Strengthening Steel Girder Bridges with CFRP Plates

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Overview:

- **Laboratory Investigation:**
  - Evaluated the feasibility of using CFRP plates in strengthening steel-concrete composite beams
  - Tested ten small-scale, steel-concrete composite beams
    » Two different arrangements of CFRP and two different levels of damage were investigated

- **Field Investigation:**
  - Used CFRP plates to strengthen an existing, structurally deficient steel girder bridge
  - Investigating short- and long-term effectiveness
  - Identified changes in structural behavior due to the addition of the strengthening system
Advantages of CFRP:

- Corrosion resistant
- Light weight
- High strength with a high fatigue life
- Can be installed with a minimal crew and common equipment
Nonlinear Analysis:

- Developed and validated an analytical model to investigate the impact of the following variables:
  - Area of the tension flange removed
  - CFRP plate ultimate strain
  - Area of CFRP added
  - CFRP stiffness
  - Compressive strength of deck slab concrete
  - Yield strength of the steel section being strengthened
Experimental Investigation:

Undamaged beam

Concrete slab

32”

3”

W8X15

CFRP Plates

Damaged beam

Concrete slab

32”

3”

W8X15

Removed part of flange
Experimental Configuration

- Hydraulic cylinder
- Reaction steel tubes
- Steel plates
- Load cell
- CFRP plate
- Neoprene pad
- Concrete support
Failure Modes

Concrete crushing

CFRP plate rupture
Impact of Repair Scheme 1

![Graph showing the impact of repair scheme 1 on load-deflection relationship.](image)
Impact of Repair Scheme 2

- **Load (lbs)** vs **Deflection (in.)**

Lines represent:
- U
- D50
- D50R2E29

Load (lbs):
- 0
- 5,000
- 10,000
- 15,000
- 20,000
- 25,000
- 30,000
- 35,000
- 40,000

Deflection (in.):
- 0
- 0.5
- 1
- 1.5
- 2
- 2.5
- 3
Description of Bridge:

- Located in Pottawattamie County, IA on State Highway IA 92
- Three-span continuous steel girder bridge
- Roadway width = 30 ft [two traffic lanes]
- Total length = 150 ft
  - Two 45.5 ft end spans and a 59 ft center span
Constructed in 1938, the bridge was originally non-composite.

In 1967, it was widen by adding two composite exterior girders.
# Strengthening System

<table>
<thead>
<tr>
<th>Beam</th>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEAM 1</td>
<td>(EXTERIOR 27WF84)</td>
<td>CFRP PLATE 10'-0&quot; E 13'-6&quot; 12'-6&quot; H 13'-6&quot; K</td>
</tr>
<tr>
<td>BEAM 3</td>
<td>(INTERIOR 27WF98)</td>
<td>CFRP PLATE 10'-0&quot; F 13'-6&quot; 12'-6&quot; H 13'-6&quot; L</td>
</tr>
<tr>
<td>BEAM 4</td>
<td>(INTERIOR 27WF98)</td>
<td>CFRP PLATE 10'-0&quot; F 12'-6&quot; I 9&quot; x ( \frac{3}{4} )&quot; x 12'-6&quot; COV. P</td>
</tr>
<tr>
<td>BEAM 6</td>
<td>(EXTERIOR 27WF84)</td>
<td>CFRP PLATE 20'-6&quot; G 12'-6&quot; J 20'-6&quot; M</td>
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</tbody>
</table>
Cutting FRP Strips to the Desired Lengths
Removal of Paint from Beams – Stage 1
Removal of Paint from Beams – Stage 2
Cleaned Surface
Cleaning of FRP Strips
Field Cleaning of FRP Strips
Final Cleaning of Beam Flanges
Installation of FRS Primer
Application of ECS 104 Structural Epoxy
Application of ECS 104 Structural Epoxy
Obtaining Desired Thickness of Epoxy
Application of Epoxy to Beam Flanges
Installation of FRP Strips to End Span Beams (continued)
Installation of FRP Strips to Center Span Beams
Installation of FRP Strips to Center Span Beams (continued)
Rolling of installed FRP Plates
Completed Installation of FRP Plates

One layer (West end span)

Three layers (East end span)
Load Testing

- Half of bridge was instrumented
- 3-axle truck used in three different load paths
- Data collected continuously as truck crossed the bridge
- Initial test and two follow-up tests completed to date
Live-load Flexural Response

- Elastic behavior
- Consistency in strains with time

![Graph showing live-load flexural response]

- Truck Position, ft
- Microstrain

Legend:
- Initial Test (Top)
- Initial Test (Bottom)
- t=0 year (Top)
- t=0 year (Bottom)
- t=1 year (Top)
- t=1 year (Bottom)
Bond Performance

- Critical to have adequate bond for force transfer
- Gages installed on CFRP plate to investigate the bond performance
- Analytical model developed based on strain compatibility relation
- Extreme fiber strains were predicted and compared with experimental data

\[
\varepsilon_{\text{EXT}} = \left( \varepsilon_T + \varepsilon_{\text{TB}} \right) \frac{h_{\text{CFRP}}}{h_{\text{web}}} - \varepsilon_T
\]
Bond Performance

-60  -40  -20  0  20  40  60  80  100  120

0  50  100  150  200

Truck Position, ft

Microstrain

-60 -40 -20 0 20 40 60 80 100 120

t=0 year (CFRP)
t=1 year (CFRP)
Analytical
Concluding Remarks....

- Strength of damaged steel girders can be fully restored with the use of CFRP plates.

- Stiffness of repaired steel girders is greater than that of the damaged girder, however not fully restored to that of the undamaged girder.
Concluding Remarks [continued]...

- CFRP plates have minimal impact on changing the member’s stiffness but can have a relatively large impact on changing member strength, ...... if properly designed

- Bond performance after one-year of service was good
Concluding Remarks [continued]....

- The use of CFRP plates appears to be a viable strengthening alternative for steel girder bridges.
- Handling and installation of CFRP plates was initially relatively labor intensive and required some training.
  A three-man crew was needed to install the system.
Sponsorship:

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