Implementation and the Value of Research

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Director

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Implementation

• It’s a matter of “taking what people know in one place, and combining it with what people know in another.” Or implementation is the activity of taking new knowledge developed through research, and successfully integrating it into what people already know about doing their work, which they have developed over years and decades of practice

• When is implementation finished?
  – When the project becomes:
    • the way the agency does business
    • & is integrated into the fabric of daily work
Organization

VCTIR Leadership Team

Commissioner of Highways

Director of Research

Business Manager

Knowledge Management Officer

Implementation Coordinator

Associate Director Materials

Associate Director Environment, Planning and Economics

Associate Director Safety, Operations and Traffic Engineering

Associate Director Structural, Pavement and Geotechnical Engineering

Research Teams
An Interesting Event in 2010

• AUDIT
  – Validated program
  – 52% of recommendations have been implemented
  – 27% of recommendations accepted but not fully implemented
  – Research is Relevant but under-utilized
  – Name was changed from VTRC to VCTIR
Commissioner took Action

- Implementation will be considered as a Research Project is established
- Sights are to be Set on Implementation
- The **Agency Will Implement** the recommendations that arise from Research
- VCTIR will designate an individual who will focus exclusively on Implementation
- Commissioner allocated $10 million annually to fund implementation (in all areas of research)
Sample Project

**VDOT Technology Implementation Project: Inverted T-Beam System**

Graduate Students: Fatmir Menkulasi, Matt Mercer, & Doug Nelson
Faculty: Tommy Cousins & Carin Roberts-Wollmann
VCTIR: Mike Brown
Why am presenting this project?

• It incorporates the five elements of a implementation project:
  – Concept Development
  – Prototype testing
  – Analysis
  – Full scale testing
  – Implementation Evaluation
Background: Typical Adjacent P/S Box Beam Construction

Low volume bridges, asphalt overlay (Kevlar)

High volume bridges, RC topping
The Problem – Reflective Cracking

Caused by transverse distribution of loads & temperature, shrinkage and creep affects
One Solution: Inverted T-Beam System


Application in Minnesota (2005-2014)
Why the Inverted T-Beam System?

- In a grouted shear key transverse tension is only resisted by grout/concrete bond & optional transverse P/T
- In the inverted T a thicker topping is used and horizontal and vertical interfaces provided. Also, reinforcement crosses any potential crack.
System Comparison

Adjacent Box Beams

Inverted T Beams
Project Objective

Improve Minnesota Inverted T Beam for use by VDOT

Minnesota

Virginia
Project Scope

- Investigate Concrete Mixtures for Topping
- Improve Minnesota Cross-section
- Develop Recommendations for Implementation
- Test Full Scale System
- Implement, Test, and Monitor
Reinforced Concrete Topping Mix Design
Investigate Topping Concrete Mixtures

- Low Shrinkage
- Moderate to high creep
Four VDOT Mixes Tested

- Normal Weight Aggregate with Fly Ash
- Normal Weight Aggregate with Slag
- Lightweight Aggregate with Fly Ash
- Lightweight Aggregate with Slag

<table>
<thead>
<tr>
<th></th>
<th>NW-FA</th>
<th>NW-SL</th>
<th>LW-FA</th>
<th>LW-SL</th>
</tr>
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<tbody>
<tr>
<td>Ultimate Shrinkage Strain ($\mu \varepsilon$)</td>
<td>466</td>
<td>483</td>
<td>603</td>
<td>606</td>
</tr>
<tr>
<td>Ultimate Creep Coefficient</td>
<td>1.87</td>
<td>1.24</td>
<td>1.22</td>
<td>0.7</td>
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</table>
Improve Minnesota Inverted T Beam
Calvin and Hobbes’ Dad Explains Bridge Design

 HOW DO THEY KNOW THE LOAD LIMIT ON BRIDGES, DAD?

 THEY DRIVE BIGGER AND BIGGER TRUCKS OVER THE BRIDGE UNTIL IT BREAKS.

 THEN THEY WEIGH THE LAST TRUCK AND REBUILD THE BRIDGE.

 OH. I SHOULD’VE GUESSED.

 DEAR, IF YOU DON’T KNOW THE ANSWER, JUST TELL HIM!
Two-way plate behavior and reflective cracking
Test setup to represent transverse bending

Section of the Inverted T beam system investigated in the laboratory for bending in the transverse direction.

The flange was replaced by a full height web to create a better bearing condition in the test setup.
Two cross-sectional shapes

**Original**

**Tapered Web**

**Stress Concentrations**

**Resistance to normal tensile stresses**
Three Inverted T Connections

**Extended Bars (Original)**

**Wheel Loads**

**Embedded Steel Plate and welded rebar (Vector Connector)**

**Wheel Loads**

**No mechanical connection**

**Wheel Loads**
Roughened Surface
**Phase I - Four Specimens**

**Specimen #1 (Control)**

- 3-#4 bars at each end
- #4 at 18 in. oc
- 2.5" clear to hooked bar
- #6 hooked bars at 12 in. oc
- 2 layers of 0.6 inch diameter strands - 12 strands on each layer and the layers are 5.0 inches apart

**Specimen #2**

- 3-#4 bars at each end
- #4 at 18 in. oc
- 2 layers of 0.6 inch diameter strands - 12 strands on each layer and the layers are 6.0 inches apart

**Specimen #3**

- 3-#4 at each end
- 4-#4 clear
- 2" to center of strand

**Specimen #4**

- 3-#4 at each end
- #4 at 12 in. oc
- 2.5" clear to hooked bar
- #6 hooked bars at 12 in. oc
- 2 layers of 0.6 inch diameter strands - 12 strands on each layer and the layers are 6.0 inches apart

**Figure 3.23 Reinforcing details for Test Specimen No.4**

The flange was replaced by a full height web to create a better bearing condition in the test setup.

**Wheel load 1**

- 3 feet

**Wheel load 2**

- 6 feet

- 3 feet

**SECTION C-C**

Primer and prefabricated waterproofing membrane with two coats of epoxy-applied directly over it.
Phase II - Three Specimens

Why? Further investigate trapezoid shape without welding

Specimen #5

Specimen #6

Note non-contact lap splices

Specimen #7
**Results**

<table>
<thead>
<tr>
<th>Specimen ID</th>
<th>P&lt;sub&gt;cr&lt;/sub&gt; (kips)</th>
<th>P&lt;sub&gt;u&lt;/sub&gt; (kips)</th>
<th>FS&lt;sub&gt;cr&lt;/sub&gt;</th>
<th>FS&lt;sub&gt;ultimate&lt;/sub&gt;</th>
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</thead>
<tbody>
<tr>
<td>Trial</td>
<td>80</td>
<td>300 (test stopped due to capacity of the frame)</td>
<td>2.27</td>
<td>7.48</td>
</tr>
<tr>
<td>1</td>
<td>90</td>
<td>260 (many cracks in CIP topping in all directions)</td>
<td>2.50</td>
<td>6.53</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>225 (fracture of weld at one location and rebar at another)</td>
<td>2.74</td>
<td>5.70</td>
</tr>
<tr>
<td>3</td>
<td>Vector</td>
<td>110</td>
<td>2.98</td>
<td>7.48</td>
</tr>
<tr>
<td>4</td>
<td>None</td>
<td>60</td>
<td>1.80</td>
<td>2.50</td>
</tr>
<tr>
<td>5</td>
<td>None</td>
<td>70</td>
<td>2.00</td>
<td>6.00</td>
</tr>
<tr>
<td>6</td>
<td>None</td>
<td>70</td>
<td>2.00</td>
<td>3.70</td>
</tr>
<tr>
<td>7</td>
<td>Shear</td>
<td>50</td>
<td>2.00</td>
<td>3.10</td>
</tr>
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Unfactored HL-93 loading used to get factors of safety
Investigate Time Dependent Behavior
Time Dependent Analysis of the US 360 Bridge
Time Dependent Analysis

At the cross-sectional level

**Differential Shrinkage**

**Section 1**

**Negative Temperature Gradient**

**Section 1**

Section 1
## Results of Time Dependent Analysis

### Tensile stresses at the top of the deck

<table>
<thead>
<tr>
<th>Section</th>
<th>Differential Shrinkage (ksi)</th>
<th>Temperature Gradient (ksi)</th>
<th>Total (ksi)</th>
<th>$f_t$ (ksi)</th>
<th>Total/$f_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.052</td>
<td>0.15</td>
<td>0.202</td>
<td>0.474</td>
<td>0.43</td>
</tr>
<tr>
<td>2</td>
<td>0.352</td>
<td>0.154</td>
<td>0.506</td>
<td>0.474</td>
<td>1.07</td>
</tr>
<tr>
<td>3</td>
<td>-0.264</td>
<td>0.15</td>
<td>-0.114</td>
<td>0.474</td>
<td>N/A</td>
</tr>
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### Tensile stresses at the bottom of the deck

<table>
<thead>
<tr>
<th>Section</th>
<th>Differential Shrinkage (ksi)</th>
<th>Temperature Gradient (ksi)</th>
<th>Total (ksi)</th>
<th>$f_t$ (ksi)</th>
<th>Total/$f_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.373</td>
<td>0.1</td>
<td>0.473</td>
<td>0.474</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>0.496</td>
<td>0.09</td>
<td>0.586</td>
<td>0.474</td>
<td>1.24</td>
</tr>
<tr>
<td>3</td>
<td>0.487</td>
<td>0.02</td>
<td>0.507</td>
<td>0.474</td>
<td>1.07</td>
</tr>
</tbody>
</table>

### Diagrams

- **Longitudinal Cracks**
  - **Section 1**: 6'-0"
  - **Section 2**: 6'-0"
  - **Section 3**: 6'-0"

- **Trans. Cracks**
  - **Section 1**: 6'-0"
  - **Section 2**: 6'-0"
  - **Section 3**: 6'-0"
Recommendations for US 360 Bridge Implementation
Recommendation #1

Use Tapered Web Cross Section with steel as shown
Recommendation #2

Use welded drop-in bar at 2 feet on center along girder length (for high volume bridges)
Recommendation #3

Time Dependent Effects

- **Mix Design for the Deck** - Specify a topping mix with low shrinkage and high creep

- **Mild Steel in CIP Topping** – Need to have it

- **Constructability**
- **Bearing Details at the Abutments**
- **End Zone Reinforcement**
- **Continuity Detail**
Recommendation #4

Provide horizontal shear transfer reinforcement and roughen interface. Roughening the precast webs and the precast flanges in the **longitudinal** direction while providing a **transverse** rake finish at the top of the precast web appears to provide the necessary cohesion for full composite action.
Full Scale Testing
Objectives

- Determine if horizontal shear reinforcement is needed to develop full composite action
- Determine if an inverted T beam can develop its calculated nominal moment capacity ($\Phi M_n$)
LVDT's at beam ends to measure slip (5 at each end)
Test Plan – Four Tests

Linear elastic response, no cracking
- Loading to simulate \( +M_{\text{service}} \) (no cracking)

No slip
- Loading to simulate \( V_u \) (no cracking)

Flexural cracking & no slip
- Loading to simulate \( +M_u \) (Beam should crack)

See next slide
- Loading to simulate \( \Phi M_n \) (Beam should fail)
Simulation of Strength Level Design Moment and Nominal Moment Capacity

No Measured Slip
Recommendation

Horizontal shear reinforcement not needed
Field Evaluation
Overview
(First Application in Virginia)

Two-span continuous bridge
Each span 43 feet
Precast Inverted T-beam
depth = 18 in.
CIP topping depth = 7.5 in.
Clear width = 110 feet

Plan View
(Source VDOT drawings)

Elevation (Source VDOT drawings)
Objectives

- Quantify LLDF for the Inverted T-beam system
- Investigate the applicability of AASHTO’s method for cast-in-place slab span bridge
- Investigate the applicability of AASHTO’s method for adjacent box structure systems
Results - Strains

**Figure 8.14.** Longitudinal strains in each girder – Truck Position 1

**Figure 8.15.** Longitudinal strains in each girder – Truck Position 2

**Figure 8.16.** Longitudinal strains in each girder – Truck Position 3

**Figure 8.17.** Longitudinal strains in each girder – Truck Position 4
Results - LLDFs
AASHTO’s method for cast-in-place slab span bridges is conservative for moment and shear and can be used in the design of inverted T-beam bridges.

AASHTO’s method for adjacent box structures is conservative for moment and extremely conservative for shear.

**Recommendation:** Use AASHTO cast-in-place slab span equations for LDF.