Steel Railroad Bridge Fabrication: Keys to a Successful Project
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Abstract
This paper and presentation address key issues related to achieving the best possible steel bridge project in terms of fabrication, with emphasis on schedule, cost, and quality. These values are affected by many factors:

- Design for constructability
- Shop drawing production, review, and approval
- Steel fabrication scheduling, including influence of the owners and general contractors
- Steel plate and shape availability and cost
- Improved methods for cutting, welding, and drilling
- Improved methods for accomplishing connections
- Use of weathering steel and structural coatings
- Shipping considerations

Understanding these issues will help engineers achieve the best possible projects with respect to designs, specifications, and construction administration practices. High Steel draws on 76 years of steel fabrication experience and work on numerous steel railroad bridges to effectively address these issues.

Introduction
This paper describes the keys to achieving a successful steel bridge project from the point of view of fabrication. A successful project as one that

- is on schedule;
- is cost-effective;
- satisfies workmanship standards for quality; and
- for private sector parties, is profitable.
Project teams can more readily achieve these values by being aware of the state of the art in steel bridge fabrication and understanding the dynamics that are important to achieving a good project.

**SCHEDULE**

Understand the factors that influence a fabricators’ schedule in order to keep things on time. The basis steps for starting fabrication are

- Receive a contract
- Ensure basic geometry is correct
- Create an “advanced bill of materials”
- Order materials
- Complete shop drawing preparation
- Receive approved drawings
- Receive materials
- Plan fabrication
- Start cutting

An idealized critical path is shown in Figure 1.

Note that a number of activities in the critical path are not entirely within the fabricator’s control. These include

- Verify geometry – The fabricator’s first step is to run through the bridge geometry and ensure that the geometry is correct and, basically, will work. Many bridges have geometry issues; often these are small, but sometimes the issues are big enough to stop progress. Then, the fabricator must rely on the engineer to answer questions to get the project moving again.

- Create advanced BOM – related to the geometry verification, the advanced bill of materials cannot be created until the geometry has been verified and material cannot be ordered. Though fabricators can stock some materials, particularly for smaller items such as stiffeners and gussets, fabricators cannot stock larger materials, such as plate for webs and flanges.
- Receive approved drawings – the fabricator can well create the drawings but must rely on others to approve them. Fabrication will not be planned and initiated until drawings are approved, or at least until the fabricator has a reasonable assurance that there will not be significant changes requested in the drawings. Engineers should consider use of an “approved as noted” status if only small changes are needed.

In order to keep fabrication on schedule, cooperation is needed from the owner and engineer. Be sure to answer RFIs and review and approve shop drawings in a timely manner. Use electronic drawings to facilitate timely reviews.

MATERIALS

High performance steel (HPS) is now a mainstream steel bridge material. It is readily available, but be aware that lead times are longer for HPS, particularly in thicknesses greater than two inches. Lead times vary with changing market conditions. For most project schedules, fabricators have no trouble getting any mainstream bridge material (ASTM A709) on time, including HPS, but if the project schedule is tight, it is best to check with industry for the latest and most accurate availability information.

Designers should also verify the availability of large shapes if they are being considered for the design. Though it is often assumed that a large rolled beam is the quickest available section, this may not be true, depending upon rolling schedules. Mills roll large sections infrequently, and large sections are not stocked by suppliers, so if a large rolled section is needed on a tight schedule, verify that the schedule can be met. Further, not all published sections are available from mills, so it is best to verify this availability as well.

Fabrication provisions for HPS are now found in AASHTO / AWS D1.5, Bridge Welding Code. Thus, the AASHTO guide specification for fabrication using HPS is now obsolete.
DETAILING / MODELING

Fabricators must convert design information from plans into information that the shop can readily use. In days past, when dimensions were laid out by steel tape and soap stone, the shop drawing directed workers on the shop floor. However, with the advent of computer numerically controlled (CNC) equipment, many shop drawings are no longer necessary. Rather, fabrication data is often communicated directly from the fabricators geometry programming to shop floor equipment via models. This improves both schedule and accuracy, particularly for drilling.

MODERN SHOP PRACTICES

Cutting and Marking

There are two basic thermal cutting processes used in bridge fabrication: oxy-acetylene cutting and plasma cutting. Both represent excellent cutting technology and do not introduce deleterious by-products into the weld metal. Oxyacetylene is the more traditional process and is suitable for cutting all thicknesses used in steel bridge fabrication.

In plasma cutting, gas is heated into plasma, resulting in high temperatures. An arc jet of plasma cuts steel and also forces away the melted material. Plasma cutting provides a more precise cut and, for thinner materials, is faster than oxyacetylene. Plasma can effectively cut thicknesses up to two or three inches, depending upon the power of the equipment being used. Edge hardness values between the two methods are comparable, except that there is less hardness variation in plasma cut edges. See Figure 2.

Plasma cutting produces a considerable amount of fumes; the fumes must be captured to maintain a suitable working environment in the shop. Typically a water table is used, with the water either just under the steel being cut (about \( \frac{1}{2} \)”), or with the steel submerged. Earlier plasma equipment operated more effectively with the steel submerged, but this is no longer the case with the latest equipment. Alternatively, a down draft system can be use, but water is more effective.

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Both plasma cutting and oxy-acetylene cutting equipment can be operated with CNC equipment to improve accuracy. See Figure 3.

**Drilling**

The two basic methods for accomplishing holes are

- start with a subsize hole, and then ream the whole to full size with plies assembled, or
- make the hole full-size from the start.

Fabricator preferences between the two have changed has technology has improved. In earlier days, bolt holes positions were laid out on the steel by hand, with punch marks showing the intended hole location; then the hole was drilled (or punched) at the punch mark. Given the accuracy of this method, fabricators often found it prudent to ream-out the holes in assembled plies to ensure accuracy. With CNC equipment, accuracy has improved considerably, and for most connections, reaming is no longer necessary: holes can be punched or drilled one time, without bringing the parts together for reaming. See Figure 4. This saves the time of drilling multiple times as well as the time required to move the pieces together for reaming, though the fabricator may use a check assembly to ensure proper accuracy is being achieved. Only more complex connections or complex framing need to be reamed in assembly, depending upon the fabricator’s equipment, possibly to include a check assembly for verification.

**Punching**

Punching is a useful alternative to drilling. The size of hole that can be punched depends upon the fabricator’s equipment. Holes can be punched in thicknesses up to about an inch; the fabricator’s capability can be readily established with test holes. Holes that satisfy workmanship tolerances can be considered acceptable. Punched holes can be located just as accurately as drilled holes using CNC equipment. See Figure 5.

Punched bolt holes offer comparable performance to drilled holes. In a recent study funded by TxDOT and FHWA, testing demonstrated that connections with punched holes perform just as well
connections with drilled holes – with one exception: connections with full-size punched holes have slightly less ductility. For this reason, AASHTO recently adopted provisions that preclude use of full-sized holes in main member materials.

**Welding**

Considerable welding technology advancements have been made over the history of steel bridge fabrication. These advancements improve quality and productivity. A comparison of historic and present day bridge welding processes:

<table>
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<tr>
<th>Historic</th>
<th>Modern</th>
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<tr>
<td>SMAW (stick)</td>
<td>SMAW (stick)</td>
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<tr>
<td>SAW</td>
<td>SAW, including AC welding</td>
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<td></td>
<td>FCAW</td>
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<td></td>
<td>GMAW, including pulse mode (GMAW-P)</td>
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<td></td>
<td>ESW-NG</td>
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The “modern” list represents processes that are used in present day bridge fabrication processes. Not all processes are found in all shops, depending upon fabricator preferences, but all processes are found in AASHTO / AWS D1.5, Bridge Welding Code, with one caveat – new provisions for ESW-NG have been approved and adopted by both AASHTO and AWS, but these provisions will only appear in the next edition of the Bridge Welding Code.

Shielded metal arc welding (SMAW) or “stick” welding was once the work horse process for handheld welding in the bridge shop, but today it is used much less. Fabricators still use it for some tacking applications, but because other processes offer improved quality and productivity, it is no longer preferred for fillet and groove welding. For handheld welding, many welders are more proficient with flux-cored arc welding (FCAW) or gas metal arc welding (GMAW) and find use of SMAW a struggle. Both flux-cored arc welding (FCAW) and gas metal arc welding (GMAW) offer significant productivity and quality
advantages over SMAW and are now the most common processes for smaller fillet welds and small groove welds. See Figure 6.

Submerged arc welding (SAW) remains the workhorse process for groove welding and longer fillet welds that can be mechanized, but there have also been significant changes to this process over time. Multiple SAW wires can be used in tandem or twin configuration to increase productivity. More recently, alternating current (AC) technology has given the fabricator much greater flexibility in welding procedure design.

Electroslag welding (ESW) is coming back to the shop floor and has the potential to revolutionize full penetration welding. With ESW, full penetration welds are always accomplished in a single pass. Productivity improves because the multiple passes required with other processes are saved, and quality improves because defects associated with multiple pass welding, such as slag, porosity, or cold lap, are avoided. Because it is configured for vertical up welding, ESW is not suitable to all full penetration welding, so fabricators who use it will balance use of this process with SAW.

Electroslag welding was a mainstream process until the 1970s when a crack found in an in-service girder resulted in a moratorium by the Federal Highway Administration (FHWA) on its use. The crack did not occur because of the process, but rather as a result of a poor repair, but the investigation found that the ESW weld was not as tough as it should have been to resist crack growth. The FHWA sponsored research to improve the toughness of ESW welds, and this was achieved with the improved “narrow gap” ESW process, now known as ESW-NG. Based on the success of the research, the FHWA lifted the moratorium. As mentioned previously, the new provisions addressing ESW-NG will be included in the next edition of the Bridge Welding Code.

Fracture Critical Fabrication

Fracture critical practices are intended to preclude the possibility that a crack in a steel bridge member will result in catastrophic collapse of a bridge. Use of this designation results in
- tougher materials: fracture critical plate must satisfy improved charpy vee notch (CVN) criteria
- increased non-destructive examination of full penetration welds: main member butt splices must be inspected by both radiography (RT) and ultrasonic testing (UT)
- increased welding procedure qualification testing: welding procedures for fracture critical welding expire earlier than those for non-fracture critical welding
- increased in-service inspection: fracture critical bridge are inspected every two years

In some cases, designers choose the fracture critical designation without regard to the potential for catastrophic failure associated with failure of the member. In such cases, a prudent approach might be to consider what material and process differences associated with the fracture critical designation will best suit the structures and choose those specifically.

**Corrosion Protection**

Years of experience have demonstrated that weathering steel provides excellent durability for both highway and railroad bridges, and certainly weathering steel is the most cost-effective option from both the first cost and maintenance perspectives. For improved appearance, it is worth considering removal of mill scale from fascia surfaces.

The most economical approach to painted steel is a multi-coat system based on a zinc primer. As with galvanized steel, the zinc in the zinc primer offers cathodic protection. Zinc primers may be divided into two classes – inorganic and organic. Both are suitable; typically inorganic zinc chosen for shop applications because it is a harder coating, and organic zinc is preferred in the field due to its flexibility of application. For top coating of inorganic primers, it is most common to choose urethane (top coat) with an epoxy coating (2nd coat) to bind the urethane to the zinc primer. With organic primers, top coats can be directly applied to the primer.

Regardless of the protection chosen, either weathering steel or painted steel, it is critical to ensure that water will not pond on the steel but rather readily drain away. For example, ensure that weep holes are
large enough to preclude blockage by normal accumulation of debris. Note that in service, weathering steel will stain local concrete if runoff is not mitigated, but a very high degree of staining may be an indication of a drainage problem.

**SHIPPING**

Steel bridge members may be shipped by truck, rail, or barge. The best economy is achieved when members can readily be shipped by truck, and this will be a function of local conditions. Generally, these dimensions will be readily shippable by truck:

- **Length:** 125 feet
- **Weight:** 35 tons
- **Height:** 9 feet

These dimensions can be and often are exceeded and still shipped by truck, but the more these dimensions are exceeded, the more important it becomes to ensure that local conditions, such as roadway geometry, bridge underpasses, and bridge capacities, will allow shipment by truck. See Figure 7.

Recognize that rail and barge shipment may not be fully available. For example, it may be possible to ship members nearby by rail or barge, but then the members may need to be conveyed the final distance by truck.

**CONCLUSION**

To achieve the best economy in steel bridge fabrication, use this fundamental approach:

- facilitate an optimal schedule by expediting RFI answers and shop drawing review and approval
- be mindful of material availability and delivery times
- facilitate use of the fabricator’s skills and equipment to best execute the project
- be aware of the implications and application of the fracture critical designation
- consider use of uncoated weathering steel, or if painting is required, consider a system based on zinc primer

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- consider the shipability of the members chosen, including local conditions
- simply allow use of AASHTO/AWS D1.5 to govern welding

The concepts presented in this paper are best applied in conjunction with advice of fabricators. Consider inviting fabricators to review and comment on the constructability of the design.

Figures

Figure 1 – Idealized fabrication schedule. Red denotes activities that are not fully within the fabricator’s control.
Figure 2 – Plasma cutting power has increased such that plasma can effectively cut material up to 3” thick (thinner material shown).

Figure 3 – CNC zinc marking facilitates accurate layout.
Figure 4 – CNC drilling allows connections to be accomplished without assembly of members.

Figure 5 – CNC punching is an excellent process for accomplishing accurate subsize or full-size holes in thinner material.
Figure 6 – Welding processes such as GMAW facilitate fabrication of complex sections.

Figure 7 – Shipping capability should be considered to optimize bridge constructability.