DIEFENBAKER BRIDGE, PRINCE ALBERT, SK
FRACTURE INVESTIGATION & REPAIR
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 29\textsuperscript{th}, 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
Rope Access Investigation
Rope Access Investigation
Rope Access Investigation
Fracture Investigation
Rope Access Investigation
Fracture Investigation

END MARKED
BY AC MP 9/15/11
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

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

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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 to 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 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.

Constraint-Induced Fracture

In many cases, brittle fractures in highway bridges have been preceded by fatigue crack growth that eventually reached a critical size (Sheffer 1944). However, the absence of a stable crack growth at the fracture origin in both of the cases 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 similar structures, details susceptible to high levels of tensile 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 welds have been used to form complex joints, brittle fractures have been observed after fabrication is complete or shortly after being placed into service (Barlow and Roll 1990; Ductek 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 an 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...
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!
Stantec = Bridge Solutions