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The Economics, Performance, and Sustainability of Internally Cured Concrete, Part 2

ACI Fall 2012 Convention
October 21 – 24, Toronto, ON

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Cleveland State University
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Case Studies of Internal Curing of Bridge Decks in the Greater Cleveland Area

Norbert Delatte, Professor and Chair,
Cleveland State University
Dale Crowl, ODOT District 12

Approaches to Internal Curing of Bridge Decks

- Moderate to high absorption coarse aggregate
- Fine lightweight aggregate (LWA)
- LWA concrete with Type K cement

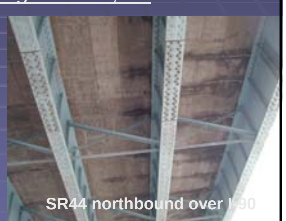
Field Observations

Dale Crowl and Mike Sutak A Survey of High Performance Concrete Bridge Decks, IV. ODOT-District 12, April 1st, 2002

Findings:

Early age cracking of bridge decks was increasing

Linked to coarse aggregate absorption capacity


SR44 northbound over I-90

Field Observations

- 1994 – 1996, 30 bridge decks, one with cracking
- 1997 – 2001, 79 bridge decks, 48 with cracking
- Increase in cracking with increasing use of HPC bridge decks

Field Observations

Concrete mixture designs were identical. The only differences were absorption capacities.

- Absorption Capacity
  - 57's Coarse Aggregate = 0.35 %
  - 8's Coarse Aggregate = 0.81 %
- Absorption Capacity
  - 57's Coarse Aggregate = 2.37 %
  - 8's Coarse Aggregate = 3.06 %

Phased Construction

Emery Road over I-271

Phased Construction

- Placed in two phases by same general contractor
- Concrete plant had changed source of coarse aggregate
- Side with cracking – CA absorption 0.39 %
- Side without cracking – CA abs 1.52 %

Adjustments – ODOT D12

- Use of blend of #57 and #8
- Therefore, reduction in water and cementitious material content
- Only medium and high absorption aggregate allowed
- Slight increase in w/cm ratio
- All reduce cracking potential – what is the relative contribution?

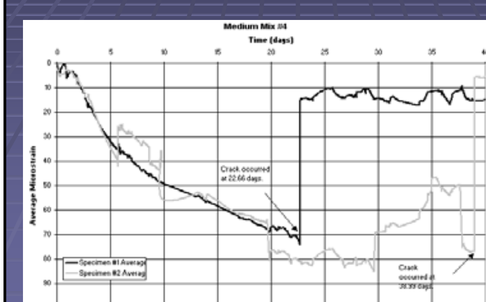
Experimental Design – CSU Project

Coarse aggregates

- Crushed Limestone
  - Low Absorption less than 1% – Cedarville
  - Medium Absorption between 1% and 2% – Calcite
  - High Absorption greater than 2% – Marblehead
- Washed River Gravel
  - Medium Absorption – Fairborn

Restrained Ring Shrinkage

Typical strain versus time to cracking



Cracking Potential

Net Time to Cracking, t_{cr}, (day)	Stress Rate at Cracking, S, (psi/day)	Potential for Cracking
$0<t_{cr}\leq 7$	$S\geq 49.3$	High
$7<t_{cr}\leq 14$	$24.65\leq S<49.3$	Moderate - High
$14<t_{cr}\leq 28$	$14.5\leq S<24.65$	Moderate – Low
$t_{cr}\geq 28$	$S<14.5$	Low

ASTM Standard ends at 28 days, this research was carried out to 90 days

Cracking Time Summary

Mixture	Minimum time	Maximum time	Average	Standard deviation
HP low absorption	23	37	32.8	6.9
HP medium absorption	23	90	47.1	29.5
HP high absorption	11	90	26.7	30
HP low absorption with LWA	19	81	46.3	29.9
HP blend	51	90	85	13.9

Summary – Restrained Shrinkage

- Addition of LWA generally improved cracking classification
- Two ring sizes used
  - 16” OD for mixtures with only #8 CA
  - 18” OD for mixtures with #57 CA
  - Correction factor of 1.53 applied to 18” rings for comparison

Summary – Restrained Shrinkage

- Ring specimens with blended aggregate concrete mixtures most resistant to cracking
- Blended mixtures either “low” or “very low” cracking risk
- Concrete mixture with only #8 aggregate cracked frequently

Full Scale Bridge Deck

- Built May 2007

Full Scale Bridge Deck

- One side ODOT D12 modified mixture with blended aggregate, moderate absorption
- One side added fine LWA
- Pumped
- Very little cracking observed
- Field samples reached 7,500 psi compressive strength, low cracking tendency

Full Scale Bridge Deck

Small Crack at 5 Weeks

Follow Up – December 13, 2011

Main Avenue Bridge Redecking

- From Gulyas et al., 2008, “High Performance Bridge Deck: Use of ASTM C845 Type K Shrinkage Compensating Cement with Lightweight Aggregate for Optimized Internal Curing, Excellent Durability, and Performance Benefits”

Main Avenue Bridge Redecking

- Bridge redecking in 1992
- Sand-lightweight concrete deck
- Reduced dead load allowed adding a traffic lane in each direction without strengthening bridge

Main Avenue Bridge Redecking

- Concrete mixture
  - 715 lb/CY Type K cement
  - Coarse aggregate 918 lb/CY LWA, ¾ inch
  - Fine aggregate 1,290 lb/CY natural sand
  - Air 6 % ± 2, w/c = 0.55
- ODOT built more than 300 bridge decks with Type K cement between 1985 and 1990

Observations by Gulyas et al., 2008

Gulyas et al. Review, 2008

- Bridge deck at 15 years of service
- Excellent condition, no cracking
- Most of deck cast on metal stay-in-place forms, so few places to view underside

Delatte and Crowl Review, 2011

- Bridge deck still in excellent condition
- No cracking, spalling, freeze-thaw damage, or scaling
- Approaches in each direction deteriorated
- Bridge very close to Lake Erie, many freeze-thaw cycles
- Road salt accumulates along edges of deck

Conclusions

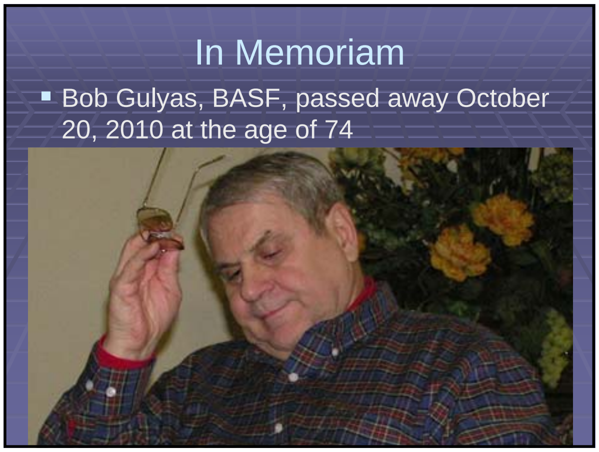
- Internal curing effective
- HPC with higher absorption aggregates can provide some internal curing
- Full deck bridge test with fine LWA replacement in excellent condition, but relatively new
- Bridge deck with Type K cement and sand-lightweight concrete in excellent condition after 20 years

Future Research

- Expansive and shrinkage compensating concrete with LWA
- Internal curing effect on freeze-thaw, fatigue, wear resistance, permeability
- Thin concrete overlays of bridge decks and pavements

Acknowledgements

- ODOT State Job Number 134227
- Bryan Struble and Lloyd Welker at ODOT Central
- John Roberts and Northeast Solite
- Blake Kreuer, Nader Amer, Aleksandar Mrkajic, Dan Miller
- Rich Martin
- CSU Staff, CSU University Transportation Center


In Memoriam
Bob Gulyas, BASF, passed away October 20, 2010 at the age of 74


Thank you – Questions?
One Test is Worth
a Thousand Expert Opinions