BUREAU OF STRUCTURES

Fatigue-Prone Detail Inspection Manual

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WisDOT Fatigue-Prone Detail Inspection Manual

Fatigue is the process by which steel is damaged from repetitive loading. Damage accumulates over the life of the structure and manifests as a crack when a member or detail has reached the end of its fatigue life. While fatigue cracking can occur in both old and new structures, it is more prevalent in older structures because a) decades of research have improved the details in modern structures to make them more fatigue resistant, and b) fatigue is a function of the number of cycles of loading. When a member or detail reaches the end of its fatigue life, it does not mean it needs to be replaced, but often it can be remediated through repair or retrofitting. In some cases, a particular detail has an assigned fatigue category, and the initiation of cracks can be predicted if the engineer has an idea of the frequency of loading and the range of stress in the detail. But in other cases, particularly when it involves defects in the steel members or their weldments, this is much more difficult to predict. And finally, some details don't offer much warning of distress and can be prone to sudden fracture.

Defects are the result of fabrication, construction, or damage imparted to the structure (e.g. vehicular impact) that provide favorable conditions for cracks to form, called stress risers. These are not design details and are not associated with any particular structure type and generally require an inspector in the field to identify them.

Design details on the other hand are intentional and can be identified prior to inspection by reviewing the design plans. Generally, by the late 1970's engineers were more conscience of fatigue prone details and began developing details that performed better. However, there are still many older structures in service that have details with poor fatigue resistance. Several design specifications have categorized common steel details, such as the AASHTO LRFD Bridge Design Spec Ta. 6.6.1.2.3-1 which has details ranging from a Category A (least fatigue prone) to E' (most fatigue prone). This classification helps the engineer and inspector identify those details more at risk to fatigue cracking. Generally, categories A, B, B', C' and C will rarely have problems in the field, and those details continue to be widely used today. Categories D, E and E' are those most likely to exhibit problems in the field and should be given special attention during inspections. Problems in these latter categories are often related to weld terminations or weld defects.

These detail categories are associated with *Load-Induced Fatigue.* As the name suggests, the fatigue is due to the force effects, for which the engineer can perform a stress analysis to determine the fatigue life of the detail, or how much of that life remains. However, there are many details and conditions that remain unclassified. *Distortion-Induced Fatigue,* which is a result of secondary or out-of-plane distortion, is a very common source of fatigue cracking and often presents itself in the connections between transverse members (floorbeams, cross frames, etc.) and the main longitudinal members (girders, ties). While not classified by AASHTO, research suggests this is a Category C, which insinuates it is fairly fatigue resistant. However, the stresses can be quite high, which is why the detail often cracks.

Fracture is rapid or sudden crack growth and can occur when a fatigue crack becomes unstable. However, if inspections are being conducted appropriately based on the risk of fatigue prone details, then this is unlikely to occur. Fatigue crack growth is slow, generally on the order of 1"-3" per year. If an inspection has found a large crack to have appeared or grown between inspection cycles, the member can be considered to have fractured. Some details, prone to constraint-induced fracture (CIF), won't show signs of fatigue and instead are prone to sudden fracture, such as what happened on the Hoan in 2000. CIF is not a very common form of failure; in fact, many CIF details have performed satisfactorily for decades. Nonetheless the inspector needs to correctly identify those details and make the engineer aware of the presence of the detail on the structure. Typically, the course of action is to accept the risk, particularly in redundant structures, or to preemptively retrofit the detail to prevent fracture.

The list below, with the following tables, describe the various fatigue prone details that can be found in Wisconsin's steel bridge inventory. The indication of commonality is in reference to the detail used, not necessarily the likelihood of finding a fatigue crack. They are categorized into three groups: The first group are load-induced fatigue prone details with AASHTO detail categories D-E'. The second group are details susceptible to distortion-induced fatigue cracking. And the third group highlight some common concerns due to damage, poor workmanship, or otherwise poor detailing.

Fatigue Prone Details (AASHTO Fatigue Category D-E')

1. Welded Cover Plate Termination (E/E')
2. Reentrant Corners at Copes (C-E')
3. Longitudinal Stiffener Termination (B-E')*
4. Shelf Plate (To Web) (C-E')*
5. Shelf Plate (To Flange) (E')
6. Pin and Hanger (E)
7. Open Holes (D)

Distortion-Induced Fatigue Details

8. Connection Plate Web Gap
9. Floorbeam Web Gap
10. Riveted or Bolted Connections Using Angles

Other

11. Notches and Gouges
12. Transverse Butt Welds
13. Discontinuous Backing Bars
14. Intermittent/Tack Welds or Other Poor-Quality Welds

1. Welded Cover Plate Termination

Detail Category: E/E’

Prevalence: Common

Note: Coverplates are often used with rolled W-shape girders in the positive and negative moment regions. The top cover plates cannot be inspected as they are covered by deck. If a redeck occurs, these should be inspected.

Nature of Crack: Often forms at the toe of the weld at the tip of the coverplate.

Repair Method: Grind out crack. If 1/16” or less in depth, no further action needed. Consider weld peening. If greater than 1/16” used bolted splice or similar.

Photo Location: B-40-196

2. Reentrant Corners at Cope

Detail Category: C-E'

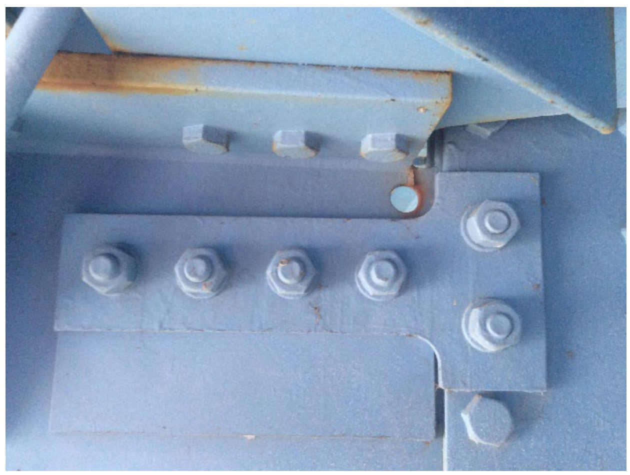
Prevalence: Common

Note: *If* a 1" min. cope is provided, the detail is a Category C, as seen in the 3rd photo. Small radii (1st photo) or flame cut copes are unclassified but can be less than an E' detail.

Nature of Crack: Emanates out of the cope as shown in the 2nd photo.

Repair Method: If the space allows, the initial approach should be to provide a 2" stop hole or provide a 1" cope radius.

Photo Location: B-15-4 (Bayview Bridge)



3. Longitudinal Stiffener Termination

Detail Category: B-E’

Prevalence: Common

Note: The fatigue category is a function of the radius provided at the termination of the longitudinal stiffener and the thickness of the stiffener plate. Generally, the concern is with stiffeners that have no radius provided at the end, as seen in the 1st photo, which is a category E. The biggest concern is in areas of tension or stress reversals. Cracks can form in compression zones but will self-arrest. <u>Note that Constraint Induced Fracture can be a concern when longitudinal stiffeners terminate at a vertical stiffener (See next page)</u>

Nature of Crack: Crack will form where the weld terminates, oriented vertically, it will continue to grow vertically running toward the tension flange.

Repair Method: provide a radius to the end of the longitudinal stiffener, as shown in the 2nd photo.

Photo Location: B-5-158 (Leo Frigo)

3. (continued) Intersecting Welds at Longitudinal Stiffener Plates

Detail Category: n/a

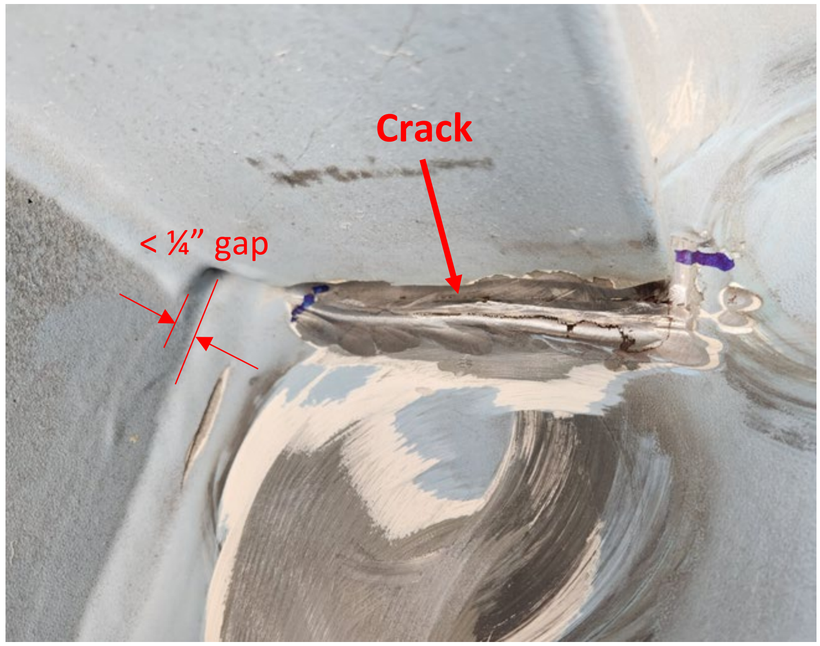
Prevalence: Uncommon

Note: Again, three conditions are needed to be considered a CIF detail. In this example a crack developed between the longitudinal stiffener and the vertical stiffener. This interrupted the flow of stress through the longitudinal stiffener which then had to pass through the web (stress riser). This detail made itself a CIF detail when it cracked, but sometimes the longitudinal stiffener is intentionally not welded to the vertical and there is an abrupt end. The ¼” gap is an important consideration when this is the case. If it is ¼” or greater than the risk is low, less than that however is more at risk of CIF, as was the case here.

Nature of Crack: little to no warning

Repair Method: cut longitudinal stiffener back and provide smooth radius as shown in the 2nd photo.

Photo Location: B-40-400 (Hoan)



4. Shelf Plate (To Web)

Detail Category: C-E’

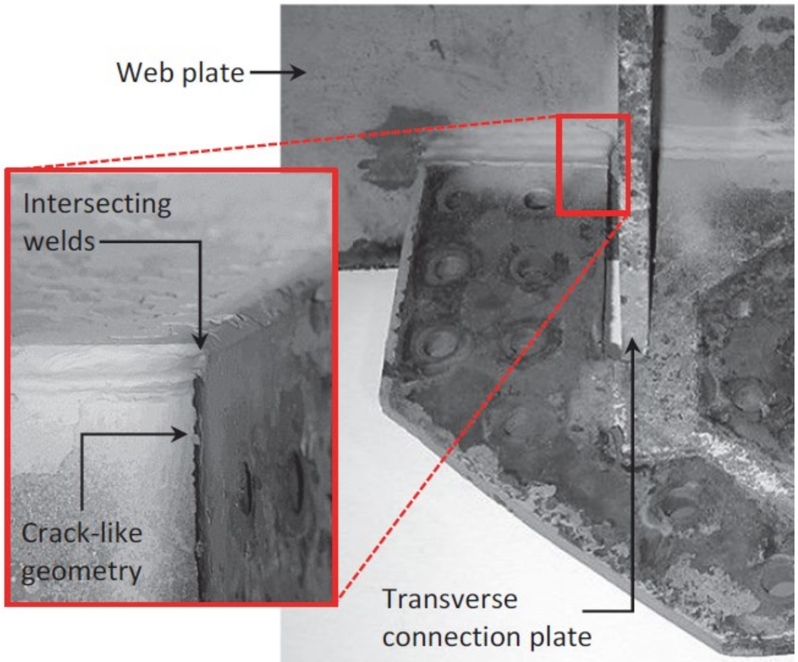
Prevalence: Common

Note: Shelf plates are present when there is lateral bracing. They have similar fatigue resistance to longitudinal stiffeners. The detail category is a function of the length of plate, but generally this will be an E or E’ detail. Cracks can form in compression zones but will self-arrest. <u>Note that Constraint Induced Fracture can be a concern as well (See next page)</u>

Nature of Crack: Similar to longitudinal stiffener.

Repair Method: Can drill a minimum 2” diameter hole into the shelf plate providing a radius at the weld tip. Alternatively web isolation holes can be drilled to “catch” a crack (shown in the 2nd photo – with shelf plates removed).

Photo Location: 1st photo: B-12-27 (Prairie du Chien) / 2nd photo: B-40-285 (Valley Bridge)

<table>
<tr><th colspan="2">4. (continued) Constraint Induced Fracture Concerns</th></tr>
<tr><td>Detail Category: n/a</td><td rowspan="4">


</td></tr>
<tr><td>Prevalence: Uncommon</td></tr>
<tr><td>Note: This detail is often referred to as the "Hoan" detail due to its role in the Hoan fracture in 2000. It is categorized as a Contraint-Induced Fracture or CIF detail. Three aspects are needed to make a CIF detail – 1) welded, 2) presence of crack-like geometry (stress concentration/riser), and 3) Highly constrained material (intersecting welds, or < ¼" gap). Many of these details had been retrofitted after the Hoan, but some may still exist.

Nature of Crack: Little to no warning is given with this detail. The presence of such detail does not mean the structure is unsafe, in fact many CIF details have performed satisfactorily over the life of many structures. However, knowledge of its presence can be used as part of a risk assessment of the structure and whether a retrofit strategy should be employed.

Repair Method: Several well documented retrofits are available.

Photo Location: B-40-400 (Hoan) *these were retrofitted following the 2000 event*</td></tr>
</table>

<table>
<tr><th colspan="2">5. Shelf Plate (To Flange)</th></tr>
<tr><td>Detail Category: E’</td><td rowspan="3">
</td></tr>
<tr><td>Prevalence: Rare</td></tr>
<tr><td>Note: Shelf plates welded the girder flange serve the same purpose as those welded to the web, however the attachment directly to the flange makes this detail riskier. One of the difficulties with inspecting this detail is that cracks tend to form at the weld root, and the crack may go undetected until the plate is almost entirely severed from the flange.

Nature of Crack: For plates with only a transverse weld, cracks tend to form at the root. Otherwise with both transverse and longitudinal welds, cracks may form at the weld toe.

Repair Method: If a longitudinal weld is not present, one can be added and all welds peened. Otherwise convert the detail to a bolted connection, as shown in the 2nd photo.

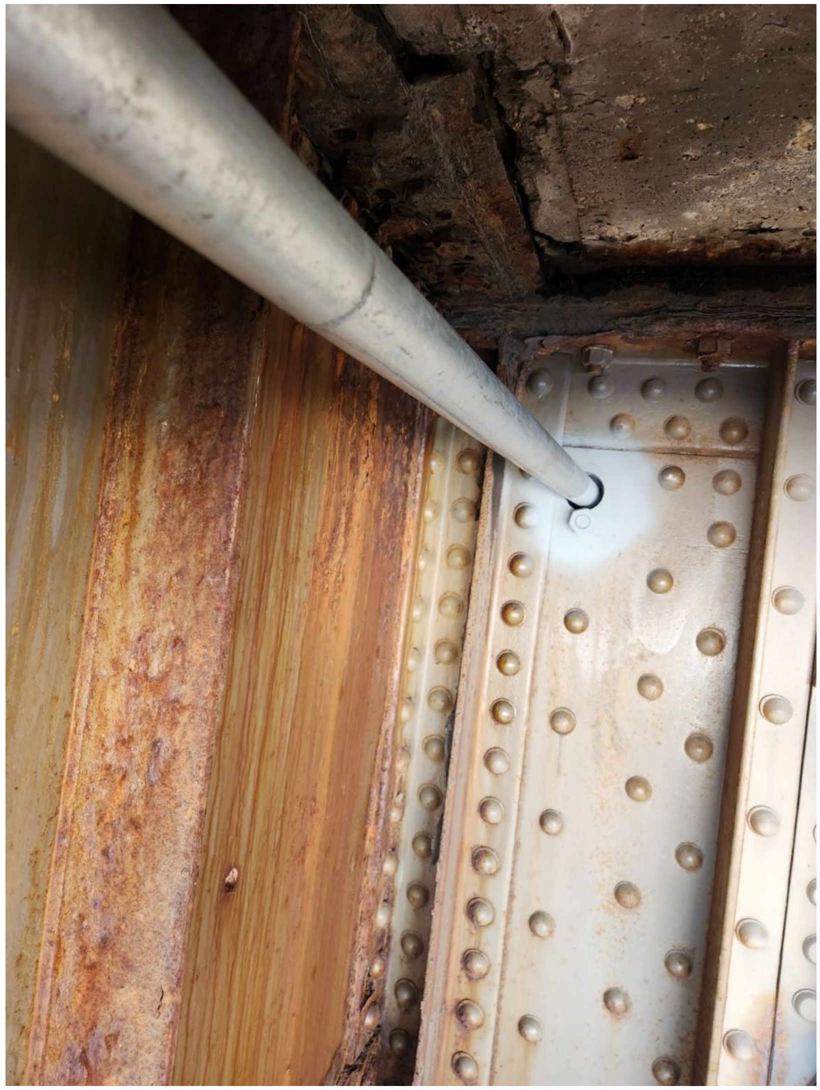
Photo Location: 1st photo B-56-48 (Mirror Lake) / 2nd photo B-40-285 (Valley Bridge)</td></tr>
</table>

<table>
<tr><th colspan="2">6. Pin and Hanger</th></tr>
<tr><td>Detail Category: E</td><td rowspan="3">
</td></tr>
<tr><td>Prevalence: Common</td></tr>
<tr><td>Note: A common detail used in steel bridge construction until the early 1980's. Lack of redundancy is the primary concern with this detail as highlighted by the 1983 Mianus River Bridge collapse. 2-girder (NSTM) bridges that have this detail are most at risk.

Nature of Crack: cracks are an unlikely cause of pin and hanger failure. More often, corrosion and/or seizing up of the pin are to blame for failure.

Repair Method: Replacement

Photo Location: B-5-158 (Leo Frigo)</td></tr>
</table>

<table>
<tr><th colspan="2">7. Open Holes</th></tr>
<tr><td>Detail Category: C/D</td><td rowspan="3"></td></tr>
<tr><td>Prevalence: Common</td></tr>
<tr><td>Note: Open holes are a Category D detail per AASHTO. However, research supports that holes that have a minimum radius of 1” and have a smooth surface will perform as a Category C.

Nature of Crack: emanating out of hole

Repair Method: enlarge hole and/or improve surface smoothness.

Photo Location: B-40-550</td></tr>
</table>

8. Connection Plate Web Gap

Detail Category: n/a

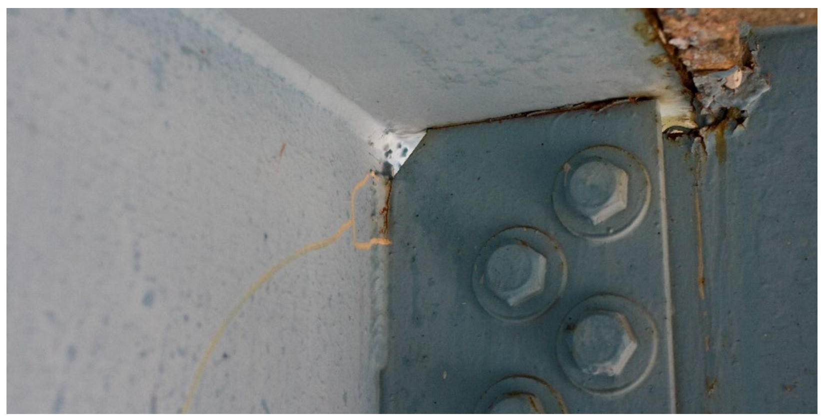
Prevalence: Common

Note: This is type of fatigue cracking is distortion induced. It is common with floorbeams or other primary transverse members that frame into the longitudinal members. It can occur with cross frames but that is rare.

Nature of Crack: The crack typically forms in one of two ways (sometimes both are present). The first is a longitudinal crack that forms along the flange-to-web weld toe. The second is in the shape of a frown, starting at the tip of the vertical weld and running down both sides of the connection plate.

Repair Method: Various

Photo Location: B-40-285 (Valley Bridge)



9. Floorbeam Web Gap

Detail Category: n/a

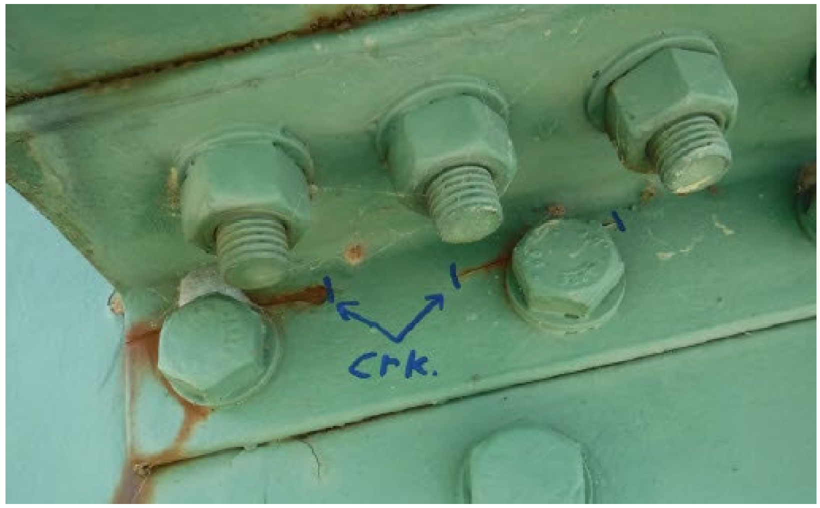
Prevalence: Common

Note: Predominantly this occurs in floorbeams attached to trusses or tied-arches, typically those nearest the supports. Differential longitudinal displacements between the deck and truss/tie cause the top flange of the floorbeam to move out-of-plane relative to the web which is fixed to the primary member.

Nature of Crack: The crack is horizontal near the top flange-to-web interface. It begins at the connection to the primary member and works its way inward.

Repair Method: Drill a large diameter hole at the tip of the crack. Cracks may reinitiate on the other side of the hole depending on the configuration. In that case, cutting the floorbeam flange back to increase flexibility may be a viable option.

Photo Location: B-52-856 (Lone Rock Truss)

<table>
<tr><th colspan="2">10. Riveted and Bolted Connections Using Angles</th></tr>
<tr><td>Detail Category: n/a</td><td rowspan="3">


</td></tr>
<tr><td>Prevalence: Common</td></tr>
<tr><td>Note: The use of angles to connect members together is very common. These connections are normally designed as “simple” connections, when in reality they do provide a certain amount of rotational stiffness. For certain configurations this can impart significant secondary forces and prying action to the angle.

Nature of Crack: cracks initiate along the angle fillet or near the edge of the fastener.

Repair Method: Varies – generally softening the connection or removing secondary members if not needed.

Photo Location: B-22-61 (USH 151 over Mississippi River)</td></tr>
</table>

11. Notches and Gouges

Detail Category: n/a

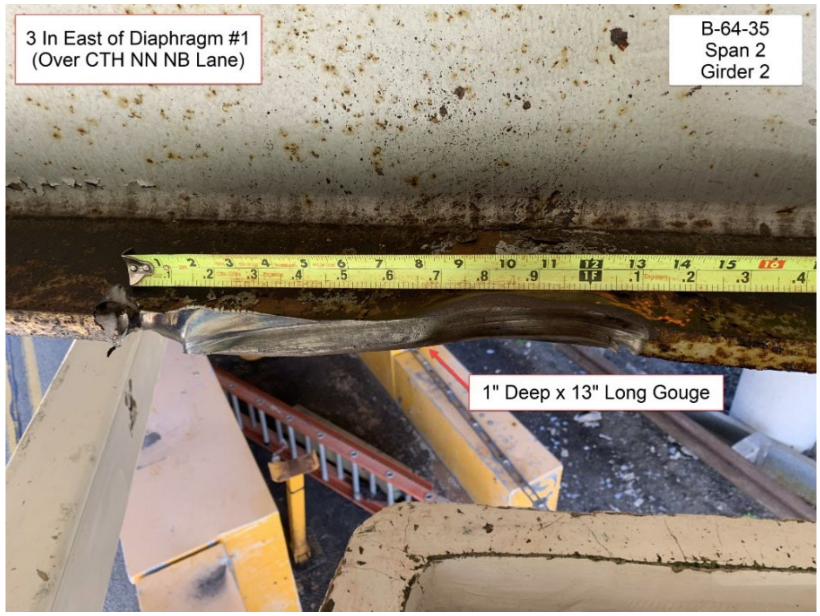
Prevalence: Common

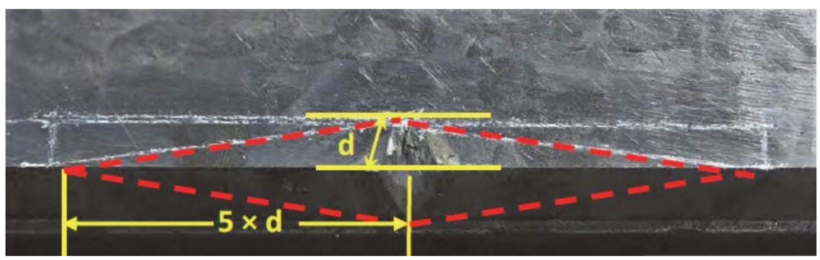
Note: Notches and gouges can take an otherwise fatigue resistant member and introduce a significant stress riser that may produce a fatigue crack. Impact damage is a common source, but construction such as saw cuts from deck removal can also introduce stress risers.

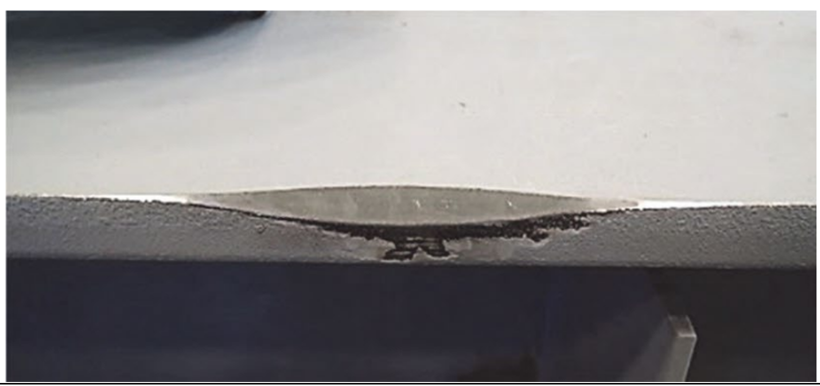
Nature of Crack: varies, but will propagate from the defect and run perpendicular to primary stress.

Repair Method: Grind out at a 5:1 taper

Photo Location: B-64-35







12. Transverse Butt Welds

Detail Category: B, B', C

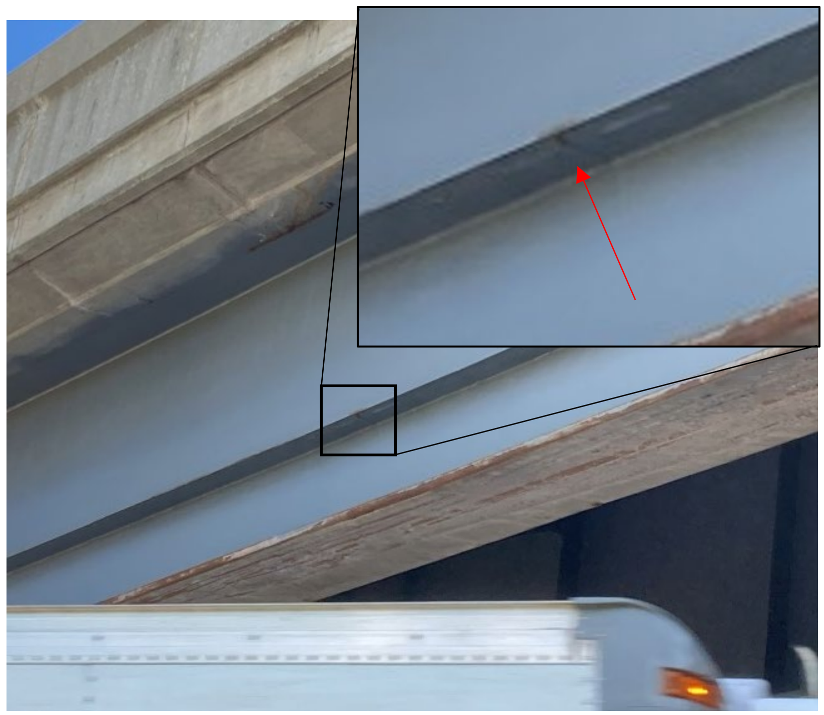
Prevalence: Common

Note: Full penetration welds, or butt welds, have been widely used since the 1940s. However, the quality of these welds from the 1940s and 1950s tended to be poorly executed with little or no inspection. Problem areas are web insert plates for haunched girders, flange and web splices, groove-welded cover plates, and continuous groove-welded longitudinal stiffeners. Note that Constraint Induced Fracture can be a concern (See detail #3).

Nature of Crack: cracks begin at the weld toe and grow perpendicular to the direction of primary stress.

Repair Method: Various – depends on detail.

Photo Location: B-40-39 (Stadium Interchange)



13. Discontinuous Backing Bars

Detail Category: n/a

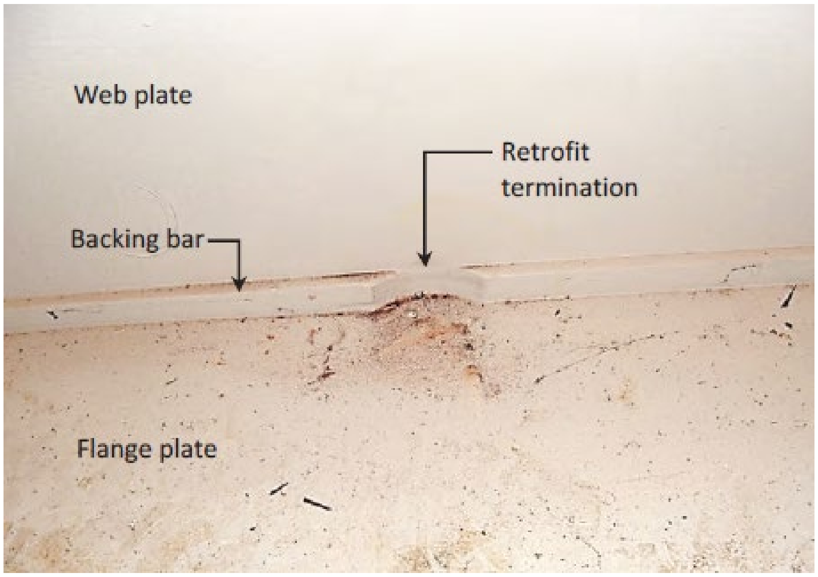
Prevalence: Uncommon

Note: Particularly with older structures, long runs of backing bar were made of multiple bars that were not always welded together, or it was of poor weld quality, as seen in the 1st photo. Because they fuse to the welded joint, they become a structural member. The abrupt ends introduce a crack-like condition.

Nature of Crack: crack will form along the discontinuity potentially extending into the base metal. Discontinuities in tension zones or stress reversals are of most concern.

Repair Method: Provide a transition similar to what is shown in the 2nd photo.

Photo Location: B-40-400 (Hoan)



14. Intermittent/Tack Welds or Other Poor-Quality Welds	
Detail Category: n/a	 
Prevalence: Uncommon	
Note: Generally, cracks in tack welds are uncommon and when they do, they are usually benign, but in rare cases they can crack into the base metal which becomes a concern. Poor-welds, as shown in the 2nd photo, can introduce stress risers which can result in fatigue cracking. Nature of Crack: Various Repair Method: Various – depending on the nature of the weld Photo Location: 1st photo: B-11-22 (Wisconsin River Bridges) / 2nd photo: B-40-285 (Valley Bridge)	