Recent Experience with MTI/MoDOT Collaborative Structures Research Program

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Missouri University of Science and Technology
March 10, 2011

Outline of My Presentation

- Introduction to the Collaborative Program
- Main Accomplishments and Deliverables
- Program Benefits to MoDOT
- Brief Assessment on the Program
- What is Next?

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Program Goal and Objectives

The goal of the Structures Program is to address MoDOT's critical needs and increase the University of Missouri System's competitiveness for national opportunities in transportation structures research. The program objectives include:

1. Extending the Service Life of Existing Bridges

   Performance goals, critical deficiency identification, cost-effective maintenance and preservation strategies (corrosion mitigation, strengthening, evaluation, etc.)

2. Optimizing Bridge Designs

   Performance goals, consistent safety margins for bridge components, advanced materials for durability and performance enhancement, and accelerated construction technologies

3. Gaining National Presence of the UM System

   Active participations in national competitions of transportation structures research, leaderships in transportation structures related national initiatives and activities

Research Projects and Team

1. Extending Service Life of Existing Bridges
   a. Structural steel coatings for corrosion mitigation

      Dr. John Myers (PI), Missouri S&T, and Dr. Glenn Washer, UMC

   b. Spalling solution of precast-pretensioned bridge deck panels

      Dr. Lesley Sneed (PI), Missouri S&T, and Dr. DJ Belarbi, University of Houston

2. Optimizing Bridge Designs
   a. Reliability-based evaluation of bridges for consistent safety margins

      Dr. Oh-Sung Kwon (PI), University of Toronto, and Dr. Sarah Orton, UMC

   b. Coated steel rebar for bond strength and corrosion resistance

      Drs. Genda Chen (PI), Jeffrey Volz and Richard Brow, Missouri S&T

   c. Alternative and cost-effective bridge approach slabs

      Dr. Ganesh Thiagarajan (PI), UMKC, and Dr. Vellore S. Gopalaratnam, UMC

   d. Calibration of load factors for LRFD foundation designs

      Dr. Genda Chen (PI), Missouri S&T, Dr. Sarah Orton, UMC, and Dr. Oh-Sung Kwon

MoDOT MISSOURI S&T MISSOURI UMKC UNIVERSITY OF MISSOURI-KANSAS CITY

Program Timeline and Funding

1. Duration (2 Years)

   Start date: September 1, 2008

   End date: August 31, 2010

2. Research Funds (~$1.9M Total)

   $1M from MoDOT

   $625K from Missouri S&T Center for Transportation Infrastructure and Safety –
   a National University Transportation Center

   $42K (cash) from UMKC

   $200K (in-kind) from Missouri S&T/UMC/UMKC

Program Deliverables

1. Faster, Cheaper, and Better Solutions
    a. Cost-effective solutions to structural steel corrosion and precast-pretensioned deck spalling
    b. Cost-effective modular bridge approach slabs for rapid construction
    c. Recommended specifications and guidelines for cost-effective designs and better end products in terms of advanced materials
2. Long-term National Presence and Impact
    a. Documented efforts to compete for national research opportunities
    b. Documented efforts to participate in and lead national initiatives and major activities

Outline of My Presentation

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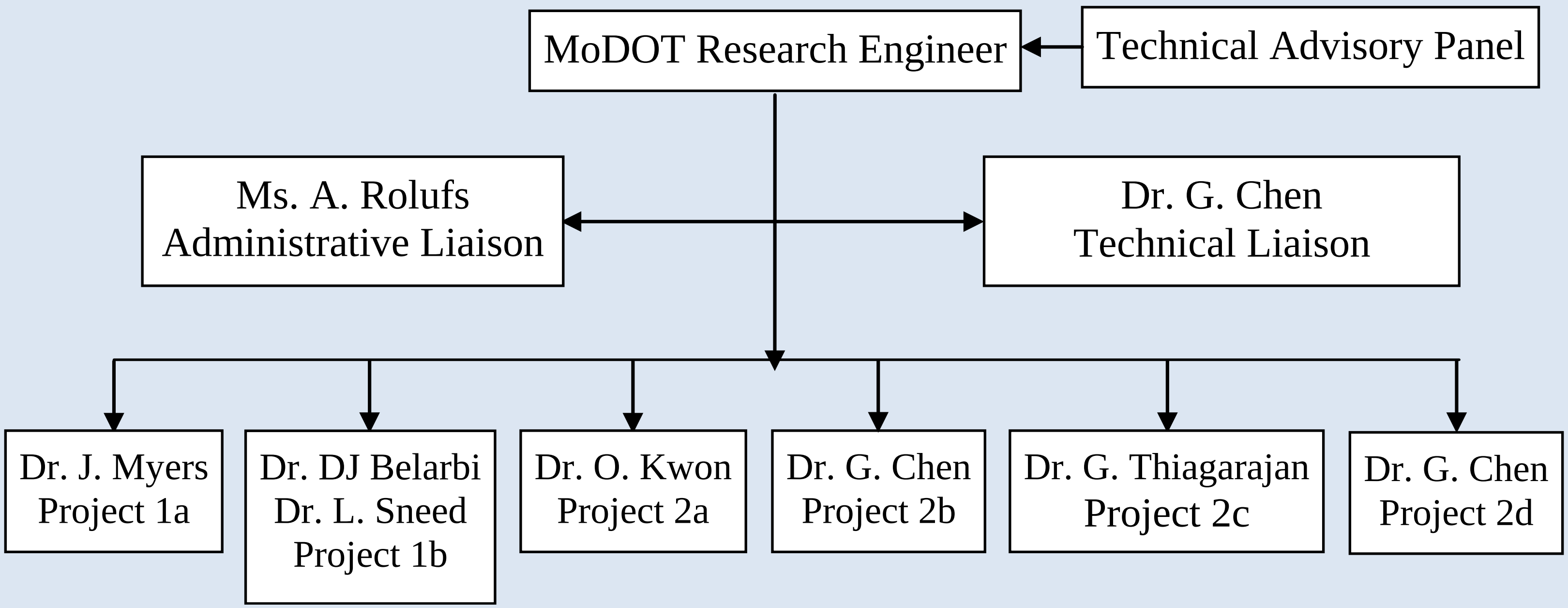
Organization of the Structures Program



1a: Structural Steel Coatings

Project Objectives

- Assess the condition of existing structural coating systems and develop a visual assessment tool to improve the reliability of condition rating.
- Determine the effectiveness and performance of the existing structural coating systems that have been used in Missouri.
- Identify and test improved systems for coating structures used in the field.

1a: Structural Steel Coatings

Findings and Deliverables – Pocket Guide

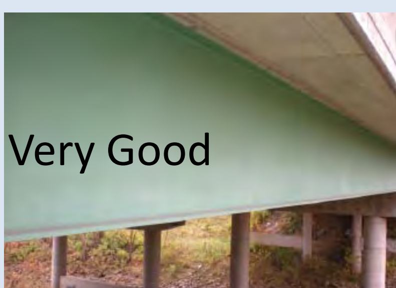
- Visual inspection guide - Rate coating conditions on log scale that relates to maintenance actions (96 bridge surveys at http://utc.mst.edu)
  - Fair condition up to 1% - Touch up
  - Poor condition up to 10% - Overcoat
  - Very poor = Recoat

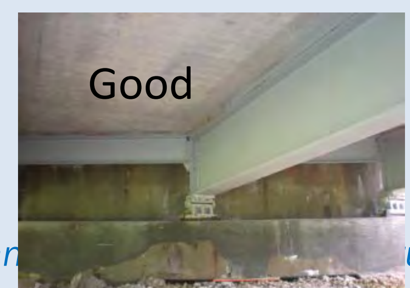
Rating	Description
Very Good	Perfect, new condition. The coating is a new coating system with very little or no damage. This condition correlates to the SSPC rating 10, less than 0.01 % rust and SSPC-9 (Greater than 0.01 up to 0.03%).
Good	Some very minor corrosion: The coating system is in good condition, with little overall corrosion/rust corresponding to SSPC 8 (greater than 0.03 and up to 0.1 %).
Fair	The coating has observable damage corresponding to SSPC-7 (greater than 0.1 and up to 0.3 %) to SSPC-6 (Greater than 0.3% up to 1%).
Poor	The coating has widespread corrosion corresponding to SSPC-5(Greater 1% up to 3%) to SSPC-4 (Greater than 3% up to 10%).
Very Poor	The coating system is in advanced stages of deterioration, with greater than 10% rust corresponding to SSPC-3 or less.

1a: Structural Steel Coatings

The pocket visual guide can be used to:

- Train inspectors
- Reference for field work
- Increase consistency/reliability of inspection data
- Tie condition to maintenance action
- Provide a methodology for field performance tracking over time leading to
  - Improved coating system selection and maintenance
  - Condition-based decision making





1a: Structural Steel Coatings

Findings and Deliverables – Laboratory Tests

- Twelve (12) Coating System Technologies Were Investigated.
  - **Topcoats:** Polyurethane, Polysiloxane, Polyurea (aromatic), Polyaspartic polyurea, and Fluoropolymer.
  - **Non-zinc primers:** (epoxy, polyurea, urethane) were also selected in the test matrix.
  - **More Conventional Primers:** Inorganic zinc (two or three component silicate zinc rich) and Organic zinc (aromatic urethane zinc, one component moisture urethane zinc and micaceous iron oxide).
- Standard and New Testing Protocols Utilized.
  - Physical property measurements: dry film thickness and gloss; adhesion test; salt fog test; QUV weathering test; freeze-thaw stability test; electrochemical test; long-term exposure testing.

1a: Structural Steel Coatings

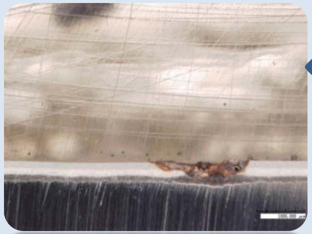
Representative Laboratory Testing Images

Electrochemical Testing

Salt Fog Testing

Freeze Thaw Resistance

Thin Slice Analysis



1a: Structural Steel Coatings

Laboratory Results and Testing Protocols

- A Miozinc + Polyaspartic Polyurea System was recommended for field trial. Testing showed that it outperformed the current MoDOT System G.
- The polyurea system is applied as a two-coat system rather than a three-coat system like MoDOT System G, which requires less labor for each installation and less frequent re-coat application and maintenance due to the potentially extended service life with the polyurea system.
- The Electrochemical Testing Methodology holds great promise as a rapid screening tool for coating performance evaluation, thus saving time and money for new coating system qualifications.

1b: Spalling Solution of PPC Panels

Project Objectives

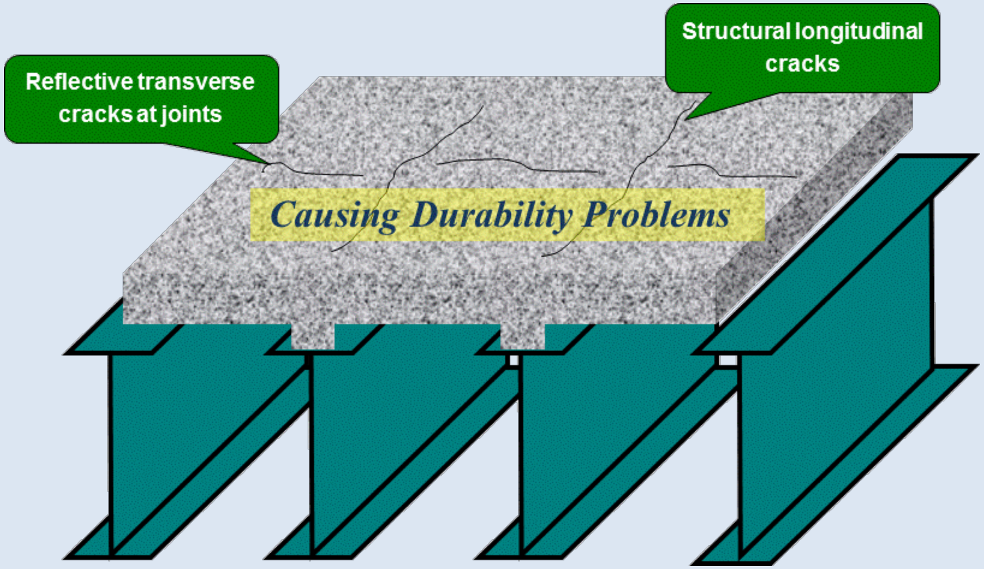
- Investigate the causes of spalling in precast-prestressed panels through questionnaire survey, field surveys, and numerical simulations
- Propose cost-effective alternative solutions including improved design options for new construction
- Suggest mitigation methods for existing deteriorated bridge decks

Proposed System/Potential Solution	Test Approach
1. Increase side cover of prestressing tendons	O, Δ
2. Use enhanced concrete using FRC	O
3. Use corrosion-free concrete using corrosion inhibitor	O
4. Enhance the reinforcement in CIP topping concrete deck	Δ
5. Substitute 2 epoxy-coated steel or CFRP tendons for all steel tendons	X
6. Substitute 2 epoxy-coated steel or CFRP tendons for 2 steel tendons each edge	O
7. Use re-shaped panel	X
8. Add surface protection	X

* O : Examine Experimentally, Δ : Examine analytically, X : Disregard

1b: Spalling Solution of PPC Panels

Spalling Problem and Durability

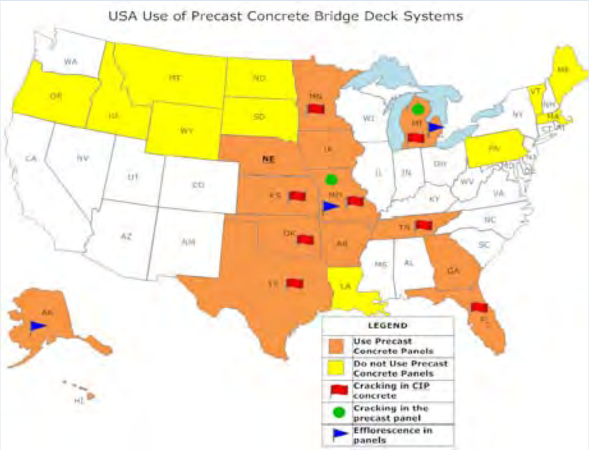


- Corrosion of embedded steel reinforcement in SIP panels results in concrete spalling and tendon rupture
- These deteriorations can be detrimental as they can result in shorter life spans for the deck panels

1b: Spalling Solution of PPC Panels

Findings and Deliverables – National Survey

- 16 out of 29 responded states use precast concrete panels
- In comparison with steel girders, prestressed concrete girders likely lead to more longitudinal cracking but similar transverse cracking.
- Transverse cracking in the CIP topping and water seepage at the panel joints appear to be associated with concrete spalling of panels
- The combination of design parameters, age, environmental conditions, and problems reported in Missouri bridges with partial-depth PPC panels is unique.

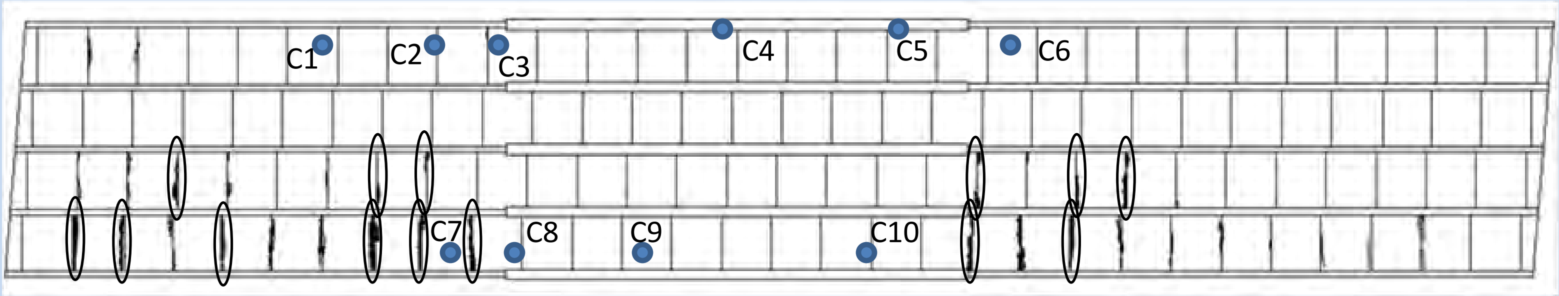


- Most of the reported *deterioration problems* with the PPC panel system appear to be related to *environmental conditions* resulting in corrosion of embedded steel rather than structural issues.

1b: Spalling Solution of PPC Panels

Findings and Deliverables – In-Depth Inspection

- Bridge A4709 built in 1991 near Mexico, MO - most severe spalling
- 2-span (127 ft + 120 ft), steel-girder, continuous US54 overpass with 3 in. SIP panels (116 joints) and 5.5 in. CIP topping
- 15 of the 116 panel joints (13%) spalling with additional 19 joints cracking at the edges, an early stage of spalling



Spalled Joints

Cracked Joints

1b: Spalling Solution of PPC Panels

Core C-1

Findings and Deliverables – Chloride Test

- Spalling in panels resulted from the penetration of water and chlorides through the transverse reflective cracking in CIP topping
- Most deterioration occurred near the area of reflective cracking

Core ID	Depth of core (in.)	Depth of reinforcement encountered (in.)	Bottom surface of core	Sampling Depths (in.)	lb Cl-/yd^3	Corrosion Possibility	Carbonation Depth (mm)
C-1	4.5	4.5	broken	3	0.332	Not Likely	1 mm
C-2	5.5	None	smooth	3	0.224	Not Likely	1 mm or less
				4	1.445	Possible	
C-3	6.125	None	smooth	3	2.610	Possible	1 mm
				4	2.614	Possible	
				5	1.377	Possible	
C-4	3.125	3.125	broken	2	0.643	Not Likely	less than 1 mm
C-5	6.5	None	broken	3	0.257	Not Likely	less than 1 mm
				4	0.363	Not Likely	
				5	0.115	Not Likely	
C-6	6.625	3.875	broken	3	0.263	Not Likely	1-2 mm
				4	0.100	Not Likely	
				5	0.252	Not Likely	
C-7	6.5	4.75	smooth	3	0.279	Not Likely	1- 2 mm
				4	0.181	Not Likely	
				5	0.268	Not Likely	
C-8	6.375	4.5	smooth	3	0.221	Not Likely	1 mm, 11 mm at large void
				4	0.183	Not Likely	
				5	0.212	Not Likely	
C-9	7	6.875	broken	3	0.189	Not Likely	1 mm, 11 mm in crack
				4	0.328	Not Likely	
				5	0.230	Not Likely	
C-10	7.125	4.25	broken	3	6.532	Possible	less than 1 mm
				4	5.393	Possible	
				5	6.051	Possible	

- Smooth bottom cores showed sign of delamination at CIP-SIP interface near panel joints, despite the roughened panel surface
- The corrosion possibility indicated by chloride content and carbonation depth is in general agreement with the observed cracking and spalling distribution in panels

1b: Spalling Solution of PPC Panels

Summary of Findings – Spalling Causes

Questionnaire Survey

- Transverse (reflective) and longitudinal crack at CIP
- Water seepage at panel joints
- Missouri panels are smaller and longer than the others

Field Survey

- Missouri bridges with partial-depth PPC panels is unique
- Spalling is the results of penetration of water and chloride
- Delamination at the interface at panel joint locations

FEM Simulation

- A bridging crack is the primary agency to trigger corrosion-induced spalling
- Butting accordance with delamination can be secondary

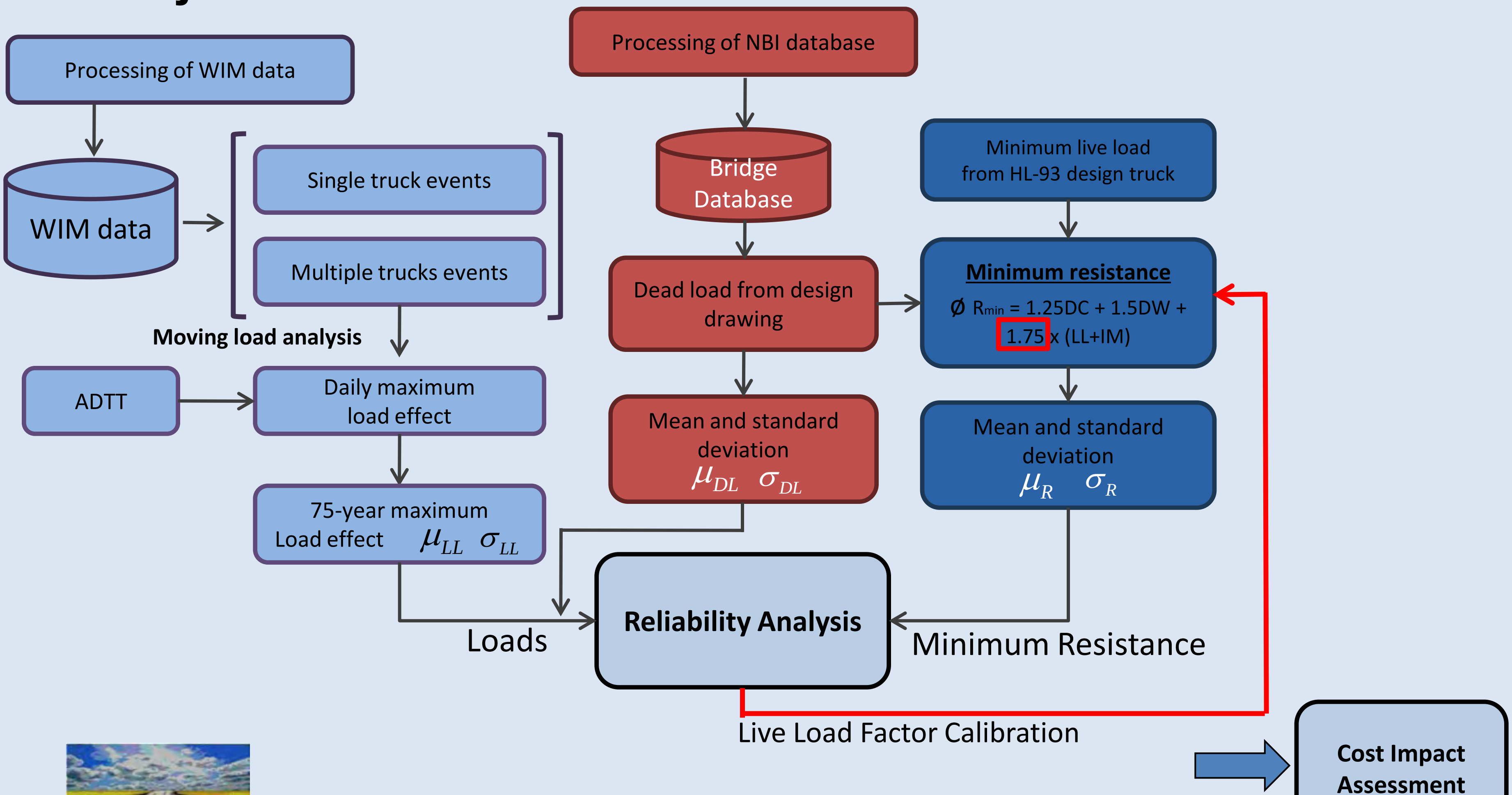
1b: Spalling Solution of PPC Panels

Summary of Findings – Solutions for New Const.

System	Evaluation Method
Increased side cover Enhanced concrete (FRC) Corrosion-free concrete (corrosion inhibitor) Enhancement of reinforcement in CIP topping concrete deck Edge-tendon substitution (epoxy-coated steel & CFRP)	▪ Comparable to the control panel with normal concrete in static and fatigue performance ▪ Less stiffness degradation than NC *CFRP Tendon* ▪ Comparable serviceability in both static and fatigue tests ▪ Reduction in peak load, displacement, and ductility compared to panels with steel ▪ Marked reduction of peak load in fatigue test specimens ▪ FE simulation showed consistency in overall behavior for all panels

2a: Reliability-Based Evaluation

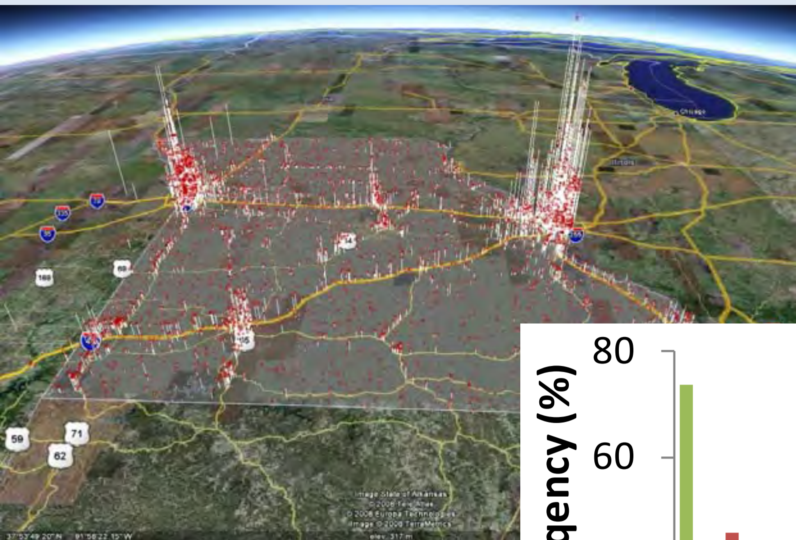
Project Overview

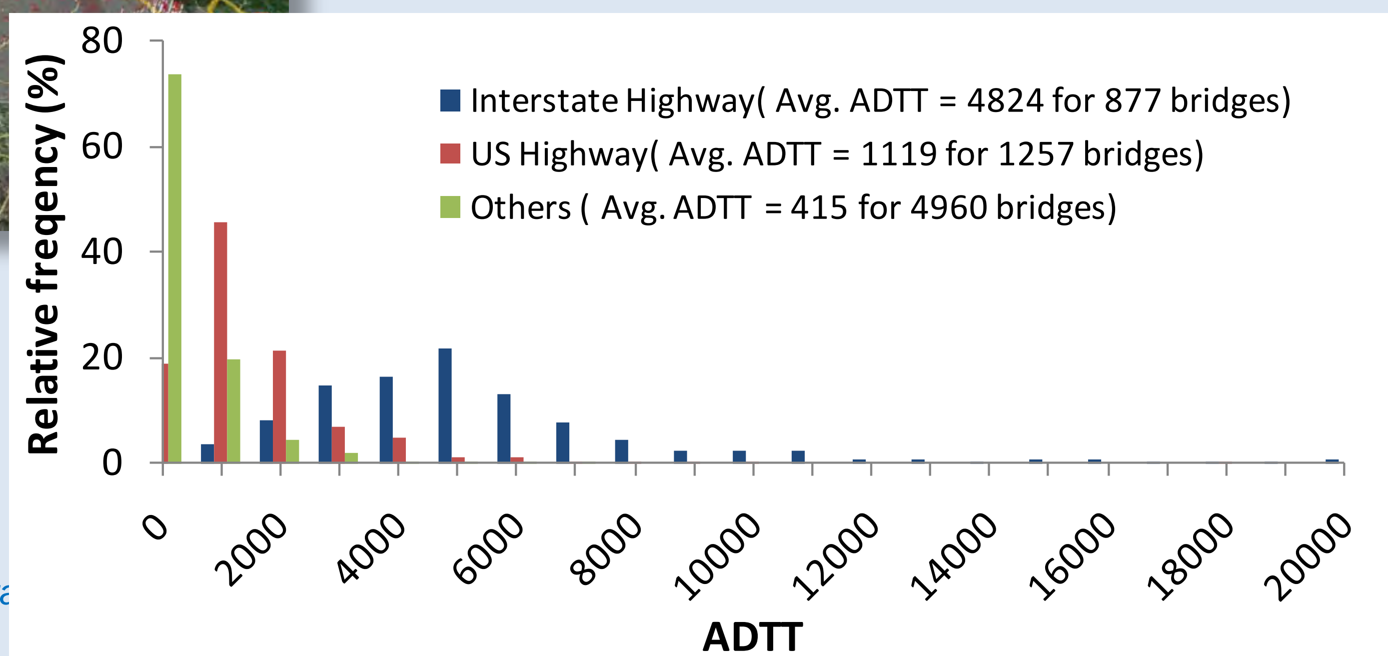


2a: Reliability-Based Evaluation

Findings and Deliverables – ADTT

- Average Daily Truck Traffic in Missouri

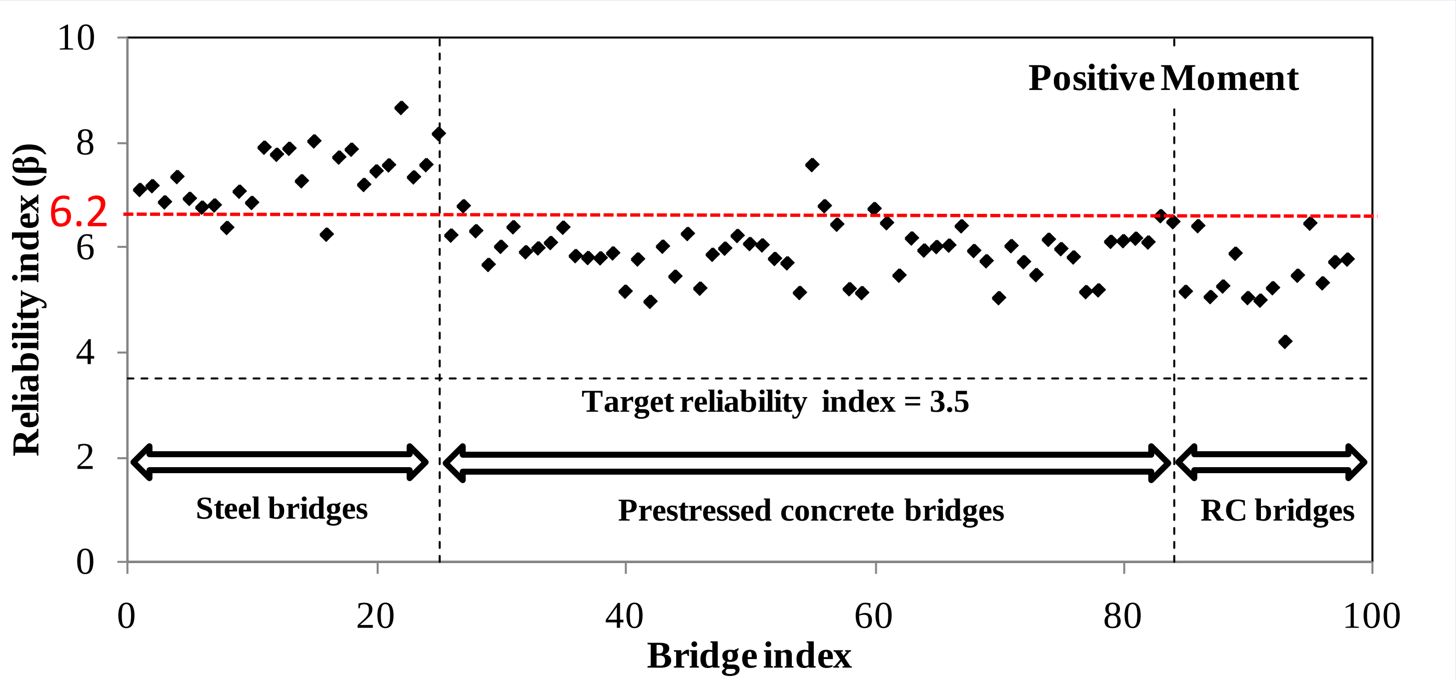




2a: Reliability-Based Evaluation

Findings and Deliverables – Reliability

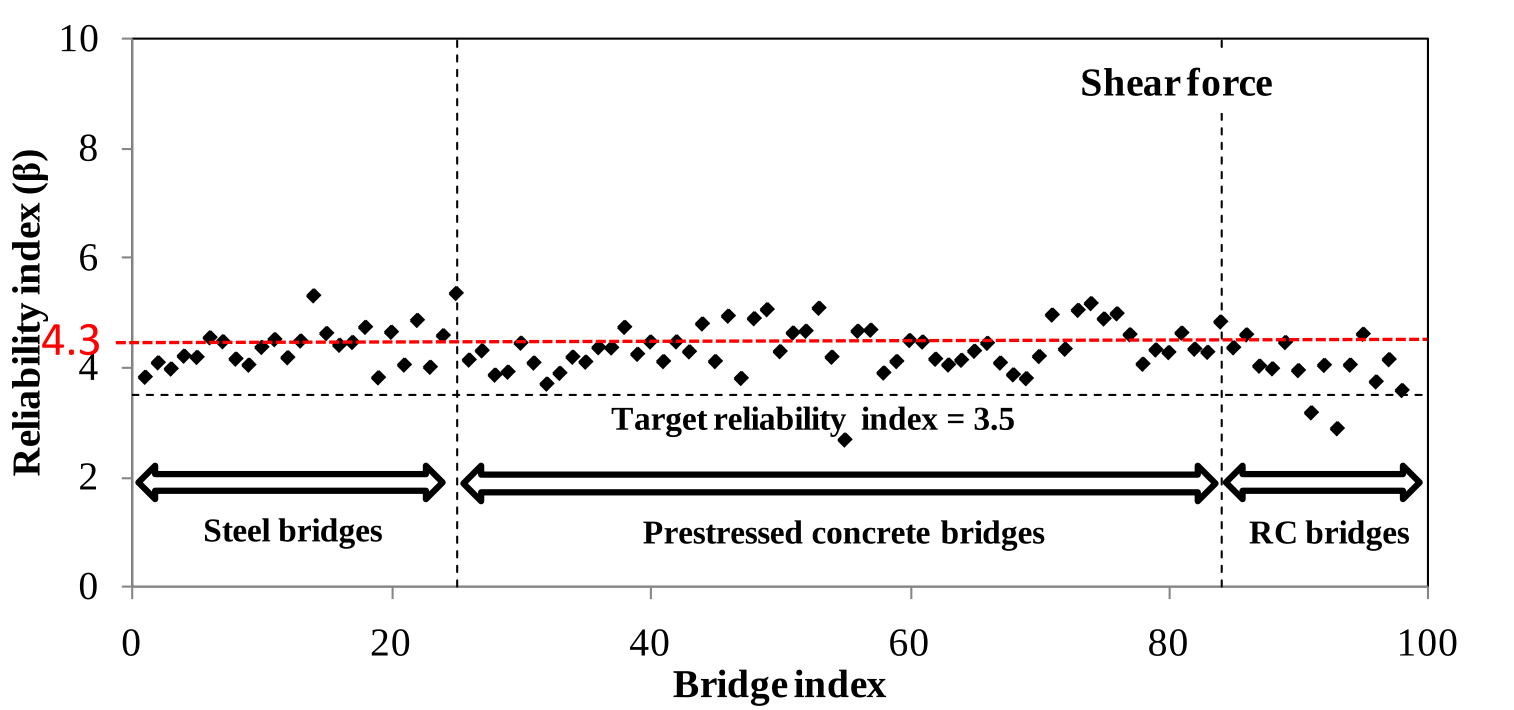
- Reliability Index of Existing Bridges – Positive Moment for ADTT=5000



2a: Reliability-Based Evaluation

Findings and Deliverables – Reliability

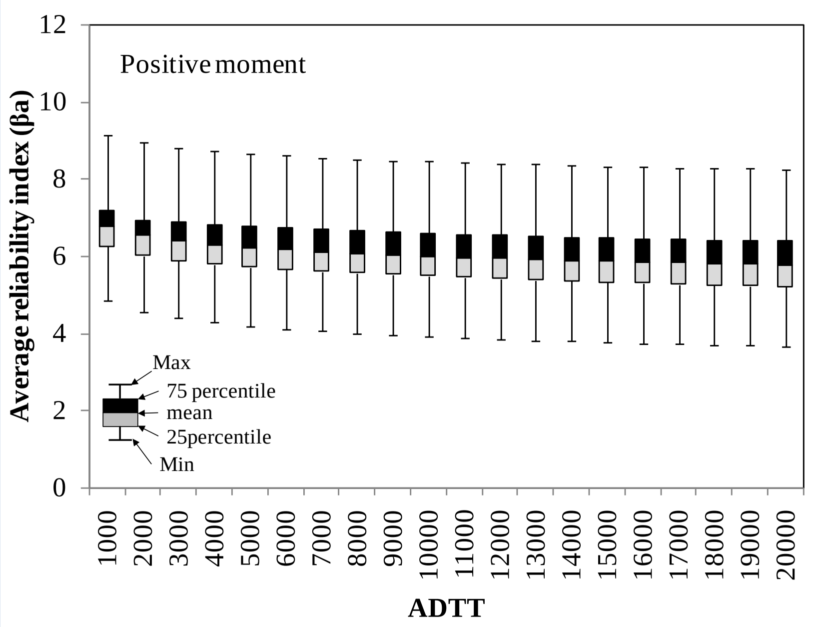
- Reliability Index of Existing Bridges – Shear Force for ADTT=5000

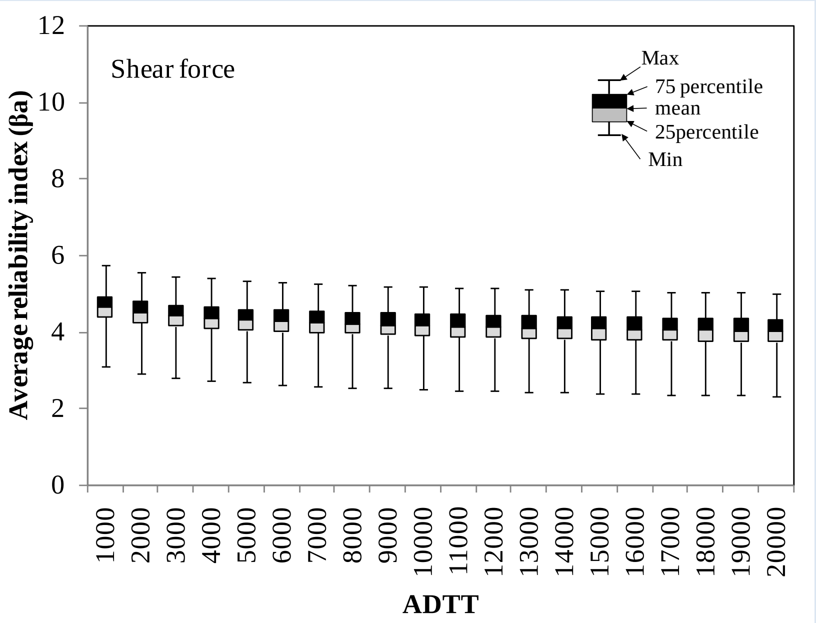


2a: Reliability-Based Evaluation

Findings and Deliverables – Reliability

- The average reliability Indices for positive moment and shear force at ADTT=5000 are 6.2 and 4.3. The lower the ADTT, the higher the reliability index.



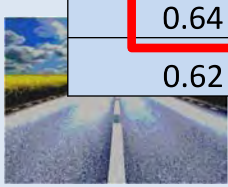


2a: Reliability-Based Evaluation

Findings and Deliverables – Calibration Factor

- Average Reliability Index – Live Load Factor Calibration Table (pos. M)

Live load calibration factor	ADTT									
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
1.0	6.79	6.55	6.41	6.31	6.23	6.17	6.12	6.08	6.04	6
0.9	5.95	5.71	5.58	5.48	5.41	5.35	5.3	5.26	5.22	5.18
0.8	5.07	4.83	4.7	4.61	4.54	4.48	4.43	4.39	4.35	4.32
0.78	4.88	4.65	4.52	4.43	4.36	4.3	4.25	4.21	4.17	4.14
0.76	4.7	4.47	4.34	4.25	4.18	4.12	4.07	4.03	3.99	3.96
0.74	4.51	4.28	4.15	4.06	3.99	3.94	3.89	3.85	3.81	3.78
0.72	4.32	4.1	3.97	3.88	3.81	3.75	3.7	3.66	3.63	3.6
0.7	4.13	3.91	3.78	3.69	3.62	3.57	3.52	3.48	3.44	3.41
0.68	3.94	3.71	3.59	3.5	3.43	3.38	3.33	3.29	3.26	3.23
0.66	3.74	3.52	3.4	3.31	3.24	3.19	3.14	3.1	3.07	3.04
0.64	3.54	3.33	3.2	3.12	3.05	3	2.95	2.92	2.88	2.85
0.62	3.35	3.13	3.01	2.92	2.86	2.81	2.76	2.73	2.69	2.66

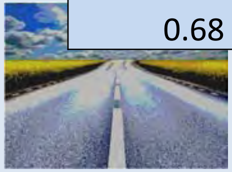


2a: Reliability-Based Evaluation

Findings and Deliverables – Calibration Factor

- Average Reliability Index – Live Load Factor Calibration Table (Shear)

Live load calibration factor	ADTT									
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
0.90	4.16	4.00	3.92	3.86	3.81	3.77	3.74	3.71	3.69	3.67
0.88	4.05	3.90	3.81	3.75	3.70	3.67	3.63	3.61	3.58	3.56
0.86	3.94	3.79	3.71	3.65	3.60	3.56	3.53	3.50	3.48	3.46
0.84	3.84	3.69	3.60	3.54	3.50	3.45	3.42	3.39	3.37	3.35
0.82	3.73	3.58	3.49	3.43	3.38	3.35	3.31	3.29	3.26	3.24
0.80	3.62	3.47	3.38	3.32	3.27	3.24	3.20	3.18	3.15	3.13
0.78	3.50	3.35	3.27	3.21	3.16	3.12	3.09	3.07	3.04	3.02
0.76	3.39	3.24	3.15	3.09	3.05	3.01	2.98	2.95	2.93	2.91
0.74	3.27	3.12	3.04	2.98	2.93	2.90	2.86	2.84	2.81	2.79
0.72	3.16	3.01	2.92	2.86	2.82	2.78	2.75	2.72	2.70	2.68
0.70	3.04	2.89	2.80	2.74	2.70	2.66	2.63	2.60	2.58	2.56
0.68	2.91	2.77	2.68	2.62	2.58	2.54	2.51	2.48	2.46	2.44



2a: Reliability-Based Evaluation

Findings and Deliverables – Recommendation

- Unless a reliable estimate of the ADTT is available, it is recommended that a live load reduction factor of 0.8 be used for bridges that don't support US or interstate highways and no live load reduction be used for bridges carrying US and interstate highways. Live load reduction will lead to significant saving in the construction cost of new bridges.

	Live load calibration factor			
	ADTT ≤ 1000	1000<ADTT ≤ 5000	5000<ADTT ≤ 10000	ADTT > 10000
Moment	**0.64**	**0.70**	**0.72**	**-**
Proposed factors	**0.65**	**0.70**	**0.75**	**1.0**

	Live load calibration factor			
	ADTT ≤ 1000	1000<ADTT ≤ 5000	5000<ADTT ≤ 10000	ADTT > 10000
Shear	**0.78**	**0.84**	**0.88**	**-**
Proposed factors	**0.80**	**0.85**	**0.90**	**1.0**

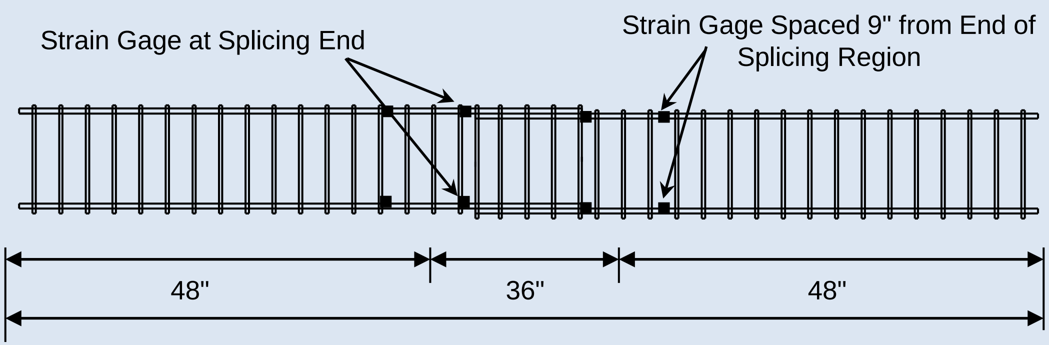
2b: Coated Steel Rebar

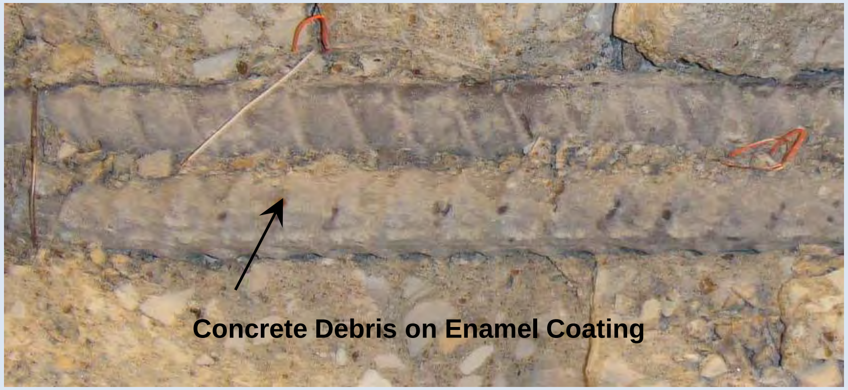
Project Objectives

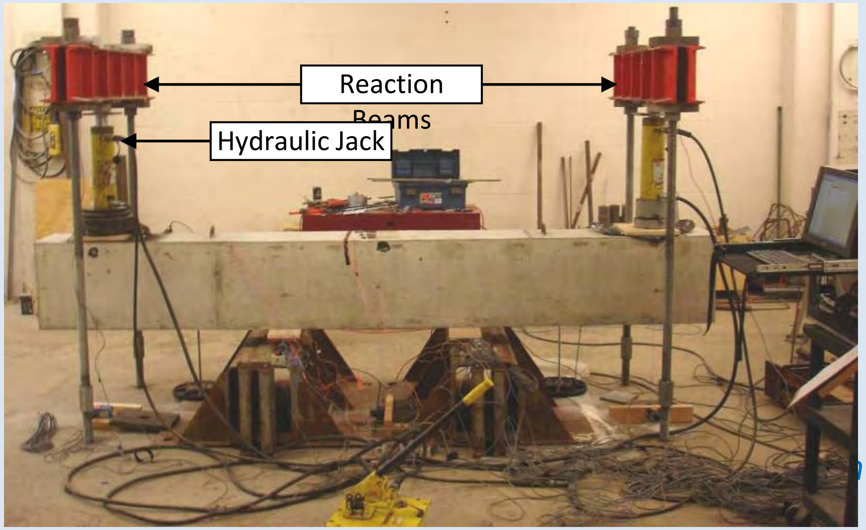
- Characterize the bond strength between coated rebar and concrete and the corrosion resistant properties of coated rebar in alkaline environments.
- Develop a new design equation for the tension *development lengths* of coated steel rebar in flexural members based on the enhanced bond strengths between the steel and concrete.
- Study the behavior of beam-column concrete structures reinforced with enamel-coated rebar, and validate new design equations for the tension *development lengths* of coated steel rebar in RC members

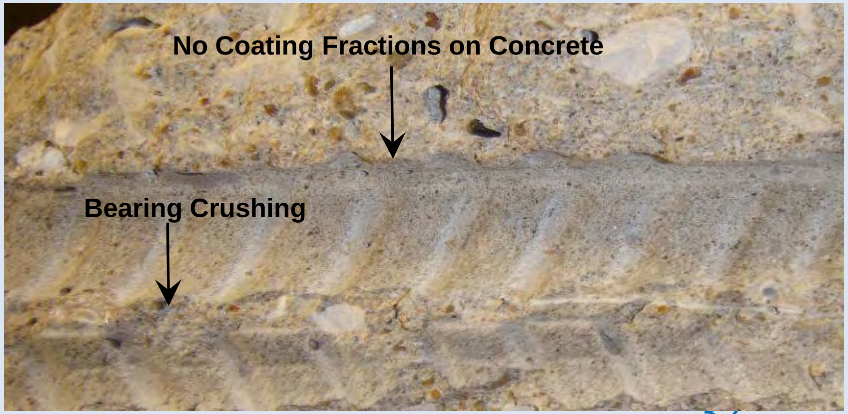
2b: Coated Steel Rebar

Findings and Deliverables – Beam Tests





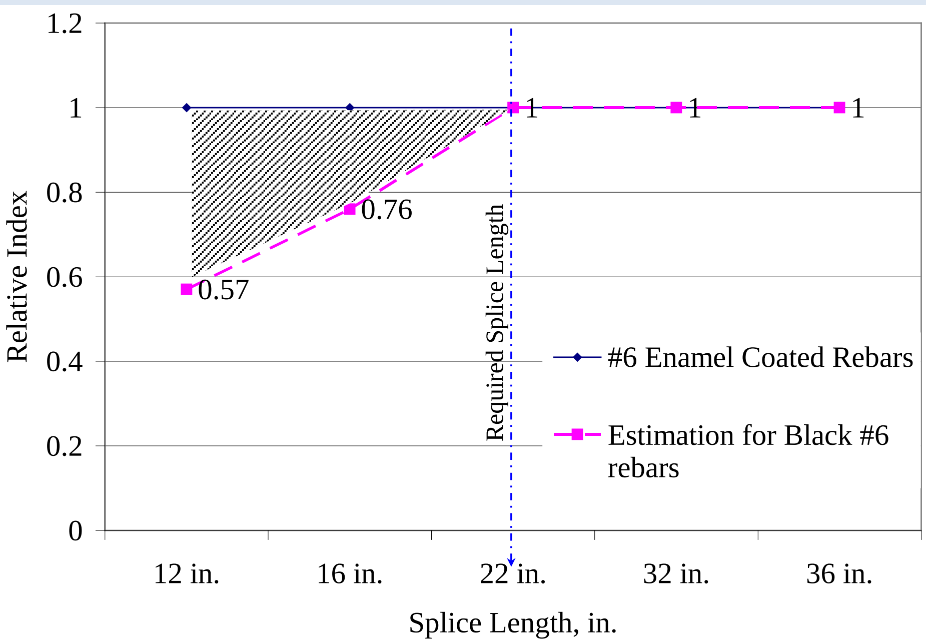




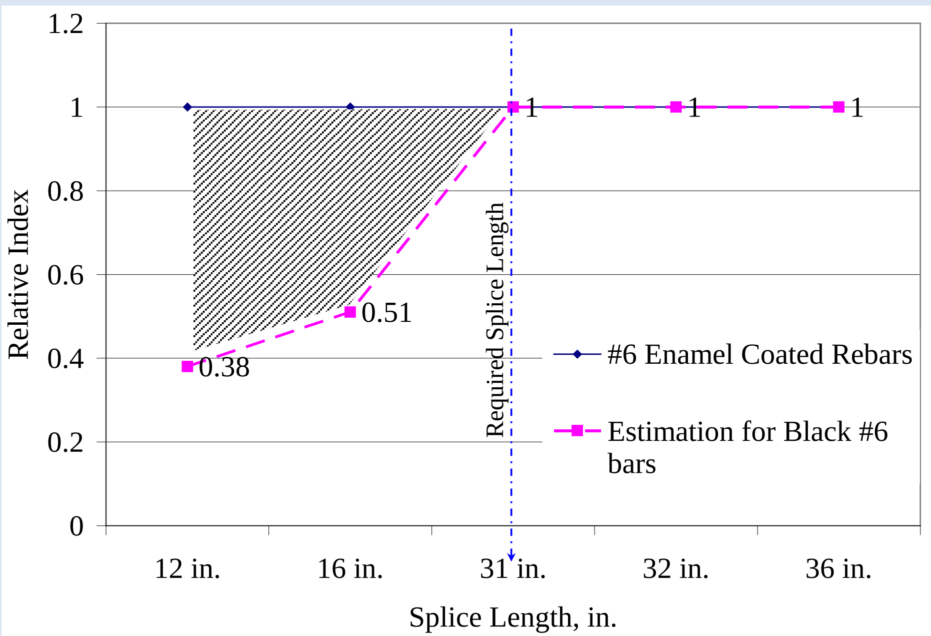
2b: Coated Steel Rebar

Findings and Deliverables – Beam Tests

- Development Length Equation in Tension



(a) With confinement

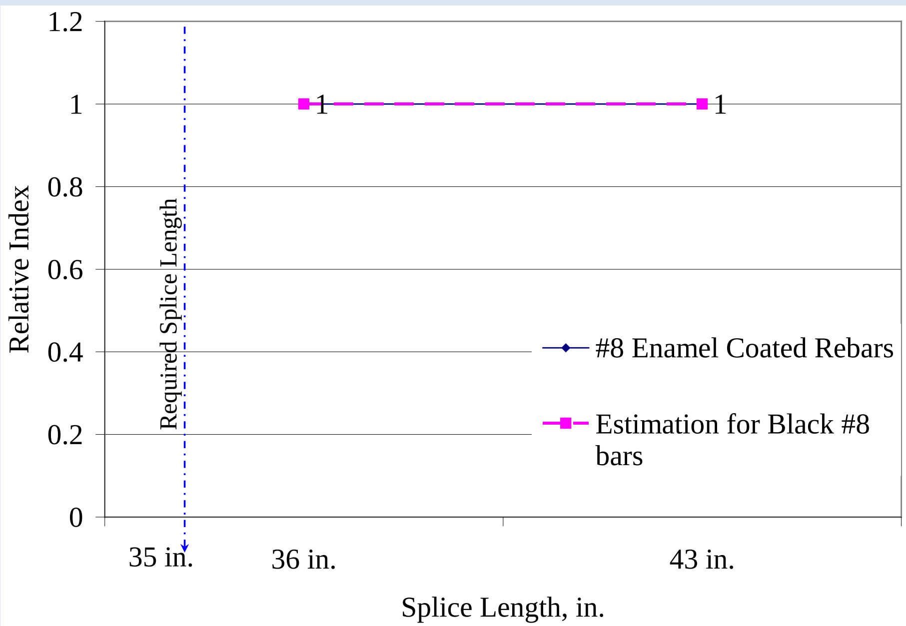


Without confinement

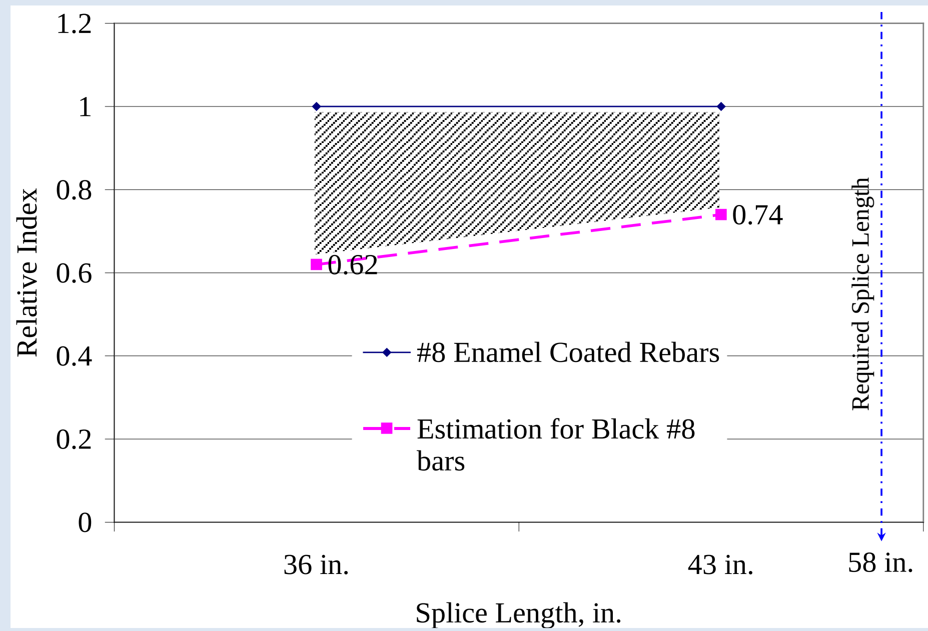
2b: Coated Steel Rebar

Findings and Deliverables – Beam Tests

- Development Length Equation in Tension



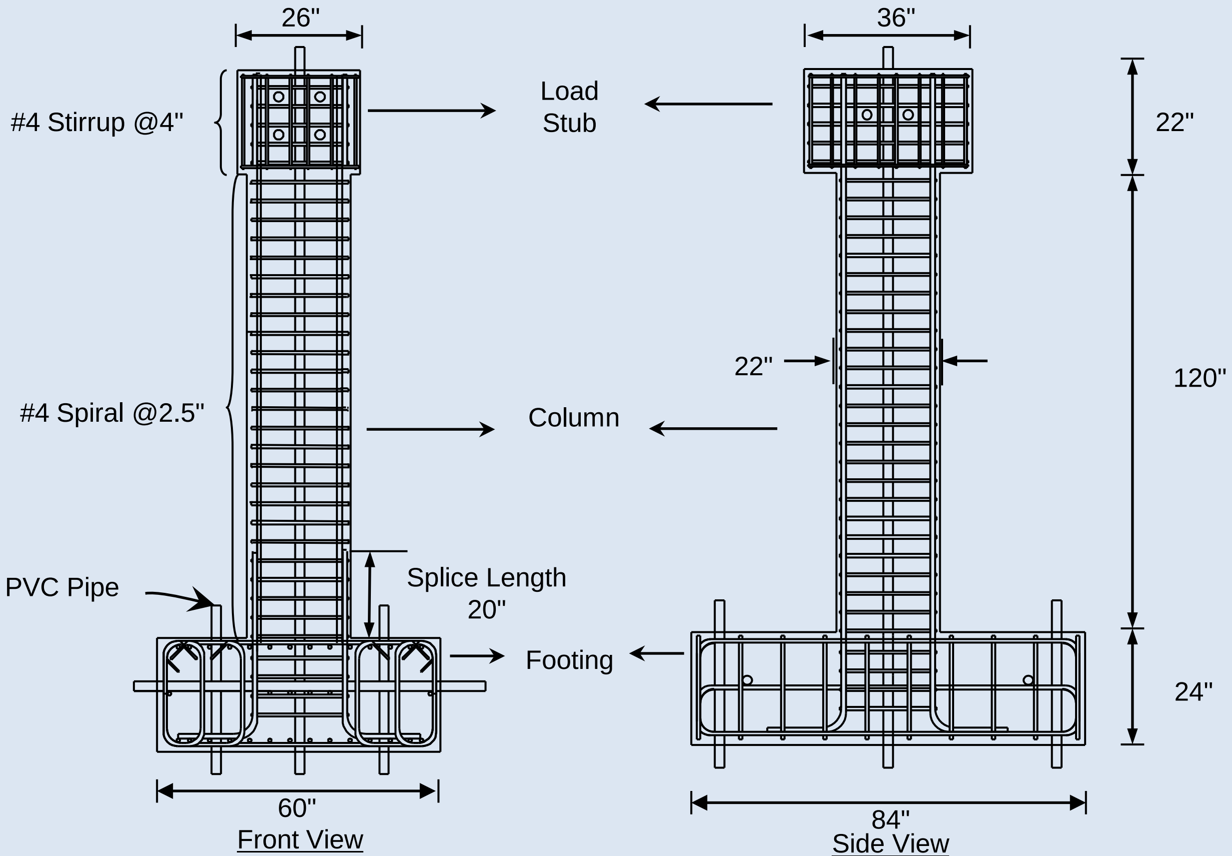
(a) With confinement

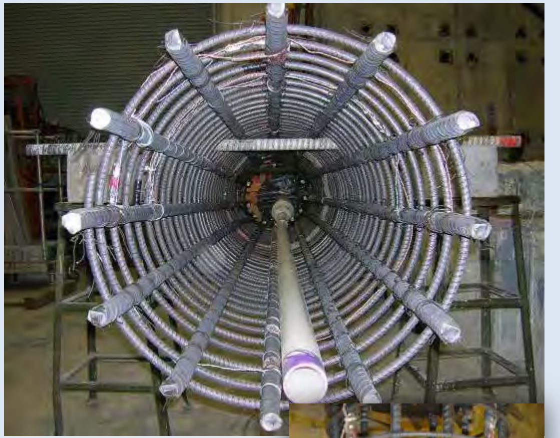


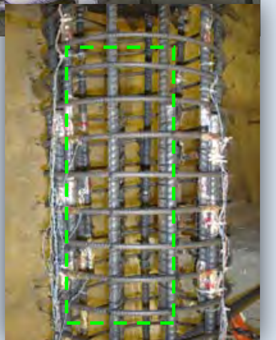
Without confinement

2b: Coated Steel Rebar

Findings and Deliverables – Column Validation

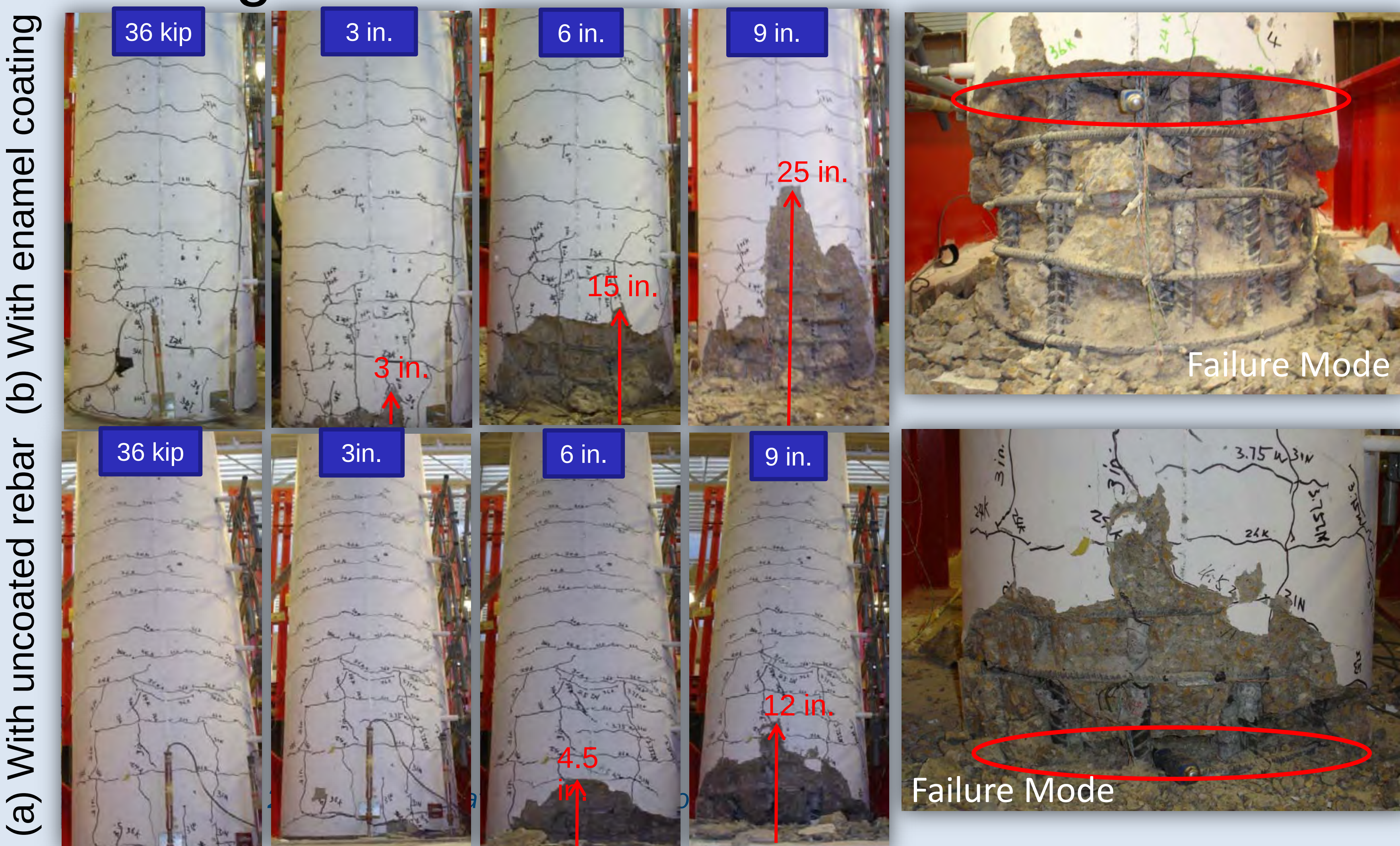






2b: Coated Steel Rebar

Findings and Deliverables – Column Validation



2b: Coated Steel Rebar

Recommendations

- Concrete-Steel Bond Behavior
  - A mixture of 50% enamel and 50% calcium silicate coating is recommended for a maximum increase of the bond strength between steel rebar and concrete. If corrosion is a concern, a double-coat system consisting of an inner layer of pure enamel and an outer layer of 50/50 enamel coating is recommended based on limited laboratory tests.
- Steel Corrosion Process
  - Pure enamel is recommended for a moderate protection of steel rebar in corrosive environments. The double-coat system is recommended for maximum corrosion protection when costs are less of a concern or where enhanced steel-concrete bond strengths are needed.
- Development Length and Splice Length Equations
  - The development length of enamel-coated steel bars in lap splice and anchorage areas shall be determined using the ACI 318-08 design equations. A coating factor of 0.85 is recommended for lap splice designs.

2c: Alternative Bridge Approach Slab

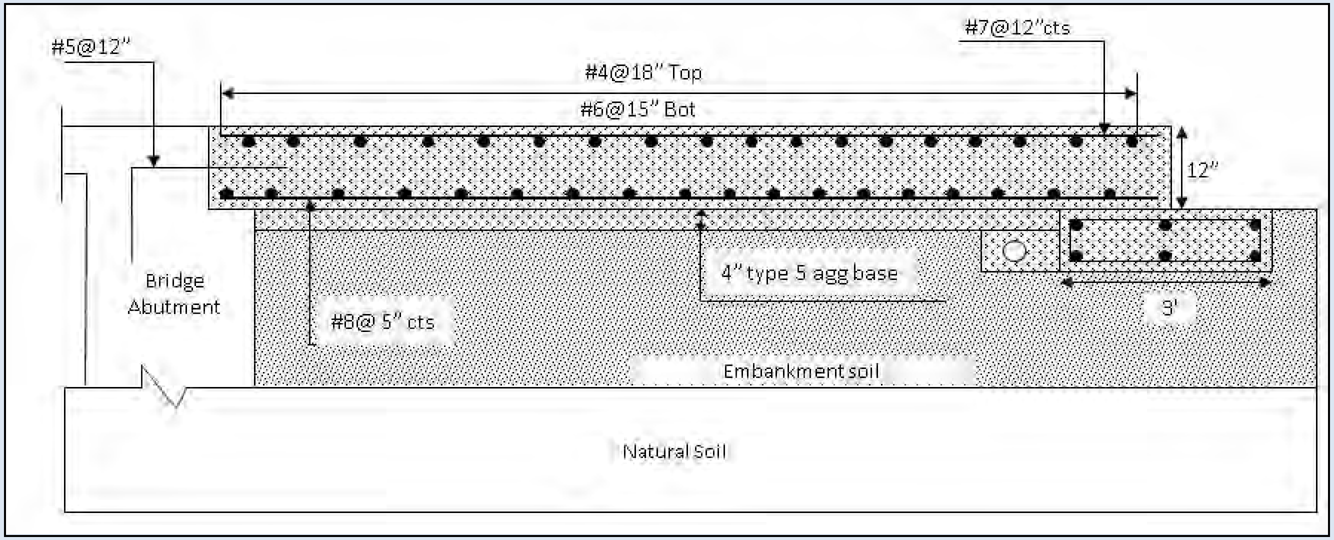
Project Objectives

- Investigate and recommend alternative design solutions with the aim to reduce the cost of construction of a bridge approach slab (BAS)
- Develop remedial measures or alternative designs for a replacement of existing bridge approaches

2c: Alternative Bridge Approach Slab

Current Designs by MoDOT

- Standard BAS for Major Routes with Sleeper Slab (L=25ft, D=12in)

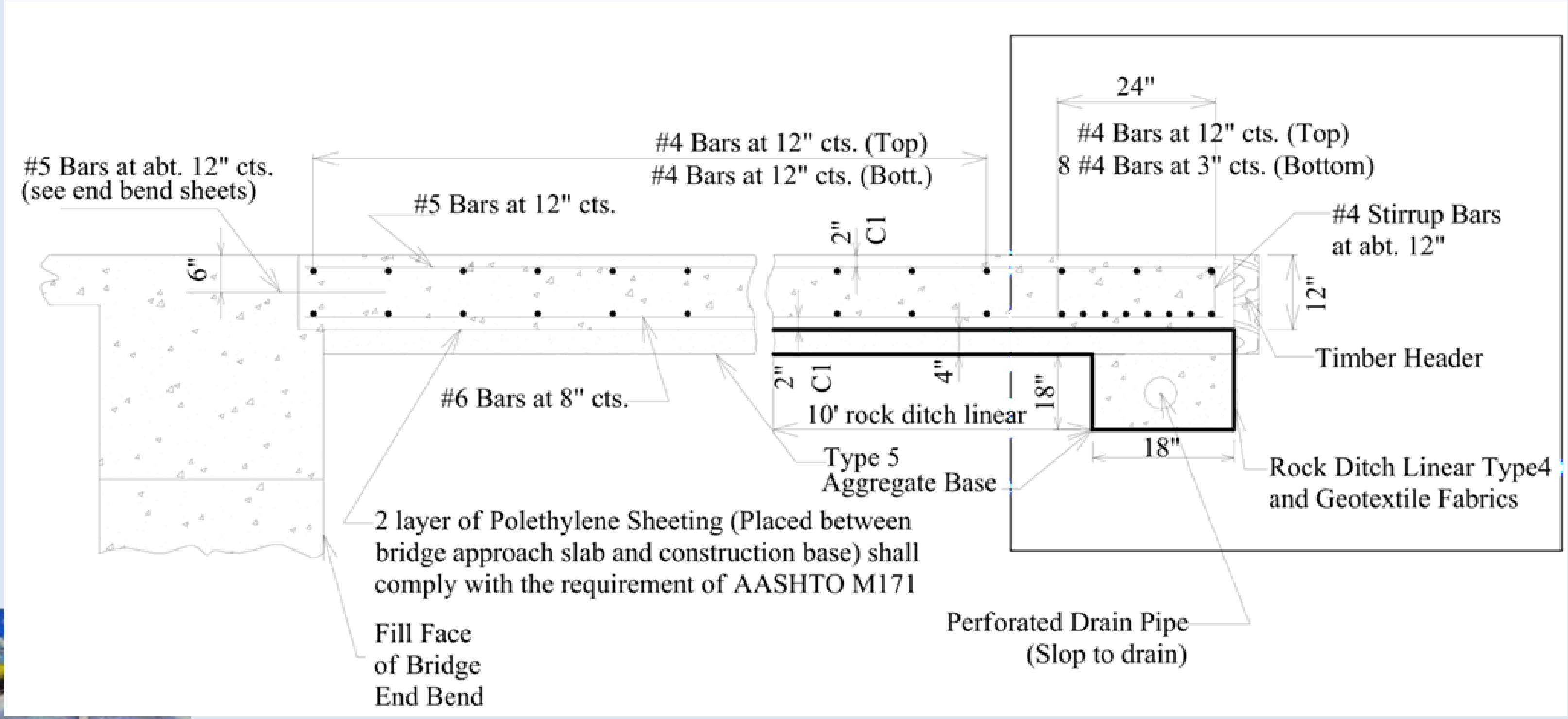


- Modified BAS for Minor Routes without Sleeper Slab (less rebar)
- Bridge Concrete Approach Pavement with 15ft Span

2c: Alternative Bridge Approach Slab

Proposed Solution – Cast-in-Place Replacement

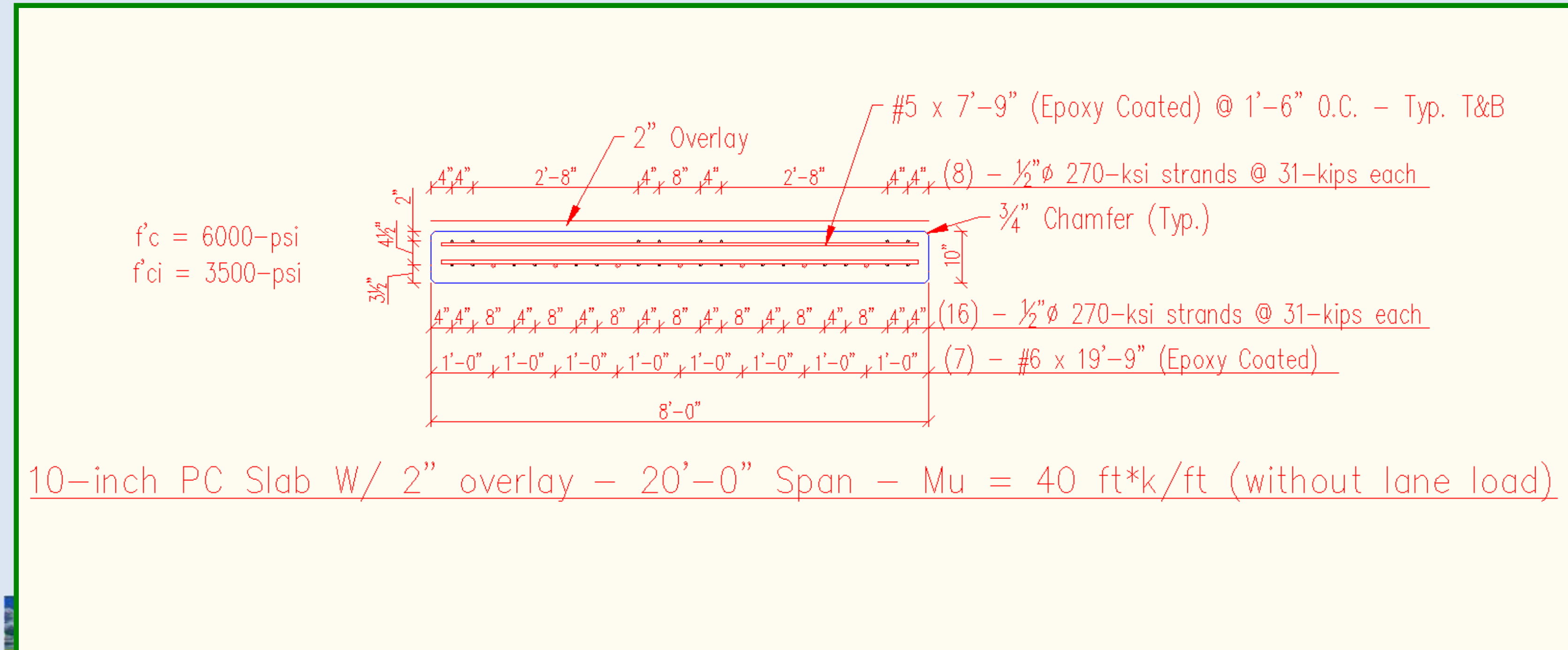
- Replace the sleeper slab with additional end reinforcement
- Use a rock ditch liner to confine aggregate ditch and drain
- Save 25% per bridge (MoDOT slab =$55k, the proposed slab = $43k)



2c: Alternative Bridge Approach Slab

Proposed Solution – New Construction

- Precast slab with transverse ties for faster installation (in day or two)
- Precast in factory for better quality control and performance
- Cost comparable to CIP slabs



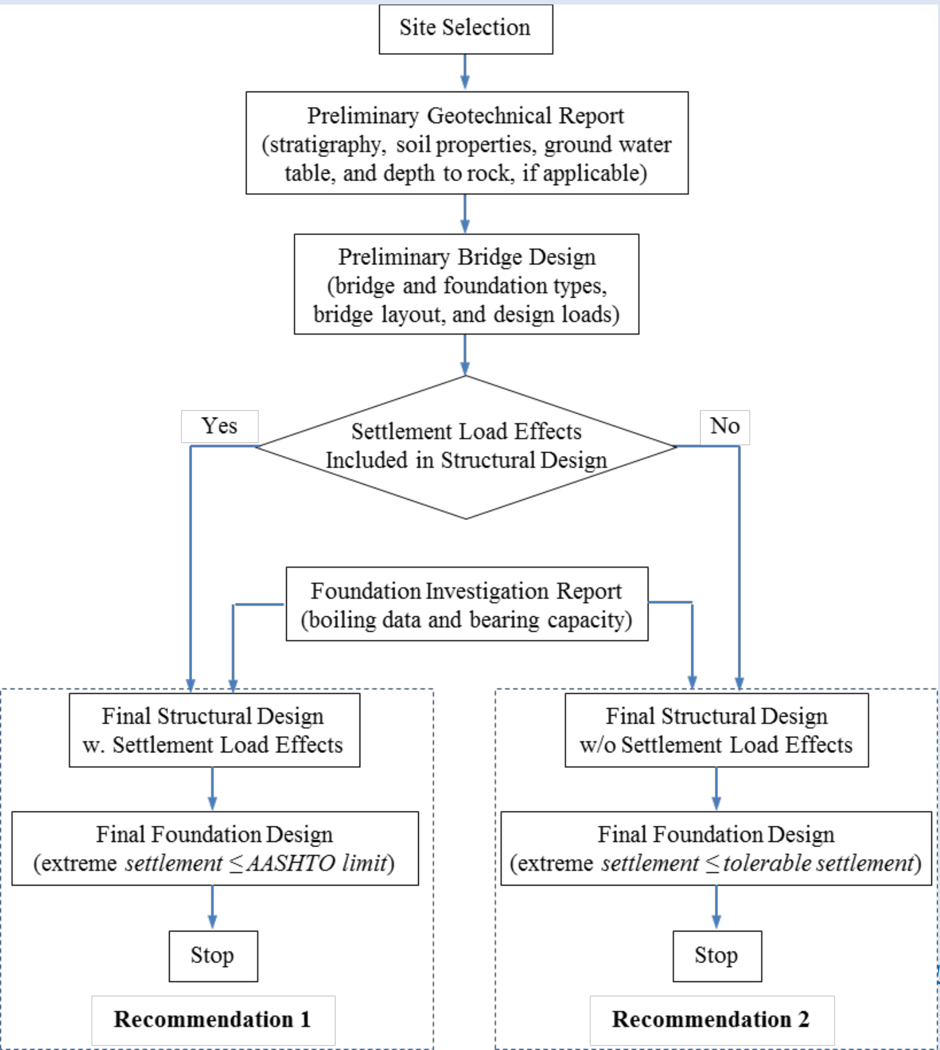
2d: Foundation Settlement Effect

Project Objectives

- Characterize the effects of foundation settlement on the reliability of superstructure design
- Develop a design framework for better dealing with foundation settlement in superstructure design

2d: Foundation Settlement Effect

Findings and Deliverables - Recommendation



The settlement effect in bridge design for Strength I Limit State requirements can be addressed with one of the following two methods:

1. Extreme settlement is considered in structural design and no special requirement is needed for foundation design unless the settlement exceeds the AASHTO recommended limit of L/250. For consistency, L represents the minimum span length of a multi-span bridge.

2. Extreme settlement is not considered in structural design as in the current MoDOT practice but ensured below what structures can tolerate in terms of reliability index. The tolerable settlement is L/450 for steel-girder bridges, L/2500 for slab bridges, and L/3500 for prestressed concrete-girder bridges.

Outline of My Presentation

- Introduction to the Collaborative Program
- Main Accomplishments and Deliverables
- Program Benefits to MoDOT
- Brief Assessment on the Program
- What is Next?

Program Benefits to MoDOT

- Collaborative Research
  - Improved communication and increasing interaction between researchers and MoDOT engineers, which has profound impact on the implementation of MoDOT research products
  - Increasing collaboration among the UM campuses, which ultimately results in a broad range of expertise for increased competitiveness in national initiatives of transportation research
- Implementable Outcomes
  - Findings are more suitable to practical application conditions
  - Specifications and guidelines can be directly adopted by MoDOT

Program Benefits to MoDOT

- Faster, Cheaper, and Better Solutions
  - Pocket guide for corrosion inspection can improve the reliability and consistency of visual inspection, leading to a better strategy for rehabilitation
  - More durable materials for corrosion such as Miozinc and Polyaspartic polyurea system and enamel coating can extend the service life of bridges, reducing the life-cycle costs and improving the Missouri transportation structures' condition
  - Precast in bridge panels and approach slabs can accelerate the process for bridge replacement and new construction while maintaining or reducing their overall construction cost
  - Reduction in required bond length with enamel coated rebar not only save material cost, but save labor in congested reinforcement areas and improve the quality of reinforced concrete.

Program Benefits to MoDOT

- Faster, Cheaper, and Better Solutions
  - Calibrated design live loads with Missouri condition can reduce the cost of building future bridges in the state of Missouri.
  - The use of reliability approach for bridge design provides a more uniform safety margin in various types of bridges.
  - Quantification on the support settlement effects on bridge superstructure performance can potentially reduce the overconservatism in bridge design.
  - Recommendation on the design procedure with support settlement provides a better and more consistent design process, leading to a more uniform safety margin in various types of bridges.

Outline of My Presentation

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Brief Assessment of the Program

- Providing Cost-Effective Solutions
  - As discussed in the previous section on Benefits to MoDOT
- Increasing National Visibility – Awarded Projects

Sponsor	**Project Title**	**Amount (Period of Performance)**	**PI and Co-PI(s)**	**Relation to MTI/ MoDOT Program**
National Science Foundation	Exploring Polymer Cross-Linked Aerogels for Their Strength and Energy Absorption in Seismic Retrofit of RC Structures	$295K (9/10 – 9/13)	Genda Chen and Nicholas Leventis	Indirect
Department of Education	Information and System Assurance for Critical Infrastructure	$131K (Year 1 of the three-year project) (8/10 – 8/13)	Ann Miller, Bruce McMillin, Sahra Sedighsarvestani, Ali Hurson, Genda Chen, Cihan Dagli, Joel Burken	Indirect
Army Research Laboratory/Leonard Wood Institute	Roadside Explosive Hazard Indicator and Deterrent System (REHIDS)	$150K (10/09 – 10/10)	John Myers	Indirect
Army Research Laboratory/Leonard Wood Institute	"Long" Carbon Fibers for Blast Resistant Concrete	$564K (9/09 – 12/10)	Jeffery Volz and Jason Baird	Indirect
Army Research Laboratory/Leonard Wood Institute	IED Crater Repair for Enduring Route Remediation	$474K (8/09 – 12/10)	John Myers	Indirect
Army Research Laboratory/Leonard Wood Institute	Blast Tests of Full-Sized Barrier Walls	$40K (7/09 – 12/09)	Genda Chen and Jason Baird	Direct
National Science Foundation	Development and Characterization of Reactive Enamel-Coated Steel Rebar for Improved Concrete-Steel Bonding and Enhanced Corrosion Resistance	$250K (6/09 – 6/12)	Genda Chen, Jeffery Volz and Richard Brow	Direct
National Cooperative Highway Research Program (NCHRP)	NCHRP 12-82 Developing Reliability-Based Bridge Inspection Practices	$400K (4/09 – 12/10)	Glenn Washer	Direct
National Science Foundation	Fracture Analysis of Concrete via Experimentation and Simulation: Examining Discrete Crack and Fracture Modeling of Concrete under Blast and Impact and Loading	$406K (10/08 – 9/12)	Ganesh Thiagarajan	Indirect
National Science Foundation	MRI: Acquisition of Mechanical Testing Equipment to Support Musculoskeletal	$234K (?-?)	Trent Guess, Ganesh Thiagarajan, Mark	Indirect

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What is Next?

- Long-Term Research Program

  Develop and/or calibrate material, design, and construction specifications/guidelines against local and regional conditions such as environmental conditions (climate and geology), operational conditions (traffic volume, tolerance to traffic disruption, and public demand on roadway condition), and resources (recycled materials, multi-mode operation) in the state of Missouri.

- Example Research Directions
  - Some field validations on Phase I findings
  - Design examples with specifications developed in Phase I
  - Secondary route performance improvement in rural areas
  - High-speed railway system safety and assessment
  - Others depending on MoDOT needs

Acknowledgement

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The findings and opinions expressed in this presentation are those of the research investigators. They don't necessarily represent those of the sponsors.