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

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

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).

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

Dimensional Stability of Type K Concrete Slabs on Ground

Dr. Shideh Shadravan, Ph.D.
ACI Fall Convention
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FearsLab
Donald G. Fears Structural Engineering Laboratory
School of Civil Engineering and Environment
University of Oklahoma

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Definitions (Drying Shrinkage)

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

ACI Definition

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

Academic Community Definition

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

Curling and Warping

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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 Temp.
  - 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

Weiss et al. (1998)
(Shrinkage Cracking of Restrained Slab)
- Shrinkage Reducing Admixture
  - Delays Cracking
- High Strength Concrete Cracks
  - More Rapidly than Normal Strength Concrete

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/SR Compensating Rapid Set
<table>
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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

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

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### Concrete Mix Designs

**PCC with Shrinkage Reducing Admixtures**

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**The Only Difference is the SRA**

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**Type K Shrinkage Compensating Cement**

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**Rapid Set Cement**

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### Scope of Work

**End- Slab Truss**

1"x3"x12" Plate
Welding Truss at Mid-Height of the Plates To Restrain Slab

9 in. End Thickness

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)
Shrinkage Comp vs. PCC with SRA
ASTM C 157 & 878

- CSA Exp.=0.09%
- PCC w/ SRA Exp.=0.02%

PCC vs. PCC with SRA
ASTM C 157

Minor Impact on Shrinkage at Short Term and at Long Term

Surface Strain
Demec Target

Slab Shrinkage Test Results
Demec Surface Strain Measurement of Slab
**PCC and PCC with SRAs - SLAB TEST RESULTS**

- **(21 Days of Drying)**
  - SRA: Delays Shrinkage

- **(600 Days)**
  - Minor Reduction on Shrinkage at Early Age
  - Minor Reduction at Long Term

**Joint Expansion Test Results**

- Essentially a Measurement of Crack Growth
Joint Expansion with Time

HPC

Joint Expansion Normal Concrete (PCC)

Note: Continued Joint Expansion at 600 days

Long term Shrinkage (Crack)

Early Age Shrinkage (Crack)

Joint Expansion PCC +SRA

Note: Continued Joint Expansion at 600 days

Delay in Shrinkage at Early Age

Joint Expansion PCC vs. PCC with SRA

Joint Expansion HPC

Note: Continued Joint Expansion at 600 Days

Long Time Shrinkage (Crack)

Early Age Shrinkage (Crack)
Joint Expansion
PCC vs. HPC

HPC: Shrinks more Rapidly
Joint Expansion is Larger

Joint Expansion
Type K (CSA)

No Additional Joint Expansion at Long Term

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.

Acknowledgement

- The Project Would not Have Been Possible without the Help and Support of.....
Thank You!