling operations. The flange width, b , should be taken as the smallest width flange within the field section being lifted. The definition of a slender beam as having an L/b ratio greater than 85 should only be used as an approximate guide; research has suggested other means of identifying the potential for instability during lifting and handling. In addition, other types of structural members may also have issues of slenderness, stability, or both, which should be addressed in the Erection Plans and Procedures as appropriate.

C2.2.7

Steel I-girders depend on their connections to adjacent girders through bracing members for their stability and stiffness during steel erection. This is especially true for curved steel girders, as the cross-frames serve as primary load-carrying members. Therefore, loosely connected cross-frames should not be used during steel girder bridge erection, as this may compromise the girder alignment (geometry control) and stability. The bolting requirements for girder field splices during steel erection need to be considered as well. In accordance with the *AASHTO LRFD Bridge Construction Specifications*, Article 11.6.5, splices and field connections shall have one-half of the holes filled with bolts and cylindrical erection pins (half bolts and half pins) before installing and tightening the balance of the high-strength bolts. In addition, the Erection Engineer developing the Erection Plans and Procedures shall ensure that the number of bolts or erection pins provides enough capacity for transfer of loads for the given stage of steel erection. The final tensioning sequence for field splices and cross-frames should be considered by the Erection Engineer when evaluating bolting requirements.

C2.2.8

Depending on their details, bridge bearings may allow movement (translation) in any direction and rotation about any axis. During steel erection, in addition to other stability provisions, the bearings may require blocking to prevent or limit the translational movements and rotations. In addition, bearings may need temporary tie-downs

2.2.9—Load Restrictions

Restrictions regarding wind loading and construction dead and live loadings, and any other applicable loading restrictions, shall be included on the Erection Plans and Procedures, as necessary.

2.2.10—Temporary Supports

The Erection Plans and Procedures shall include the location of any temporary support structures (see Article 2.2.2) and bracing, as well as details of the temporary support structure itself. If the temporary support is to be prefabricated (selected from a supplier's catalog), the type and capacity shall be defined in the Erection Plans and Procedures; lateral capacity as well as vertical capacity requirements shall be considered, as appropriate. If the temporary support is to be constructed by the Contractor on site, a complete design with full details, including member sizes, material properties, connections, and bracing elements, shall be provided in the Erection Plans and Procedures. In either case, details regarding the upper grillage and temporary bearing assembly,

to prevent uplift at various stages during construction. The Erection Engineer should determine the blocking and tie-down requirements such that the structure remains stable during all stages of erection and such that the behavior of the physical structure shall be consistent with the behavior determined in the analysis and assumed in the Erection Plans and Procedures.

C2.2.9

Limits may be placed on wind velocities during lifting of girder field pieces or during various stages of erection when the structure is only partially complete. The limitations on wind velocities are intended to prevent girder overstress and instabilities that could be caused by certain wind speeds and associated wind pressure loading. Calculations may show that a girder or girder system may not be stable at a certain wind velocity, and this needs to be communicated to the Contractor and Erector via the Erection Plans and Procedures. If appropriate, the Erection Plans and Procedures should include instructions and details for temporary support or tie-down of partially completed structures during high wind conditions. The Erection Plans and Procedures should also explicitly state restrictions on construction live loads (vehicles, equipment, personnel, etc.) and construction dead loads (formwork/falsework, stored materials, etc.). Inadvertent overloading by construction loads could lead to structural collapse and could also affect geometry control.

For additional recommendations and guidance on the application of wind loads during construction, see AASHTO's *Guide Specifications for Wind Loads on Bridges During Construction*.

C2.2.10

In many cases, temporary supports are integral to maintaining profile and alignment in the construction of a steel bridge. As such, they should be included in the Erection Plans and Procedures, whether the support is a falsework tower, hold crane, tie-down, bearing blocking, or other support.

Refer to Article C9.3 for discussion of “as-fabricated” camber and how it may influence girder erection elevations.

(e.g., details of how the steel girders will bear on the temporary support), including the top of falsework (bottom of structural steel) elevations, shall also be included in the Erection Plans and Procedures. In addition, all foundation requirements for temporary support structures shall be provided in the Erection Plans and Procedures.

The Erection Plans and Procedures shall indicate the location of hold cranes used to provide temporary support to the steel assembly (see Article 2.2.2) and the associated crane loads. The hold crane type, capacity, boom lengths, pick radius, and means of attachment to the girders shall also be indicated in the Erection Plans and Procedures.

The Erection Plans and Procedures shall include the location and details for temporary tie-downs that are required to facilitate the steel erection, as well as the associated tie-down loads. At a minimum, the details shall include the tie-down, girder attachment devices, and anchoring devices.

The Erection Plans and Procedures shall clearly indicate when, and under what conditions, any temporary supports or holding cranes may be released in the erection sequence, and if they may be left in place while subsequent erection proceeds.

The Erection Plans and Procedures shall clearly indicate appropriate restraint of girders from twisting or layover at supports. Girders should be restrained from twist or layover at supports unless the need for such restraint is demonstrated to be unnecessary by appropriate analysis in the Erection Engineering Calculations.

2.2.11—Jacking Devices

The Erection Plans and Procedures shall indicate jacking devices that will be required to complete the steel erection. Their location, type, size, and capacity shall be indicated on the Erection Plans and Procedures, as well as their intended use, sequence of engagement, load level, jack pressure table, and any other key parameters of their operation.

2.3—GUIDELINES FOR METHODS OF STRUCTURAL ANALYSIS

The Owner may specify in the Contract Documents the minimum requirements regarding the methods of structural analysis used in any structural engineering calculations supporting the erection procedures submittal. Note that the Owner's specification of minimum requirements for methods of analysis does not in any way relieve

C2.2.11

In some cases, jacking devices may be required at temporary support structures, or at the permanent supports, to align the structure during the erection process. If the Erection Plans and Procedures do indeed require jacking devices, they should be indicated in the Erection Plans and Procedures to alert the Contractor to their need, and their intended use should be explicitly presented.

C2.3

The Owner should specify their minimum expectations regarding the methods of structural analysis in order to identify prior to bidding what is required. This helps establish a uniform basis for bidding by communicating these requirements to the Contractor in advance. The required methods of analysis should reflect the complexity

the Contractor or the Erection Engineer of their obligations to perform correct and appropriate structural analyses.

If the Owner does not specify the minimum requirements regarding the methods of structural analysis to be used, the Contractor may elect to use any appropriate methods of analysis, provided that the methods can be demonstrated to be appropriate for the given analysis task(s), and that the methods meet or exceed the recognized or implied standard of care for similar analysis tasks.

of the structure and the complexity of the erection sequence (at least of the erection sequence presented in the Contract Documents). Since each project is different, requirements regarding the methods of structural analysis will vary from project to project. Some Owners may choose to establish standing rules or categories in this regard and publish those in their standard specifications. In lieu of this, the minimum requirements should be specified in the Contract Documents.

Recommendations for the selection of the appropriate method of structural analysis can be found in NCHRP Report 725, *Guidelines for Analysis Methods and Construction Engineering of Curved and Skewed Steel Girder Bridges* (NCHRP Project 12-79). NCHRP Report 725 provides recommendations on the appropriate methods of analysis to employ when investigating the adequacy of the erection sequence of curved or skewed steel girder bridges. The methods of analysis considered include 1D (approximate), 2D, and 3D methods. Tables are provided to aid in selection of the appropriate analysis method. For bridges with straight girders and non-skewed supports, 1D (approximate) analysis methods are generally adequate. A summary of these recommendations, including some more recent updated recommendations, can be found in Appendix B of AASHTO/NSBA Steel Bridge Collaboration document G13.1, *Guidelines for Steel Girder Bridge Analysis*.

The FHWA's *Engineering for Structural Stability in Bridge Construction*, publication number FHWA-NHI-15-044, provides guidance for erection engineering analysis of steel girder bridges and preparation of erection submittals. It also serves as the reference manual for the identically named National Highway Institute training course, NHI 130102.

Note that a checklist, listing all items discussed below, is provided in Appendix B as an aid for preparing or reviewing erection submittals.

2.4—REQUIREMENTS FOR ERECTION ENGINEERING CALCULATIONS FOR STRUCTURAL ADEQUACY AND STABILITY

Appropriate Erection Engineering Calculations to substantiate the structural adequacy and stability of the bridge system for each step of the steel erection shall be performed to substantiate the erection procedures. Requirements addressing the submittal of calculations are presented in

C2.4

This Section provides guidance on a variety of topics associated with calculations for structural adequacy and stability. As a general default, the AASHTO specifications referenced in this commentary are cited for criteria, but some opportunity is provided for the Erection Engineer

Article 2.1. This Section only addresses the content of calculations.

The Erection Engineering Calculations shall be performed in accordance with erection design criteria established or approved by the Owner, or as stated in the Contract Documents.

2.4.1—Design Criteria

The Erection Engineering Calculations shall be prepared in accordance with the *AASHTO LRFD Bridge Design Specifications*, the *AASHTO LRFD Bridge Construction Specifications*, and the *AASHTO Guide Design Specifications for Bridge Temporary Works*, unless otherwise directed by the Owner or the Contract Documents. The Contractor can propose supplemental criteria for specific items necessary for erection engineering. Supplemental criteria shall be limited to specifications published by AISC, American Society of Civil Engineers (ASCE), American Concrete Institute (ACI), or other recognized, national specification-writing organizations. Proposals for supplemental design criteria shall be submitted by the Contractor for review and approval by the Owner prior to the Contractor or the Erection Engineer beginning work on the Erection Plans and Procedures, procedures, and calculations. Unless otherwise specified in the Contract Documents, the Owner shall be allowed a minimum of 10 working days to review the submittal, after which the Contractor may assume the submittal has been approved by the Owner, unless the Owner provides written notification that the submittal was not approved.

to exercise reasonable discretion, subject to the approval of the Owner in advance.

For each project, the Owner (or the Owner's Design Engineer) should evaluate the complexity of the bridge and of the proposed erection sequence prior to bidding. If there are any particular areas of concern, the Owner (or the Owner's Design Engineer) should specify their expectations explicitly in the Contract Documents. This may include specification of design criteria, analysis methods, or identification of specific items to be addressed in the Erection Plans and Procedures, procedures, and calculations submittal, including identification of how these items are expected to be addressed.

The specifications in this Section provide only the minimum requirements regarding calculations for structural adequacy and stability. This Section does not provide a comprehensive "checklist" of items needing evaluation for erection of any steel bridge; each project is unique and may have particular issues requiring the attention of the Erection Engineer. Only basic requirements and suggested evaluation items (in commentary) are presented herein.

C2.4.1

Traditionally, the Erection Engineer has been allowed reasonable discretion in identifying appropriate design criteria for Erection Engineering Calculations for the design of temporary works, etc. In some cases, the provisions published in AASHTO documents do not address the unique situations associated with erection engineering and temporary works. In other cases, Erection Engineers have established efficient and effective methods based on criteria other than AASHTO specifications. Commonly cited supplemental design specifications include AISC specifications for steel design and ASCE specifications for wind loads, among others. Applicable design criteria are provided in Appendix D of FHWA-NHI-15-044, *Engineering for Structural Stability in Bridge Construction*.

2.4.2—Loads and Load Combinations

The Erection Engineering Calculations shall consider all applicable loads, including permanent dead load, construction dead load, construction live load, and wind loads, and any other loads which may be applicable.

Wind loads shall be considered in each step of the steel erection analysis and are to be computed in accordance with the agreed erection design criteria. Provisions shall be made by the Erection Engineer to ensure that girders are stable in wind events. It is permissible to set limits on maximum wind velocities during steel erection; these limits shall be stated in the Erection Plans and Procedures. If applicable, include provisions in the Erection Plans and Procedures for temporary supports, tie-downs, or both to address high wind conditions.

Load combinations shall be in accordance with the *AASHTO LRFD Bridge Design Specifications*, unless otherwise noted in the Contract Documents, or unless otherwise approved by the Owner. If the Contractor proposes supplemental design criteria (in accordance with the provisions of Article 2.4.1), the Contractor may also propose supplemental load combinations for specific items provided the supplemental load combinations are consistent with the proposed design criteria. Proposals for supplemental load combinations shall be submitted by the Contractor for review and approval by the Owner prior to the Contractor or the Erection Engineer beginning work on the Erection Plans and Procedures and the Erection Engineering Calculations. Unless otherwise specified in the Contract Documents, the Owner shall be allowed a minimum of 10 working days to review the submittal, after which the Contractor may assume the submittal has been approved by the Owner, unless the Owner provides written notification that the submittal was not approved.

2.4.3—Girder and System Stability

The Erection Engineering Calculations supporting the erection procedures shall verify the stability both of individual girders and also of the entire erected steel framing for each step of the bridge erection. These calculations are dependent upon the particular features of the bridge being erected and also of the particular sequence of erection of each part of the bridge. The assumptions used in the analysis should directly

C2.4.2

Permanent dead loads typically include the self-weight of the structural members and detail attachments. Construction dead and live loads may consist of deck placement machinery, Contractor's equipment, deck overhang brackets, concrete formwork, or other similar attachments applied in the appropriate sequence.

C2.4.3

The constructability provisions of Article 6.10.3 of the *AASHTO LRFD Bridge Design Specifications* should be referenced by the Erection Engineer when investigating structural adequacy and stability during steel erection. A partial list of suggested evaluation items and guidelines regarding appropriate investigations follows:

and fully conform to all steps and all details in the Erection Plans and Procedures.

Single-Girder Stability

Particular attention should be given to the lateral–torsional buckling capacity of a singly erected I-girder. One of the most critical stages during I-girder erection is when the first girder has been erected, but not yet connected to adjacent girders in the cross section. Assuming the girder is adequately braced at the supports, and there is no additional bracing within the span, the unbraced length for the girder will be the distance between supports. Long unbraced lengths typically correspond to very low lateral–torsional buckling capacity of the girder. Tub-girders typically have much higher lateral–torsional buckling capacity, but only if provided with a properly-designed top flange lateral bracing system that provides for quasi-closed section behavior of the girder.

Global overturning stability is also a concern for single curved girders, whether I- or tub-girders. The offset of the center of gravity of the girder from a chord line drawn between the support points results in an overturning moment. Single girders typically have no torsional restraint at their supports unless tie-downs or bracing, or temporary shoring or hold cranes, are provided.

Multi-Girder (Global) Stability

A girder system may be vulnerable to global buckling during the steel erection sequence, during deck placement, or both. Narrow, long-span segments during steel erection are the most susceptible to this global buckling phenomenon. Methods to investigate the global stability of girder systems are available in FHWA *Engineering for Structural Stability in Bridge Construction*, publication number FHWA-NHI-15-044.

Second-Order Amplification Estimates

Second-order amplification of the girder lateral–torsional stresses may cause a loading condition that is greater than the theoretical elastic buckling load. In this situation, the lateral–torsional displacement of the girder results in non-linear torsional loading. In addition, the displacement amplifications may complicate the prediction and control the structure's geometry during erection. AASHTO/NSBA Steel Bridge Collaboration document G13.1, *Guidelines for Steel Girder Bridge Analysis*, provides further discussion of second-order amplification considerations.

In addition, a relatively simple method for identifying potentially adverse response