NCHRP 20-68 – US Domestic Scan Program

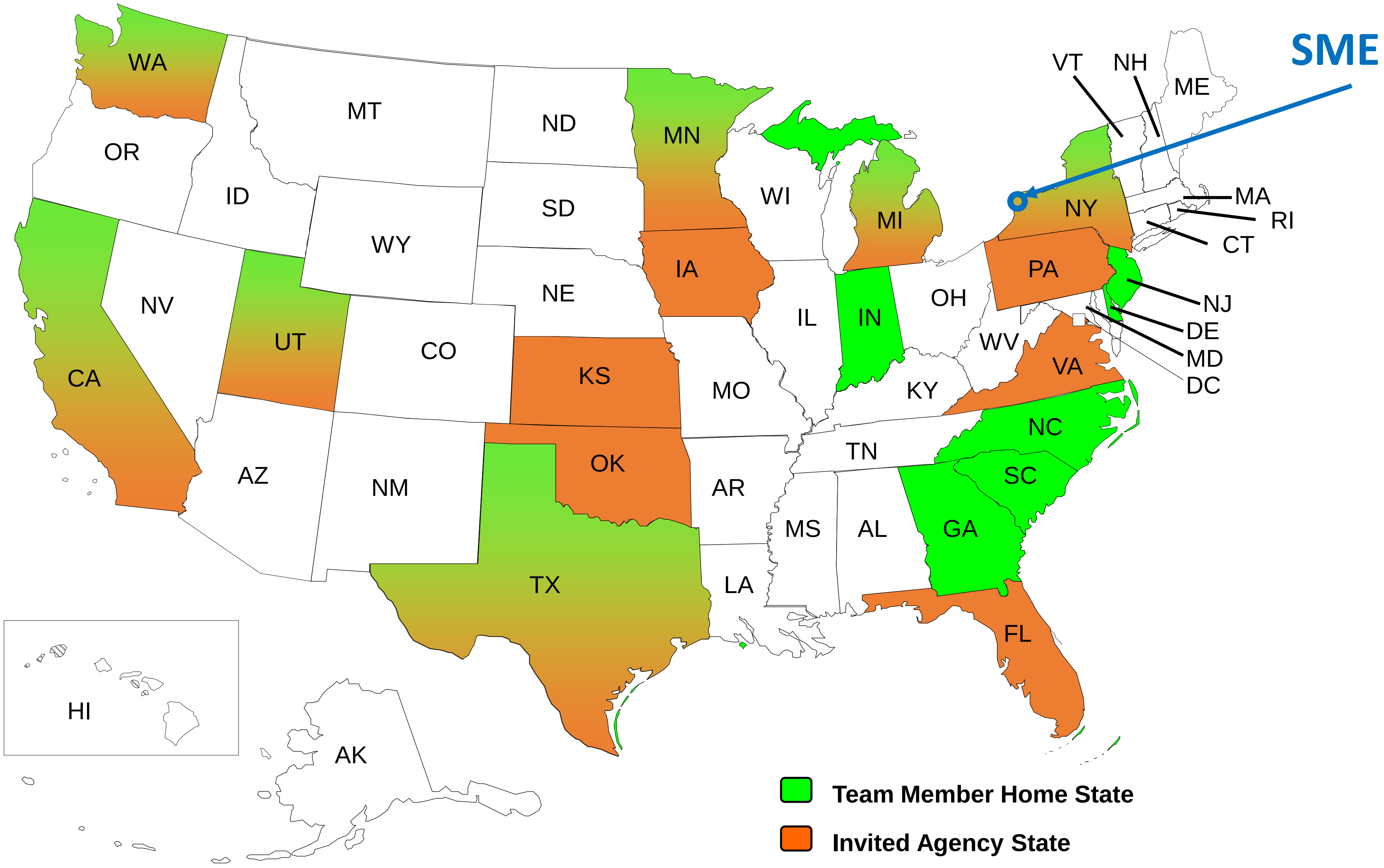
Scan 22-01:
Recent Leading Innovations in the Design, Construction and Materials Used for Concrete Bridge Decks

Motivation for the Scan

Need for innovation in materials, construction and design to improve:

- Deterioration
- Limited deck service life
- Maintenance costs

Team Member and Invited Agency States



Report Contents

Concrete Mixes, Placement, Protection

- Concrete Mixes
  - Paste Content
  - Performance-Based Mixes
  - Limiting Shrinkage
  - Supplementary Cementitious Materials
  - Test Methods for Concrete
- Placement
- Curing
  - External Curing
  - Internal Curing
- Surface Protection

Fiber Reinforced Concretes

- Mixes with Fiber
- Ultra High-Performance Concrete
  - Link Slabs
  - Precast Concrete Deck Panel Joints
  - Decks with Optimized Geometry
  - Overlays
  - Non-proprietary mixes
- Engineered Cementitious Composites

QA/QC, Workforce Knowledge and Continuity

- Construction Quality Assurance/Control
- Workforce Knowledge
- Knowledge Continuity

Corrosion Resistant Reinforcement

- Fiber Reinforced Polymers
- Galvanized Reinforcing Bars
- Stainless steel
- Stainless Steel Clad Bar
- ASTM A1035 Steel

Prefabrication

- Deck Prefabrication
- Partial-Depth Decks
- Full-Depth Decks
- Decked Precast Girders
- Proprietary systems

Design and Detailing Practices

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<u>Design and Detailing Practices</u>

Concrete Paste Content

- Limiting paste (water and cement) content of concrete can help reduce cracks.
- E.g.,

	Cementitious Materials	Water to Cement Ratio
Kansas DOT	< 540 lb/yd^3	0.43-0.45
Virginia DOT	< 600 lb/yd^3	< 0.45
Pennsylvania DOT	< 640 lb/yd^3	0.43-0.45

- The result is low slump and moderate strength

Performance Based Specifications

- Defines:
  - required results
  - criteria to judge performance
  - verification methods
- Does not define:
  - how the results are obtained
- Are alternative to prescriptive specifications that define material amounts, proportions, workmanship, production, installation.
- Challenges:
  - Availability/feasibility of test methods that can measure performance
  - Long lead times for developing and testing concrete.
- Scan conclusion: Hybrid mixes tend to provide suppliers better options.

Limiting Concrete Shrinkage

- A common performance requirement is to limit shrinkage
- Can be achieved with the mix or with shrinkage reducing admixtures
- E.g.,

	Shrinkage Strain Limit at 28 days
Virginia DOT	350 microstrain
Utah DOT	350 microstrain
Washington DOT	350 microstrain
California DOT	300 microstrain

- California DOT has shrinkage reducing admixtures in specifications, reported great benefits without a significant cost change.

Placement and Finishing

- Higher quality concrete when:
  - Minimal finishing
  - Avoiding walking in the mix after vibrating
  - Avoiding finishing aids
  - Starting curing without delay
  - Replacing tining with saw grooving
  - Specifying plastic concrete temperature changes
  - Pouring when ambient temperature fluctuations are small
  - Pouring when concrete and contact surface temperature differences are small
  - night time pours
  - Using foggers and wind barriers to control evaporation

External Curing

- Preventing delays in curing is critical. To achieve this:
    - Minimize finishing
    - Apply misting
    - Use work bridges over the wet deck
    - Consider monetary penalties proportional to delay time

Internal Curing

- A fraction of aggregates is replaced with pre-wetted lightweight aggregate
- Water in the aggregate is released to help hydration
- Standard practice in states that have quality lightweight aggregates with pre-determined moisture content.

E.g.,

  - New York
  - Virginia

- Mixed results in other states due to lack of aggregates, questionable quality or conditioning of aggregates, lack of contractor experience, insufficient owner oversight

Surface Protection

- Overlays, waterproofing membranes, sealers
- Various types of overlays:
  - E.g. from New York: polymer concrete, waterproof hit mixed asphalt, hot mixed asphalt and membranes, ultra high performance concrete, concrete overlays
- Regardless of the type, overlays require proper surface preparation and installation
- Most states in the scan prefer not to use an asphalt overlay, and use deck top cover as a structural overlay

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Design and Detailing Practices

Mixes with Fibers

- Micro (diameter < 0.012 in.) fibers can control shrinkage cracks.
- Macro (diameter > 0.012 in.) fibers can improve post-cracking properties
- Fiber type
  - Steel (stainless, alloy, carbon, …)
  - Synthetic (polypropylene, polyethylene, polyvinyl alcohol, carbon, …)
  - Glass
  - Natural (cellulose, …)

Most common in construction (Steel and Synthetic)

Mixes with Fiber

- A measure to protect against material or construction quality issues
- Used as standard practice in some states, e.g. California
- Fiber material, diameter, length, amount, orientation, distribution impact results
- Tests and criteria are needed to approve fiber types and suppliers

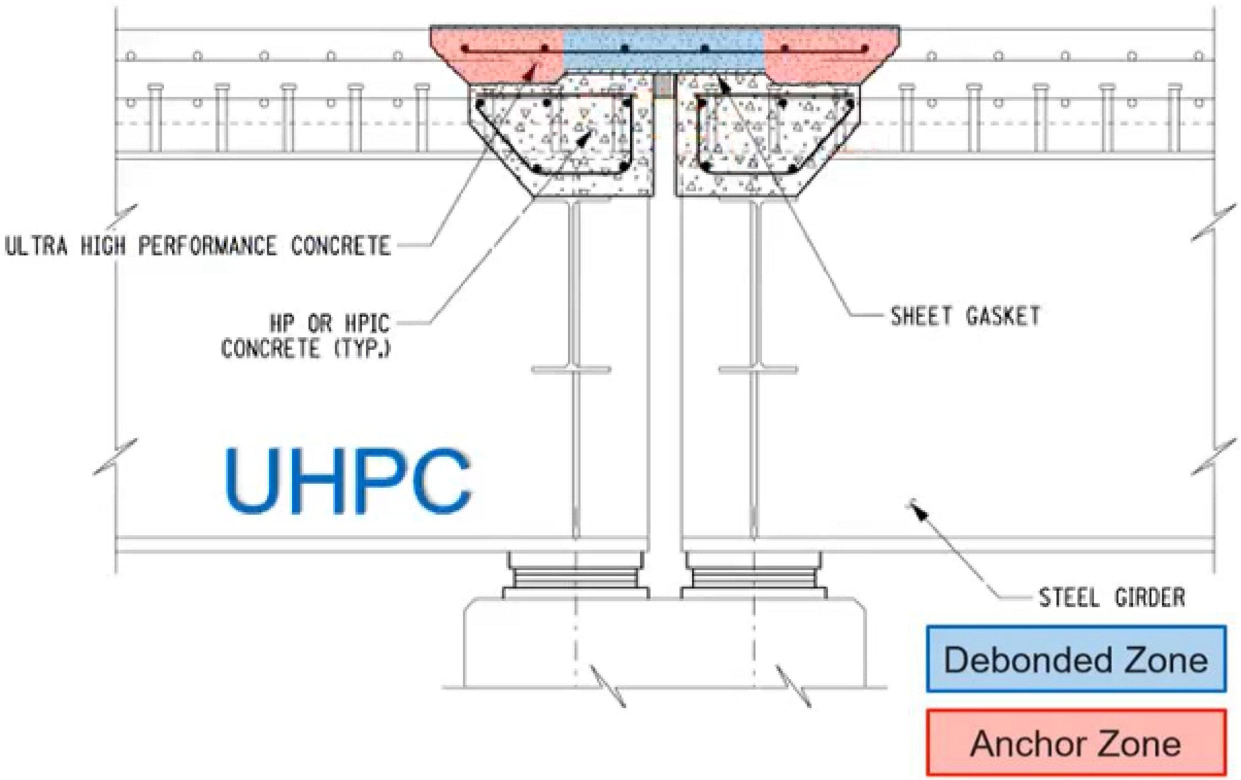
Fiber reinforced concrete link slab from Virginia

Ultra High Performance Concrete (UHPC)

- A fiber reinforced concrete with a specific performance objective
- Tensile strain hardening
- Typically steel fibers
- High compressive strength (>17 ksi or > 22 ksi)
- High binder ratio
- High packing density, low permeability

UHPC Link Slabs

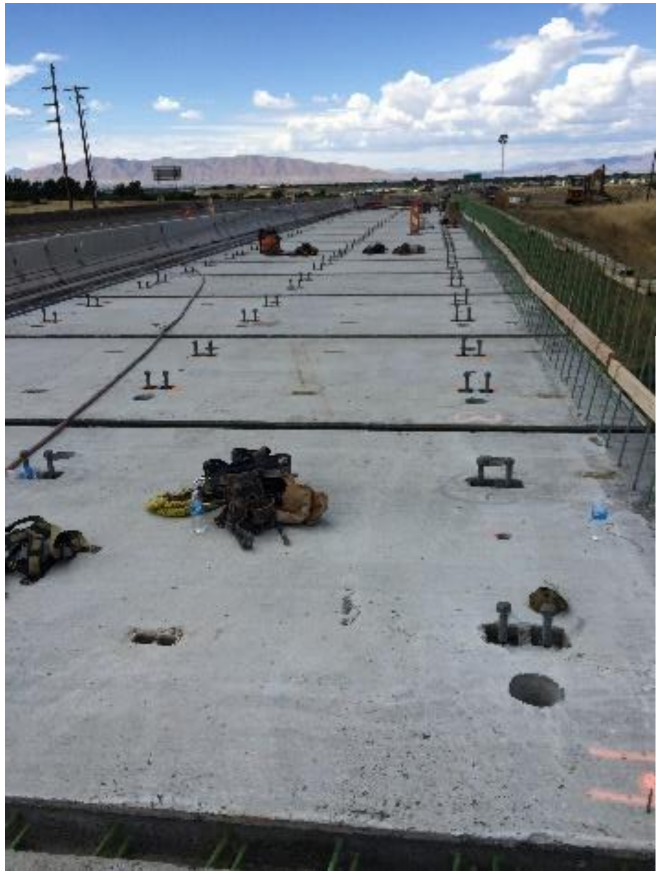
- Used to eliminate expansion joints
- UHPC allows much smaller link slab lengths and thickness than concrete

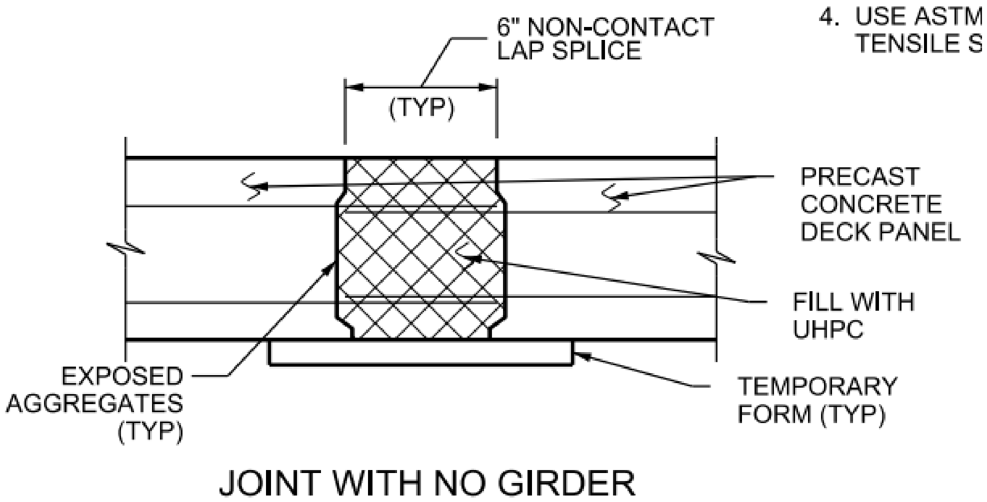


UHPC link slab from New York

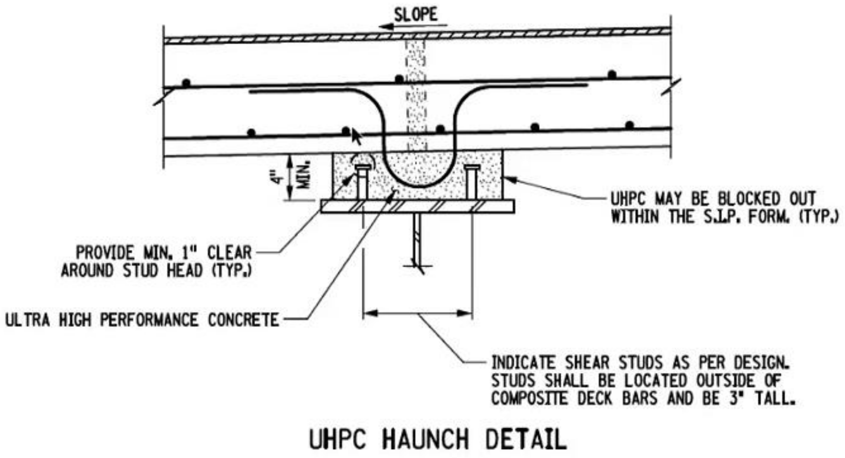
UHPC Deck Panel Joints

- UHPC joints can provide equivalent performance to joint post-tensioning.





UHPC deck joint from Utah

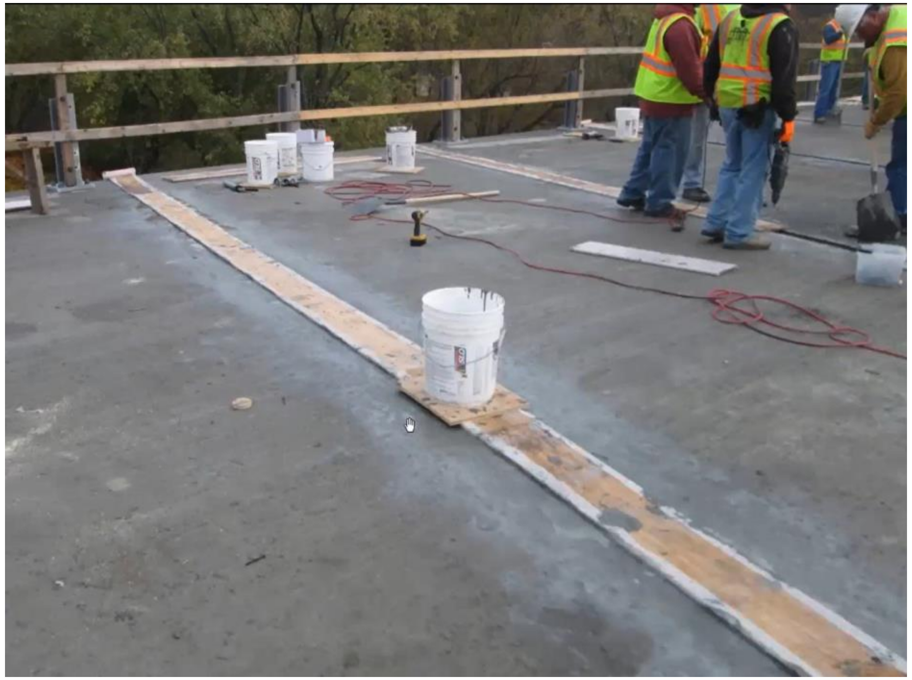


UHPC girder-deck joint from New York

UHPC Deck Panel Joints

For successful applications:

- Seal forms against leakage
- Maintain hydraulic pressure over joints as UHPC tends to settle
- Prevent fiber settlement
- Limit flow length to prevent fibers aligning in the flow direction
- Roughen concrete surfaces
- Bring surfaces to saturated surface dry before placing UHPC
- Require supplier to be on site



Sealing of forms from New York

Non-proprietary UHPC mixes

Proprietary mixes can be costly (although come with support)

States and Universities are developing their own mixes.

E.g.,

Ingredient	Cement	Sand	Masonry Sand	Silica Fume	Water
Volume Ratio (for 1.0 ft^3)	0.425	0.226	0.200	0.060	0.089
Proportion (lb/yd^3)	1500	790	710	210	320

Iowa DOT

w/c	Portland Cement Type I	GGBFS	Silica Fume	HRWR	Silica Sand (Fine)	Silica Sand (Coarse)	Steel Fiber, 0.5 in
0.22	0.5	0.5	0.25	3%	0.30	1.21	2.0 % by volume

Michigan DOT

Constituent	lb/yd^3	Material
Cement	1522	Alamo Type III
Silica fume	114	BASF MasterLife SF 100
Fly ash	158	Boral, Class F
Sand	1706	Heldenfels' sand (Max. #4)
Water	326	--
HRWR	36.6	Sika ViscoCrete 4100
Steel fiber	200	0.5" long, 0.008" diameter
w/cm	0.181	Excluded water from HRWR

Texas DOT

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Fiber Reinforced Polymer (FRP) Rebar

- Glass FRP rebar is the most common with vinylester or epoxy resin.
- Differences with metallic reinforcement:
  - Does not corrode
  - Light weight: facilitates construction, but may float during pour
  - Does not yield
  - Design is often controlled by crack control requirements
  - Deck replacement or widening is not possible because rebar gets damaged
  - Can be used with metallic reinforcement
  - Cannot be field bent
  - Mostly proprietary products
- Florida DOT used FRP rebar since 1980's.

Glass FRP bars in a deck from Kansas

Galvanized Rebar

- Rebar with a metallurgically bonded zinc layer
- Two types:
  - Hot-dip or batch galvanizing (ASTM A767)
  - Continuous galvanizing (ASTM A1094)
- Better bond to concrete than epoxy coated rebar
- University of Kansas research shows:
  - hot-dip and continuous galvanizing have similar performance
  - higher initial cost but ~½ service-life cost of uncoated rebar
- Minnesota, Texas, Pennsylvania, Utah, Washington (from the scan) provide galvanized rebar as an alternative to epoxy rebar.

Galvanized rebar in Washington

Stainless Steel Rebar

- Level of corrosion protection depends on the composition of the alloy. i.e., not all stainless steel is the same.
- Virginia DOT reports:
  - An additional cost of 5% of the entire bridge cost.
  - Cost may be smaller than a future overlay.
  - Cost is sensitive to alloy cost that vary over time.
- Michigan DOT reports:
  - An additional cost of $17.43 / sq. ft. in 2011.
  - Stainless steel is used when 100 year life is needed.
- X-ray fluorescence can be used to verify alloy composition

X-ray fluorescence by Virginia DOT

ASTM A1035 Steel (aka MMFX or ChromX)

- Low-carbon, chromium alloy steel
- Alloy type
  - CS
  - CM
  - CL

  Higher corrosion resistance (higher price)
- 100 ksi or 120 ksi yield strength
- Michigan DOT reports:
  - $2.03-$3.00/lb (for CS) vs $1.50-$1.98/lb for epoxy coated bars in 2021
- Most states use CS to be conservative
- Minnesota had quality control issues with CM bars

Utah DOT

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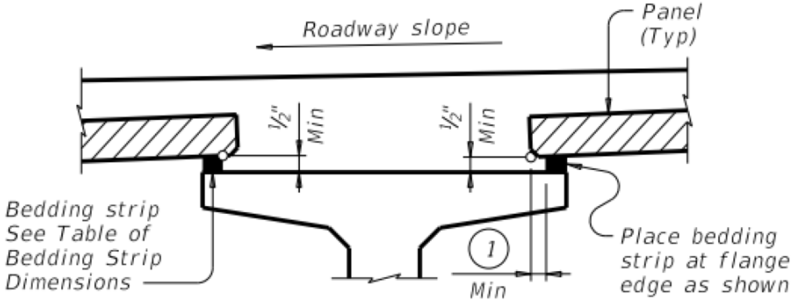
Partial-Depth Precast Decks

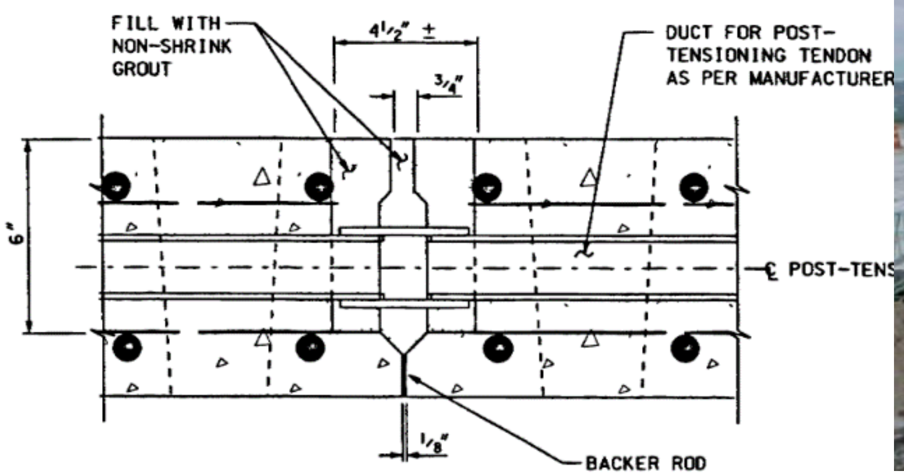
- Thin (~half deck thickness) pretensioned panels that are ~ 8ft long
- Serve as stay-in-place forms made composite with the cast-in-place topping
- Standard practice in Texas, others report reflective cracking.
- Keys to success:
  - Provide bedding strips to support panels over girders, so that well-consolidated concrete can form permanent support
  - Pre-wet panels to achieve saturated surface dry condition.

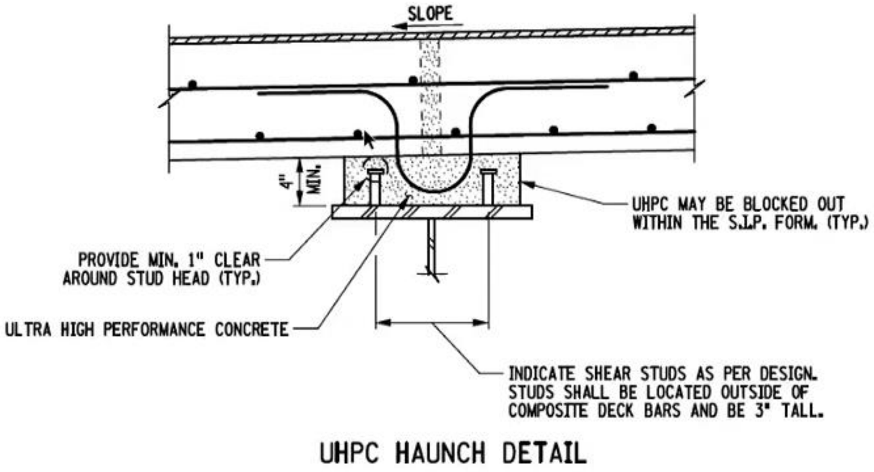


Texas DOT

Full-Depth Precast Decks

- Benefits for rapid construction and for areas far from concrete suppliers
- Likely costly for bridges with complex geometries
- Joint details and materials are critical for performance.
- Utah experience:
  - Either post-tensioned or UHPC joints perform well.
  - Wider, normal concrete joints had transverse cracking.





Utah DOT

Hidden UHPC joint detail of New York DOT

Decked Girders

- Standard plans are developed by some states
- Members tend to limited by weight

Precast deck overhang in Texas

Decked girders in Washington

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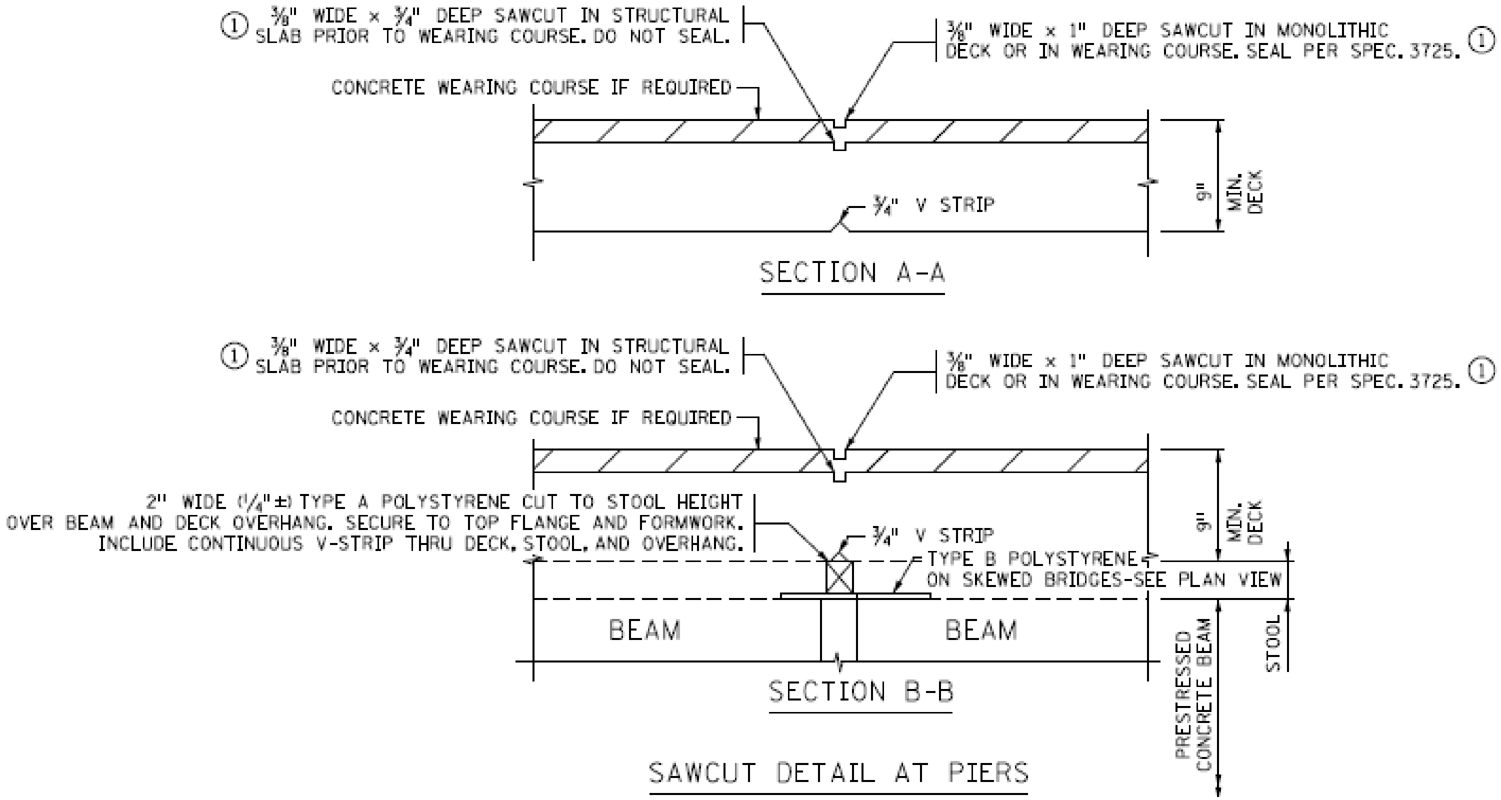
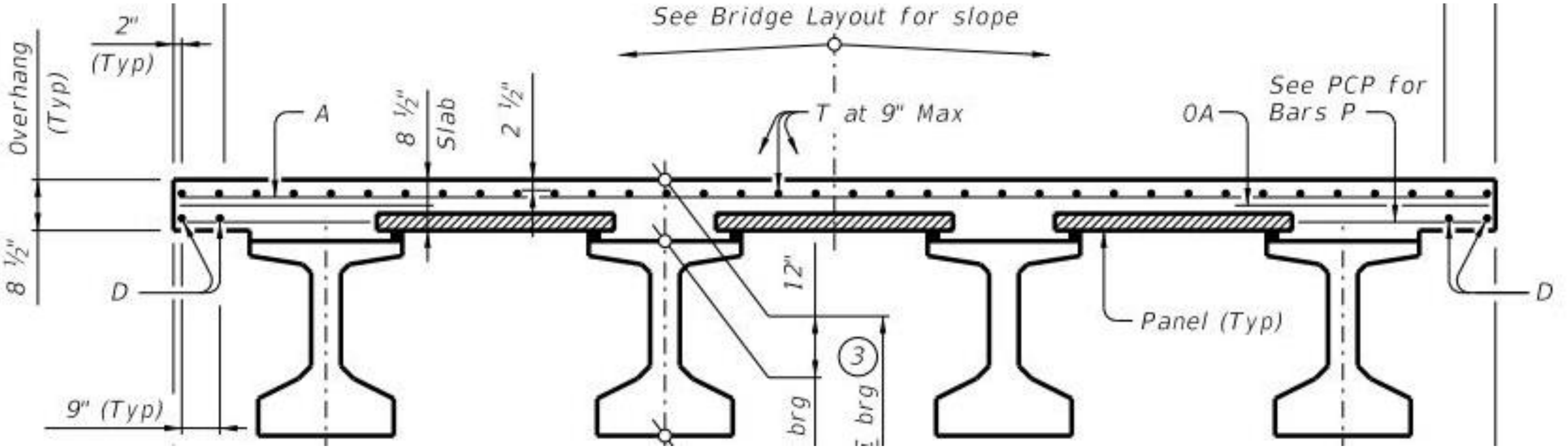
Design and Detailing Practices

- Large variations in design and detailing among states
- Critical to document the implications of design changes on performance
- Examples:
  - Minnesota saw cuts deck over piers to restrain cracking to this region



Design and Detailing Practices

- Examples (continued):
  - Texas uses a smaller reinforcement amount using AASHTO LRFD's Empirical Method
  - Texas placed longitudinal bars closer to deck top surface
  - This reduced overall cracking (smaller transverse crack density and more longitudinal crack density)



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Construction Quality

- Preparation is key:
  - On-site or off-site test pours for each new mix
  - Pre-deck pour meetings
  - Construction checklists
  - Training field crew and inspectors
  - Slump and cylinder sampling on-site
  - Frequent sampling and testing of alternative rebars…

Pre-Pour-Planning the Placement: It is required that a pre-pour meeting with the Contractor be scheduled to specifically discuss:

- ☐ Time of starting of pour -- Anticipated weather conditions?
- ☐ Anticipated rate of delivery of concrete?
- ☐ How much material will be needed? At what rate? Haul time from plant?
- ☐ Discuss pouring sequence concerns. Admixtures, dosage rates?

Example checklist from Minnesota

Test pour by Washington

Workforce Knowledge

- Training is a smart investment:
  - Texas trained internal and external inspection personnel and contractors on bridge decks. They are currently working to develop an inspection certification program.
  - Minnesota has a 2-week long inspector certification program (2-days on bridge decks) and a 3-day long online bridge project engineer training program.

Knowledge Continuity

- Need to keep track of innovative projects through:
  - Innovation specific databases/inventories (e.g., Utah)
  - Websites (e.g., Florida)
  - Inspection reports
  - Research studies
  - Internal committees
  - Surveys
  - Lessons learned reports
  - Agency defined elements for inspection (e.g., Minnesota)
- Innovations require iterations, which require continuity of knowledge.

Scan Recommendations

1. Develop documentation strategies
2. Invest in training and certification
3. Provide opportunities to predict potential issues with new practices
4. Invest in research to refine life cycle and deterioration models
5. Prioritize improving concrete quality over corrosion resisting rebar. Develop modern mixes.
6. Use corrosion resisting rebar following service life approaches.
7. Integrate design, materials, inspection and construction perspectives. Allow sufficient time for planning.
8. Explore automated technologies for quality control.
9. Develop acceptance guidelines for fibers, lightweight aggregate, shrinkage reducing admixtures
10. Support research to generate field and lab data on corrosion performance of deck materials

Questions?

Scan team:

- Donn Digamon, Georgia DOT, Team Chair
- Bijan Khaleghi (retired), Washington State DOT
- Hannah Cheng, New Jersey DOT
- Trey Carroll, North Carolina DOT
- Terry B. Koon, South Carolina DOT
- Edward Lutgen, Minnesota DOT
- Cheryl Hersh Simmons, Utah DOT
- Don Nguyen-Tan, California DOT
- Pete White, Indiana DOT
- Kevin R Pruski, Texas DOT
- Scott M. Walls, Delaware DOT
- Rick Liptak, Michigan DOT
- Harry L. White 2nd, New York State DOT
- Linh Warren, FHWA
- Pinar Okumus, University at Buffalo, SUNY, Subject Matter Expert (pinaroku@buffalo.edu)

Scan Management:

- Harry Capers, Arora and Associates, P.C.
- Mellissa Jiang, Arora and Associates, P.C.