Virginia Center *for* Transportation
INNOVATION
& RESEARCH

We bring innovation to transportation.

Fiber Reinforced Concrete and Overlays

Celik Ozyildirim, PhD, PE

Hari Nair, PhD, PE

Virginia Concrete Conference, 2015

Outline

- Introduction
  - Crack width vs. Permeability
  - Crack Reduction
- Fibers
  - High-Performance Fiber-Reinforced Concrete
  - Applications: shear key, closure pour
- Overlays
  - Dunlap Creek
- Conclusion

Introduction

- Concrete kept dry lasts a long time.
- Low permeability concretes resist penetration of water and solutions.
- Cracks facilitate the intrusion of water and solutions.

Cracks

- Cracks act as a pathway for water and aggressive chemical ions to penetrate concrete and enable its deterioration.
- Difficult to penetrate cracks < 0.1 mm wide.
- Cracks can result from excessive loading, environmental conditions, chemical reactions, construction or design errors.

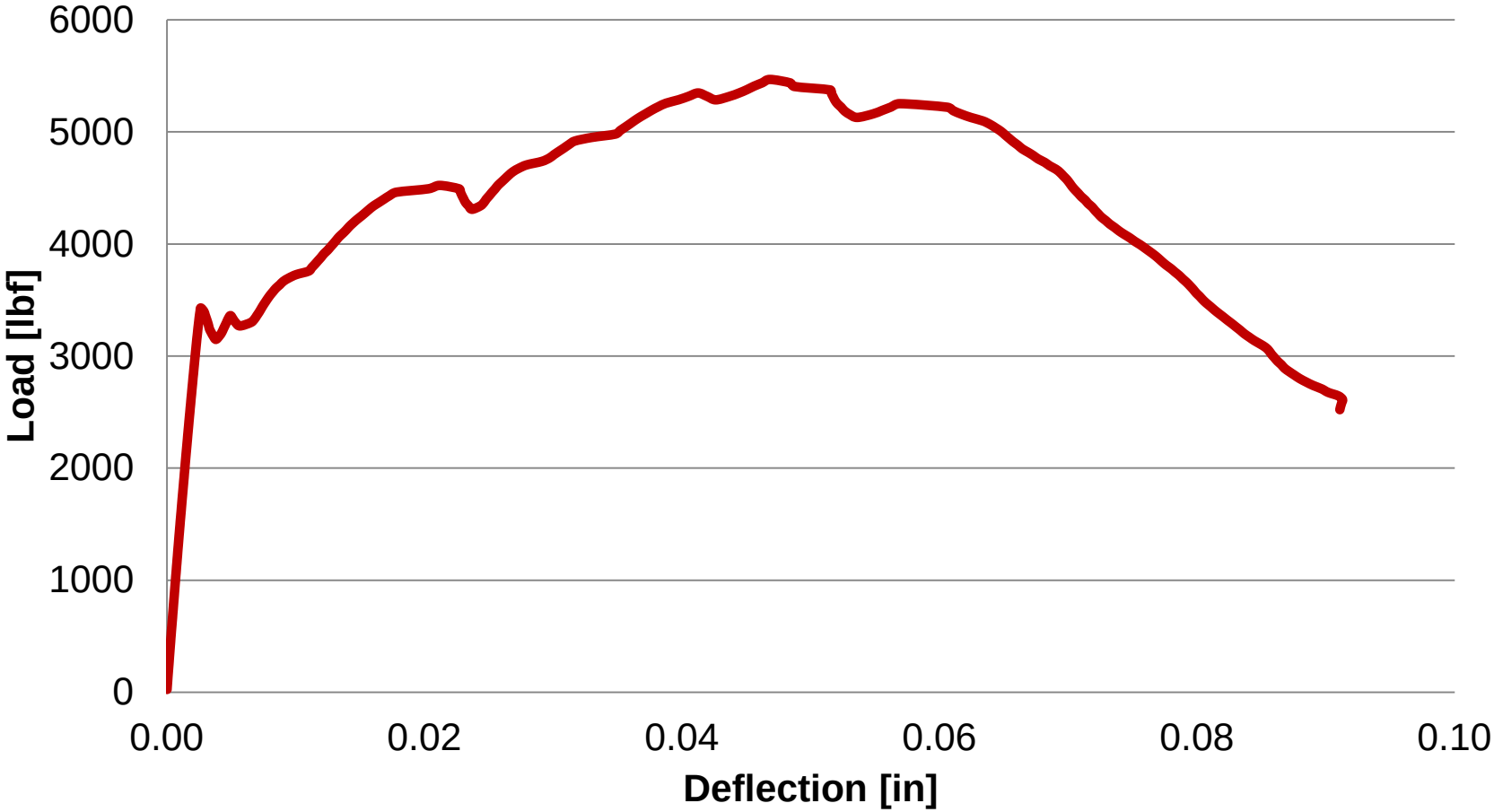
Crack Reduction Through Ingredients

- Lower Paste Contents
- Shrinkage Reducing Admixtures
- Lightweight Concretes
- Fibers

Fibers

- Low Fiber Dosage: Plastic shrinkage cracking control
- High Fiber Dosage: High-performance fiber-reinforced concrete (HPFRC) for crack control in hardened concrete

HPFRC - Deflection Hardening



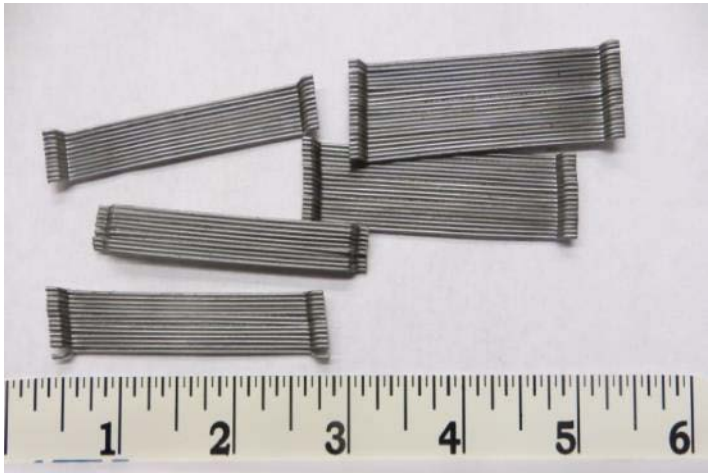
HPFRC

- Fibers
  - Polyvinyl alcohol, PVA
  - Polypropylene, PP
  - Steel with hooked ends
- Fibers are used for deflection and strain hardening to achieve many tight cracks (< 0.1 mm).
- Tight cracks hinder the penetration of solutions.
- Used in shear keys and closure pours

Fibers

Polyvinyl alcohol

Polypropylene

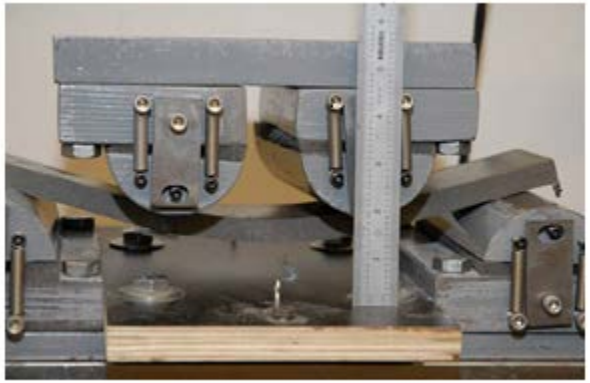


Steel with hooked ends

HPFRC Beam with ECC

Crack Pattern at Failure:

Bendable Under Loading:



ECC: Engineered Cementitious Composite contains PVA (polyvinyl alcohol) fibers

Applications of HPFRC

- Shear Keys
  - Winchester
  - Surry
- Closure Pours
  - I-64 Bridge over Dunlap Creek

HPFRC in Shear Keys - Winchester

HPFRC - Winchester

Property at 28 days	Grout	ECC	UHPC
Compressive Strength (psi)	8,235	6,240	16,220
Slant Shear Bond Str. (psi)	3,820	4,640	4,410
Permeability at 100 ºF (C)	3,691	174	0
Elastic Modulus (10^6 psi)	4.55	2.96	8.64
First peak strength (psi)	1,150	912	2,204

Shear Keys - Winchester Bridge (Route 645 after 3 months)

Non-shrink grout

ECC

UHPC

Non-shrink grout

Non-shrink grout

HPFRC in Shear Keys - Surry

HPFRC - Surry

Property at 28 days	ECC
Compressive Strength (psi)	5,690
Permeability at 100 ºF (C)	325
Elastic Modulus (10^6 psi)	2.50
First peak strength (psi)	855

Closure Pour Cracks

I-64 over Dunlap Creek

Closure Pour-Dunlap Creek Bridge

Closure Pour

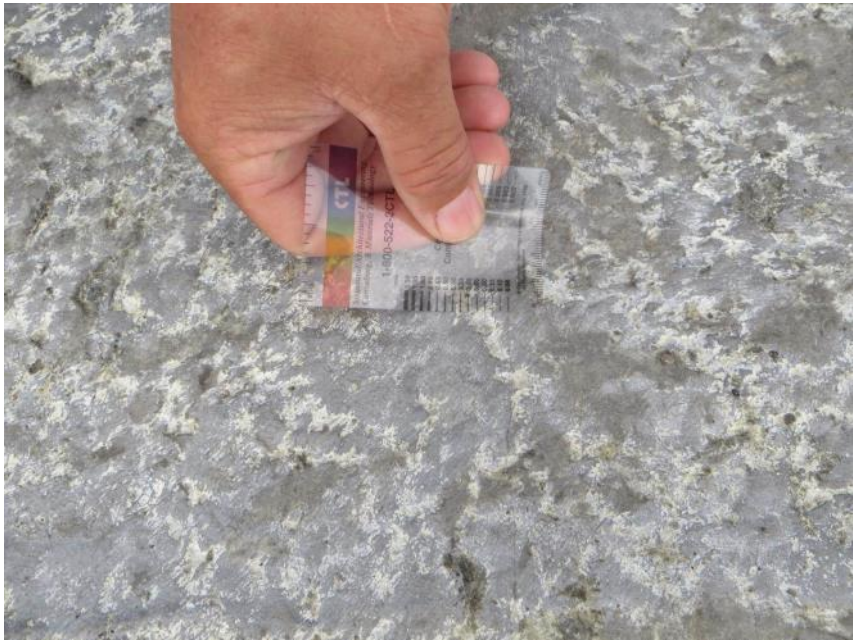
Crack Width Control

Rapid Set Latex

No fibers

ECC

With fibers



ECC Mix Design-Batch 1 and 2	
Ingredient	lb/yd³
Cement	961
Fly Ash	1153
Mortar Sand	725
Water	571
w/c	0.27
PVA Fibers	44
HWRA	6 oz/cwt
Accelerator	30 oz/cwt
SRA	1.5 oz/cwt

ECC Mix Design-Batch 3 and 4	
Ingredient	lb/yd³
Cement	933
Fly Ash	1153
Mortar Sand	715
Water	548
w/c	0.26
PVA Fibers	44
HWRA	7 oz/cwt
Accelerator	15 oz/cwt
SRA	1.5 oz/cwt

Fresh Properties of ECC

Test	Batch 1	Batch 2	Batch 3	Batch 4
Air Content (%)	2.0	1.8	2.5	2.5
Density (lb/ft^3)	125.3	122.8	122.4	122.4
Slump Flow (in)	24.0	17.5	20.1	20.1
Concrete T (˚F)	92	92	79	79

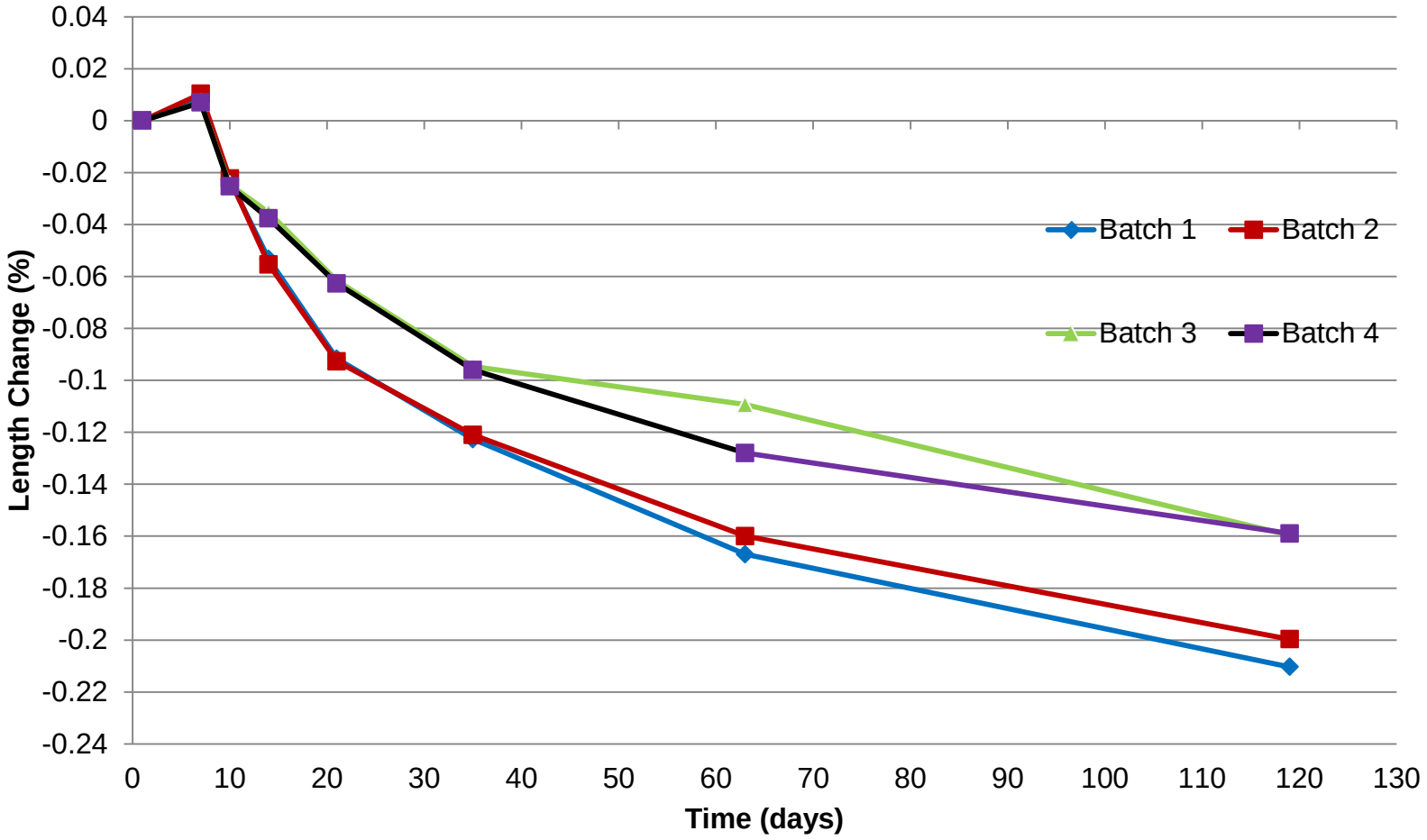
Hardened Properties of ECC

Test	Age (d)	Batch 1	Batch 2	Batch 3	Batch 4
Compressive Strength (psi)	1	2480	2100	2770	3440
	7	4230	3890	4380	5300
	28	6380	6140	6520	6730
Permeability (C)	7	-	-	169	129
	28	401	330	-	-
Flexural Strength (psi)	28	1374	1262	1245	1062
Elastic Modulus (10^6 psi)	28	1.96	2.06	2.43	2.59

Rapid Set Latex Modified Concrete Mix Design	
Ingredient	lb/yd^3
Type I/II pc	658
Sand	1529
No. 8 Stone	1232
Water	146
w/c	0.39
Latex	205.8

Hardened Properties of Rapid Set Latex Modified Concrete				
Test	Age (d)	Batch 1	Batch 2	Batch 3
Compressive Strength (psi)	3 hr	2780	3660	-
	6 hr	2600	4400	-
	1	2810	-	-
	28	3870	6400	6670
Splitting Tensile (psi)	1	340	510	-
	28	460	810	805
Permeability (C)	28	1947	499	468
Elastic Modulus (10^6 psi)	28	2.82	2.92	3.87

ECC - Shrinkage



ECC - Separation Between Existing and New Concrete at the Closure Pour

Overlay was placed after the closure pour and closed the gap.

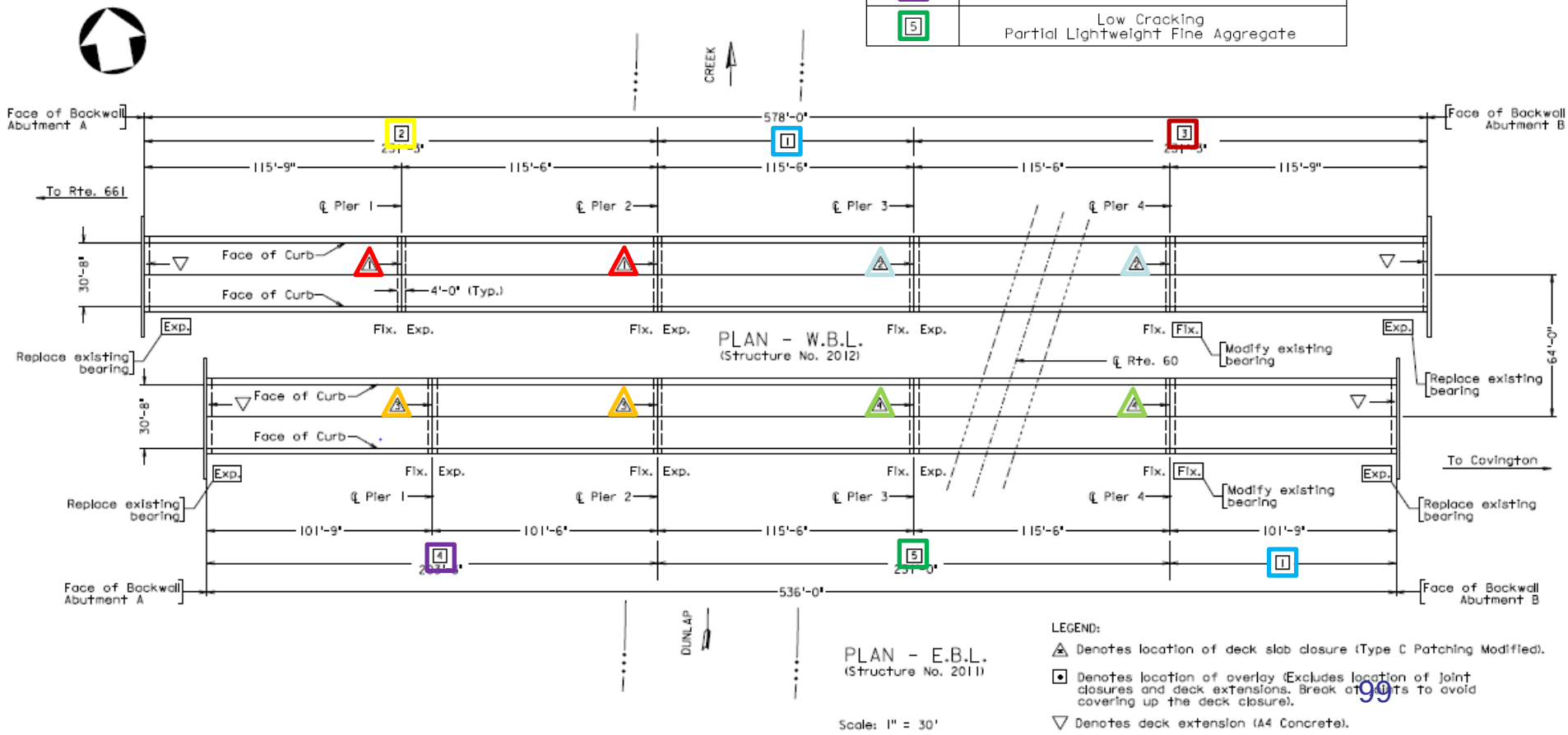
Overlays

- Cost effective solution to deck preservation and rehabilitation
- Sustainable since they extend design life

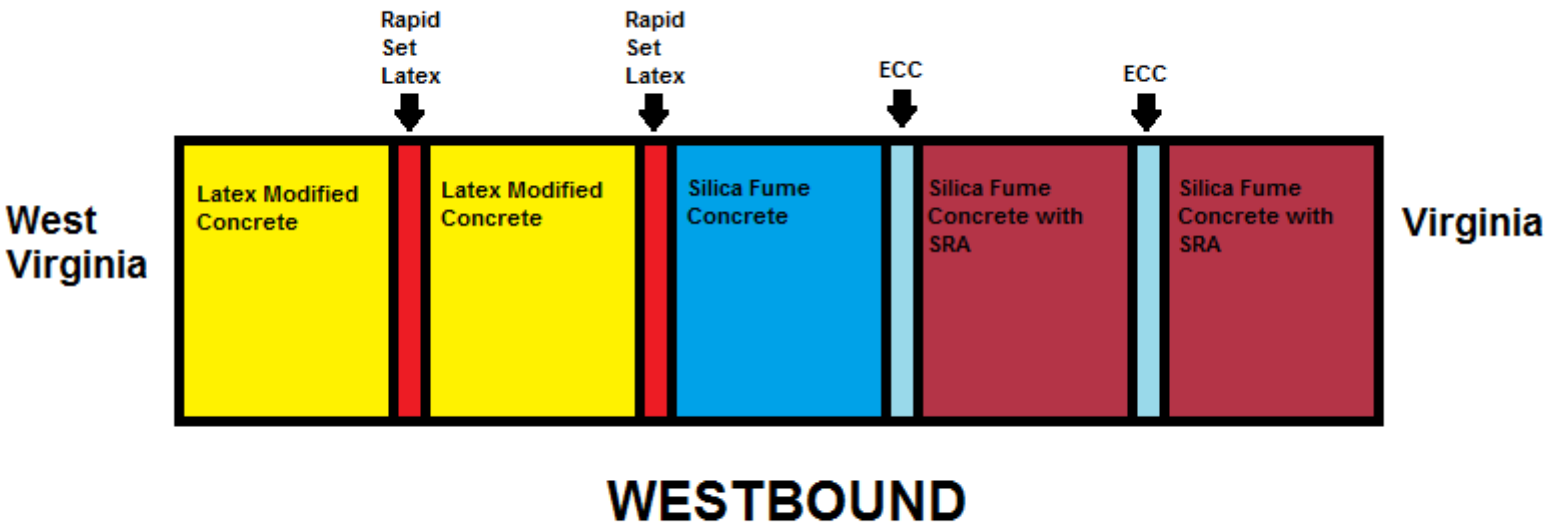
Overlays-Dunlap Creek Bridge

- Rapid Set Latex Concrete
- Silica Fume Concrete
- Silica Fume with Shrinkage Reducing Admixture
- Lightweight Concrete
  - Lightweight coarse aggregate (<120 lb/ft^3)
  - Internal curing with lightweight fine aggregate

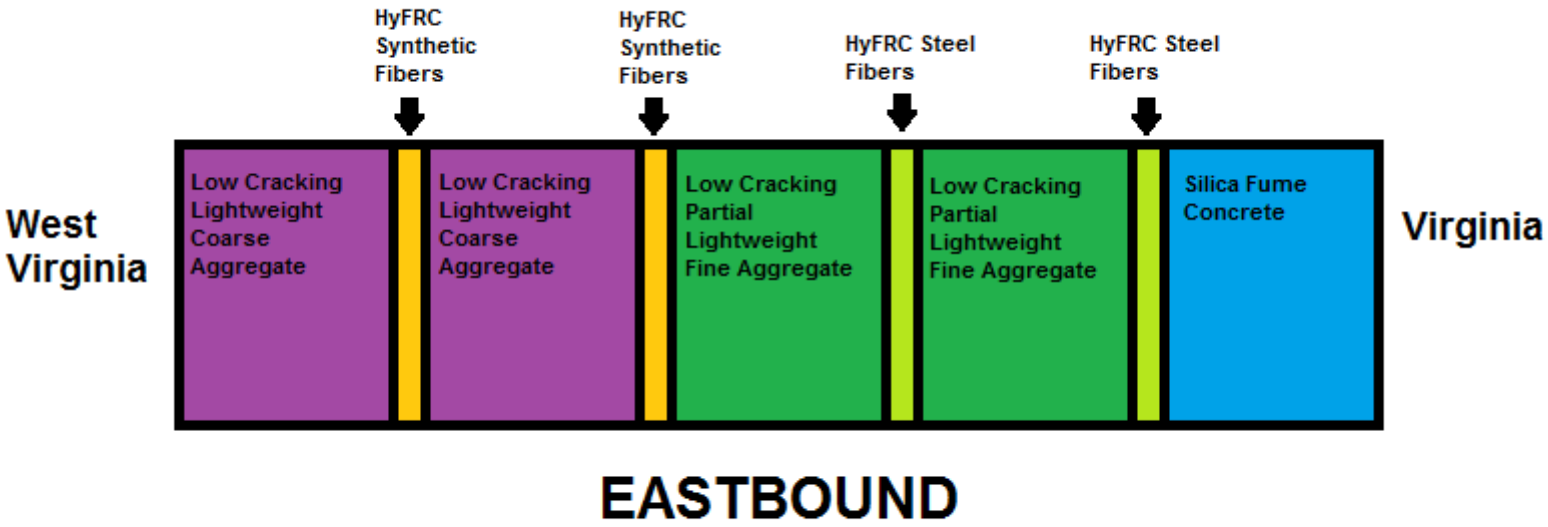
DECK CLOSURE/OVERLAY MATERIAL	
Location	Material
1	Rapid Set Latex Concrete
2	ECC: 2% PVA Fibers (0.4")
3	HyFRC: Synthetic Fibers 1.2% PP (2")
4	HyFRC: 0.6% Steel Fibers (2.4")
1	Silica Fume Concrete
2	Latex Modified Concrete
3	Low Cracking Shrinkage Reducing Admixture
4	Low Cracking Lightweight Coarse Aggregate
5	Low Cracking Partial Lightweight Fine Aggregate



Dunlap Creek West Bound - 2014



Dunlap Creek East Bound - 2015



Silica Fume Concrete Mix Design	
Ingredient	lb/yd³
Type I/II pc	508
Fly Ash (16%)	102
Silica Fume (4%)	25
Sand	1451
No. 78 Stone	1481
Water	267
w/c	0.44
Air	7%

Silica Fume Concrete with SRA Mix Design	
Ingredient	lb/yd³
Type I/II pc	508
Fly Ash (16%)	102
Silica Fume (4%)	25
Sand	1451
No. 78 Stone	1481
Water	267
w/c	0.44
Air	7%
SRA	1.5 gal

Admixtures: AEA, Retarder, HRWRA

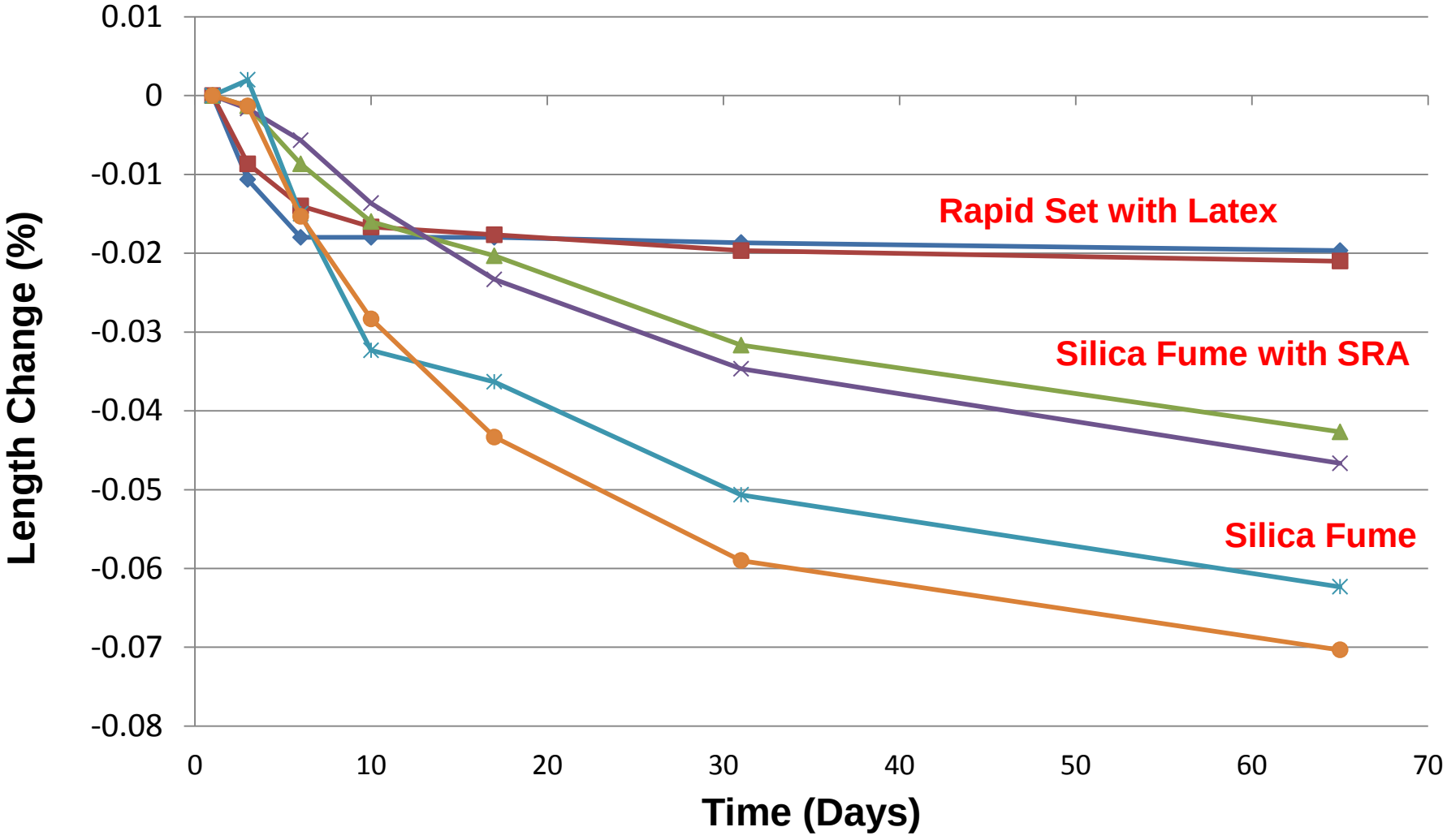
Fresh Properties of Concrete Overlays

Test	RSL1	RSL2	SF-SRA1a	SF-SRA1b	SF-SRA2a	SF-SRA2b	SF1	SF2
Air (%)	5.0	4.2	6.1	7.0	5.2	6.8	6.4	6.4
Density (lb/ft^3)	142.0	141.6	-	143.2	-	141.2	142.8	142.8
Slump (in)	7.5	8.5	6.0	7.0	7.0	6.0	5.5	5.0
Concrete T ˚F)	83	71	75	70	68	73	75	70

Hardened Properties of Concrete Overlays

Test	Age (days)	RSL1	RSL2	SF-SRA1	SF-SRA2	SF1	SF2
Compressive Strength (psi)	1	4000	4710	2030	-	2120	-
	3	5620	5240	3040	2810	3110	2980
	28	6740	6180	5300	4770	5110	5620
Splitting Tensile (psi)	28	690	580	500	530	500	555
Permeability (C)	28	-	-	638	905	507	841
	56	348	292	-	-	-	-
Elastic Modulus (10^6 psi)	3	3.53	3.52	2.76	2.71	-	2.79
	28	-	3.69	3.82	-	3.71	-

Overlay Shrinkage Plot



Conclusion

- Fiber reinforced concrete that deflection or strain hardens will exhibit multiple tight cracks (less than 0.1 mm).

- Addition of shrinkage reducing admixture results in reduced shrinkage in concretes.

Virginia Center *for* Transportation
INNOVATION
& RESEARCH

We bring innovation to transportation.

Thank you.

Virginia Concrete Conference, 2015