Strengthening of Steel Girder Bridges Using Fiber Reinforced Polymer (FRP)

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Background

- Need some level of strengthening due to
  - Increases in live loads
  - Loss of capacity (deterioration)
- Bridges not critical enough to warrant replacement
- Need to employ structurally efficient but cost-effective means of strengthening
Primary Objectives

- Investigate the effectiveness of FRP composite materials in strengthening of deteriorated steel girder bridges
- Identify changes in structural behavior due to addition of strengthening system
Two Strengthening Schemes

- Strengthening with Carbon Fiber Reinforced Polymer (CFRP) Post-Tensioning Rods
- Strengthening with CFRP Plates
Advantages

- Corrosion resistance
- Very light (one tenth of steel)
- Can be installed with minimal crews and scaffoldings
- Load capacity may be fully restored without exceeding original weight
Strengthening with CFRP Post-Tensioning Rods
Strengthening with CFRP Post-Tensioning (P-T) Rods

- Guthrie County, IA
- Constructed in 1956
- 210 ft x 26 ft Three-span continuous steel girder bridge
- Two 64 ft End spans & 82 ft Center span
- Two WF 30x116 exterior & two WF 33x141 interior I-beams
Strengthening with CFRP Post-Tensioning (P-T) Rods
Strengthening with CFRP Post-Tensioning (P-T) Rods

Corrosion on steel and spalls on bottom of concrete deck

Corroded abutment bearing
Strengthening System

- Positive moment region of Exterior girders in all three spans
- Design force of 12 kips per rod, 48 kips per location (4 rods)
Strengthening System

- CFRP rods
  - Outstanding mechanical characteristics and non-corrosive nature
  - 3/8 inch in diameter
  - Fiber Content: 65% by volume
  - Tensile Strength: 300 ksi
  - Tensile Modulus: 20,000 ksi

- Anchorage assemblies
  - 5 in. x 5 in. x 3/4 in. stiffened angles
  - 1 in. couplers
  - Steel tube anchors
Installation Process (anchorage assembly)
Installation Process (Placing CFRP Rod)

Top rod placed

Placement of CFRP Rod
Installation Process
(Application of P-T force)

Center Span

End Span
Completed CFRP P-T System

End Span (Exterior)

Center Span

End Span (Interior)
Load Testing & Classic Analysis

- To assess changes in performance due to addition of P-T system and time
- Tested before & shortly after installation, and one & two years of service
- Standard 3-axle dump trucks used in Load Testing and HS-20 Truck utilized in Classic Beam Analysis
Monitoring (During P-T)

- P-T generates strain opposite in sign to those generated by dead and secondary load
Monitoring (In service over two year period)

- Consistency in strain readings over two year period
Beam Analysis (LL Moment)

Before P-T

**Before P-T**

- **6064 in-kips** (Exterior Beam)
- **4 kips**
- **16 kips**

**5672 in-kips** (Interior Beam)

**100 ft-kips**

Due to P-T

**42.2 kips**

**574 in-kips** (Exterior Beam)

**416 in-kips** (Interior Beam)

**371 in-kips**

**268 in-kips** (Interior Beam)

**416 in-kips**
Beam Analysis (LL Moment)

After P-T

- Exterior Beam: 5693 in-kips
- Interior Beam: 5404 in-kips
Conclusion

- Consistency in strain readings
  - CFRP P-T system had negligible impact on changing stiffness of bridge
- 5 to 10 % of Live load moment carrying capacity enhanced
Strengthening with CFRP Plates
Strengthening with CFRP Plates

- Pottawattamie County
- Constructed in 1938 & widened with addition of exterior girders in 1967
- 150 ft x 30 ft Three-span continuous steel girder bridge
- Two 45.5 ft End spans & 59 ft Center span
- Two W 27x84 exterior, and two W 27 x91 & two W 27x98 interior I-beams
Strengthening with CFRP Plates
Strengthening System

- **CFRP Plates**
  - Specially designed for flexural strengthening
  - Outstanding mechanical characteristics, non-corrosive nature & relatively ease of application
  - Tensile Strength : 300 ksi
  - Tensile Modulus : 20,000 ksi
  - Ultimate strain : 1.5 %

- **Design**
  - Completed for Iowa Legal Load utilizing LRFD approach
  - Overstressed girders can be adequately strengthened by adding CFRP plates bonded to bottom flange
Strengthening System

- Positive moment region of both interior and exterior girders in all three spans with different numbers of layers (one layer in West End Span, two layers in Center Span, & three layers in East End Span)

- Half CFRP on the top of bottom flange on one of Ext. beam to investigate performance and in-service durability under detrimental environmental conditions
Detailed Layout of CFRP Plates

- BEAM 1 (EXTERIOR 27WF84)
  - CFRP PLATE
  - 10'-0" to 20'-6"

- BEAM 3 (INTERIOR 27WF98)
  - CFRP PLATE
  - 10'-0" to 20'-6"
  - 12'-6"

- BEAM 4 (INTERIOR 27WF98)
  - CFRP PLATE
  - 10'-0" to 20'-6"
  - 12'-6"

- BEAM 6 (EXTERIOR 27WF84)
  - CFRP PLATE
  - 10'-0" to 20'-6"
  - 12'-6"
Installation of CFRP Plates

- **Surface Preparation**
  - Proper preparation of both beam and plate bonding surfaces is crucial in order to achieve an optimum composite action of the beam and plate
  - Sand blasting to remove unsound material
  - Cleaning bonding surface with Acetone

- **Primer**
  - To prevent galvanized corrosion between beam surface and carbon fibers
  - To provide an improved substrate for epoxy adhesive
Installation Process

- Surface Preparation (sandblasted beam surface)
Installation Process

- Surface Preparation (cleaning bonding surface with Acetone)
Installation Process (primer application)

- End Span
- Center Span
Installation Process (Epoxy adhesive application)

- Beam surface
- CFRP Plate
Installation Process (Installing CFRP Plates in End Span)

- Ext. Beam
- Int. Beam
Installation Process (Installing CFRP Plates in Center Span)

- Ext. Beam
- Int. Beam
Installation Process (completed)

- Ext. Beam (Top & Bottom)
- Int. Beam
Load Testing and Future work

- Diagnostic load test prior to installation
  - To establish a baseline static behavior
- Second load test conducted on Aug 19th
  - Being processed
- Two other tests in two years of period
  - To assess any change in performance and behavior due to installation and time
  - Conclusion on performance and behavior of the bridge will be made as follow-up test takes place
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