Presentation to:

2013 Western Bridge Engineers' Seminar

Bellevue, Washington

September 5th, 2013

Speakers:

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DIEFENBAKER BRIDGE, PRINCE ALBERT, SK

FRACTURE INVESTIGATION & REPAIR

One Team. Infinite Solutions.

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Agenda

- Structure Overview
- Observation
- Emergency Response
- Rope Access Investigation
- Verification of Detail
- Fracture Retrofit
- Preventative Mitigation

Structure Overview

- Parallel Twin 6 ½ foot Girders on Common Substructure
- 7 Span
- 1000 ft
- Fracture Critical
- Non-Composite
- Year Built – 1959
- HS20-S16-44 Design Loading
- A373-56T Steel

Structure Overview

- Prince Albert is SK 3rd Largest City
- Hwy 2 is Major Arterial
- North SK River is Historic Fur Trade Waterway
- Nearest Crossing – ~125 miles

Structure Overview

- Structure Vital to Industry & Tourism
  - Agriculture
  - Forestry
  - Tourism
    - Hunting
    - Fishing
  - Mining
    - Diamonds
    - Uranium
    - Forestry

Canoeist Observation

- August 29th, 2011
- What would you think if you looked up and saw this?
  - Notify Police!

Canoeist Observation

Canoeist Observation

Canoeist Observation

Canoeist Observation

Emergency Response Scope of Work

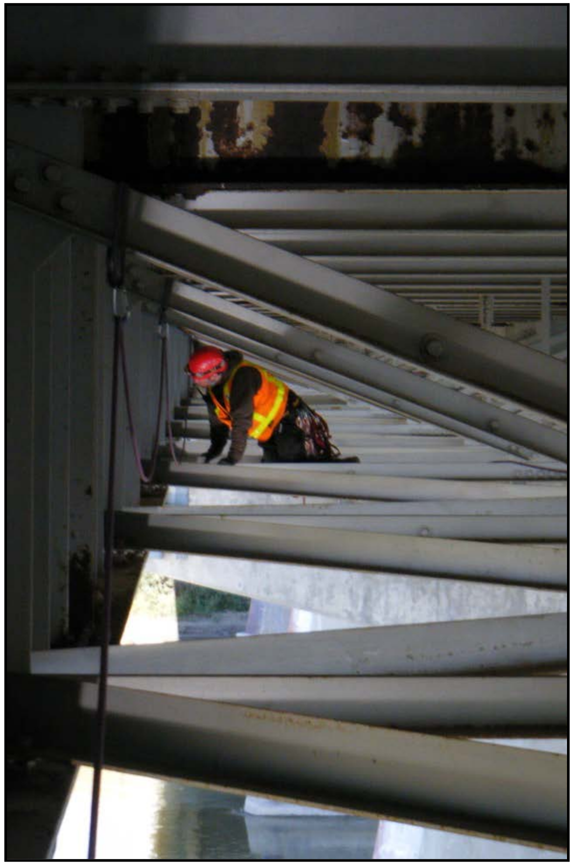
- Close SB Bridge/Restrict NB
- Phase I
  - Make Travel Arrangements
  - Review Permits/Inspection Reports
  - Survey Monitoring
  - Initial Analysis for Stability and Safety
- Phase II
  - Rope Access Arm's Length Inspection & NDE
  - 3D FEA
    - Load Transfer, Continuity

Emergency Response Scope of Work

- Phase III
  - Determine Cause
  - Design Major Repair
  - Implement /Open to Traffic
- Phase IV
  - Risk Management Strategy
  - Design Preventative Repair
- Phase V
  - Long Term Program Strategy

Rope Access Investigation

- 3D FEA proved
  - Structure stable
  - No vehicular loading allowed (obvious)
- Rope Access was only choice
- Team of 4 SPRAT Certified Engineers
- Lead Climbing/Belay Techniques
- In-Depth Inspection
- Less than Arm's Length at Critical Detail
- NO JUMPING!



Rope Access Investigation

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Rope Access Investigation

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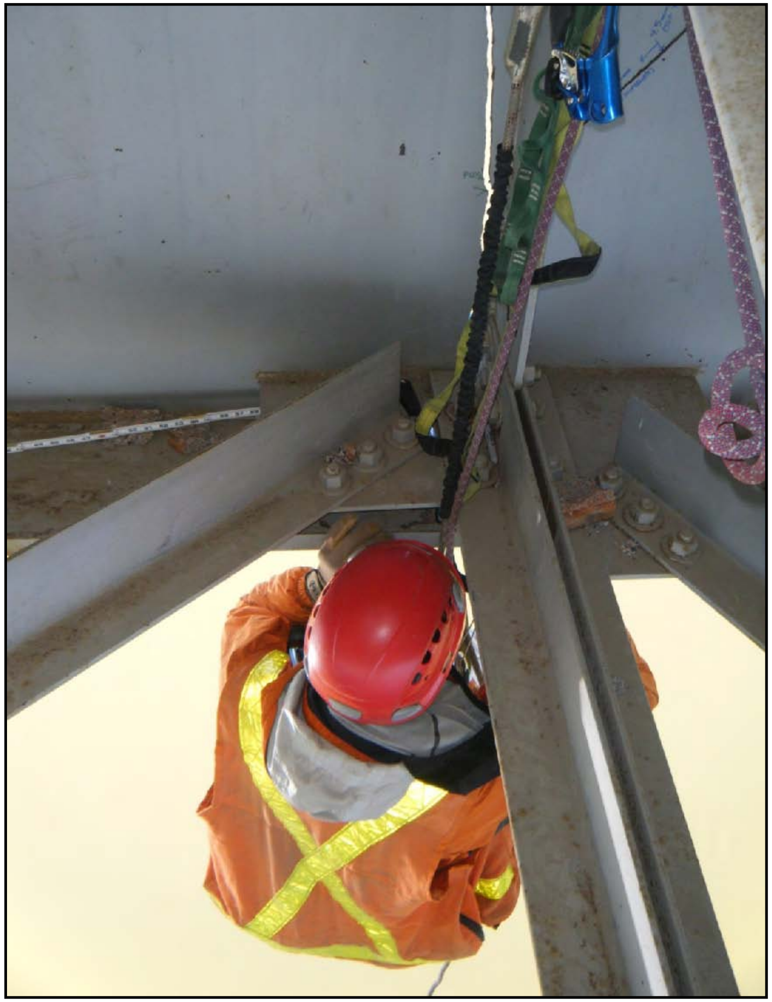
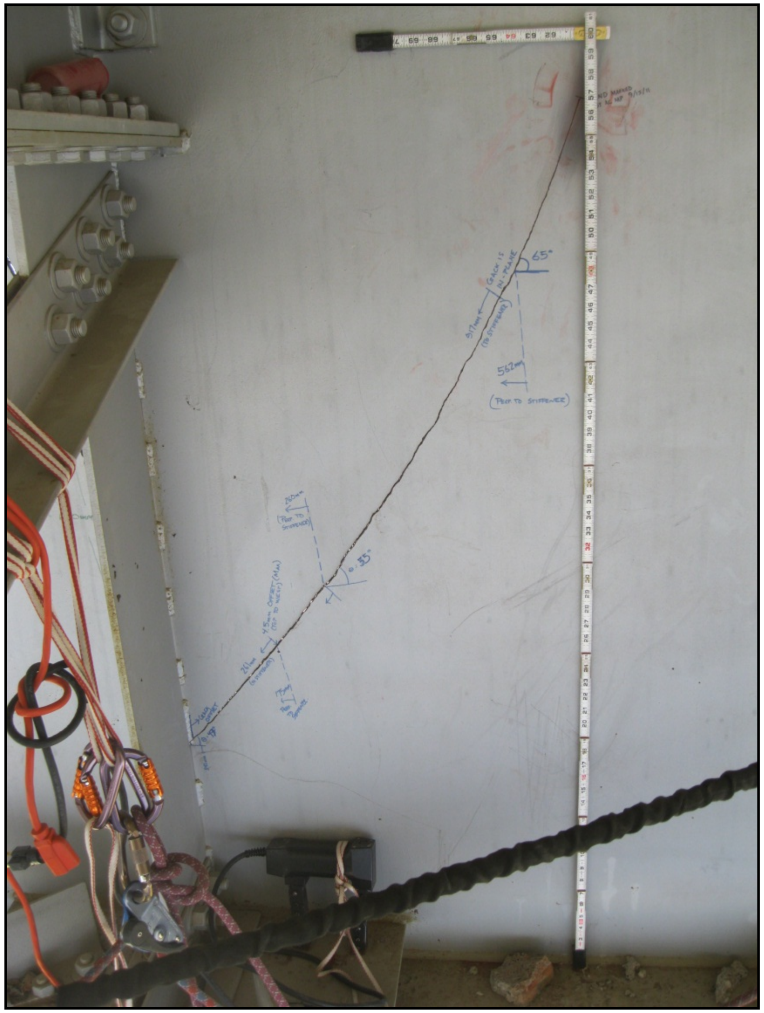
Rope Access Investigation





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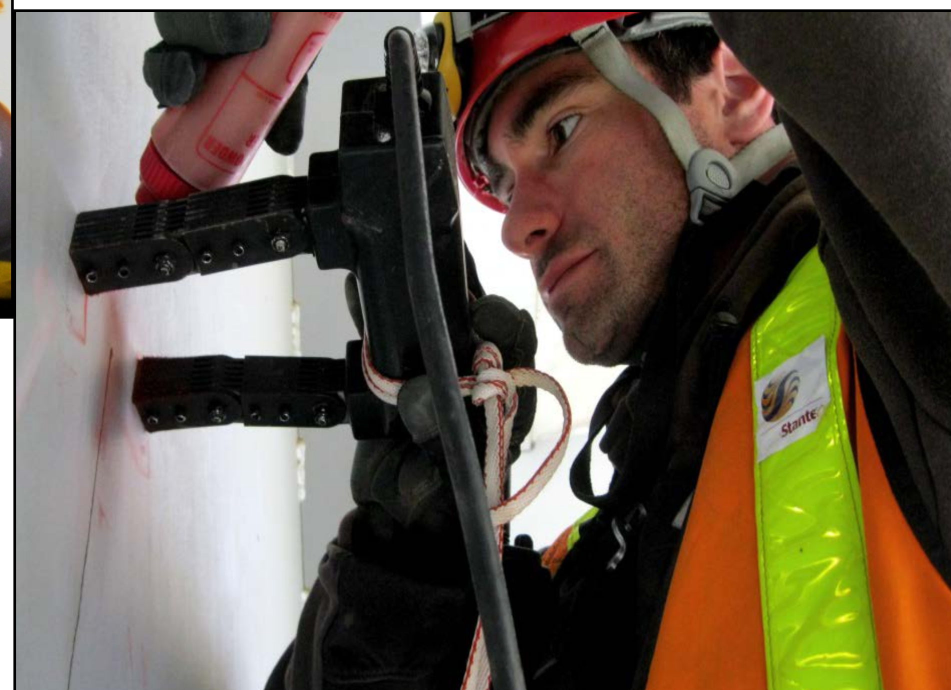
Fracture Investigation

Rope Access Investigation



Fracture Investigation

Fracture Investigation

Fracture Investigation

Fracture Investigation

Fracture Research/Verification

- Hoan Bridge Failure
  - Milwaukee, WI
  - Dec 13, 2000
- Fracture at Gusset Plate
- Detailed Study (Fisher)
- Highly Constrained Stress
- Intersecting Welds
- Crack Like Geometry
- No Fatigue Growth

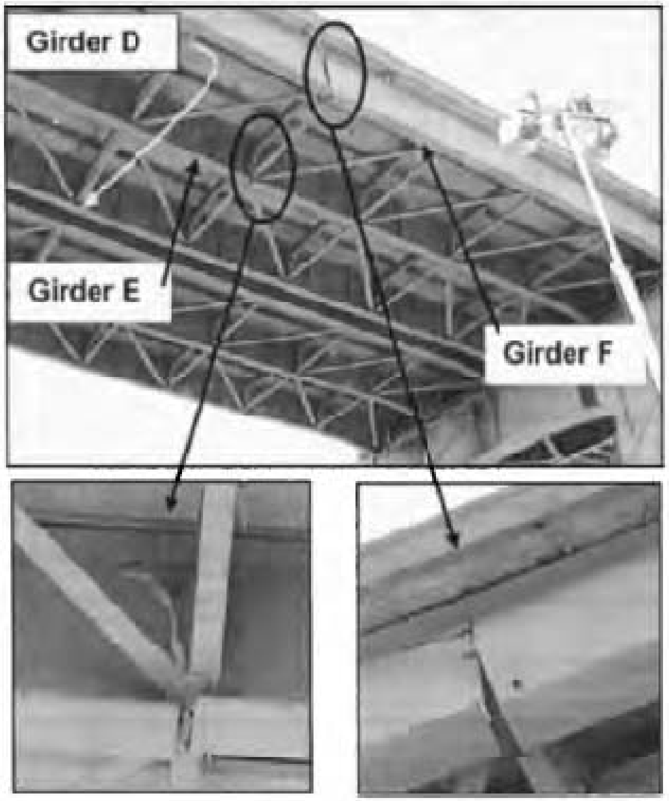


Fig. 9. Fractured girders at floorbeam 28 on Hoan Bridge

Fracture Research/Verification

- US 422 Bridge
  - Schuylkill River
  - Pottstown PA
  - May 20, 2003
- Fracture at Gusset Plate
- Detailed Study (Connor)
- Highly Constrained Stress
- Intersecting Welds
- No Fatigue Growth
- Partial Height Web Crack

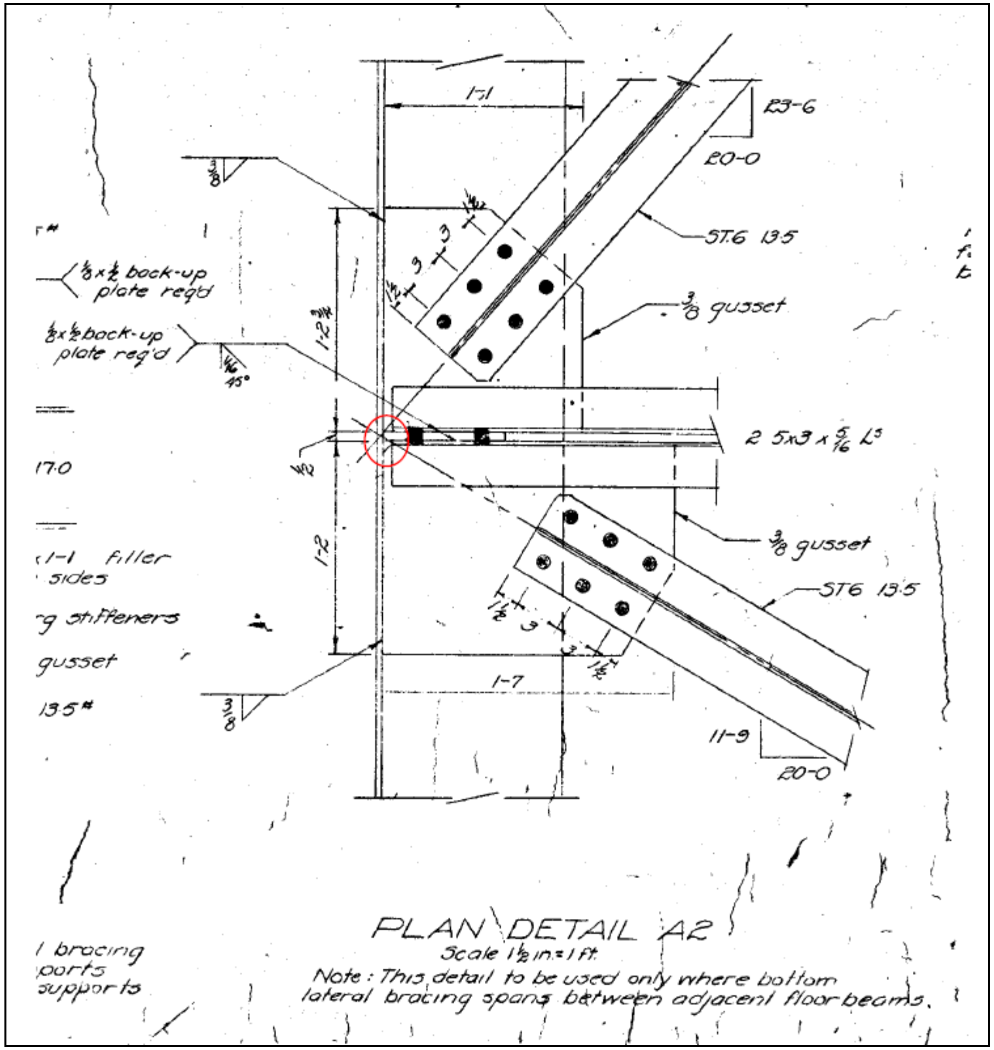
Fracture Research/Verification

- Diefenbaker Bridge
  - Overwhelming Similarities
- Fracture at Gusset Plate
- Gussets Connected via Vertical Stiffener
- Gusset-to-Web, Top Fillet Only

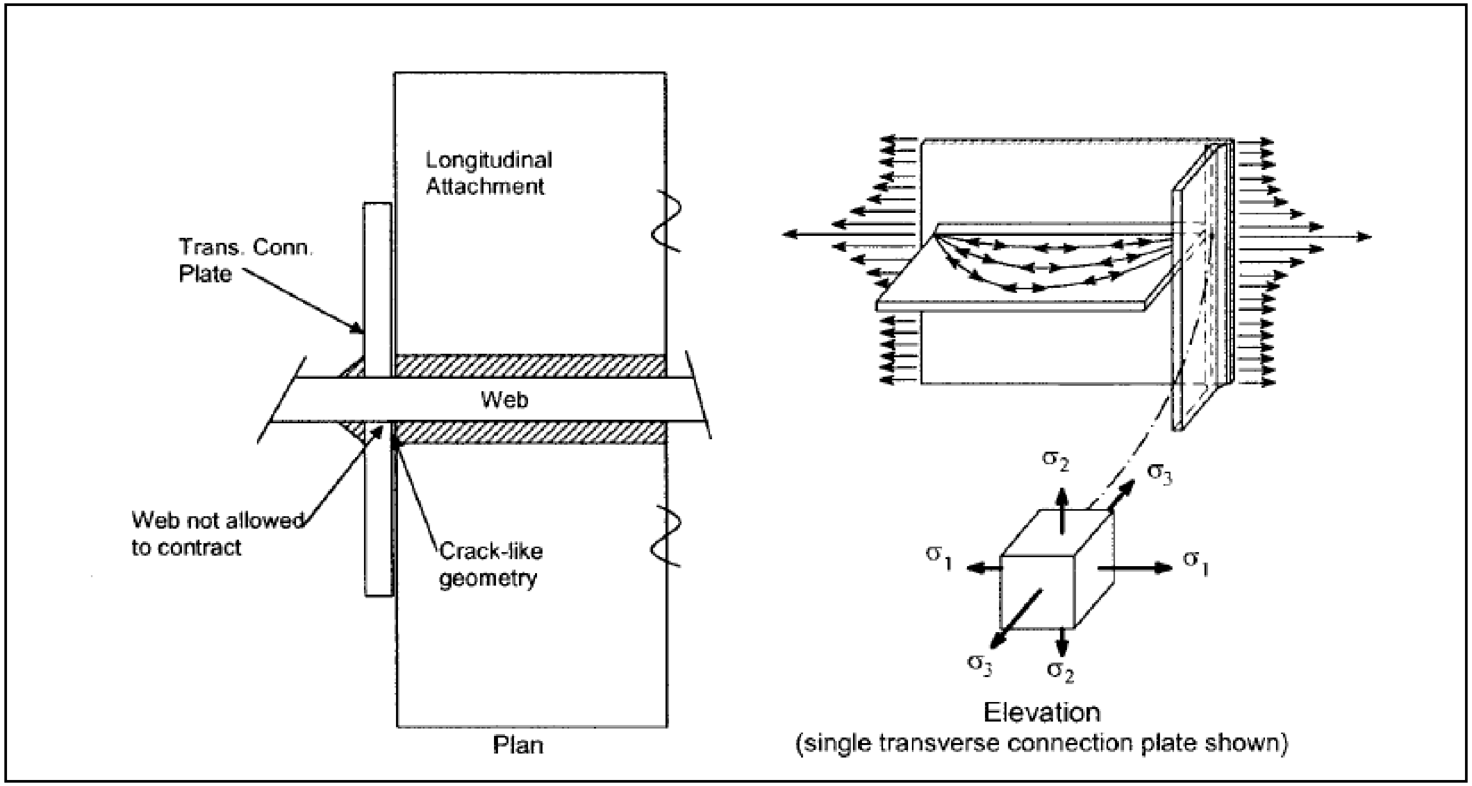
- Vertical Stiffener Stitch Welded Above, Cont. Below GP

Fracture Research/Verification

- Little Fatigue Growth
- Highly Constrained Stress
- Intersecting or Nearly Intersecting Welds
- Brittle Fracture …
- CONSTRAINT INDUCED FRACTURE (CIF)
- Not Fatigue

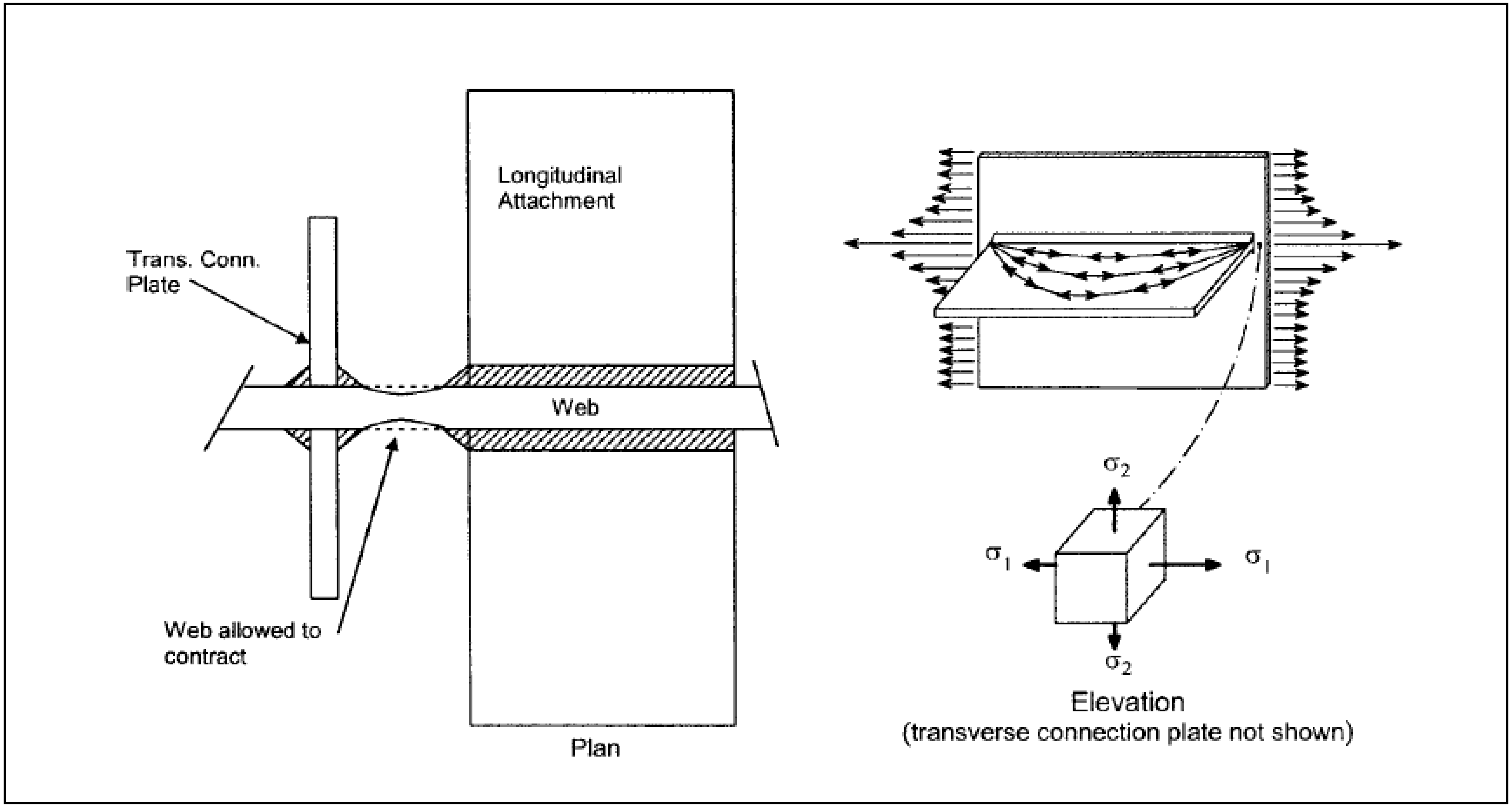


Fracture Research/Verification



Insufficient Yielding Allowed by Small Web Gap

Fracture Research/Verification



Sufficient Yielding Allowed by Larger Web Gap

Fracture Repair

Alberta Transportation

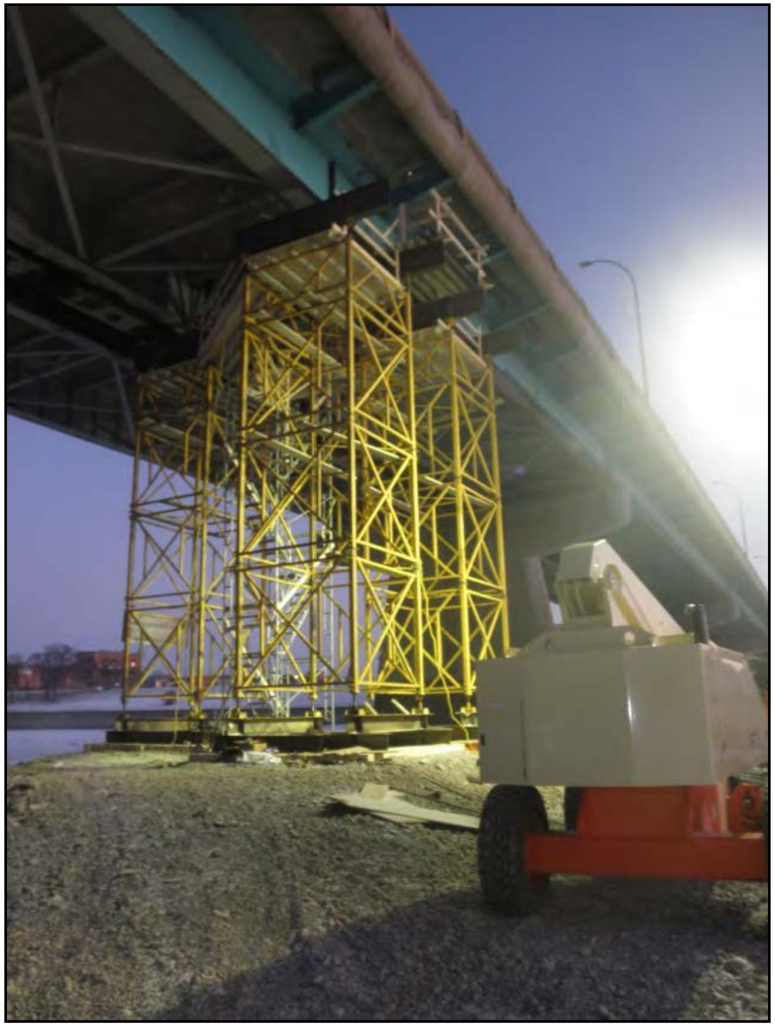
- Repairing Steel Bridges with CIF Potential
- Several CIF Structures Repaired
- Procedures Developed
  - Remove & Replace Section of Girder at Midspan
  - Splice In New Section
  - Bridge to be Open By December 23
    - Less Than 4 mths from Discovery

Fracture Repair

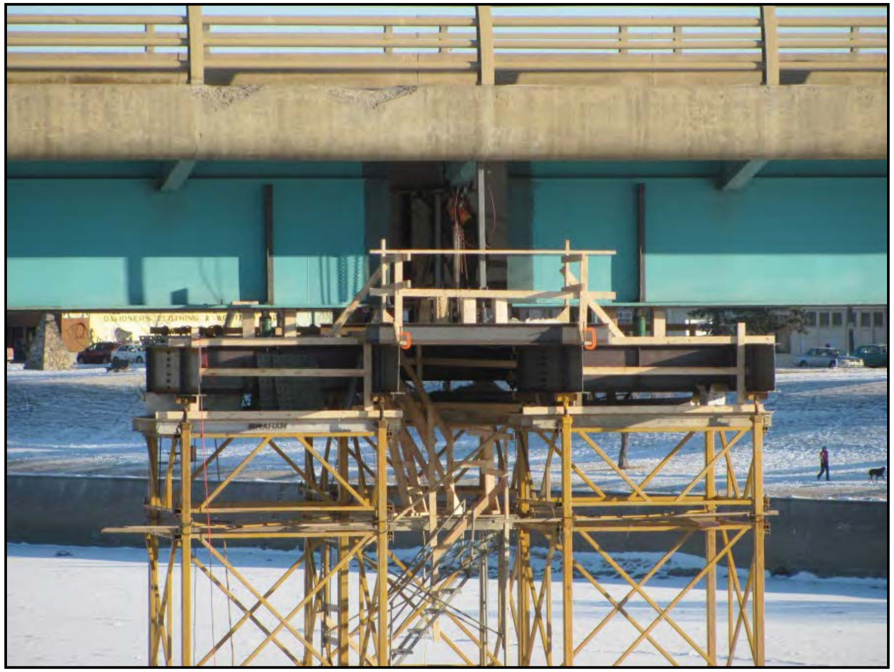
- Mid-Winter Retrofit in Northern Canada
  - Engineering
  - Permitting
  - Berm Design
  - Construction
  - Tower Erection
  - Jacking
  - Repair
  - Load Testing/Monitoring
- 3 Months For A Christmas Present!

Fracture Repair Procedures

- Support Structure From River Berm
- Remove Web & Bottom Flange
- Pre-determined Load & Displacement Graph
- Constant Monitoring of Strains
- Load Testing after Splice in Place



Fracture Repair



Not Unless You Have To!

Fracture Repair

Fracture Repair

Fracture Mitigation

NCHRP
SYNTHESIS 354

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Inspection and Management of Bridges with Fracture-Critical Details

A Synthesis of Highway Practice

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Prevention and Mitigation Strategies to Address Recent Brittle Fractures in Steel Bridges

Robert J. Connor, M.ASCE[1]; Eric J. Kaufmann[2]; John W. Fisher, Hon.M.ASCE[3]; and William J. Wright, M.ASCE[4]

Abstract: Brittle fracture results in unplanned loss of service, very costly repairs, concern regarding the future safety of the structure, and potential loss of life. These types of failures are most critical when there is no evidence of fatigue cracking leading up to the fracture and the fracture origin is concealed from view. Hence, the failure occurs without warning and the details are, essentially, noninspectable. In these cases, it appears desirable to take a proactive approach and introduce preventative retrofits to reduce the potential for future crack development. These efforts will help ensure that the likelihood of unexpected fractures is minimized. This paper examines the behavior of two bridge structures in which brittle fractures have developed in recent times, discusses the causes of the failures, and offers suggested design strategies for prevention and retrofit mitigation techniques. In situations where considerable uncertainty exists in the prediction of accumulated damage or in the ability to reliably inspect critical details, preemptive retrofit strategies appear to be highly desirable.

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CE Database subject headings: Fracture; Fatigue; Bridge failure; Forensic engineering.

Introduction

Compared to fatigue cracking, the number of brittle fractures in highway bridges has been relatively small over the past 40 years (Connor et al. 2005). However, brittle fracture results in unplanned loss of service, very costly repairs, concern regarding the future safety of the structure, and potential loss of life. These types of failures are most critical when there is no evidence of fatigue cracking leading up to the fracture and the fracture origin is concealed from view. The failure occurs without warning and the details are essentially noninspectable.

Field instrumentation and in-service monitoring is a very useful tool in estimating the remaining fatigue life in a bridge. However, for the fracture limit state, many details are very difficult to inspect and instrumentation cannot provide the needed information to make a meaningful evaluation. In these cases, it appears desirable to take a proactive approach and introduce preventative retrofits to reduce the potential for future unstable crack development. These efforts will help ensure that the likelihood of unexpected fractures is minimized.

This paper examines the behavior of two bridge structures in which brittle fractures have developed in recent times, discusses the causes of the failures, and offers suggestions for mitigation techniques. In situations where considerable uncertainty exists in the prediction of accumulated damage or in the ability to reliably inspect critical details, preemptive retrofit strategies appear to be highly desirable.

Constraint-Induced Fracture

In many cases, brittle fractures in highway bridges have been preceded by fatigue crack growth that eventually reached a critical size (Fisher 1984). However, the absence of stable crack growth at the fracture origin in both of the case studies discussed herein confirmed that fracture was not due to the presence of a large fatigue crack that subsequently became unstable. In both cases, fracture was attributed to what is referred to as constraint-induced fracture (CIF).

In highway bridges and other welded structures, details susceptible to high levels of triaxial constraint are typically avoided through good detailing. However, in some structures, large welds connecting multiple plates cannot be avoided and special care is taken during fabrication (i.e., preheat, inspection, etc.) to ensure robust performance. In cases where thick plates have been welded to form complex joints, brittle fractures have been observed after fabrication is complete or shortly after being placed into service (Barsom and Rolfe 1999; Dexter and Fisher 1997; Fisher 1984). In some cases, geometric effects combined with the large restraining forces produced by differential cooling of welds was not properly accounted for, leading to fracture of the connection under no external load. However, such fractures are far less common when thin plates, like those in the webs of highway bridge girders, are used due to the inherent flexibility of the plates, lower restraining forces, good detailing, and generally higher toughness of the material. However, in the presence of large crack-like geometrical conditions (e.g., at the intersection of a gusset plate and vertical

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Note. Discussion open until August 1, 2007. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on January 27, 2005; approved on February 15, 2006. This paper is part of the ***Journal of Bridge Engineering***, Vol. 12, No. 2, March 1, 2007. ©ASCE, ISSN 1084-0702/2007/2-164–173/$25.00.

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Fracture Mitigation

160 Similar Locations

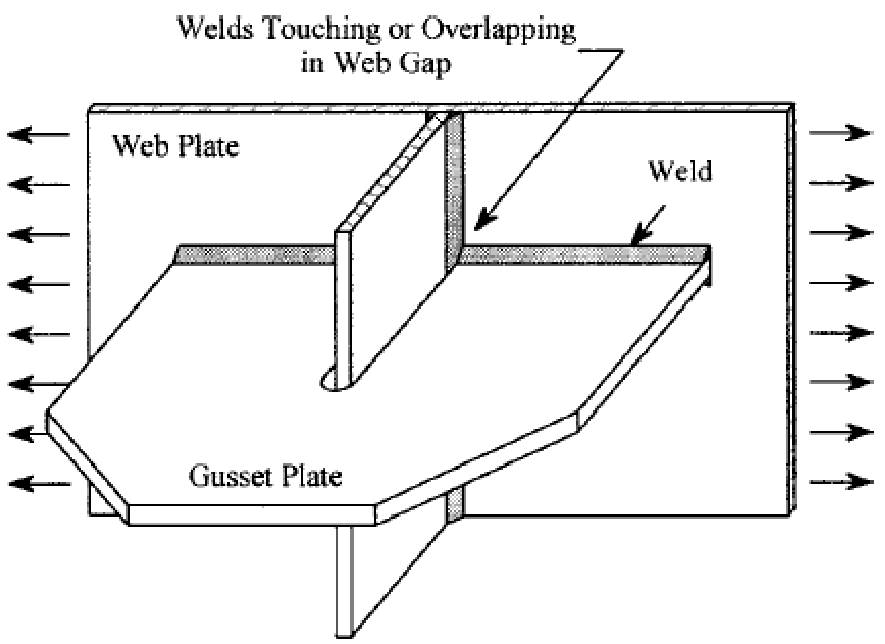


Fig. 11. Illustration of typical lateral gusset intersection with transverse connection plate susceptible to CIF

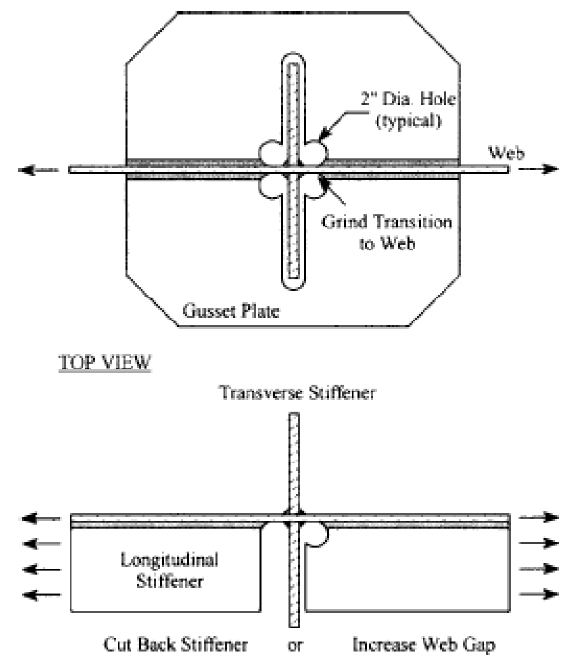
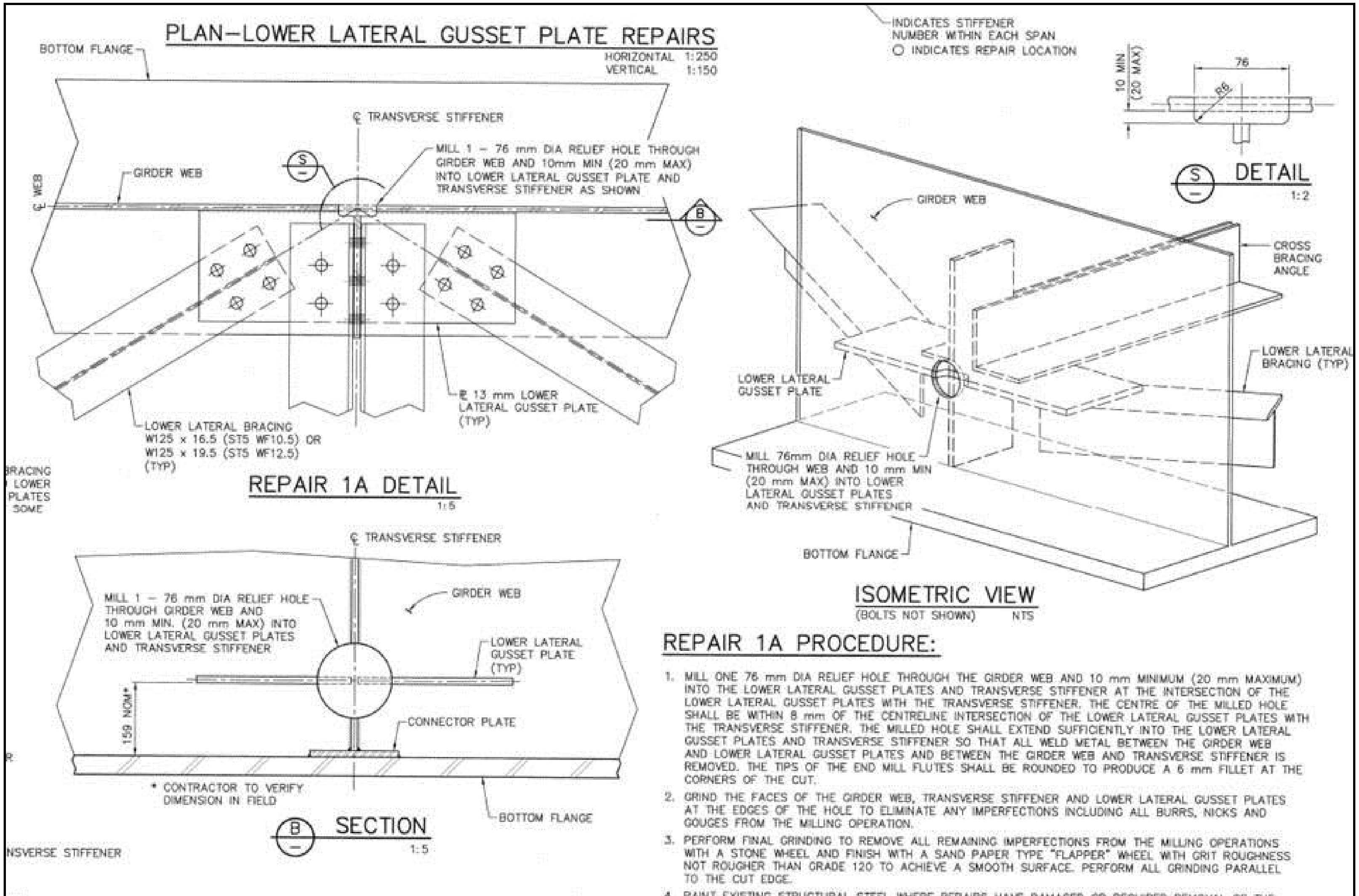


Fig. 12. Typical retrofits for gusset plates and longitudinal stiffeners to address CIF (in the above examples, the gusset plate and longitudinal stiffener are not welded together)

Fracture Mitigation



Fracture Mitigation

Crack Indications Found at Multiple Locations

Summary

- Rope Access is Viable Means
- Constraint Induced Fractures are Likely On-Going
- Occurs Below Anticipated Fatigue Levels
- Emergency Repairs Require Large Team Effort
- Mitigation Repair Documentation Exists
- Inspectors Beware!
- Owners - Review Your Inventory!

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QUESTIONS?