INFLUENCE OF FIELD CURING CONDITIONS ON CYLINDERS

JAMES KRSTULOVICH, PE

ILLINOIS DOT

ICT PROJECT R27-219 RESEARCH TEAM

- Dr. Pranshoo Solanki

  Construction Management Program, Department of Technology, Illinois State University

- Dr. Haiyan “Sally” Xie

  Department of Technology, Illinois State University

WHERE WE STARTED: IL MODIFIED AASHTO R 100

- Strength specimens shall be field cured when:
  - opening patches
  - opening pavement prior to 14 days
  - before proceeding w/ the next portion of a sequential deck pour
  - as directed by the Engineer.
    - e.g., when it's cool but not cold

WHERE WE STARTED: FALSEWORK & FORMWORK REMOVAL

- Falsework/formwork shall remain in place until tests show the required flexural strength has been attained (and the curing period is completed).
- A compressive strength established through field testing to be equivalent to the required flexural strength may be used if approved by the Engineer.

WHERE WE STARTED: OPENING PATCHES

- When tests show 250-psi flexural or 1600-psi compressive strength has been attained.
  - Additionally, for acceptance, tests shall show 600-psi flexural or 3200-psi compressive strength is attained in the time specified by their class.
  - This specified time ranges from 4 to 48 hours.
  - Also, opening strength may be determined via time-temperature relationship (i.e., maturity).

WHAT'S THE PROBLEM?

- Maturity was a non-starter from the beginning.
- Districts are moving away from beams.
  - Historically, were convenient in the field because we allow a portable center-point beam breaker.
  - But hard to handle, which is problematic since both specimen and test are sensitive.
- But cylinders didn't seem to produce comparable results in the same timeframe as beams, which led to contractors electing to use beams.

WHAT'S THE PROBLEM?

- Is there a simple, inexpensive way to field cure cylinders to better mimic the poured item's maturation?

WHAT DO THE STANDARDS SAY: AASHTO R 100

- AASHTO R 100
- Store cylinders in or on the structure as near to the point of deposit of the concrete represented as possible.
- Protect all surfaces of the cylinders from the elements in as near as possible the same way as the formed work. Provide the cylinders with the same temperature and moisture environment as the structural work.
- Test the specimens in the moisture condition resulting from the specified curing treatment.
- To meet these conditions, specimens made for the purpose of determining when a structure is capable of being put in service shall be removed from the molds at the time of removal of form work.

WHAT DO THE STANDARDS SAY: IDOT STANDARD SPECIFICATIONS

- The Contractor shall provide a field curing box for initial curing and a water storage tank for final curing.
- The field curing box will be required when an air temperature below 60 °F is expected during the initial curing period. The device [...] may be insulated or power operated as appropriate.

WHAT'S THE STATUS QUO: DISTRICT PRACTICES

- Alongside item poured when possible.
- Gang-curing in a wood box or cooler.
- On top of item poured, under insulation, if used.
- One contractor is known to flip beam boxes over so that there's concrete-on-concrete contact with the item poured.

EXPERIMENTAL PLAN

- Two pours at ISU
  - Oct 2021
  - Feb 2022
- Multiple pours during cast-in-place culvert project
  - Stage I: May 12, 20, & 27 and June 8
  - Stage II: June 21 and Aug 11 & 22

MIX DESIGNS

- ISU Pours

Cement	Fly Ash, C	w/c	Air	FA	CA
430	145	0.42	5-8%	1260	1790
430	145	0.42	5-8%	1280	1800

- Culvert Pours

Cement	Fly Ash, C	w/c	Air	FA	CA
630	--	0.37	5-8%	1174	1831
630	--	0.36-0.41	5-8%	1152	1848

  - Additionally, Stage II used a C-S-H strength-enhancing Type S liquid admixture for ICT Project R27-213

ISU POURS

- Mimicking at-scale, in-situ pour conditions
  - Three small slabs: 24 x 24 x 8 in.
  - Three large slabs: 36 x 36 x 12 in.
  - Each accommodated 4 cast-in-place cylinders and 4 cylindrical cores
  - CIP cylinders were cast according to ASTM C873 (modified by Popovics, et al. 2014).

ISU POUR CONDITIONS

Pour	Slump	Air Content	w/c	Concrete Temp	Air Temp
Oct '21	4.25	6.9	0.416	76.7	66.6
Feb '22	2.75	6.4	0.418	60.5	22.0

ISU POURS

Solanki and Xie, forthcoming

ISU SPECIMEN CURING CONDITIONS

- Condition 1: huddled together in ambient conditions
- Condition 2: gang-cured in insulated “5-day” cooler
- Condition 3: gang-cured in powered curing box

- 10 cylinders per cooler/box: 9 tested, 1 to monitor temp
- All specimens removed from molds immediately prior to testing @ 1, 3, & 7 days

ISU POURS

- Condition 1 (ambient)

Solanki and Xie, forthcoming

ISU POURS

- Condition 2 (insulated cooler)

Solanki and Xie, forthcoming

ISU POURS

- Condition 3 (powered curing box)

Solanki and Xie, forthcoming

ISU EXPERIMENT FINDINGS

- Following the experimental plan, statistical analyses were performed
  - Paired t-tests with confidence interval of 95%
  - And Mann Whitney U tests because comparative sample sizes were not sufficiently large (n > 30)

ISU EXPERIMENT FINDINGS

- @ Day 1: only Condition 2 (cooler) did NOT differ significantly from cast-in-place
- @ Day 3: Conditions 2 & 3 (curing box) did NOT differ from CIP
- @ Day 7: Conditions 1 (ambient), 2, and 3 did NOT differ significantly from CIP
  - Condition 1 effectively had NO difference from CIP

ISU EXPERIMENT FINDINGS

- Condition 1 (ambient) underestimates strength at early ages (1 to 3 days)
  - by 11-12% for 4-in cylinders in cool temps (Oct pour)
  - by 11-19% for 6-in cylinders in cool temps
  - by 30-84% for 4-in cylinders in cold temps (Feb pour)
  - by 22-77% for 6-in cylinders in cold temps

ISU EXPERIMENT FINDINGS

- Condition 2 (insulated cooler) estimates strength at early ages (1 to 3 days)
  - within 95-110% for 4-in cylinders in cool temps (Oct)
  - within 105-108% for 6-in cylinders in cool temps
  - within 100-102% for 6-in cylinders in cold temps (Feb)

But underestimates strength

- by 22-54% for 4-in cylinders in cold temps (Feb)

ISU EXPERIMENT FINDINGS

- Condition 3 (powered curing box) estimates strength at early ages (1 to 3 days)
  - within 99-104% for 4-in cylinders in cool temps (Oct)
  - within 99-107% for 6-in cylinders in cool temps

But overestimates strength

- by 1-48% for 4-in cylinders in cold temps (Feb)
- by 13-46% for 6-in cylinders in cold temps

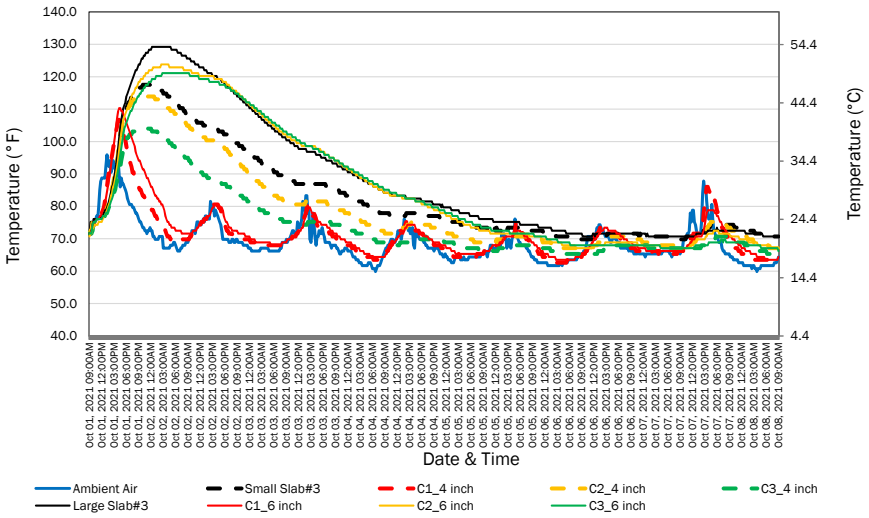
FIELD EXPERIMENT: CAST-IN-PLACE BOX CULVERT PROJECT

FIELD EXPERIMENT CURING CONDITIONS: AMBIENT & INSULATED COOLER

KEY FIELD EXPERIMENT FINDINGS

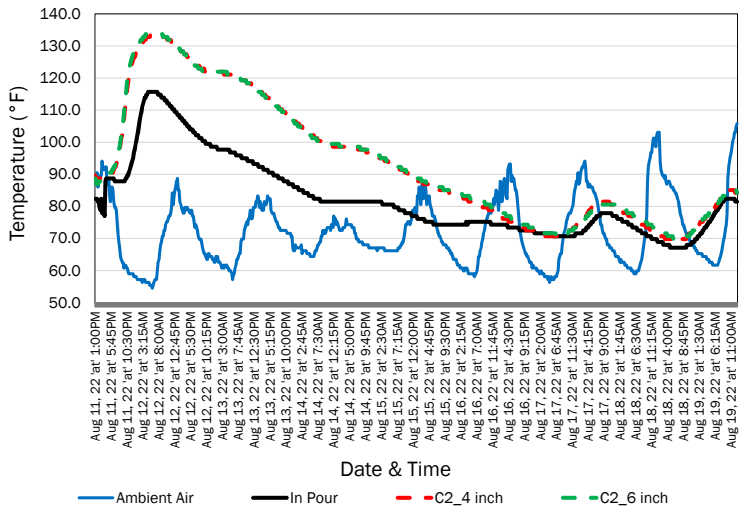
- Condition 2 (insulated cooler) may overestimate early strength due to higher curing temperatures compared to in-place curing temperatures.

OCTOBER ISU POUR



Solanki and Xie, forthcoming

AUGUST 11 FIELD POUR



Solanki and Xie, forthcoming

KEY FIELD EXPERIMENT FINDING

Pour	Air Temperature	Condition 2 Curing Temperatures vs. In-Place Curing Temperatures
ISU, Oct 2021	66.6	Lower
ISU, Feb 2022	22	Lower
Field, 5/20/22	85	Higher
Field, 6/8/22	65	Lower
Field, 8/11/22	88	Higher
Field, 8/22/22	77	Higher

PROPOSED SPECIFICATION UPDATE

- For Standard Curing: When air temperatures below 60 °F is expected during the initial curing period, an insulated (5-day) cooler or power-operated curing box shall be provided. However, the power-operated curing box shall be set to 60 – 63 °F, and strength specimens shall be transported no later than 32 hours after casting.
- For Field Curing: When an air temperature below 70 °F is expected during the field curing period, an insulated (5-day) cooler may be used.