Recent Durability Performance Results in Closure Joints of Modular Bridge Decks

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Outline

- Introduction
- Connection Concepts and Design
- Durability of Closure Pour (CP) Materials
- Conclusions

NCHRP 10-71
Cast-in-Place Concrete Connections for Precast Deck Systems (2006-2010)

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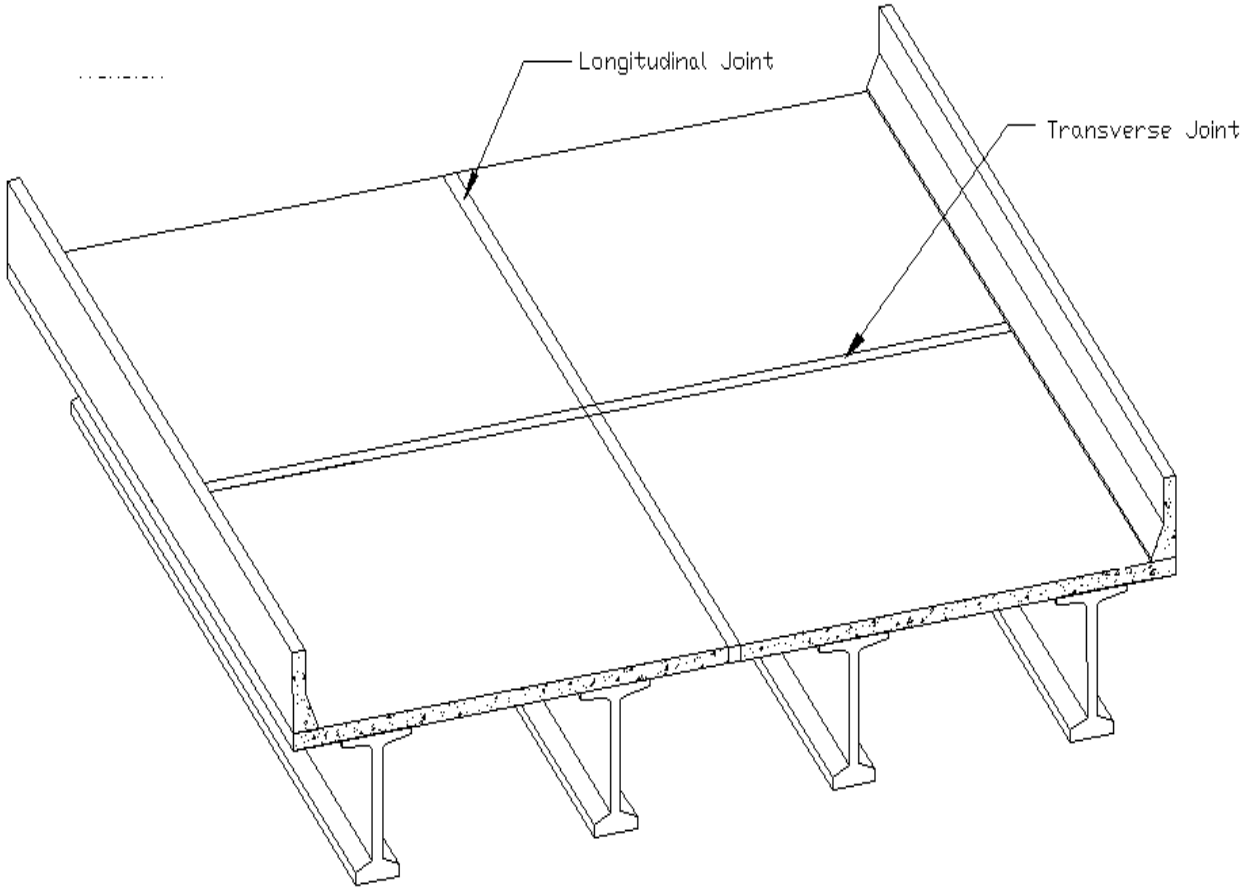
Consultants

- **UTK Subtasks Objectives (NCHRP10-71):**
  - **Develop design guidelines for longitudinal and transverse connections between full-depth deck panels or deck flanges (no overlays or post-tensioning to be used)**
  - **Emphasize increasing construction speed while achieving durability and ride quality**

Longitudinal and Transverse Joints in Deck Panels



Longitudinal Joint in Deck Bulb Tees

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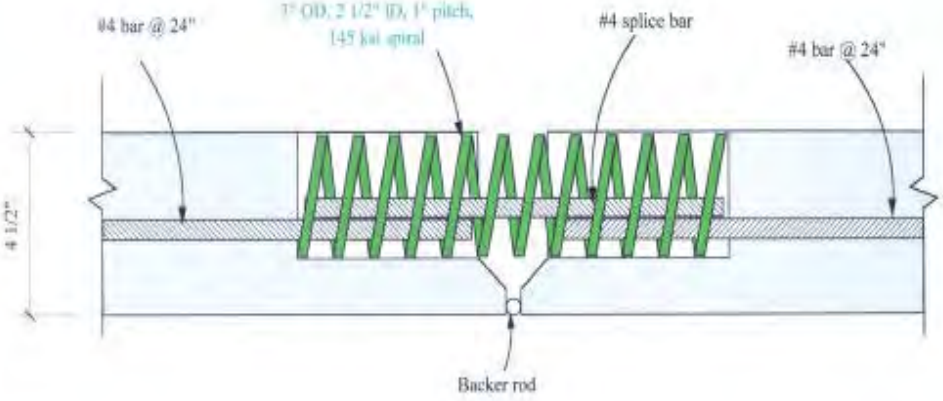
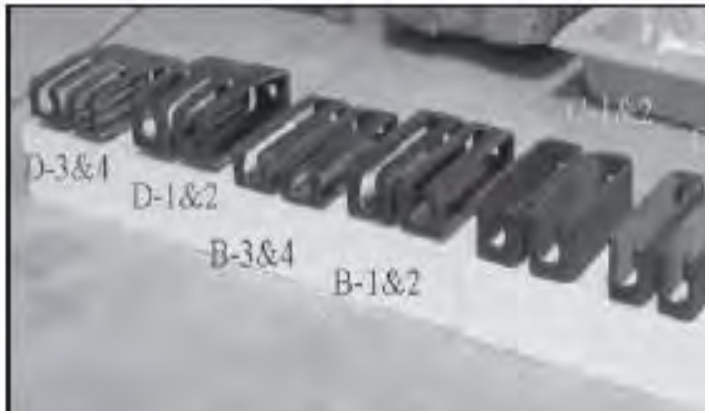
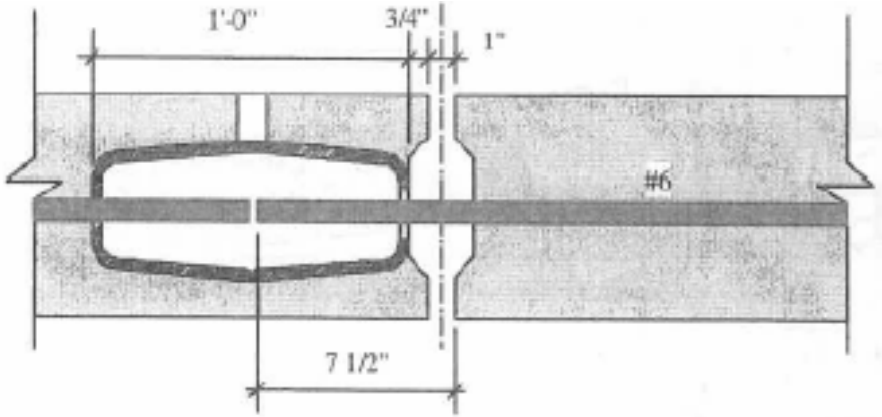
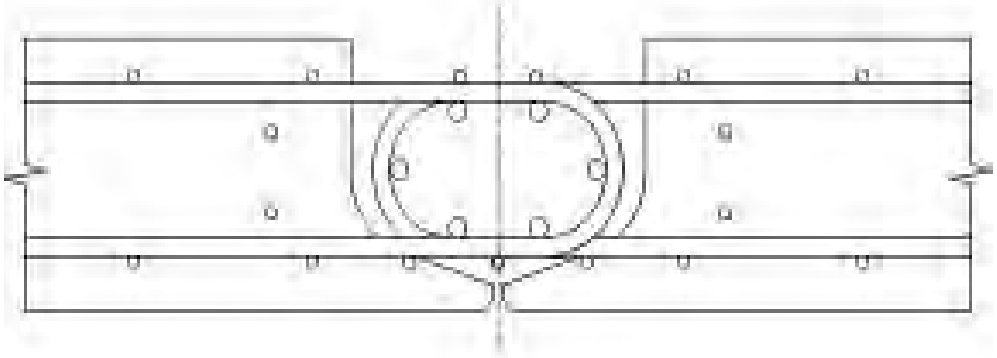
Current Joint Details

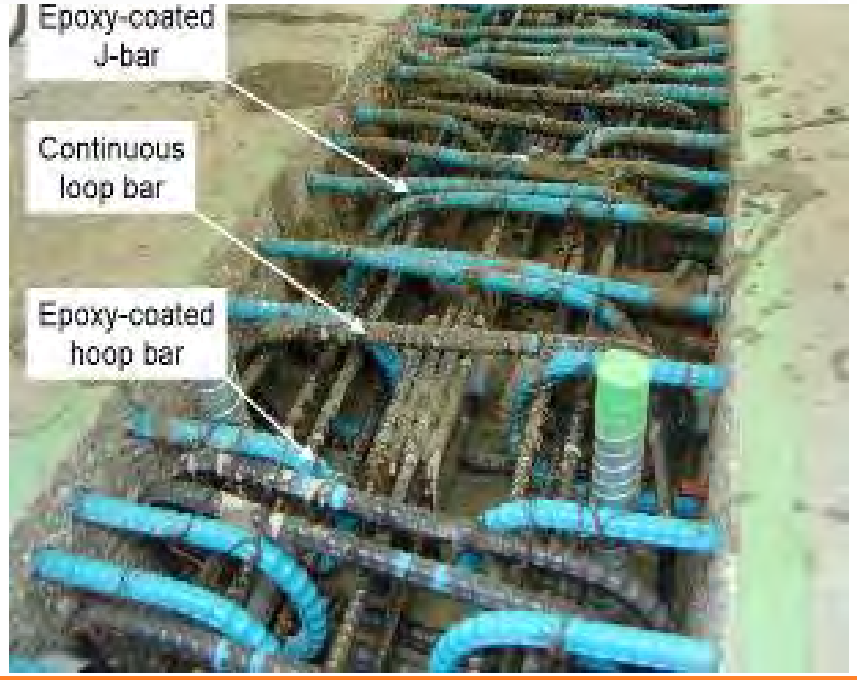






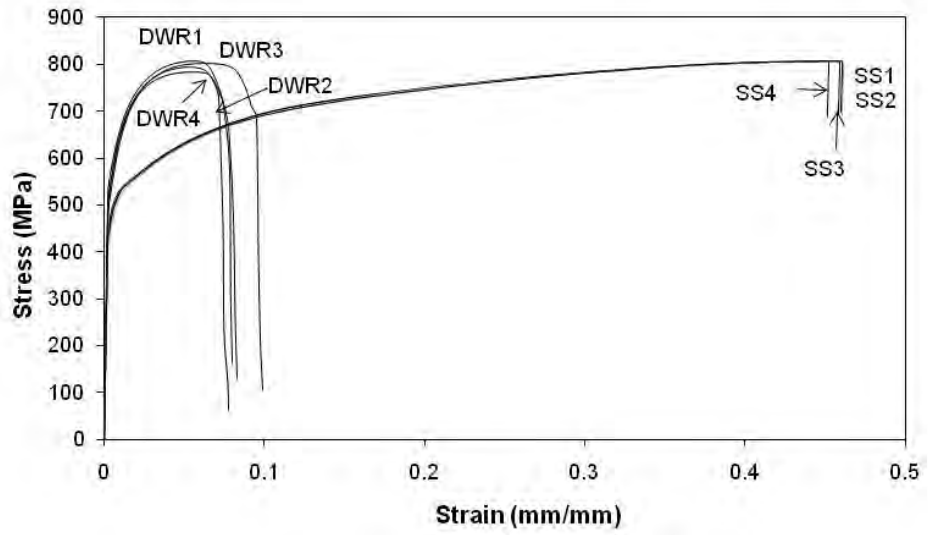
U-/Loop Joint used in Japan





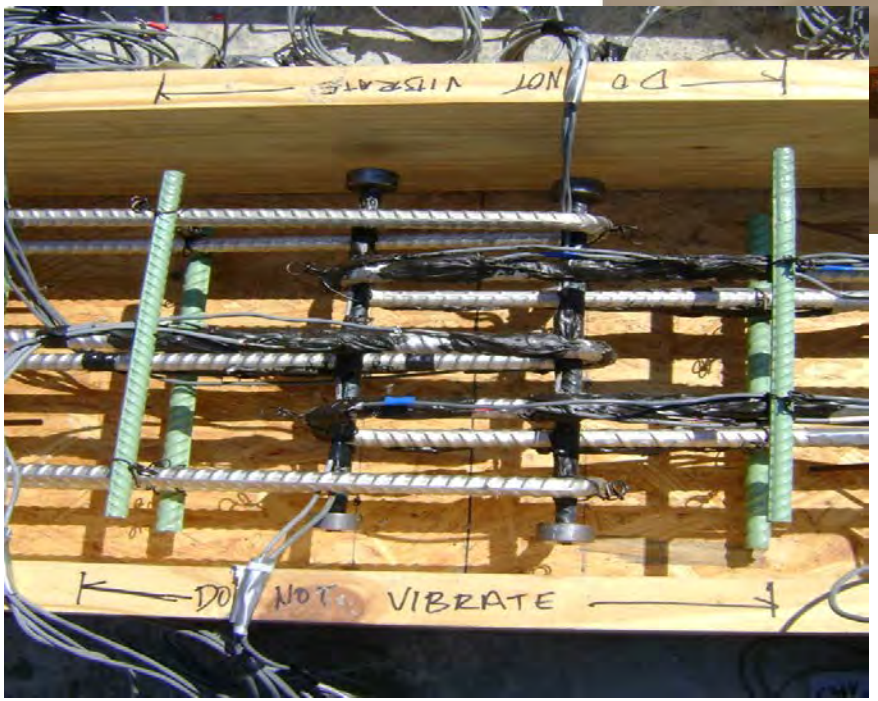
Rebar Bend Diameter Requirements

Reinforcement Type	Publication	Bar Size	Bend Diameters
Conventional Rebar	ACI Code	#5	6*d
Deformed Wire Reinforcement (DWR)	ASTM Standards	D31 (approx. #5)	4*d
Stainless Steel	ASTM Standards	#5	3.5*d

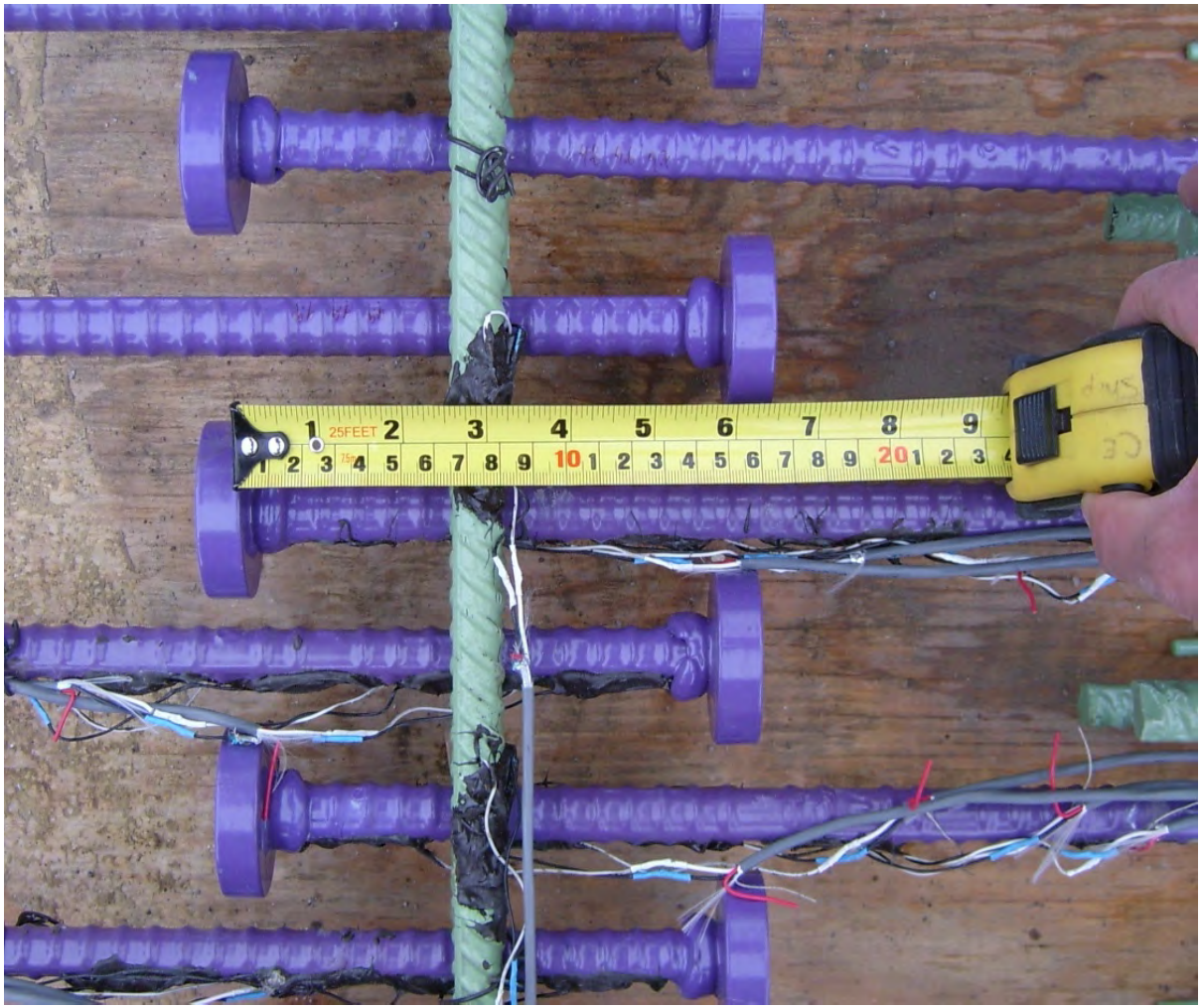


U-Bar Detail

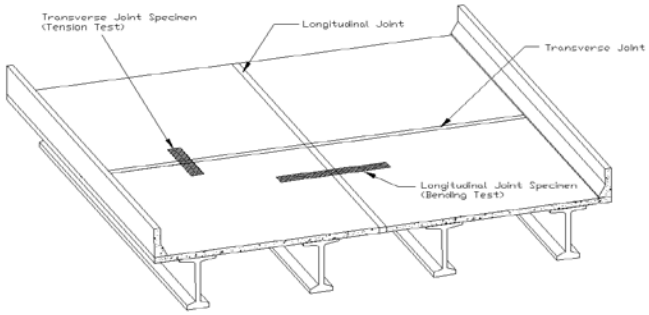
- 3d (1 7/8") bend used to minimize deck thickness
- *Using DWR and SS*



Headed Rebar Joint Detail



Test Set-Ups

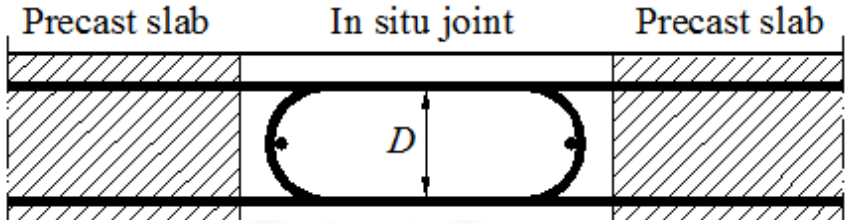


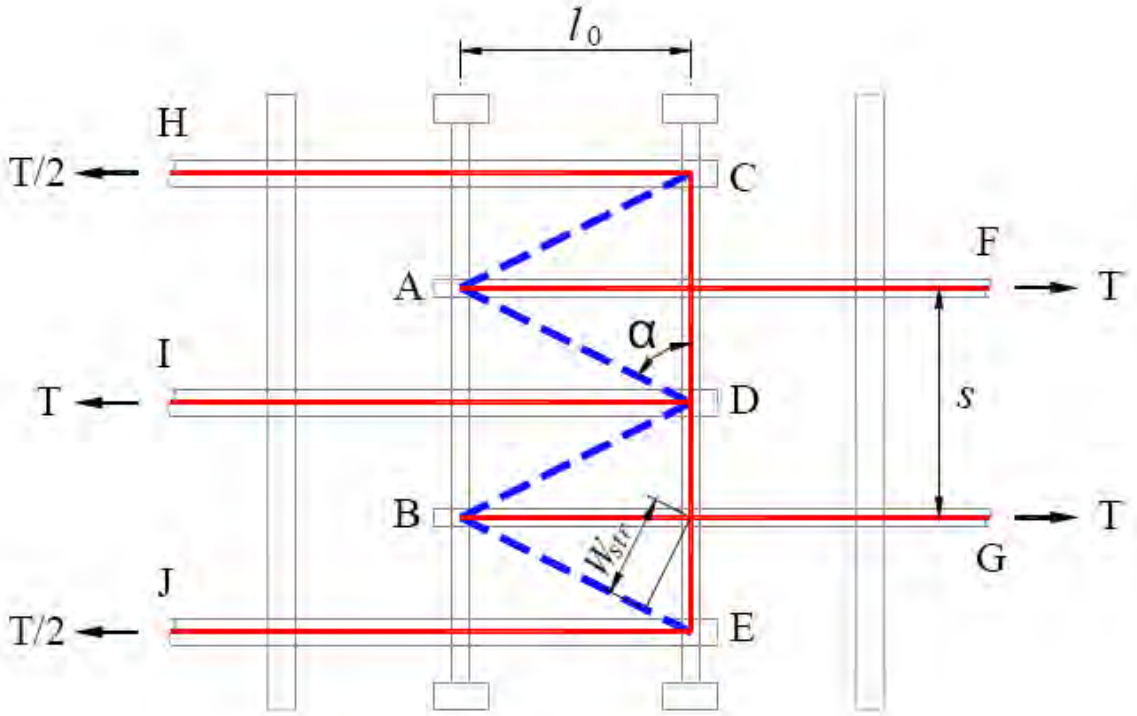
Longitudinal Joint Test

Transverse Joint Test

Joint Design by Strut-and-Tie Model (STM)

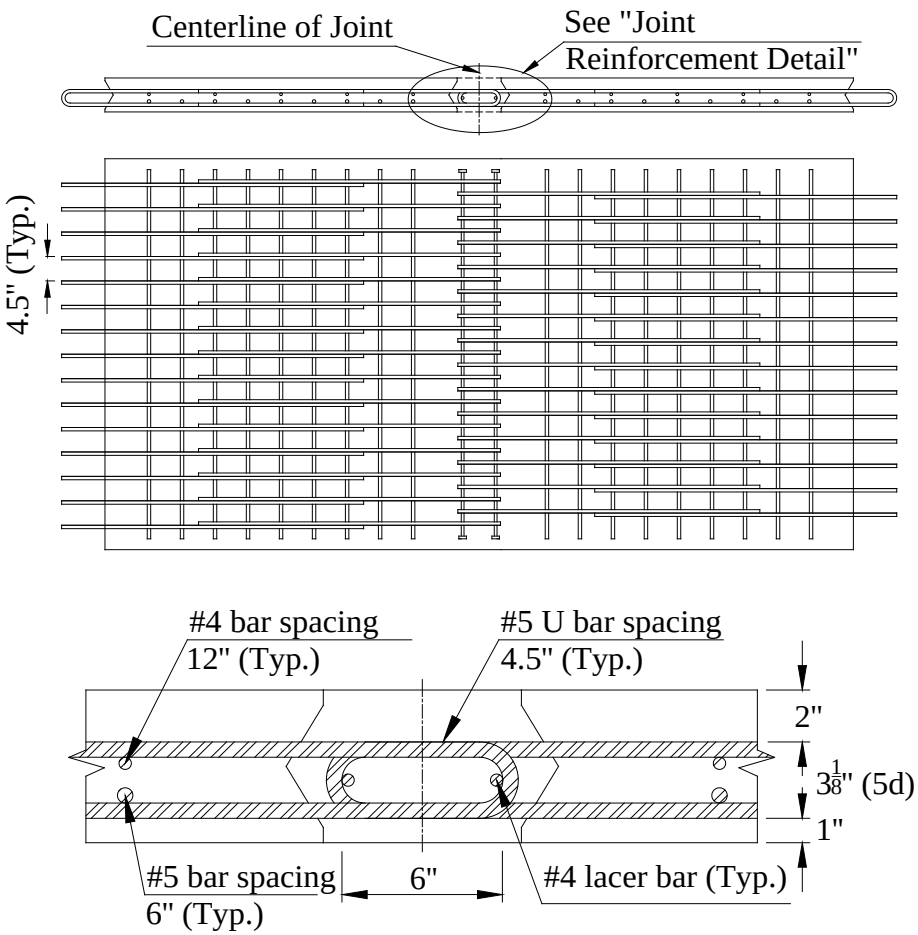
The tension capacity may be controlled by the yielding of U-bars or lacer bars, or crushing of concrete within the overlapping U-bars.





$$T_u = n_\Delta \cdot \min\left[0.85 f_c' \frac{D l_0^{\,2} s}{l_0^{\,2} + (s/2)^2},\ f_{y,ubar} A_{ubar},\ \frac{4 f_{y,lbar} A_{lbar} l_0}{s}\right]$$

Joint Design Example



"Joint Reinforcement Detail "

For detailed design examples, please see the following NCHRP Web-only Document 173:

http://www.trb.org/Publications/Blurbs/164971.aspx

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- **Durability of Closure Pour (CP) Materials**
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Two categories for accelerated construction:

- Overnight (8 hours) cure of CP materials
- 7-day cure of CP materials

Performance Characteristics Investigated

To have a more durable deck joint

- Shrinkage
- Chloride Penetration
- Freezing-and-thawing Durability
- Bond Strength

To develop headed bars and/or U-bars within a short overlap length

- Compressive Strength

Literature Review

Bob Gulyas from BASF Construction Chemicals, LLC – Project consultant

- "Nonshrink" grouts are still susceptible to drying shrinkage
- Cementitious grouts must be kept continuously wet to keep them from shrinking
- Grout materials that do not shrink include magnesium ammonium phosphate (MAP)
- If MAP is used, surface preparation is very important

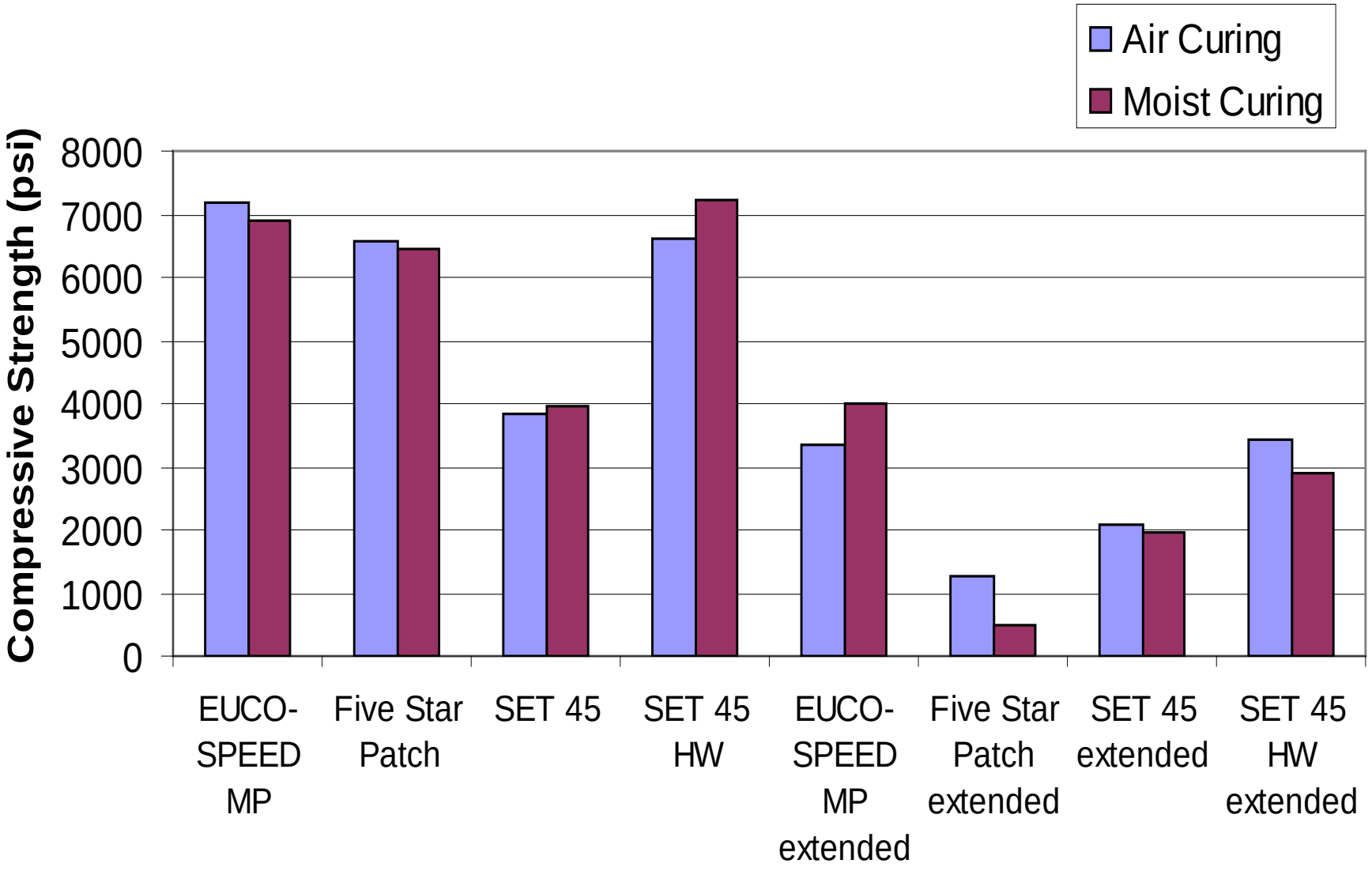
Literature Review

- **Overnight Cure**:
  - Two magnesium ammonium phosphate (MAP) based grouts (with and without aggregate extension)
  - Non-shrink cement grout
  - Polymer-modified grout**
- **7-day Cure**:
  - Five HPC mixes (Three from HPC Showcase Bridge Projects; and two from Lafarge North America)
  - Rapid set low permeability (RSLP) hydraulic cement mix
  - Two latex modified concrete mixes
  - UHPC**

Candidate Overnight Cure Materials Selection

Product Name		Mixing Quantities per 50-lb, Bag				
		Initial Water, pints	Additional Water, pints	Aggregate Extension, % by weight	Aggregate Extension, lb	Yield Volume, cu. ft.
Neat Grout	EUCO-SPEED MP	3.1	0.5	0	0	0.42
	Five Star® Patch	5.00	1.00	0	0	0.40
	Set® 45	3.25	0.50	0	0	0.39
	Set® 45 HW	3.25	0.50	0	0	0.39
Extended Grout	EUCO-SPEED MP	3.1	0.5	60	30	0.57
	Five Star® Patch	5.00	1.00	80	40	0.66
	Set® 45	3.25	0.50	60	30	0.58
	Set® 45 HW	3.25	0.50	60	30	0.58

Compressive Strength at 8 hours



HPC Mixes Selection

- NCHRP project 18-08A (NCHRP Report 566: Guidelines for Concrete Mixtures Containing Supplementary Cementitious Materials to Enhance Durability of Bridge Decks)

Predicted Desirability for the Five HPC Mixes

	MIX 1	MIX 2	MIX 3	MIX 4		MIX 5	
Predicted Overall Desirability	0.71	0.71	0.81	0.89[1]	0.83[2]	0.85[1]	0.82[2]
7-day Compressive Strength Desirability	0.96	0.46	0.60	1.0	0.67	1.0	0.74

1 - Type C Fly ash; 2 - Slag

7-day Cure Mixes Selection

	HPC MIX# 1	HPC MIX# 4	HPC MIX# 5	LMC-VE	RSLP	Emaco T430 mix
Compressive Strength (psi)	6394	4112	2784	4404	11640	1470

Candidate 7-day Cure CP Materials

Mix Number	HPC Mix 1	RSLP
W/CM Ratio	0.31	0.40
Cement Type	I	CTS RSLP
Cement Quantity, lb/yd^3	750	658
Type C Fly Ash Quantity, lb/yd^3	75	
Fine Aggregate, lb/yd^3	1400	1695
#8 Coarse Aggregate, lb/yd^3	1400	1454
Water, lb/yd^3	255	263
Air Entrainment, fl oz/yd^3	5	
Water Reducer, fl oz/yd^3	30	
HR Water Reducer, fl oz/yd^3	135	

Candidate Materials (Long-term Tests)

Overnight: Two magnesium ammonium phosphate (MAP) mortars [MAP1 ="EUCO-SPEED MP" and MAP2="SET 45 HW"]

7-Day: HPC (i.e., HPC Mix 1) and RSLP

Shrinkage Test Method

Cracks due to the restraint, the stiffness, and the drying shrinkage.

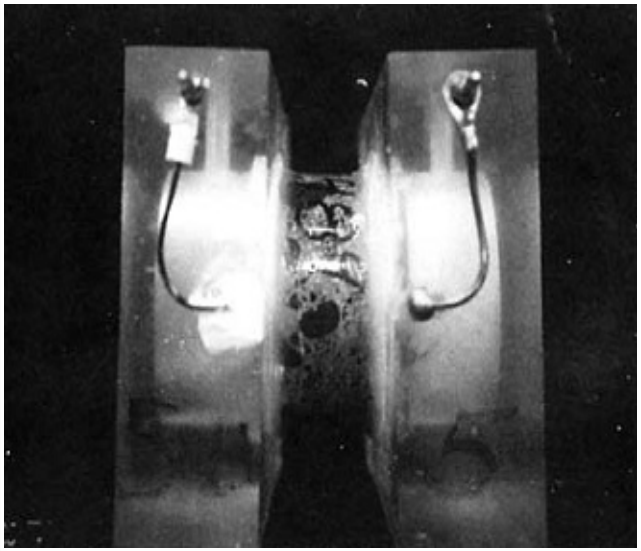
ASTM
C157

AASHTO
PP34

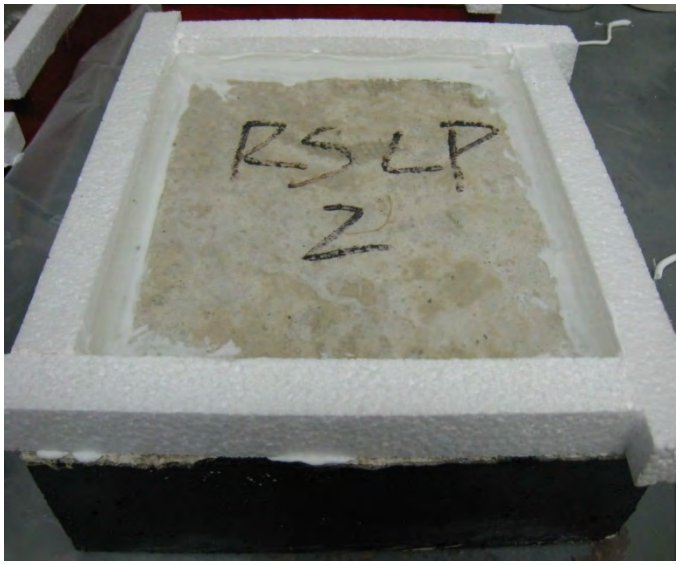
Chloride Penetration Test Method

RCP test has some interference problems with materials such nitrate corrosion inhibitors and even the test materials (e.g. Set-45).

ASTM C1202 RCP test



ASTM C1543 Ponding test



Freezing-and-Thawing Durability

- ASTM C666

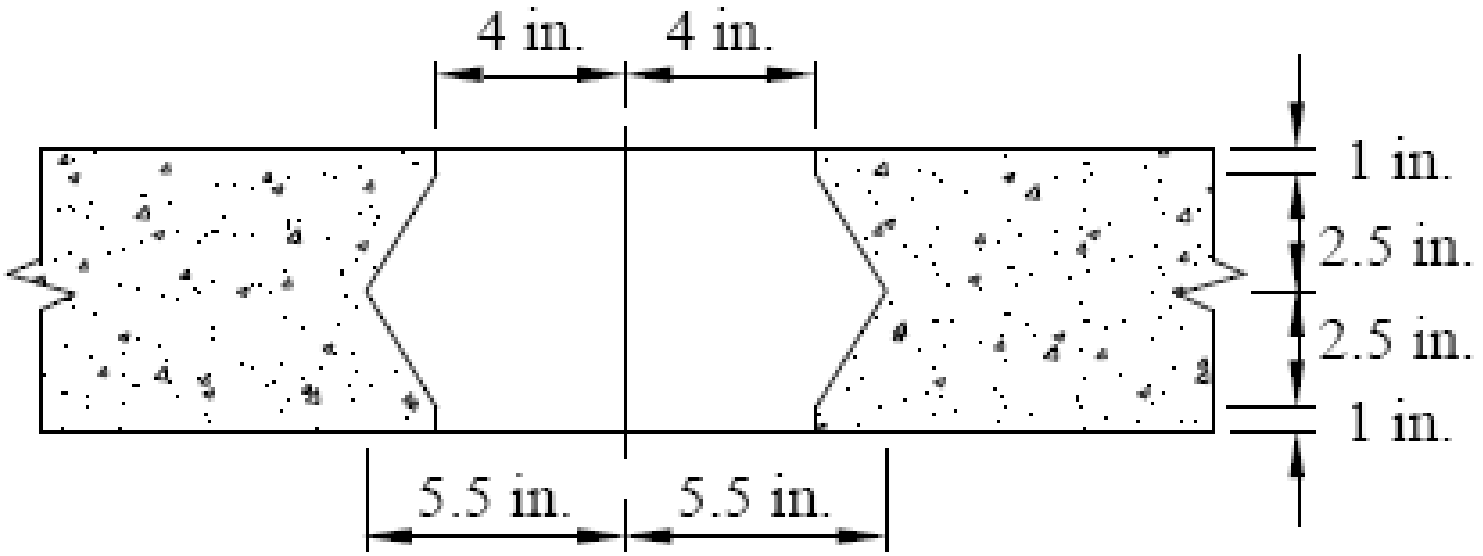
Freezing-and-Thawing Apparatus

Temperature Recorder

Bond Strength

- ASTM C882

Shear Key Detail



Shear Key Detail

Joint Surface Preparation

Before

After

Black Beauty 2050 sand was chosen for **sandblasting** to prepare the surface

Curing

Worst case scenario (no cure):

Air cure

Best case scenario (100% humidity cure):
Moist Room OR Water Storage Tank

Something in between: **Curing compound**

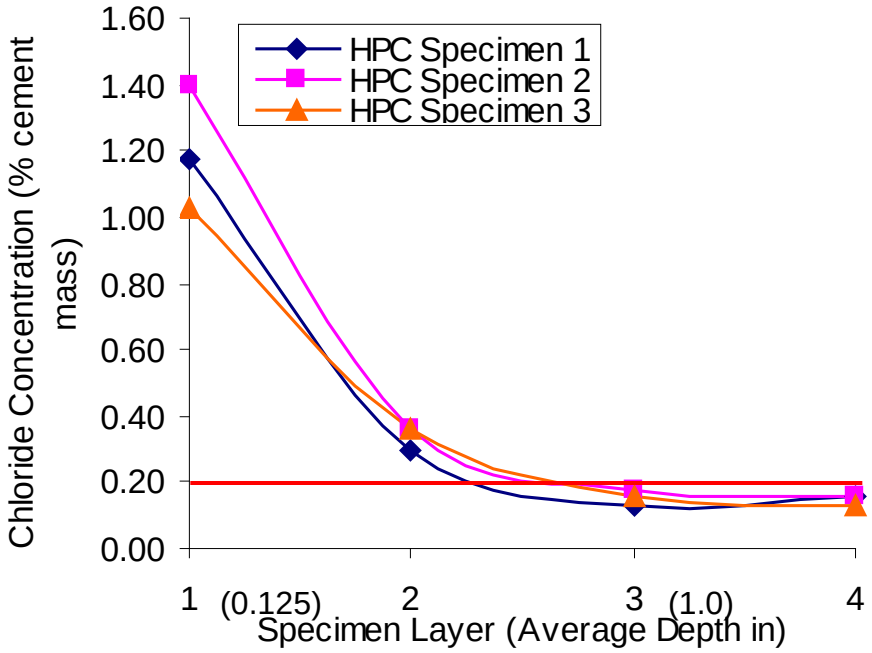
Both the membrane-forming compound method
and the water method with burlap

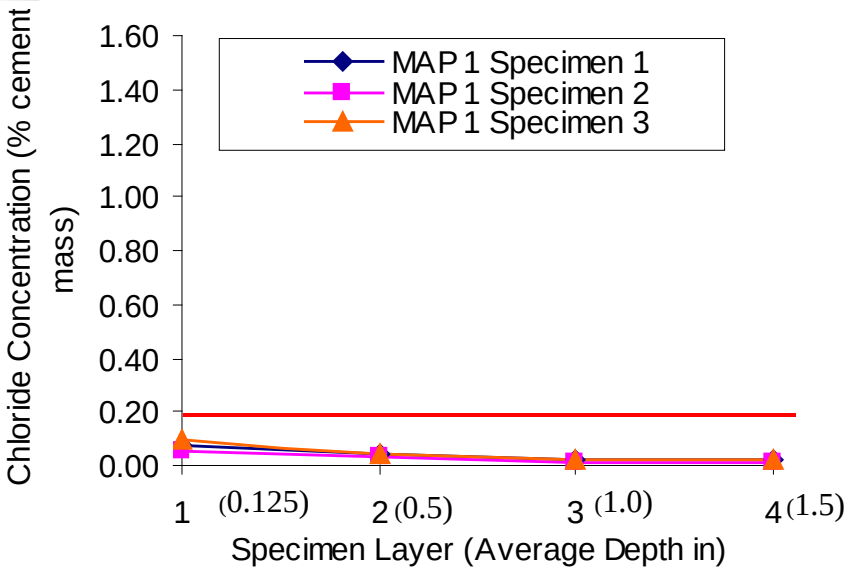
Shrinkage Steel Ring Test Results

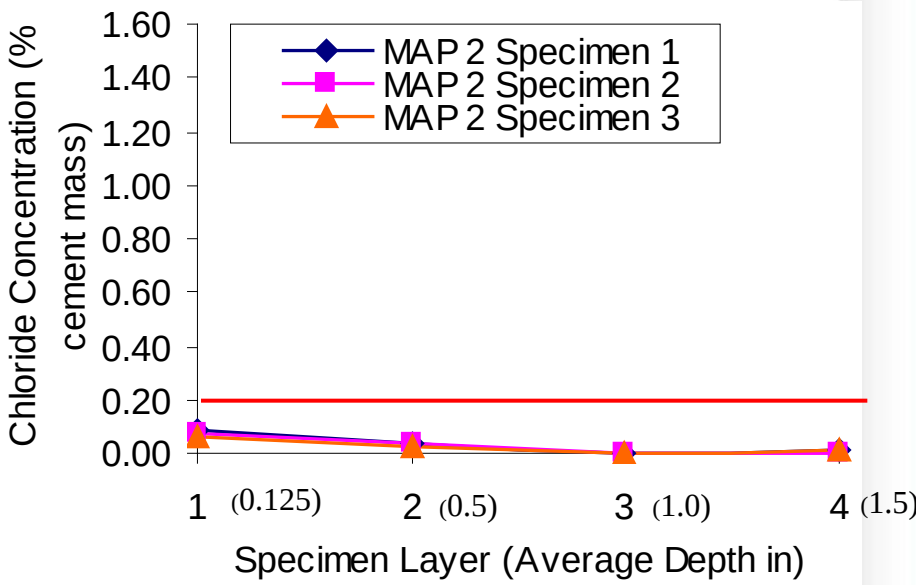
- Cracks were found for specimens of the HPC at the age of 20.5 days.

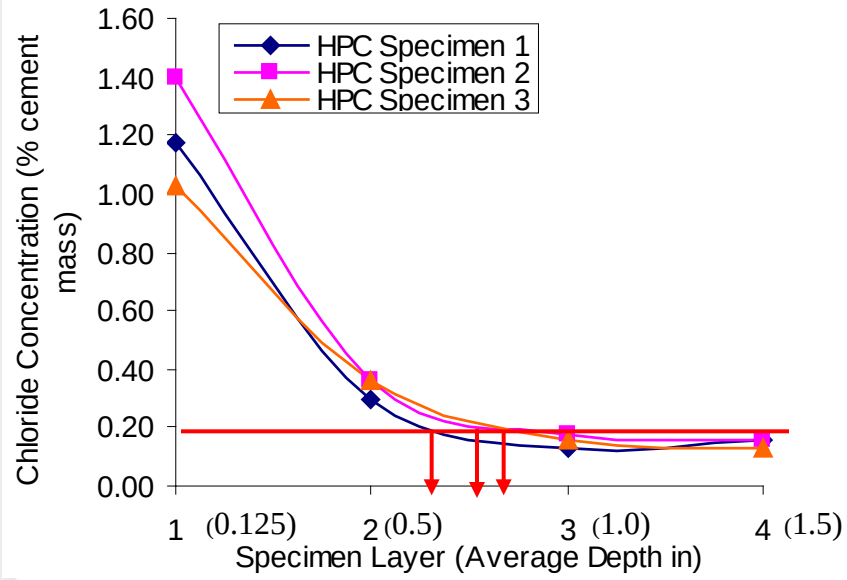
- No crack was observed to occur for MAP1, MAP2, and RSLP throughout the tests which were terminated at the ages of 62, 58, and 61 days, respectively.

Chloride Content Profile (90-day ponding)




MAP 1 Specimen 1
MAP 1 Specimen 2
MAP 1 Specimen 3
Chloride Concentration (% cement mass)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1 (0.125) 2 (0.5) 3 (1.0) 4 (1.5)
Specimen Layer (Average Depth in)


MAP 2 Specimen 1
MAP 2 Specimen 2
MAP 2 Specimen 3
Chloride Concentration (% cement mass)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1 (0.125) 2 (0.5) 3 (1.0) 4 (1.5)
Specimen Layer (Average Depth in)


HPC Specimen 1
HPC Specimen 2
HPC Specimen 3
Chloride Concentration (% cement mass)
1.60
1.40
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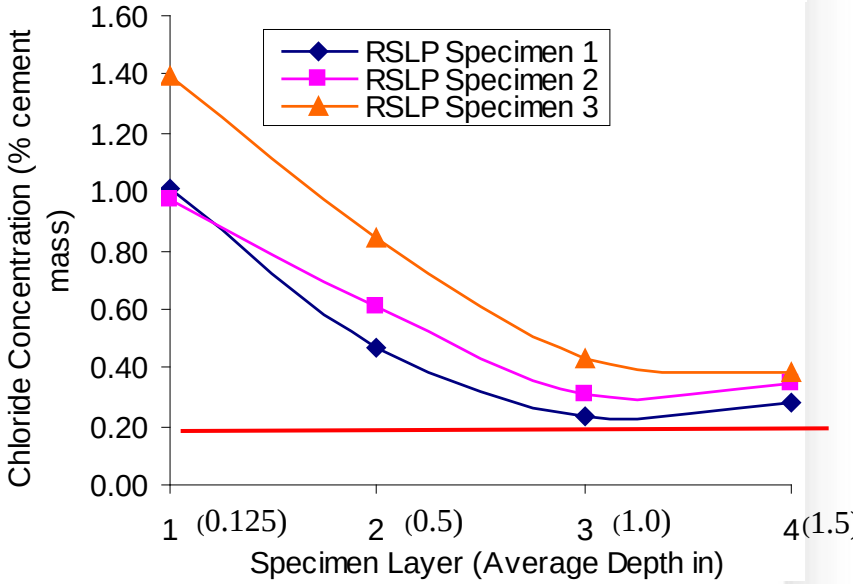
0.00
1 (0.125) 2 (0.5) 3 (1.0) 4 (1.5)
Specimen Layer (Average Depth in)


RSLP Specimen 1
RSLP Specimen 2
RSLP Specimen 3
Chloride Concentration (% cement mass)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1 (0.125) 2 (0.5) 3 (1.0) 4 (1.5)
Specimen Layer (Average Depth in)

Freezing-and-thawing Durability Test Results

	MAP 1	MAP 2	HPC	RSLP
Relative dynamic modulus of elasticity after 300 cycles	92%	96%	96%	Fail after 70 cycles

Bond Strength Test Results

Material Type	Specimen Number	Test Age	Shear Stress (psi)	Average Shear Stress (psi)	
MAP 1	1	8 hours	456	397	
	2		159		
	3		576		
MAP 2	1	8 hours	1161	1176	
	2		1121		
	3		1240		
HPC	1	7 days	1607	1817	
	2		1917		
	3		1925		
RSLP	1	7 days	659	705	
	2		634		
	3		823		

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Conclusions

- **Development of a comprehensive design guide (**Research Results Digest 355, **http://www.trb.org/Main/Blurbs/165677.aspx) for the design and construction of longitudinal and transverse joints for full depth deck panels and decked bulb T's**
- **Development of both loop bar and headed bar details**
- **For loop bar detail, shallow deck thicknesses (e.g. 6 inches) required the use of tighter bends; and thus recommendations are restricted to wire reinforcement and stainless steel reinforcement which may accommodate tighter bends due to their higher levels of ductility**

Conclusions: Proposed Performance Criteria of CP Materials

Performance Characteristic	Test Method	Performance Criteria		
Compressive Strength (CS), ksi	ASTM C39 modified	6.0≤CS @ 8 hours (overnight cure) @ 7 days (7-day cure)		
Shrinkage(S), (Crack age, days)	AASHTO PP34 modified	20<S		
Chloride Penetration(ChP), (Depth for Percent Chloride of 0.2% by mass of cement after 90-day ponding, in.)	ASTM C1543 modified	ChP<1.5		
Freezing-and-thawing Durability (F/T), (relative modulus after 300 cycles)	ASTM C666 Procedure A modified	Grade 1	Grade 2	Grade 3
		70%≤F/T	80%≤F/T	90%≤F/T
Bond Strength (BS), psi	ASTM C882 modified	300<BS		

Acknowledgements

UTK Graduate Students (Peng Zhu, Sam Lewis, Beth Chapman, Lungui Li, and Qi Cao)
Panel Members of NCHRP10-71
NCHRP Senior Program Officers (David Beal and Waseem Dekelbab)

BASF Construction Chemicals, LLC
CTS Cement Manufacturing Corporation
Dow Reichhold, Specialty Latex LLC
Enco Materials, Inc.
Engineered Wire Products
Five Star Products, Inc.
Gerdau Ameristeel
Lafarge North America, Inc.
Ross Prestressed Concrete, Inc.
Salit Specialty Rebar Inc.

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