Steel Bridge Design Handbook

CHAPTER 2

Steel Bridge Fabrication

February 2022

Smarter.
Stronger.
Steel.

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by

American Institute of Steel Construction

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Printed in the United States of America

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 in various forms and publications. The more recent editions of the Handbook were developed and maintained by the Federal Highway Administration (FHWA) Office of Bridges and Structures as FHWA Report No. FHWA-IF-12-052 published in November 2012, and FHWA Report No. FHWA-HIF-16-002 published in December 2015. The previous development and maintenance of the Handbook by the FHWA, their consultants, and their technical reviewers is gratefully appreciated and acknowledged.

This current edition of the Handbook is maintained by the National Steel Bridge Alliance (NSBA), a division of the American Institute of Steel Construction (AISC). This Handbook, published in 2021, has been updated and revised to be consistent with the 9th edition of the AASHTO LRFD Bridge Design Specifications which was released in 2020. The updates and revisions to various chapters and design examples have been performed, as noted, by HDR, M.A. Grubb & Associates, Don White, Ph.D., and NSBA. Furthermore, the updates and revisions have been reviewed independently by Francesco Russo, Ph.D., P.E., Brandon Chavel, Ph.D., P.E., and NSBA.

The Handbook consists of 19 chapters and 6 design examples. The chapters and design examples of the Handbook are published separately for ease of use, and available for free download at the NSBA website, www.aisc.org/nsba.

The users of the Steel Bridge Design Handbook are encouraged to submit ideas and suggestions for enhancements that can be implemented in future editions to the NSBA and AISC at solutions@aisc.org.

TECHNICAL REPORT DOCUMENTATION PAGE

1. Title and Subtitle Steel Bridge Design Handbook Chapter 2: Steel Bridge Fabrication	**2. Report Date** February 2022
3. Original Author(s) Scott Krause (High Steel Structures, Inc.)	**4. Revision Author(s)** Brandon Chavel (NSBA)
5. Sponsoring Agency Name and Address National Steel Bridge Alliance, a division of the American Institute of Steel Construction 130 E. Randolph, Suite 2000 Chicago, IL 60601	**6. Revision Performing Organization Name and Address** National Steel Bridge Alliance, a division of the American Institute of Steel Construction 130 E. Randolph, Suite 2000 Chicago, IL 60601
7. Supplementary Notes The previous edition of this Handbook was published as FHWA-HIF-16-002 and was developed to be current with the 7th edition of the AASHTO LRFD Bridge Design Specifications. This edition of the Handbook was updated to be current with the 9th edition of the AASHTO LRFD Bridge Design Specifications, released in 2020.	
8. Abstract The purpose of this chapter is to explain the basic concepts of fabricating steel bridge structures. It is intended to serve as a resource for the engineer while preparing the design of the structure and as a reference throughout the life cycle of the bridge. The methods employed in the fabrication of a bridge structure are as variable as the structure itself. Each fabricator has its own way of solving the problems associated with each structure. This module is to serve as a reference document to facilitate fabricator/engineer communication.	
9. Keywords Steel Bridge, Fabrication, Quality Control, Quality Assurance, Welding, Plate Girders	**10. AISC Publication No.** B902-22

Steel Bridge Design Handbook:
Steel Bridge Fabrication

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1.0 INTRODUCTION

The purpose of this chapter is to explain the basic concepts of fabricating steel bridge structures. It is intended to serve as a resource for the engineer while preparing the design of the structure and as a reference throughout the life cycle of the bridge. The reader should be familiar with the AASHTO/NSBA Steel Bridge Collaboration Standards; S2.1, *Steel Bridge Fabrication Guide Specification* (1), and G12.1, *Guidelines for Design for Constructability and Fabrication* (2).

The methods employed in the fabrication of a bridge structure are as variable as the structure itself. The terms and procedures listed in the text are general and do not reflect any single firm's process. Each fabricator has its own way of solving the problems associated with each structure. This chapter is to serve as a reference document to facilitate fabricator/engineer communication.

2.0 GOVERNING SPECIFICATIONS

AISC (American Institute of Steel Construction) is the governing body that certifies fabricators. There are multiple levels of certification, from simple bridges to advance bridges with fracture critical endorsements and sophisticated paint endorsements. The AISC Certification website provides more information on the certification types as well as the identifying those fabricators that have been certified by AISC: https://www.aisc.org/certification/.

AASHTO (American Association of State Highway and Transportation Officials) adopts specifications that are generally the controlling documents for the design and construction, including tolerances, of steel bridges. These documents include the *AASHTO Standard Specifications for Highway Bridges*, (3), and the *AASHTO LRFD Bridge Design Specifications, 9th Edition* (4) *and the AASHTO LRFD Bridge Construction Specifications* (5).

ASTM (American Society for Testing and Materials) documents provide guidelines for acceptability of the material purchased. These guidelines include, among others, dimensional tolerances, chemical compositions and tensile and yield strengths.

The AASHTO/AWS (American Welding Society) *D1.5 Bridge Welding Code* (6) controls the welding, testing and quality assurance portions of the superstructure including tolerances of fabricated members. This document also contains the Fracture Control Plan for Non-Redundant Members.

Association for Materials Protection and Performance (AMPP) (7) produces documents which apply to the coating and surface preparation of steel superstructures. In 2021, the National Association of Corrosion Engineers (NACE) International and the Society for Protective Coatings (SSPC) combined to form the AMPP to serve the global corrosion and coatings industry.

Owner Specifications augment and/or supersede the above documents.

AASHTO/NSBA Steel Bridge Collaboration Documents provide beneficial information regarding the state-of-the-art principles for steel bridges. These include the following:

- S2.1, *Steel Bridge Fabrication Guide Specification* (1)
- G12.1, *Guidelines for Design for Constructability and Fabrication* (2)
- S8.1, *Guide Specification for Application of Coating Systems* (8)
- S8.2, *Specification for Application of Thermal Spray Coatings for Steel Bridges* (9).

3.0 MATERIAL PROCUREMENT

3.1 Steel Attributes

3.1.1 ASTM vs. AASHTO

Steels for bridge structures manufactured domestically are generally specified to conform to either ASTM A709 or AASHTO M270. These specifications are generally equivalent and include the composition of the steel and the grades allowed by the specification. Although ASTM A709 is specified more frequently, the owner stipulates which specification to use.

3.1.2 Grades

The names of the grades covered by the ASTM and AASHTO requirements are equivalent to the yield strength of the steel, e.g. Grade 50 indicates that $F_y = 50$ ksi.

3.1.3 Weathering Steel

Weathering steel has a certain metallurgical composition that permits the steel to form a protective coating and not require additional coatings to prevent corrosion. Material with this composition is appended with a “W”, e.g. Grade 50W indicates that $F_y = 50$ ksi and it is a weathering steel.

3.1.4 High Performance Steels (HPS)

ASTM A709 HPS50W, HPS70W and HPS100W steels are products that have F_y of 50, 70 and 100 ksi (respectively). In addition, these classes of steels have superior toughness properties compared to non-HPS materials.

The production of HPS steel at the mill imposes certain market realities that limit their use to specialized situations. HPS steels generally are more expensive than non-HPS steels. HPS steels generally have a longer lead time than non-HPS steels. In addition to these two items, there is a minimum tonnage required for ordering HPS material per thickness. The fabricator may be able to combine tonnages from several projects to obtain the minimum tonnage required for ordering. Because of this requirement, it is generally better to limit the use of HPS material to webs and flanges, and not field splice material or stiffeners. Additionally, HPS material is available only in plates; structural shapes are not available.

3.1.5 Charpy V-Notch (CVN) Testing

Charpy testing is a process used to determine a measure of the fracture toughness of the subject steel. Material requiring CVN testing should be noted as such on the contract documents. The fabricator incurs additional cost to obtain these tests. Material requiring CVN testing shall be so noted on the mill orders and test reports, and in some cases, noting of CVN testing may be placed on the steel itself. CVN requirements on structural shapes subject to Zone 3 service temperatures (-31°F to -60°F) are difficult to achieve with consistency.

3.1.6 Fracture Critical Members (FCM)

Fracture Critical Members (FCM's) must be called out on the contract documents. The steel for FCM's is required to exhibit a higher toughness (and cost) than corresponding non-FCM steels.

The AASHTO/AWS *D1.5 Bridge Welding Code* (6) outlines fracture critical member requirements in the Fracture Control Plan (Section 12 in D1.5). The fabricator incurs additional cost due to increased documentation requirements, more restrictive testing and heating parameters for welding.

3.2 Ordering of Material

3.2.1 Steel Plates

Due to the lead times associated with structural steel, material required for the structure typically must be ordered in advance of fabrication. These lead times range from a few days to 10 to 14 weeks depending upon the grade, thickness and market conditions. Generally, plate material for main members (webs, flanges, etc.) is ordered per specific project requirements. Fabricators do not inventory large stocks of raw material. Plate material for stiffeners, gusset plates, etc. will more likely come from a steel service center.

Plate mills generally roll material in preset widths and thicknesses. The fabricator nests the parts required to fabricate the project (webs, flanges, etc.) on these preset sheet sizes to maximize the use of the material. The fabricator may combine pieces from different projects to best use the material.

3.2.2 Steel Shapes

Structural shapes are rolled on a schedule. This may lead to longer lead times if the order is not placed when the mill is rolling that shape, and the next rolling will not be for a while. Additionally, due to the minimal tonnage of shapes required for secondary members, it is more likely the shapes will be purchased from a steel service center. Steel service centers often have large stocks of structural steel shapes.

Minimizing the number of different steel grades, thicknesses and structural shapes on a project is the most cost-effective.

3.3 Material Traceability

All material for steel bridges must be marked with the grade, specification, and heat number as a minimum. The material will arrive from the mill with the heat numbers stenciled on the plate. Chemical composition and testing results are recorded by heat number. These are two main criteria that are reviewed by the owner's representatives. The fabricator needs to record this heat number and the piece it is consumed into so each component of the bridge can be traced back to the heat it was produced from. The heat numbers must remain traceable throughout the fabrication process.

4.0 QUALITY CONTROL/ASSURANCE

4.1 Role of QC/QA Staff of Fabricator

Generally, all work completed by the fabricator is inspected and signed off in process by the fabricator's Quality Control (QC) department. The QC department documents information needed during fabrication, assembly, painting and shipment. This includes material test reports (MTR). They also will serve as liaison between the owner's representative and the fabrication group.

4.1.1 Non-Destructive Weld Testing (NDT)

Certain welds on bridge superstructures are required to be tested for weld soundness and quality. There are several methods of testing with the following being the most prevalent. AWS D1.5 and owner specifications stipulate which welds need to be tested and the method that is to be used.

4.2 Radiographic Testing (RT)

RT is essentially an X-ray of the welded joint. RT is capable of detecting embedded flaws and is generally used for butt splices in webs and flanges. RT is not used for corner and T-joint complete joint penetration (CJP) welds due to the inability to get an accurate radiograph of the joint.

Due to the radiation used for this test, metal shielding and a clear space around the testing environment are necessary for safety. Figure 1 shows the shielding apparatus required for this testing method. Qualified personnel are mandatory to administer the inspection. Where other options are available, this method is not preferred due to these issues which increase cost and duration.

Figure 1 Photo showing the radiographic testing (RT) of a complete joint penetration weld (CJP) with clear area and shielding provided

4.3 Ultrasonic Testing (UT)

UT is similar to an ultrasound for a joint. UT is capable of detecting embedded flaws and is used for butt splices in webs and flanges as well as corner and T-joint complete penetration welds.

Ultrasonic waves are directed at the joint to discover discontinuities and defects in the weld. Qualified personnel are required to administer the test, but because shielding and clear space are not required for this test, it is generally more economical to utilize this form of testing than RT.

4.4 Magnetic Particle

Magnetic Particle Inspection utilizes red oxide powder and a magnet to determine the soundness of fillet welds and partial joint penetration (PJP) welds. The powder is spread over the joint and a magnet is placed at the area to be tested. The oxide gravitates toward any defect in the weld. Generally, defects up to 1/8” deep can be detected.

4.5 Dye Penetrant

Dye Penetrant testing is used sparingly in the fabrication process. The test consists of placing dye on the weld. The dye migrates toward any defect in the weld, and highlights the extent of the defect. It is employed by welders to insure they have reached sound weld metal.

4.6 Visual

Visual inspection can and should be used for all welds, although it can detect only surface flaws such as surface porosity, undercuts and inclusions. A proper weld profile can also be verified visually.

4.6.1 Coatings

To be certified to apply coatings on fabricated steel, a fabricator will have a quality control program that satisfies AISC requirements. This includes proper application and inspection methods to ensure the coating system complies with the project specifications.

4.7 Role of Owner's Inspection Representative

All documentation generated by the fabricator is subject to a Quality Assurance (QA) check by an agency hired by the owner to verify the work complies with the plans and specifications of the contract. Additionally, the representative may be required to be present to witness some activities performed by the fabricator.

5.0 PRE-FABRICATION PREPARATION

5.1 Creation of Components

Much work is completed prior to the fabrication of girders, cross-frames, etc. This section details the more common operations used to create the components required to fabricate the steel members necessary to construct the superstructure.

5.1.1 Layout

There are two common methods utilized to layout steel components. The first is a manual layout process, and the second is utilizing Computer Numerically Controlled (CNC) machines.

The manual method of layout uses the shop detail drawings to lay out the cut lines, orientation marks and hole locations on the steel.

Many CNC machines have the capability to lay out these same markings. Multiple processes can be utilized to place markings on the steel to use as fabrication aids. The more common methods are stamping, zinc marking and plasma marking. Generally, stamping is allowed but there are limitations on the depth permitted by state specifications. Zinc marking is allowed and is very common. Plasma marking is not allowed by some states, as depth of marking is a concern.

5.1.2 Computer Numerically Controlled (CNC) Programs

Many fabricators utilize CNC machinery in the fabrication process. The tool, be it a burning, drilling, punching or milling head, moves along a path which is controlled by a computer. This reduces the chance for error and increases the effectiveness and efficiency of the fabricator.

The program to run the machine can be generated at the machine, by the detailer or the fabricator’s own CNC group. The operator then downloads the code to drive the machine.

5.2 Cutting of Steel

5.2.1 Oxy-fuel

Oxy-fuel is the standard cutting process for most steel bridges (see Figure 2). Oxy-fuel cutting essentially burns the steel, so the process is somewhat slower than plasma. Due to the increased duration of high temperatures from the burning operation, some grinding of the burned edges may be required for coatings to adhere.

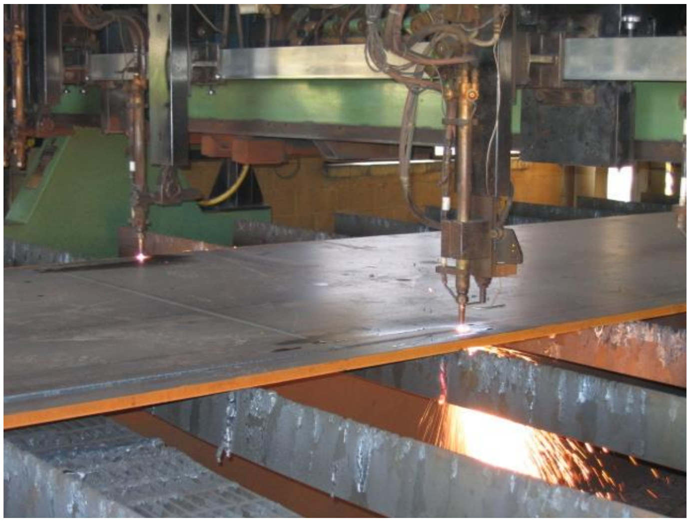

Figure 2 Photo showing oxy-fuel torches burning in tandem

5.2.2 Plasma

Plasma cutting is one of the most efficient means of cutting steel. An electrical arc, which liquefies the steel, superheats a high-pressure stream of gas, and the gas pressure "cuts" the steel. Due to the increased speed, less heat is transferred to the steel, resulting in less distortion experienced throughout the fabrication process. This process is illustrated in Figure 3.

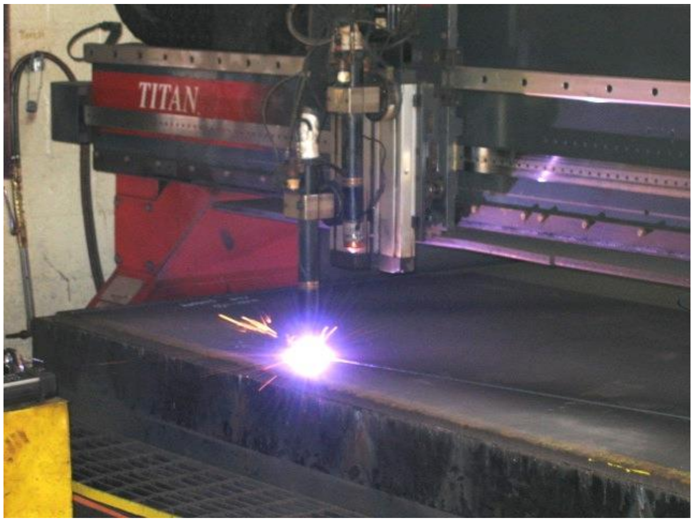

Figure 3 Photo showing a plasma torch in process

5.2.3 Shearing

Shearing of steel is an effective way to cut straight lines. It utilizes hydraulic "knife edges" to shear the steel where the two edges meet.

5.2.4 Saw Cutting

Saw Cutting is generally reserved for structural shapes. The saw is shaped similar to a large band saw or circular saw, with the saw head moving through the steel, rather than the steel moving through the saw. See Figure 4 below.

Figure 4 Photo showing the saw cutting of a shape

5.2.5 Hole Placement

5.2.5.1 Punching

Punching is where a steel cylinder is hydraulically pressed into a die, thus creating the hole in the material. There are limits governing whether material can be punched. One limit is the thickness of the material and the size of the hole. Another limit is the usage of the material, such as whether the member is a primary or secondary member, or whether the member is a fracture critical member. Article 11.4.8.1.1 of the AASHTO *LRFD Bridge Construction Specifications* (5) specifies the limits for punching of bolt holes. .

5.2.5.2 Drilling

Holes for bolted field connections of primary members must be drilled. Additionally, holes in material thicker than allowed for punching must be drilled. Article 11.4.8.1.1 of the AASHTO *LRFD Bridge Construction Specifications* (5) specifies the limits for punching and drilling of bolt holes.

5.2.5.3 Burning

Certain holes, generally larger diameter holes not associated with bolts, may be burned (flame cut). Depending upon the thickness and equipment possessed by the fabricator the hole may be placed by plasma or oxy-fuel.

5.2.6 Bending of Steel

Steel may be bent one of two ways, with or without heat. The fabricator will choose to bend certain portions of the steel with heat, primarily to reduce the force required to bend the plate. The affected area is heated to a temperature range, which varies depending upon grade, size and owner specification, and then an outside force is applied to the piece that is to be bent. Spring back from this process can be an issue that needs to be addressed before forming. Heat assisted forming is used typically on thick plates and when bending with the grain of the material.

Cold bending is generally faster and less expensive than heat bending. The piece that is to be bent will either be placed into a hydraulic press brake or into a series of rollers. The steel is then incrementally formed to the required shape.

There are limitations to the use of cold bending. AASHTO/AWS D1.5 and owner specifications must be adhered to when proposing method of bending. Article 11.4.3.3 of the AASHTO *LRFD Bridge Construction Specifications* (5) specifies certain limitations regarding bending of steel as well.

5.3 Determination of Primary (Main Load Carrying) Members

Primary members, also referred to as “main members” should be listed on the contract documents as well as noting tension and compression flanges. Primary are subjected to more stringent fabrication and testing requirements. There is additional testing of the material, additional NDT on the welds, restrictions in the methods employed in the placement of holes and additional assembly requirements may apply. Clear documentation of what is a primary member will streamline this process.

6.0 WELDING

6.1 Shielded Metal Arc Welding (SMAW)

SMAW or "stick" welding is the welding process with which most people are familiar. The electrode for this process is coated with flux that vaporizes upon use, thus shielding the molten metal from impurities in the outside environment.

This process is generally used to "tack" pieces of steel together until these welds can be absorbed by the full welds placed by a subsequent process, typically SAW. Other uses of SMAW occur when the configuration of the pieces to be joined does not allow the space required for the equipment of the subsequent process or if the welding needs to be performed out of position.

6.2 Submerged Arc Welding (SAW)

SAW is the most prevalent process used in the fabrication of steel superstructures. The electrode for this process is solid wire while the flux is supplied via a separate gravity-fed tube. See Figure 5 for the basic equipment used in this process. The arc is submerged below a blanket of flux, protecting it from impurities in the outside environment. Use of the SAW process is limited to the downhand position, thus the material must be manipulated to the proper position for welding.

The equipment used to create this weld is somewhat bulky and sufficient clearance is required to allow the use of this process. The primary advantage of this process is it is semi-automatic and thus highly productive.

Figure 5 Photo of Submerged Arc Welding (SAW) equipment

6.3 Flux Core Arc Welding (FCAW)

FCAW is another process used to join material. The electrode for this process contains material in its core that, when burned by the heat of the arc, creates shielding gases and fluxing agents that protect the weld from impurities in the outside environment.

6.4 Gas Metal Arc Welding (GMAW)

GMAW is a process that utilizes inert gases to protect the weld from the outside environment. The electrode is solid wire and the gas is supplied from an external supply. Since gases are used to shield the weld, this process is generally not used outdoors without protective shelters. GMAW is prevalent in other industries and is gaining acceptance in the bridge industry; preferred for its versatility, speed and the relative ease of adapting the process to robotic automation.

6.5 Narrow Gap Improved Electro-Slag Welding (NGI-ESW)

NGI-ESW is a welding process that deposits a large amount of weld per minute, reducing the amount of time spent welding joints, such as shop flange splices. Economy is generally realized when welding plates 1½" or greater in thickness.

The plates to be welded are aligned vertically ¾" apart (see Figure 6). Water-cooled copper shoes are positioned on both sides of the gap creating a cavity between the two plate ends. Welding wire is fed down through a consumable guide tube into the cavity. The arc creates a molten puddle from the steel, consumable guide tube and welding wire.

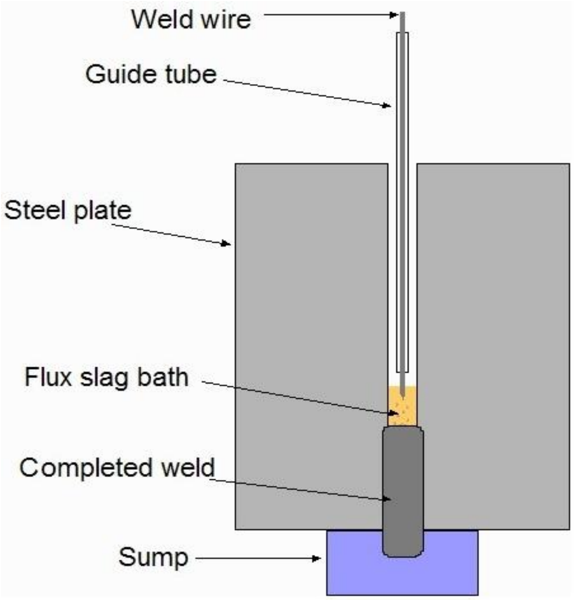

Figure 6 Schematic of the Narrow Gap Improved Electro-Slag Welding (NGI-ESW) process

6.6 FHWA Bridge Welding Reference Manual

For more information regarding welding techniques and the technical aspects of welding steel highway bridges, the reader should review the FHWA Bridge Welding Reference Manual (10). The reference manual explains welding specifications governing highway structures, and the relationships to structural performance and design intent. The manual provides a detailed overview of welding materials, equipment and processes; includes a discussion of various inspection techniques and methods; addresses the special welding requirements in the fracture control plan (FCP); and discusses the engineer’s role in welded fabrication including the creation of contract documents, approval, and dealing with unexpected circumstances.

7.0 FABRICATION: PLATE GIRDERS

Plate girders comprise the majority of longitudinal members in steel superstructures. They consist of a web and two flange assemblies, fabricated from a series of flat plates that are welded together. The length of plate girders is generally constrained by shipping and erection limitations. This section details the general steps of fabricating steel plate girders.

7.1 Preparation of Webs and Flanges

Web plates are burned with the required camber from the ordered plates. Generally, the cutting is done by CNC burning machines, but some fabricators still utilize a manual layout and mechanically guided burning equipment. Depending upon the length of the girders, shop splices may be introduced. If so, a complete joint penetration weld is used to make the web the correct length. The weld is subjected to NDT per the specifications.

Fabricators have different facilities, so the maximum length of raw plate varies. Certain fabricators can receive and handle plates as long as the mill can roll them; others will introduce butt splices if the plate is longer than they can handle (Figure 7). Each mill has limits on the dimensions of plates they are able to roll due to equipment at their site. The fabricator will designate on the shop drawings proposed butt splice locations.

Figure 7 Photo in a fabrication shop showing the butt welding of steel plate slabs prior to cutting the flanges

Flange plates are burned from a parent plate as well. Depending upon the configuration of the girder, the fabricator may be able to weld the slabs together and then strip the flanges from this assembly as illustrated in Figure 8. It is economical for the fabricator to utilize this procedure. However, this procedure can only be used if the flange thickness transitions are consistent between adjacent girders and if girder shop splices transition in thickness but not in width. It is recommended that the flange dimensions remain consistent between adjacent girders within a field section. Flange widths should be constant within a field section. Varying flange widths or curved girders do not permit slab welding.

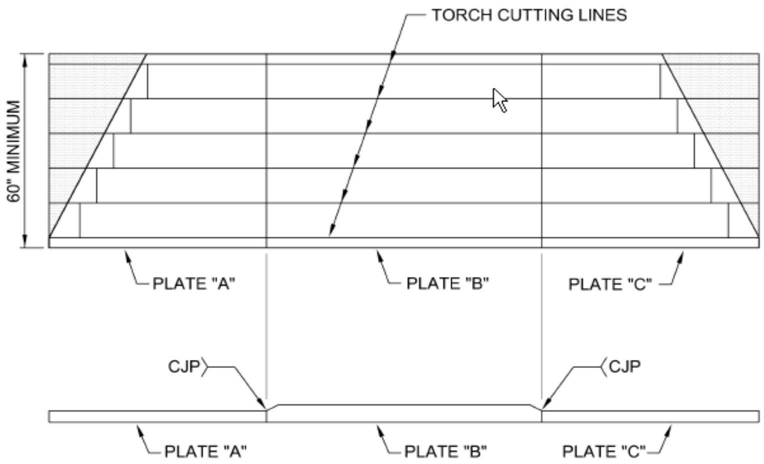

Figure 8 Sketch showing slab welding

The number of different flange plates on a girder should be kept to a reasonably small number. Too many splices, even though saving cost on raw steel, increase the fabricator's cost and time spent in the shop.

7.2 Assembling the Girder

After the individual web and flange assemblies are welded and all NDT has been completed, they are ready to be assembled into girders. The two most common methods to build a girder are with the web either horizontal, or vertical.

When building a girder with the web vertical, one of the flanges is blocked to the proper camber, and the web is brought into the flange. It is centered on the flange, and then tack welded to the flange. The other flange is set on the web and tack welded to the web. When building a girder with the web horizontal (Figure 9), the web is supported on blocks, the flanges are brought into the web and tack welded in place.

There are many variations of machinery that automate this building process. The machinery can build the girders web horizontal or web vertical. The machines also incorporate the next step (welding) into the process.

Figure 9 Photo showing the building of girders with its web horizontal

Moving the pieces necessary to build a girder requires several cranes (Figure 10). Not only are the pieces heavy, but they are also flexible. It is only after the girder is assembled that some rigidity is attained.

Figure 10 Photo showing overhead gantry type cranes handling material

7.3 Welding the Girder

After the webs and flanges have been tack welded to each other, they are welded together. Generally, this is accomplished using the submerged arc welding process, which remelts and incorporates the tack welds into the finished weld (Figure 11).

Figure 11 Photo showing the welding of a plate I-girder web to its flange

Single pass welds are the most economical, as the equipment travels the length of the girder only once. Multiple pass welds should be avoided where possible to minimize the cost and duration of fabrication.

Where design stresses permit, fillet welds rather than complete joint penetration (CJP) welds should be used to make the web-to-flange connection. With CJP welds, additional preparation of the base metal, additional welding passes, back gouging of the weld root, and NDT are required to complete the joint, adding time and cost to the product.

7.4 Fitting Transverse Stiffeners

After the girder has been assembled and welded, the stiffeners are installed (Figure 12). They are laid out and placed in the proper position, and welded into place. If a certain fit is required between the stiffener and flange (e.g., tight fit or mill to bear), it is accomplished at this point. Due to the equipment used to weld the stiffener in place, it is generally desirable to maintain 8" minimum between adjacent stiffeners.

Figure 12 Photo taken in a fabrication shop showing the fitting of transverse stiffeners

7.5 Finishing

After the stiffeners have been welded, any ancillary pieces are added to the girder (e.g., drip bars, handrails, etc.). Once all fabrication and NDT (e.g., magnetic particle testing on fillet welds) have been completed, a final geometry check is completed to ensure conformance with fabrication tolerances.

8.0 FABRICATION: STRINGERS

Stringers are efficient superstructure members. There is minimal fabrication compared to other main members. Stringers are generally "W" shapes and are subject to mill rolling dimensions and schedules. Due to the changing of the rollers at mills, certain shapes may have longer lead times than others. Additionally, due to the ingot size, certain sizes have length limitations.

The fabrication of stringers is straightforward. A beam is brought into the shop, where camber and sweep are introduced into the beam. This is done by heating the beam or cold gagging depending on the specifications. It may be more economical for the fabricator to build a welded girder due to the camber and sweep required on a rolled beam stringer. The fabricator should be allowed to substitute a girder for a stringer in these circumstances.

Cover plates may be required. These are put on after some camber has been introduced. If cover plates are required, thought should be given to the configuration of the cover plate on the stringer to allow the weld to be completed efficiently. Generally, a minimum of 1" from the edge of the cover plate to the edge of the beam is required to efficiently weld a cover plate to the beam. Additionally, the use of cover plates requires specific considerations regarding fatigue design by the engineer, in accordance with the AASHTO *LRFD Bridge Design Specifications* (4).

The stiffeners and field splice hole patterns are then laid out on the beam. The stiffeners are welded, and the holes are drilled. Any NDT is completed at this time, and a final geometry check is made to ensure conformance with the shop drawings.

9.0 FABRICATION: TRANSVERSE FRAMING MEMBERS

Transverse framing members are generally considered secondary members. When these members are designated secondary members, it allows the most flexibility to the fabricator and makes the members less costly to fabricate. When transverse framing members are designated as primary members, additional testing of the base material, restrictions in the methods employed in the placement of holes, and NDT of the members occurs, adding cost.

9.1 Rolled Shape Diaphragms

Rolled shape diaphragms are efficient transverse framing members. Fabrication is generally less involved than it is for other types of framing members, but their use is limited to shallow girder or stringer structures.

9.1.1 Fabrication

Generally, there are two methods to fabricate a rolled shape diaphragm. It is the fabricator's preference, based on his equipment and personnel, as to which method to choose. With the first method, the fabricator cuts the diaphragms to size first, and then places the holes. This method is effective for square or simple diaphragms. The second method is to place the holes in the beam first, then cut the diaphragms after the holes are in. This method is generally preferred if the fabricator has a CNC drill line which allows the fabricator to process longer pieces with CNC accuracy. The fabricator can linearly nest the diaphragms into the larger ordered piece, and then cut them apart later.

9.1.2 Cope vs. Cut Flush

When a rolled shape diaphragm (typically a W- or WT-shape) bolts directly to a connection plate, the flanges of the shape must be trimmed to allow the web of the shape to mate flat against the stiffener by eliminating the fillet at the web and flange interface. The two methods used to accomplish this are "coping" and "cutting flush". When coping, the fabricator cuts the flange and portion of the web, allowing the shape to mate to the stiffener (Figure 13).

Figure 13 Photo showing an example of a coped girder web and flange

When "cutting flush", the fabricator cuts one side of the flange flush to the web of the shape, creating a planar surface to mate to the stiffener (Figure 14). Again, it is the fabricator's preference which method to use.

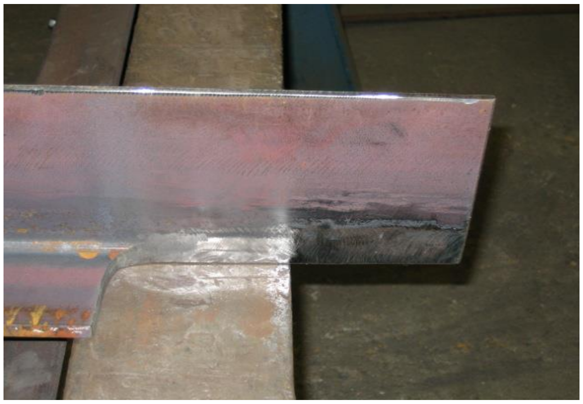

Figure 14 Photo showing a cut flush example

9.2 Plate Diaphragms

Plate diaphragms are essentially small girders. They are used when a diaphragm is needed but there are no rolled sections that will satisfy the design criteria. They may be appropriate to use when the configuration will not allow a cross-frame to be used efficiently.

9.2.1 Fabrication

There are two basic methods of fabrication. The first is to cut the webs and flanges to size, and then weld the pieces together, similar to a girder. The flanges may need to be jigged to the web to maintain critical dimensions (e.g., holes in flanges for a moment connection). The other method is to build a longer girder and cut the diaphragms to length after fabrication is complete.

9.2.2 Cope vs. Cut Flush

Coping of plate diaphragms is generally more efficient than cutting the flange flush due to the web to flange welds. If cut flush is to be used with plate diaphragms, generally a partial joint penetration weld is used in the cut flush area in lieu of a fillet weld. This weld increases fabrication time and requires additional NDT.

9.3 Bent Plate Diaphragms

Bent plate diaphragms are efficient alternatives to plate diaphragms, if the design criteria allow this member to be chosen. A "bent plate diaphragm" is made by using a comparatively thin plate (⅜" or ½"), which is then formed via a press brake to create a "C" shape. The depth of the plate may be variable, and holes are then placed in the plate for connection to stiffeners. No coping or cutting flush is necessary due to the planar surface created by the shape. Lengths of bent plate diaphragms should be monitored, as many fabricators do not have a large press brake capable of handling plates exceeding approximately eight feet in length.

9.4 Cross-Frames

Cross-frames are essentially small truss panels that frame between primary longitudinal girders. There are two types of cross-frames: built-up cross-frames and “knock-down” cross-frames. Built-up cross-frames are comprised of structural shapes, generally angles (L) or small WT-shapes, which are shop welded or bolted to gusset plates, which then bolt to connection stiffeners. Knock-down cross-frames are essentially several small rolled shape diaphragms which are configured to mimic a truss panel. The shapes are bolted directly to the connection stiffener.

It is preferable to avoid back-to-back members or cross-frames “sandwiched” between connection plates on painted structures.

AASHTO/NSBA Steel Bridge Collaboration Guidelines *G1.4 Guidelines for Design Details* (11) and *G12.1 Guidelines to Design for Constructability and Fabrication* (2) both provide recommendations with regard to cross-frame type selection as well as member and welding options.

9.4.1 Built-up vs. Knock-Down Cross-Frames

There are arguments to be made whether built-up cross-frames or knock-down cross-frames are less costly to specify. Generally, knock-down cross-frames are less costly to fabricate, but there are more pieces to track, ship and erect, as typically there are 4 or more pieces at each cross-frame location. Additionally, the connection stiffeners are unique to each cross-frame location. When variations in the cross-frame geometry occur, different connection stiffeners result.

Built-up cross-frames are fabricated as one piece in the shop. They are "jigged" to match the geometry (e.g., no dead load, steel dead load or full dead load) anticipated in the field. The associated pieces are then welded or bolted together. As there is one fabricated assembly per cross-frame location, there are fewer pieces to ship and erect. Less variation in the connection stiffeners occurs because the gusset plates generally have a consistent hole pattern.

Welded built-up cross-frames are generally less costly to fabricate than bolted frames. With bolted cross-frames, each piece requires holes, and then the bolts must be properly tensioned. This is especially true on painted cross-frames, where each bolt is then required to be brush painted prior to spraying. The welds on cross-frames only need to be touched up by grinding prior to blasting and painting.

Cross-frames that are welded on one side only are generally preferred by the fabricator. Additionally, angles should be oriented such that the outstanding legs are not adjacent. If the outstanding legs of the angles are adjacent, this creates an issue of reduced clearance when welding. Welds should not be specified as all around welds. The joints of the cross-frame that are required to be welded should be called out.

10.0 ASSEMBLY OF CONNECTIONS

Field connections of main members are often required to be assembled in the shop or yard to ensure proper fit prior to shipment. This requirement is generally limited to field splices or floor beams that have moment connections. These connections may be made by several different methods, each with its own advantages and disadvantages. Depending upon the fabricator’s equipment and expertise different methods can be employed. It should be the fabricator’s option which method to utilize.

10.1 Drill from Solid

When using this option, the fabricator builds the pieces to be joined with the ends blank. The pieces are then assembled to the correct line and elevation with the joining parts and drilled from solid while assembled.

10.2 Sub-punch or Sub-drill and Ream

This option requires the fabricator to place the holes in the pieces to be joined ¼” undersize by either punching or drilling. The pieces are then assembled to the correct line and camber and tapered drill bits are used to enlarge the holes to the finished size while connected.

10.3 Unit Assembly

Unit assembly, or “special complete structure assembly”, as it is sometimes called, is required for certain structures with complex geometry. As the name implies, the entire structure is “erected” to the proper line and elevation in the fabrication shop (Figure 15). All connections are prepared by one of the methods mentioned above. The pieces are match-marked to ensure that they are placed in the same relative position in the field as was assembled in the fabrication shop.

Unit assembly should not be specified on the design unless absolutely necessary, as the additional cost and time spent on the job is substantial.

Figure 15 Photo showing the unit assembly of a structure

11.0 SURFACE PROTECTION

11.1 Surface Preparation

Generally, all members of a steel superstructure receive some level of surface preparation. There are two reasons to do this preparation. The first is to prepare the steel for painting, and the second is to remove any mill scale or fabrication markings for aesthetic reasons.

There are two methods of surface preparation that are used, grinding and blast cleaning. Grinding is generally used to prepare the edges of members for blast cleaning. Blast cleaning is a process that uses a mixture of steel particles that are "shot" at the steel to produce a surface profile that will allow paint to adhere.

The type of surface preparation is stipulated by the owner and is defined by the AMPP documents (7). A standard profile for paint adherence is a "dimpled" surface with the dimples varying in depth from 1.0 to 3.0 mils.

See Figure 16 and Figure 17 to compare girders before and after blast cleaning.

Figure 16 Photo showing a girder before blast cleaning

Figure 17 Photo showing a girder after blast cleaning

11.2 Weathering Steel

When weathering steel is specified for a project, the fabrication of the structure is the same as non-weathering steel. By definition, weathering steel does not require a coating system and is therefore the most cost-effective solution. Certain owners require a coating system at the ends of the structure and sometimes on the exterior of the fascia girders.

11.3 Painting

Depending on the owner's specifications, the product is applied in either the shop or the field. The steel must be cleaned (e.g., by blast cleaning) prior to coating, and then the product is applied in conformance with the manufacturer's recommendations. Paint is applied by spraying, but certain areas do not provide enough clearance to be sprayed and the paint must be applied by brush. Most paint systems have a range of thicknesses that are acceptable per coat, which may be measured when the paint is wet or dry. Target ranges (min/max film thickness) need to be defined in accordance with the product data sheets. Figure 18 shows material painted in the shop.

Cross-frames or diaphragms with double members (e.g., back-to-back angles) should be avoided on painted jobs, as the initial coating is difficult to put on, and future inspection and maintenance of the paint system is hindered by the proximity of the members.

Figure 18 Photo showing painted members in a fabrication shop, note the masked area is for prime coat only

11.4 Galvanizing

Another method of protecting steel is to galvanize it. The galvanizing process involves several preparatory steps culminating in dipping the member into a vat of molten zinc. The heat absorbed by the member during this process may alter the camber of the beam or induce some distortion or twisting of the web. This requires subsequent measurements to ensure that the piece remains within acceptable fabrication tolerances after galvanizing. Due to the size of the vats, members that require galvanizing may have length limitations. Additional details are required as well to facilitate the galvanizing process. Vent and drain holes are required to allow the free flow of the molten zinc to and from all parts of the member. The fabricator should coordinate the exact size and location of these details with the galvanizer and engineer.

11.5 Metalizing

Metalizing is yet another method of protecting steel members. The process of metalizing involves spraying molten metal onto the cleaned steel, providing a protective coating. Although a costly investment up front, metalizing has gained popularity in the steel bridge industry as it provides the long-term durability of galvanizing steel, while promoting a more flexible and simplified application process similar to painting.

12.0 SHIPPING

Shipping is generally the biggest constraint on the size of the field section. There are three options available to ship steel – rail, truck or barge. These options are then limited by the destination of the structure and the geographic location and facilities available to the fabricator. Each of the methods has its own set of constraints.

Most steel bridge components are shipped via truck. Depending upon the location of the fabricator and the job site, rail and barge are also alternatives. When shipping by rail or barge, there may be an additional loading onto a truck to maneuver the pieces to their final destination.

For truck shipping, weight is becoming the biggest constraint on the shipping of field sections, followed by length and depth. Depending upon the states that the load is going to go through, there is a weight limit that can be shipped without a permit. If the load exceeds this weight, the fabricator must obtain shipping permits. Length is generally the second biggest constraint on shipping. Depending upon the site conditions and the route taken to get to the job site, the maximum length that can be shipped may be shorter than the maximum length that can be fabricated. The turning radius of the power unit and trailer combined with the overhang of the girder may prevent the vehicle combination from clearing objects along the side of the route when sharp turns are made. Additionally, severe grade changes may cause the load to bottom out or exceed underpass clearances due to the long wheelbase. Height is a concern as well. The route may need to be surveyed and adjusted accordingly to clear overpasses due to the height of the load.

Stability is an issue when shipping curved girders. Stability and stress calculations may be required to prove the feasibility of the shipping configuration. Additional fixtures in the shipping rigging may be required to maintain this stability. Rail and barge shipping have similar constraints.

12.1 Summary

The fabrication industry continues to advance technically, as the demand for stronger and more complex steel structures continues to grow. Fabricators have invested in their businesses with CNC machinery, promoting enhanced precision and efficiency. Welding technology is a continually advancing sector. Geometric controls are better than they have ever been. Specialty haulers can haul the most complex pieces from the fabricator to the job site. This is a trend that will continue well into the future. For more information, contact a fabricator or specialty hauler in the jobsite region for specific answers to questions.

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