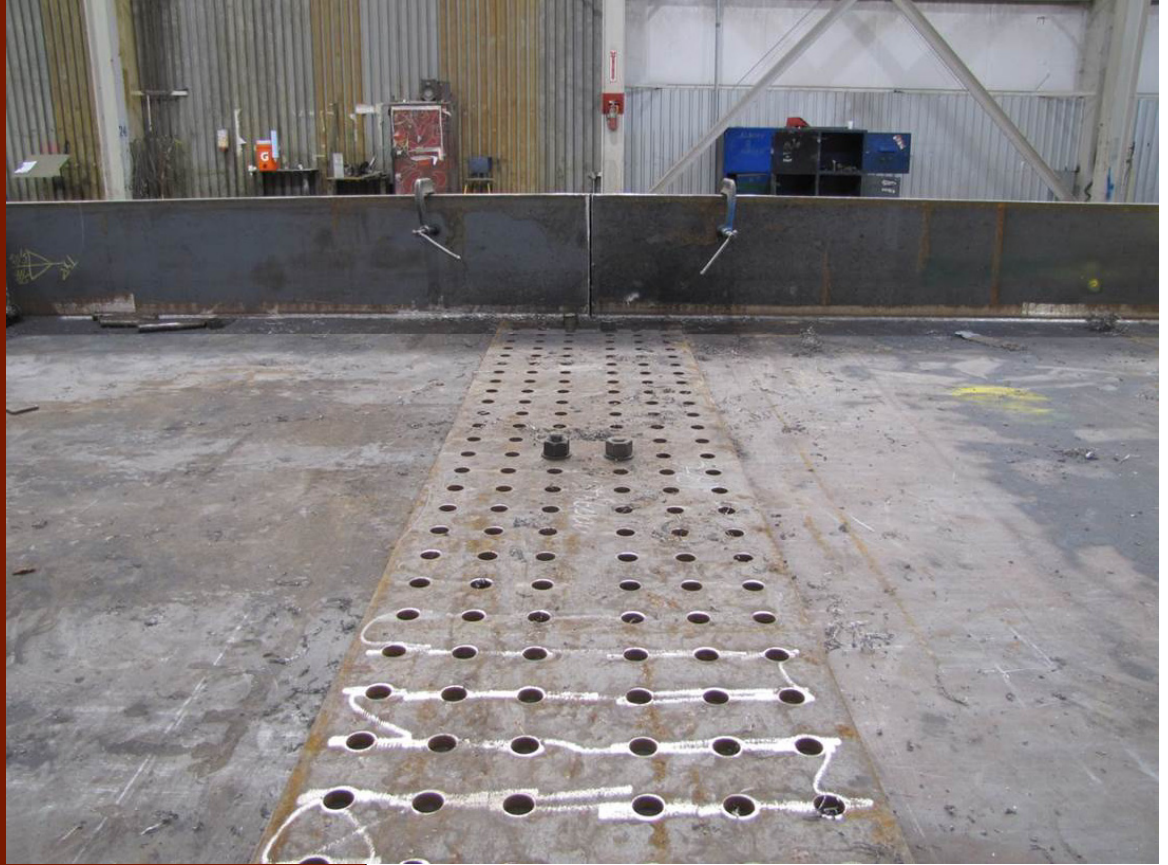


Guidelines for Resolution of Steel Bridge Fabrication Errors

G2.2-2016



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FOREWORD

Errors occurring during the fabrication of steel bridges need to be recognized and corrected according to the situation. To achieve practical solutions, engineers need not only knowledge of design, material, and construction (including fabrication) specifications but also experience and good understanding of fabrication practices and limitations. This expertise varies among individuals, with very few having a sufficiently broad background to address all circumstances.

This document provides suggested guidelines in a form intended to assist engineers, inspectors, and fabricators, introducing the issues necessary for structurally and economically viable resolutions of fabrication errors. This document has been prepared as a guide and thus, much of the information is general in nature, representing a consensus of various positions of owners as well as fabricators to provide guidance and improve confidence in solutions to unusual but non-unique problems. Recommendations should not be considered as hard and fast rules.

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Publication Code: NSBAGRSB-1-OL

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ACKNOWLEDGEMENTS

The following individuals and organizations contributed the development of this document.

Regional Pooled Fund Study SPR-3 (083) and Technical Committee members. States participating: ID, IL, KS (Lead State), MI, MN, MO, MT, NH, NJ, NV, PA, TX, and WY. Principal investigator: Kim Roddis.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
AISC	American Institute of Steel Construction
ASTM	ASTM International, formerly American Society for Testing and Materials
AWS.....	American Welding Society
AASHTO/AWS D1.5M/D1.5	AASHTO/AWS D1.5 <i>Bridge Welding Code</i>
.....	(referenced clause numbers from 2015 edition)
CJP	Complete Joint Penetration
CVN	Charpy V-Notch
FC.....	Fracture-Critical
FCM	Fracture-Critical Member
FHWA.....	Federal Highway Administration
HAZ	Heat Affected Zone
MT	Magnetic Particle Testing
MTR.....	Mill Test Report
NDE	Non-Destructive Examination
NSBA.....	National Steel Bridge Alliance
PT	Dye or Liquid Penetrant Testing
Q&T	Quenched and Tempered
RCSC	Research Council on Structural Connections
RCSC specification.....	RCSC Specification for Structural Joints Using High Strength Bolts
RT	Radiographic Testing
SAW.....	Submerged Arc Welding
SBC.....	AASHTO/NSBA Steel Bridge Collaboration
SMAW	Shielded Metal Arc Welding
TCE.....	Thermally Cut Edge
UT	Ultrasonic Testing
WPS	Welding Procedure Specification

CHAPTER 1

INTRODUCTION

1.1—GUIDELINES

Fabrication errors in the steel bridge industry are seldom identical, but are often similar. These guidelines are intended to assist engineers, inspectors, and fabricators in categorizing situations and determining the optimal solutions for errors not specifically addressed in the governing contract documents. Fabricators or owners may propose actions suggested herein with adequate background information for evaluation and acceptance. Work must conform to the contract documents with designs usually based upon AASHTO *LRFD Bridge Design Specifications* or *Standard Specifications for Highway Bridges*, and fabrication governed by the AASHTO/AWS D1.5M/D1.5 *Bridge Welding Code* and the Owner's specifications. However, some flexibility by the Owner may be required, permitting limited deviations from those documents to avoid unnecessary delays and potentially counterproductive rework. Some suggestions in this document involve the Owner permitting deviations from contract requirements, so the Owner needs to determine if such modifications would make the nonconformance acceptable.

This document covers common fabrication problem situations. Coverage of each topic begins with a statement of the problem issue, followed by a description of one or more recommended repair resolutions, and concludes with commentary on the issue and recommendations. If several recommendations are made on a single issue, they are presented in the order of preference.

This document does not provide an exhaustive listing of all possible repair options.

1.2—ERRORS

The term “error” in this document indicates a fabrication problem, not necessarily equivalent to the more specific application of “error” used in contractual language.

Errors covered in this document may include, but are not limited to:

- material or weld discontinuities;
- geometric and fit-up problems;
- dimensional errors for holes, cuts, angles, etc.; and
- substandard materials.

Coating problems are addressed in the appendices to SBC S8.1, *Guide Specification for Application of Coating Systems with Zinc-Rich Primers to Steel Bridges*. Any deficiency serious enough to cause rejection is a “defect.” According to the AASHTO/AWS D1.5M/D1.5 “Terms and Definitions” annex, a defect is “a discontinuity or discontinuities that by nature or accumulated effect (for example, total crack length) render a part or product unable to meet minimum applicable acceptance standards or specifications. This term designates rejectability.” If a fabrication error occurs in a small element, such as a splice plate, unattached connection plate, or cross-frame piece, it is usually most economical to just replace the item if appropriate material is available. For major members, errors may be economically corrected using the methods described in this document.

Deficiencies may be discovered as the material is being handled, during various stages of the fabrication process, or during loading, shipping, and field erection operations. Some deficiencies are often only found after the material is blast cleaned. The surfaces and edges of members and inner perimeter of holes should be inspected for defects during various steps of fabrication.

The repairs suggested in this document are appropriate for occasional errors, but are not intended to allow wholesale changes to plan details. Extensive errors can be cause for rejecting a member.

While minor deficiencies or defects may not require repair, recurring minor items may be indicators of serious procedural or material problems.

Nonconformances are identified and documented as part of the quality control/quality assurance (QC/QA) process. AASHTO/AWS D1.5M/D1.5 and SBC Guide Specification S4.1, *Steel Bridge Fabrication QC/QA Guide Specification*, provide descriptions of the duties and activities of the fabricator’s and the owner’s inspectors.

1.3—NONDESTRUCTIVE EXAMINATION

Based on the requirements of ASTM A6 and AASHTO/AWS D1.5M/D1.5, repairs to base metal and welds may require a formal repair plan approved by the Engineer or they may be performed by the mill using standard, industry-accepted operating procedures. (Mill weld repairs are prohibited for FC material, but the Owner has no control over weld repairs by the mill on non-FC material unless they are prohibited by the contract documents.) For shop welds correcting material defects, the repair process requires NDE, which always includes visual inspection. For material carrying design stresses, NDE may also include MT, PT, UT, RT, or other testing methods to evaluate the defect, its removal, and subsequent repair. For an overview of nondestructive examination in steel bridge fabrication, refer to Clause 6 in AASHTO/AWS D1.5M/D1.5, Volume 1 of the AWS Welding Handbook, and publications by the American Society for Nondestructive Testing (ASNT).

1.4—DEFINITIONS AND RESPONSIBILITIES

The term “error” in this document is defined at the beginning of Section 1.2, “Errors.”

Throughout this document, the terms “Contractor,” “Engineer,” “Fabricator,” and “Owner” are used frequently. the following definitions apply:

Contractor: the Contractor is responsible for proper completion of all tasks required by the Contract. Subcontractors, including fabricators, erectors, and field painters, may be employed by the Contractor, but the Contractor retains responsibility for all material, operations, and the final product. The Contractor should permit direct subcontractor interaction with the Owner to expedite the project, but subcontractors must inform the Contractor of any proposed modifications to Contract requirements, and of subsequent acceptance by the Owner.

Engineer: In this document, the Engineer is the Owner’s authorized representative, responsible for monitoring the Fabricator’s work. The Engineer has the authority to allow exceptions to Contract document requirements.

Fabricator: In this document, “Fabricator” refers to the facility or facilities performing such shop

activities as cutting, welding, drilling, punching, cleaning, and painting of structural steel. Some of these functions may be subcontracted. “Fabricator” also includes any agents of the Fabricator, such as those who prepare shop detail drawings. In some cases the Fabricator may also be the Contractor, but usually the Fabricator is a subcontractor or supplier.

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

1.5—STANDARD UNITS OF MEASUREMENT

This document makes use of both U.S. Customary Units and the International System of Units (SI) (i.e., the metric system). The default system for this document is U.S. units, with SI units shown within brackets []. The measurements may not be exact equivalents, so each system is to be used consistently and independently of the other.

CHAPTER 2

ERRANT HOLES

During the fabrication of steel bridge members or components, holes are sometimes misplaced and drilled too close to the ends or edges of flanges, webs, or splice plates; to adjacent holes; or to other components. (See Figure 2-1.) These errors can occur because of shifted templates or layout dimension errors and sometimes due to CNC (computer-numerically controlled) equipment programming errors. When errant or mislocated holes are made in a bridge element, the Engineer should be notified and will determine if repair will be permitted or replacement of the steel member is required.

Consult the governing documents for fastener spacing, edge distance, and end distance requirements and for the definitions of standard, oversized, and slotted holes. The AASHTO *LRFD Bridge Design Specifications* do not distinguish between rolled, thermally cut, and planed edges. It does penalize sheared edges, but those are not generally allowed as final boundaries of load carrying elements. AASHTO *Standard Specifications for Highway Bridges* provide more conservative minimum for TCEs than for planed or milled edges, so required edge distances can be reduced if the TCEs are planed or milled. *LRFD Bridge Design Specifications* and *Standard Specifications for Highway Bridges* and have the same minimum edge distances for rolled beam flanges. Designers should be encouraged to specify edge distances about $\frac{1}{4}$ " [6 mm] greater than the minimum clearances to provide some fabrication tolerance.

If the errant hole location is too close to another hole, bolt installation and tightening might be difficult or impossible, and the bolt may not be fully effective for ensuring load transfer. The clearance requirements for installing high-strength bolts are given in Part 7 of the AISC *Steel Construction Manual*.

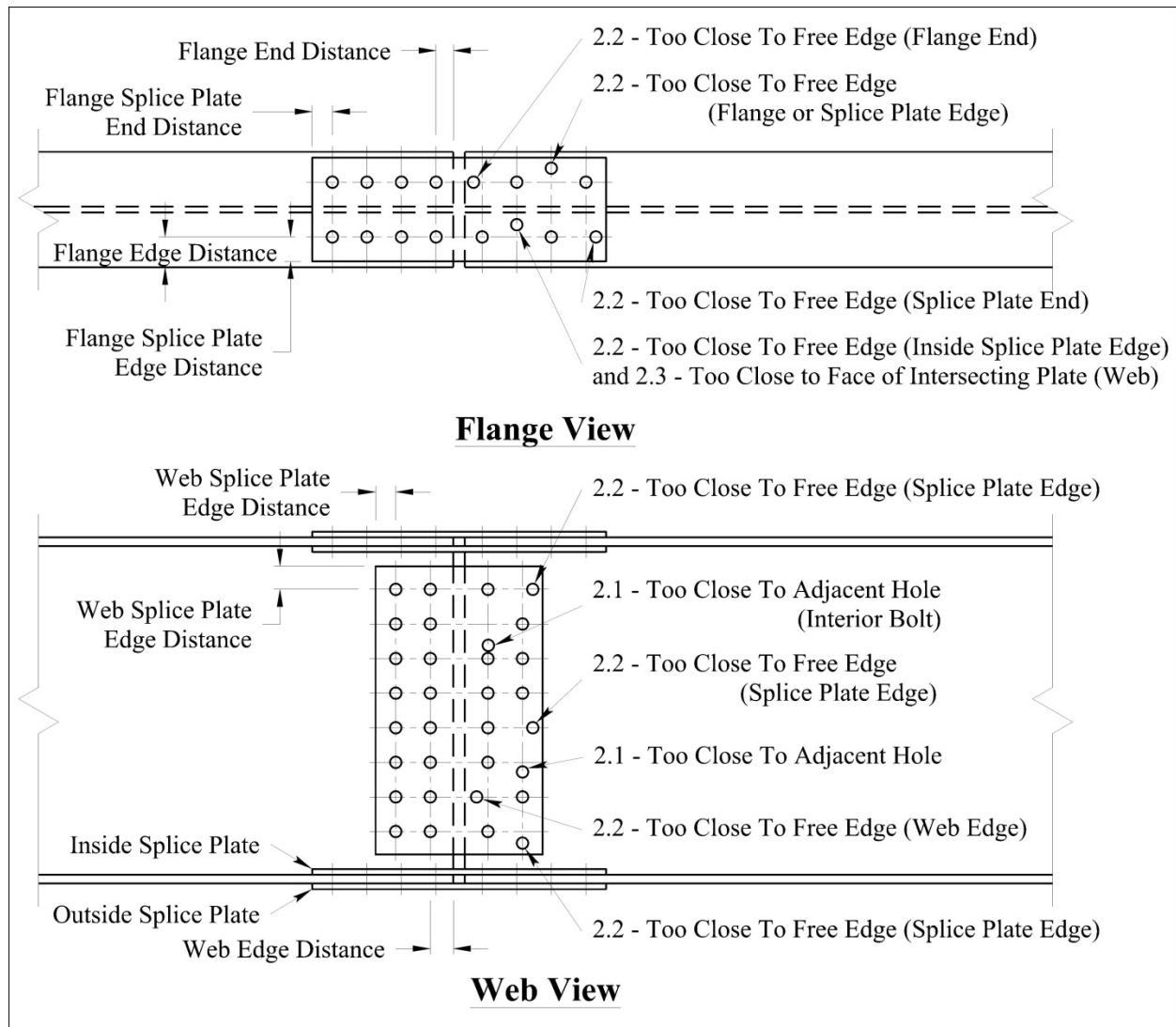


Figure 2-1—Errant Holes at a Bolted Field Splice

2.1—TOO CLOSE TO ADJACENT HOLE

Error:

A mislocated hole is too close to an adjacent hole.

Repair Recommendation:

1. Evaluate the situation:
 - a. Determine whether the resulting hole spacing permits bolt installation in each hole. If bolts can be installed in all holes, determine whether the resulting spacing satisfies the RCSC specifications so each bolt individually develops a slip-critical

C2.1

High strength bolted connections in steel bridges are often specified as slip-critical. In this type of connection, the prevention of slip in the service load range is the limit state. Since the load transfer mechanism is friction on the faying surfaces, the design assumption is that the slip resistance provided by the clamping force of each fastener is equal and additive with that at the other fasteners, provided the presumed areas of pressure transfer for the bolts do not overlap. See Figure C-3.1 in the RCSC specification. Slip resistance is also affected by the surface condition and hole size, so if any holes become oversize or slotted, the contribution by that

- connection. Use the RCSC specification to calculate reductions in clamping force.
- b. For connections transferring moment and shear, such as web splices, determine whether the potential bolt pattern's section modulus is adequate for the design moment and shear, considering reductions due to missing bolts or substandard spacing. This will not usually be a concern unless multiple bolts near the outside corners are involved.
2. If the calculated capacity based on the preceding evaluation is adequate, then the hole spacing may be accepted "as is." If there is not room to install bolts in all the existing holes, unused holes may need to be covered or closed to address fatigue concerns, to prevent corrosion, or for aesthetics. See Chapter 3.
 3. If the calculated capacity is inadequate (in recommended order of preference):
 - a. Determine whether there is sufficient space within the existing bolt pattern for adding bolts to compensate for the deficiency.
 - b. Determine whether larger splice or connection plates with additional bolts could be employed. See Figure 2.2-1. Note that for web splices, increasing the number of vertical rows increases design requirements.
 - c. Determine whether repairing the errant holes by welding and redrilling the hole pattern correctly is appropriate. Weld-repaired holes may be more susceptible to fatigue damage and should not be used in high stress range areas.

To restore the hole by welding and re-drilling, see Chapter 3.

- d. Determine whether larger diameter or higher strength bolts could add sufficient capacity, either with the existing connection or with a larger

bolt is reduced. Therefore, all locations must develop the slip force before a total joint slip can occur at that plane. However, although a slip-critical connection is designed to not slip into bearing under service loads, the connection must also meet the bearing requirements in an overload condition. This results in a final connection that does not slip under service loads, but also performs in bearing under extreme loads.

It is only for the bearing load transfer mechanism that the hole spacing is treated as a direct design parameter. The bearing strength is a function of the hole spacing, so inadequate hole spacing reduces the total bearing strength.

For the friction load transfer mechanism, the clamped areas of the plates in contact around each bolt must provide for friction load transfer. There must be enough room to correctly install the bolt.

one. Changing bolt size or strength will adversely affect field installation and must be closely coordinated with the erector and clearly noted on erection framing drawings. Do not mix different strength bolts of the same size within a single connection.

If there is not room to install bolts in all the existing holes, unused holes may need to be covered or closed to address fatigue concerns, to prevent corrosion, or for aesthetics. See Chapter 3.

4. Relocating the splice or removing and replacing part of the member are last-choice options because of their complexity and potential for defects. Costs of additional material, increased erection labor, engineering to design and verify alternates, fabrication, and NDE should be the Contractor's responsibility.

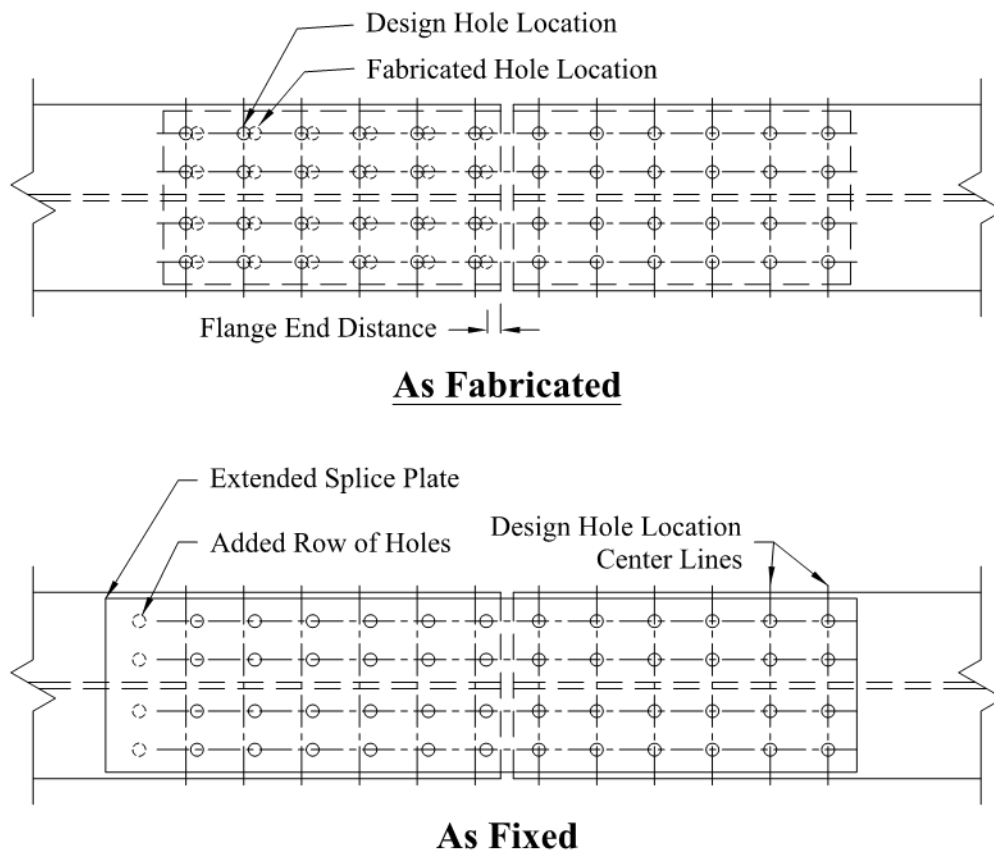


Figure 2.2-1—Too Close to End of Flange

2.2—HOLE TOO CLOSE TO FREE EDGE

Error:

A hole is drilled closer to the free edge than permitted by the applicable design specifications or drawings. A “free edge” is a rolled or thermally cut boundary not welded to another component. This includes the end or side edges of a flange, the end of a web, or any edge of a splice plate.

Repair Recommendation:

1. If the hole is adjacent to a TCE and bolt placement is based on criteria from the *AASHTO Standard Specifications for Highway Bridges*, for errors up to $\frac{1}{8}$ " [3 mm], grind the adjacent edge of the plate to approximate a planed finish and allow a smaller clearance than for a TCE.
2. For errors reducing clearance below AASHTO specified minimums but not breaking the edge, determine whether the contribution of the bolt to the connection's total capacity can be neglected.
 - a. If so, the connection may be used as is, but a bolt must still be inserted in the errant hole to address fatigue concerns, maintain the sealing pitch, and avoid confusion on future inspections.
 - b. If neglecting the bolt makes the connection inadequate, follow Repair Recommendation 3 in Section 2.1, “Too Close to Adjacent Hole.”
3. If the mislocated hole breaks through the edge of one element in the connection, it cannot be ignored, even if the connection has adequate strength without it. If only a very small portion of the hole encroaches into the material, consider grinding 1:10 tapers to the surface if the remaining material will be adequate.

If penetration is significant (more than $\frac{1}{2}$ hole diameter or remaining material will not be adequate), the material must be replaced or repaired. If this

occurs in a splice or gusset plate or a bracing member, it should be replaced if possible.

Elements that cannot be replaced (because of material availability or other considerations) need to be either repaired or strengthened. A welded repair may be done in accordance with Clause 3.2.3 of AASHTO/AWS D1.5M/D1.5 (and Clause 12 for FCMs). See also Chapter 3.

2.3—HOLE TOO CLOSE TO FACE OF INTERSECTING PLATE

Error:

A hole is drilled through a flange and is too close to the web to allow installation of the bolt without encroaching on the flange-to-web junction (weld, rolled fillet, etc.). If there is a splice plate on the inside face of the flange, an edge distance problem of the type addressed in Section 2.2, “Hole Too Close to Free Edge,” may also occur.

Repair Recommendation:

1. If the hole does not cut into the intersecting plate, in order of preference:
 - a. Slot the hole transversely to allow the bolt to be installed further away from the web.
 - b. Determine whether the connection is adequate with the bolt omitted.
 - i. If the bolt can be omitted, fill the hole in accordance with Chapter 3. Filling the hole addresses fatigue concerns and also prevents confusion in the field.
 - ii. If the bolt is structurally necessary, consider enlarging the connection by adding bolts. (See Figure 2.3-1.)
2. An errant hole entering the intersecting plate (e.g., goes through the flange-web fillet and into the web) may be a significant stress riser in a tensile stress area, and an in-situ welded repair would be very difficult. In this case, consider the following:
 - a. At a bolted splice:

- i. For a plate girder, remove flange-to-web fillets sufficiently beyond hole to allow individual repairs of web and flange. This might entail welded repairs to both web and flange or welded repair of the flange and a radiused opening in the web, avoiding adjacent restrained welds.
 - ii. Lengthen the flange splice plate to develop the splice beyond the damaged area. The original designed pattern will be beyond the damaged area. Bolts will still be required between the damaged area and the end of the member; observe required minimum bolt spacing.
- b. Not at a bolted splice (e.g., at a bracing connection):
 - i. Reinforce the area with external flange plates bridging the area to reduce stress range.
 - ii. Provide a bolted flange splice, developed on each side of the hole and neglecting any contribution from the flange at the hole. This conservatism may be justified for an FCM.

If all or a portion of the hole remains and will be visible to the public or may accumulate moisture (bottom flange), or if it is in an area where a Category D fatigue detail is not appropriate, it should be filled in accordance with Chapter 3.

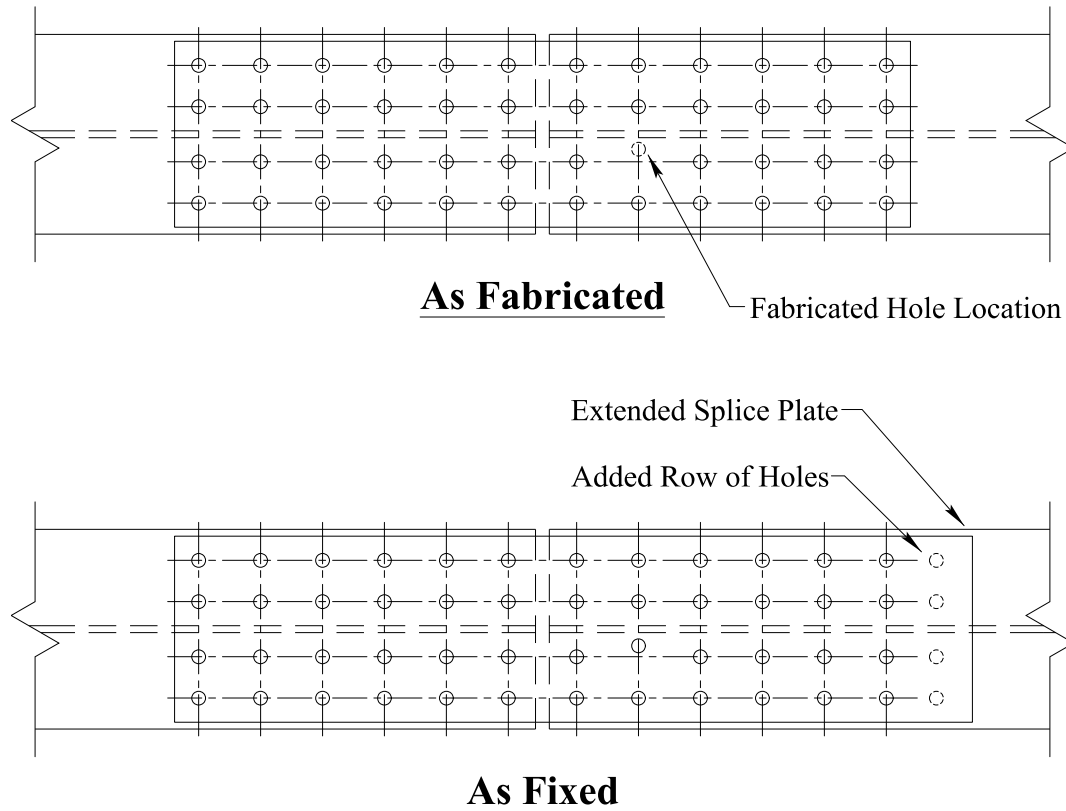


Figure 2.3-1—Hole Too Close to Face of Intersecting Plate

2.4—ELONGATED AND OVERSIZE HOLES

Error:

A standard hole is improperly drilled, resulting in an oversized, misshaped, or elongated hole.

Repair Recommendation:

Standard and oversized holes are defined in the AASHTO bridge design standards. In main members, investigate whether the connection can tolerate the reduced capacity of an oversized hole.

1. For most cases, where the oversize dimension is not severe and is limited to a small portion of the holes at any location, it may be acceptable to leave the hole(s) “as is.” If many (or most) of the holes at a connection are oversized, evaluate whether the oversize

C2.4

Avoid changing to specialty bolts and washers for only certain holes in a connection since the field bolting crew will have equipment calibrated for a specific size, and the wrong bolts could easily be installed. Acquiring different bolts may require testing and approval, significantly delaying field work. If necessary, ream or re-drill the hole as necessary and increase the bolt one size (e.g., $\frac{3}{4}$ " to $\frac{7}{8}$ ") at those locations, documenting locations with notes on the erection sheets, and marking the locations of the larger bolt(s) clearly for field personnel. Using this approach in the shop for individual bolt locations has a high potential for field installation errors and is not recommended.

holes are structurally acceptable, and if so, consider drilling new splice plates to match with core-type bits (to avoid further enlarging existing holes), using the holes in the member as a template. (Reaming or drilling the existing splice plates can lead to alignment problems.) This will not increase design capacity, but will provide a better connection and may justify slightly exceeding overload limitations. A hardened washer or ply must cover any exposed non-standard hole, as required by the RCSC specification.

2. If there are a number of non-conforming holes at a single splice location and calculations indicate that the design bolts in oversize holes will not be structurally adequate, consider using larger diameter bolts if spacing and edge distances permit. If the problem is discovered in the field, larger bolts may be provided for just the oversize holes, but if found in the shop, larger bolts should be used for the whole pattern to avoid field confusion. The larger bolts may theoretically provide more strength than the original bolts, but need only meet plan requirements. If spacing will not permit the use of larger diameter bolts, higher strength bolts may be considered, but the same strength bolt should be used for the whole connection. Mixing ASTM A325 bolts in standard holes and A490 bolts in oversize holes within the same connection may require sophisticated review and result in jobsite confusion. Changing bolt size or strength will adversely affect field installation and must be closely coordinated with the erector and clearly noted on erection framing drawings.
3. If there is poor hole quality and inadequate edge distance, then that splice may need to be re-designed (e.g., lengthen the flange splice or add rows of bolts to a web splice), considering the effect of oversize holes on capacity. If the problems are concentrated in a transverse row of holes in a member adjacent to the splice centerline, another alternative may be removing the end portion of the member with the “problem” row. This may entail revising splice geometry based on