HIGH PERFORMANCE CONCRETE

by

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Early Louisiana HPC Research

- Law & Rasoulian (1980)
- Adelman & Cousins (1990)
- Bruce, Russell & Roller – (1990-1993)

Law & Rasoulian (1980)

- 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.

Bruce, Russell & Roller (1990-93)

- 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.

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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)

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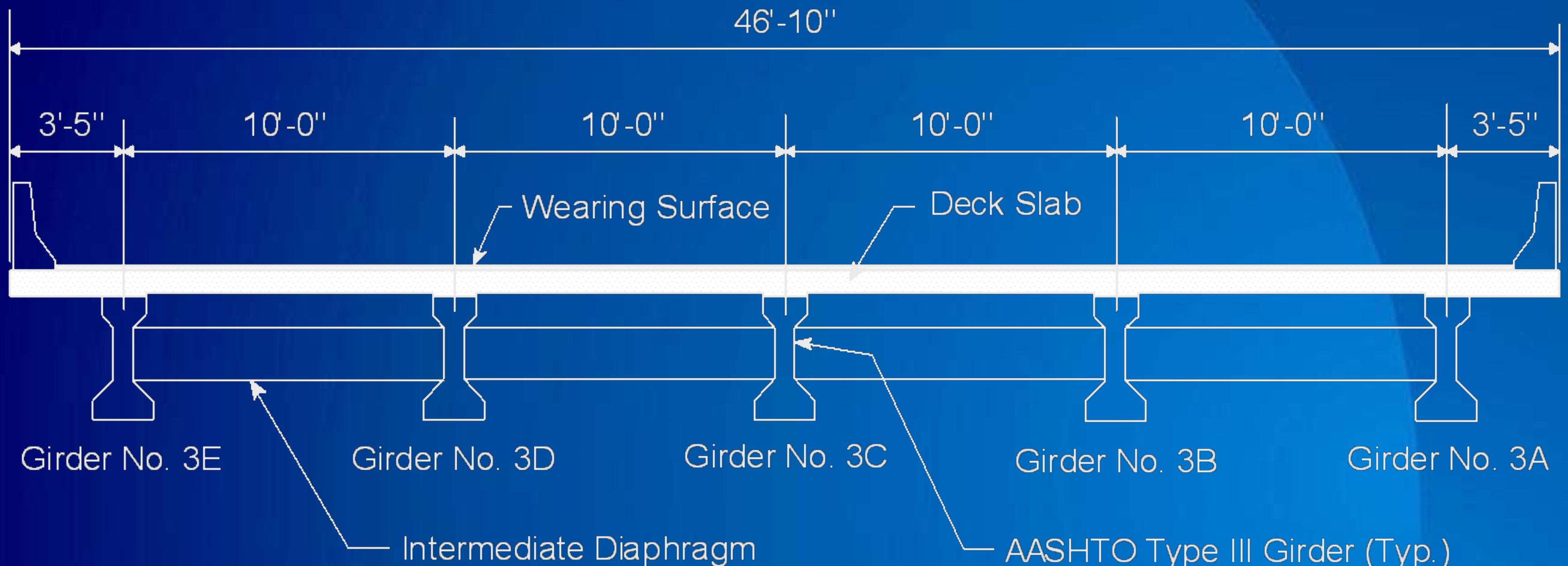
Charenton Canal Bridge - Section



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.

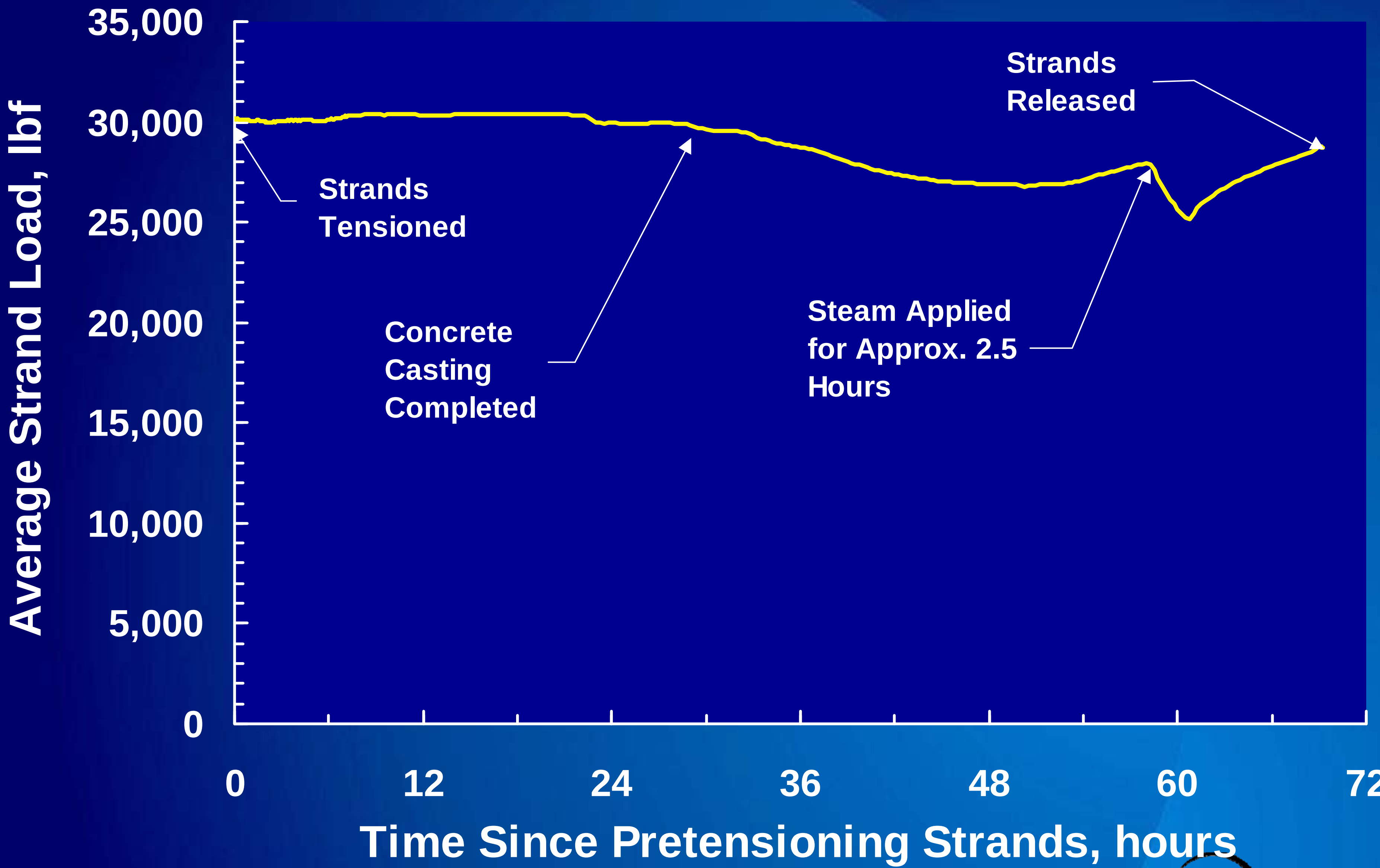
Charenton Canal Bridge - Conclusions

- 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.

Charenton Canal Bridge - Conclusions

- 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.

Measured Prestress Force



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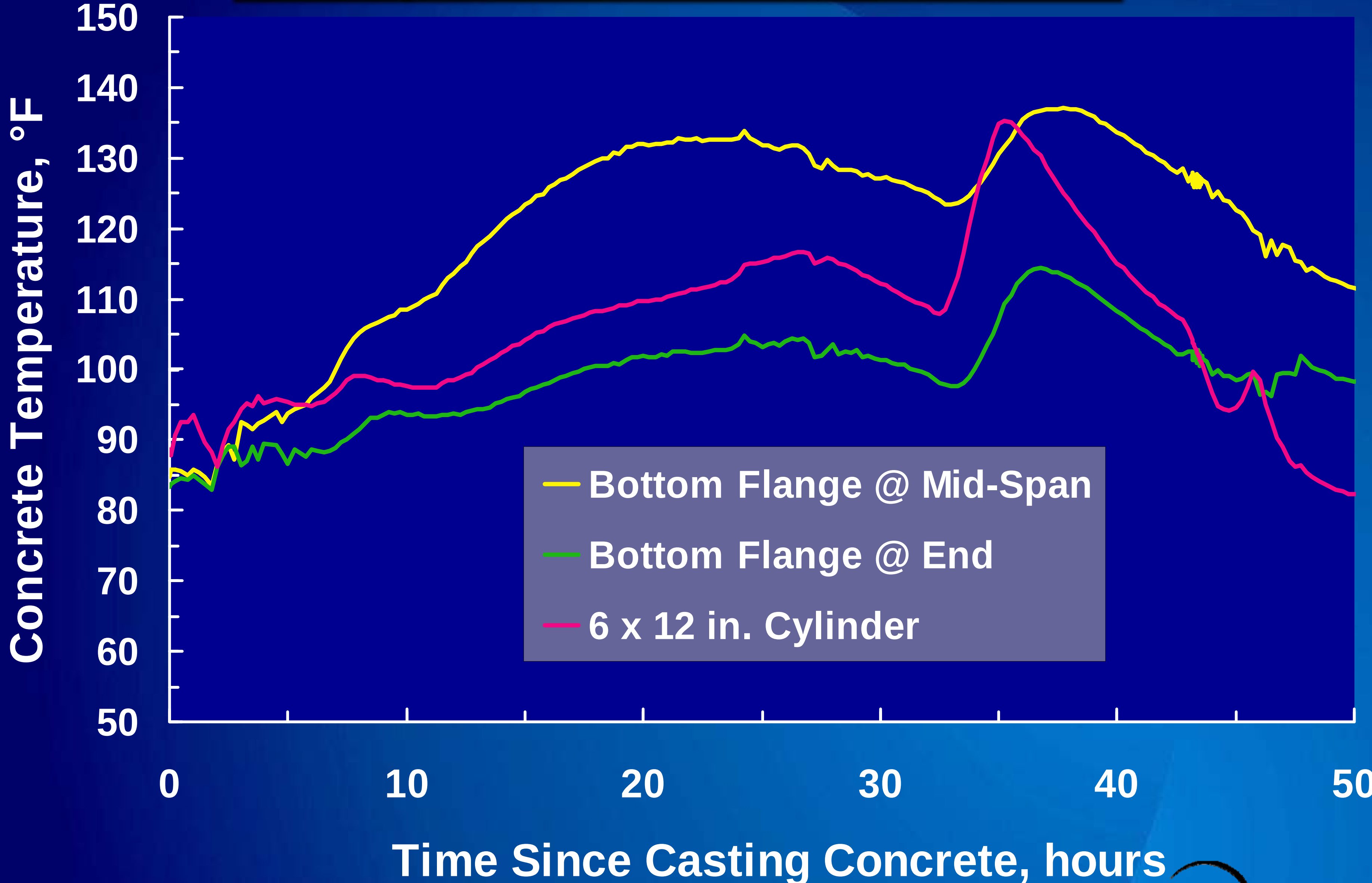
Temperature Variations



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Compressive Strength

Concrete Age, Days	Initial Curing Method	Concrete Compressive Strength, psi
28	Field	9,610
	Match	10,570
90	Field	10,670
	Match	11,950

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Prestress Losses

Prestress Loss Component	Measured Loss, psi	Design Loss, psi
Elastic - ES	14,336	16,234
Relaxation - CR_s	-	1,805
Creep - CR_c	18,589	25,686
Shrinkage - SH		5,750
Total	39,925	49,475

Girder Camber

Event (Time After Release, days)	Measured Camber, In.	Calculated Camber, In.
After Release (0.01)	1.00	1.41
Before Shipping (271)	2.40	2.51
After Casting Deck (303)	1.61	1.64
Final Reading (631)	1.58	0.87

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

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Test Matrix - Fatigue

Specimen	Peak Extreme Fiber Tensile Stress, psi	Stress Range	Bottom Flange Status	Loading Frequency
BT6	$6.0\sqrt{f'_c}$	HS-20	Pre-cracked	2.0 Hz
BT7	$8.6\sqrt{f'_c}$	HL-93	Pre-cracked	1.9 Hz
BT8	$7.5\sqrt{f'_c}$	HL-93	Pre-cracked	1.9 Hz
BT11	$6.0\sqrt{f'_c}$	HL-93	Uncracked	1.0 Hz
BT12	$7.5\sqrt{f'_c}$	HL-93	Uncracked	1.0 Hz

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Fatigue Test Results

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

* Parameters calculated based on uncracked section properties.

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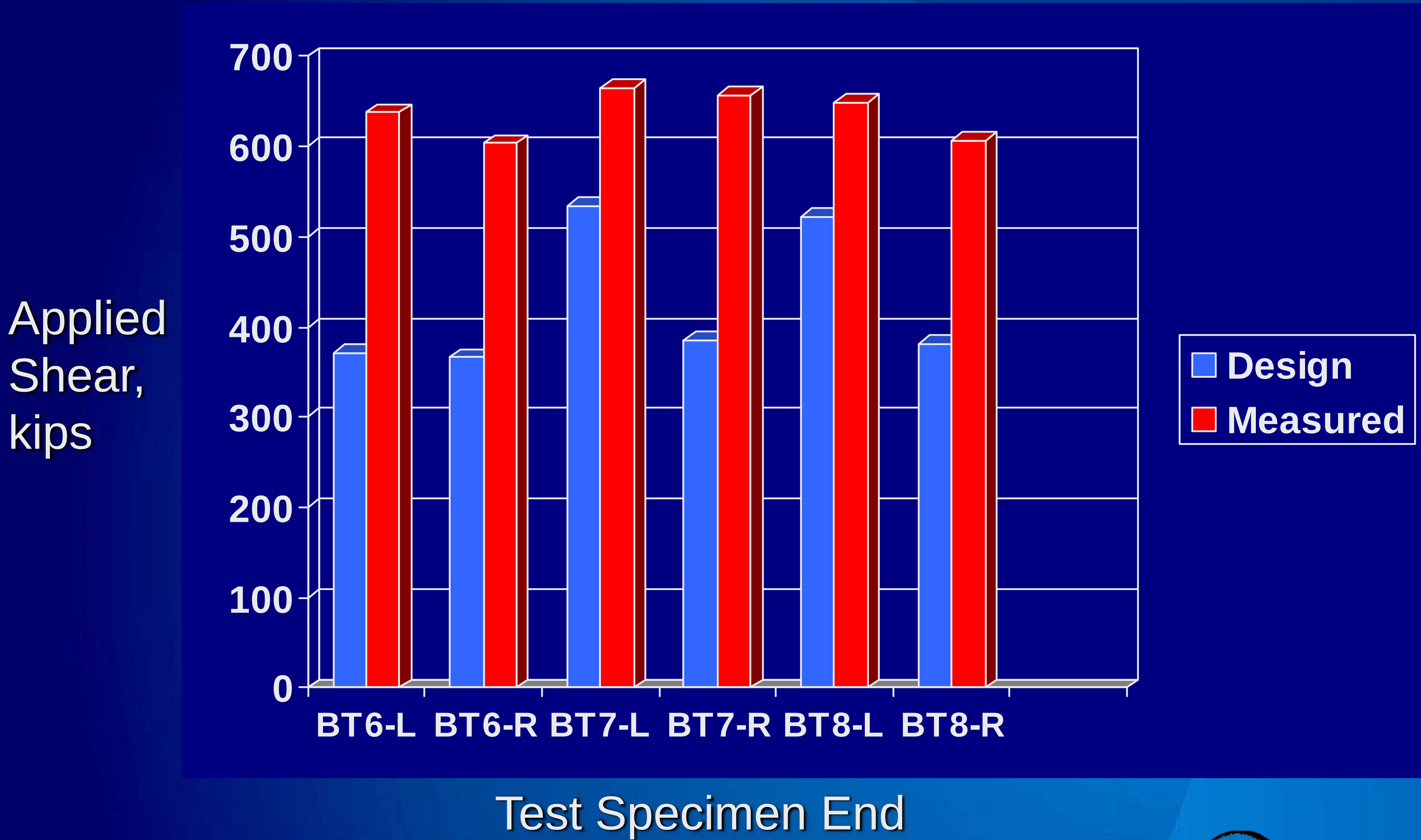
Post-Fatigue Flexural Strength

Shear Strength Tests

Test Matrix - Shear

Specimen	AASHTO Design	Deck Slab	Girder End	Test Region Reinforcement
BT6	Standard	GGBFS (50%)	R	No. 4 @ 10 in.
			L	D20 @ 12 in.
BT7	LRFD	Silica Fume (5%)	R	No. 4 @ 6.5 in.
			L	No. 4 @ 15 in.
BT8	LRFD	Fly Ash (20%)	R	D20 @ 8 in.
			L	D20 @ 12 in.

Shear Strength Test Results



Fatigue & Shear Study - Conclusions

- 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.

Implementation Project – US 90 Rigolets Pass Bridge (2007)

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

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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.

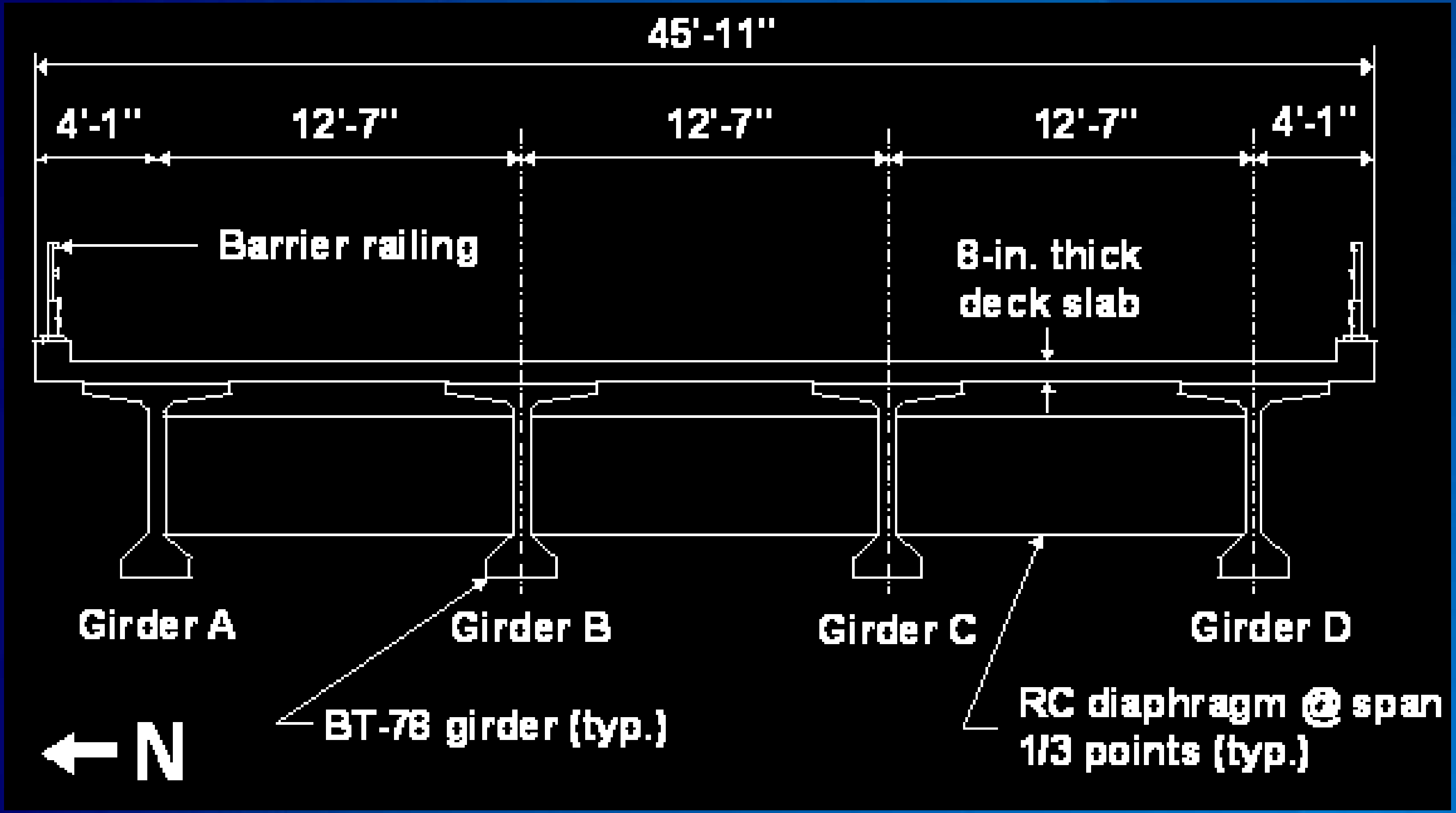
Project Team

- 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)



Design Information

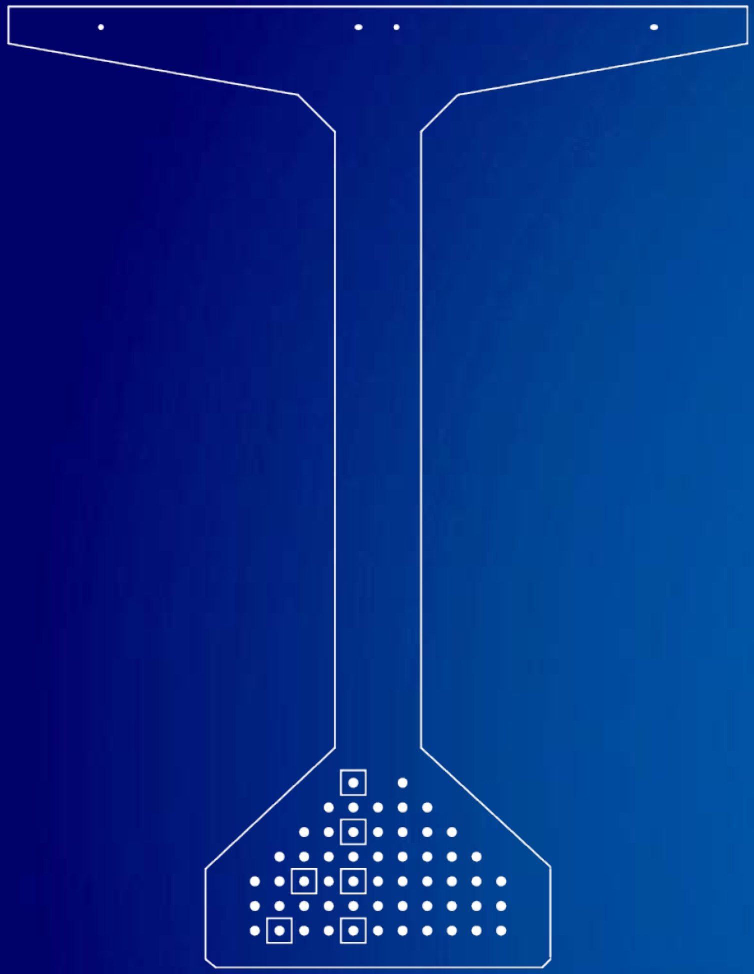
- Structural design per AASHTO Standard Specifications (Sixteenth Edition).
- Design live load based on greater of MS-18 or HST-18(M).
- Specified girder concrete compressive strength of 6,670 psi at release and 10,000 psi at 56 days.
- Specified deck slab concrete compressive strength of 4,200 psi at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

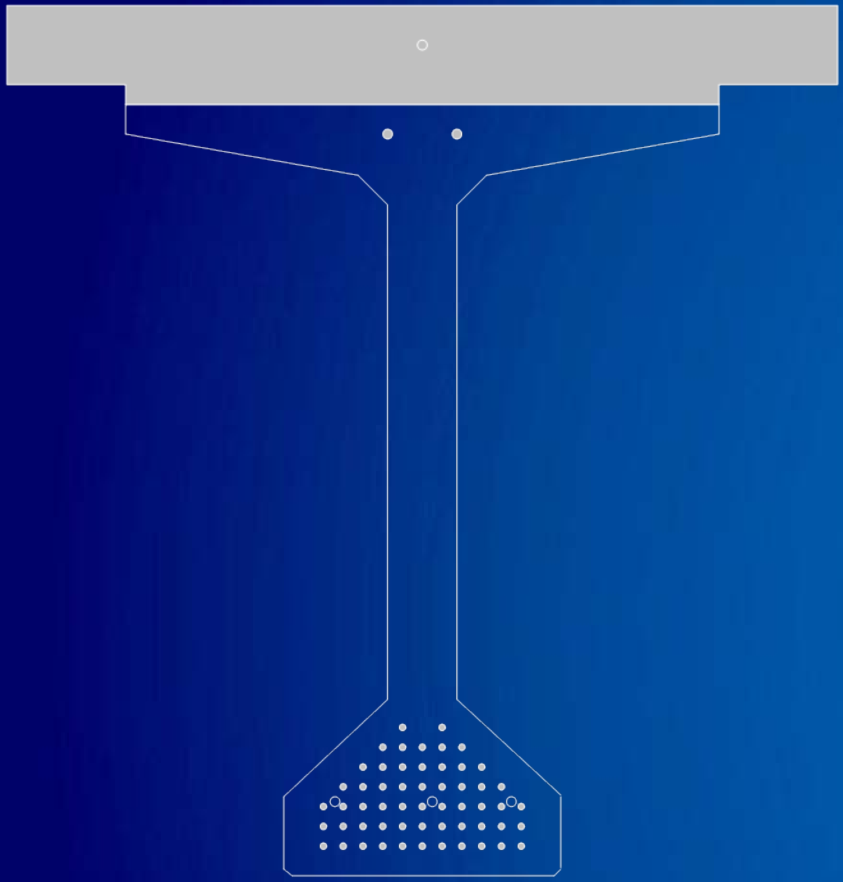
GIRDER INSTRUMENTATION & FABRICATION

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

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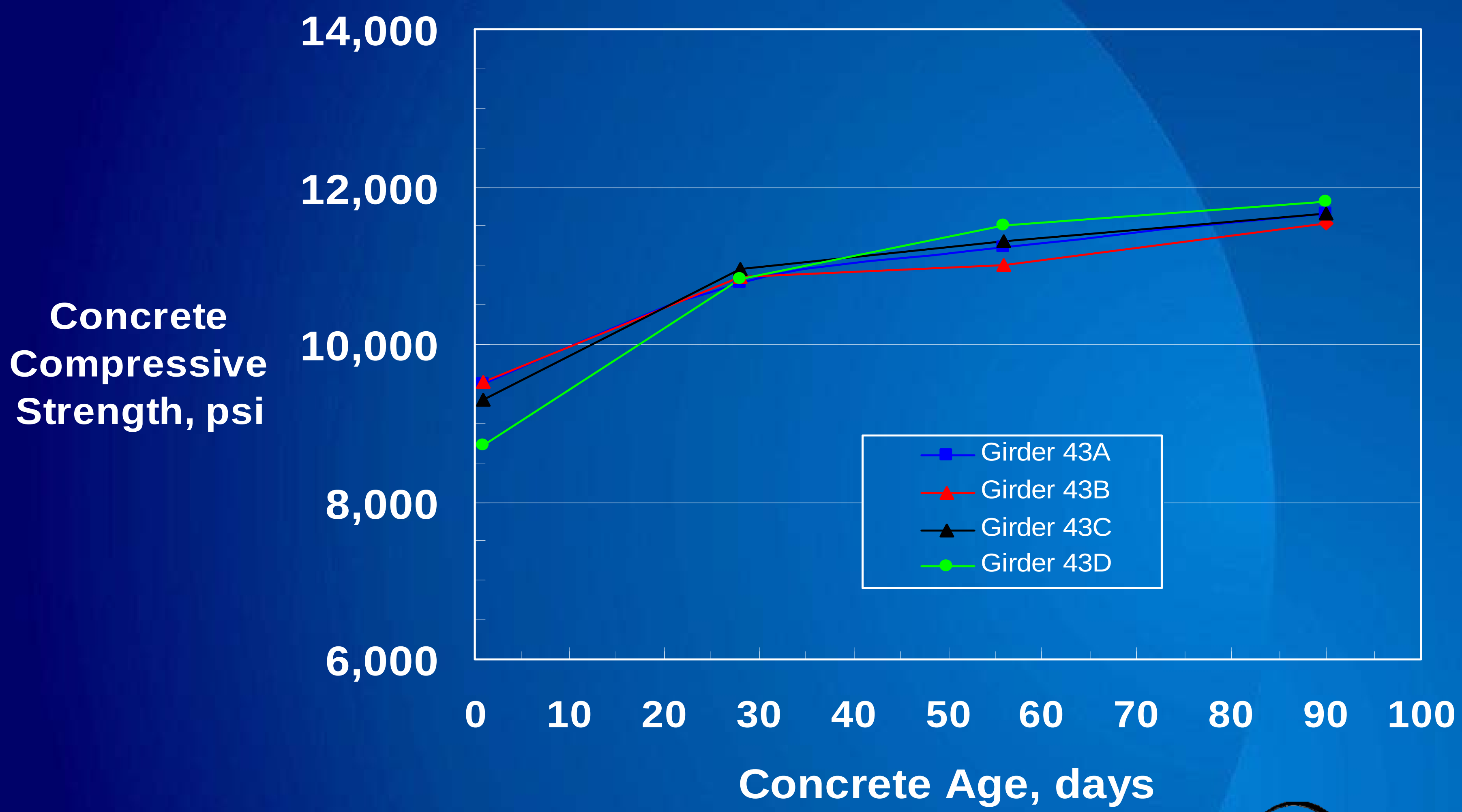
Deck Concrete Placement

PRELIMINARY RESEARCH RESULTS

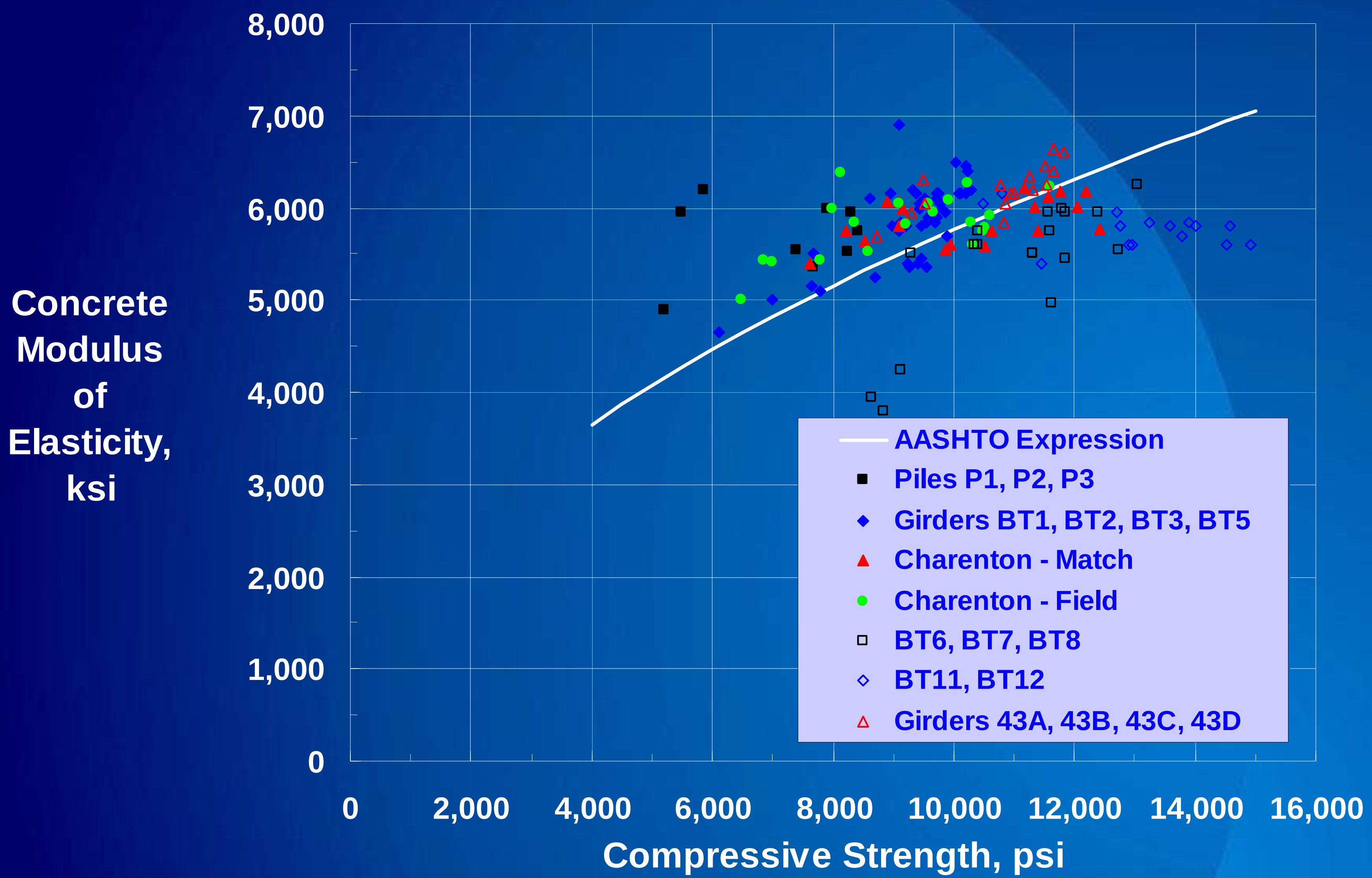
Girder Concrete Mix Design

Material	Quantity per yd^3
Portland Cement (Type III)	846 lb
Silica Fume	100 lb
Fine Aggregate	1,149 lb
Course Aggregate - Limestone	1,866 lb
Water	204 lb
Water Reducer (ASTM C494, Type D)	38 oz
High-Range Water Reducer (ASTM C494, Type F)	51 oz
Air Entrainment	None
Water/Cementitious Ratio	0.22

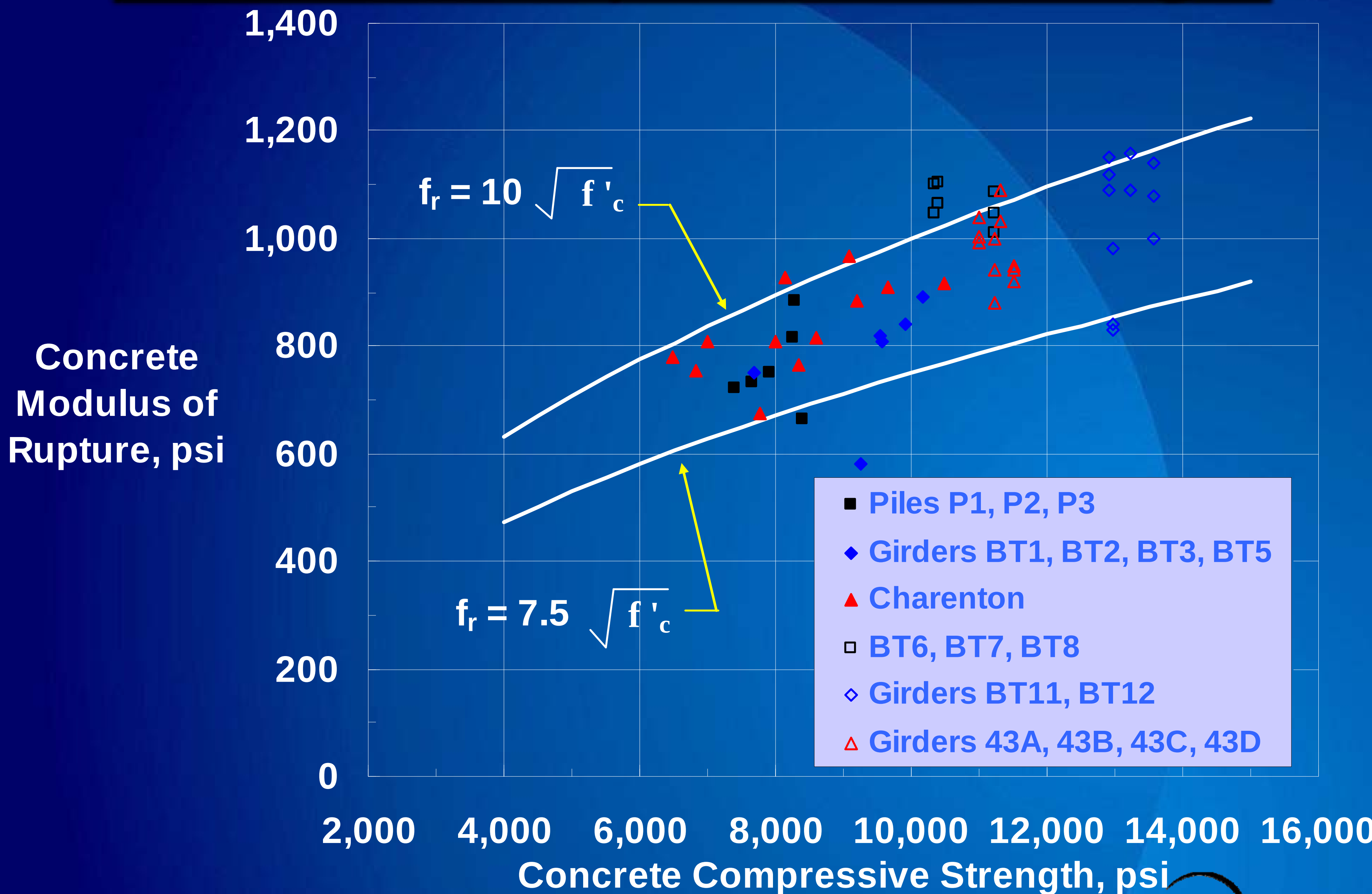
Girder Concrete Compressive Strength



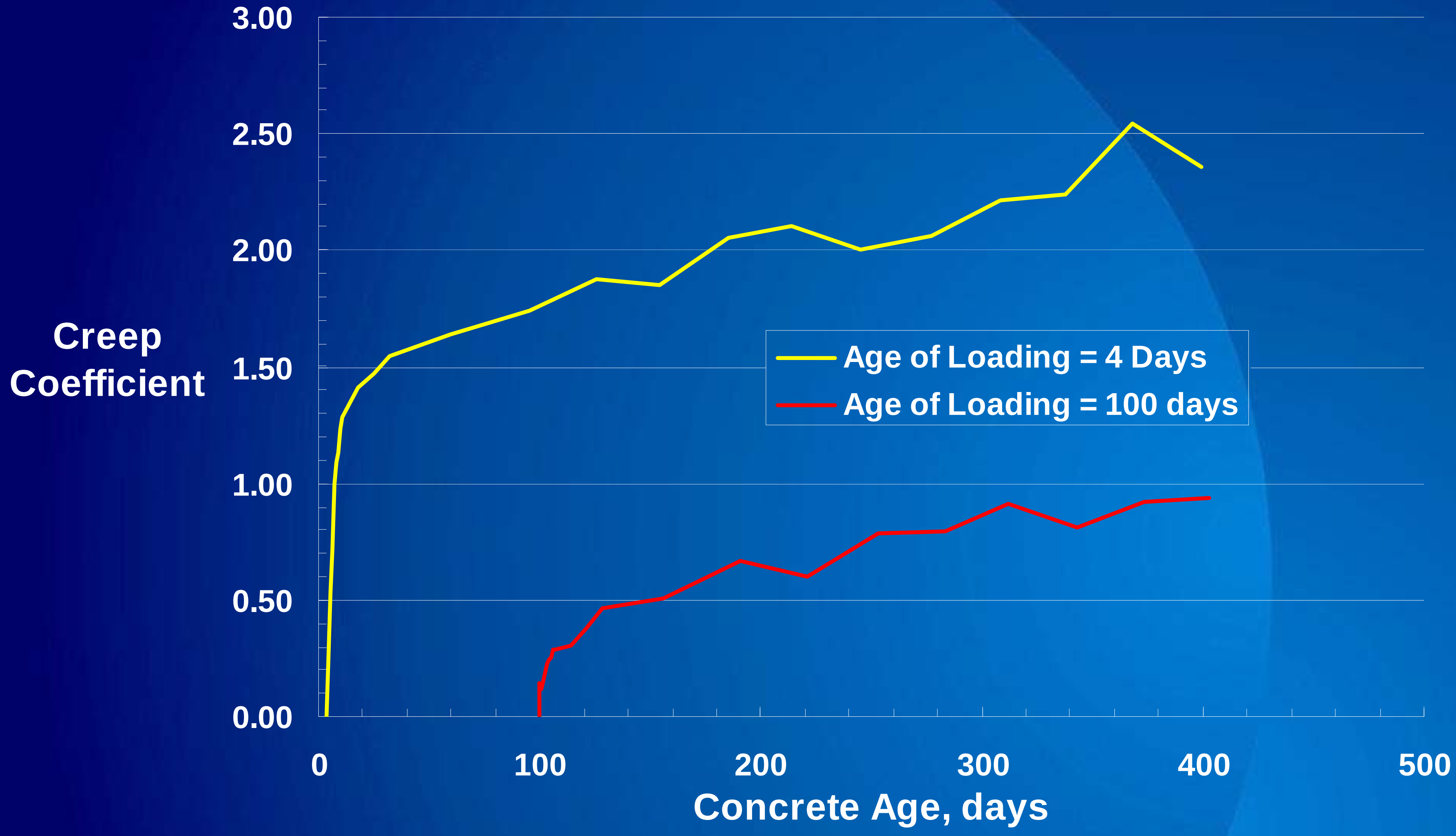
MOE vs Compressive Strength



MOR vs Compressive Strength



Creep Coefficient



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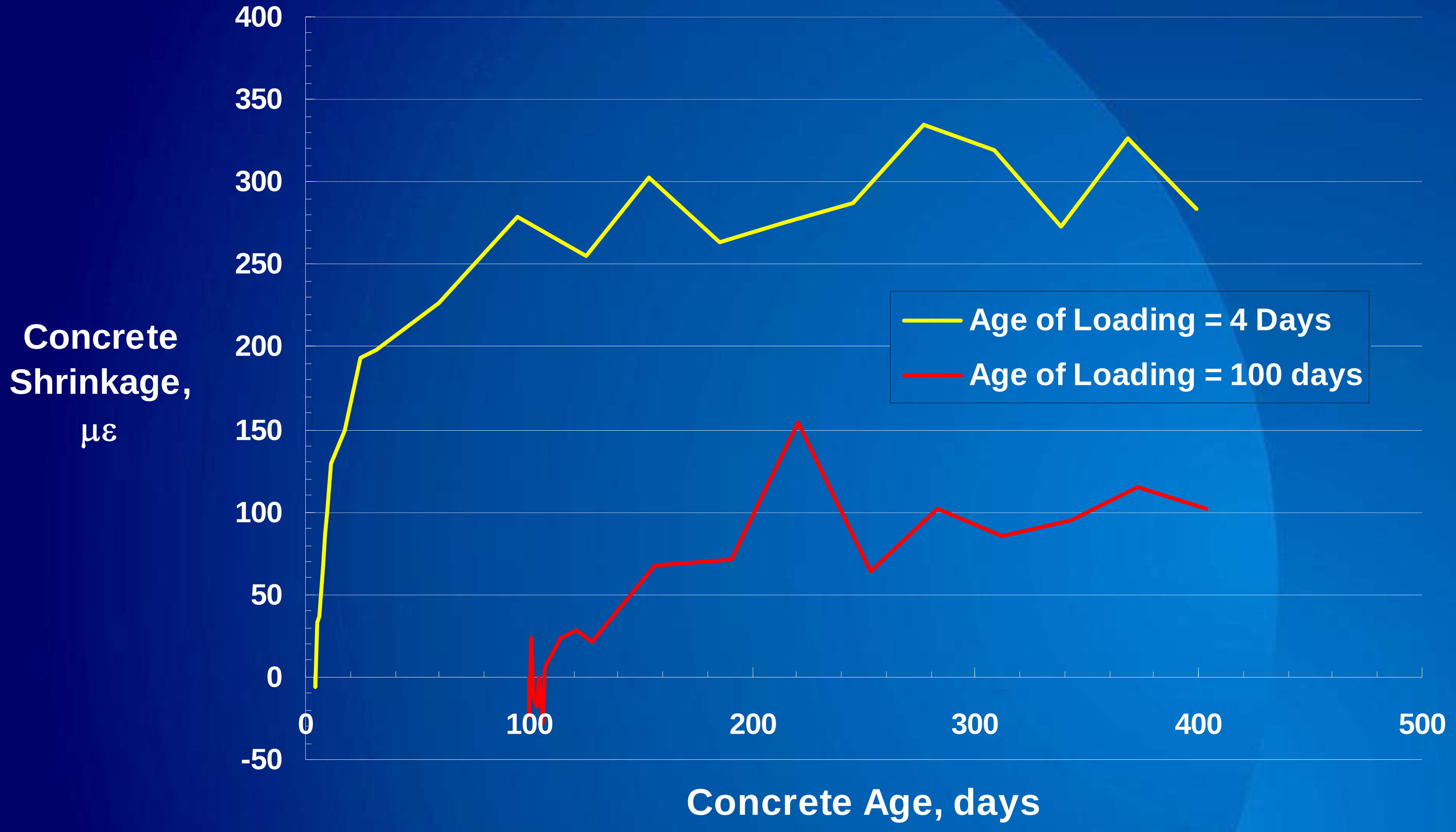
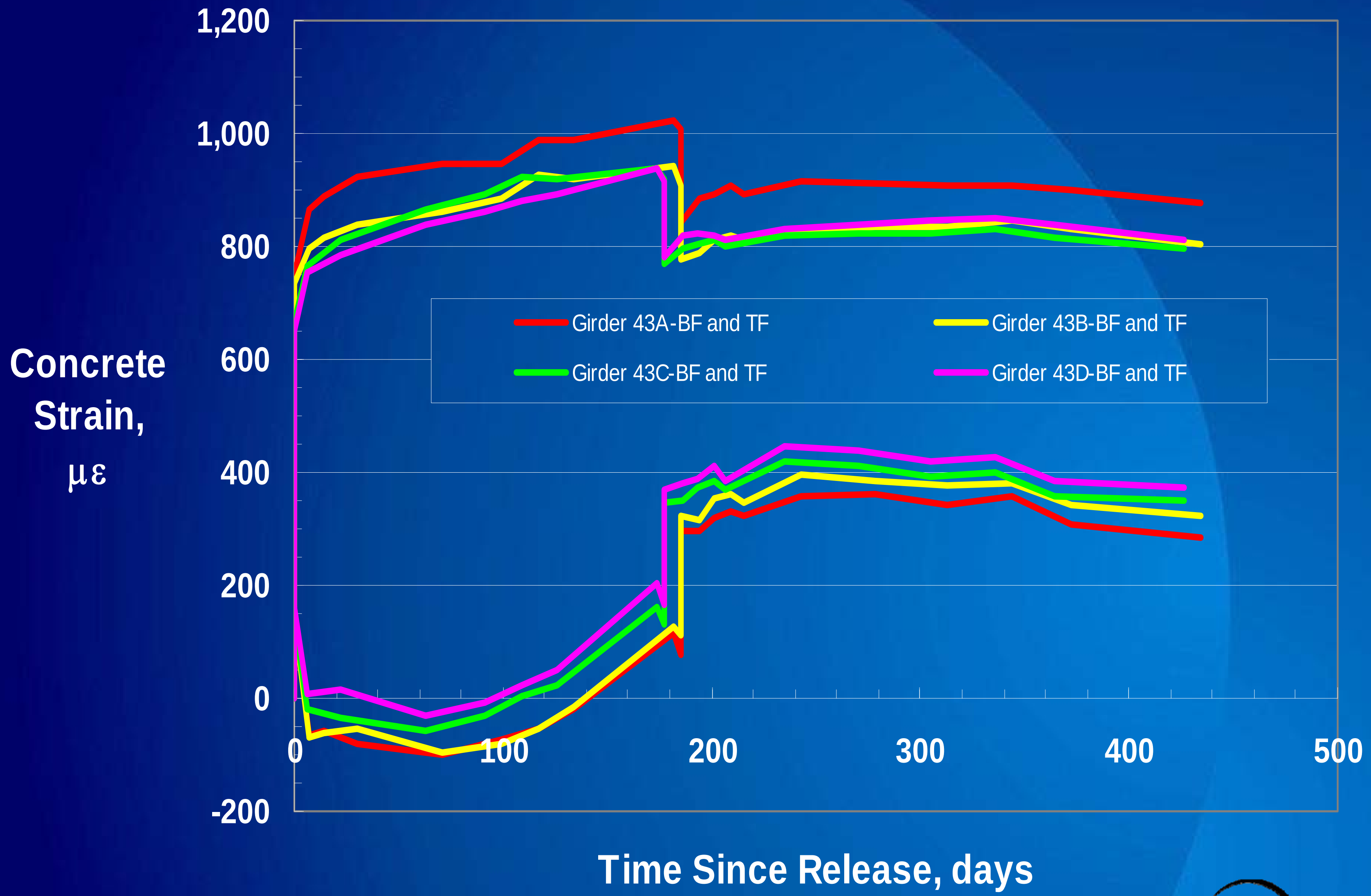
Shrinkage


400
350
300
250
200
150
100
50
0
-50
0
100
200
300
400
500
Concrete Shrinkage, με
Concrete Age, days
Age of Loading = 4 Days
Age of Loading = 100 days

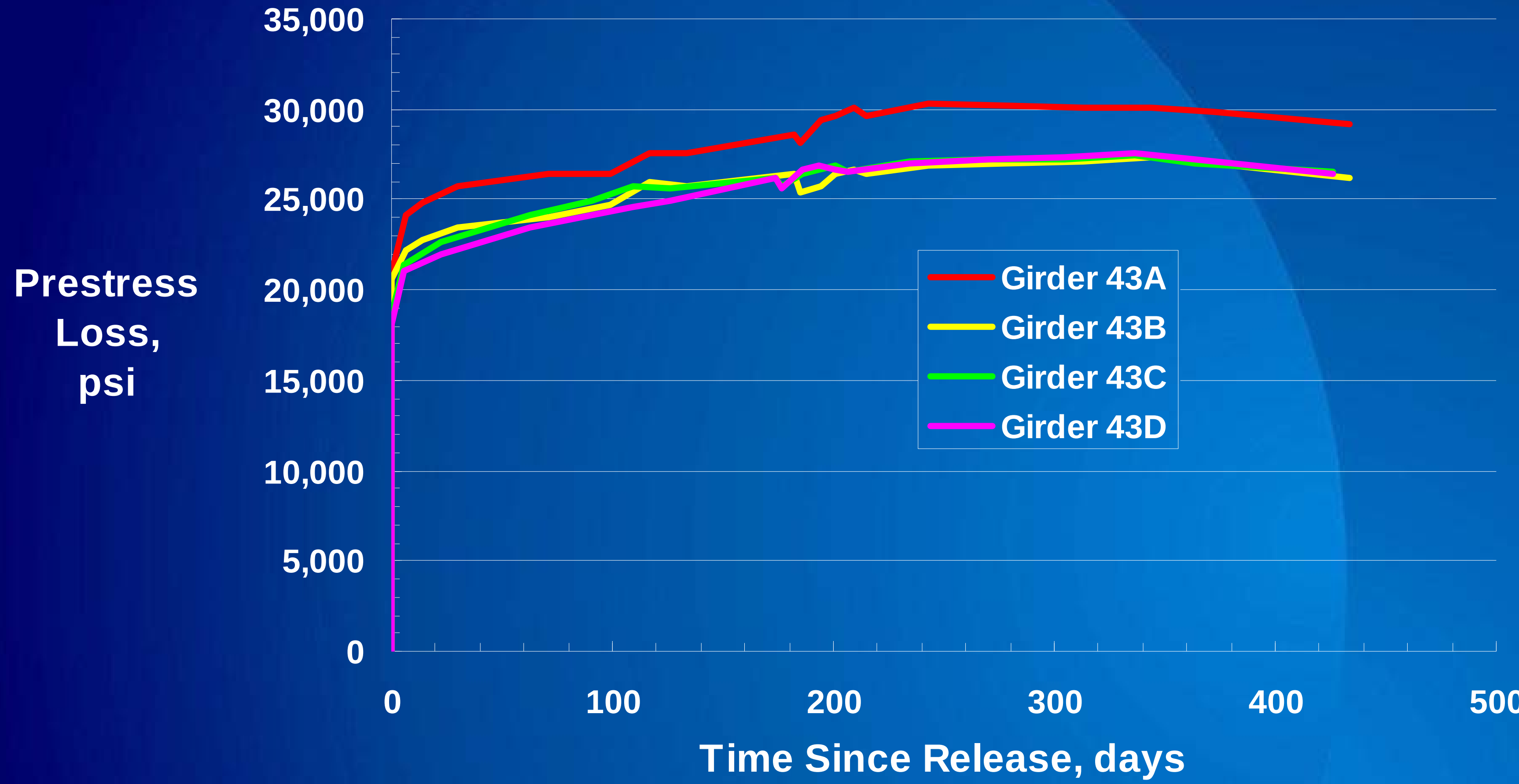
Prestress Force Measurement

Girder Production Run	Average Force After Stressing All Strands		Average Force Prior to Release of Prestress	
	Kips	% Reduction	Kips	% Reduction
43 A and 43B	42.01	4.4	40.94	6.8
43C and 43D	41.80	4.9	40.04	8.9
Average	41.90	4.7	40.49	7.9
Specified	43.95	<5.0	-	-

Measured Girder Concrete Strains



Measured Prestress Loss



Prestress Losses

Prestress Loss Component	Measured Loss, psi	Design Loss, psi
Elastic - ES	19,563	20,545
Relaxation - CR_s	-	908
Creep - CR_c	6,720	34,993
Shrinkage - SH		5,750
Total	26,283	62,197

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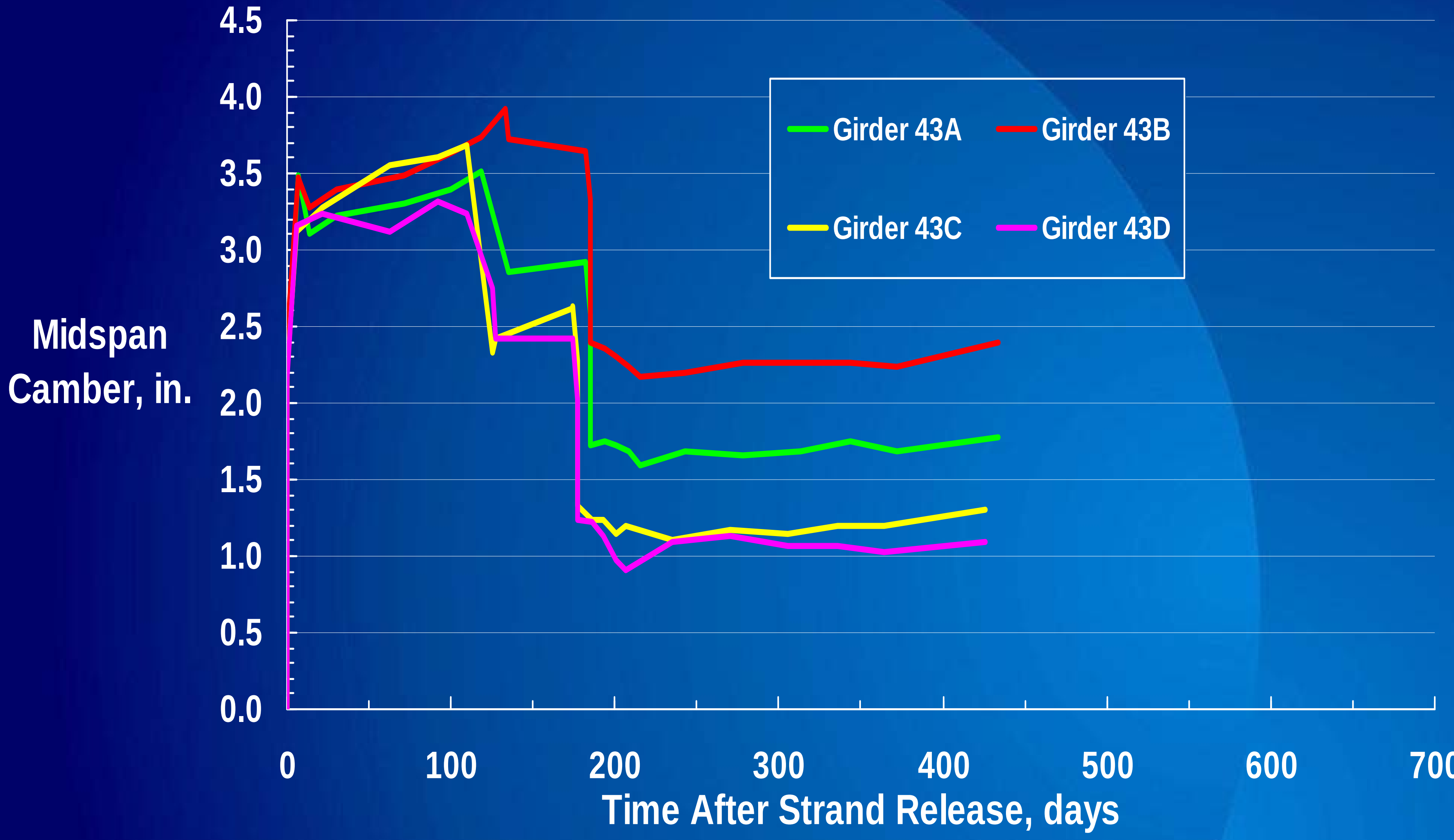
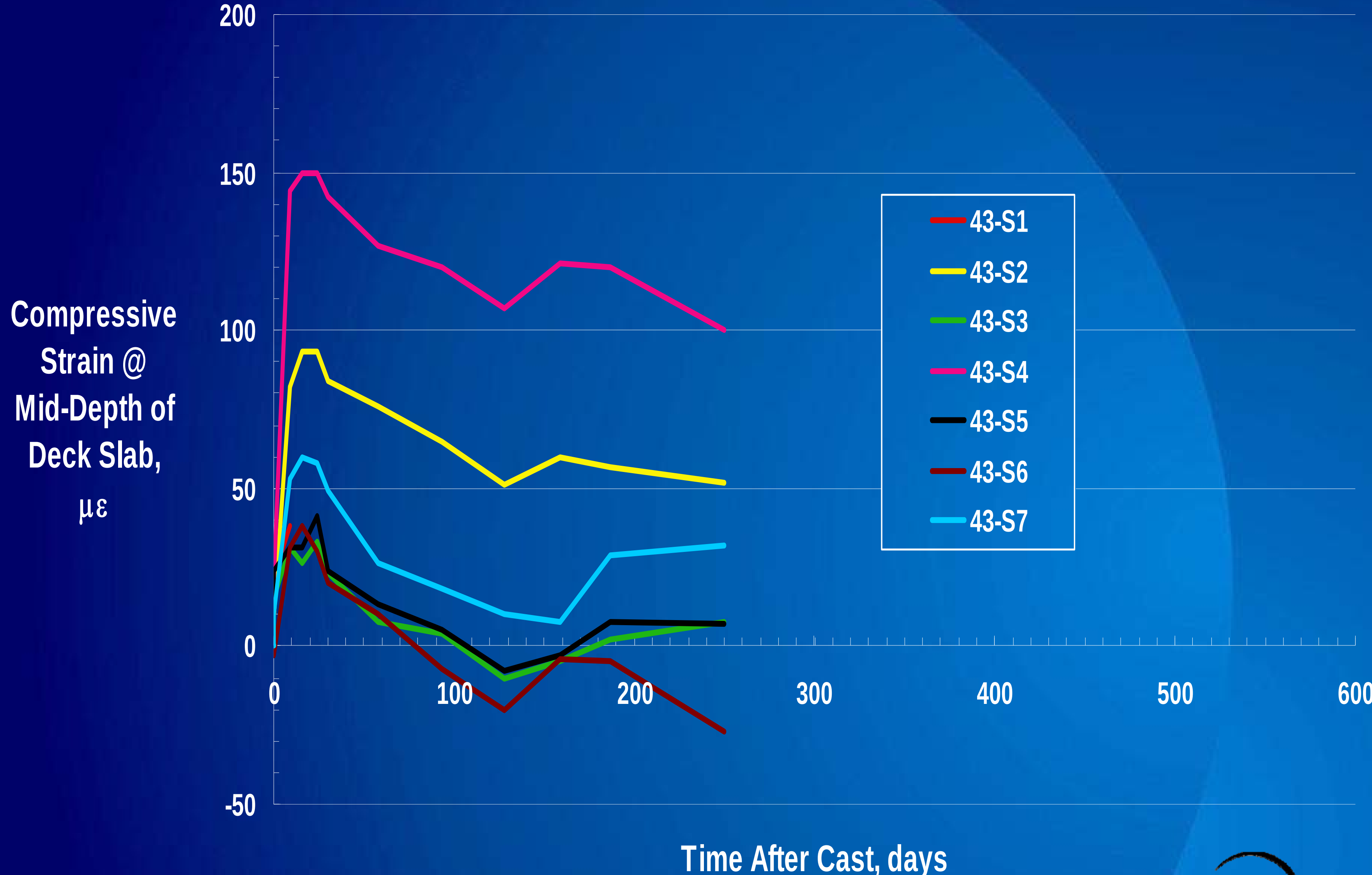
Measured Midspan Camber



Girder Camber

Event (Time After Release, days)	Measured Camber, In.	Calculated Camber, In.
After Release (0.01)	2.25	3.15
Before Shipping (110-118)	3.54	3.49
After Casting Deck (177-185)	1.86	1.93
6 Mo. After Deck Cast (364-372)	1.72	1.93
Final Reading (?)	?	-

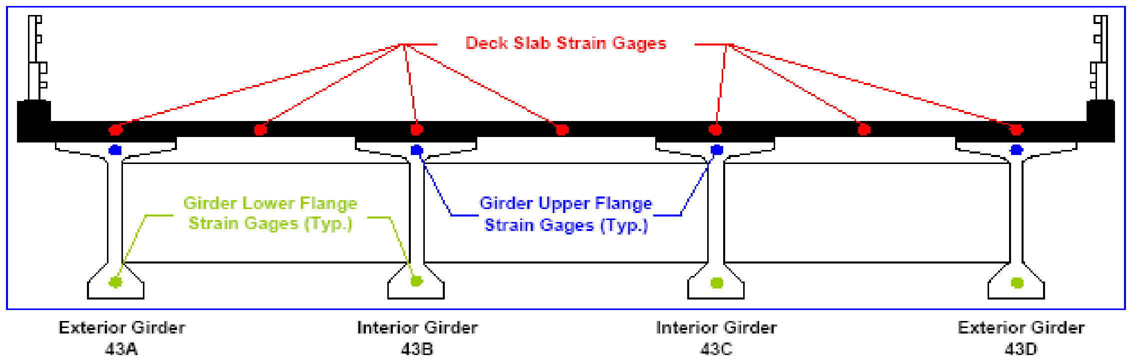
Measured Deck Slab Strain



On-Site DAS w/Remote Access

Web-Based Data Posting

INSTRUMENTATION AND MONITORING OF THE RIGOLETS PASS BRIDGE



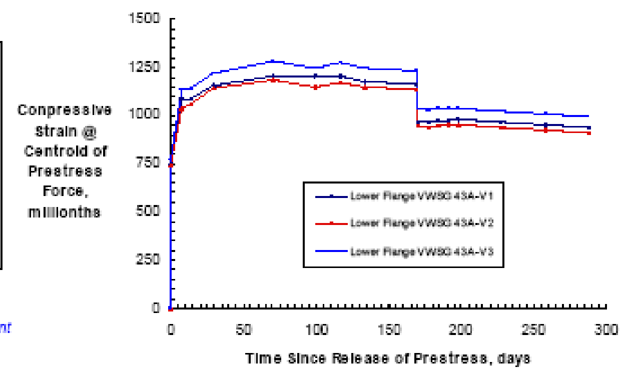
HPC SPAN NO. 43 - CROSS SECTION THRU MIDSPAN – LOOKING EAST

SELECT SENSOR FROM ARRAY SHOWN BELOW

- SLAB VWSG-S1
- SLAB VWSG-S2
- SLAB VWSG-S3
- SLAB VWSG-S4
- SLAB VWSG-S5
- SLAB VWSG-S6
- SLAB VWSG-S7
- VWSG – 43A – 4,5
- VWSG – 43B – 4,5
- VWSG – 43C – 4,5
- VWSG – 43D – 4,5
- VWSG – 43A – 1,2,3
- VWSG – 43B – 1,2,3
- VWSG – 43C – 1,2,3
- VWSG – 43D – 1,2,3

☒ Plot concrete strain versus time history

☐ Plot temperature versus time history



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THANK YOU!