EDC-7 Innovation : Enhancing Performance with Internally Cured Concrete (EPIC^2)

HIGH PERFORMANCE INTERNALLY CURED CONCRETE (HPIC)

NJSTIC Meeting
April 30th, 2025

Samer Rabie, Project Manager, DPM Team D
Jess Mendenhall, PE, Structural Engineer, Structural Engineering Services

AGENDA

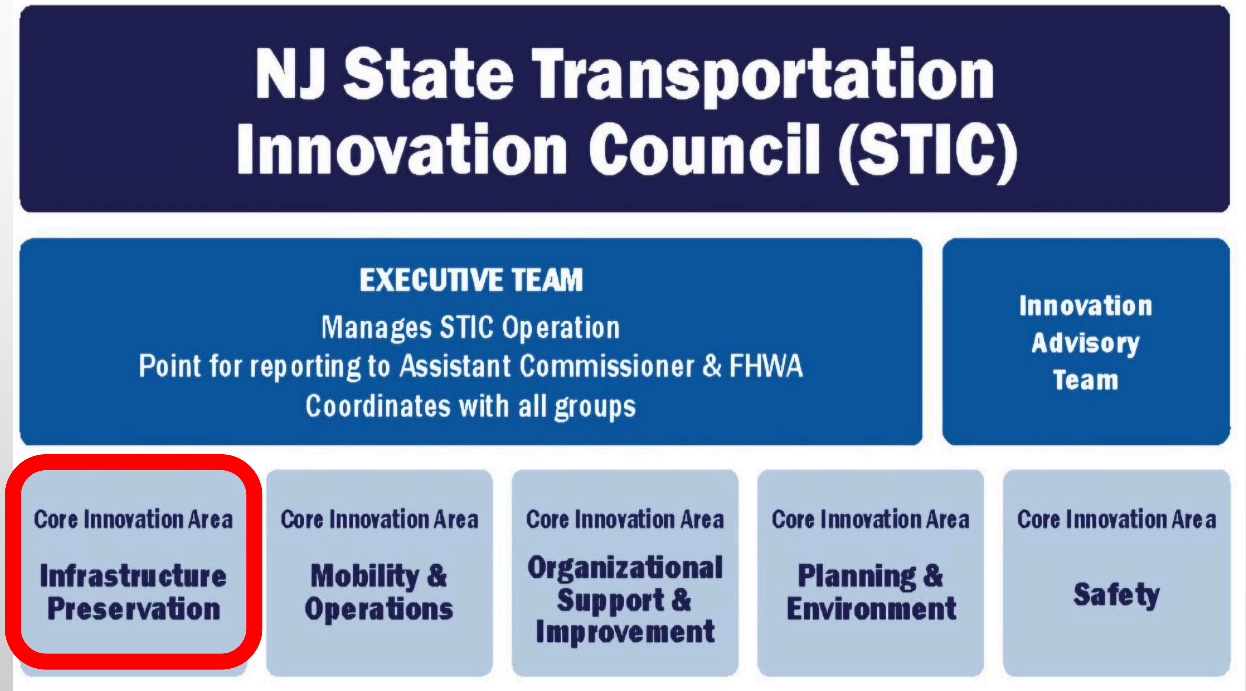
DEFINE THE PROBLEM & OBJECTIVE

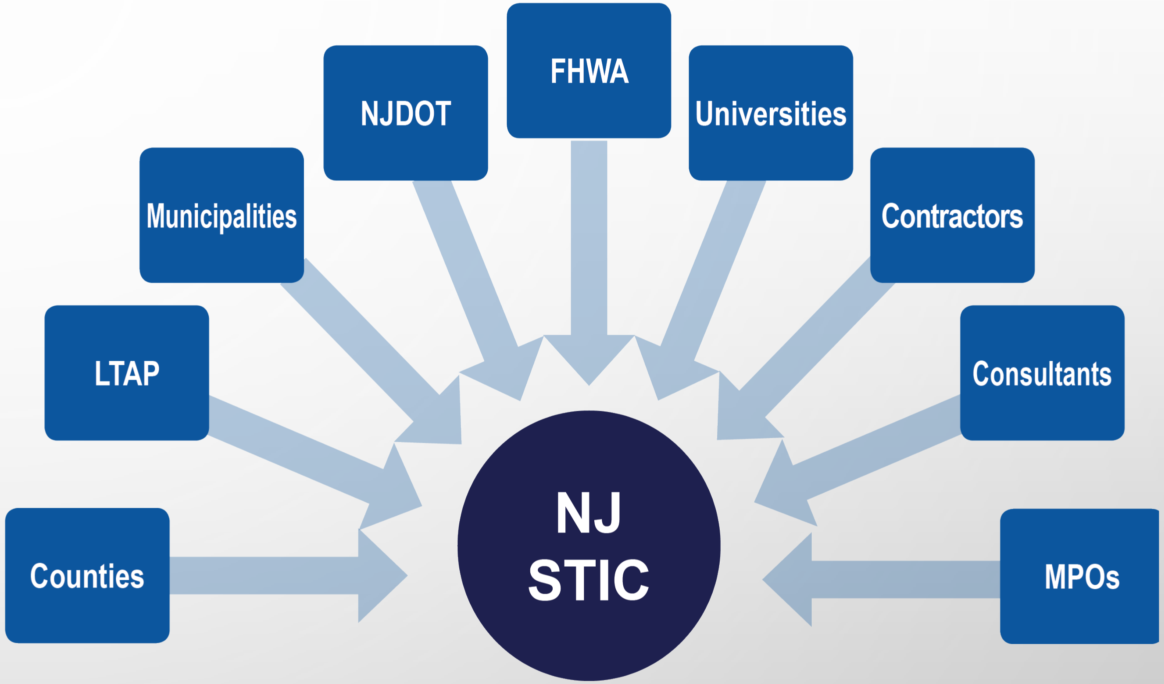
INTRODUCE INTERNAL CURING

DISCUSS THE IMPLEMENTATION PLAN

NEXT STEPS & GOALS

The State Transportation Innovation Council (STIC)





“Identify and rapidly deploy proven yet underutilized innovations…

shorten the project delivery process, enhance roadway safety, reduce traffic congestion, or integrate automation.”

The State Transportation Innovation Council (STIC)

- **EDC 1 (2011-2012) :**
  PREFABRICATED BRIDGE ELEMENTS & SYSTEMS (PBES)

- **EDC 2 (2013-2014) :**
  ACCELERATED BRIDGE CONSTRUCTION

- **EDC 3 & 4 (2015-2018) :**
  ULTRA HIGH PERFORMANCE CONCRETE (UHPC) FOR PBES

- **EDC 6 (2021-2022) :**
  UHPC FOR BRIDGE PRESERVATION & REPAIR

- **EDC 7 (2023-2024):**
  ENHANCING PERFORMANCE WITH INTERNALLY CURED CONCRETE (EPIC^2)

Core Innovation Area

Infrastructure Preservation

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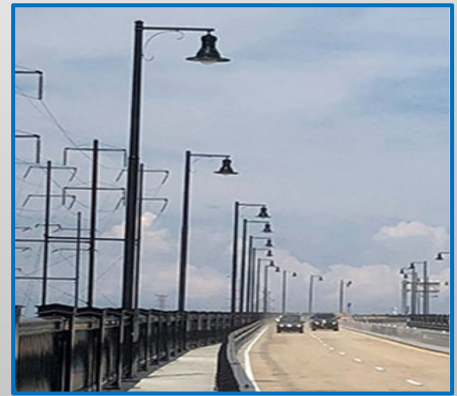


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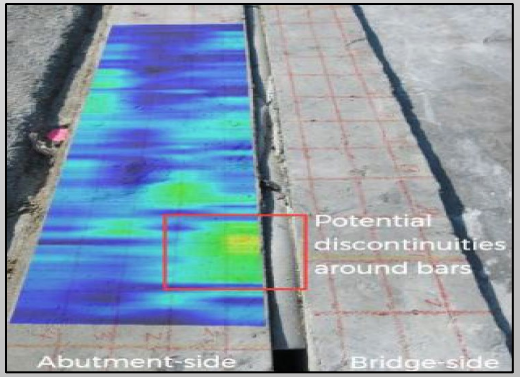


The State Transportation Innovation Council (STIC)

- EDC 1 (2011-2012): **Institutionalized**

  PREFABRICATED BRIDGE ELEMENTS & SYSTEMS (PBES)

- EDC 2 (2013-2014) : **Institutionalized**

  ACCELERATED BRIDGE CONSTRUCTION

- EDC 3 & 4 (2015-2018) : **Institutionalized**

  UHPC FOR PBES

- EDC 6 (2021-2022) : **Assessment**

  UHPC FOR BRIDGE PRESERVATION & REPAIR

- **EDC 7 (2023-2024):**

  ENHANCING PERFORMANCE WITH INTERNALLY CURED CONCRETE (EPIC^2)

Institutionalized
Assessment
Demonstration
Development
Not Implemented

HIGH PERFORMANCE CONCRETE (HPC)

HPC Section 903.05 :

- Low w/cm ratio : 0.40
- Large amount of Pozzalonic or SCM's (fly ash, slag, silica fume)
- Improved durability properties

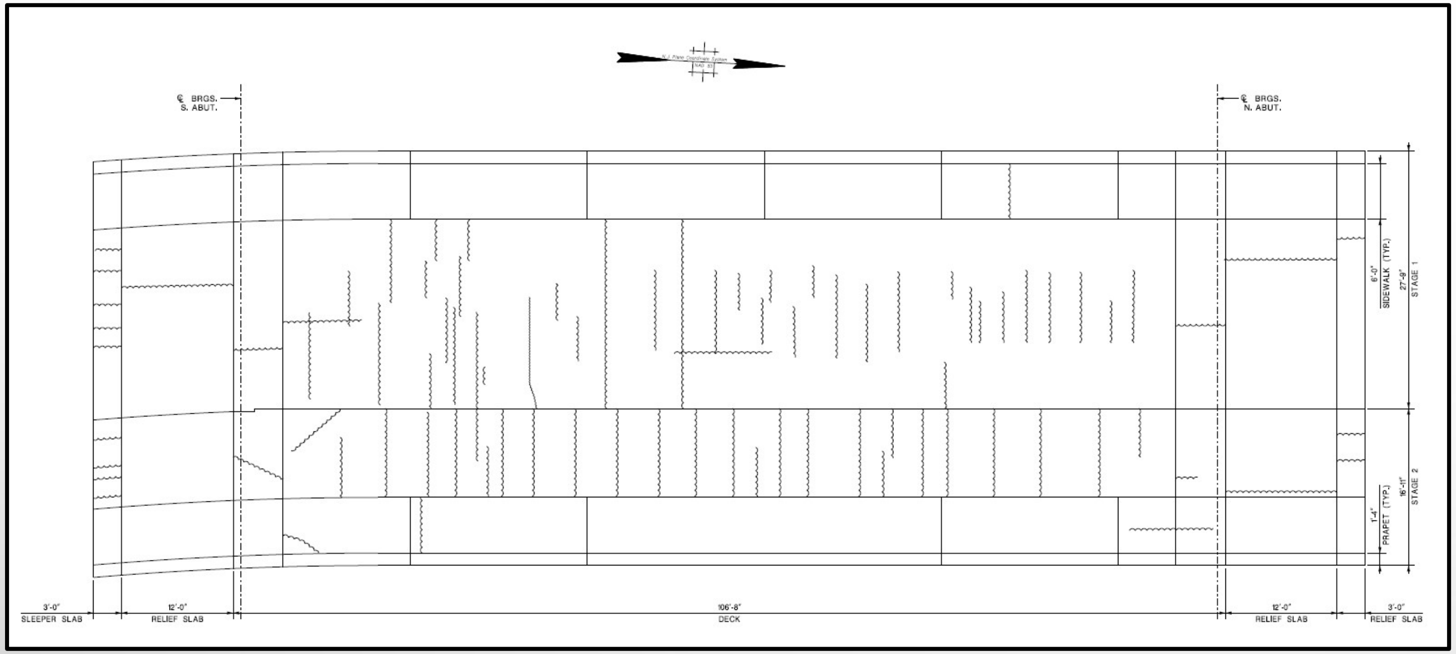
However,

- Increased susceptibility of cracking
- Undermined durability improvements
- Most HPC Bridge Decks experience shrinkage cracking
- Sealing of the cracking recommended

Curing Section 507.03.02.J :

- Within 30 min of texturing, apply wet burlap and white polyethylene sheeting for at least 14 days.
- Reduces Shrinkage, Cracking & Water movement.

HPC BRIDGE DECK TRANSVERSE CRACKING



New Jersey Department of Transportation
1035 Parkway Avenue, PO Box 600, Trenton, New Jersey 08625-0600

Baseline Document Change Announcement

ANNOUNCEMENT: BDC21S-05

DATE: January 06, 2023

SUBJECT: Concrete Deck Repair
- Revision to the 2019 Standard Specifications for Road and Bridge Construction, Subpart 507.02.01 and Subsection 507.04, & addition of Subpart 507.03.08

Subpart 507.02.01 and Subsection 507.04 have been revised & new Subpart 507.03.08 has been added to the 2019 Standard Specifications for Road and Bridge Construction in order to allow the RE to direct if and where to apply BRIDGE DECK AND BRIDGE APPROACH SEALING.

	QTY	UNITS	UNIT PRICE	SUBTOTAL	MARK UP	SUB TOTAL
MATERIAL						
FURNISH SIKAGARD -705L (2 COATS APPROX. 11,000SF/CT) - 5 GAL PAIL	20	EA	$ 375.00	$ 7,500.00	$ 1,875.00	$ 9,375.00
FURNISH PUMP SPRAYERS	2	EA	$ 180.00	$ 360.00	$ 90.00	$ 450.00
LABOR (6 MAN CREW, 10 HR SHIFTS) 2 SHIFTS TO PREP, 2 SHIFT TO APPLY						
LABOR FOREMAN	40	HR	$ 127.36	$ 5,094.40	$ -	$ 5,094.40
LABORER	200	HR	$ 124.79	$ 24,958.00	$ -	$ 24,958.00
EQUIPMENT PER SHIFT						
FOREMAN TRUCK	40	HR	$ 24.26	$ 970.40	$ -	$ 970.40
LIGHT TOWER	40	HR	$ 14.82	$ 592.80	$ -	$ 592.80
GENERATOR	40	HR	$ 8.80	$ 352.00	$ -	$ 352.00
COMPRESSOR	40	HR	$ 16.68	$ 667.20	$ -	$ 667.20
PRESSURE WASHER	40	HR	$ 5.79	$ 231.60	$ -	$ 231.60
TMA	40	HR	$ 41.27	$ 1,650.80	$ -	$ 1,650.80
BOX TRUCK	40	HR	$ 27.42	$ 1,096.80	$ -	$ 1,096.80
ARROW BOARD	40	HR	$ 2.43	$ 97.20	$ -	$ 97.20
GRAND TOTAL						$ 45,536.20

TYPES OF SHRINKAGE CRACKS

Type	What is happening	When	What is driving this	Mitigation strategies
Plastic	Water leaving the concrete <u>before setting</u>	First few hours	Bleeding & evaporation rate	Use fibers, curing membranes, foggers, etc..
Drying	Water leaving the concrete after setting	Weeks and months	Relative humidity of the environment	External curing, aggregate choice, minimize water, shrinkage reducing admixtures, reinforcement, expansive cements
Thermal	Concrete temperature changing	First few days and on-going	Environmental temperatures swings and high heat of hydration	Minimize heat of hydration, low thermal expansion aggregates
Autogenous (Chemical)	Water consumed by hydration of cementitious materials <u>after setting</u>	First few days	Self-desiccation of cementitious materials (insignificant when w/c>0.42)	Minimize self desiccation and rate of hydration (lower cement content), reinforcement, and <u>**INTERNAL CURING**</u>

Source: WJE

PROBLEM

Early-age Cracking (within 60 days) in HPC Bridge Decks and the resulting Reduction in Service Life.

OBJECTIVE

Reduce Autogenous Shrinkage and the resulting Transverse Cracking in new HPC Bridge Decks.

EDC-7:

ENHANCING PERFORMANCE WITH INTERNALLY CURED CONCRETE (EPIC^2)

More than 30 years of extensive studies have shown that internal curing addresses:

- **Durability:** targets and mitigates the source of shrinkage cracking particularly in lower w/cm concretes, resulting in lower permeability concretes to improve durability

- **Versatility:** can be used anywhere traditional concrete is used.

- **Cost Savings:** higher-durability and reducing the need to rehabilitate or replace critical elements such as bridge decks during the design life of the bridge, resulting in life-cycle cost savings.

- **Embodied Carbon Reduction:** opportunities for increased utilization of natural, waste, or recycled SCMs without reduced performance or increased risk of cracking.

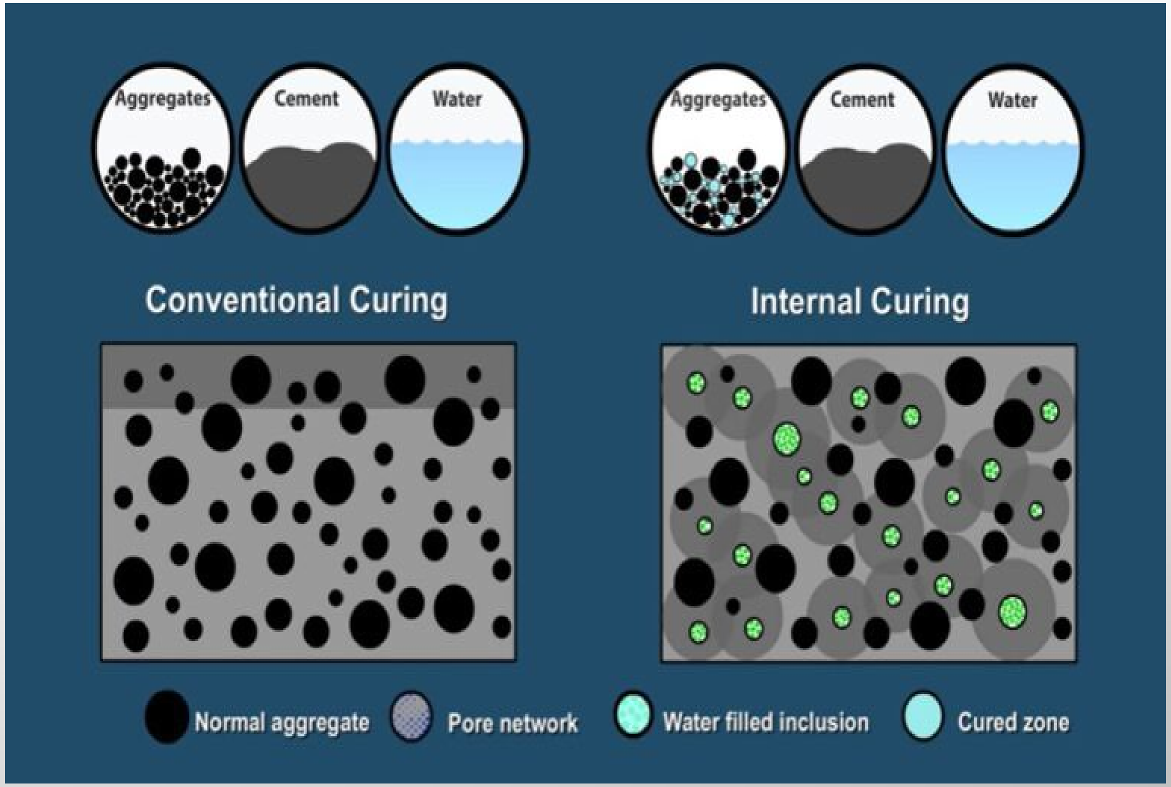
INTERNAL CURING

- Internal curing is simply curing where the water is provided from inside.

- The main difference between HPC and HPIC is
  Replacing **some** conventional fine aggregate (sand) with pre-wetted lightweight fine aggregate (LWFA).

- Water absorbed :
  - Does not contribute to the w/cm ratio
  - Remains in the LWFA during mixing and until set.

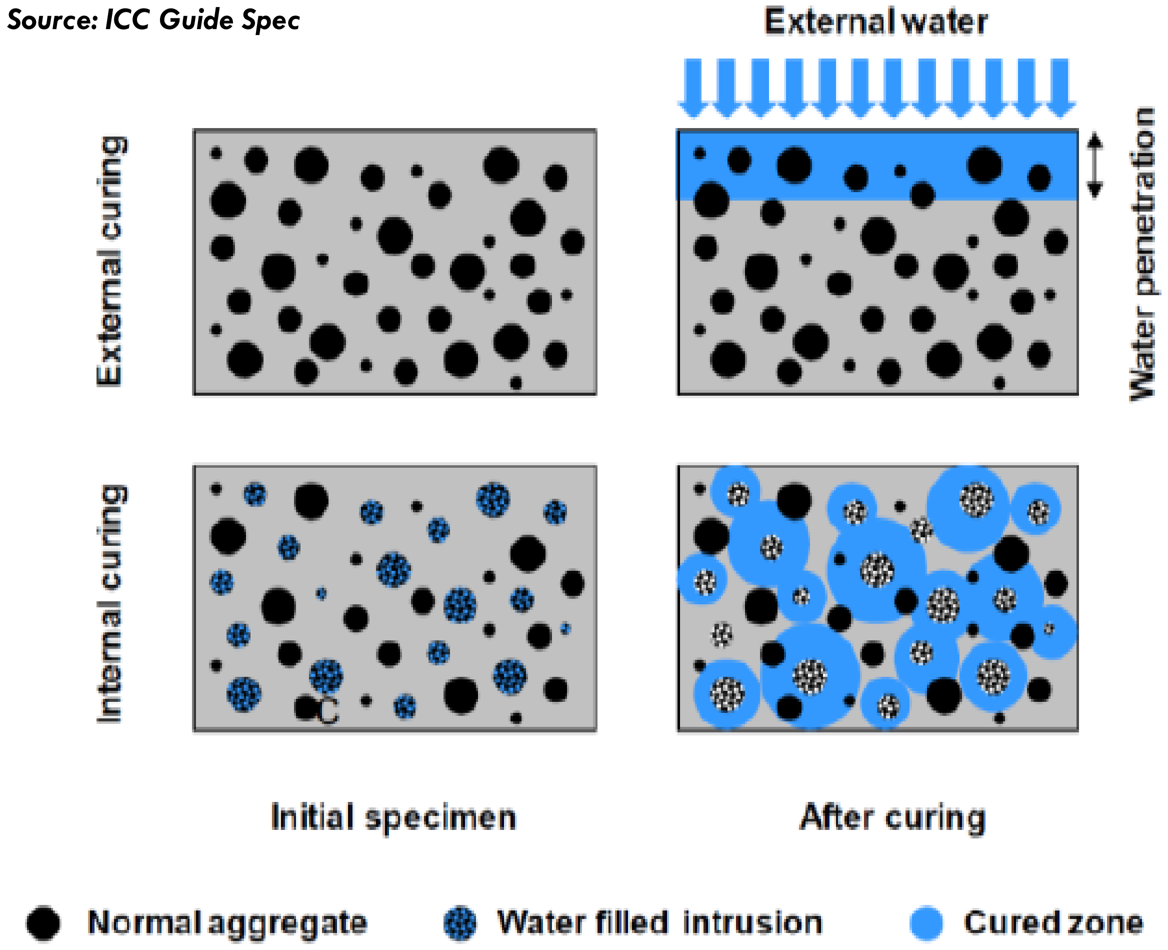
- Results in better dispersion of curing water throughout the concrete depth.



INTERNAL CURING

- At the time of set, capillary stresses draw the water out of the LFWA and cures the concrete section.
- Supplemental to, not replacement for, external curing.
- Increases the hydration of the cement and reaction of SCMs.
- Utilizing the cementitious materials more efficiently and reduces the porosity.

Source: ICC Guide Spec



It is not lightweight concrete!

INTERNAL CURING DEPLOYMENT

Deployed and institutionalized by more than 15 States or transportation agencies :

- **Bridge Decks:** ~150 bridge decks

New York State, Indiana, Louisiana, North Carolina, Ohio, and Utah DOTs; Western Federal Lands Highway Division; and the Illinois State Toll Highway Authority.

- **Pavements:** Kansas and Texas DOTs and the North Texas Tollway Authority.

- **Pavement Patches:** City of West Lafayette, Indiana; Texas DOT; and Michigan municipalities.

INTERNAL CURING DEPLOYMENT

NYSDOT Experience :

- Experimental Features plan for FHWA:
  12 projects, up to 20 decks using IC
- Increased durability and higher cracking resistance. (70% reduction in early age cracking).
- No increase in cost.
- Curing period reduced from 14 to 7 days for HPIC.
- Mandatory for continuous bridges & all NYC bridges.




New York State Peer Exchange - FHWA EDC-7 EPIC2
Albany, NY | May 29-30, 2024

NJDOT IMPLEMENTATION PLAN

- Finalized HPIC guide specifications

  NJDOT/ FHWA/ UTCA-NJ/ LWFA suppliers/ Concrete Plants/ Designers

- NJDOT-Approved mix plants list within the theoretical 90-minute commute of the project

- Awarded STIC Incentive Grant - $125,000

- NJDOT Bureau of Research awarded Rutgers RIME Internal Curing Project

NJDOT IMPLEMENTATION PLAN

Comparative Studies : Twin Bridges HPC vs HPIC

CANDIDATE BRIDGES/PROJECTS

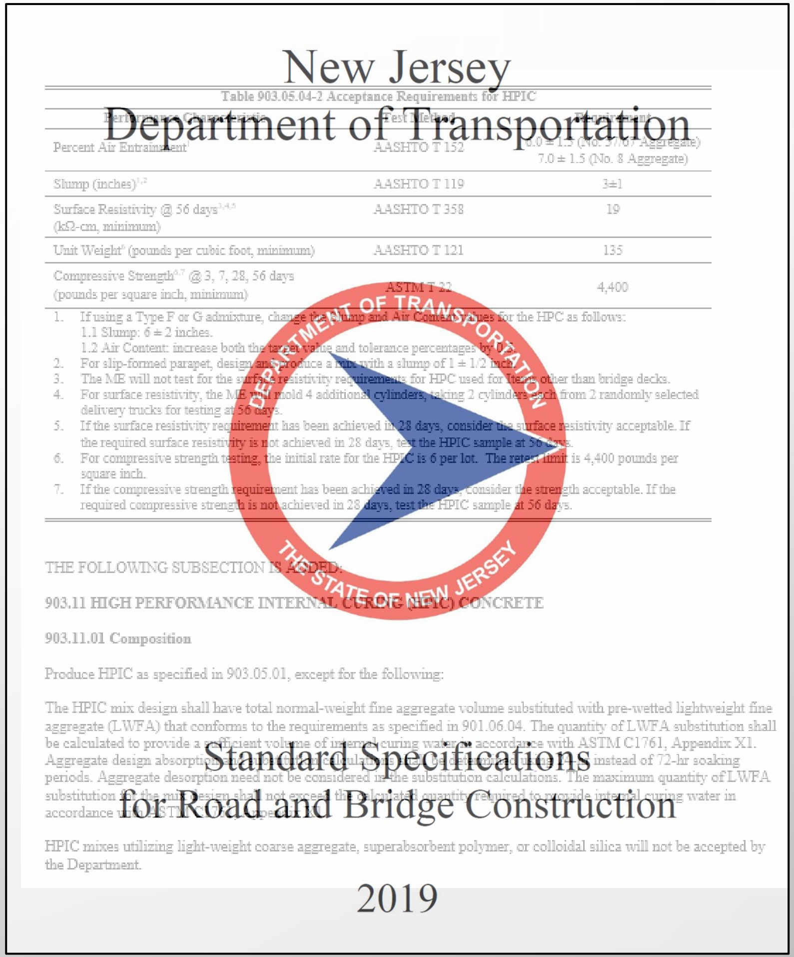
Project Name	Scope	County	Region	Current Phase	FDS	Award
North Munn Ave, Bridge over Rt 280	LS Super. Repl.	Essex	North	Con.	2024	**2024**
CR 507 (Maple Ave), Bridge over Rt 208	LS Super. Repl.	Bergen	North	FD	2025	**2025**
Hanover Ave (CR650), Bridge over I-287	LS Deck Repl.	Morris	North	FD	2025	**2026**
Prince Rodgers Ave, Bridges over Rt 287	LS Deck Repl.	Somerset	Central	FD	2025	**2026**
Rt 202 Bridge over North Branch of Raritan River	FS Bridge Repl.	Somerset	Central	FD	2026	**2026**
Rt 45 Bridge over Woodbury Creek	FS Bridge Repl.	Gloucester	South	FD	2026	**2026**
Rt 23 SB Bridge over NYS&W Railroad	LS Deck Repl.	Passaic	North	FD	2026	**2027**
Rt 124 Bridges over Passaic River	LS Deck Repl.	Morris	North	FD	2026	**2028**
Change Bridge Rd (CR 621), Bridge over Rt 80	LS Deck Repl.	Morris	North	CD	2027	**2029**
Blue Heron Rd Bridge over Rt 15	LS Deck Repl.	Sussex	North	CD	2028	**2029**

PROJECT IMPLEMENTATION

- Specifications (Special Provisions)
- Contract Pay Items
- Local concrete supplier coordination
- Design
- Contract Plans

SPECIAL PROVISIONS

- Section 500 (Construction)
- Section 900 (Materials)
- Performance Specification
  - Contractor Mix Design
  - Verification – Materials Testing
- Light-weight aggregate
- Test slab and trial batching
- Guide Specification developed



MATERIALS – LIGHTWEIGHT AGGREGATE

- Expanded shales, clays, slates, slags
- High absorption capacity %
- <u>Fine LWA (LWFA)</u> preferred over Coarse LWA
  - Concrete sands
- ASTM C1761

Source: Hydrocure ©

MATERIALS - NJDOT QPL

Producer	Address	Quarry/Pit Location	Size	%Abs	Bulk Sp. Gr.	SSD Sp. Gr.	App. Sp. Gr.	Unit Wt.	DRW
Carolina Stalite Co.	217 Klumac Rd. P.O. Box 1037 Salisbury, NC 28144	Gold Hill,NC	lt. wt. agg. for internal curing HPC	9.8	1.745	1.912	2.095	60	65
Norlite Corp.	628 South Saratoga Street Cohoes,NY 12047	Cohoes,NY	lt. wt. agg. for internal curing HPC	23.2	1.587	1.831	2.100	53	59
Northeast Solite	PO Box 437 Mount Marion,NY 12456	Saugerties,NY	lt. wt. agg. for internal curing HPC	12.0	2.172	1.936	1.734	62	68

LW AGGREGATE STOCKPILE MANAGEMENT

- Pre-soak with sprinkler or soaker (24-48 hrs)
  - Aggregate absorbs water
- Drain-down period (12-16 hrs):
  - Reduce surface moisture.
  - Mix & increase uniformity.
- At concrete production facility

Source: FHWA

LW AGGREGATE - MOISTURE TESTING

- Paper-towel method (ASTM C1761 / NYSDOT)
- Centrifuge Method (INDOT/Purdue Univ.)
- Performed by regional Materials personnel.
- Confirm minimum absorption % met.
- Determine excess free-moisture:
  - Batch adjustments

Source: FHWA

HPIC MIX DESIGN

- Mix <u>conversion</u>
- Convert existing HPC mix to internally cured
- Substitute ~30-50% of total fine aggregate (volume) with LWFA.
- LWFA substitution volume dependent on aggregate absorption/desorption properties.

MIX PROPORTIONS:	CONVERTED INTERNALLY CURED										
COMPONENT	TYPE	NAME	PRODUCER / SUPPLIER	AGGREGATE SIZE / GRADATION	RELATIVE DENSITY	ABSORPTION		WEIGHT (lb)	VOLUME (ft^3)	% MIX WEIGHT	% MIX VOLUME
<u>Cement</u>											
PCC1	Type III	-	Riverside Cement	-	3.150	-		570	2.900	14.3%	10.7%
PCC2	None	-	-	-	0.000	-		0	0.000	0.0%	0.0%
							Σ	570	2.90	14.3%	10.7%
<u>Supp. Cementitious Mat.</u>											
SCM 1	Silica Fume	-	-	-	2.200	-		25	0.182	0.6%	0.7%
SCM 2	Slag	45 Slag (E1)	EarthCEM	-	2.870	-		130	0.726	3.3%	2.7%
SCM 3	None	-	-	-	0.000	-		0	0.000	0.0%	0.0%
							Σ	155	0.91	3.9%	3.4%
<u>Coarse Aggregate</u>					SSD	SSD					
CA 1	Stone	-	Gilbraltar Rock	#57	2.795	0.5%		1320	7.568	33.1%	27.9%
CA 2	Stone	-	Gilbraltar Rock	#8	2.770	0.5%		650	3.761	16.3%	13.9%
							Σ	1970	11.33	49.5%	41.8%
<u>Fine Aggregate</u>					SSD/WSD	SSD/WSD					
FA 1 (NW)	Concrete Sand	-	Sahara Sand	-	2.637	0.4%		501	3.047	12.6%	11.2%
FA 2 (LW)	Solite	-	-	-	1.745	14.4%		363	3.334	9.1%	12.3%
							Σ	864	6.38	21.7%	23.6%
<u>Water</u>											
Mix Water	-	-	-	-	1.000	-		235	3.766	5.9%	13.9%
							Σ	235	3.77	5.9%	13.9%
<u>Air Content</u>											
Air Entrainment	6.5%	-	-	-	-	-		0	1.755	0.0%	6.5%
							Σ	0	1.76	0.0%	6.5%
<u>Admixtures</u>											
ADM. 1	Air Entraining	-	Sika Corp.	-	1.000	-		0.169	0.003	0.00%	0.01%
ADM. 2	Retarder	Plastiment	Sika Corp.	-	1.000	-		0.945	0.015	0.02%	0.06%
ADM. 3	HRWR	Viscocrete 2100	Sika Corp.	-	1.000	-		1.890	0.030	0.05%	0.11%
ADM. 4	None	-	-	-	-	-		0.000	0.000	0.00%	0.00%
							Σ	3.004	0.05	0.1%	0.2%
						BATCH TOTAL	Σ	**3797**	**27.09**	**1.00**	
								lb	**ft^3**	**yd^3**	

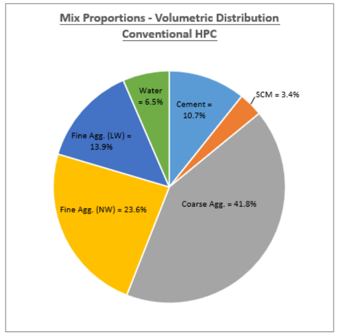
MIX DESIGN PROPERTIES:	CONVERTED INTERNALLY CURED		
Plastic Unit Weight =	140	lb/ft^3	[Theoretical unit weight of plastic concrete mixture]
Total Weight Cementitious =	725	lb	[Weight of cement + SCMs]
Sack Content (Cement) =	6	sack	[# of 94 lb Cement sacks per CY]
Sack Content (Cement + SCM) =	8	sack	[# of 94 lb Cement sacks per CY, including SCMS]
Gallons Water =	28.2	gal	[Gallons mix water required]
W/C =	0.41	-	[Water-Cement ratio, by weight]
W/CM =	0.32	-	[Water-Cementitious Materials ratios, by weight]
Paste Volume Fraction =	0.28	-	[Fraction of volume of paste (cement, SCMs, and water) to total batch volume]
Mortar Volume Fraction =	0.58	-	[Fraction of volume of mortar (cement, SCMs, fine aggregate, water, and entrained air) to total batch volume]
SCM/CEMENT =	0.27	-	[Ratio of SCMs to Cement, by weight]
Sand / Total Aggregate =	0.36	-	[Ratio of sand to total aggregate, by volume]

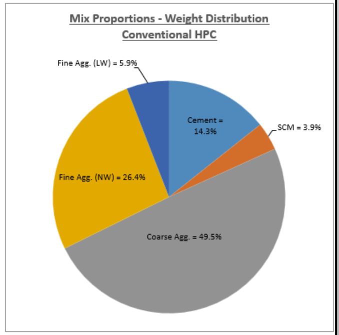
<u>Volumetric Distribution:</u>

Cement =	10.7%
SCM =	3.4%
Coarse Agg. =	41.8%
Fine Agg. (NW) =	11.2%
Fine Agg. (LW) =	12.3%
Water =	13.9%
Air =	6.5%

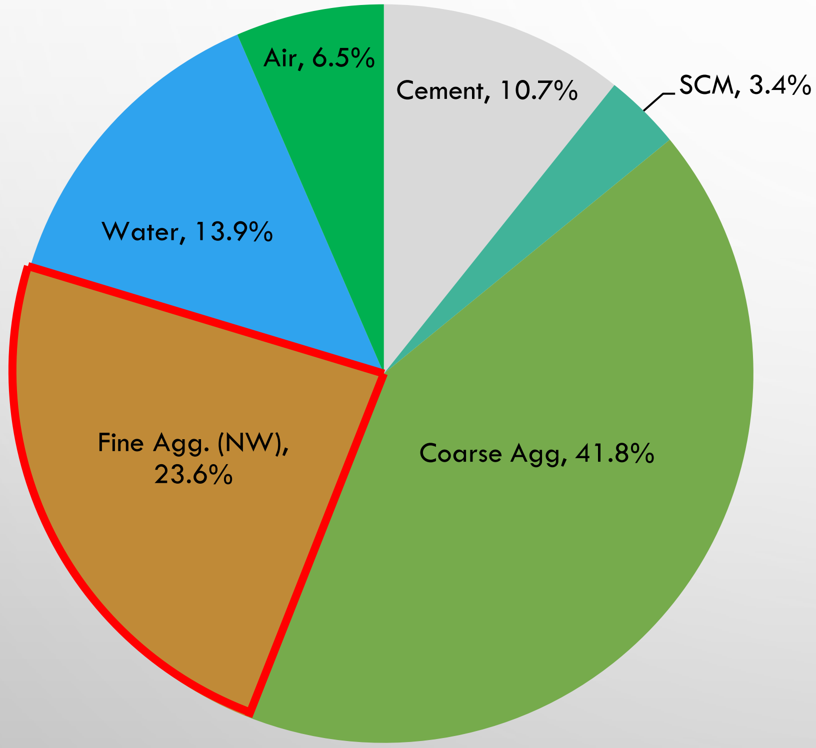
<u>Weight Distribution:</u>

Cement =	14.3%
SCM =	3.9%
Coarse Agg. =	49.5%
Fine Agg. (NW) =	12.6%
Fine Agg. (LW) =	9.1%
Water =	5.9%

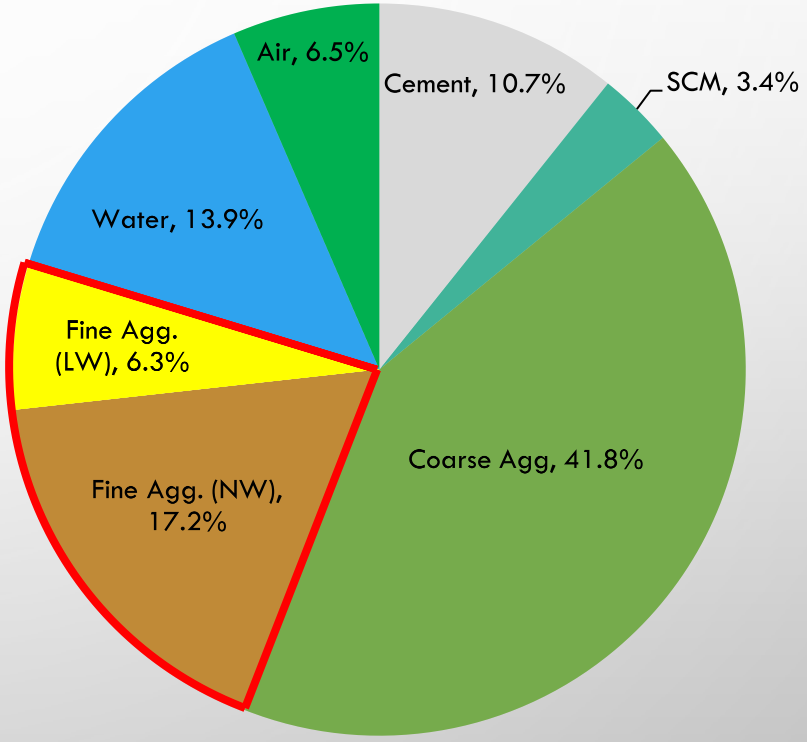




HPIC MIX CONVERSION
(VOLUMETRIC DISTRIBUTION)



HPC



HPIC
(27% LWFA) –Norlite (23% Abs.)

TRIAL BATCH & TEST SLAB

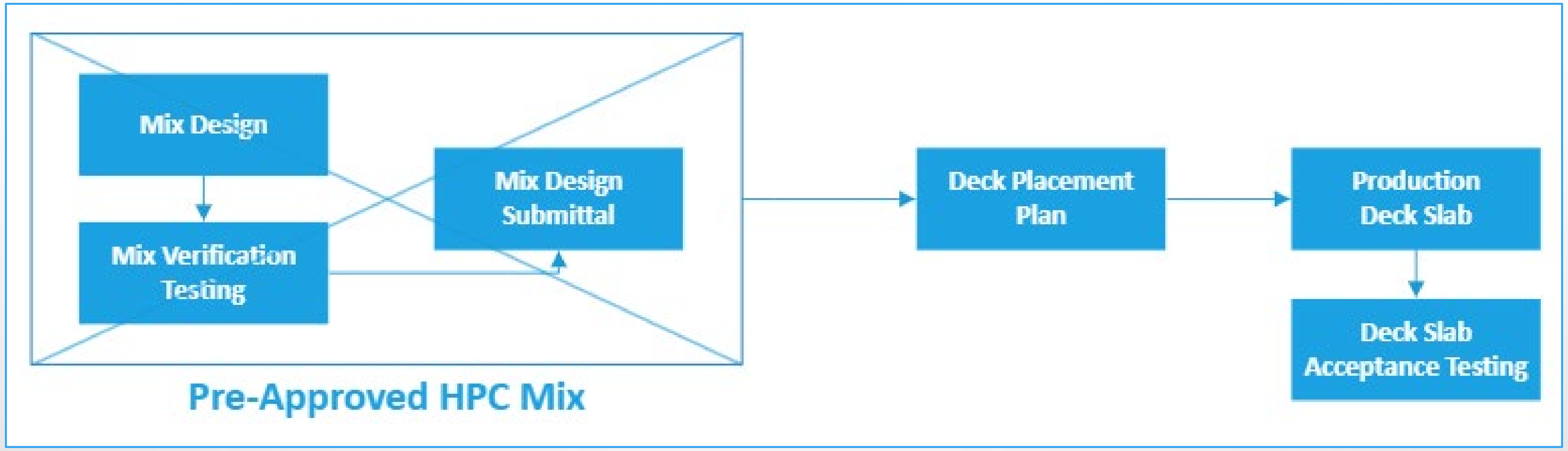
- Demonstrate contractor capabilities and provide experience to contractor & Department.
- Same stockpile management, batching, delivery and placement, and acceptance testing methods on test slab as production deck.
- Separate contract pay item.

PRODUCTION & CONSTRUCTABILITY

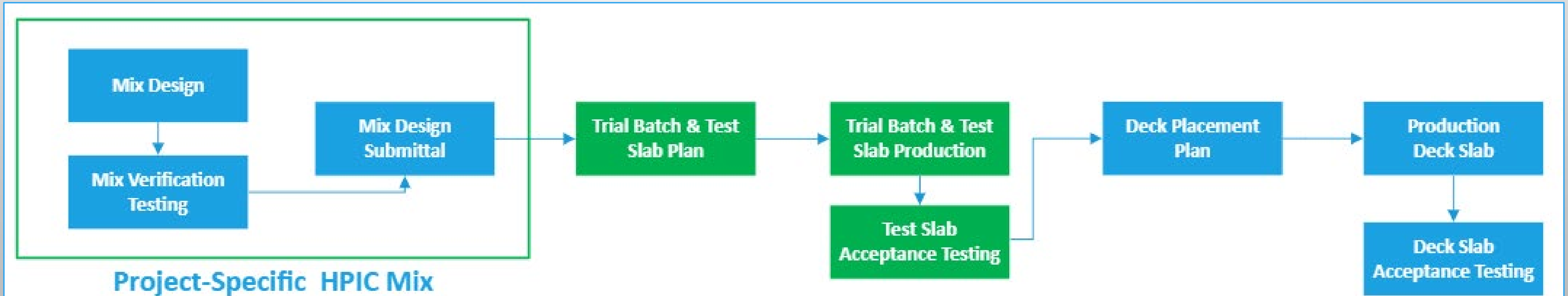
- Batching:
  - LWFA stockpile management (soaking & moisture adjustments)
  - additional material needs to be batched
- Same placement/finishing methods as HPC:
  - Comparable workability and placement
  - Pumpable
  - Slump
- External Curing:
  - Reduced duration from 14 to 7 days possible

CONSTRUCTION PROCESS FLOW-CHART

HPC

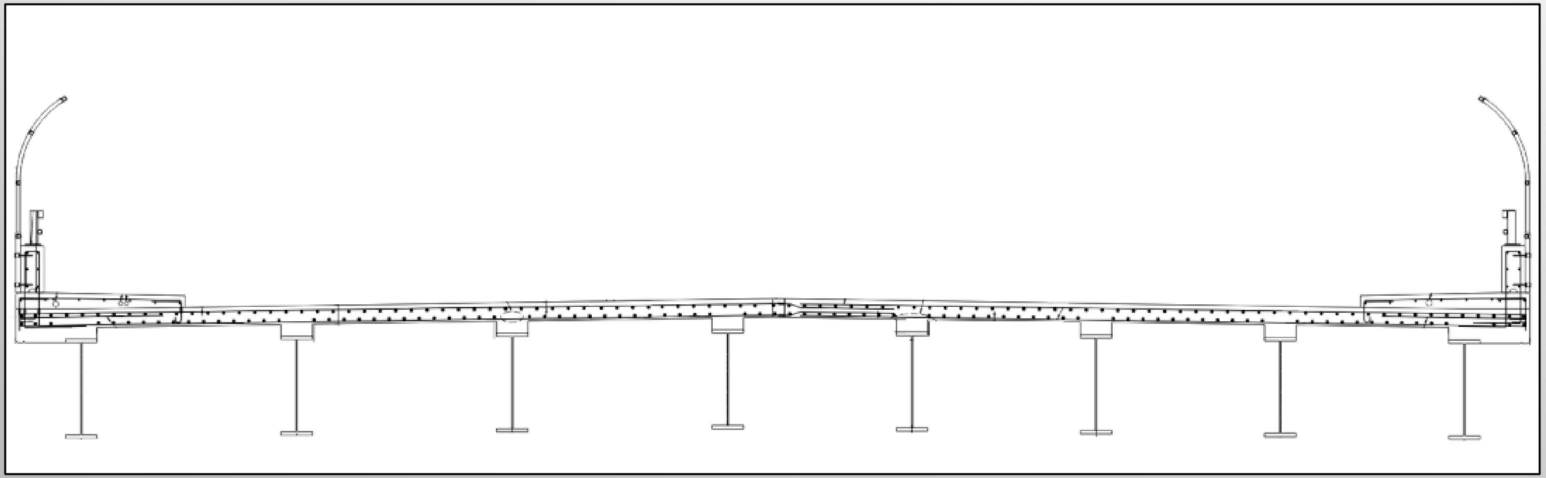


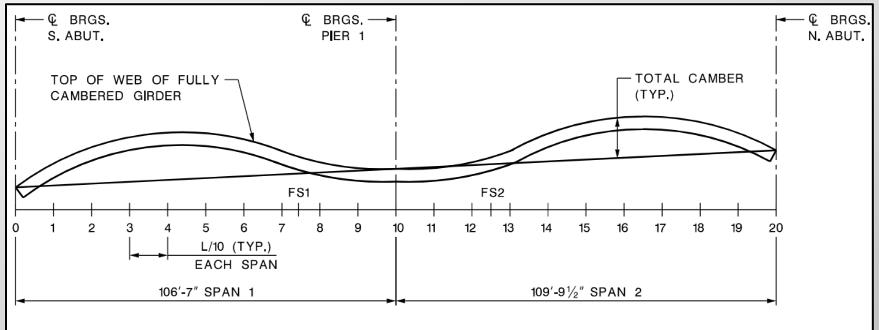
HPIC



DESIGN

- Minimal effect on concrete design properties
- Minor improvement in compressive strength
- Minor reduction in unit weight & modulus
    - ➢ Consider deck weight, girder camber, stiffness effects on design





CAMBER DIAGRAM

$$E_c = 120{,}000 K_1 w_c^{2.0} f'^{0.33}_c$$

EFFECTS ON PROJECT

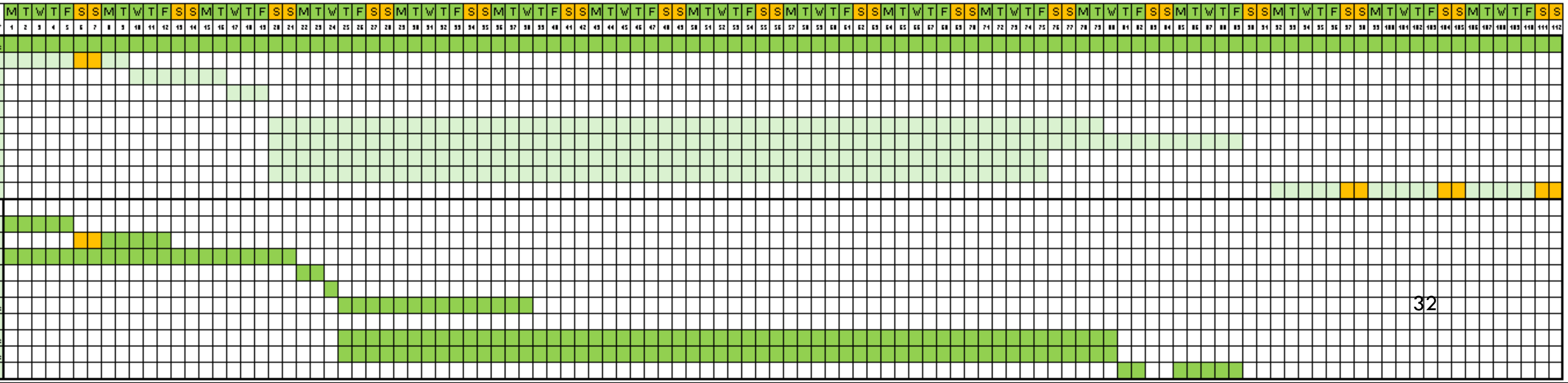
Design Phase:

- Designer additional effort:
  - Confirm design properties
  - Incorporate guide specifications
  - Coordinate with local concrete plants

Construction Phase:

- Additional HPIC construction costs:
  - new mix design and verification testing (25k)
  - trial batch & test slab (25k)
  - unit cost for production (per CY) (+20-40% unit cost increase)
- Schedule – additional 'up-front' construction duration: mix verification testing, trial batch, test slab **(~6 months)**

#	Activity Name	Duration	Business / Consecutive
1	**HPIC Mix Design Submittal:**	112	Consecutive
a	Mix Design Calculations & Development	7	
b	Procure Materials	7	
c	Verification Batching	3	
d	Verification Testing:	-	
d.i	Scaling Resistance (ASTM C672) [28-day specimen cure]	60	
d.ii	Freeze-Thaw Durability (ASTM C666) [14-day specimen cure]	70	
d.iii	Surface Resistivity (AASHTO T358) [56-day specimen cure]	56	
d.iv	Compressive Strength (AASHTO T22) [56-day specimen cure]	56	
e	Department Reviews HPIC Mix Design Submittal	21	
2	**HPIC Test Slab (Subsequent to Activity 1)**		
a	Contractor Submits HPIC Test Slab Plan		
b	Department Reviews HPIC Test Slab Plan		
c	Procure Materials		
d	Site Preparation	2	Business
e	HPIC Trial Batching & Slab Casting	1	Business
f	Curing	14	Consecutive
g	Acceptance Testing		
g.i	Surface Resistivty [56-day specimen cure]	56	Consecutive
g.ii	Compressive Strength [56-day specimen cure]	56	Consecutive
h.	Department Reviews/Accepts Test Slab	10	Business



HPIC Submittal, Mix Design, Verification Testing, & Test Slab Schedule

NORTH MUNN AVE. OVER I-280

- FIRST PILOT PROJECT
- STATUS:
  - MIX DESIGN - COMPLETE ✓
  - VERIFICATION BATCHING - COMPLETE ✓
  - VERIFICATION TESTING (SURFACE RESISTIVITY, COMPRESSIVE STRENGTH, FLEXURAL STRENGTH, SHRINKAGE) - COMPLETE ✓
  - VERIFICATION TESTING (SCALING, FREEZE-THAW) – **PENDING…**
  - TRIAL BATCH & TEST SLAB – **PENDING…**
  - PRODUCTION – **PENDING…**

CHALLENGES

- Costs – Initial vs Life Cycle
- Specifications – Restrictions
- Concrete Plants:
  - Experience and willingness to produce IC mixes
  - Concerns with restrictive HPC acceptance testing
- Materials Availability / Supply Chain:
  - Ample availability, but coordination required
- Economy of Scale & Standardization
- Awareness/Education

NEXT STEPS..

- CONCRETE PLANT OUTREACH PROGRAM - SUMMER 2025
- HPIC WORKSHOPS - SUMMER 2025
- CENTRIFUGE TRAINING PROGRAM - FALL 2025
- UPDATE SPECIFICATIONS
- ASSESS PILOT PROJECTS
- MONITOR PERFORMANCE

TEAM EFFORT

- FHWA
- NJDOT:
  - CONSTRUCTION & MATERIALS
  - BRIDGE ENGINEERING
  - PROJECT MANAGEMENT
  - CAPITAL PROGRAM SUPPORT
- RUTGERS
- HNTB
- INITIAL INVESTIGATIONS TO CONSTRUCTION WITHIN 2 YEARS

QUESTIONS?