Steel Bridge Design Handbook

CHAPTER 11

Design for Constructability

Foreword

The Steel Bridge Design Handbook covers a full range of topics and design examples to provide bridge engineers with the information needed to make knowledgeable decisions regarding the selection, design, fabrication, and construction of steel bridges. The Handbook has a long history, dating back to the 1970s

TECHNICAL REPORT DOCUMENTATION PAGE

1. Title and Subtitle
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2.0 GENERAL

Bridge erection takes on many forms based on the site, the complexity of the structure, the availability of equipment, and the expertise of the erection contractor. In the following paragraphs, basic erection equipment is discussed with specific examples shown for different bridge types including considerations regarding the access to and topography of the construction site.

2.1 Equipment

Cranes come in various types and sizes. Each type of crane has specific advantages and disadvantages depending on numerous variables such as pick weight, pick height and radius, number of picks, site access, site location, constraints, etc. The following crane types are used in typical bridge erection:

Mobile hydraulic cranes are used for light- to medium-weight picks up to 650 tons. These cranes are used where the site is readily accessible via existing roadways, where pick heights are relatively low, and where crane area is limited. A typical application would be in the replacement of an existing grade separation bridge. These cranes come in a wide variety of sizes such that the appropriate crane can be used for the given pick weight and space availability. The set-up and tear down are quick through the use of telescoping hydraulic outriggers. In addition, the mobility and reach are versatile due to the telescoping boom and 360-degree rotational capability.

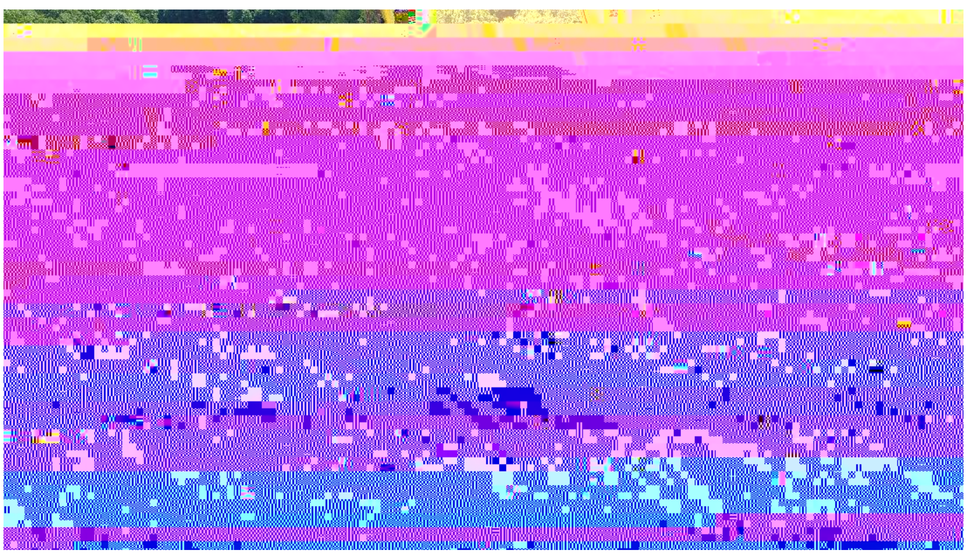

Figure 1 Mobile hydraulic cranes used during bridge erection

Mobile lattice boom cranes are used for light-to medium-weight picks up to 300 tons. These cranes are used when the site is accessible via existing roadways and where pick heights are high. Through the use of telescoping hydraulic outriggers and self-assembly capabilities, the set-up and tear down are quick compared to other crane types, generally one to two days for assembly of multiple trailer loads. In addition, the reach is versatile with 360-degree rotational capability.

It should be noted that mobile lattice boom cranes and mobile hydraulic cranes cannot move once the pick is lifted.

Figure 2 Mobile lattice boom crane

Lattice boom crawler cranes

Figure 3 Lattice boom crawler crane

Lattice ringer cranes are used for heavyweight picks up to 1,400 tons. These cranes are used where the site is typically unfinished open terrain and where pick heights are high (up to 400 feet). Typically, once assembled the crane is immobile due to the track work used to suppe s79 Tm0 g0 G[( )] T

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Figure 4 Lattice ringer crane

Tower cranes are used for lightweight picks up to 20 tons. These cranes are used where no mobility is required, and excessive vertical heights must be overcome. A typical application would be in the construction of a tower for a suspension or cable stayed bridge. These cranes come in a wide variety of sizes to meet the need for a particular height and reach. The setup and tear-down are extremely long due to the assembly process. Quite often, a separate foundation must be constructed to support the base of the tower leg. Once in place the crane can be highly productive in delivering materials to the elevation required. Some models come with self-jacking tower legs that allow the crane to adjust its height as construction progresses.

Figure 5 Tower crane

Along with these different crane types, various erection accessories are typically used to maximize the crane's capabilities and function. Some of these accessories are described in the following paragraphs.

2.2 Erection

The art of bridge erection has evolved over time to keep pace with technological advancements in machinery and accessories. Even with today's advanced computer-controlled equipment, the most important aspect of bridge erection lies in the experience of the personnel performing the work. Since the objective of safely assembling the structure into its required configuration remains unchanged, the experience necessary to achieve this goal is paramount to success. The following paragraphs discuss different rigging schemes that are traditionally used in bridge erection along with various methods of erection available for I-girder, box girder, truss, arch and cable supported structures.

The rigging of a member in preparation for erection can take on many forms based on the size, weight, geometry and capacity of the individual member as well as the size, capacity and location of the erection crane. In its simplest form, rigging could consist of a single vertical sling hooked to the crane and attached to the member with a beam clamp or through the use of a wire rope sling around the member. In a more complex form, rigging could consist ETQ2 792 /F2 12 Tf1 0 0 1 72.02

Crane mats are a series of timber or steel members assembled in sections beneath the crane to

Figure 8 Pier brackets in an I-girder bridge

Hydraulic jacks are often used in c

Figure 9 Use of a spreader beam for I-girder erection

Figure 10 Box girder erection using two crawler cranes

An alternate girder erection method consists of launching the completely assembled bridge longitudinally across the permanent supports. This method of erection can be utilized for both I-girder and box girder bridges. To accomplish a girder launch, the superstructure is assembled on a roller system behind one of the abutments in segments of sufficient length to maintain stability

Figure 13 Cantilever erection of a continuous truss using barge mounted cranes

Arch bridge erection is typically performed using a temporary stay tower located at the spring line (end pier for tied arches) with stay cables connecting the partially completed arch to the tower on the leading end and the tower to counterweights or ground anchors on the trailing end. Erection begins at each spring line and progresses toward the crown. As arch pieces are erected, additional stay cables are added to provide temporary support until the closure piece is in place and the arches are self-supporting. Arch pieces can be erected into place by cable and winch systems attached to the leading end of the previous segment or by cranes located beneath the bridge, if feasible. Using temporary stay towers is the most common erection method since arch bridges are predominantly used to span deep canyons (true arch) or wide bodies of water (tied arch).

Figure 16 Arch bridge erection using the floor system as an erection tie to the canyon wall

Cable stayed bridge erection is performed utilizing a permanent tower to support all loads during

Figure 17 Cantilever cable stayed bridge erection using deck mounted derricks

Suspension bridge erection is performed by using the permanent bridge members for support of the partially completed superstructure. After the main towers are constructed and the main suspension cables are strung, the superstructure erection begins at the tower.

One method of erecting the deck members follows the cantilever scheme where members are erected directly at the tower and attached using temporary supports. After the first members are stabilized, additional pieces are cantilevered from each end in an alternating fashion until the location of the first permanent suspender is passed. At this point, the first set of suspenders is installed to connect the cantilevers to the main cable. Alternating cantilever erection of members continues along with suspender installation until the end pier or mid-span is reached. This procedure is repeated for each tower of the bridge. In ofuf12 792 nrcidge. In ofuf12 792 nrcidge.Mf13(nmuur)-

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Figure 19 Tied arch sliding laterally in place, by use of barges

Another method of Accelerated Bridge Construction is by way of constructing superstructure modules. Modules typically consist of multiple girders (usually two), associated cross-frames, and a concrete deck spanning between the girders. Modules are constructed, either in a staging area adjacent to the bridge's final location or in a fabrication shop. During erection, the modules are lifted into place and are connected to adjacent modules by way of cross-frames at the girder level and by closure pours (typically with fast-setting, high performance concrete) at the deck level. This technique reduces the construction duration and minimizes road closures.

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Another scenario could be the replacement of an existing bridge that spans commuter rail lines in a congested urban area. Again, due to required rail clearances the recommended solution would be to construct a new multi-span girder bridge based on least material cost. If the commuter rail line imposes restrictions on the construction times with extreme penalties associated with violating track outage criteria, the contractor may need to include a large contingency to cover the potential fines. A more economical solution may be to design a single span structure to limit the construction work over and adjacent to the rail lines. The entire simple span structure could be completely erected on the adjacent roadway and lifted into position during a brief off-peak closure of the rail line. Again, the construction time would be greatly reduced, the contractor's risk would decrease, his productivity would increase, and consequently his overall cost would go down.

Another important consideration deals with equipment and storage areas. If the construction site

3.0 DESIGN CONSIDERATIONS

Various factors must be evaluated by the bridge designer to verify the constructability of the bridge. In the following paragraphs, basic design topics dealing with construction loads, deck placement, stability, and member fit-up are discussed as they relate to construction of the bridge. In addition, a brief overview of erection engineering and erection drawings is provided. All assumptions made during the design relating to construction loads and construction methods should be documented on the drawings for the contractor to use in developing his/her detailed construction plans.

3.1 Construction Loads

The *AASHTO LRFD Bridge Design Specifications, 9th Edition,* (referred to herein as the AASHTO LRFD BDS (9th Edition, 2020)) [4] do not completely address the loadings that should be considered during construction of steel bridges. Requirements for deck placement sequences and overhang deck brackets are supplied, but other conditions are not. Some general statements are provided stating that investigations should be made for handling, transportation and erection, but no quantification is given. Some guidance is provided for the application of load factors for dead loads, dynamic effects (impact) and wind, but specific load combinations are not explicitly defined.

Construction loads that would affect the component forces in the bridge during construction include deck formwork, overhang formwork and brackets, screed rail loads, walkways, handrails, construction live loads, screed live loads, wind loads on the structure and equipment, and any other anticipated loads specific to the particular bridge being designed. In addition, permanent loads, such as the weight of the uncured deck concrete, need to be considered in combination with the construction loads.

Construction equipment loads can be estimated based on bridge construction methods typically used by contractors in the region. Construction equipment could consist of power screeds used for concrete deck placement, work bridges used to support personnel performing deck placement activities, bridge-mounted erection systems (used more often in large, specialized bridge construction), bridge-supported concrete delivery systems, etc. The anticipated equipment loads should be determined for each individual bridge based on bridge type, member size, site location, etc. For example, a typical I-girder bridge would usually be subjected to only screed and work bridge loads.

Wind loads during construction can be one of the most critical aspects to evaluate for conventional girder bridges, since the concrete deck is typically used to transmit these force effects back to the support locations. Until the deck is placed and cured, the individual girders must be capable of transmitting these loads back to the supports through lateral flange bending. If the girders are not capable of resisting the wind loads on their own, a permanent lateral bracing system or another temporary system designed to resist these loads must be provided. Wind loads on the uncompleted steel superstructure should be considered by the designer during design, as well as the contractor’s engineer prior to construction.

Construction live loads should also be considered in evaluating the adequacy of the bridge. This loading is intended to cover all miscellaneous equipment and personnel that cannot easily be quantified at the time of design. Often a blanket allowance of 20 psf is used to account for these loadings [6].

Load combinations must be evaluated to capture all critical conditions during construction of the bridge after a thorough determination of all anticipated construction loads is complete. Article 3.4.2 of the AASHTO LRFD BDS (9th Edition, 2020) calls for the use of Strength Load Combinations I and III during construction. In evaluating these combinations, engineering judgment must be exercised to verify that the maximum feasible forces are being evaluated. Some sample load combinations are:

$$\gamma_p(DC+DW) + 1.5(CEL+CLL) + 0.5(TU) \text{ for STR I}$$

where:

γ_p is the load factor for dead load 0.9 min and 1.25 max (see the Steel Bridge Design Handbook module titled Loads and Load Combinations for a detailed explanation).

DC includes all dead load associated with the bridge members and all formwork, attachments, deck, etc.

DW includes all utilities.

CEL includes all construction equipment loads such as screeds, etc.

CLL is the construction live load.

TU is the thermal effect during construction

$$\gamma_p(DC+DW) + 1.25\ (CEL) + 1.0(WS) + 0.5(TU) \text{ for STR III}$$

Where:

WS is the wind on the exposed height of the structure including all forming.

Article 3.4.2 of the AASHTO LRFD BDS (9th Edition, 2020) also specifies an additional strength limit state load combination for the investigation of loads applied to fully erected steelwork. A sample load combination for this additional case is:

$$1.4(DC) + 1.4(CEL+CLL)$$

If there are varying stages of structural configuration associated with the design, additional construction load combinations should be evaluated to verify that all pertinent conditions are checked. For example, if the girders behave as simply supported for self-weight and continuous

triangular shape that are suspended from the top flange and supported by the girder web. The brackets are normally spaced on three to four-foot centers along the length of the bridge and support traditional wood forming. In addition to supporting the formwork for the deck overhang, the brackets usually carry an access walkway and screed rail to allow for deck placement machinery and personnel. The overhang brackets can create significant lateral flange bending forces in the top and bottom flanges of the fascia girder due to the eccentricity of the loads and the hanger connection to the flange. Since these lateral flange bending loads can often control the design of the top flange, the designer must calculate the magnitude of these loads and verify the capacity of the girder. The AASHTO LRFD BDS (9^{th}

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Figure 23 Sample deck placement sequence

Figure 24 Half-width construction staging sequence

3.3 Stability

Stability of the girders during erection and subsequent construction stages is of primary importance to the designer since it is typically the driving factor in the selection of cross-frame spacings, top flange width and lateral bracing requirements. The following paragraphs discuss

Once a cross-frame spacing and configuration are determined, the girder's flange lateral bending stresses must be checked for construction loads and permanent wind loads to determine if the results are acceptable. If the lateral effects control the design of the flanges, the cross-frame spacing should probably be reduced to allow for a balance between the vertical and lateral bending effects. The maximum limit for flange lateral bending stress, per AASHTO BDS, is $0.6F_y$, per equation 6.10.1.6-1.

Lateral bracing is typically used in longer span structures where the lateral flange bending stresses and/or lateral deflection cannot be effectively controlled by flange width and cross-frame spacing. The need for lateral bracing may often be dictated by the owner. One owner requires designs that do not use lateral bracing for spans under 200 feet, allows it to be investigated for spans between 200 and 300 feet, and requires it for spans over 300 feet. The bracing usually consists of WT sections and is normally connected directly to either girder flange. The lateral bracing creates a truss system between adjacent girders with the girder flanges acting as the chords, and the bracing members and cross-frames acting as the diagonals and "verticals", respectively. The optimum location (top or bottom flange) and configuration of the bracing has been debated for years and no explicit conclusions have been determined. The only definitive observation that can be made is that lateral bracing dramatically increases the lateral stiffness of the bridge regardless of location and configuration.

Often the largest drawback in the use of lateral bracing is the need to design the bracing need for addition hold cranes. One drawback to this scenario is the cost associated

Construction staging must be evaluated by the designer to verify stability of the bridge during all phases of the initial deck placement sequence, the conditions anticipated for the proposed future redecking scheme, and every stage associated with halfon the overall behavior of the bridge. For example, arch bridges must be properly cambered so

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