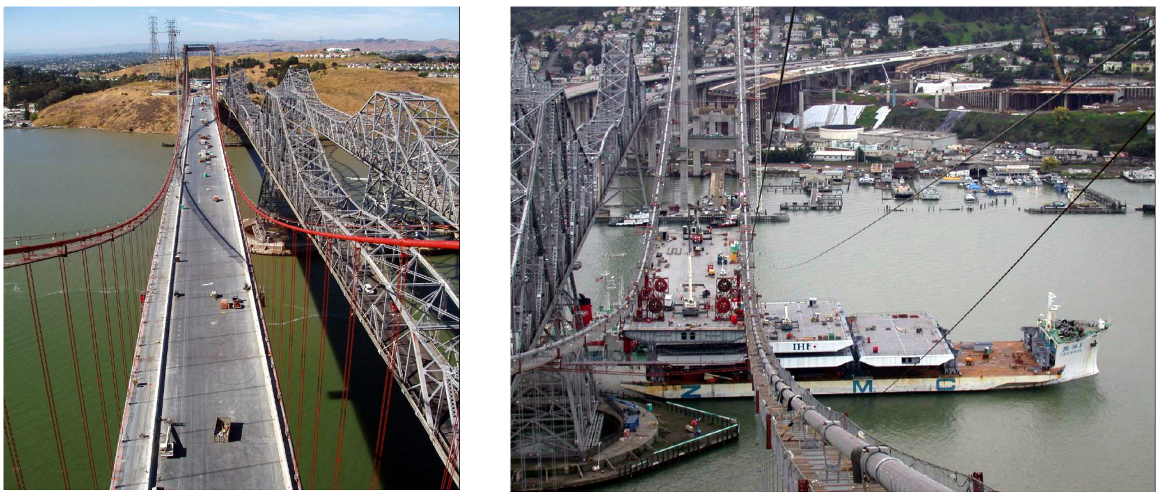
CONSTRUCTABILITY ISSUES IN ORTHOTROPIC STEEL BRIDGE DECK BRIDGES

by
David L. McQuaid, D. L. McQuaid & Associates, Inc.
Ronald D. Medlock, Texas Department of Transportation

INTRODUCTION

Orthotropic deck bridges represent a popular superstructure solution for long span bridges. However, compared to stringer type bridges, they are built relatively infrequently, and many engineers are not familiar with this type of construction. Engineers need to understand the unique aspects of orthotropic deck bridges to optimize design and detailing of these bridges and facilitate effective construction.



Orthotropic decks provide an effective solution for long span bridges, but their unique characteristics must be understood and considered to achieve a cost-effective design.

Orthotropic deck bridges consist of a steel deck plate that is stiffened longitudinally, or along the length of the bridge, with ribs, and transversely, or across the width of bridge, with diaphragms or floor beams. In early bridges longitudinal ribs were torsionally soft or "open" ribs, such as plates, inverted tees, I-shapes, or angles. Torsionally stiff or "closed" ribs are more popular today due to their design efficiency.

Like other steel bridge types, early orthotropic deck bridges experienced fatigue performance issues that have been largely resolved using modern detailing. The intersection of the deck plate, rib, and diaphragm / floor

Typical closed ribbed orthotropic deck segments.

State of the art details provide good fatigue life in orthotropic steel bridges.

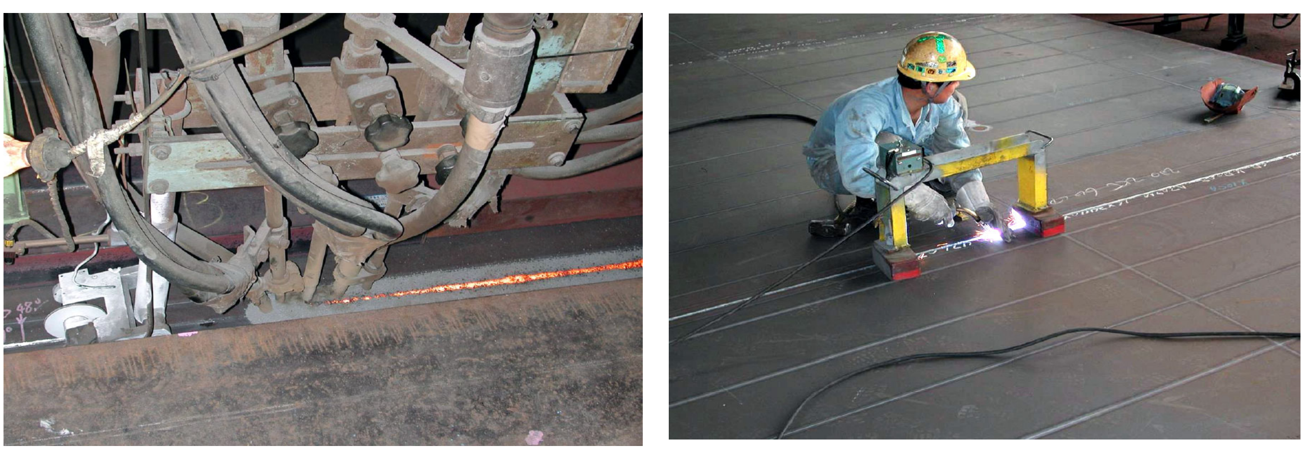
beam was particularly problematic in the past. However, research has led to state-of-the-art details that provide good fatigue life.

GENERAL WELDING CONSIDERATIONS

Achievement of a successful orthotropic deck bridge project depends upon effective weld detailing, especially for rib connections that are common to orthotropic deck bridges, including rib to deck, rib to diaphragm or floor beam, and rib to bulk-head. In addition to the detailed considerations discussed below, the engineer must be mindful of weld access. Quality welds demand clear access to the work and sufficient space for personnel and equipment. To ensure a constructable design, engineers must evaluate welding access before finalizing component details.

Position

The most common and therefore most readily achievable welding positions are flat for full-penetration welds and flat and horizontal for fillet welds. However, "out-of-position" welding (which reflects others positions) is readily achievable by qualified welders. The complex geometries inherent in orthotropic deck fabrication necessitate out-of-position welding. Because the AASHTO/AWS D1.5 – 2002 Bridge Welding Code addresses welder qualification for various positions (section 5.22), the designer does not need to be concerned about quality of out-of-position welds, but for the sake of constructability, the designer should keep in mind that fabrication is generally more economic when the welding is done "in position".



Through out-of-position welding achieves high quality, welding is generally more cost effective when accomplished in the flat position.

Fillet weld size

Increases in fillet weld size have an exponential effect on costs. It is optimal to use fillet welds that can be accomplished with one pass. Most fillets welds are accomplished in the horizontal position, and, typically, the largest single pass weld that can be accomplished in this position is 5/16". By contrast, a 3/8" weld in the horizontal position will require two or three passes; so, for example, a fillet weld size increase from 5/16" to 3/8" can double or triple the number of passes required to achieve the larger weld size. Larger single pass welds can be accomplished in the flat position or, using weave technique, in the vertical position. Usually, the designers cannot know what position the fabricators will prefer so it is best to design with the horizontal position in mind.

Processes

The optimal approach is not to proscribe welding processes in design; constructability is best achieved by leaving this to the fabricator. Specifying the Bridge Welding Code will ensure a suitable process will be used in the work.

The Bridge Welding Code recognizes five welding processes:

- Shielded metal arc (SMAW), also known as "stick" welding – a manual process
- Submerged arc welding (SAW) – an automatic process
- Flux-cored arc welding (FCAW) – usually semi-automatic but can also be automatic
- Gas metal arc welding (GMAW) – usually semi-automatic but can also be automatic
- Electroslag / electrogas (ESW/EGW) – an automatic process

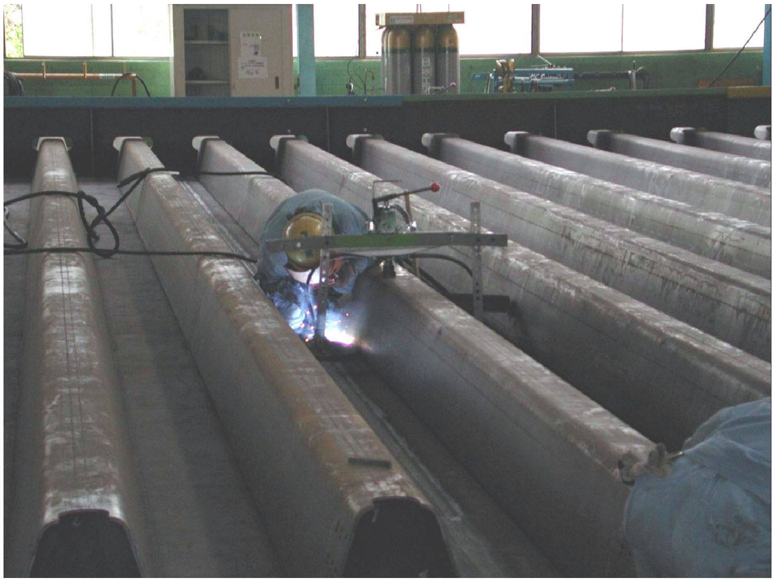
Because of its development history, the Bridge Welding Code can be read to favor the SMAW or SAW welding process. Early bridges were all welded with SMAW, so as welding codes were developed, code writers approached SMAW with more confidence. Hence, in the Bridge Welding Code, SMAW is the only fully prequalified process, which some engineers have interpreted to mean it is the most reliable and therefore the best process. This is not correct. While it is reasonable that the SMAW welding process need not be qualified because there is little variation in the normal operating range welding parameters (amps, volts, travel speed, heat input, etc.) and it does produce excellent weld metal properties, however, it is a low deposition rate process and requires a more highly skilled welder to make quality welds. For these reasons the shops tend to have fewer welders who are proficient in this process, and SMAW is generally not the best choice for a fabricator.

SAW has become the work-horse process in bridge fabrication because it is well suited to girder fabrication, including large full-penetration welds of flanges and webs and long, readily accessible web-to-flange and stiffener to web fillet welds. However, SAW is only efficient in the flat position for groove welds and in the flat and horizontal positions for fillet welds. While girders and girders parts can readily facilitate these positions, this is not always so for orthotropic decks and associated parts.

The Bridge Welding Code presently precludes ESW/EGW for tension members, but this is changing. Restrictions were based on fatigue concerns related to a failure that occurred in the 1970s, but FHWA research since that time has improved the ESW process such that it is now suitable for tensions members. Changes in the Bridge Welding Code are under development. Owners can allow use of the improved process based on FHWA findings, and, for constructability, are encouraged to do so. ESW accomplishes full penetration welds in one pass at approximately two inches per minutes, regardless of plate thickness; therefore, use of ESW can dramatically improve splice production, depending on the thickness of the members being spliced. For example, splicing of a two-inch thick, two-foot wide flange by traditional means (SAW) will take six hours, but splicing by ESW will take about 15 minutes of welding, plus about 30 minutes of set-up time. While production increases using ESW can be remarkable for girder flange splicing, there may not be significant advantages for orthotropic decks. Regardless, a fabricator may be able to find ways to improve constructability through use of the process.

Tack welds

Tack welds hold the work together to facilitate final welding. Tack welding requirements are reflected in section 3.3.7 of the Bridge Welding Code. The Code has distinct requirements between tack welds that are totally remelted and those that are not. Fabricators use the smallest tack welds necessary to effectively hold the work together. Usually the final weld will completely remelt the tack weld, but sometimes it will not, depending upon which welding process is used and how large the tack weld needs to be to hold the parts together.



Rib to deck tack welding.

When tack welds can be completely remelted by subsequent submerged arc welds, it is not necessary to preheat before tack welding. It is also not necessary to observe the minimum weld size requirements of the Bridge Welding Code. These exceptions to the Code requirements are permitted because any unacceptable hardening of the weld or base metal will be removed by the subsequent submerged arc weld.

The Bridge Welding Code requires that tack welds which will not be totally remelted must be made to the requirements of an approved Weld Procedure Specification. This requirement is sometimes strictly enforced for the orthotropic rib-to-deck partial penetration welds when it fact if you remelt up to 90% of the tack weld you have tempered the unmelted portion of the tack weld and heat affected zone so that it should be treated as if the tack weld was 100% remelted.

Aside from tack weld hardness concerns some Engineers require that the rib-to-deck tack welds must be 100% remelted by the final weld pass based on the tack welds being perceived as fatigue crack initiation sites. This is an unnecessary restriction and allowing the tack weld to stay in the completed weld does not alter the fatigue performance of the final weld.

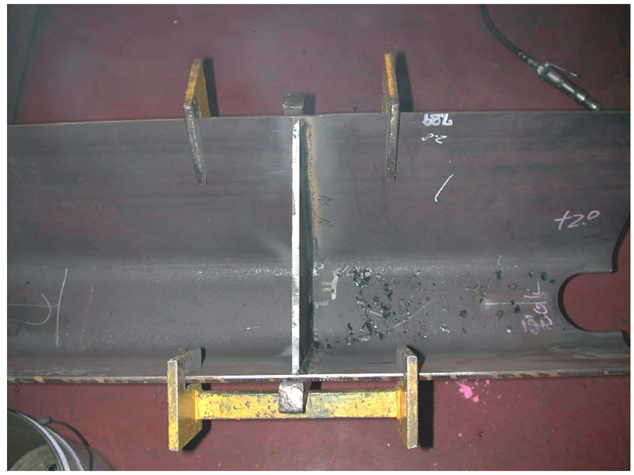
Remelting 90% of rib to deck tack welds results in retempering of the remaining 10%.

100% rib to deck weld remelting is unnecessary.

DETAILS

Stiffening Rib Details

Internal bulkhead stiffeners provide diaphragm continuity through the rib. Typically, these stiffeners are not attached to the deck plate and may not attach to the bottom of the rib, both of which facilitate fabrication. Open ribs eliminate the pressure test problems that occur since sealing the ends of the ribs is not required.



Internal bulkhead stiffeners.

Trapezoidal ribs are formed by bending the relatively thin (8 mm) rib plates in a break press. Cold bending, versus heat assisted bending, provides the best material properties assurance. Cold bending radius limits are reflected in AASHTO/NSBA Guide Specification S2.1. Typically, bridge fabricators will subcontract rib forming to a specialist shop. The length of the rib that can be fabricated without addition of a welded splice is a function of available break press capabilities. Industry capability in the United States is 40'. Panel lengths can be increased to reduce transverse field welds, but this will be a trade-off because of additional rib splices. Panel length economics will also be affected by shipping constraints. Efforts to roll form ribs have resulted in

Cold bending is the most economic way to produce ribs.

excessive twist, but the fabricator should be free to try this method if he chooses.

Though rib splicing is relatively costly, such splicing can be readily accomplished. Designers can specify splice location, but it is more effective to detail the ribs as continuous along the length of the panel and add a note indicating the shop splices are acceptable. A volumetric (through-thickness) non-destructive examination

(NDE) should be applied to ensure workmanship in these splices. Ribs can fall under item 6.7 of the Bridge Welding Code, which states, "CJP groove welds in main members shall be QC tested by NDT. Unless otherwise provided, RT shall be used for examination of CJP groove welds in butt joints subject to calculated tension or reversal of stress." Since this provision is most commonly applied to flanges, a note should be included to avoid interpretation conflicts. Further, UT should be specified for rib splicing. UT is more cost-effective than RT and is superior at finding cracks than RT, but the most compelling reason for choosing UT is that the trapezoidal or v-shape of ribs makes RT performance very difficult; effective RT of the corners will not be possible.

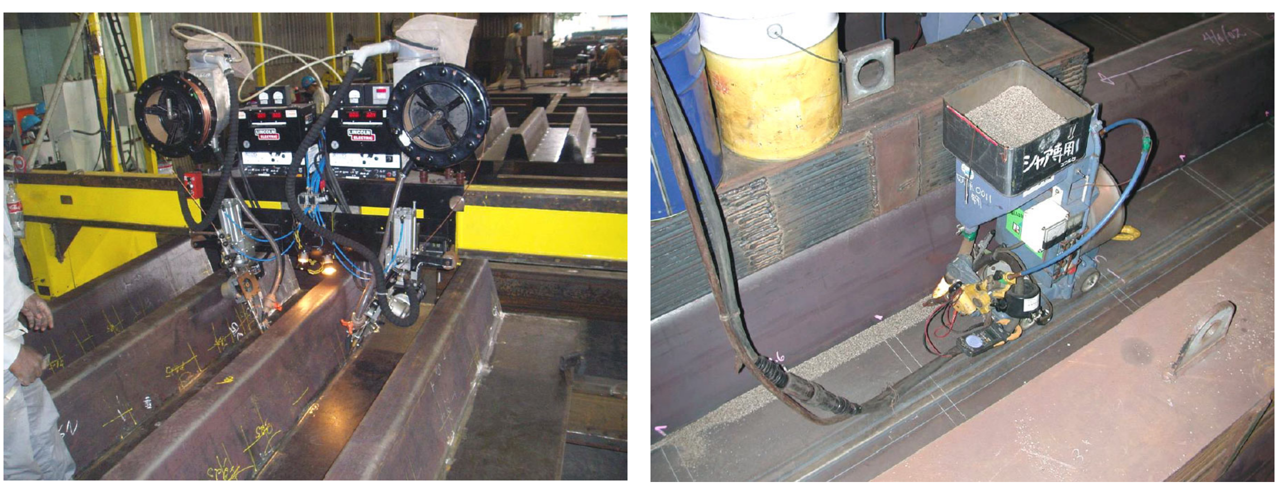
Rib splicing is relatively expensive but readily accomplished.

Bulkhead Stiffener Alignment

Alignment of bulkhead stiffeners with diaphragms is difficult to achieve without some tolerance. Bulkhead stiffeners must be attached to ribs before ribs are welded to the deck plates because once welded the bulkhead stiffeners will not be accessible. However, ribs shrink when they are welded to the deck plates, which cause the bulkhead stiffeners to move from the intended position. A 1/2t alignment tolerance between bulkhead stiffener and diaphragm, with "t" being the thickness of the bulkhead stiffener, is readily achievable; a plan note providing this tolerance is recommended.

Rib to deck plate welding

Ribs are attached to deck plates using partial penetration welds, welded from the outside only. This is necessary because, as is obvious, it is not possible to back-gouge and weld on the inside of the rib. AASHTO requires 80% penetration for design, but does not provide a tolerance for fabrication. The requirement for 80% penetration was based on an average of what was tested in fatigue research, but the test specimens actually varied from 55% penetration to 100%. A fabrication tolerance is needed to account for variability; even melt-though up to 2 mm will not reduce the fatigue performance of the weld joint. A reasonable

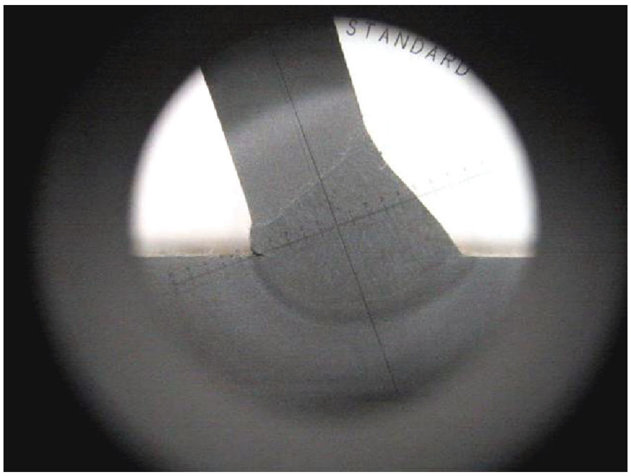


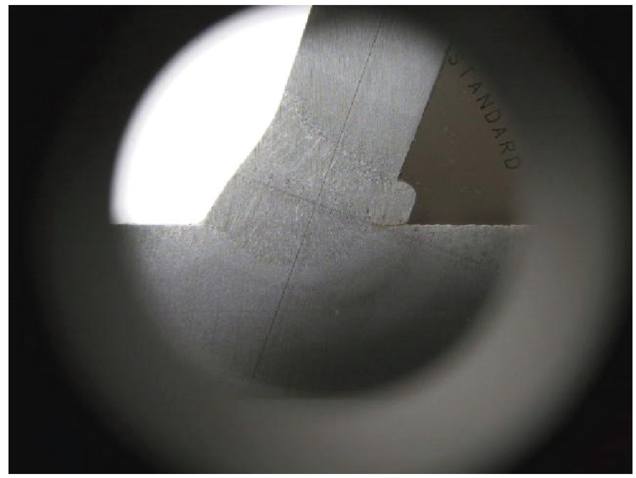
A ± 15% depth of penetration tolerance is recommended for rib to deck partial penetration joints.

tolerance is 80% + / - 15% penetration and is suggested as a plan note.

If a minimum reinforcing is desired, this should be separate from the 80% that is required for the effective throat. By AWS definition, reinforcing does not count towards effective throat for groove welds, whether they are full penetration or partial penetration.

Given the tolerances proposed above, achievement of proper penetration in production can be assured by requiring special welding procedure qualification prior to production. Three separate small mock-up weldments are recommended. The depth of penetration and consistency can be verified through visual inspection of a macro-etch specimen from each weldment.





Melt-through is typical and acceptable.

Given that ribs are relatively thin and the target penetration is 80%, the possibility of getting melt-through is very likely, and such melt-through is acceptable. It is also acceptable if the nose of the rib bevel bulges down because it becomes red hot and flows plastically.

Melt-through should not be confused with blow-through, which is a complete loss of continuity of the back weld and should be rare. A melt through of up to 2 mm is not blow through. Occurrence of more than occasional melt-through indicates a system problem that must be addressed, such as poor-fit-up, improper beveling, weld wire placement or welding out of the WPS parameters such as the volts or amps too high .

Melt through should not be confused with blow through; however, occurrence of more than occasional melt through should be addressed.

It is not unusual to have melt through up to 5% of the total weld length especially if you require a minimum of 80% penetration and 100% remelting of all tack welds.

Rib - diaphragm welding

Optimal fatigue detailing governs choices for rib to diaphragm welds, but when there is room for flexibility, the constructability preference are fillet welds over partial penetration welds, and partial penetration over full-penetration. Many designs have a mixed weld along the full length of the internal rib diaphragm, with a partial penetration weld for part of the length and a complete penetration weld for the rest of the length. Where one stops and the other one begins is difficult to inspect properly. When a full penetration weld is needed for part of the length, it may be easier to control by detailing a full-penetration weld for the entire length and just change the inspection requirements for the lengths where a PJP weld will suffice.

Shop assembly should be required for field units, especially for suspension bridges.

Recent designs have changed the rib diaphragms to a stiffener plate being added to the inside of the rib where the outside diaphragm attaches to the side wall of the diaphragm only.

General Fabrication

A prototype field section is recommended to help develop proper fit-up, assembly and welding techniques and ensure fabricator proficiency before work begins on the actual bridge deck panels. The requirements for the prototype should be spelled out in detail in the project specifications.

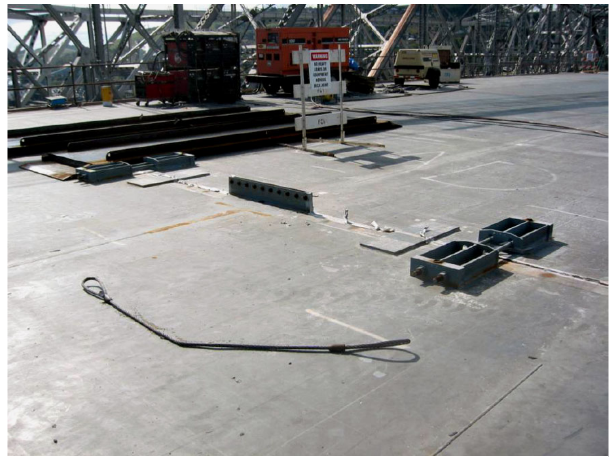
Units should be pre-cambered along the length of the panel, but it is not possible to pre-camber transverse to the panel at the same time. However, the panels should be retrained in the transverse direction.

Shop assembly

Shop assembly of field units should be required to facilitate proper fit in the field. This is especially important for suspension bridges, which are more difficult to assemble than when welding deck plates on a girder assembly system.

TxDOT Std. Spec. Item 441, Table 1 Web Alignments Tolerances for Deep Girders	
Web depth (in.)	Maximum Web Misalignment (in.)
48	1/16
60	1/8
72	1/4
84	5/16
96	5/16
108	3/8
120	7/16
132	7/16
144	1/2

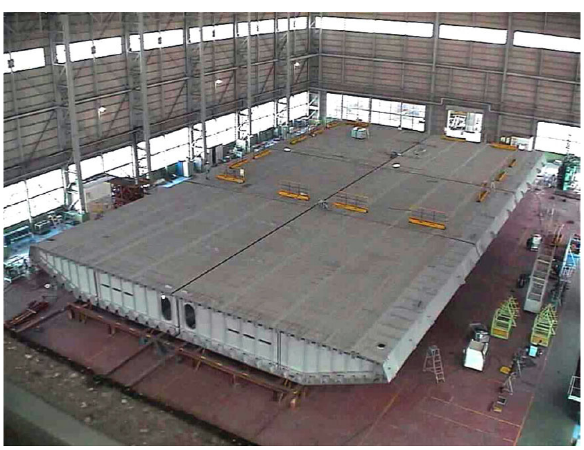
Fit-up tolerances for field welded connections are described in the AASHTO/NSBA Steel Bridges Collaboration standard S2.1, Steel Bridge Fabrication Guide Specification, 7.3.3, which states, “Prepare joints so that the centerlines of land of opposing web and flange bevels do not deviated from each other by more than 2 mm (1/16”) and root faces do not vary by move that 2 mm from contact”. This tolerance is recommended for preparing subassemblies for field welding, except that in cases where plates are thin and deep and therefore relative flexible, more tolerance is recommended. TxDOT addresses this for deep webs in their standard specifications as follows, “…webs 48 in. deep or deeper must meet the tolerances of Table 1…”.



Fit-up lugs are needed to facilitate field assembly.

Fit-up lugs are recommended to facilitate field assembly. It is preferable to allow the fabricator and erector to work out the best places for the lugs, with lugs added in the shop and then, after erection, properly removed by the contractor or left in place if determined acceptable by the engineer. Lugs will provide positive control

Full penetration field welds, versus partial penetration welds, facilitate non-destructive testing.



It is not necessary to conduct shop assembly in doors, in controlled temperatures; consider that such control is not possible in the field during erection.

for field fit-up and weld joint openings.

Where possible, field welds should be CJP instead of PJP. Typically, it is more difficult to achieve proper workmanship in the field, where weather and access makes work more difficult. Use of full penetration welds facilitates effective NDE. As expressed above for rib to deck welding, UT is more cost-effective than RT because use of UT does not necessitate clearing the area to preclude radiation exposure, UT equipment is more transportable, and UT is generally less expensive than RT. Out-of-position welding is to be expected in field welding of orthotropic bridges, but this should not be a cause for concern provided welders are properly qualified.

Some design engineers believe that shop lay down assembly should be controlled so that the differential temperature is restricted to as little as 4 degrees C across the deck assemblies. This adds no value to the final produce and it fact is not achievable when the assemblies are erected, fit-up and welded in the field.

There are varying opinions on whether the field deck plate welds joints should be CJP welds with or without backing left in place. There are welding issues on how to make those welds that should be addressed in detail by the erector during the prototype assembly.