Internally Cured Concrete Bridge Decks

ODOT Implementation Strategy

David Dobson, PE

Statewide Structural Materials Engineer

Oregon Dept. of Transportation | Structure Services

FHWA EPIC^2 Webinar

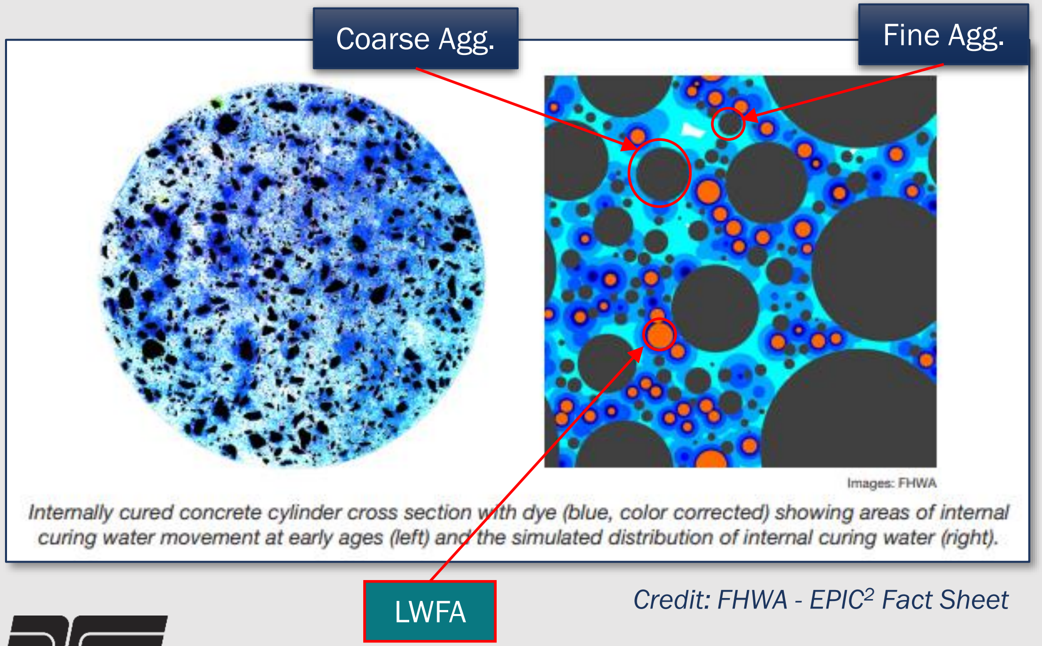
October 16th, 2024

Oregon Department of Transportation

What is Internally Cured (IC) Concrete?

<u>Lightweight Fine Aggregate (LWFA)</u>

- Absorption and desorption properties
- Releases and disperses water during hydration



Internally cured concrete cylinder cross section with dye (blue, color corrected) showing areas of internal curing water movement at early ages (left) and the simulated distribution of internal curing water (right).

Credit: FHWA - EPIC² Fact Sheet

"Benefits from internal curing include increased hydration and strength development, reduced autogenous shrinkage and cracking risk, reduced permeability and increased durability"

ODOT & Oregon State University Research – SPR 711 (2013)

"Internal curing increases concrete's resistance to early cracking, allowing the production of higher-performance concretes that may last more than 75 years"

FHWA EDC-7 EPIC²

Oregon Department of Transportation

IC for Bridge Decks in Oregon

- ODOT started the process of adopting IC for bridge decks in 2017
- Bridge decks tend to crack, even with low shrinkage mix designs (High Performance Concrete)
- Salt and deicing chemicals applied to roads and bridges has increased reinforcement corrosion rates
- Deck cracking decreases service life and increases maintenance costs

South Yamhill River Bridge | McMinnville, OR

Blue River Bridge | Blue River, OR

50 YR

Poll Question 2

Poll Question 3

Oregon Department of Transportation

Material Implementation

Concept

- Theory
- Material properties
- Initial research
- Sample products

Research

Specifications

Materials

Suppliers

Trial Projects

Implementation

Fully Implemented

- Fully vetted by research
- Material supply chains
- Mature specifications
- Biddable
- Contractor buy-in

Oregon Department of Transportation

- Research
- Specifications
- Materials
- Suppliers
- Trial Projects
- Implementation

Research

- ODOT & Oregon State University Research – SPR 711 (2013)
- No shortage of research
- FHWA EPIC²
- ASTM C1761 – Standard Specification for Lightweight Aggregate for Internal Curing of Concrete

Credit: Iowa State University CP Tech Center

internal curing

End Date	Title
May 2026	Revised Curing Practices for NDOT Bridge Decks to Minimize Restrained Shrinkage Cracks
December 2024	SPR-4727: Practical Implementation of Superabsorbent Polymers for Internally Cured Concrete
June 2024	Concrete Shrinkage Measurement and Man
January 2024	Influence of Internal Curing on Concrete's P… Conditions
December 2023	Construction of Low-Cracking High-Performa… New Technology: Phase II
August 2023	Use of Sand Lightweight Concrete and All Li… Properties
September 2022	Impacts of Internally Cured Concrete Paving
February 2022	Durability of Rapid-Hardening-Cement Conc
November 2021	Influence of Internal Curing on Measured Re
September 2021	Superabsorbent Polymers in Concrete to Im
May 2021	Summary Findings of Re-Engineered Contin… Pavement: Volume 1
April 2021	Impacts of Internally Cured Concrete Paving… Phase II—Field Implementation of Internally… Pavement Systems
March 2021	Reducing Shrinkage in Concrete Bridge Dec… Ring Test Methods
September 2020	Construction of Low-Cracking High-Performa… New Technology
April 2020	Application of Internal Curing to Improve Co

End Date	Title
January 2020	Development of Rapid Pavement Repair Materials
January 2020	Feasibility Study of Development of Ultra-High Performance Concrete (UHPC) for Highway Bridge Applications in Nebraska
September 2019	SPR-4419: Superabsorbent Polymers (SAP) for Internally Cured Concrete
August 2019	SPR-4003: Improving the Quality of Concrete for INDOT Projects
May 2019	Rapid Concrete Repair
April 2019	Investigation into Shrinkage of High-Performance Concrete Used for Iowa Bridge Decks and Overlays – Phase II Shrinkage Control and Field Investigation
November 2018	Curing Concrete Paving Mixtures
October 2018	Internal Curing of Bridge Decks and Concrete Pavement to Reduce Cracking
July 2018	Use of Internal Curing Materials to Improve Performance of Concrete Infrastructure
March 2018	Use of Lightweight Sand for Internal Curing to Improve Performance of Concrete Infrastructure
July 2016	Internal Curing of Pervious Concrete Using Lightweight Aggregates
June 2016	Bridge Decks: Mitigation of Shrinkage Cracking and Increased Durability
December 2015	Documentation of INDOT's Experience with the Construction of Bridge Deck's Containing Internal Curing in 2013
April 2015	Extended Life Concrete Bridge Decks Utilizing Improved Internal Curing to Reduce Cracking
September 2014	Preliminary Evaluation of Cool-crete
August 2014	Developing a Low Shrinkage, High Creep Concrete for Infrastructure Repair
July 2014	A Mobile Concrete Laboratory to Support Testing in 2014 on Internal Curing and High Early Strength Patches
February 2014	Internal Curing of High-Performance Concrete Using Lightweight Aggregates and Other Techniques
January 2014	Internally Cured Concrete for Pavement and Bridge Deck Applications
	Extend Service Life of Concrete Bridges Decks with Internal Curing

https://cptechcenter.org/concrete-infrastructure-research-database/

Oregon Department of Transportation

Research

Specifications

Materials

Suppliers

Trial Projects

Implementation

ODOT Draft Specifications

ODOT Draft Specifications - 2017

Aggregate for internal Curing - Internally Cured (IC) concrete shall utilize lightweight fine aggregate (LWFA) from the QPL. Provide the most current Quality Compliance Certification showing the material meets the requirements of ASTM C1761.

Determine fine aggregate replacement quantities according to subsection X1.3 of ASTM C1761, using an absorption value 5% less than the average of a minimum of three representative samples from the lot of material to be used on the project.

The LWFA shall be conditioned to Saturated Surface Dry (SSD) by saturating with water for at least 48 hours. No less than 12 hours prior to batching, remove saturation equipment and allow drain down of material. Maintain at or above SSD condition during all batching operations.

Oregon Department of Transportation

Research

Specifications

Materials

Suppliers

Trial Projects

Implementation

ASTM C 1761

Material Requirements

- **Water Absorption** –Min. 5% at 72 hours
- **Water Desorption** – Release 85% of absorbed water at 94% relative humidity

Replacement Amount

- **ASTM C 1761 - Subsection X1.3**

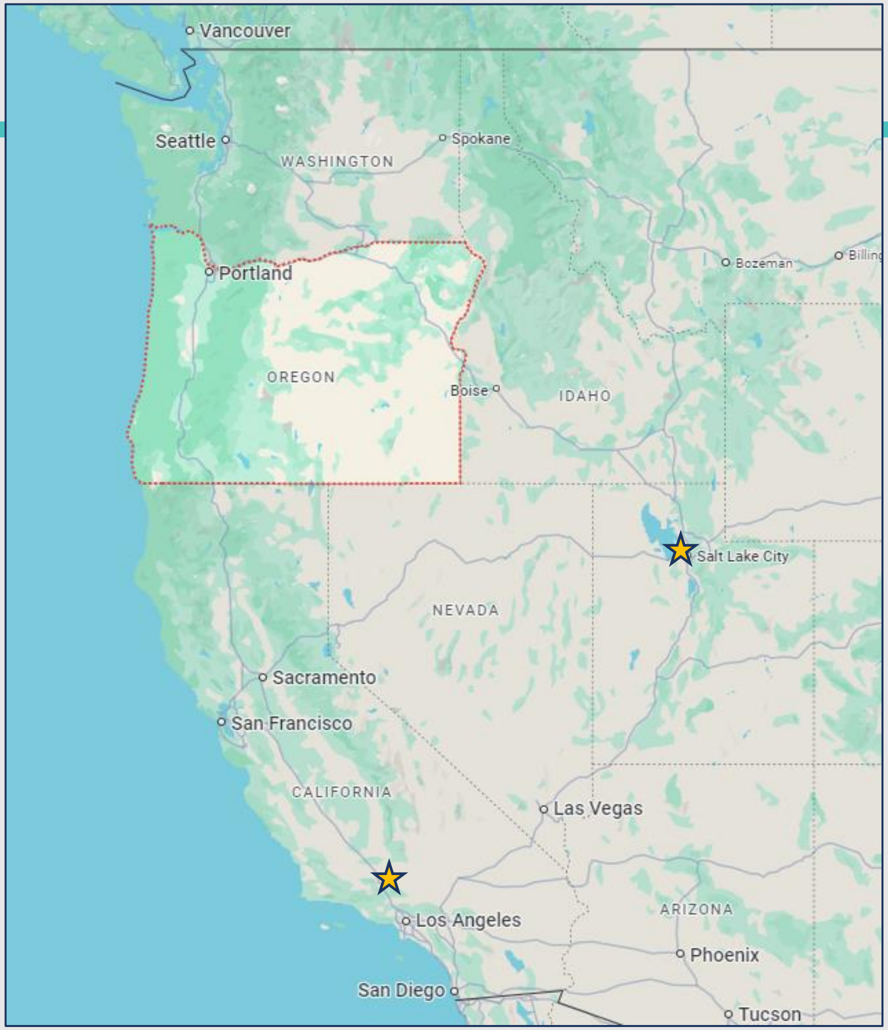
$$M_{LWA} = \frac{C_f \times CS \times \alpha_{max}}{S\ W_{LWA}}$$

$M_{LWA} = mass\ of\ lightweight\ aggregate\ needed\ per\ unit\ volume$

Oregon Department of Transportation

Materials

- Freight distances, limited trucking options
- Variable lead times
- Approving on a project-by-project basis, ASTM C 1761 test results
- No QPL (Qualified Products List) listings during trial projects



Oregon Department of Transportation

Research

Specifications

Materials

Suppliers

Trial Projects

Implementation

Material Handling and Trial Batches

ODOT Specification

"The LWFA shall be conditioned to Saturated Surface Dry (SSD) by saturating with water for at least 48 hours. No less than 12 hours prior to batching, remove saturation equipment and allow drain down of material. Maintain at or above SSD condition during all batching operations."

- Sprinklers, drain down, rotate stockpile
- Insufficient conditioning led to problems in expedited projects
- ASTM C1761 Centrifuge testing
- Education and coordination with suppliers was critical

Oregon Department of Transportation

Research

Specifications

Materials

Suppliers

Trial Projects

Implementation

Trial Projects

Contract	Contract Name	CY	Date Bid
C15035	US97 Spanish Hollow & Trout Creek	280	9/11/2018
C15035	US97 Spanish Hollow & Trout Creek	508	11/15/2018
C15138	US97 Passing Lanes	74	10/3/2019
C15173	I84 Hood River Bridges	320	10/24/2019
MBM21	I5 Elk Creek Deck Repair	20	5/10/2021
C15318	Old Hwy 99N: Oakland Bridge	440	10/28/2021
C15318	Melrose Rd: Conn Ford Bridge	647	10/28/2021
C15336	OR82: Bear Cr (Wallowa River) Bridge	646	12/16/2021
C15346	OR153: Salt Creek (Ash Swale)	476	1/13/2022
C15379	OR42: Frenchie Creek Culvert	120	4/7/2022
C15292	US97 & US20 Bend North Corridor	DB	5/20/2022
C15430	OR34: Van Buren Bridge (Corvallis)	1190	2/23/2023
C15445	Southern Oregon Seismic BR Phase 3	96	3/30/2023
C15445	Southern Oregon Seismic BR Phase 3	121	3/30/2023
C15445	Southern Oregon Seismic BR Phase 3	71	3/30/2023

Oregon Department of Transportation

Research

Specifications

Materials

Suppliers

Trial Projects

Implementation

Trial Projects – Perceived Risk & Costs

- Had assumed a small premium for material, freight, and stockpiling
- Did not account for Contractor perceived risk
- Prime Contractors continued to resist the new material
- In 2021, bid prices exceeded $4,000 per cubic yard
    - High cost was also due to haul time, limited supplier, coarse aggregate size
    - Internal Cure took the blame for the cost

600 cuyd Bridge Deck
Engineers Estimate - $600k
Contractor Bid - $2.6M

Oregon Department of Transportation

STRATEGIC PAUSE

Replacement Percentage

ASTM C1761

$$M_{LWA} = \frac{C_f \times CS \times \alpha_{max}}{S\ W_{LWA}}$$

02001.20(f) Internal Curing - For HPC(IC) concrete, internally cure the mixture according to the following:

Substitute 350 lbs (SSD) LWFA for standard Fine Aggregate.

		Cement	Fly Ash	Slag	Silica Fume	Total Cementitious	Water	W/CM Ratio	Degree of Hydration	ASTM C1761 LWFA Replacement Quantity
1	19-CMD490	420		280		700	255	0.36	1.0000	357
2	19-CMD474	504		229	30	763	259	0.34	0.9429	367
3	19-CMD461	517	113			630	229	0.36	1.0000	321
4	19-CMD456	492	222		26	740	272	0.37	1.0000	377
5	19-CMD443	474		256		730	260	0.36	0.9893	368
6	19-CMD409	434	198		26	658	238	0.36	1.0000	335
7	19-CMD395	475		216	29	720	277	0.38	1.0000	367
8	18-CMD382	420	191		25	636	230	0.36	1.0000	324
9	18-CMD377	482		219	29	730	260	0.36	0.9893	368
10	18-CMD374	430		195	25	650	250	0.38	1.0000	331
11	18-CMD370	416	189		25	630	242	0.38	1.0000	321
12	18-CMD363	449	204		27	680	252	0.37	1.0000	347
13	18-CMD352	498		226	30	754	267	0.35	0.9836	378
14	18-CMD345	559	254		34	847	275	0.32	0.9019	389
15	18-CMD344	488	222		30	740	270	0.36	1.0000	377
					AVG:	707	256	0.36		355

Assumed LWFA Properties

Absorption	18.0%
Desorption	90.0%
Chemical Shrinkage	0.07

Oregon Department of Transportation

Research

Specifications

Round 2

Materials

Suppliers

Trial Projects

Implementation

Conditioning

02690.50 Lightweight Fine Aggregate - Provide lightweight fine aggregate (LWFA) from the QPL. Maintain LWFA at or above saturated surface dry (SSD) condition by uniformly saturating and allowing drain down prior to batching and verify moisture condition by sampling and testing according to ODOT TM 249. Maintain the SSD condition during all batching operations.

- Shortcut to test for aggregate moisture at any time
- Modification to the 72-hour ASTM C 1761 absorption test
- Assumes absorption, does not calculation absorption
- Can be done directly before batching or during
- Provides a moisture content to enter into batching system

MATERIALS LABORATORY

ODOT Test Method 249-20

Method of Test for

MOISTURE CONTENTS OF LIGHTWEIGHT FINE AGGREGATES

SCOPE

1.1 This test method covers the procedure for determining the absorption, surface moisture and total moisture of lightweight fine aggregates used in portland cement concrete.

SUMMARY

2.1 A representative sample of aggregate is removed from a previously sealed container, weighed and then placed into a centrifuge where the surface moisture is spun off. The resulting surface dry material is weighed and placed into a drying oven until a constant weight is achieved. With the final material dry weight the absorption, surface moisture and total moisture can be calculated.

APPARATUS

3.1 Containers - Suitable sampling containers with moisture tight lids.

3.2 Balance - A balance having a capacity of 5000 g and accurate to 0.1 g.

3.3 Centrifuge – Any suitable high-speed (3,000-r/min or higher) centrifuge of the continuous-flow type, capable of handling a minimum of 1,500 g samples.

Oregon Department of Transportation

Research

Specifications

Materials
Round 2

Suppliers

Trial Projects

Implementation

Qualified Products List

Qualified Products List (QPL)

- Provides a quick reference of material suppliers
- Decreases approval time for mix design development and submittals

Standard Guidelines for Product Review
Light Weight Fine Aggregate
Section 02690.50
January 2023

Oregon
DEPARTMENT OF TRANSPORTATION
Construction Services
800 Airport Road SE
Salem, OR 97301-4792
503-986-3059

02690.50 – Light Weight Fine Aggregate

To Apply:

- ODOT Preliminary Information for Product Evaluation Form 734-5098.
- Most recent ASTM C330 independent test report.
    - Note: Absorption desorption requirements.
        - Minimum 5% absorption when tested in accordance with ASTM C1761
        - Minimum 85% desorption when tested in accordance with ASTM C1761
- Specification Data Sheet.
- Detailed installation instructions.
- List of Limitations and Precautions for the aggregate, storage, handling, etc.
- Copy of your QC/QA program as it relates to this material production.
- Two (2) 5-gallon buckets of the Fine Aggregate. Full buckets.

https://www.oregon.gov/ODOT/Construction/Pages/Qualified-Products.aspx

Oregon Department of Transportation

Implementation

Since 2021:

- Prices have stabilized to approx. $1,700/cuyd
- Most suppliers have an approved IC mix design
- Bridge Design Section has included it in the Bridge Design Manual as the standard for bridge decks

Salt Creek Bridge | Amity, OR

Research

Specifications

Materials

Suppliers

Trial Projects

Implementation

Contractor Buy-In

"Prominent and local concrete suppliers perceive the IC concrete as too risky and will not quote or furnish the material."

"They recommended that ODOT conduct a lifecycle cost-benefit analysis for IC Concrete with more recent IC concrete cost information."

"The Contractors with experience placing IC Concrete struggled to see the value in it."

Oregon Department of Transportation

“They recommended that ODOT conduct a lifecycle cost-benefit analysis for IC Concrete with more recent IC concrete cost information.”

"They recommended that ODOT conduct a lifecycle cost-benefit analysis for IC Concrete with more recent IC concrete cost information."

Cost-Benefit Analysis

Bridge Deck Service Life – 100-year Forecast

"Normal" Non-IC Bridge Deck

Year	Deck Maintenance
0	Original Construction (assume cracks)
10	Deck Seal
20	Thin Polymer Overlay (PPC/MPCO)
50	Structural Overlay
75	Structural Overlay or Deck Replacement
100	100 YR Design Service Life

IC Bridge Deck

Year	Deck Maintenance
0	Original Construction (assume limited cracks)
50	Thin Polymer Overlay (PPC/MPCO)
75	Structural Overlay
100	100 YR Design Service Life

Oregon Department of Transportation

Cost-Benefit Analysis

"They recommended that ODOT conduct a lifecycle cost-benefit analysis for IC Concrete with more recent IC concrete cost information."

Compare Non-IC Bridge Deck Concrete with a PPC Overlay

vs.

IC Bridge Deck without overlay

Span	Length (ft)	Width (ft)	Deck Thickness (in)	Deck Area (SY)	Deck Concrete Volume (CY)
1	40	52.5	8	233	52
2	185	52.5	9	1079	270
3	245	52.5	9	1429	357
4	185	52.5	9	1079	270
5	75	52.5	9	438	109
			Totals =	4258	1058
	Item		Quantity	Unit Cost	Total
	Construct PPC Overlay :		4258 SY	$ 35	$ 149,042
	Furnish PPC Material :		1058 CY	$ 2,500	$ 2,645,255
				Total :	$ 2,790,000
				Additional cost for PPC overlay/CY Deck Concrete :	$ 2,637

Oregon Department of Transportation

IC Bridge Decks are still comparable at 3x the bid price of normal deck mix

“The Contractors with experience placing IC Concrete struggled to see the value in it.”

HPC vs HPC(IC) Crack Survey

Goals

Determine performance of internally cured concrete decks in Oregon over the past 6 years, compared to similar standard cured HPC concrete mix design decks.

- Develop repeatable data collection method
- Preform soffit inspections
- Calculate crack density

Challenges

Due to Oregon's small sample size of internally cured bridge decks, gathering a large quantity of data from IC and comparable conventional bridge decks was challenging.

To eliminate uncertainty in making decisions about comparable bridge decks we focuses on 3 attributes:

- Geographically similar locations
- Cast during similar times of the year
- Similar deck geometries

Oregon Department of Transportation

Deck Crack Survey

- 11 bridge deck soffit inspections
- 5 IC decks, 6 conventional decks
- All built in past 6 years with similar geometries, geographical locations, and cast in similar environmental conditions
- Take photographs and scale them in BlueBeam to measure crack lengths and then report crack density

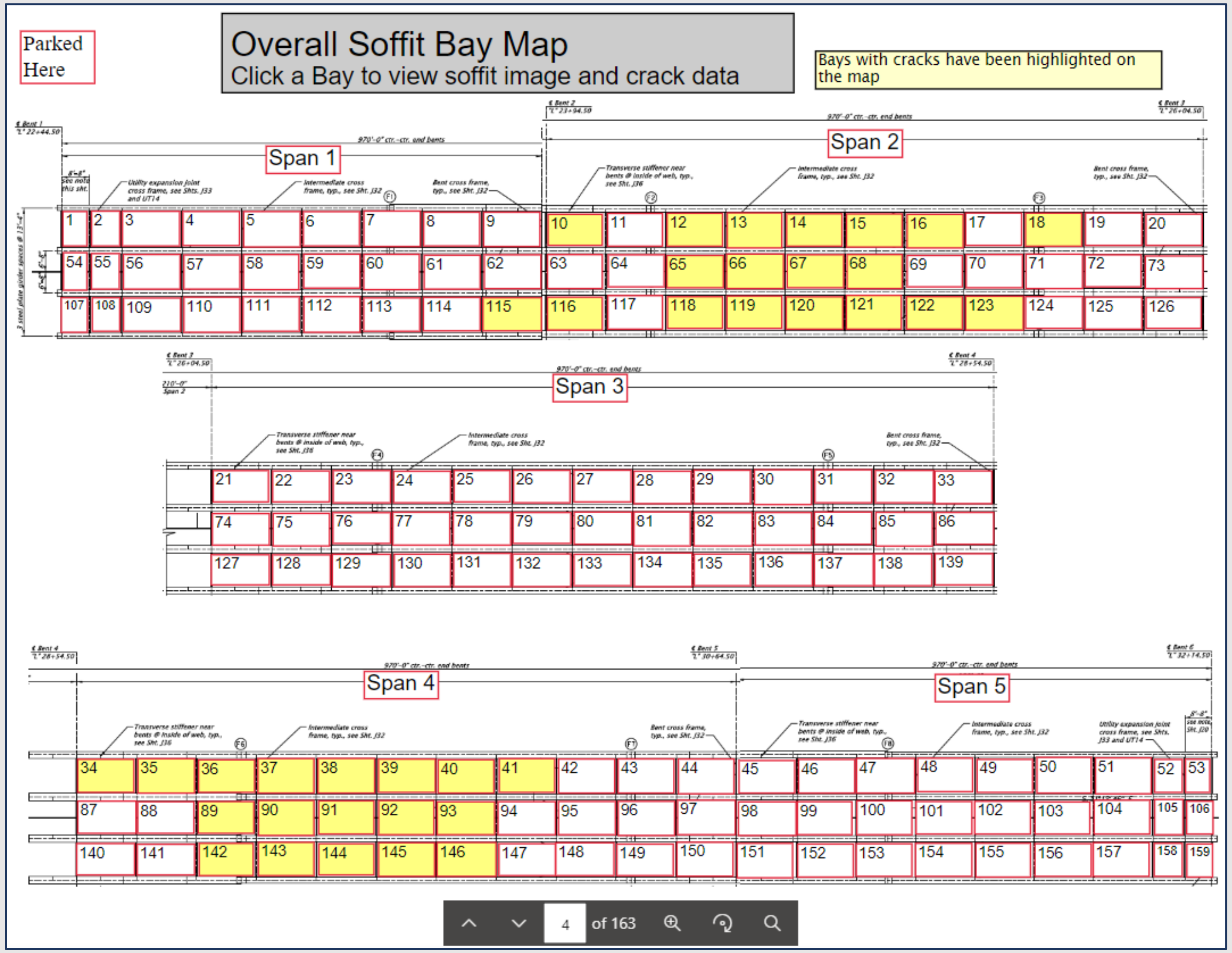
Calapooya Creek | Oakland, OR

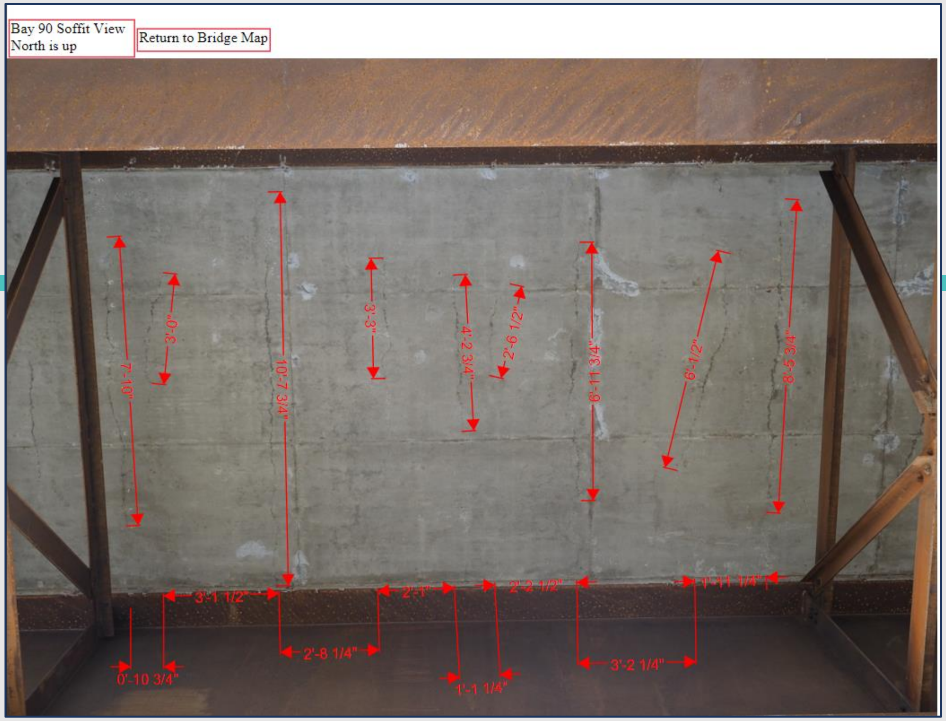
Calapooya Creek | Oakland, OR

Wildlife Crossing | Bend, OR

Oregon
Department
of Transportation

Survey Methodology





South Yamhill River Bridge | McMinnville, OR

Bridge Information:					
Overall Structure Length:	970	feet			
Deck Width:	49.25	feet			
Number of Spans:	5	count			
Span Lengths (feet):	Span 1	Span 2	Span 3	Span 4	Span 5
	150	210	250	210	150

Span #	Bay #	# of Cracks	Total Length of Cracks (in	Average Crack Spacing (inch)
4	89	2	112.75	30
4	90	9	636.25	25.81
4	91	9	627.75	23.5
4	92	5	474	43.38
4	93	2	134	53.75

Value

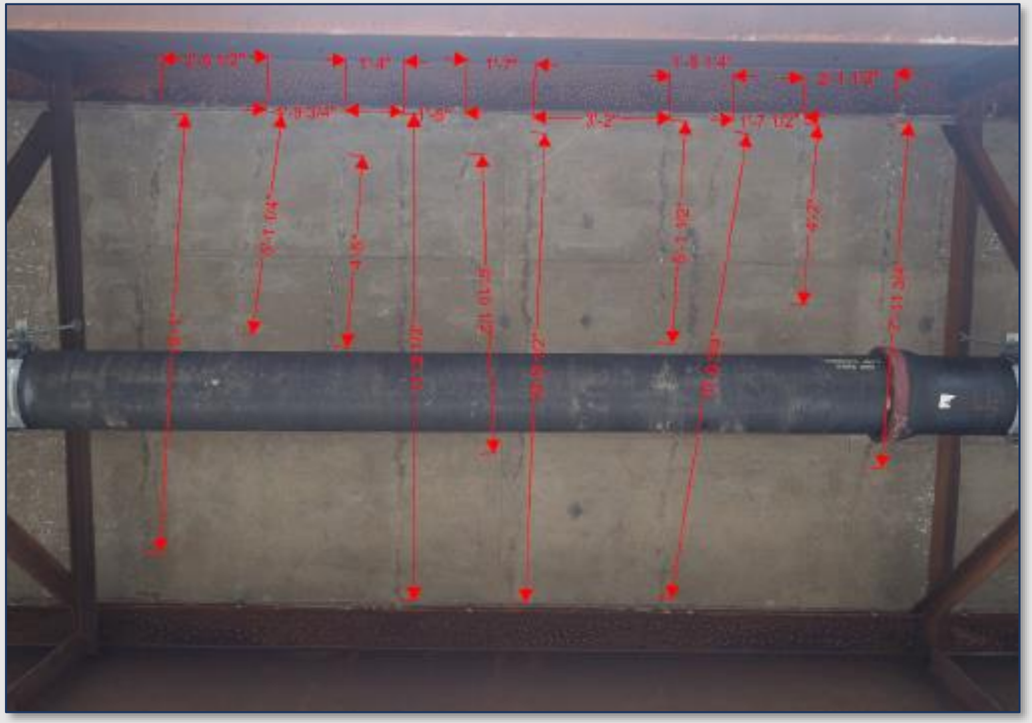
70% *reduction in crack density*

Internal / External Cure	Bridge Name	Bridge Number	Overall Crack Density (ft/sqft)	Worst Span Crack Density (ft/sqft)	Best Span Crack Density (ft/sqft)	Average Crack Spacing (inch)
External	Wildlife Pass_Hwy004_NB_MP154.33	BR23931	0.0064	0.0064	0.0064	78
External	Wildlife Pass_Hwy004_SB_MP154.33	BR23932	0.0092	0.0092	0.0092	13
External	Burchard Creek, Hwy 45	BR22430	0.0227	0.0227	0.0227	50.62
External	South Yamhill River Hwy 483 MP: 46.75	BR22688	0.0318	0.0593	0.0006	33.7
External	Grabb Cr_Hwy 45	BR22431	0.0477	0.0477	0.0477	38.91
External	Bridge Cr_Hwy 041_MP65.05	BR23890	no cracks	no cracks	no cracks	no cracks
Internal	Trout Cr_Hwy 004_MP75.04	BR22576	0.0025	0.0032	0.0019	34
Internal	Spanish Hollow Creek_Hwy 042_ MP0.39	BR22538	0.0028	0.0044	0.0014	61.1
Internal	Salt Creek (Ash Swale) HWY 153_MP5.88	BR23871	0.0086	0.0149	0.0036	75.1
Internal	Wildlife Crossing_Hwy 004_MP180.13	BR22757	0.0119	0.0119	0.0119	15.7
Internal	Frenchie Cr_Hwy 035_MP35.57	BR23265	no cracks	no cracks	no cracks	no cracks

	External	Internal	Percent Difference	
Average Cure Type Crack Density (ft/sqft)	0.02356	0.0064475	**72.63370119**	**<- This means crack density, on average, was reduced by 72.6%**
Average Cure Type Crack Spacing (inch)	42.846	46.475	**-8.469868833**	**<- This means crack spacing, on average, was widened by 8.47%**

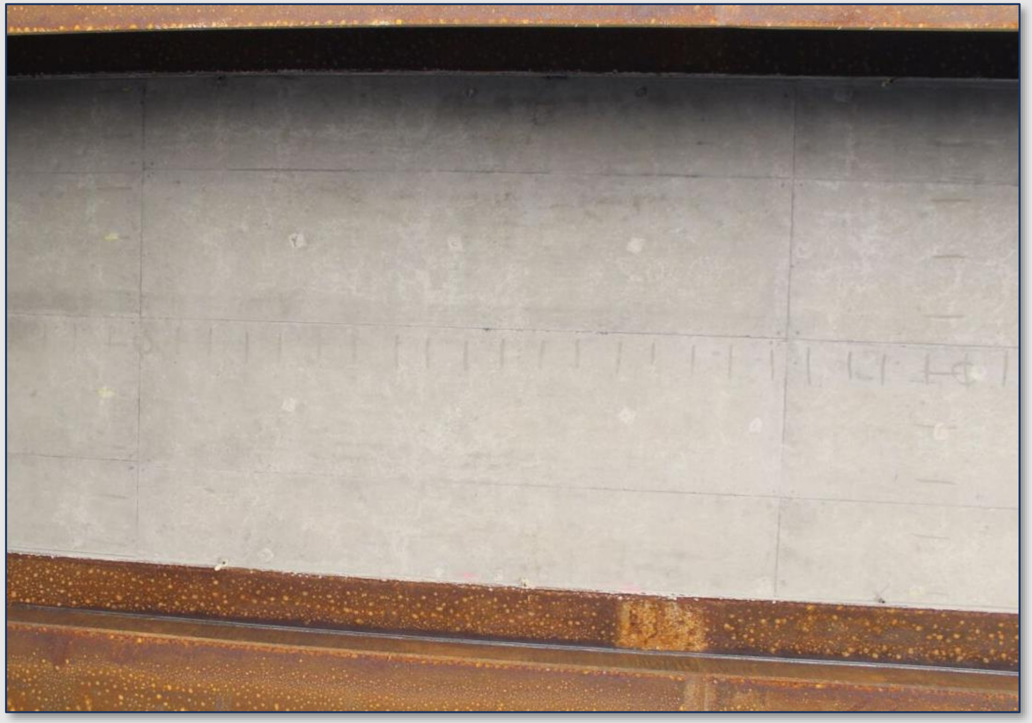
Oregon Department of Transportation

Visual Comparison



Typical HPC Deck Soffit

South Yamhill River Bridge | McMinnville, OR



Typical HPC-IC Deck Soffit

Salt Creek Bridge | Amity, OR

Oregon Department of Transportation

Summary

- Greatest challenge was getting support from Contractors due to perceived risk
- Reduced complications and improved buy-in through simplifying the specifications
- Internally Cured bridge decks are now the default design and recommending the practice to other Agencies within Oregon
- As-installed prices are decreasing and stabilizing
- Reduction in cracking by 70% increases service life estimates and changes maintenance strategies of ODOT bridge decks
- ODOT is pursuing a decrease in wet-cure duration for IC bridge decks (From 14 days -> 7 days)
- Looking into additional material sources within the region
- Looking into other use cases including paving and overlays

Salt Creek Bridge | Amity, OR

Oregon Department of Transportation

Poll Question 4

Questions

David Dobson, PE
Structural Materials Engineer
ODOT | Structure Services
971.900.7118
David.dobson@odot.oregon.gov

Spanish Hollow Bridge | Biggs Junction, OR

Oregon Department of Transportation

Poll Question 5

EPIC² On-Demand Webinars

History & Performance of Internally Cured Concrete
Mixture Proportioning for Internally Cured Concrete
Lessons Learned in NY, IN, and LA