Bridge Design Innovations

Jeff Triezenberg: Bridge Support Engineer Specialist (MDOT)
Brad Wagner: Bridge Design Supervising Engineer (MDOT)
Jeremy Hedden, (Bergmann & Associates)
Dave Juntunen, Bridge Development Engineer, (MDOT)

MDOT ACEC/Michigan Partnering Workshop
February 4, 2016
Four Innovations Presented

- Guidelines for Bridge Plan Preparation
  - Jeff Triezenberg, MDOT
- MDOT Bridge Design QA/QC
  - Bridge Design Reinvention
  - Brad Wagner, MDOT
- CFRP - M-102 OVER PLUM CREEK BRIDGE
  - Jeremy Hedden, (Bergmann & Associates)
- Update MDOT use of CFRP Prestressed Beams
  - Dave Juntunen, MDOT
Reason for Update

- Update plans for current practices
  - Current sample plans > 10 years old
  - Still have metric units
Comments from all stakeholders have not been incorporated. Sample plans presented here are not final.
Example Followed
Major Changes

A = The way things are
B = The way things will be
C = Smaller than you think

Hagy, Jessica. Card 1456 www.thisisindexed.com
General Guides

**PURPOSE AND APPLICATION**

The use of spans plates is intended for use in general guides for preparing a set of drawings and specifications for the Michigan Department of Transportation. The purpose of this guide is to provide general techniques for using the plans and specifications. It is intended for use by engineers, designers, and contractors who are preparing plans for bridge projects. The guide should be read in conjunction with the General Specifications and the specific project specifications.

**SITE PLAN**

Site Plans include:

- Site Plan
- Site Plan with Utilities
- Site Plan with Environmental Features
- Site Plan with Adjacent Properties

**PLAN DETAILS**

Plan Details include:

- Plan Details
- Plan Details with Elevations
- Plan Details with Sections
- Plan Details with Details

**GENERAL GUIDES**

General Guides include:

- General Guides
- General Guides with Sections
- General Guides with Details
- General Guides with Elevations

**DEVELOPMENTS**

Developments include:

- Developments
- Developments with Sections
- Developments with Details
- Developments with Elevations

**REFERENCES**

References include:

- References
- References with Sections
- References with Details
- References with Elevations

**TABLES**

Tables include:

- Tables
- Tables with Sections
- Tables with Details
- Tables with Elevations

**DELIVERABLES**

Deliverables include:

- Deliverables
- Deliverables with Sections
- Deliverables with Details
- Deliverables with Elevations

**REFERENCES AND SOURCES**

References and sources include:

- References and Sources
- References and Sources with Sections
- References and Sources with Details
- References and Sources with Elevations

**Figure 1: Span Plates Example**

A typical span plate example is shown in Figure 1. The span plate is shown as a rectangular element with dimensions specified. The plate is designed to support the structure above it and is designed to meet the requirements of the project specifications.

**Figure 2: Span Plates in Context**

In Figure 2, span plates are shown in their context within a bridge structure. The plates are shown in their proper position, with the proper connections and support systems. This figure is intended to illustrate how span plates are used in the construction of bridges.

**Figure 3: Span Plates Details**

In Figure 3, details of the span plates are shown. This figure includes sectional views, elevation views, and plan views of the span plates. The details are shown in a manner that allows for easy interpretation and use in the construction of bridges.

**Figure 4: Span Plates Specifications**

In Figure 4, the specifications for span plates are shown. This figure includes the detailed specifications for the design and construction of span plates, including the materials used, the dimensions, and the installation methods.

**Figure 5: Span Plates Installation**

In Figure 5, the installation of span plates is shown. This figure includes a step-by-step guide for installing span plates, along with visual aids and diagrams to assist in the installation process.

**Figure 6: Span Plates Testing**

In Figure 6, the testing of span plates is shown. This figure includes a series of tests that are performed to ensure the quality and durability of the span plates. The tests are described in detail, along with the results and conclusions of each test.

**Figure 7: Span Plates Maintenance**

In Figure 7, the maintenance of span plates is shown. This figure includes a schedule for the regular inspection and maintenance of span plates, along with instructions for performing the necessary maintenance tasks.

**Figure 8: Span Plates Replacement**

In Figure 8, the replacement of span plates is shown. This figure includes a step-by-step guide for replacing span plates, along with visual aids and diagrams to assist in the replacement process.

**Figure 9: Span Plates Records**

In Figure 9, the records for span plates are shown. This figure includes a record system for tracking the installation, testing, and maintenance of span plates. The records are critical for ensuring the quality and durability of the span plates.

**Figure 10: Span Plates Documentation**

In Figure 10, the documentation for span plates is shown. This figure includes a guide for creating and maintaining documentation for span plates. The documentation is critical for communication and record-keeping.

**Figure 11: Span Plates Standards**

In Figure 11, the standards for span plates are shown. This figure includes a set of guidelines and standards for the design, construction, and maintenance of span plates. The standards are designed to ensure the quality and safety of span plates.
Stamping Guidelines

- Addressed in Road Design Manual 1.02.01E
- Addressed in Road Sample Plans
- Similar instructions added to Bridge Sample Plans.
  - Prime stamps Title sheet
  - Subs to consultants add logo to sheets
  - Subs to MDOT stamp the first sheet
Site Sheet Changes

Alignment with road sheets
Site Sheet Changes

Coordinates for new substructure

COORDINATES

<table>
<thead>
<tr>
<th>REF PT</th>
<th>NORTH</th>
<th>EAST</th>
<th>ELEV</th>
</tr>
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<tr>
<td>PR A</td>
<td>223198,55</td>
<td>13434784,41</td>
<td>585.70</td>
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<tr>
<td>PR B</td>
<td>223119,73</td>
<td>13434806,02</td>
<td>585.92</td>
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COORDINATES PROVIDED ARE TO ESTABLISH THE GEOFIC LOCATION OF THE STRUCTURE. HOWEVER, SHALL NOT TAKE PRECEDECENCE OVER STRUCTURAL DIMENSIONS.
Soil Borings

Locate borings on
General Plan of Structure
Reinforcement Sheet

Every 5th Row Shaded
Proposed Location

Keep current plans as an archive

New Sample Plans Here
Bridge Design Innovations

MDOT BRIDGE DESIGN QA/QC
Bridge Design QA/QC

- Background
Bridge Design QA/QC

Background

- 2007 – I-35W Collapse & Investigation
- 2011 – FHWA Guidance on QC/QA in Bridge Design
- 2012 – FHWA Review of MDOT’s Practices
- 2014/2015 – Development of MDOT Guidance
Background

2012 FHWA Findings – MDOT Owned Bridges
“MDOT in-house designs generally follow the guidance on QC…….”

“(For consultant designs)…..MDOT doesn’t routinely verify the Consultant QC/QA plan is actually implemented.”

MDOT’s QC/QA processes for both in-house and consultant designs are not well documented.
Bridge Design QA/QC

MDOT Guidance for Bridge Design Quality Assurance & Quality Control

MICHIGAN DEPARTMENT OF TRANSPORTATION
DRAFT Guidance
Bridge Design Quality Assurance & Quality Control
November 2015

CONTENTS
I. Purpose.
II. Overview.
III. Definitions.
IV. Implementing and Documenting Procedures.
V. Role of EIP/A.
VI. References.

I. PURPOSE.
The purpose of this guidance is to document the Michigan Department of Transportation (MDOT) Bridge Design QC/QA procedures for design and plan preparation of crude line highway bridge projects.

II. OVERVIEW.
A. To ensure bridges are designed correctly, with no errors once the design calculations, drawings, and specifications are finalized, MDOT requires QC/QA procedures in accordance with this document.

B. The MDOT Bridge Design QC/QA program consists of organizational procedures established to ensure a deliberate and systematic process that reduces the risk of introducing errors and omissions into bridge design and contract documents. The MDOT QC/QA program provides checks and balances within the organization to ensure quality in final contract plans and specifications. The MDOT QC/QA program is implemented at different levels or phases of project activity, as defined in the MDOT Bridge Design Manual, the MDOT Road Design Manual, and the MDOT Quality Assurance and Quality Control Process Guide for Project Managers (as included in this document).

C. The major and level of resources allocated to QC/QA applications on a given bridge are impacted by the size, complexity, and degree of redundancy in the structural system involved, and by the degree of standardization of the design. For major projects involving unusual, complex, and innovative features, a peer review may be desirable to raise the level of confidence in the quality of design and construction.

III. DEFINITIONS.
A. Quality Control (QC). Procedures followed within a unit or working group to check the accuracy of the calculations, drawings, and specifications for the purpose of detecting and correcting design omissions and errors to accomplish the overarching goal of producing complete and error-free final plans and specifications. QC occurs continuously throughout the course of a project.
Bridge Design QA/QC

Bridge Design QA/QC Guidance Document

■ Purpose

“… to document (MDOT) Bridge Design QC/QA procedures for design and plan preparation of trunk line highway bridge projects. “

■ Objective

“To ensure bridges are designed correctly, with no errors once the design calculations, drawings, and specifications are finalized…”
Bridge Design QA/QC

Bridge Design QA/QC Guidance Document

- What it does:
  - Establishes definitions of QA/QC for Bridge
  - Provides framework for individual QA/QC Plans

- What it doesn’t do:
  - Does not replace consultant QA/QC Plans
  - Does not set requirements for methods of performing QA/QC.
Bridge Design QA/QC

Document Overview

- Definitions
- Qualifications of key personnel
- Minimum areas to be checked
- Quality Control Procedures
- Quality Assurance Procedures
- In House/Consultant requirements
- Corrective Actions
Bridge Design QA/QC

What to expect

- Receipt of QA/QC documentation.
- Load Rating completed prior to turn-in
- MDOT Bridge Field services reviews
- Project Level QA (PLQA)
- Peer reviews
Bridge Design Reinvention

Process Improvement Process
- Recommended by management in early 2015
- Bridge Design ‘As is” mapping session in July
- Very successful – many ideas proposed
- Decided to proceed with process improvement
Bridge Design Reinvention

Many Stakeholders

Road Designer

Bridge Designer

Construction

Real Estate

MDNR/MDEQ/USACE

Railroad

Load Rating

Aesthetics

Municipality

Hydraulics

Signing/Signals

Traffic & Safety

Geotechnical
Bridge Design Reinvention

Process Takeaways

- Need to start projects at the right time, but how?
- Need to bring project deliverables together between Plan Preview and OEC
- Fiscal year constraints can leave few options if something happens during design
Bridge Design Reinvention

What's next?
CARBON FIBER REINFORCED POLYMER
LESSONS LEARNED IN THE USE OF CARBON FIBER COMPOSITE CABLE (CFCC) ON THE M-102 OVER PLUM CREEK BRIDGE

IN COORDINATION WITH:

MDOT
Lawrence Tech.
Michael Baker
ACEC
BRIEF HISTORY OF CFCC IN MICHIGAN

• DR. GRACE AND MDOT HAVE PARTNERED TO PROMOTE THE USE OF THIS MATERIAL

• EXTERNAL POST TENSIONING COMBINED WITH INTERNAL ON A DOUBLE “T” BEAM IN SOUTHFIELD (THE BRIDGE STREET BRIDGE)

• POST TENSIONING FOR SBS BOX BEAMS

• LONGITUDINAL PRESTRESSING IN CONCRETE BEAMS

• “MILD” REINFORCEMENT IN BEAMS, DECK AND BARRIER
our people and our passion in every project

PROJECT OVERVIEW

M-102 over Plum Creek
SITE

Plum Creek

Eight Mile Drain

WB M-102

EB M-102
PROJECT OVERVIEW

- TWIN 75’ LONG BRIDGES
- EIGHT (8) 33” DEEP BY 48” BOX BEAMS
- COMPOSITE CONCRETE DECK
- STANDARD IN EVERYWAY, EXCEPT…
BRIDGE DETAILS

• CARBON FIBER COMPOSITE CABLE USED IN ALL SUPERSTRUCTURE ELEMENTS
  • BOX BEAMS
    • P/S STRANDS
    • SHEAR STIRRUPS
    • SLAB TIES
    • “MILD” REINFORCEMENT IN TOP FLANGE

• DECK SLAB
  • TRANSVERSE AND LONGITUDINAL REINFORCEMENT

• BARRIER
  • LONGITUDINAL TEMP & SHRINKAGE REINF
  • GRADE 60 STEEL BAR USED TO CONNECT DECK TO BARRIER (CRASH WORTHY)
DESIGN CHALLENGES

• SCHEDULE / LEAD TIME

• DESIGN CODE AND LACK OF STANDARDS

• MATERIAL LIMITATIONS

• SKEW

• ADVANCED PROCUREMENT CONTRACT

• ESTIMATING QUANTITY NEEDS INCLUDING WASTE

• COORDINATING FABRICATOR AND CONTRACTOR EFFORTS BY SPECIFICATION
DESIGN CHALLENGES

• SCHEDULE / LEAD TIME

• DESIGN CODE AND LACK OF STANDARDS

• MATERIAL LIMITATIONS

• SKEW

• ACI 440

• DR. GRACE AND LTU RESEARCH

• SPECIAL PROVISIONS
DESIGN CHALLENGES

- SCHEDULE / LEAD TIME
- DESIGN CODE AND LACK OF STANDARDS
- MATERIAL LIMITATIONS
- SKEW

- STRONG IN TENSION / WEAK IN SHEAR (ELIMINATE CRACKING)
- STRENGTH REDUCTIONS (BAR BENDS AND CREEP RUPTURE)
- PULLING ON THE CFCC STRANDS
- SHEAR CAPACITY OF BEAM VS. DEMANDS
DESIGN CHALLENGES

- SCHEDULE / LEAD TIME
- DESIGN CODE AND LACK OF STANDARDS
- MATERIAL LIMITATIONS
- SKEW

- TENSION IN TOP OF BEAMS IN OBTUSE CORNERS DUE TO SKEW / BACKWALLS
- INTERMEDIATE DIAPHRAGM LOCATION AND DIFFERENTIAL BEAM DEFLECTION
- END DIAPHRAGM DIFFERENTIAL DEFLECTION
CONSTRUCTION CHALLENGES

• MATERIAL HANDLING
• STRESSING OPERATIONS
• DECK REINFORCEMENT

• NO SMOKING!
• KEEP AWAY FROM ABRASIONS
• STORAGE AND PROTECTION
CONSTRUCTION CHALLENGES

• MATERIAL HANDLING

• STRESSING OPERATIONS

• DECK REINFORCEMENT

• ONE OF THE FIRST USES OF MDOT’S DEBONDING SLEEVE SPEC (NO SPLIT SLEEVES)

• DIFFERENTIAL TEMPERATURES DURING PRESTRESSING OPERATION

• TYPICAL BEAM CONSTRUCTION METHODS…MOSTLY

• ARRANGEMENT OF PRESTRESSING COUPLERS
CONSTRUCTION CHALLENGES

• MATERIAL HANDLING

• STRESSING OPERATIONS

• DECK REINFORCEMENT

• CABLE KEEPS IT CURVE WITHOUT TENSION

• WORKER ACCESS DURING DECK PLACEMENT AND VIBRO COMPACTION

• TIEING BARS
SUMMARY

• PROMISING MATERIAL

• CONTINUE TO RESEARCH AND IMPROVE

• USE AS “MILD” REINFORCEMENT NOT PRACTICAL

• POTENTIAL PRODUCTION PLANT PLANNED FOR THE U.S.

• CFCC AND CONCRETE ARE NOT DUCTILE, MUST DESIGN ACCORDINGLY

<table>
<thead>
<tr>
<th></th>
<th>CFCC</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Cost per Foot</td>
<td>$5/ft</td>
<td>$0.67/ft</td>
</tr>
<tr>
<td>Material Cost per SFT</td>
<td>$115</td>
<td>$15</td>
</tr>
<tr>
<td>Total Bridge $/sft</td>
<td>$510</td>
<td>$415</td>
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</tbody>
</table>
our **people** and our **passion** in every **project**

QUESTIONS?
Update: MDOT use of CFRP Prestressed Beams

- 2011: Pembroke Ave over M-39
- 2012: M-50 / US-127 BR ov RR
- 2013-14: EB & WB M-102 over Plum Creek
- 2014-15: I-94 over Lapeer Road. EB & WB
- 2015: M-66 over West Branch
- 2015: M-100 over Sharp Drain
- 2016: M-86 over Prairie Creek
- 2017: Several Projects being considered.
  - I-75 over Godard and Sexton Kilfoil
  - I-94 Projects
CFRP Research – Latest Completed

- **RC-1620 - Evaluation and Analysis of Decked Bulb T Beam Bridges**
  - Polled fund Research project
  - MICHIGAN, IOWA, MINNESOTA, WISCONSIN, OREGON
CFRP Research - Ongoing

- Research
  - EVALUATING LONG TERM CAPACITY & DUCTILITY OF CFRP PRESTRESSING AND POST TENSIONING STRANDS
Experimental Investigation

Explicit Performance

Un-bonded strands (10 sets)

Overall performance

Five pre-tensioned decked bulb T beams

Evaluate anchorage

Creep

Relaxation

Bond fatigue

Splice length

Fire

Freeze-Thaw

Conc. creep, Shrinkage.

Two sets tested @ 0 & 42 days

Four @ 1 yr. (lab. vs. outdoor)

Four @ 2 yrs. (lab vs. outdoor)

One beam tested @ 28 days

Two @ 1 yr. (lab. vs. outdoor)

Two @ 2 yrs. (lab. vs. outdoor)
Development of Design Guides

- NCHRP 12-97: Guide Specification for the Design of Concrete Bridge Beams Prestressed with CFRP Systems
- MDOT Research: Develop Design Guide Specifications

 ITERATION FOR THE FINAL DEPTH OF NEUTRAL AXIS

\[
\begin{align*}
N_A_{\text{depth}} &> \text{while } \left| \frac{c}{d_0} - m \right| > \text{TOL} \\
&\text{for } i = 0 \ldots \text{length}(Row) - 1 \\
&\quad s_i \leftarrow d_{i+1} - d_i \\
&\quad m \leftarrow \frac{c}{d_0} \\
&\quad A_{eq,i} \leftarrow \left[ 1 - \frac{s_i}{(1 - m) d_0^2} \right] A_i \\
&\quad \varepsilon_{i}(c) \leftarrow \varepsilon_{i,\text{eff}} \left( \frac{d_0 - c}{c} \right) \\
&\quad 1(c) \leftarrow 0.85 f_{c,\text{deck}} (b_1 c b_2 + 0.85 f_{c,\text{deck}} (b_{eff} - b_1) \text{deck}_{eff} \\
&\quad + 0.85 f_{c,\text{deck}} (b_3 c - \text{haunch} - \text{deck}_{eff}) \text{b}_{eff}_{eq} - b_1) \\
&\quad \left( 10 \varepsilon_{eq} A_{eq} + \sum R_{ei} \right) \\
&\quad c \leftarrow \text{root}(f(c), c, 10, 20) \\
\end{align*}
\]

\[ \nu = N_A_{\text{depth}} = 12.14 \text{ in} \]
\[ a := \beta_1 c = 9.41 \text{ in} \]
Creep Rupture

Long term monitoring of five test specimens

Average ultimate strength  68.2 kip

Prestressing level  54.8 kip/strand

Prestressing ratio  80%

Test Temperature  68 °F ± 4 °F

Test start date  01/14/2014

Test Duration to date  11 months
Bond Splice Length (Instrumentation & Testing)

- LVDT for strain measurement
- MTS loading actuator
- 4-ft load spreader
- Strain gages
- LMT for deflection measurement
Bond Fatigue Strength (for Stirrups Splice)

Establish bond strength of CFRP

Perform fatigue test on bond test specimens

ACI440.3R-12-B.3 Test method for bond strength of FRP bars by pullout testing

ACI440.3R-12-B.7 Test method for tensile fatigue of FRP bars (performed on bond strength specimens)
Ongoing Fire Testing of Prestressed CFCC Beams

CFCC prestressed decked bulb T beam under fire/loading event (ASTM E119)

<table>
<thead>
<tr>
<th>Initial Prestressing force (kip)</th>
<th>Service load (kip)</th>
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<tbody>
<tr>
<td>72</td>
<td>14</td>
</tr>
<tr>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>132</td>
<td>25</td>
</tr>
</tbody>
</table>

Applied service load

15' 0"
Ongoing Fire Testing of Prestressed CFCC Beams

After 52 minutes from the start of test
What we’ve learned

- Effective Cross Sectional Area
  - Steel = 0.217 inch\(^2\)
  - CFCC = 0.179 inch\(^2\)
What we’ve learned

- Looking for the “Killer App”
  - Longitudinal pre-tensioning
- Need to go from .6 inch diameter strand to .7 inch diameter strand
  - .6 inch diameter strand $1.6 - 1.8$ factor for increase of number of strands if using CFRP vs Steel
  - .7 inch diameter strand $1.2$ factor for increase of number of strands if using CFRP vs Steel
We are not alone

- Virginia DOT
  - Bridge Beams with Carbon Fiber Reinforced Polymer Strands
  - Piles with Carbon Fiber Reinforced Polymer Strands
Next Steps

- Continue to do projects and research
  - Looking for candidate for Decked Bulb-T beam.
- Research to confirm .7 inch diameter CFCC strands can be used.
- Working through AAASHTO SCOBS (Bridge Committee) Technical Committee T-6 Fiber Reinforced Polymer Composites
Questions?