BRIDGE INSPECTORS GUIDE

FOR

FRACTURE CRITICAL BRIDGES

AND

BRIDGES WITH SPECIAL FEATURES

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PREFACE

The Federal Highway Administration requires that all structures that are fracture critical or have unique features be placed on master lists. The structures on these master lists must receive special inspections. The structures that require these special inspections are identified on the SI&A sheets under items 92A and 92C. The NDBIP (North Dakota Bridge Inspection Procedures) describes the coding procedures for the structures identified in items 92A and 92C.
INTRODUCTION

A fracture critical bridge is defined as a structure with one or more fracture critical member (FCM). A FCM is a tension member or a component whose failure will produce a sudden collapse of the structure.

Redundancy is the ability of other members to help carry the load when a member becomes weak or fails. A two-girder bridge or a truss is considered non-redundant since the other members are unable to help share the load, and therefore these bridges are fracture critical.

A fracture critical bridge may have numerous fatigue prone details. Fatigue prone details are only able to bend so many times before cracking occurs. These fatigue prone details would not cause the collapse of the bridge if the bridge was redundant. However, since the bridge does not have any built in ability to shift the load to other members if a fracture occurs, the bridge may collapse.

A fracture critical member is a member in tension, which means it is being pulled apart. This causes cracks to grow and a fracture to occur. A member in axial tension is stressed the same throughout the cross section for the total length between connections. Hangers, suspension cables, and some truss members normally are stressed in axial tension. Direct tension members, even though they may have no welding associated with them, are the most critical because they are usually used in situations where virtually no redundancy exists, and defects can initiate and grow to possible critical flaw size without being detected. Eyebars and hangers that have been repaired by field welding become highly susceptible to fatigue cracking.

Members in bending have variable stresses throughout. On a simple beam, the maximum tension is in the bottom flange at midspan. An equally important location on a continuous span is the top flange over the support. High stress may also be concentrated at locations along a member where the cross section changes or where there is a discontinuity.

Many of the problems being discovered in in-service bridges are associated with weld terminations or defects which are inherent to the welding process. Welding of structures generally started in the 1950's. The state-of-the-art at that time, both from a welding procedure standpoint, as well as shop inspection techniques that were available, makes it very likely that defects are present, and the bridge inspector now has to find them before they reach the critical flaw size. Welds made in the field are especially susceptible to fatigue cracking. Even tack welds could initiate cracking under certain conditions.

A FCM is endangered by corrosion which can lead to loss of section, pack rust, and shortened fatigue life. Proper maintenance and painting can reduce this problem. Rust can build up between plates and add additional stresses to members.
FRACTURE CRITICAL BRIDGE INSPECTION

A. Preparation

A fracture critical bridge inspection begins before the bridge inspection crew arrives at the bridge. The crew should study the maintenance file carefully while still in the office. It is important for each inspector to understand which members are fracture critical and where the fracture critical zones are located. Fatigue prone details should also be identified. A copy of the plans with fracture critical areas and fatigue prone details marked on them should be taken along. Records of damage to the structure due to collision or corrosion and repairs are also important. In addition to access equipment such as ladders and snoopers, the crew may need special tools such as magnifying glasses, spotlights, or dye penetrant testing kits. Premade forms or booklets listing the locations to be inspected, crack locations, size, and direction, etc., would be helpful.

When more than one person is making the inspection, it is important to coordinate the activities. It is the crew leader's responsibility to insure that duplications and omissions in inspection of FCM's are minimized. Data collection should be coordinated so that it can be easily put into a report.

B. Inspections

The inspection should begin with a general evaluation of the structure and fracture critical members. Look for things such as misalignment of spans either horizontally or vertically. Unusual movement or noise might also indicate serious problems. During the overall evaluation, inspectors should also look for distortions or damage created by traffic, flooding, etc.

After the overall evaluation, each member of each fracture critical detail should be checked closely. The inspector should focus on tension zones of fracture critical members and fracture critical connections (see pages 6-13). Pin and hanger assemblies should be visually inspected for any defects or corrosion, but item 93C on the SI&A sheet should not be coded as an inspection. All pin and hanger assemblies are inspected by special contracted inspections, which are handled through the NDDOT Bridge Division, hereafter referred to as the Bridge Division.

The inspector's eye should be within 24 inches of the surface. The member should be viewed from all sides and all angles. The inspector should use additional light and magnification to evaluate the member if necessary. If a crack or flaw is suspected, the inspector should use a magnifying glass or a dye penetrant test kit to verify the crack or flaw. The location and length of the crack or flaw should be marked for future reference. Any further nondestructive testing will be done by special contract, which will be handled by the Bridge Division.
C. **Inspection Reports**

By definition, fracture critical bridges are prone to failure which may result in a catastrophe. It is important that the inspection of a fracture critical bridge be documented thoroughly and accurately. This should include a narrative description of all FCM's whether there are serious problems or not. Photographs and sketches should be included. Where there are many details and findings, tables and charts are also necessary. The data should be organized efficiently for ease in interpreting the report. The data should provide information on why problems occurred (out-of-plain-bending, poor weld, corrosion, etc.). Repairs are only effective when the cause of the problem is known. The report should also include conclusions, and a summary of the findings.

Along with stating the existing condition, the inspection report should provide an ongoing record of the condition of the bridge and verification of the thoroughness of the inspection activities. Occasionally there will be serious flaws that cannot be seen by the inspector. If a fracture occurs, the report can be used to verify that a proper inspection was made.

D. **What to do if a Flaw or Crack is Found**

A flaw or crack on a fracture critical member is a very critical finding and should be handled differently than other findings. Ordinarily the inspector would prepare the report and forward it to the Bridge Division for review. The report may not be looked at for several weeks. Flaws on fracture critical members should not wait that long for evaluation by an engineer. Some flaws such as a visible crack in a tension flange of a two-girder bridge should be reported immediately. The inspector should go to a phone and call the Bridge Division at (701) 328-2592. Traffic should be shifted off the girder. Other problems such as a flaw in a web may be reported when the inspector returns to the office. It is better for the inspector to error on the side of safety. If there is a question about the significance of a finding, the Bridge Division should be contacted as soon as possible.

When problems are identified, it is a good idea to go back and look at similar details throughout the bridge. Often inspectors have found cracks at other locations that had already been inspected after finding the first. This demonstrates that it helps to know exactly where to look and what to look for on the other details. After a flaw or crack has been identified, it may be helpful to do additional evaluation with NDT such as magnetic particles, ultrasonic or radiographic. These types of test will be handled through contract, by the Bridge Division.
FRACTURE CRITICAL BRIDGES

A. Examples of Fracture Critical Details Are:

1. Suspended Spans

Links and hangers and the connecting pins are susceptible to fatigue cracking; pack rust can push hangers off pins.

2. Trusses

If the floor system is rigidly connected to the verticals, redistribution of forces can take place in the event of member fracture, but bridge deflection would be excessive.

3. Two-Girder Bridges

Where the floor system, including the deck and the lateral bracing members, provides alternative load paths and redundancy, fracture of one girder would not cause collapse of the bridge but would lead to excessive deck deflection. If alternative load paths do not exist, it is fracture critical.

Where the lateral bracing connects to horizontal gusset plates, which are attached to webs, differential forces in laterals could cause fatigue cracks in girder webs at the ends of the gusset plates, particularly when the gusset plates are not attached to the floor beam or diaphragm connection plate. The vertical crack could grow toward the tension flange and may cause brittle fracture.

4. I-girder Pier Cap Supporting Bridge Girders or Stringers

Continuous multi-girders or stringers composite with the bridge deck may permit redistribution of forces providing alternative load paths. If simply supported, the cap is fracture critical.
B. **Examples of Details That Should be Checked Closely Are:** (See examples on pages 14-26).

1. Intermittent welds between the web and tension flange. (B-1)

2. Areas of sudden change of cross-section. Examples, near the ends of cover plates. (B-2)

3. Location of stress risers such as nicks, scars, flaws, and holes that have plug welds, irregular weld profile, and areas where the base metal has been undercut during welding. (B-3)

4. Locations where stiff bracing members of horizontal connection plates are attached to thin webs and girder flanges. (B-4)

5. The web adjacent to a floor beam connection plate. (B-5)

6. Gusset plates, improperly coped members re-entering corners, and the gap between web stiffeners and flanges. (B-6)

7. Stiffeners that have been connected together with butt welds. (B-7)

8. Longitudinal and vertical stiffeners intersections. (B-8)

9. Location of welds at gusset plate-transverse stiffener-web or flange intersections. (B-9)

10. Flanges that pass through a web, such as a girder flange passing through a box girder pier cap. (B-10)

11. Eyebars. (B-11)

12. Pin and Hanger. (B-12)

C. **Areas Where Corrosion Is Likely to Cause Problems Are:**

1. Under deck joints.

2. In the areas around scuppers and drain pipes.

3. On flat surfaces where debris accumulates.

4. At overlapping steel plates.

5. At corners of steel angles and channels.
D. Other Special Details That Should be Given Attention During FCM Inspection Are:

1. Shear connectors in the negative moment region.
2. Pin and hanger assemblies.
3. Tack welds on bolted or riveted connections.
4. Unfilled holes or holes filled with weld metal.
5. Field welds in tension zones.
6. Suspicious attachments made in tension zones, such as utility attachments.
7. Field welded girder splices.
8. Fabricator stamps on girders.
9. The connections to tension members in trusses.
FATIGUE PRONE DETAILS

A. Groove Welds

1. Flange Groove Welds:
   Relatively older structure with groove welds in flanges made prior to adequate non-destructive inspection.

2. Web Groove Welds:
   Same comments as for A 1.

3. Groove Welds in Longitudinal Stiffeners:
   Longitudinal stiffeners on girder webs are structural components and the weld should be treated as structural welds. Older bridges seldom had these connections inspected.

4. Groove Welds Between Longitudinal Stiffeners and Intersecting Members:
   Often lack of fusion exists in the transverse weld connection. This is particularly acute when no cope exists at the web.

B. Ends of Welded Cover Plates

1. Cover Plates with End Welds:
   Cracks develop at toe of weld or in throat of weld most likely at mid-width of flange.

2. Cover Plates Without End Welds:
   Cracks develop at end of longitudinal weld at the end of cover plate (and near flange tip).
C. **Ends of Various Reinforcement or Attachment Plates Welded on Girder Flange or Web or on Truss Members**

1. Welded splices between adjacent parts; lateral gusset plates: These are equivalent to cover plates.

2. Repairs using welded double plates: These are equivalent to cover plates if more than eight inches long.

3. Attachments for signs, railings, light fixtures, and other fittings with the attachment plate parallel to the bridge members: These are equivalent to cover plates if more than eight inches long.

4. Welded attachment plates perpendicular to the direction of the bridge member: These have higher resistance to fatigue than details described in C1 and C3.

D. **Diaphragm Connections in Girder Bridges:**

1. Ends of welded diaphragm connection plates on girder webs where the connection plate is not welded to the flange: Cracks may occur at the gap (cope), either horizontal along the web-to-flange weld, or at the top of web-to-connection plate weld. These cracks can occur at the upper and lower end of the connection plate when no positive attachment is made to the flange.

2. Ends of riveted diaphragm connection angles on girder webs where the angles are not connected to the flange: Cracks may occur in the web horizontal along the flange, or in the angles vertically, or in the first (highest or lowest) rivets. The web cracks are most likely when connection angles do not overlap the flange angles. Also, rivet heads or bolts may crack from prying.

E. **End Connections of Floor Beams or Diaphragms**

1. Copes and blocked flanges at the ends of floor beams: Cracks occur at the re-entrant angle of the cope or the blocked flange, particularly when the re-entrant angle is flame cut with re-entrant notches.

2. Connection plates and angles may have cracks, similar to those described in D above.
F. **Floor Beam Brackets**

1. Bracket connections to girder webs:
   These are similar to diaphragm connections for Item D above.

2. Tie plates between top flange of outrigger brackets and the floor beams:
   Cracks may develop from edge of rivet holes of these plates if connected
to top flange of longitudinal girder. Relative movement also results in web
cracks in the floor beam and bracket webs.

G. **Stringer to Floor Beam Connections**

1. Crack in cope (see E 1).

2. Crack in connection (see D).

H. **Lateral (Wind) Bracing Connections to Girders**

1. Gusset plates welded to girder web or flange:
   These plates are welded attachments (see C 3). These gussets are also
   force-transmitting connection plates. When the gusset plate is attached to
   the web, but not connected to the diaphragm connection plate, cracks may
   occur in the web gap at the toe of the weld.

2. Gusset plate to diaphragm connection plate welds:
   These welds are often groove welds similar to those described in A 4, but
   are subjected to more forces. If the welds joining the gusset to the web
   and welds joining the gusset to the diaphragm connection plate intersect,
   high restraint develops in the region. The probability of defects in the high
   restraint region increases the possibility of fatigue crack growth. Special
   attention should be given to these types of details.

I. **Transverse Stiffeners**

1. These intermediate stiffeners are not connection plates for diaphragms or
   floor beams. These stiffener plates are transverse attachments normally
   with adequate fatigue strength (C4).

2. Occasionally cracks may occur at the ends of cut-short intermediate
   stiffeners, due to handling or transportation during fabrication and
   construction. Excessive web plate vibration may also result in cracking.
   At fitted stiffeners, movement can be revealed by the paint film.
J. **Box Girder Diaphragms and Connections**

1. Connection plates for X or K type interior and exterior diaphragms: These connection plates are load-carrying members. Cracks may occur at the ends of the connection plates in the web gaps, as described in D1.

2. Interior plate diaphragms which are not connected to the tension flange: Cracks may develop in the web at the gap between the diaphragms and the flange.

3. Floor beam connections to box girder webs: Cracks may occur at copes at connection plate or angle (see D and E).

4. Girder connection to the pier cap box girder: Same comment as for J 3 above (see D and E).

K. **Truss Bridge Floor Beams**

1. Connection of floor beam to verticals: Cracks may develop in connection angles, at rivet or bolt heads (D 2) or at copes (E 1).

2. Connection of lateral (wind) bracing to floor beams: Cracks may occur in horizontal gussets connecting the laterals to the floor beam flanges, or in the flange or web of the floor beam, often near bridge bearings.

L. **Truss Bridge Verticals and Diagonals**

1. Verticals near bridge ends: Cracks may occur in the first vertical member, at the top near the gusset plate or in the gusset plate usually starting from the rivet hole. Cracks may also occur near the floor beam connection.

2. Verticals and diagonals which are eyebars: These flat eyebars with enlarged heads may develop cracks at the pin holes when a forge lap exists. Cracks may also occur at the transition from the shank to the head when the bar edge is flame cut.
M. Pin-Connected Links or Hangers of Multispan Bridges

1. Eyebar links:
   Cracks may occur at the edge of pin holes, at the width transition, or at the edge of bar (see L 2).

2. Hanger plates:
   These plates are similar to eyebar links, but without reduction of width. Cracks may occur at the pin holes or at the edge of the plate.

3. Most pin connected links and hanger plates are subjected to in-plane bending, because the pins are not frictionless. Extra attention should be given to these links if corrosion and fixity is apparent.

N. Tack Welds

1. Tack welds which were used for attaching bridge components during construction and erection are often sources of fatigue cracks.

2. Tack welds between gusset and main members between bearing plates and beam flanges, between floor beam top flanges and outrigger bracket tie plates, between riveted and bolted connection angles and webs., etc., are examples.
EXAMPLES OF FRACTURE CRITICAL DETAILS
B-1 INTERMITTENT FLANGE TO WEB WELDS
CRACKS

COVER PLATE

FLANGE

COVER PLATE

B-2 COVER PLATES
WELDED HOLES

B-3 PLUG WELDED HOLES
B-4 GUSSET TO FLANGE WELD
Figure 11.3 Cracks found at end of cut short stiffeners. (a) Schematic of crack at end of stiffener welds; (b) schematic of crack at end of stiffener to weld (and web).
B-7 BUTT SPLICED STIFFENERS
LONGITUDINAL AND VERTICAL STIFFENER INTERSECTION
B-9 CRACK IN GIRDER WEB AT LATERAL GUSSET PLATE
CONCRETE SLAB

TYPICAL HANGER SECTION FOR SUSPENDED SPANS

B-12 PIN AND HANGER
GLOSSARY OF TERMS

BOX BEAM - A beam made from four plates welded together in the shape of a box.

COPE - A cut or notch in a plate or bar used to leave room for welds.

COVER PLATES - A plate added to a girder flange to increase strength.

EYEBARS - Formed by making a rectangular bar or plate with an enlarged head and boring a hole in this head to enable it to be pin connected.

FATIGUE - The tendency of a material to break under repeated stress; frequent variations or reversals in stress.

FATIGUE PRONE DETAILS - Details in a bridge that will only bend a given number of times, or go through a certain number of stress cycles, before cracking occurs.

FLANGE - The wide top and bottom plates of a steel girder.

FLOOR BEAM - The beams which are perpendicular to the roadway of the bridge, and are used to transfer the floor loads from the stringers to the supporting girder or truss.

FRACTURE CRITICAL - A member whose failure will produce a sudden collapse of the structure.

GUSSET PLATES - A plate or bracket for strengthening an angle in a framework.

NON-REDUNDANT - Having less than three girders or trusses.

PEENING - Tapping, usually with a light vibratory hammer on surfaces or weld passes to provide some relief of internal stress.

PIN - A single large solid cylinder introduced into a predrilled hole.

REDUNDANT - The ability of other members to help carry the load when a member becomes weak or fails.

STIFFENER - A plate or bar used to stiffen a girder web.

STRESS RISERS - Sudden changes of cross section in a structural member such as notches, holes, welds or flaws, which cause stress concentration.

TENSION - Being stretched or elongated.

TRUSS - An assemblage of members forming a rigid framework.

WEB - A thin metal plate connecting the upper and lower flanges of a girder.
REFERENCES


