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Shrinkage-Compensating Concrete—Past, Present, and Future, Part 2

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

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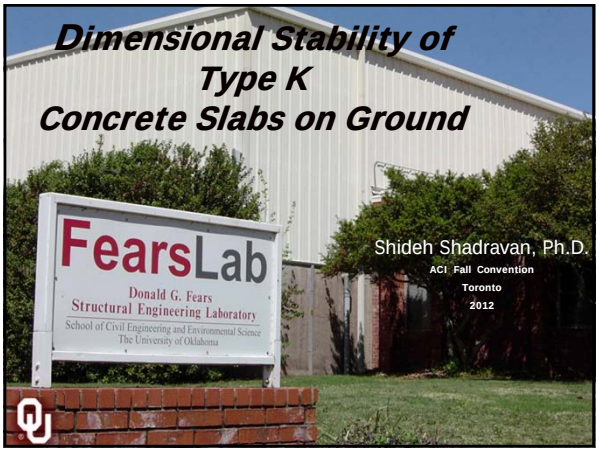
WEB SESSIONS

Dr. Shideh Shadravan researched in the fields of concrete materials and steel structures due to maintaining a broad set of interests, knowledge, and experiences. Shideh has over fifteen years of practical and research experience in design, construction, experimental testing on concrete slabs-on-grade, and research in behavior of cold-formed Z-purlin steel members. In the past, she served in various capacities including project manager and construction director for municipal projects in a major metropolitan area. Shideh is a member of the American Society for Civil Engineering (ASCE), American Concrete Institute (ACI), and American Institute of Steel Construction (AISC).

ACI
WEB SESSIONS



OUTLINE

- Introduction
  - Background
  - Definitions
- Previous Studies
- Purpose of This Research
- Scope of Work
- Test Results
- Conclusion

Background

Problems Observed with Slab on Ground

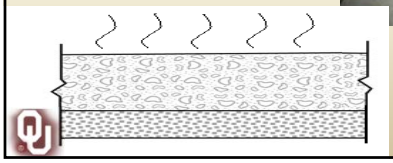
- Volumetric Distortion
- i.e. Drying Shrinkage
- Results in Cracking
  - Poor Serviceability
  - Poor Performance

Slab Distortion

- Hundreds of Millions of Dollars Spent
  - Grinding, Cost
    - California, Repairing Cost > $31 Million in ONE year

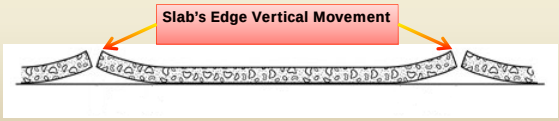
Definitions
(Drying Shrinkage)

- Drying Shrinkage → Cracks
  - Reduction in Volume of Concrete
    - Loss of Water
      - Differential Shrinkage



Curling and Warping

- ACI Definition
  - Vertical Movement of Slab's Corners and Edges
    - Moisture Gradient
    - Temperature Gradient

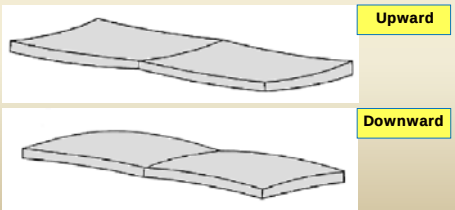


Curling and Warping

- Academic Community Definition
  - Definition Used in This Research
    - Volumetric Distortion of Slab
      - Curling : Uneven Temperature Conditions
      - Warping: Uneven Moisture Conditions

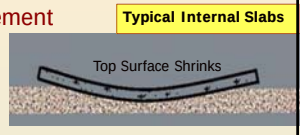
Curling and Warping

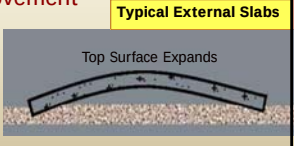
- Curling and Warping
  - Upward
  - Downward



Upward and Downward Vertical Movement
Due to Temperature or Moisture Gradient

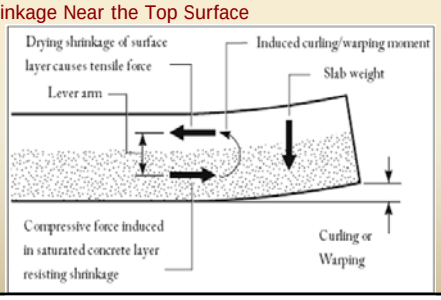
- Upward Vertical Movement
  - Curling
    - Top Surface-Cooler
  - Warping
    - Top Surface-Drier
- Downward Vertical Movement
  - Curling
    - Top Surface-High Tem.
  - Warping
    - Top Surface-High Moist.





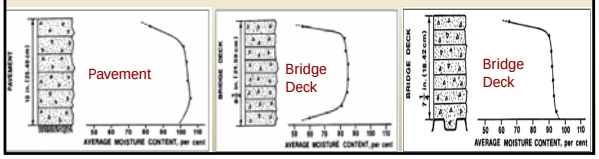
Previous Studies
Carlson (1938)
(Drying Shrinkage of Concrete)

- Moisture Loss Greater at Top Surface
- Shrinkage Near the Top Surface



Carrier et al. (1975)

- Moisture Contents of a Pavement and two Bridge Decks
  - (Plywood Forms & Metal Forms)
  - Moisture Loss Occurs at the Top Few Inches of Slabs
    - Exposed to the Ambient



Ytterberg (1987)
(Shrinkage and Curling of Interior Building Slab)

- Common Causes for Shrinkage Cracking and Upward Curling
  - Moist Subgrade
  - Low Relative Humidity (RH) on Top Surface of Slab
  - Free Water in Concrete
- Recommendations for Controlling Cracks
  - Using Distributed Reinforcement
  - Using Shrinkage-Compensating Concrete
  - Using Post Tensioning Slab
  - Removing Shrinkage Restraining Factors

Weiss et al. (1998)
(Shrinkage Cracking of Restrained Slab)

- Shrinkage Reducing Admixture
  - Delays Cracking
- High Strength Concrete Cracks
  - More Rapidly than Normal Strength Concrete

Bissonnette et al. (2007)
Drying Shrinkage, Curling, and Joint Opening of Slabs on Ground

- Developing Curling and Joint Opening
  - Early Age
    - Drying Shrinkage
- Rate of Developing Curling
  - Proportional to Drying Shrinkage
- Increasing Reinforcement Ratio
  - Cracking at Mid-Span
    - Cracks Caused by High Stiffness Reinforcement

Purpose of This Research
(Building on Bissonnette Test Method)

- Improve Understanding of Dimensional Stability of Concrete
- Compare Shrinkage and Warping Sensitivity of Various Materials
  - PCC
  - PCC w/ SRA
  - HPC
  - CSA/ Type K

Concrete Mix Design

- Seven 3 in x 3 ft x 20 ft Test Specimens

Materials (per cubic yard)	SRA#1	SRA#2	PCC	HPC	CTS Shrinkage Compensating		Rapid Set
					#1	#2	
Komp I	-	-	-	-	120	120	-
PC	356	355	355	543	370	370	-
Flyash	88	88	88	180	-	-	-
Rapid Set Cement	-	-	-	-	-	-	658
Citric Acid	-	-	-	-	-	-	5
Course Aggregate 57	1850	1850	1850	1850	1750	1750	1772
Sand	1463	1463	1463	1196	1315	1315	1307
Water	266	266	266	264	269.5	271.5	290
MR (Polyheed (oz))	-	-	-	-	17.3	17.5	52.6
MR (Pozzolith 80 (oz))	13	14	14	29	-	-	-
Eclipse (oz)	35.9	-	-	-	-	-	-
Tetraguard (oz)	-	36.1	-	-	-	-	-
W/C ratio	0.60	0.60	0.60	0.37	0.55	0.55	0.44

Concrete Mix Designs

PCC with Shrinkage Reducing Admixtures

Materials (per cubic yard)	SRA#1	SRA#2	PCC	HPC	CTS Shrinkage Compensating		Rapid Set
					#1	#2	
Komp I	-	-	-	-	120	120	-
PC	356	355	355	543	370	370	-
Flyash	88	88	88	180	-	-	-
Rapid Set Cement	-	-	-	-	-	-	658
Citric Acid	-	-	-	-	-	-	5
Course Aggregate 57	1850	1850	1850	1850	1750	1750	1772
Sand	1463	1463	1463	1196	1315	1315	1307
Water	266	266	266	264	269.5	271.5	290
MR (Polyheed (oz))	-	-	-	-	17.3	17.5	52.6
MR (Pozzolith 80 (oz))	13	14	14	29	-	-	-
Eclipse (oz)	35.9	-	-	-	-	-	-
Tetraguard (oz)	-	36.1	-	-	-	-	-
W/C ratio	0.60	0.60	0.60	0.37	0.55	0.55	0.44

Concrete Mix Designs

The Only Difference is the SRA

Materials (per cubic yard)	SRA#1	SRA#2	PCC	HPC	CTS Shrinkage Compensating		Rapid Set
					#1	#2	
Komp I	-	-	-	-	120	120	-
PC	356	355	355	543	370	370	-
Flyash	88	88	88	180	-	-	-
Rapid Set Cement	-	-	-	-	-	-	658
Citric Acid	-	-	-	-	-	-	5
Course Aggregate 57	1850	1850	1850	1850	1750	1750	1772
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W/C ratio	0.60	0.60	0.60	0.37	0.55	0.55	0.44

Concrete Mix Designs

PCC and HPC

Materials (per cubic yard)	SRA#1	SRA#2	PCC	HPC	CTS Shrinkage Compensating		Rapid Set
					#1	#2	
Komp I	-	-	-	-	120	120	-
PC	356	355	355	543	370	370	-
Flyash	88	88	88	180	-	-	-
Rapid Set Cement	-	-	-	-	-	-	658
Citric Acid	-	-	-	-	-	-	5
Course Aggregate 57	1850	1850	1850	1850	1750	1750	1772
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MR (Pozzolith 80 (oz))	13	14	14	29	-	-	-
Eclipse (oz)	35.9	-	-	-	-	-	-
Tetraguard (oz)	-	36.1	-	-	-	-	-
W/C ratio	0.60	0.60	0.60	0.37	0.55	0.55	0.44

Concrete Mix Designs

Type K Shrinkage Compensating Cement

Materials (per cubic yard)	SRA#1	SRA#2	PCC	HPC	CTS Shrinkage Compensating		Rapid Set
					#1	#2	
Komp I	-	-	-	-	120	120	-
PC	356	355	355	543	370	370	-
Flyash	88	88	88	180	-	-	-
Rapid Set Cement	-	-	-	-	-	-	658
Citric Acid	-	-	-	-	-	-	5
Course Aggregate 57	1850	1850	1850	1850	1750	1750	1772
Sand	1463	1463	1463	1196	1315	1315	1307
Water	266	266	266	264	269.5	271.5	290
MR (Polyheed (oz))	-	-	-	-	17.3	17.5	52.6
MR (Pozzolith 80 (oz))	13	14	14	29	-	-	-
Eclipse (oz)	35.9	-	-	-	-	-	-
Tetraguard (oz)	-	36.1	-	-	-	-	-
W/C ratio	0.60	0.60	0.60	0.37	0.55	0.55	0.44

Concrete Mix Designs

Rapid Set Cement

Materials (per cubic yard)	SRA#1	SRA#2	PCC	HPC	CTS Shrinkage Compensating		Rapid Set
					#1	#2	
Komp I	-	-	-	-	120	120	-
PC	356	355	355	543	370	370	-
Flyash	88	88	88	180	-	-	-
Rapid Set Cement	-	-	-	-	-	-	658
Citric Acid	-	-	-	-	-	-	5
Course Aggregate 57	1850	1850	1850	1850	1750	1750	1772
Sand	1463	1463	1463	1196	1315	1315	1307
Water	266	266	266	264	269.5	271.5	290
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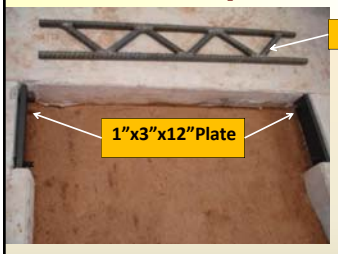
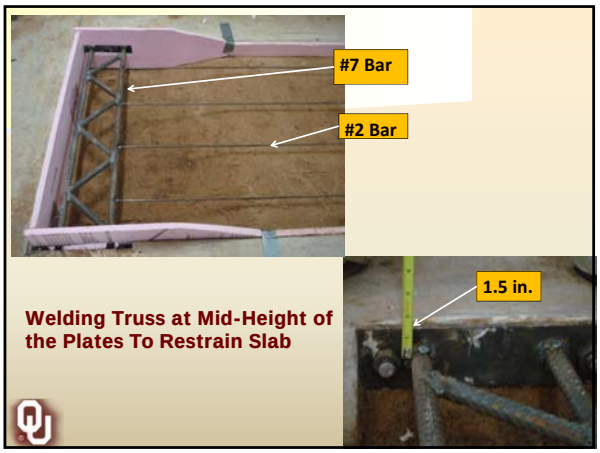
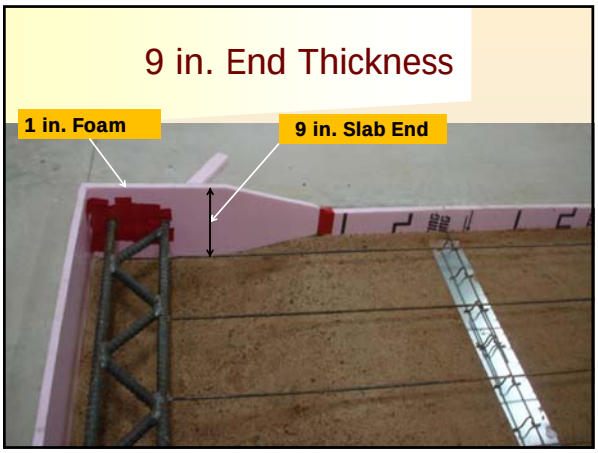
MR (Pozzolith 80 (oz))	13	14	14	29	-	-	-
Eclipse (oz)	35.9	-	-	-	-	-	-
Tetraguard (oz)	-	36.1	-	-	-	-	-
W/C ratio	0.60	0.60	0.60	0.37	0.55	0.55	0.44

Scope of Work

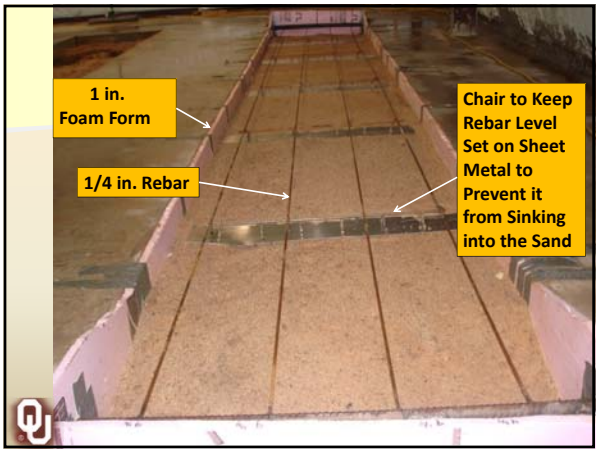


End of Slabs


#7 Bar
#2 Bar
1.5 in.
Welding Truss at Mid-Height of the Plates To Restrain Slab


9 in. End Thickness
1 in. Foam
9 in. Slab End


4 in. Moist Compacted Sand


1 in.
Foam Form
1/4 in. Rebar
Chair to Keep Rebar Level Set on Sheet Metal to Prevent it from Sinking into the Sand

Ready Mix Concrete

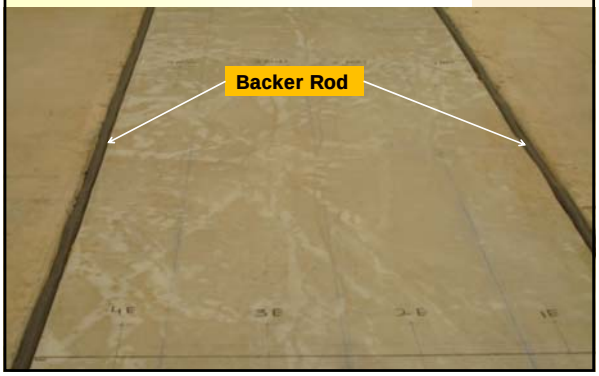
Finishing Concrete

Finished Slab

1 in. Saw-Cut Joints Cut at 24 hours

7 Day Curing Concrete with Wet Burlap & Plastic Sheet

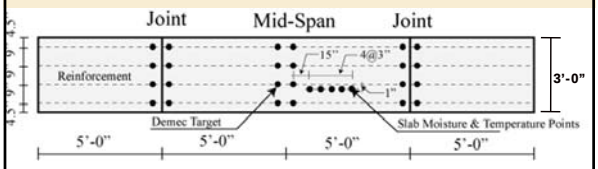
Two Layers of 1 in. Backer Rod



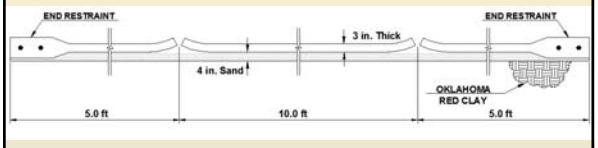
Slab Specimens Located on Ground

(Top Surface Exposed to the Controlled Environment)

Slab Plan View



Profile of Slab Deformation Due to Warping

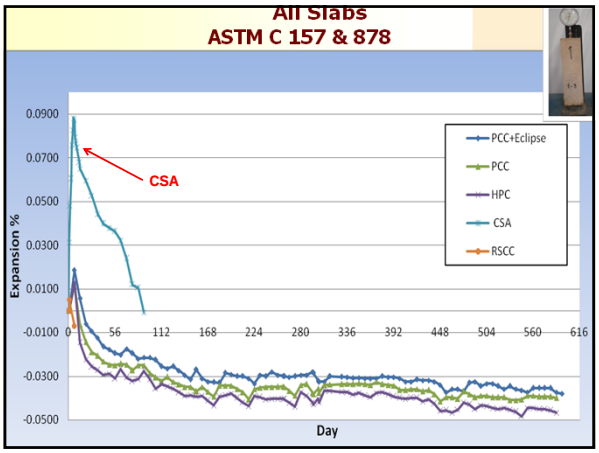


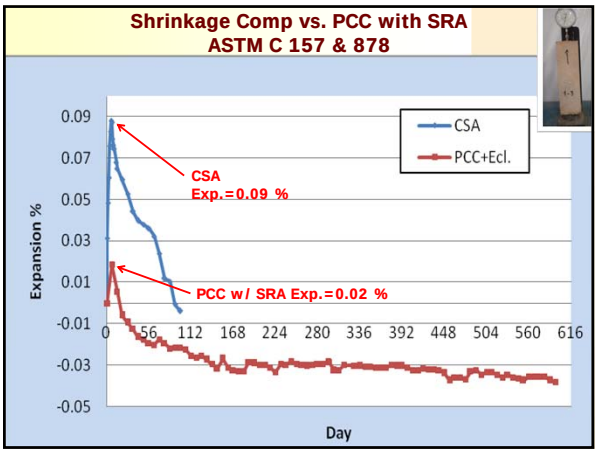
TEST RESULTS

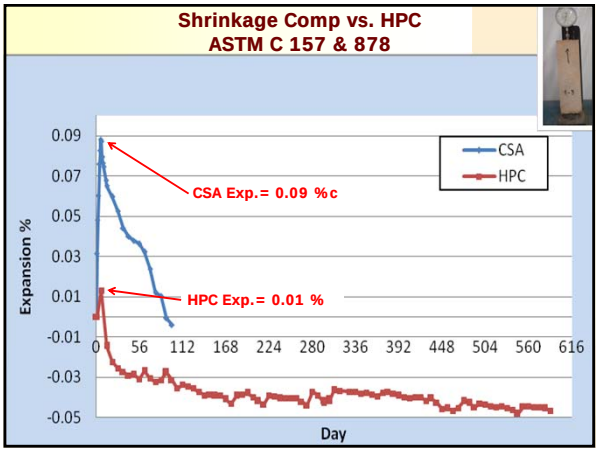
Large Scale Specimen Tests

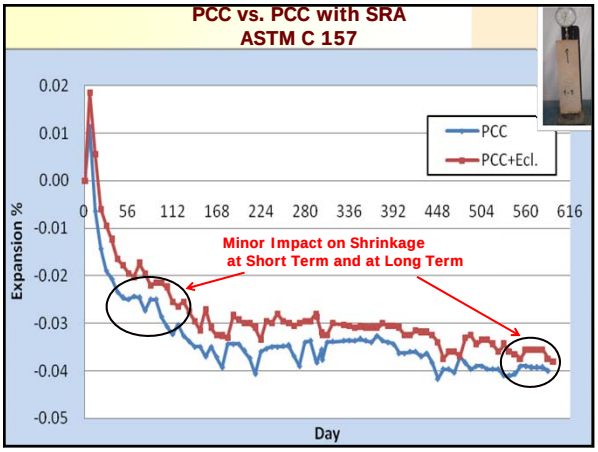
Testing

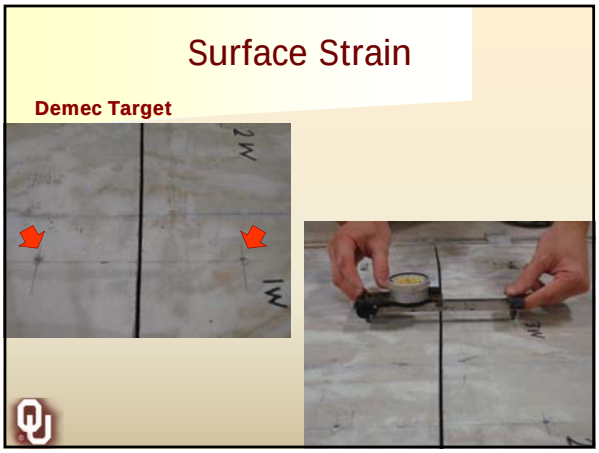
Test Sample (ASTM C 157 & C 878)

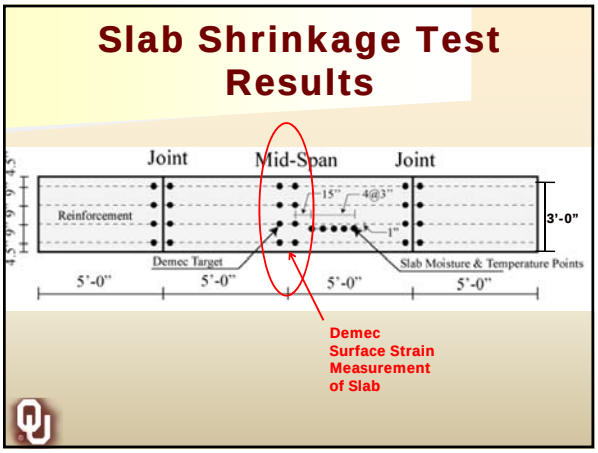

All Slabs
ASTM C 157 & 878
PCC+Eclipse
PCC
HPC
CSA
RSCC
CSA
Expansion %
Day


Shrinkage Comp vs. PCC with SRA
ASTM C 157 & 878
CSA
PCC+Ecl.
CSA
Exp.=0.09 %
PCC w/ SRA Exp.=0.02 %
Expansion %
Day

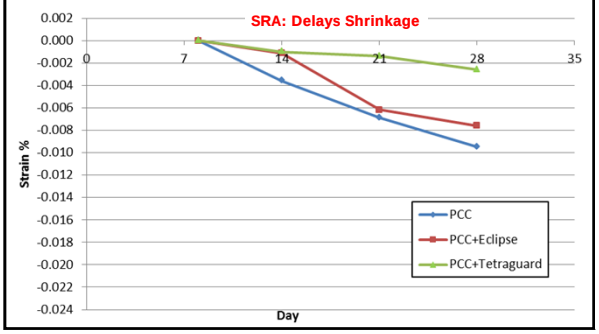

Shrinkage Comp vs. HPC
ASTM C 157 & 878
CSA
HPC
CSA Exp.= 0.09 %c
HPC Exp.= 0.01 %
Expansion %
Day


PCC vs. PCC with SRA
ASTM C 157
PCC
PCC+Ecl.
Minor Impact on Shrinkage
at Short Term and at Long Term
Expansion %
Day

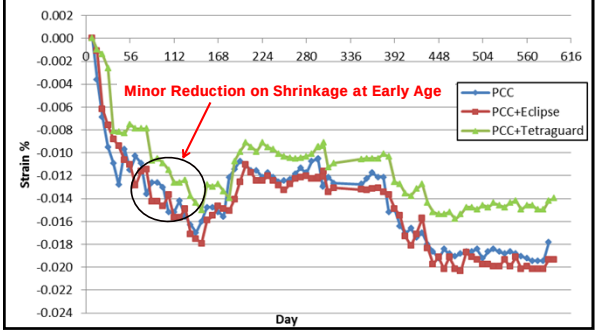

Surface Strain
Demec Target


Slab Shrinkage Test Results
Joint
Mid-Span
Joint
Reinforcement
Demec Target
Slab Moisture & Temperature Points
3'-0"
5'-0"
Demec
Surface Strain
Measurement
of Slab

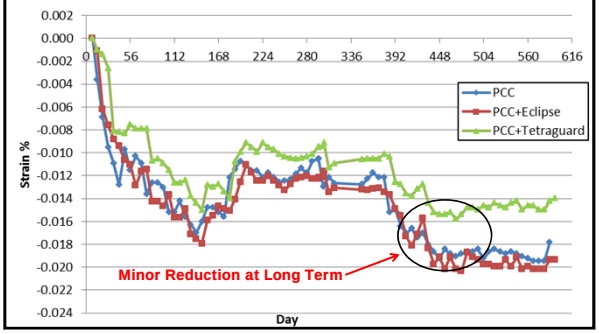
PCC and PCC with SRAs - SLAB TEST RESULTS (21 Days of Drying)



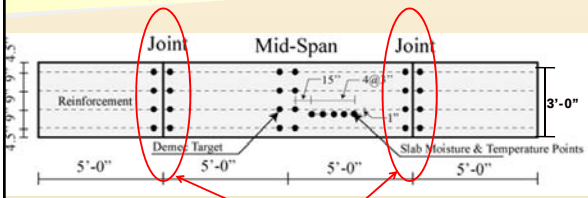
PCC and PCC with SRAs - SLAB TEST RESULTS at 600 Days



PCC and PCC with SRAs - SLAB TEST RESULTS at 600 Days

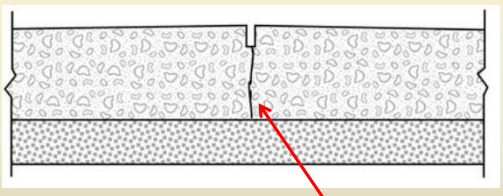


Joint Expansion Test Results



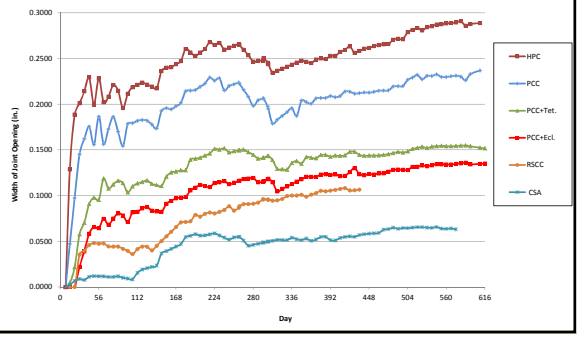
Demec Strain Measurement Across Joint, Minus the Material Behavior

Joint Expansion Test Results

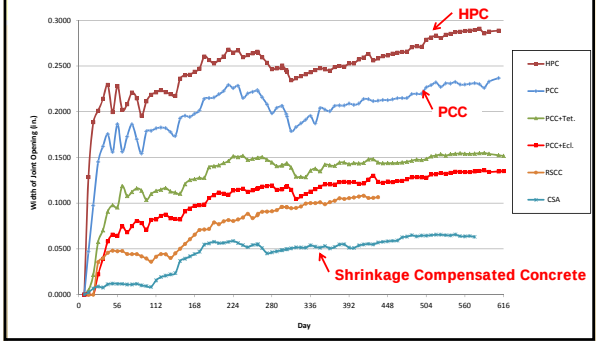


Essentially a Measurement of Crack Growth

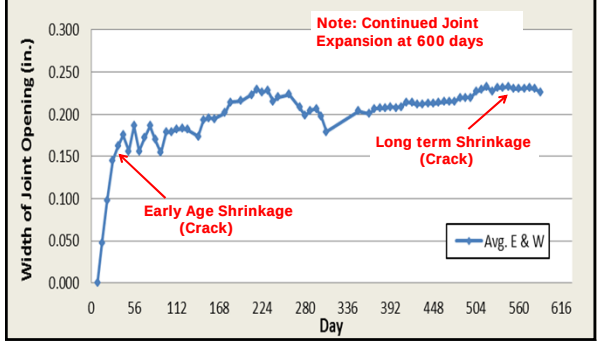
Joint Expansion with Time



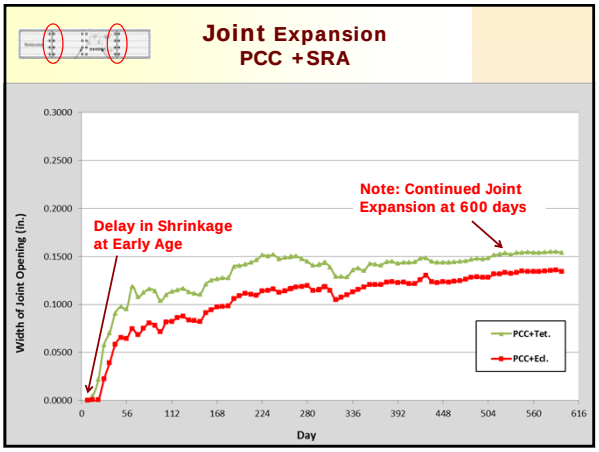
Joint Expansion with Time



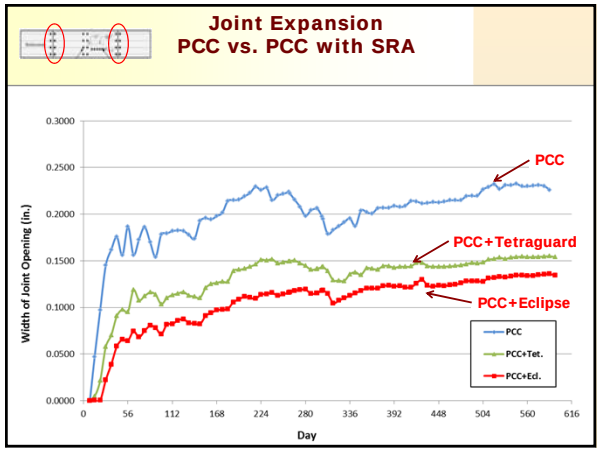
Joint Expansion Normal Concrete (PCC)



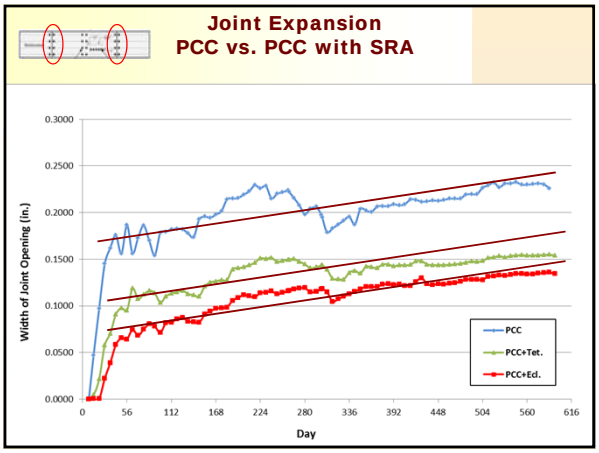
Joint Expansion PCC +SRA



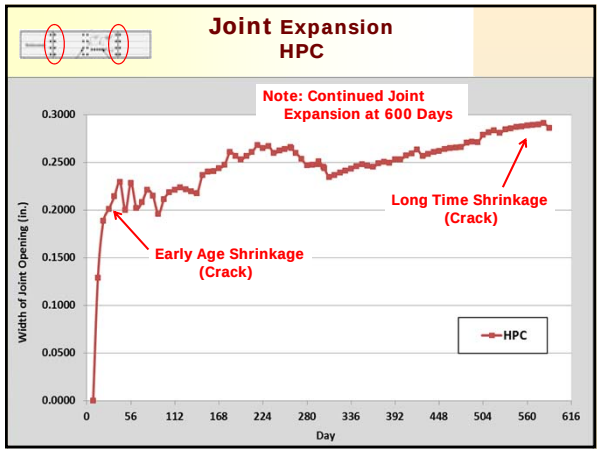
Joint Expansion PCC vs. PCC with SRA



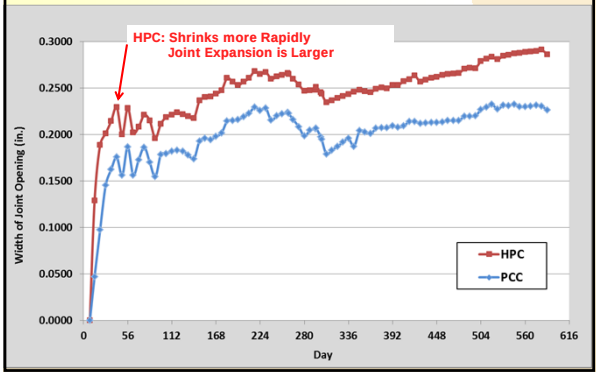
Joint Expansion PCC vs. PCC with SRA



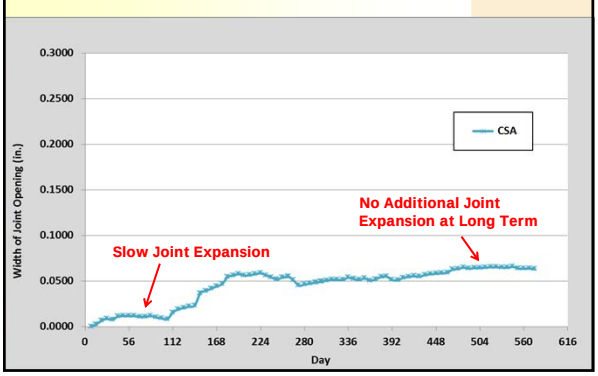
Joint Expansion HPC



Joint Expansion
PCC vs. HPC



Joint Expansion
Type K (CSA)



Joint Expansion
at 574 Days

Mix	inch	> Type K, Shrinkage Comp
Type K, Shrinkage Comp	0.0631	
PCC + Eclipse	0.1348	213%
PCC + Tetraguard	0.1543	244%
PCC	0.2313	367%
HPC	0.2895	459%

Conclusions

- Typical PCC, HPC and SRAs Continue to Exhibit Joint Expansion at Approximately 2 Years.
  - Joint Expansion is Essentially a Measurement of the Crack that Occurs at This Location.
- ASTM C 157 does not Provide an Accurate Method to Predict the Behavior of the Material Used in a Slab on Ground.
  - Comparing Slab on Ground Shrinkage at Mid-span to ASTM C 157, There are Significant Differences in the Results

Conclusions Continued

- Shrinkage Reducing Admixtures Have a Minor Impact at both Early Age and 600 days.
  - Shrinkage and Cracking are Nearly Similar to Typical PCC.
- Shrinkage Compensating Concrete is Extremely Stable, with Little or No Long Term Shrinkage or Cracking.
  - This Sectional Stability is Noted at both Early Age and at Approximately 2 Years.

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Thank You!