Early Louisiana HPC Research

- Law & Rasoulian (1980)
- Adelman & Cousins (1990)
- Bruce, Russell & Roller – (1990-1993)
Concrete strengths of 6,500 psi and higher could be achieved using regionally available materials. High strengths could best be achieved through use of crushed limestone aggregate.
Adelman & Cousins (1990)

- A mix design was developed that consistently yielded 28-day compressive strength in excess of 10,000 psi.
- Measured MOR values compared well with results reported in other literature.
- Measured MOE values represented the upper bound for the range of values reported in other literature.
- Increasing design compressive strength from 6,000 psi to 10,000 psi resulted in an approximate 10% increase in span length and 5% decrease in superstructure cost.
With special attention to quality control, HPC with compressive strengths of 10,000 psi can be produced in a precast plant environment using regionally available materials.

HPC structural members performed in a manner that would be conservatively predicted using current AASHTO design provisions.

AASHTO provisions for estimating prestress loss due to creep and shrinkage may be too conservative for HPC with high compressive strengths.
Feasibility Study – Recommendations

- Use of HPC with compressive strengths up to 10,000 psi should be considered by the Louisiana DOTD.

- The effects of steam curing on the properties of high-strength HPC should be investigated further.

- A HPC quality control training program should be developed for regional fabricators.

- HPC with compressive strength up to 10,000 psi should be implemented in a bridge. This bridge should be instrumented.
Early Louisiana HPC Implementation

- 1988 – Specifying 8,000 psi concrete for a bridge project.
- 1992 – Successfully fabricating, shipping and driving a 130-ft long prestressed pile with concrete compressive strength of 10,450 psi.
- 1993 – Utilization of AASHTO Type IV girders with 8,500 psi compressive strength in Shreveport Inner Loop Expressway.
Implementation Project - Charenton Canal Bridge (2001)
Charenton Canal Bridge - Section

SECTION VIEW THROUGH SPAN NO. 3 LOOKING WEST
Charenton Canal Bridge - Research Plan

- Measure prestress force levels in selected strands during fabrication of girders for Span 3.
- Measure concrete temperatures during initial curing of girders fabricated for Span 3.
- Measure early-age and long-term concrete strains in girders and bridge deck slab for Span 3.
- Measure early-age and long-term mid-span deflections for girders incorporated in Span 3.
- Perform material property testing program for Span 3.
Charenton Canal Bridge -
Conclusions

- Reduction in prestress force occurring between the time of initial stress and release were greater than the PCI QC Manual tolerance and calculated steel relaxation prestress loss.

- Concrete temperatures along the length of prestressed girders were not uniform during initial curing. In addition, curing temperatures measured in field-cured cylinders were considerably less than those measured in the girders. The consequence of this temperature variation was evident in the measured concrete compressive strengths.
Measured early-age and long-term prestress losses were considerably less than the design loss calculated using provisions of the AASHTO Standard Specification.

Measured early-age girder camber agreed well with the calculated design values. However, the calculated design values (with the appropriate PCI multipliers applied) did not provide a reliable estimate of long-term camber after the deck slab was cast.
Temperature Variations

Time Since Casting Concrete, hours

Concrete Temperature, °F

- Bottom Flange @ Mid-Span
- Bottom Flange @ End
- 6 x 12 in. Cylinder
# Compressive Strength

<table>
<thead>
<tr>
<th>Concrete Age, Days</th>
<th>Initial Curing Method</th>
<th>Concrete Compressive Strength, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>Field</td>
<td>9,610</td>
</tr>
<tr>
<td></td>
<td>Match</td>
<td>10,570</td>
</tr>
<tr>
<td>90</td>
<td>Field</td>
<td>10,670</td>
</tr>
<tr>
<td></td>
<td>Match</td>
<td>11,950</td>
</tr>
</tbody>
</table>
# Prestress Losses

<table>
<thead>
<tr>
<th>Prestress Loss Component</th>
<th>Measured Loss, psi</th>
<th>Design Loss, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic - ES</td>
<td>14,336</td>
<td>16,234</td>
</tr>
<tr>
<td>Relaxation - CR(_s)</td>
<td>-</td>
<td>1,805</td>
</tr>
<tr>
<td>Creep - CR(_c)</td>
<td>18,589</td>
<td>25,686</td>
</tr>
<tr>
<td>Shrinkage - SH</td>
<td>5,750</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>39,925</strong></td>
<td><strong>49,475</strong></td>
</tr>
</tbody>
</table>
## Girder Camber

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>After Release (0.01)</td>
<td>1.00</td>
<td>1.41</td>
</tr>
<tr>
<td>Before Shipping (271)</td>
<td>2.40</td>
<td>2.51</td>
</tr>
<tr>
<td>After Casting Deck (303)</td>
<td>1.61</td>
<td>1.64</td>
</tr>
<tr>
<td>Final Reading (631)</td>
<td>1.58</td>
<td>0.87</td>
</tr>
</tbody>
</table>
Charenton Canal Bridge - Recommendations

- Louisiana DOTD should continue specifying HPC on all bridges where its use is beneficial and economical.

- When HPC is specified for a bridge, the Louisiana DOTD should consider conducting further research to investigate the early-age and long-term behavior of structural components. This objective could be accomplished by implementing instrumentation and testing programs similar to the one used for the Charenton Canal Bridge.
Fatigue & Shear Study (2000-2004)
Tulane University; CTLGroup; HGR, Inc.

- Provide assurance that 72-in. deep bulb-tee girders made with 10,000 psi compressive strength concrete will perform satisfactorily under fatigue and shear loading conditions.
- Determine if a higher allowable concrete tensile stress can be used in design.
- Investigate the use of welded-wire deformed shear reinforcement as an alternative to conventional bars.
Fatigue Endurance Tests
# Test Matrix - Fatigue

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Peak Extreme Fiber Tensile Stress, psi</th>
<th>Stress Range</th>
<th>Bottom Flange Status</th>
<th>Loading Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT6</td>
<td>$6.0 \sqrt{f'_c}$</td>
<td>HS-20</td>
<td>Pre-cracked</td>
<td>2.0 Hz</td>
</tr>
<tr>
<td>BT7</td>
<td>$8.6 \sqrt{f'_c}$</td>
<td>HL-93</td>
<td>Pre-cracked</td>
<td>1.9 Hz</td>
</tr>
<tr>
<td>BT8</td>
<td>$7.5 \sqrt{f'_c}$</td>
<td>HL-93</td>
<td>Pre-cracked</td>
<td>1.9 Hz</td>
</tr>
<tr>
<td>BT11</td>
<td>$6.0 \sqrt{f'_c}$</td>
<td>HL-93</td>
<td>Uncracked</td>
<td>1.0 Hz</td>
</tr>
<tr>
<td>BT12</td>
<td>$7.5 \sqrt{f'_c}$</td>
<td>HL-93</td>
<td>Uncracked</td>
<td>1.0 Hz</td>
</tr>
</tbody>
</table>
# Fatigue Test Results

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Bottom Flange Status</th>
<th>Calculated Extreme Fiber Stress, psi *</th>
<th>Measured Steel Stress Range, ksi</th>
<th>Fatigue Cycles Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT6</td>
<td>Pre-cracked</td>
<td>610, 1,247</td>
<td>9.1</td>
<td>5,000,000</td>
</tr>
<tr>
<td>BT7</td>
<td>Pre-cracked</td>
<td>857, 1,269</td>
<td>11.8</td>
<td>1,910,000</td>
</tr>
<tr>
<td>BT8</td>
<td>Pre-cracked</td>
<td>750, 1,276</td>
<td>9.6</td>
<td>2,500,000</td>
</tr>
<tr>
<td>BT11</td>
<td>Uncracked</td>
<td>600, 1,273</td>
<td>6.2</td>
<td>5,000,000</td>
</tr>
<tr>
<td>BT12</td>
<td>Uncracked</td>
<td>750, 1,285</td>
<td>5.8</td>
<td>5,000,000</td>
</tr>
</tbody>
</table>

* Parameters calculated based on uncracked section properties.
Post-Fatigue Flexural Strength
Shear Strength Tests
### Test Matrix - Shear

<table>
<thead>
<tr>
<th>Specimen</th>
<th>AASHTO Design</th>
<th>Deck Slab</th>
<th>Girder End</th>
<th>Test Region Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT6</td>
<td>Standard</td>
<td>GGBFS</td>
<td>R</td>
<td>No. 4 @ 10 in.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(50%)</td>
<td>L</td>
<td>D20 @ 12 in.</td>
</tr>
<tr>
<td>BT7</td>
<td>LRFD</td>
<td>Silica Fume</td>
<td>R</td>
<td>No. 4 @ 6.5 in.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5%)</td>
<td>L</td>
<td>No. 4 @ 15 in.</td>
</tr>
<tr>
<td>BT8</td>
<td>LRFD</td>
<td>Fly Ash</td>
<td>R</td>
<td>D20 @ 8 in.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(20%)</td>
<td>L</td>
<td>D20 @ 12 in.</td>
</tr>
</tbody>
</table>
Shear Strength Test Results

Applied Shear, kips

Test Specimen End
High-strength concrete girders incorporating mid-span flexural cracks can be expected to perform adequately under fatigue loading conditions when extreme fiber tensile stress is limited to the current allowable level.

Fatigue test results indicate that higher allowable tensile stresses for HPC can be used if the concrete remains uncracked. However, the potential for unanticipated cracking makes utilizing reserve strength a risky proposition.
Fatigue & Shear Study - Conclusions

- Measured shear strengths for high-strength concrete girders exceeded the corresponding calculated strengths determined using current design provisions from either the AASHTO Standard Specifications or AASHTO LRFD Specifications.

- The existing 60 ksi limit for the design yield strength of transverse reinforcement is conservative, and higher yield strength values can be conservatively utilized for deformed welded wire reinforcement.
Fatigue & Shear Study - Recommendations

- The allowable concrete tensile stress used in flexural design of HPC girders should be limited to $6 \sqrt{f'c}$.

- The Louisiana DOTD may implement the use of 72-in. deep HPC bulb-tee girders designed in accordance with current AASHTO provisions with the knowledge that girder performance will be satisfactory.

- Deformed welded wire reinforcement with a design yield strength of 75 ksi may be used as an alternative to conventional deformed bars.

- 62-Span Bridge
- Total Length = 5,489 ft
- HPC Incorporated in Two 131-ft Long Spans
- HPC Spans Incorporate Four BT-78 Girders
Overall Research Objective

Monitor the structural behavior of one of the two HPC spans in the Rigolets Pass Bridge for the purpose of obtaining additional data for the State’s growing HPC data base that will be useful in the development of specifications and designs for future HPC bridge structures.
Project Team

- Tulane University
- CTLGroup
- Henry G. Russell, Inc.
Rigolets Pass Bridge – Research Plan

- Measure prestress force levels in selected strands during fabrication of girders for Span 43.
- Monitor early-age and long-term concrete strains in girders and bridge deck slab incorporated in Span 43.
- Monitor early-age and long-term mid-span deflections for girders incorporated in Span 43.
- Perform material property testing program for Span 43.
- Install on-site automated data acquisition system with remote access capability and web-site presentation.
Instrumented Bridge Span (Span No. 43)

Barrier railing

8-in. thick deck slab

Girder A

Girder B

Girder C

Girder D

BT-78 girder (typ.)

RC diaphragm @ span 113 points (typ.)

← N
Design Information

- Structural design per AASHTO Standard Specifications (Sixteenth Edition).
- Design live load based on greater of MS-18 or HST-18(M).
- Specified girder concrete compressive strength of 6,670 psi at release and 10,000 psi at 56 days.
- Specified deck slab concrete compressive strength of 4,200 psi at 28 days.
Girder Fabrication Information

- Girders fabricated by Gulf Coast PreStress, Pass Christian, Mississippi.
- Each BT-78 HPC girder incorporated fifty-six 0.6-in. diameter, Grade 270, low-relaxation strands in lower flange.
- Each strand in lower flange stressed to initial force of 43.95 kips (75% of specified minimum breaking strength).
GIRDER INSTRUMENTATION & FABRICATION
Strand Load Cells

DEAD END VIEW
Vibrating Wire Strain Gages

DEAD END VIEW
Material Sampling
Camber Instrumentation
SPAN NO. 43
CONSTRUCTION
Deck Slab VWSGs
Camber/Deflection Reference
Deck Concrete Placement
PRELIMINARY RESEARCH RESULTS
## Girder Concrete Mix Design

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity per yd³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement (Type III)</td>
<td>846 lb</td>
</tr>
<tr>
<td>Silica Fume</td>
<td>100 lb</td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>1,149 lb</td>
</tr>
<tr>
<td>Course Aggregate - Limestone</td>
<td>1,866 lb</td>
</tr>
<tr>
<td>Water</td>
<td>204 lb</td>
</tr>
<tr>
<td>Water Reducer (ASTM C494, Type D)</td>
<td>38 oz</td>
</tr>
<tr>
<td>High-Range Water Reducer (ASTM C494, Type F)</td>
<td>51 oz</td>
</tr>
<tr>
<td>Air Entrainment</td>
<td>None</td>
</tr>
<tr>
<td>Water/Cementitious Ratio</td>
<td>0.22</td>
</tr>
</tbody>
</table>
Girder Concrete Compressive Strength

Concrete Compressive Strength, psi

Concrete Age, days
MOE vs Compressive Strength

Concrete Modulus of Elasticity, ksi

Compressive Strength, psi

- AASHTO Expression
- Piles P1, P2, P3
- Girders BT1, BT2, BT3, BT5
- Charenton - Match
- Charenton - Field
- BT6, BT7, BT8
- BT11, BT12
- Girders 43A, 43B, 43C, 43D
MOR vs Compressive Strength

Concrete Compressive Strength, psi

Concrete Modulus of Rupture, psi

$f_r = 10 \sqrt{f'_c}$

$f_r = 7.5 \sqrt{f'_c}$

- Piles P1, P2, P3
- Girders BT1, BT2, BT3, BT5
- Charenton
- BT6, BT7, BT8
- Girders BT11, BT12
- Girders 43A, 43B, 43C, 43D

Concrete Compressive Strength, psi
Creep Coefficient

Age of Loading = 4 Days
Age of Loading = 100 days
Shrinkage

Concrete Age, days

Concrete Shrinkage, με

Age of Loading = 4 Days
Age of Loading = 100 days
# Prestress Force Measurement

<table>
<thead>
<tr>
<th>Girder Production Run</th>
<th>Average Force After Stressing All Strands</th>
<th>Average Force Prior to Release of Prestress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kips</td>
<td>% Reduction</td>
</tr>
<tr>
<td>43 A and 43B</td>
<td>42.01</td>
<td>4.4</td>
</tr>
<tr>
<td>43C and 43D</td>
<td>41.80</td>
<td>4.9</td>
</tr>
<tr>
<td>Average</td>
<td>41.90</td>
<td>4.7</td>
</tr>
<tr>
<td>Specified</td>
<td>43.95</td>
<td>&lt;5.0</td>
</tr>
</tbody>
</table>
Measured Girder Concrete Strains

Concrete Strain, $\mu\varepsilon$

Time Since Release, days

Girder 43A-BF and TF
Girder 43B-BF and TF
Girder 43C-BF and TF
Girder 43D-BF and TF
Measured Prestress Loss

Prestress Loss, psi

Time Since Release, days

- Girder 43A
- Girder 43B
- Girder 43C
- Girder 43D
# Prestress Losses

<table>
<thead>
<tr>
<th>Prestress Loss Component</th>
<th>Measured Loss, psi</th>
<th>Design Loss, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic - ES</td>
<td>19,563</td>
<td>20,545</td>
</tr>
<tr>
<td>Relaxation - CR&lt;sub&gt;s&lt;/sub&gt;</td>
<td>-</td>
<td>908</td>
</tr>
<tr>
<td>Creep - CR&lt;sub&gt;c&lt;/sub&gt;</td>
<td>6,720</td>
<td>34,993</td>
</tr>
<tr>
<td>Shrinkage - SH</td>
<td>5,750</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>26,283</strong></td>
<td><strong>62,197</strong></td>
</tr>
</tbody>
</table>
Measured Midspan Camber

Time After Strand Release, days

Midspan Camber, in.

Girder 43A
Girder 43B
Girder 43C
Girder 43D
## Girder Camber

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>After Release (0.01)</td>
<td>2.25</td>
<td>3.15</td>
</tr>
<tr>
<td>Before Shipping (110-118)</td>
<td>3.54</td>
<td>3.49</td>
</tr>
<tr>
<td>After Casting Deck (177-185)</td>
<td>1.86</td>
<td>1.93</td>
</tr>
<tr>
<td>6 Mo. After Deck Cast (364-372)</td>
<td>1.72</td>
<td>1.93</td>
</tr>
<tr>
<td>Final Reading (?)</td>
<td>?</td>
<td>-</td>
</tr>
</tbody>
</table>
Measured Deck Slab Strain

Compressive Strain @ Mid-Depth of Deck Slab, $\mu\varepsilon$

Time After Cast, days
On-Site DAS w/Remote Access
Web-Based Data Posting

INSTRUMENTATION AND MONITORING OF THE RIGOLETS PASS BRIDGE

HPC SPAN NO. 43 - CROSS SECTION THRU MIDSPAN – LOOKING EAST

SELECT SENSOR FROM ARRAY SHOWN BELOW
- Red: SLAB VWSC-51
- Blue: VWSC - 43A - 1.5
- Green: VWSC - 43A - 1.3
- Yellow: VWSC - 43B - 1.2
- Purple: VWSC - 43C - 1.3
- Black: VWSC - 43D - 1.3

- Vygov: VWSG-52
- Blue: VWSG - 43A - 1.5
- Green: VWSG - 43A - 1.3
- Yellow: VWSG - 43B - 1.2
- Purple: VWSG - 43C - 1.3
- Black: VWSG - 43D - 1.3

- Red: SLAB VWSC-53
- Blue: SLAB VWSC-53
- Green: SLAB VWSC-53
- Yellow: SLAB VWSC-53
- Purple: SLAB VWSC-53
- Black: SLAB VWSC-53

- Red: SLAB VWSC-56
- Blue: SLAB VWSC-56
- Green: SLAB VWSC-56
- Yellow: SLAB VWSC-56
- Purple: SLAB VWSC-56
- Black: SLAB VWSC-56

- Red: SLAB VWSC-57
- Blue: SLAB VWSC-57
- Green: SLAB VWSC-57
- Yellow: SLAB VWSC-57
- Purple: SLAB VWSC-57
- Black: SLAB VWSC-57

LADOTD Louisiana Department of Transportation and Development
LTRC Louisiana Transportation Research Center

CTLGroup
THANK YOU!