Performance Comparison of In-Service, Full-Depth Precast Concrete (FDPC) Deck Panels to Cast-in-Place (CIP) Decks

October 25, 2019

PI: David Garber, PhD, PE
RA: Esmaeil Shahrokhinasab (PhD student)
Outline

• Background
  • Accelerated Bridge Construction (ABC)
  • Full-Depth Precast Concrete (FDPC) Deck Panels
• Objectives and Methodology
• Results
• ABC-UTC Guide to FDPC Deck Panels
• Conclusions
Background

Accelerated Bridge Construction (ABC)

ABC involves the use of innovative planning, design, materials, and construction methods to reduce on-site construction times.

One way of accelerating construction is using prefabricated bridge elements and systems (PBES).

I-10 Bridge over Escambia Bay (near Pensacola, FL): used precast pile caps and footings with pocket connections.
Background

Prefabricated Bridge Elements and Systems (PBES)

There are numerous different types of PBES. Below are several categories as defined by AASHTO T-4 (construction committee):

- Deck elements (e.g. full-depth precast decks)
- Deck beam elements (e.g. adjacent deck bulb T beams)
- Pier elements (e.g. precast pile caps, precast column cap)
- Abutment and wall elements (e.g. precast abutment cap)
Background

Full-Depth Precast Concrete (FDPC) Deck Panels

There are two main types of full-depth precast decks:

- **Full-Depth Precast Deck Panel w/PT**
  
  A full thickness deck panel that makes up the entire structural deck. Connected in the distribution direction with post-tensioning.

- **Full-Depth Precast Deck Panel w/o PT**
  
  A full thickness deck panel that makes up the entire structural deck. Connected in the distribution direction without post-tensioning (typically with a reinforced concrete closure joint).

(definitions from NCHRP 12-102)
Background

Full-Depth Precast Concrete (FDPC) Deck Panels

Key Components:

- **Pockets/block-outs**: create composite connection with girders
- **Transverse/longitudinal joints**: connect adjacent panels
- **Connection material**: concrete, grout, UHPC
- **Overlay material**
Background

Full-Depth Precast Concrete (FDPC) Deck Panels

Benefits

- **Quality**: better quality assurance for precast (controlled plant environment) versus cast-in-place construction

- **Reduced Construction Time**: 50% to 75% of time required for conventional CIP deck construction

- **Weight Reduction**: Thickness of deck can often be reduced or lightweight concrete can be used in the panels to reduce weight

- **Economy**: Initial cost is usually higher, but can be decreased with increased use or states with short construction windows (e.g. Alaska); lower traffic maintenance costs

(Precast/Prestressed Concrete Institute, 2011, p. 3-6)
Background
Full-Depth Precast Concrete (FDPC) Deck Panels

Successful Projects

<table>
<thead>
<tr>
<th>Bridge Name</th>
<th>State</th>
<th>City/County</th>
<th>Year Completed</th>
<th>Rehab/New</th>
<th>Beam Type</th>
<th>Total Bridge Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pintala Creek Bridge</td>
<td>Alabama</td>
<td>Montgomery County</td>
<td>pre 1973</td>
<td>New</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chulitna River Bridge</td>
<td>Alaska</td>
<td></td>
<td>1992</td>
<td>Rehab</td>
<td>Steel trusses &amp; stringers</td>
<td>790'</td>
</tr>
<tr>
<td>No. 1257 - South Fork Bonanza Creek Bridge</td>
<td>Alaska</td>
<td></td>
<td>1992</td>
<td>Rehab</td>
<td>Steel, Timber</td>
<td>90'</td>
</tr>
<tr>
<td>No. 1439 - Atigun River No. 1 Bridge</td>
<td>Alaska</td>
<td></td>
<td>1992</td>
<td>Rehab</td>
<td>Timber</td>
<td>90'</td>
</tr>
<tr>
<td>CA-17 High Street Overhead Separation Bridge</td>
<td>California</td>
<td></td>
<td>1978</td>
<td>Rehab</td>
<td>Rolled steel</td>
<td>1750'</td>
</tr>
<tr>
<td>Oakland-San Francisco Bay Bridge</td>
<td>California</td>
<td>Oakland - San Francisco</td>
<td>1961</td>
<td>Rehab</td>
<td>Cable stayed / Steel truss</td>
<td></td>
</tr>
<tr>
<td>Waterbury Bridge 03200</td>
<td>Connecticut</td>
<td></td>
<td>1989</td>
<td>Rehab</td>
<td>Steel plate girder</td>
<td>700'</td>
</tr>
<tr>
<td>Milford-Montague Toll Bridge</td>
<td>Delaware</td>
<td></td>
<td>1989</td>
<td>Rehab</td>
<td>Truss, steel stringer</td>
<td>1150'</td>
</tr>
<tr>
<td>Seneca Bridge</td>
<td>Illinois</td>
<td>LaSalle County</td>
<td>1986</td>
<td>Rehab</td>
<td></td>
<td>1510' - 3&quot;</td>
</tr>
<tr>
<td>Structure No. 048-0059</td>
<td>Illinois</td>
<td>Knox County</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structure No. 100-0039</td>
<td>Illinois</td>
<td>Williamson County</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US-24 Bayview Bridge over the Mississippi River</td>
<td>Illinois / Missouri</td>
<td>Quincy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Precast/Prestressed Concrete Institute, 2011, p. 91)
Objectives

1. Compare the long-term performance of FDPC deck panels to CIP decks
2. Identify successful and unsuccessful details for FDPC deck panels and joints
3. Identify owner perceptions of FDPC deck panels and determine perceived successes and challenges
Methodology

Select Comparison Projects

Collect data from ABC Project Database, available literature, developed survey and NBI/LTBP Program (Tasks 1, 2, and 3)

Inspection Review

Collect and analyze inspection information from above sources and compare performance of bridge decks (Tasks 4 and 5)

Report Findings

Determine successful panel or joint details and provide a detailed summary of results (Tasks 6 and 7)
Project Tasks

• Task 1 – Literature Review
• Task 2 – FDPC Survey
• Task 3 – Determine Comparison Projects
• Task 4 – Collect Required Inspection Information
• Task 5 – Analysis of Inspection Information
• Task 6 – Design Recommendations
• Task 7 – Final Report
Literature Review

- **Full-Depth Precast Concrete Deck Panels** – successful completed projects and research
Literature Review

• Full-Depth Precast Concrete Deck Panels – successful completed projects and research

• NBI and LTBP

LTBP Portal

Clusters and Corridors

LTBP Protocols
Literature Review

• Full-Depth Precast Concrete Deck Panels – successful completed projects and research

• NBI and LTBP

LTBP InfoBridge
https://infobridge.fhwa.dot.gov/

Web-based platform compiling data including National Bridge Inventory (NBI), National Bridge Element (NBE), traffic, environmental, bridge elevation, inspection, and maintenance data.
Literature Review

• Full-Depth Precast Concrete Deck Panels – successful completed projects and research

• NBI and LTBP

• Utah DOT Resources: Lessons Learned Reports
Utah DOT Resources: Lessons Learned Reports

Bridges with different ABC technologies or techniques were monitored between 2009 to 2016

Some examples:
- Transverse connections with welded tie plates, longitudinal post-tensioning, dowel bar pockets, UHPC connections
- Deck panels with shear connector pockets
- Parapets, SPMT installation

Some of them were experiencing early-age deterioration
Literature Review

Utah DOT Resources: Lessons Learned Reports

Worst observed performance:
*Welded tie connection between FDPC deck panels*

Bridges using full-depth precast decks with welded tie connections experienced leakage and efflorescence between deck panels

![Typical joint leakage at deck panels (I-84 WB over Weber Canyon with welded-tie connections from 2009 inspection)](image)

Typical transverse cracking in the overlay which worsened from 2013 to 2016

I-84; US-89 to SR-167, Weber Canyon (Built 2008)
Literature Review
Commonly Used Joint Details

Grouted Shear Key

<table>
<thead>
<tr>
<th>Mechanical</th>
<th>UHPC</th>
<th>Conventional Concrete</th>
</tr>
</thead>
</table>

Longitudinally Post-Tensioned (C1.a)

Non-Post-Tensioned (C1.a)

Sample detail from Utah DOT

Sample detail from Alaska DOT
Literature Review

Commonly Used Joint Details

Grouted Shear Key

Mechanical

UHPC

Conventional Concrete

Welded (C1.b)

Grouted Dowel (C1.c)

Sample detail from Texas DOT (Live Oak Creek Bridge)

Sample detail from Utah DOT
## Literature Review

Commonly Used Joint Details

<table>
<thead>
<tr>
<th>Grouted Shear Key</th>
<th>Mechanical</th>
<th>UHPC</th>
<th>Conventional Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waffle Slab w/Straight Bars (C1.d)</td>
<td>Headed Bar (C1.e)</td>
<td>Straight Bar (C1.f)</td>
<td>Hooped Bar (C1.g)</td>
</tr>
</tbody>
</table>

- **Waffle Slab w/Straight Bars (C1.d)**
- **Headed Bar (C1.e)**
- **Straight Bar (C1.f)**
- **Hooped Bar (C1.g)**

Little Cedar Creek Bridge, IA (ABC Project Database)

Sample details from Aeleti and Sritharan (2014)

Sample detail from NYDOT

Sample detail from Maine DOT
Literature Review
Commonly Used Joint Details

Grouted Shear Key | Mechanical | UHPC | Conventional Concrete

<table>
<thead>
<tr>
<th>Hooped Bar (C1.h)</th>
<th>Straight Bar (C1.i)</th>
<th>Headed Bar (C1.j)</th>
<th>Hooked Bar (C1.k)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Hooped Bar (C1.h)" /></td>
<td><img src="image" alt="Straight Bar (C1.i)" /></td>
<td><img src="image" alt="Headed Bar (C1.j)" /></td>
<td><img src="image" alt="Hooked Bar (C1.k)" /></td>
</tr>
</tbody>
</table>

Sample detail from Florida DOT  Sample detail from MassDOT  Sample detail from Iowa DOT
FDPC Deck Panel Survey

• Developed with help of Research Advisory Panel
• Distributed through AASHTO T-4

Currently: 42 states responded
FDPC Deck Panel Survey
FDPC Deck Panel Usage

Previously Used FDPC Deck Panels
- Yes: 31
- No: 12
- 72% usage

Currently Allow Use of FDPC Deck Panels
- Yes: 31
- No: 12
- 72% usage
FDPC Deck Panel Survey
State Perception

Example Response
“The quality of deck panels made in a shop is easier to control than CIP decks...”
Example Responses

“Partial-depth over full-depth precast deck panels preferred. Partial-depth precast panels save time, low labor cost and contractor prefer”

“Flexibility of cast in place because it can easily suit our p/s members (in terms of camber, use of p/s planks, etc.)”
FDPC Deck Panel Survey

FDPC Projects per Decade

Total of 301 projects (including new project under design)

<table>
<thead>
<tr>
<th>Year Deck Constructed</th>
<th># of FDPC Deck Panel Bridges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1970</td>
<td>4</td>
</tr>
<tr>
<td>1970-1979</td>
<td>7</td>
</tr>
<tr>
<td>1980-1989</td>
<td>13</td>
</tr>
<tr>
<td>1990-1999</td>
<td>53</td>
</tr>
<tr>
<td>2000-2009</td>
<td>64</td>
</tr>
<tr>
<td>After 2010</td>
<td>160</td>
</tr>
</tbody>
</table>
FDPC Deck Panel Survey

Distribution of FDPC Projects

Legend
- $n = 0$
- $15 \leq n < 35$
- $1 \leq n < 5$
- $35 \leq n < 100$
- $5 \leq n < 15$
- $n \geq 100$
Joint Usage by State

Primary Joint Details:
- Post-tensioned
- UHPC – straight bar
- Conventional concrete – hairpin/hooked

Joint Type

Currently Used | Previously

<table>
<thead>
<tr>
<th>Joint Type</th>
<th>Currently Used</th>
<th>Previously</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Mechanical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UHPC</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>CC</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FDPC Deck Panel Survey

Cost Comparison

Average Cost (Current):
- FDPC Deck Panels $77.55/ft^2
- CIP Deck $45.74/ft^2

(similar cost for FDPC deck panels and CIP decks in some states, e.g. AK)
## FDPC Deck Panel Database

Database of FDPC deck panel projects with NBI numbers for 280 projects

<table>
<thead>
<tr>
<th>State</th>
<th>NBI</th>
<th>Bridge Name</th>
<th>Year of Deck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska</td>
<td>2125</td>
<td>Wilson Creek (IRR Airport Access)</td>
<td>2012</td>
</tr>
<tr>
<td>Alaska</td>
<td>1298</td>
<td>Grayling Creek (IRR Airport Road)</td>
<td>2006</td>
</tr>
<tr>
<td>Alaska</td>
<td>1308</td>
<td>Kouwegok Slough (Landfill Road)</td>
<td>2000</td>
</tr>
<tr>
<td>Alaska</td>
<td>183</td>
<td>IRR Marine Hwy Rt over Tatitlek Dock</td>
<td>1995</td>
</tr>
<tr>
<td>Alaska</td>
<td>184</td>
<td>IRR Marine Hwy Rt over Chenega Dock</td>
<td>1995</td>
</tr>
<tr>
<td>Alaska</td>
<td>185</td>
<td>IRR Marine Hwy Rt over Chenega Ramp</td>
<td>1995</td>
</tr>
<tr>
<td>Alaska</td>
<td>255</td>
<td>Parks Highway over Chulitna River</td>
<td>1970</td>
</tr>
<tr>
<td>Alaska</td>
<td>446</td>
<td>Water Street No. 2 Trestle</td>
<td>1979</td>
</tr>
<tr>
<td>Alaska</td>
<td>556</td>
<td>Richardson Hwy over Valdez Glacier Stream</td>
<td>1999</td>
</tr>
<tr>
<td>Alaska</td>
<td>797</td>
<td>South Tongass Hwy over Water St. Viaduct</td>
<td>1955</td>
</tr>
<tr>
<td>Alaska</td>
<td>1185</td>
<td>Subdivision Rd over Gate Creek</td>
<td>2014</td>
</tr>
<tr>
<td>Alaska</td>
<td>1255</td>
<td>Dalton Hwy over Fish Creek</td>
<td>1992</td>
</tr>
<tr>
<td>Alaska</td>
<td>1256</td>
<td>Dalton Hwy over North Fork Bonanza Creek</td>
<td>1992</td>
</tr>
<tr>
<td>Alaska</td>
<td>1257</td>
<td>Dalton Hwy over South Fork Bonanza Creek</td>
<td>1992</td>
</tr>
<tr>
<td>Alaska</td>
<td>1258</td>
<td>Dalton Hwy over Prospect Creek</td>
<td>1992</td>
</tr>
<tr>
<td>Alaska</td>
<td>1259</td>
<td>Dalton Hwy over Jim River No. 1</td>
<td>1992</td>
</tr>
<tr>
<td>Alaska</td>
<td>1260</td>
<td>Dalton Hwy over South Fork Koyukuk River</td>
<td>1992</td>
</tr>
<tr>
<td>Alaska</td>
<td>1261</td>
<td>Dalton Hwy over Mid Fork Koyukuk River 1</td>
<td>1992</td>
</tr>
<tr>
<td>Alaska</td>
<td>1282</td>
<td>Dalton Hwy over Mid Fork Koyukuk River 2</td>
<td>1992</td>
</tr>
<tr>
<td>Alaska</td>
<td>1283</td>
<td>Dalton Hwy over Mid Fork Koyukuk River 3</td>
<td>1992</td>
</tr>
<tr>
<td>Alaska</td>
<td>1284</td>
<td>Dalton Hwy over Mid Fork Koyukuk River 4</td>
<td>1992</td>
</tr>
<tr>
<td>Alaska</td>
<td>1304</td>
<td>Klondike Highway over Captain WM Moore Creek</td>
<td>1992</td>
</tr>
<tr>
<td>Alaska</td>
<td>1332</td>
<td>Dalton Hwy over Slate Creek</td>
<td>1992</td>
</tr>
<tr>
<td>Alaska</td>
<td>1334</td>
<td>Dalton Hwy over No Name Creek</td>
<td>1992</td>
</tr>
</tbody>
</table>
FDPC Deck Panel Database

Alaska
(40 projects)

Utah
(37 projects)

New York
(125 projects)

https://www.darrinward.com/lat-long/?id=5afbc064eaa0.52487562
Comparison Projects

Source of comparison projects:
1. Provided by DOT in survey
2. Obtained from survey and LTBP Portal

State Survey

https://infobridge.fhwa.dot.gov/
Comparison Projects

Procedure of Select/evaluate comparison projects is based on LTBP Clusters and Corridors methodology

- Type of bridge
- Geometry, design and protection layer
- Concentrated geographic areas
- Traffic
- Climate

<table>
<thead>
<tr>
<th>NBI</th>
<th>1717 056</th>
<th>1675 006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge Name</td>
<td>I-95 over SR1</td>
<td>SR141 NB over I-95 SB</td>
</tr>
<tr>
<td>Source</td>
<td>DOT provided</td>
<td>DOT provided</td>
</tr>
<tr>
<td>Deck Type</td>
<td>FDPC Panels</td>
<td>CIP</td>
</tr>
<tr>
<td>Year</td>
<td>2016</td>
<td>2018</td>
</tr>
<tr>
<td>ADT</td>
<td>72,039</td>
<td>34,000</td>
</tr>
<tr>
<td>Bridge Type</td>
<td>Steel Girder</td>
<td>Steel Girder</td>
</tr>
<tr>
<td>Total Bridge Length (ft)</td>
<td>209</td>
<td>265</td>
</tr>
<tr>
<td>Max Span Length (ft)</td>
<td>70.3</td>
<td>130</td>
</tr>
<tr>
<td>ABC Database?</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Reported Issues</td>
<td>No</td>
<td>Deck cracking (shrinkage cracking)</td>
</tr>
<tr>
<td>Notes</td>
<td>UHPC connection; polyester polymer concrete overlay</td>
<td>No protection system; added a thin epoxy overlay after deck was complete</td>
</tr>
</tbody>
</table>

Similar comparison set up for most projects in FDPC Deck Panel Database
Collect and Analyze Data

Data Available on LTBP Portal

1. Summary of Important Characteristics from NBI

Data shown from NBI# 015984 (Alabama)
Collect and Analyze Data

Data Available on LTBP Portal

2. Historical NBI Condition Data

Historical NBI Condition (Alabama - 015984)

Condition Rating Code


Inspection Date

Deck Condition Superstructure Condition Substructure Condition

Data shown from NBI# 015984 (Alabama)
Collect and Analyze Data

Data Available on LTBP Portal

3. Historical NBI Daily Traffic Data

4. Climate
Collect and Analyze Data

Procedures for Analyzing Data

1. Direct side-by-side comparison using NBI data
2. Comparison of general system performance
   • Group bridges by type of bridge, climate, concentrated geographic areas, traffic, type of joint, etc.
   • Compare performance for different groups

Joint Types

- Post-Tensioned
- Mechanical
  - Welded
  - Grouted Dowel
- UHPC
  - Waffle-Deck
  - Headed Bars
  - Hairpin/Hooked Bars
  - Straight Bars
- Conventional Concrete
  - Hairpin/Hooked Bars
  - Straight Bars
  - Headed Bars

DOE Climate Zones
Collect and Analyze Data

Procedures for Analyzing Data

1. Direct side-by-side comparison using NBI data

**FDPC:** Minnesota #69071

**CIP:** Minnesota #69065

Comparing side-by-side deterioration rates of two similar bridges
Collect and Analyze Data

Procedures for Analyzing Data

1. Direct side-by-side comparison using NBI data
2. Comparison of general system performance

<table>
<thead>
<tr>
<th>Joint Category (Transverse Joint)</th>
<th>Long. PT - C1.a</th>
<th>Non-PT - C1.a</th>
<th>Welded - C1.b</th>
<th>Grouted Dowel - C1.c</th>
<th>UHPC - C1.f</th>
<th>UHPC - C1.g</th>
<th>CC - C1.h</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_{\text{bridges}} )</td>
<td>40</td>
<td>38</td>
<td>10</td>
<td>5</td>
<td>12</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Avg. ( n_{\text{inspections per bridge}} )</td>
<td>7.8</td>
<td>14.9</td>
<td>6.2</td>
<td>4.6</td>
<td>3.8</td>
<td>8.0</td>
<td>11.0</td>
</tr>
<tr>
<td>Deterioration Rate</td>
<td>-0.12</td>
<td>-0.07</td>
<td>-0.13</td>
<td></td>
<td>-0.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated Service Life (year)</td>
<td>31</td>
<td>36</td>
<td>29</td>
<td></td>
<td>32</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Collect and Analyze Data

Procedures for Analyzing Data

**Deterioration Rate**

\[
D = \frac{n(\sum R_{d,i}t_i) - (\sum R_{d,i})(\sum t_i)}{n(\sum t_i^2) - (\sum t_i)^2}
\]

where:
- \(D\) = deterioration rate for deck calculated based on NBI database (rating / year)
- \(R_{d,i}\) = deck rating obtained from NBI database for year \(i\) after deck construction
- \(t_i\) = time of inspection after deck construction (years)

**Estimated Service Life of Deck**

\[
S = \frac{R_{d,0} - 4}{D}
\]

where:
- \(S\) = estimated service lift based on the deterioration rate calculated
- \(R_{d,0}\) = initial deck rating immediately after deck construction
An upper limit for the estimated service life was set at 40 years. This meant that if a bridge was found to have a deterioration rate of zero, the estimated service life was set to 40 years.
Collect and Analyze Data

Ranking of Comparison Projects

Rating system was established to evaluate quality of the comparison project

Comparison projects must have these in common

Variables
- Span Length
- ADT
- Age
- ADTT

Common Factors
- Material and Structure Type
- Climate Zone
- Presence of Wearing Surface

Increased difference decreases rating
Collect and Analyze Data

Ranking of Comparison Projects

Criteria for rating of comparison projects

<table>
<thead>
<tr>
<th>Comparison Rating</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span Length</td>
<td>$X_{\text{span}}$</td>
<td>$\geq \pm 30%$</td>
<td>$\pm 25$ to $29.9%$</td>
<td>$\pm 20$ to $24.9%$</td>
<td>$\pm 15$ to $19.9%$</td>
</tr>
<tr>
<td>Year</td>
<td>$X_{\text{year}}$</td>
<td>$\geq \pm 10$ yr</td>
<td>$\pm 5$ to $9.9$ yr</td>
<td>$\pm 3$ to $4.9$ yr</td>
<td>$\pm 1$ to $2.9$ yr</td>
</tr>
<tr>
<td>ADT</td>
<td>$X_{\text{ADT}}$</td>
<td>$\geq \pm 90%$</td>
<td>$\pm 70$ to $89.9%$</td>
<td>$\pm 50$ to $69.9%$</td>
<td>$\pm 30$ to $49.9%$</td>
</tr>
<tr>
<td>ADTT</td>
<td>$X_{\text{ADTT}}$</td>
<td>$\geq \pm 90%$</td>
<td>$\pm 70$ to $89.9%$</td>
<td>$\pm 50$ to $69.9%$</td>
<td>$\pm 30$ to $49.9%$</td>
</tr>
</tbody>
</table>

% $\text{diff}_{\text{span}} = \left(\frac{91.1' - 77.6'}{91.1'}\right) \times 100\% = 14.8\% < 15\% \implies X_{\text{span}} = 5$

- Different types of wearing surface, $X_{\text{WS}} = -0.5$ rating
- Number of spans is different by $> 3$ spans, $X_{\#\text{spans}} = -0.5$ rating

$$X = \frac{1}{5} \left( X_{\text{span}} + 2X_{\text{year}} + X_{\text{ADT}} + X_{\text{ADTT}} \right) + X_{\text{WS}} + X_{\#\text{spans}}$$

$X \geq 3.0 \implies \text{Include in side-by-side comparison analysis}$
Collect and Analyze Data

Ranking of Comparison Projects

Of the 280 total comparisons, 172 of them had an overall comparison rating greater than or equal to 3.0 ($X \geq 3.0$).
Results

FDPC versus CIP

Higher Deterioration Rate between Comparison Projects:

<table>
<thead>
<tr>
<th>Deck Type</th>
<th>FDPC</th>
<th>CIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_{bridges} )</td>
<td>206</td>
<td>177</td>
</tr>
<tr>
<td>Avg. ( n_{inspections per bridge} )</td>
<td>12.6</td>
<td>13.0</td>
</tr>
<tr>
<td>Avg. Year of 1(^{st}) Inspection</td>
<td>2004</td>
<td>2005</td>
</tr>
<tr>
<td>Deterioration Rate</td>
<td>-0.12</td>
<td>-0.09</td>
</tr>
<tr>
<td>Estimated Service Life (year)</td>
<td>33</td>
<td>35</td>
</tr>
</tbody>
</table>
# Results

## Performance Comparisons

### Transverse Joint Type

<table>
<thead>
<tr>
<th>Joint Category <em>(Transverse Joint)</em></th>
<th>Long. PT - C1.a</th>
<th>Non-PT - C1.a</th>
<th>Welded - C1.b</th>
<th>Grouted Dowel - C1.c</th>
<th>UHPC - C1.f</th>
<th>UHPC - C1.g</th>
<th>CC - C1.h</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>n\textsubscript{bridges}</strong></td>
<td>40</td>
<td>38</td>
<td>10</td>
<td>5</td>
<td>12</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td><strong>Avg. n\textsubscript{inspections} per bridge</strong></td>
<td>7.8</td>
<td>14.9</td>
<td>6.2</td>
<td>4.6</td>
<td>3.8</td>
<td>8.0</td>
<td>11.0</td>
</tr>
<tr>
<td><strong>Avg. Year of 1\textsuperscript{st} Inspection</strong></td>
<td>2009</td>
<td>2003</td>
<td>2008</td>
<td>2012</td>
<td>2014</td>
<td>2010</td>
<td>2006</td>
</tr>
<tr>
<td><strong>Deterioration Rate</strong></td>
<td>-0.12</td>
<td>-0.07</td>
<td>-0.13</td>
<td>-0.14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Estimated Service Life (year)</strong></td>
<td>31</td>
<td>36</td>
<td>29</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Non-PT (C1.a)  →  Most common with low traffic volume (36 in Alaska)*
## Results

### Performance Comparisons

#### Longitudinal Joint Type

<table>
<thead>
<tr>
<th>Joint Category (Longitudinal Joint)</th>
<th>Non-PT - C1.a</th>
<th>Welded - C1-b</th>
<th>Grouted Dowel - C1.c</th>
<th>UHPC - C1.f</th>
<th>UHPC - C1.g</th>
<th>CC - C1.h</th>
<th>CC - C1.i</th>
<th>CC - C1.j</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>n bridges</td>
<td>4</td>
<td>3</td>
<td>10</td>
<td>11</td>
<td>2</td>
<td>12</td>
<td>16</td>
<td>2</td>
<td>52</td>
</tr>
<tr>
<td>Avg. n inspections per bridge</td>
<td>13.5</td>
<td>21.7</td>
<td>4.0</td>
<td>3.7</td>
<td>5.5</td>
<td>6.0</td>
<td>6.4</td>
<td>4.0</td>
<td>12.7</td>
</tr>
<tr>
<td>Deterioration Rate</td>
<td>-0.08</td>
<td>-0.16</td>
<td>-0.09</td>
<td>-0.11</td>
<td>-0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated Service Life (year)</td>
<td>29</td>
<td>32</td>
<td>34</td>
<td>31</td>
<td>34</td>
<td></td>
<td></td>
<td></td>
<td>34</td>
</tr>
</tbody>
</table>
## Results

### Performance Comparisons

#### Traffic Impact Category

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>Tier 1</th>
<th>Tier 2</th>
<th>Tier 3</th>
<th>Tier 4</th>
<th>Tier 5</th>
<th>Tier 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_{bridges}$</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>Avg. $n_{inspections \ per \ bridge}$</td>
<td>4.0</td>
<td>12.0</td>
<td>19.0</td>
<td>3.0</td>
<td>8.9</td>
<td>8.6</td>
</tr>
<tr>
<td>Deterioration Rate</td>
<td>0.0</td>
<td>-0.04</td>
<td>-0.09</td>
<td>-0.25</td>
<td>-0.16</td>
<td>-0.16</td>
</tr>
<tr>
<td>Estimated Service Life (year)</td>
<td>40</td>
<td>39</td>
<td>34</td>
<td>22</td>
<td>29</td>
<td>31</td>
</tr>
</tbody>
</table>

Shorter impact to traffic (Tiers 1 to 3) had longer estimated service lives

- Tier 1: traffic impacts within 1 day
- Tier 2: traffic impacts within 3 days
- Tier 3: traffic impacts within 2 weeks
- Tier 4: traffic impacts within 1 month
- Tier 5: traffic impacts within 3 months
- Tier 6: overall project schedule is significantly reduced by months to years

(Photos from the [ABC Project Database](https://abc.utc.fiu.edu/resources/project-research-databases/))
Results

Performance Comparisons

DOE Climate Zone

<table>
<thead>
<tr>
<th>Climate Category</th>
<th>Very Cold</th>
<th>Cold</th>
<th>Mixed humid</th>
<th>Hot humid</th>
<th>Marine</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_{\text{bridges}}$</td>
<td>41</td>
<td>147</td>
<td>14</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Avg. $n_{\text{inspections per bridge}}$</td>
<td>14.8</td>
<td>12.1</td>
<td>12.7</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Deterioration Rate</td>
<td>-0.067</td>
<td>-0.135</td>
<td>-0.098</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated Service Life (year)</td>
<td>36</td>
<td>31</td>
<td>35</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

New York, Alaska, and Utah

As expected, the bridges in cold climate zones had the highest deterioration rates and shortest average estimated service life due to freeze-thaw cycles, which combined with moisture and deicing salts.
## Results

### Performance Comparisons

<table>
<thead>
<tr>
<th>Overlay Treatment</th>
<th>Monolithic Concrete (none)</th>
<th>Integral Concrete</th>
<th>Latex Concrete</th>
<th>Epoxy Overlay</th>
<th>Bituminous</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n_{bridges})</td>
<td>46</td>
<td>17</td>
<td>7</td>
<td>26</td>
<td>99</td>
<td>14</td>
</tr>
<tr>
<td>Deterioration Rate</td>
<td>-0.09</td>
<td>-0.15</td>
<td></td>
<td>-0.11</td>
<td>-0.11</td>
<td></td>
</tr>
<tr>
<td>Estimated Service Life (year)</td>
<td>36</td>
<td>32</td>
<td></td>
<td>30</td>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>

**Monolithic Concrete**
- No CIP wearing surface

**Integral Concrete**
- CIP wearing surface

**Integral Concrete (Route 23 Bridge over Otego Creek)**

**Epoxy Overlay (I-70 Bridge over Eagle Canyon (Eastbound))**
## Results

### Performance

<table>
<thead>
<tr>
<th>Overlay Treatment</th>
<th>Monolithic Concrete (none)</th>
<th>Integral Concrete</th>
<th>Latex Concrete</th>
<th>Epoxy Overlay</th>
<th>Bituminous</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_{\text{bridges}} )</td>
<td>46</td>
<td>17</td>
<td>7</td>
<td>26</td>
<td>99</td>
<td>14</td>
</tr>
<tr>
<td>Deterioration Rate</td>
<td>-0.09</td>
<td>-0.15</td>
<td>-0.11</td>
<td>-0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated Service Life (year)</td>
<td>36</td>
<td>32</td>
<td></td>
<td>30</td>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>

### Polymer Concrete Overlay

- (Martin Branch Bridge)

### Micro-Silica Concrete Overlay

- (Lewis and Clark Bridge)

**Examples:**
- 2.4-inch microsilica concrete
- 0.75-inch polyester polymer
- 1.5-inch silica fume concrete
## Results

### Performance Comparisons

#### Main Span Material Type

<table>
<thead>
<tr>
<th>Main Span Material</th>
<th>Concrete continuous</th>
<th>Steel</th>
<th>Steel continuous</th>
<th>Prestressed concrete</th>
<th>Prestressed concrete continuous</th>
<th>Wood or timber</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_{bridges}$</td>
<td>1</td>
<td>143</td>
<td>30</td>
<td>26</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td><strong>Deterioration Rate</strong></td>
<td>-0.114</td>
<td>-0.089</td>
<td>-0.127</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Estimated Service Life (year)</strong></td>
<td>34</td>
<td>32</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Similar performance between concrete and steel superstructures.
Results

Performance Comparisons

Average Daily Truck Traffic (ADTT) and Average Daily Traffic (ADT)

<table>
<thead>
<tr>
<th></th>
<th>ADTT</th>
<th></th>
<th>ADT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≤ 6000</td>
<td>&gt; 6000</td>
<td>≤ 30000</td>
</tr>
<tr>
<td>n_bridges</td>
<td>182</td>
<td>27</td>
<td>180</td>
</tr>
<tr>
<td>Avg. n_inspections</td>
<td>13.6</td>
<td>4.9</td>
<td>13.7</td>
</tr>
<tr>
<td>per bridge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg. Year of 1\textsuperscript{st} Inspection</td>
<td>2003</td>
<td>2011</td>
<td>2003</td>
</tr>
<tr>
<td>Deterioration Rate</td>
<td>-0.11</td>
<td>-0.16</td>
<td>-0.11</td>
</tr>
<tr>
<td>Estimated Service Life</td>
<td>34</td>
<td>28</td>
<td>33</td>
</tr>
</tbody>
</table>

FDPC deck panel bridges with higher traffic volumes on average have a higher deterioration rate and shorter estimated service life than those with lower traffic volumes.
ABC-UTC Guide to FDPC Deck Panels

ABC-UTC Guide for:
Full-Depth Precast Concrete (FDPC) Deck Panels

March 2019
Performing Institution:
Florida International University
Principal Investigator:
David Garber, PhD, PE
Graduate Research Assistant:
Ismail Shahrokhisab
## Table of Contents

1. Introduction
2. Overview of Design of FDPC Deck Panel Decks
3. Panel Design
   3.1. Dimensions and Configuration
   3.2. Precast Panel Reinforcement Detail
   3.3. Overhang and Barrier Design
   3.4. Shear Pockets and Horizontal Shear Connectors
   3.5. Panel Leveling System
   3.6. Concrete Mixture for FDPC Deck Panels
4. Joint Design
   4.1. Longitudinal Post Tensioning with Grouted Shear Key
   4.2. Conventional Concrete with Hooped or Straight Bars
   4.3. UHPC with Straight Bar
   4.4. Grouted Shear Key without Post-Tensioning
   4.5. Surface Preparation for Joints
5. Materials for Joints, Shear Pockets, and Post-Tensioning Ducts
   5.1. Grouts
      5.1.1. Grout for haunches, pockets, voids, and joints
      5.1.2. Grout for post-tensioning ducts
   5.2. Conventional Concrete
   5.3. Ultra-High Performance Concrete (UHPC)
   5.4. Polymer Concrete
6. Wearing Surface and Overlays
7. Available Resources
   7.1. General Resources
   7.2. UHPC Materials and Joint Design
   7.3. Post-Tensioning
   7.4. Past Performance
8. Past Performance
9. List of Successful Projects in ABC Project Database
10. References
### ABC-UTC Guide to FDPC Deck Panels

#### Common Joints

**Most common joint combinations from the FDPC Deck Panel Database**

<table>
<thead>
<tr>
<th>#</th>
<th>Transverse Joint</th>
<th>Longitudinal Joint</th>
<th>Percent of Bridges*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>UHPC with straight bar detail</td>
<td>UHPC with straight bar detail</td>
<td>25.3%</td>
</tr>
<tr>
<td>2</td>
<td>Longitudinal post-tensioning</td>
<td>Conventional concrete with hooped or straight bar detail</td>
<td>24.2%</td>
</tr>
<tr>
<td>3</td>
<td>Conventional concrete with hooped or straight bar detail</td>
<td>Conventional concrete with hooped or straight bar detail</td>
<td>13.7%</td>
</tr>
</tbody>
</table>

*Percent of bridges with a longitudinal joint; bridges without a longitudinal joint were not included*
# ABC-UTC Guide to FDPC Deck Panels

## Common Joints

Most common joint combinations from the FDPC Deck Panel Database

<table>
<thead>
<tr>
<th>#</th>
<th>Transverse Joint</th>
<th>Longitudinal Joint</th>
<th>Percent of Bridges*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>UHPC with straight bar detail</td>
<td>UHPC with straight bar detail</td>
<td>25.3%</td>
</tr>
<tr>
<td>2</td>
<td>Longitudinal joint</td>
<td>UHPC with straight bar detail</td>
<td>24.2%</td>
</tr>
<tr>
<td>3</td>
<td>Conventional concrete</td>
<td>UHPC with straight bar detail</td>
<td>13.7%</td>
</tr>
</tbody>
</table>

*Percent of bridges with a longitudinal joint; bridges without a longitudinal joint were not included.

---

![Diagram of UHPC with straight bars](image)

**Traffic**

UHPC with straight bars

UHPC with straight bars
# Common Joints

Most common joint combinations from the FDPC Deck Panel Database

<table>
<thead>
<tr>
<th>#</th>
<th>Transverse Joint</th>
<th>Longitudinal Joint</th>
<th>Percent of Bridges*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>UHPC with straight bar detail</td>
<td>UHPC with straight bar detail</td>
<td>25.3%</td>
</tr>
<tr>
<td>2</td>
<td>Longitudinal post-tensioning</td>
<td>Conventional concrete with hooped or straight bar detail</td>
<td>24.2%</td>
</tr>
<tr>
<td>3</td>
<td>Conventional concrete with hooped or straight bars</td>
<td></td>
<td>13.7%</td>
</tr>
</tbody>
</table>

*Percent of bridges with a longitudinal joint were not included
### Most common joint combinations from the FDPC Deck Panel Database

<table>
<thead>
<tr>
<th>#</th>
<th>Transverse Joint</th>
<th>Longitudinal Joint</th>
<th>Percent of Bridges*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>UHPC with straight bar detail</td>
<td>UHPC with straight bar detail</td>
<td>25.3%</td>
</tr>
<tr>
<td>2</td>
<td>Longitudinal post-tensioning</td>
<td>Conventional concrete with hooped or straight bar detail</td>
<td>24.2%</td>
</tr>
<tr>
<td>3</td>
<td>Conventional concrete with hooped or straight bar detail</td>
<td>Conventional concrete with hooped or straight bar detail</td>
<td>13.7%</td>
</tr>
</tbody>
</table>

*Percent of bridges with a longitudinal joint; bridges without a longitudinal joint were not included.
Conclusions

• Similar performance between bridges with FDPC deck panel and CIP decks
  → room for improvement with joints

• Performance based on categories:
  • **Joint Type**: UHPC with straight bar (for transverse or longitudinal joints), longitudinal post-tensioned (for transverse joints), and conventional concrete with hooped bar details (for longitudinal joints) are most popular and have good performance
  • **Traffic Impact Category**: from a limited sample size, shorter traffic impacts (Tiers 1 to 3) are performing better than those with longer traffic impacts (Tiers 4 to 6); possibly due to contractor qualifications
  • **Climate Zone**: shortest average estimated service life in cold climate zones
  • **Overlay Treatment**: similar performance for all overlay types and bridges without overlays
  • **Traffic**: higher traffic volumes increases deterioration rate

• **Limitation of Study**: Limited sample size and the subjectivity of the NBI inspection data

<table>
<thead>
<tr>
<th>Deck Type</th>
<th>FDPC</th>
<th>CIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>n\textsubscript{bridges}</td>
<td>206</td>
<td>177</td>
</tr>
<tr>
<td>Avg. n\textsubscript{inspections per bridge}</td>
<td>12.6</td>
<td>13.0</td>
</tr>
<tr>
<td>Avg. Year of 1\textsuperscript{st} Inspection</td>
<td>2004</td>
<td>2005</td>
</tr>
<tr>
<td>Deterioration Rate</td>
<td>-0.12</td>
<td>-0.09</td>
</tr>
<tr>
<td>Estimated Service Life (year)</td>
<td>33</td>
<td>35</td>
</tr>
</tbody>
</table>
Thank You

David Garber, PhD, PE
dgarber@fiu.edu
Assistant Professor

Esmail Shahrokhinasab
eshah004@fiu.edu
Research Assistant (PhD student)

Research Advisory Panel
Ahmad Abu-Hawash (Iowa DOT)
James Corney (Utah DOT)
Romeo Garcia (FHWA)
Bruce Johnson (Oregon DOT)
References


• Precast/Prestressed Concrete Institute. (2011). State-of-the-Art Report on Full-Depth Precast Concrete Bridge Deck Panels. PCI Committee on Bridges, PCI Bridge Producers, Committee, Federal Highway Administration.

• Precast/Prestressed Concrete Institute Northeast. (2011). Full Depth Deck Panels Guidelines for Accelerated Bridge Deck Replacement or Construction. PCI Northeast.

• Precast/Prestressed Concrete Institute Northeast. (2014). Guidelines for Accelerated Bridge Construction Using Precast/Prestressed Concrete Elements Including Guideline Details. PCI Northeast.
