Control of Cracking in Bridge Decks

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- FHWA
- Lead state – Kansas

Outline

- Background
- Experiences
- Laboratory work

Background

Project Scope

20 Low-Cracking High Performance Concrete (LC-HPC) Bridges

So far –

- 13 planned for Kansas
- 2 planned for South Dakota
- 1 planned for Missouri
- 1 planned for Minnesota

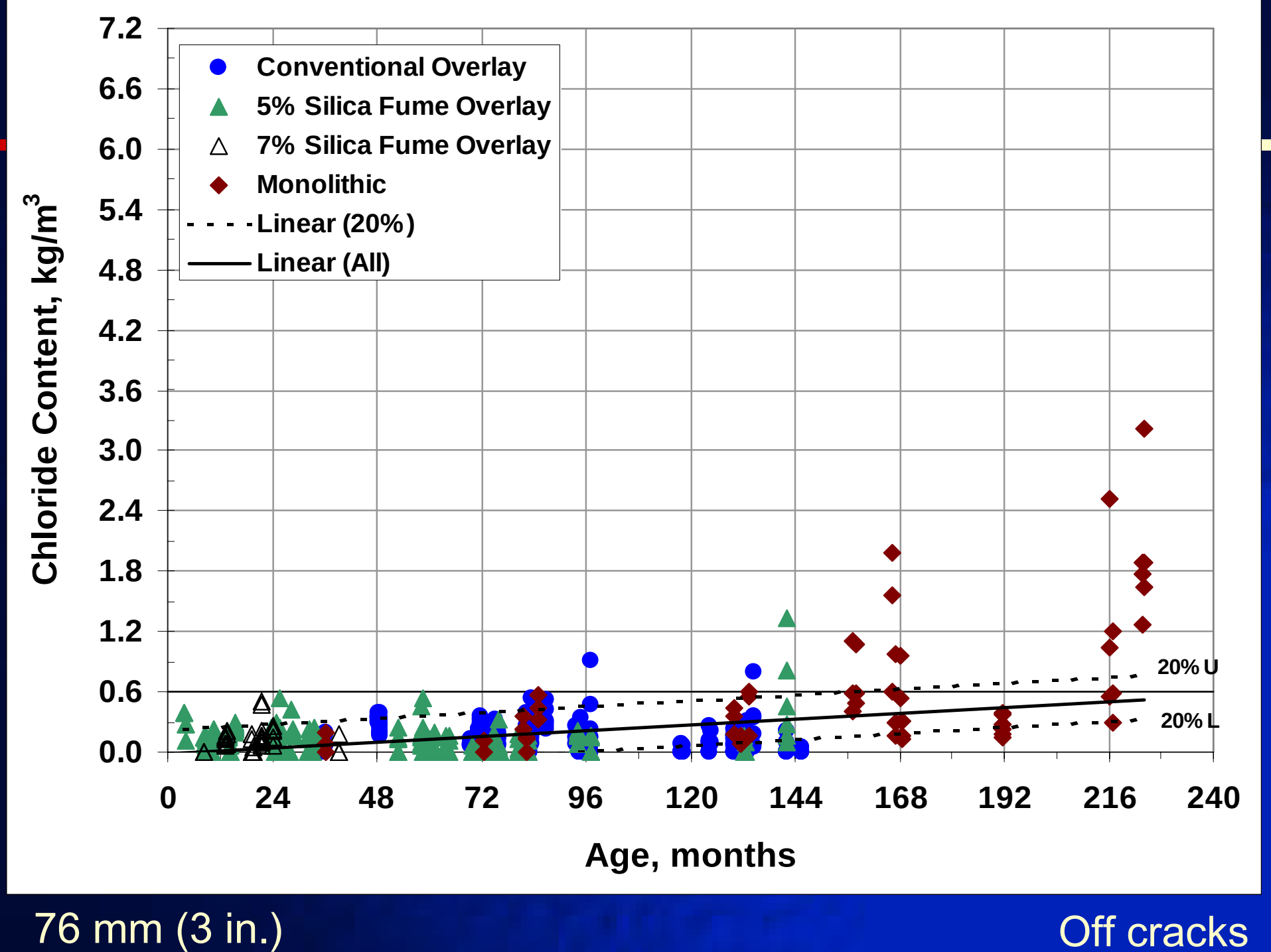
Selection of Bridges

- Composite steel girder bridges
- Full-depth slabs
- Removable forms
- Matching bridges to serve as a control where possible

Background

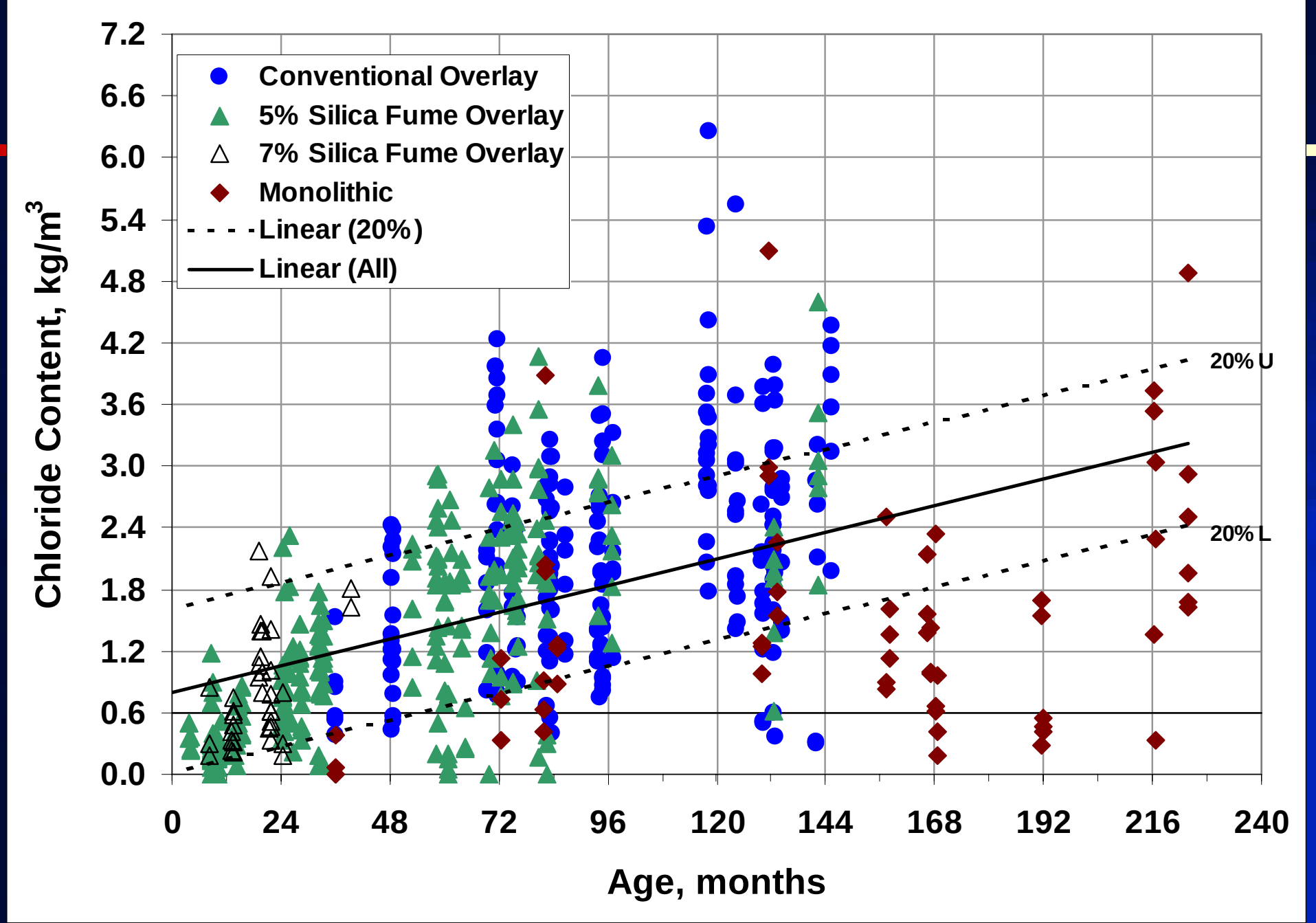
Why we use LC-HPC

Specifications for LC-HPC decks



76 mm (3 in.)

Off cracks



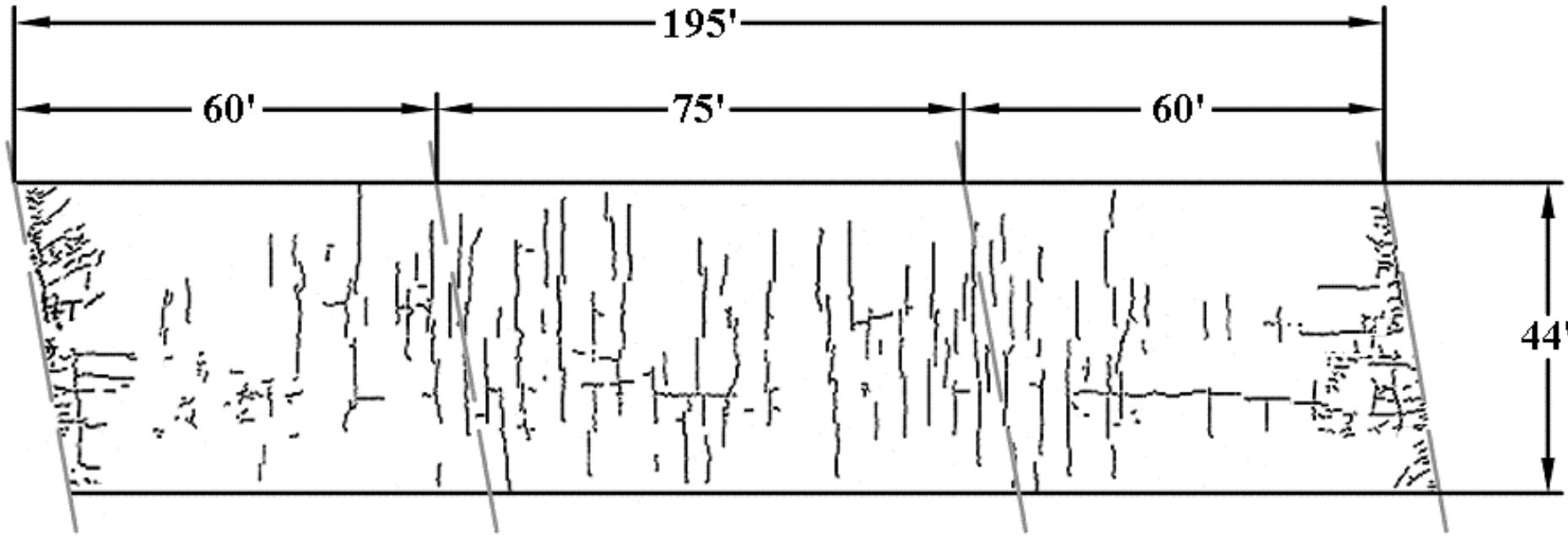
76 mm (3 in.)

On cracks

Crack Surveys

Composite steel girder bridges
3 deck types
- Monolithic
- Conventional Overlay
- Silica Fume Overlay

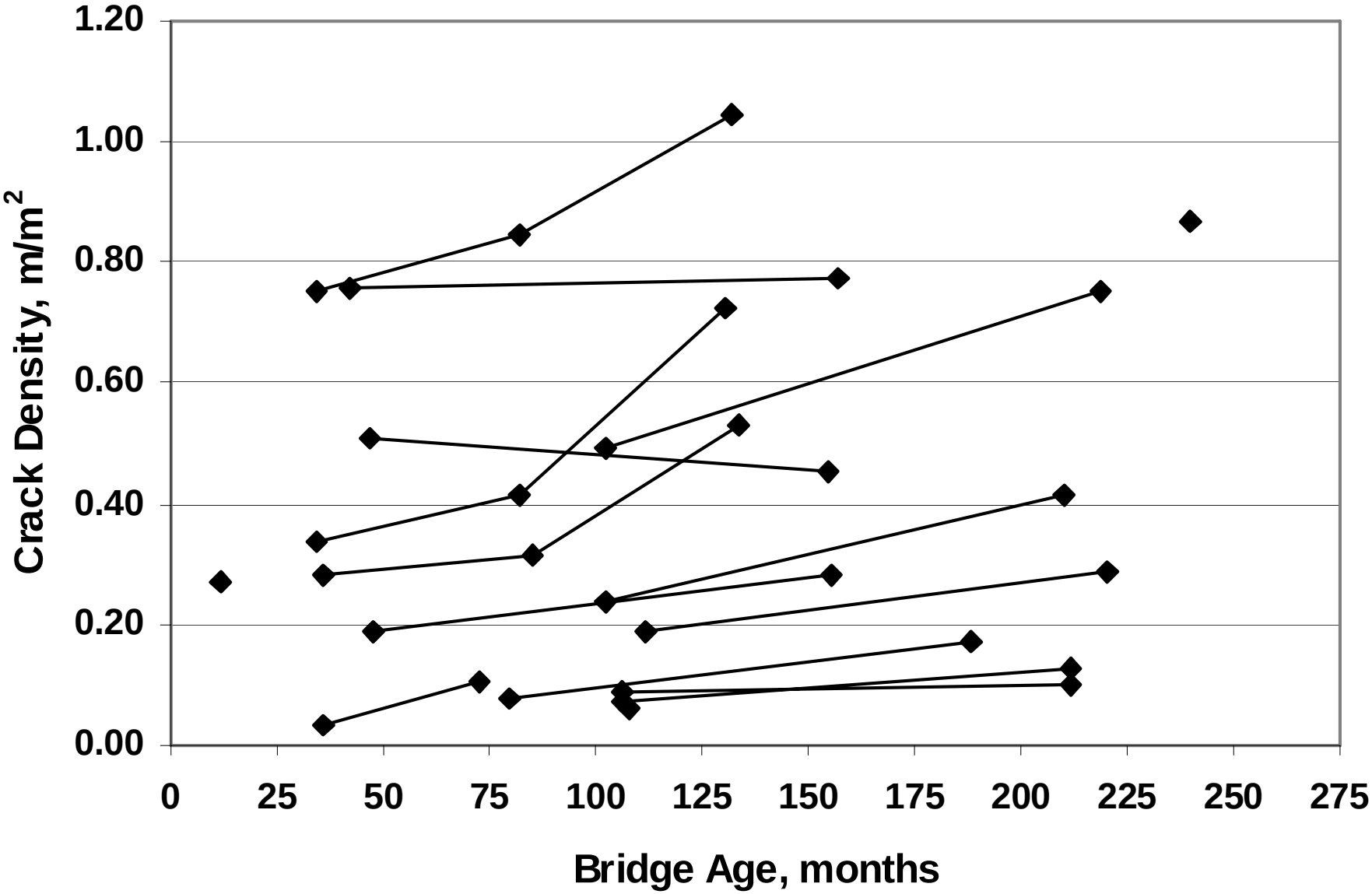
3 studies – over 11 years
76 bridges
160 individual concrete placements
139 surveys


195'
60'
75'
60'
44'

Factors

- Age
- Bridge Deck Type
- Material Effects
- Site Conditions - Temperature
- Date of Construction

Age


1.20
1.00
0.80
0.60
0.40
0.20
0.00
Crack Density, m/m2
0
25
50
75
100
125
150
175
200
225
250
275
Bridge Age, months

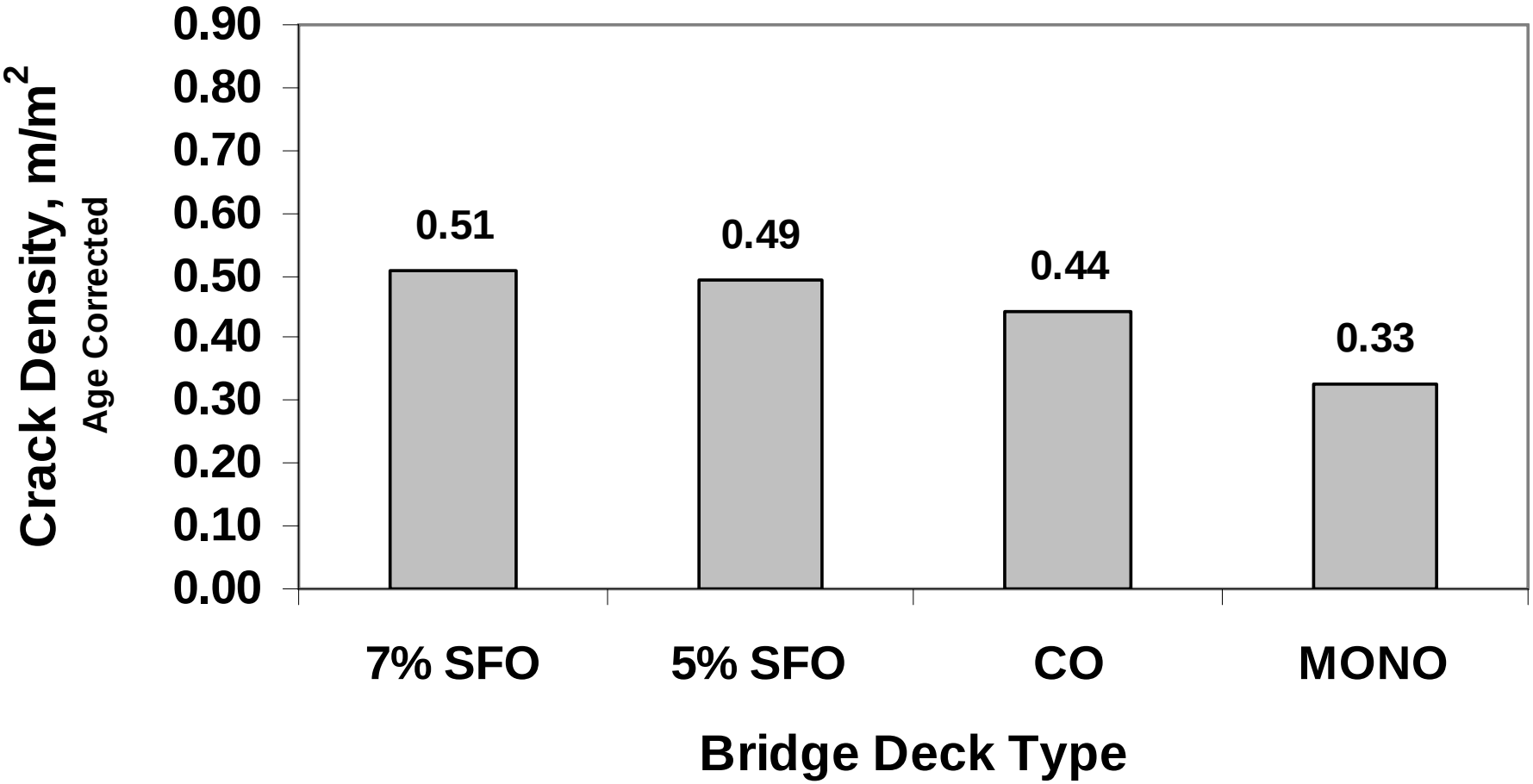
Bridge Deck Type

Monolithic

Conventional Overlay

Silica Fume Overlay

Overlay decks evaluated based on the properties of the subdeck

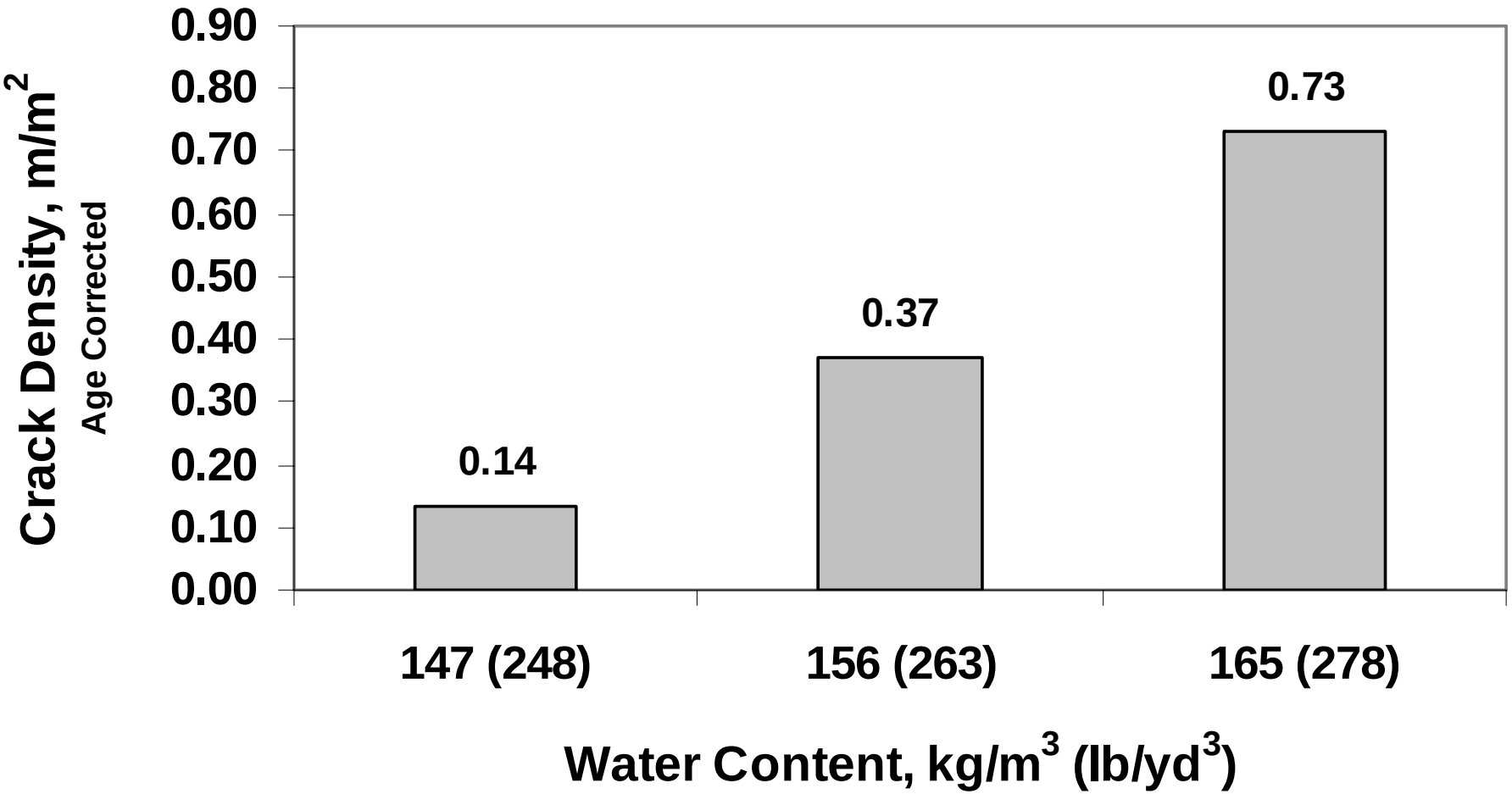


Number of Bridges	(9)	(18)	(30)	(16)
Number of Surveys	(9)	(36)	(52)	(32)

Material Effects

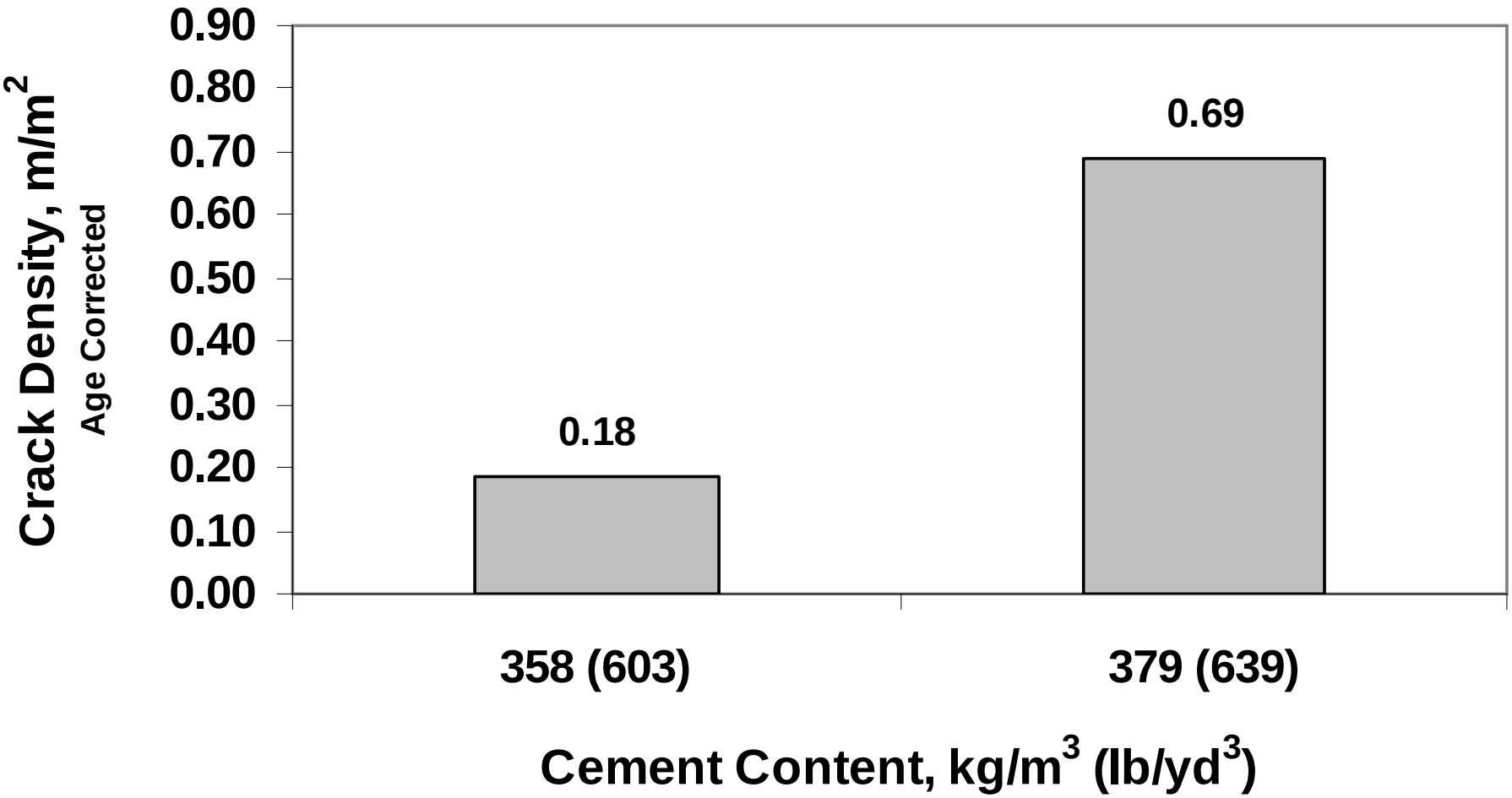
- Concrete Mixture Proportions
  - Water content
  - Cement content
  - Volume of cement paste
- Slump
- Compressive Strength
- Air content

Water content



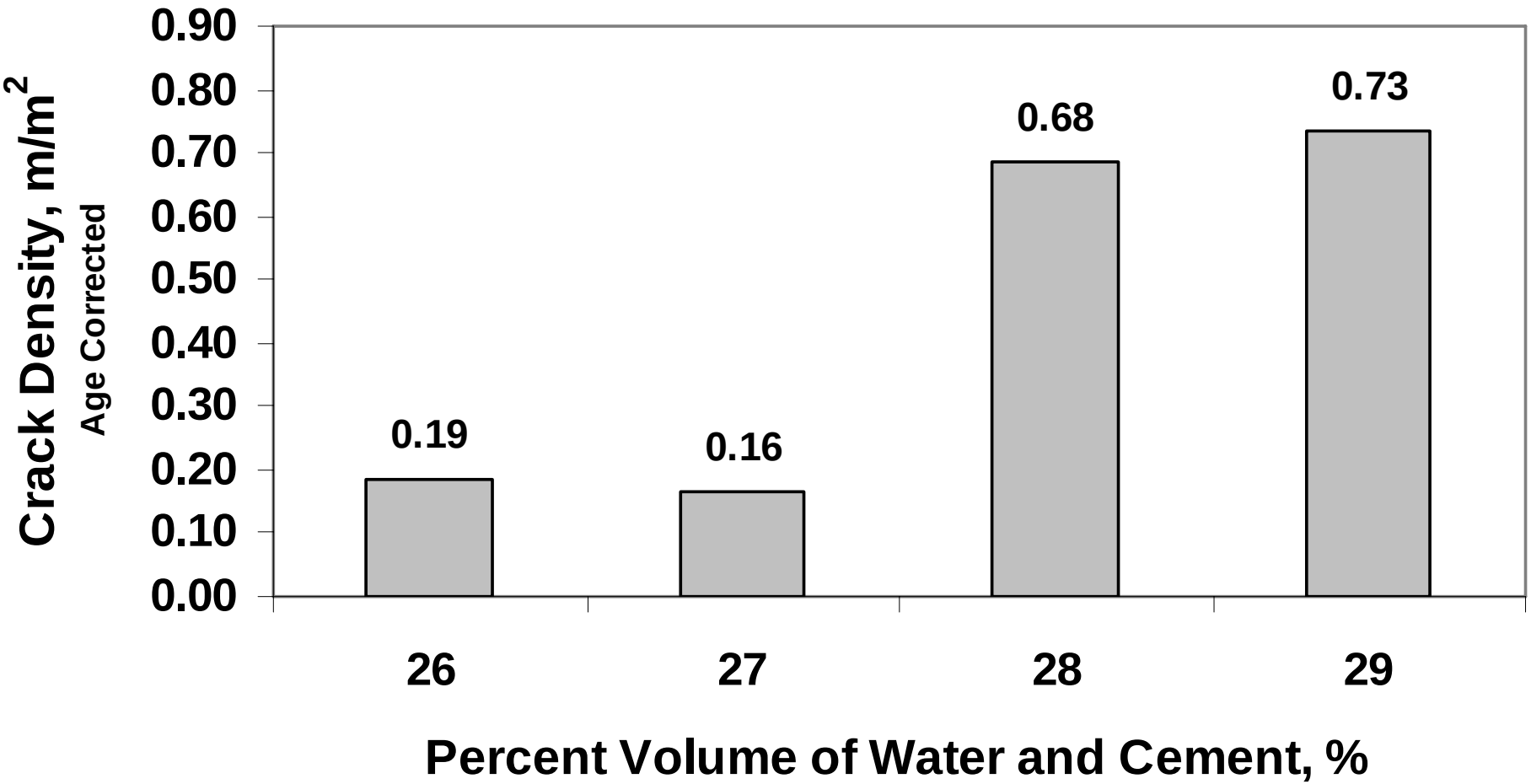
Number of Placements	(15)	(13)	(5)
Number of Surveys	(29)	(26)	(11)

Cement content



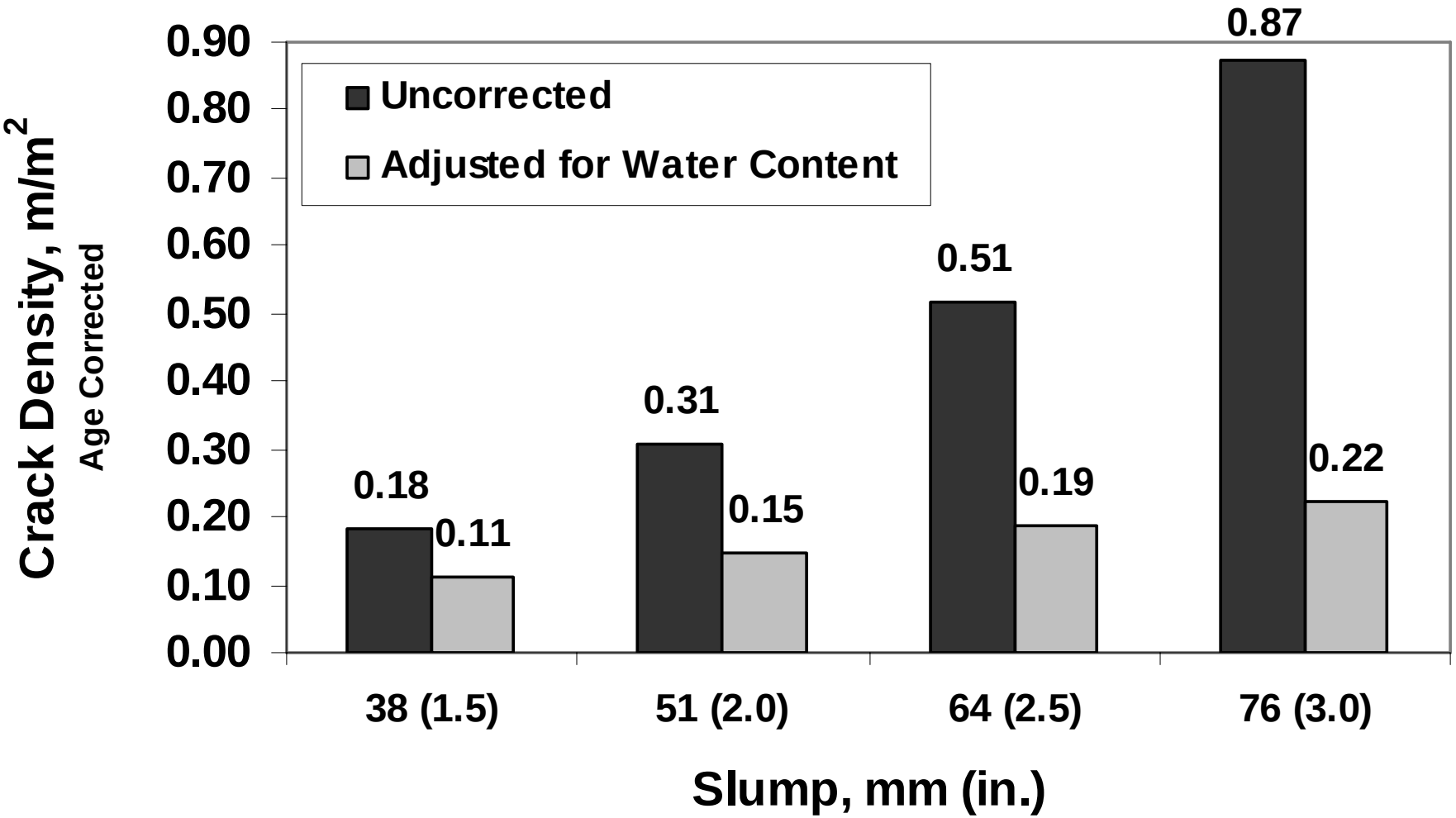
Number of Bridges	(24)	(8)
Number of Observations	(47)	(16)

Volume of cement paste

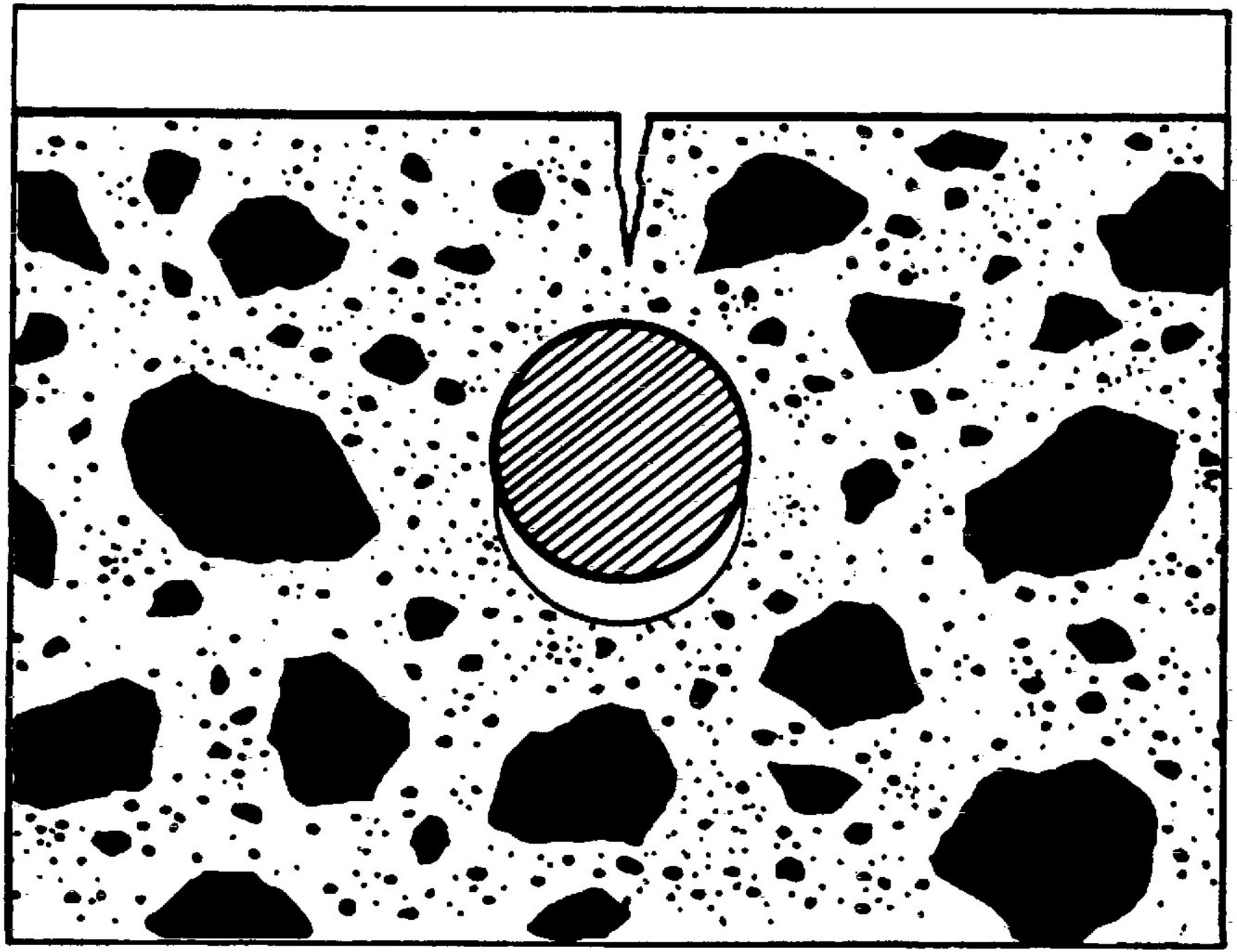


Number of Placements	(8)	(16)	(4)	(5)
Number of Surveys	(16)	(31)	(8)	(11)

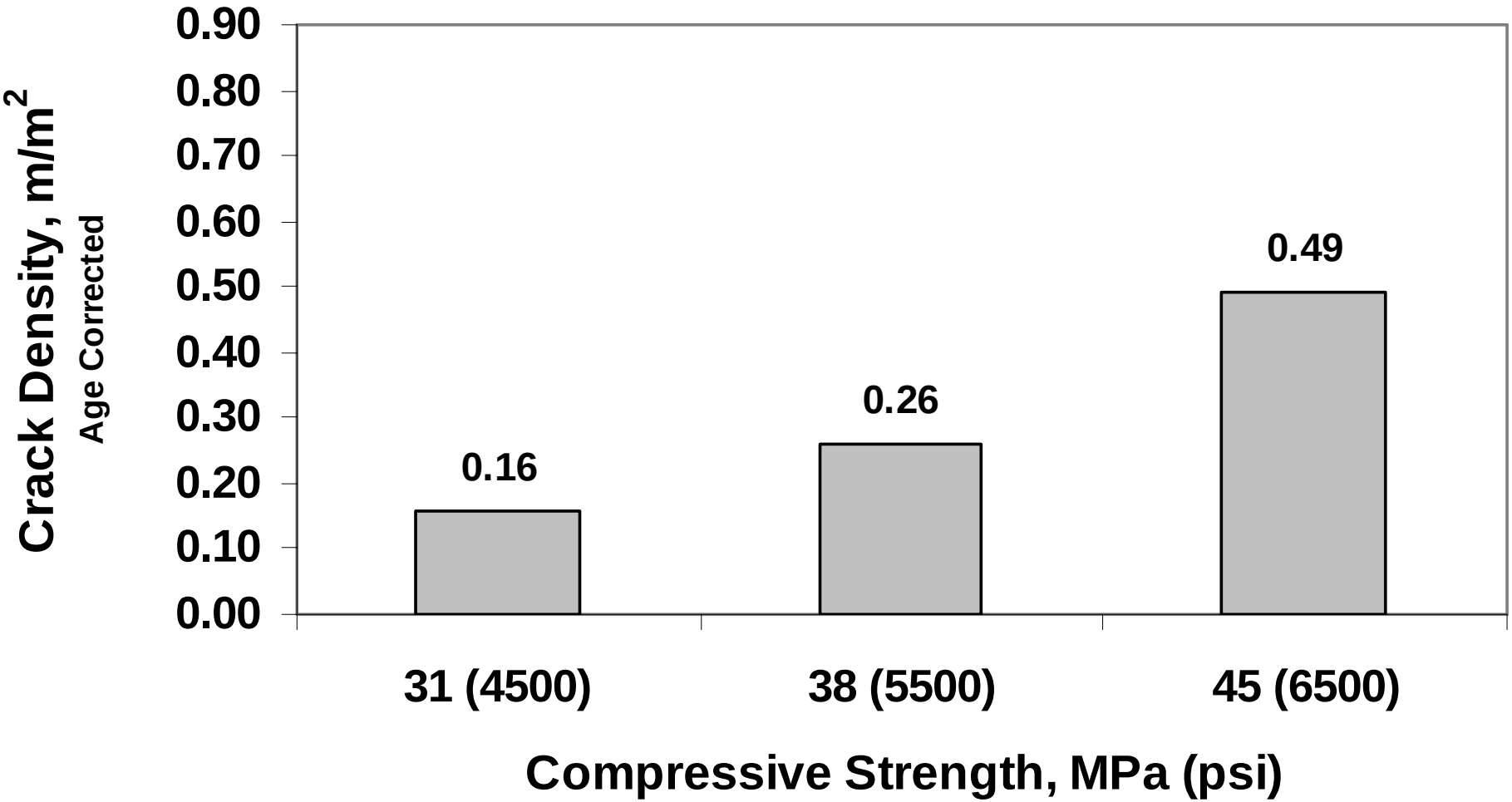
Slump



Number of Placements	(5)	(20)	(5)	(1)
Number of Surveys	(10)	(40)	(11)	(3)

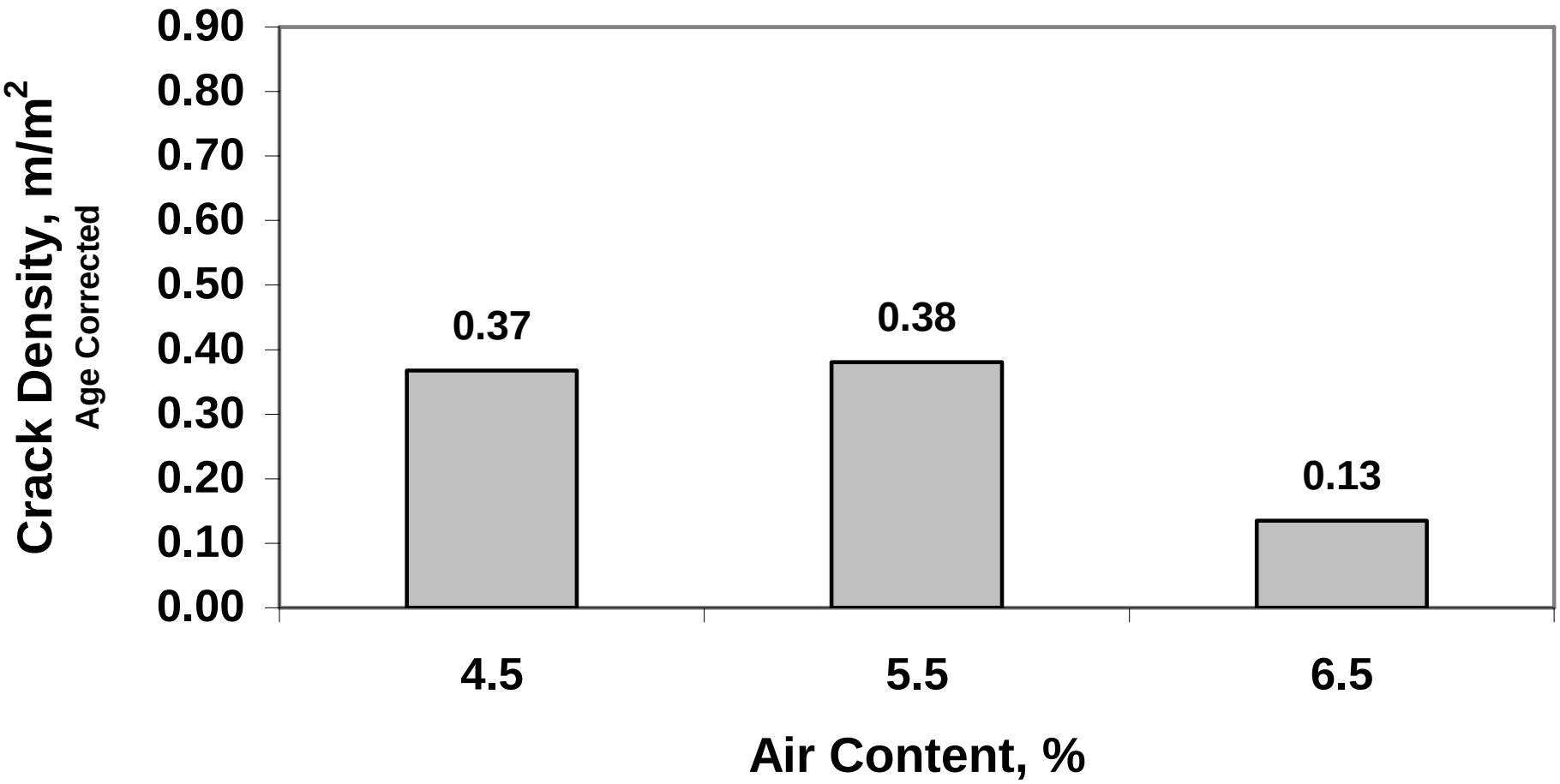


Compressive Strength



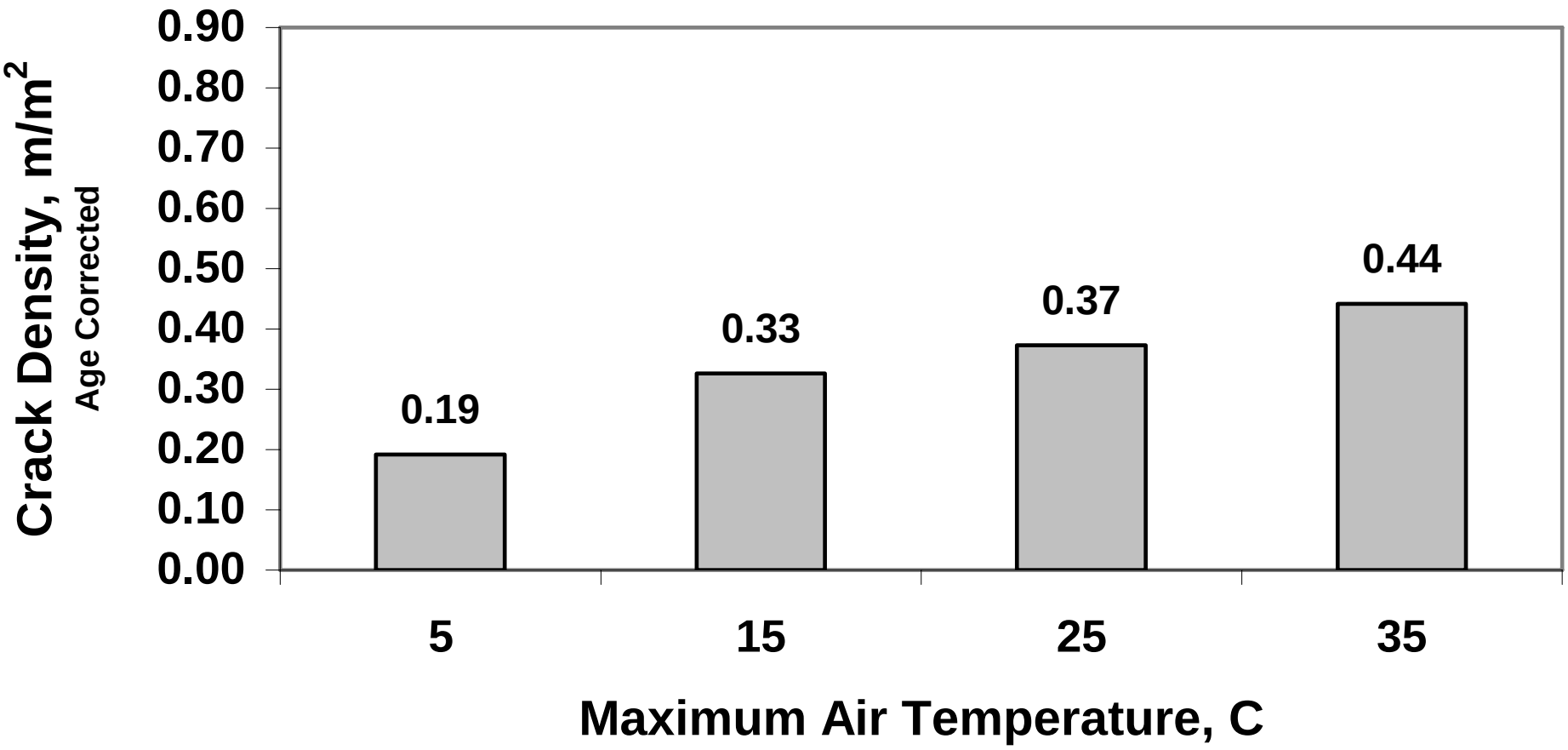
Number of Placements	(7)	(12)	(10)
Number of Surveys	(13)	(24)	(23)

Air content

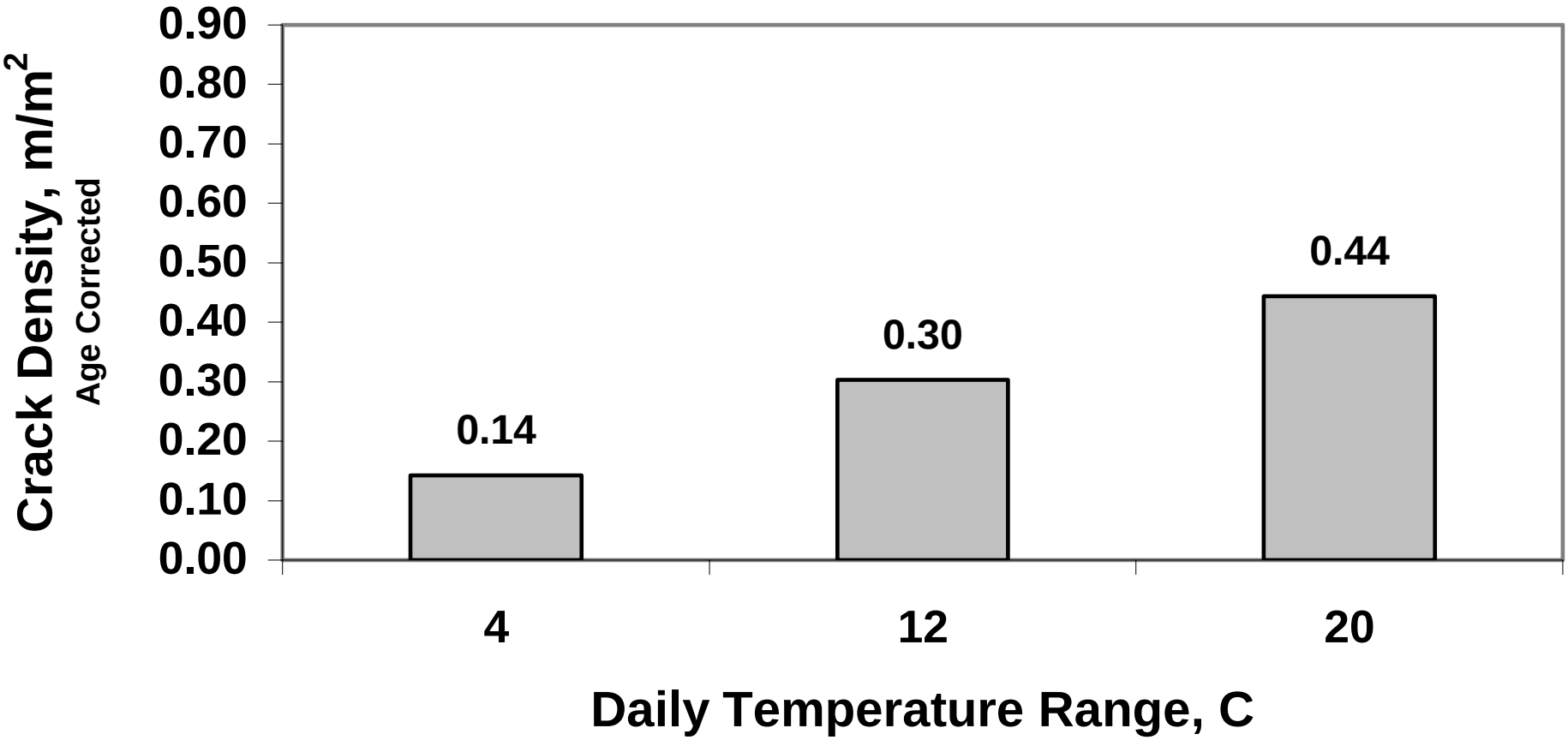


Number of Placements	(7)	(19)	(5)
Number of Surveys	(14)	(40)	(10)

Site Conditions - Temperature



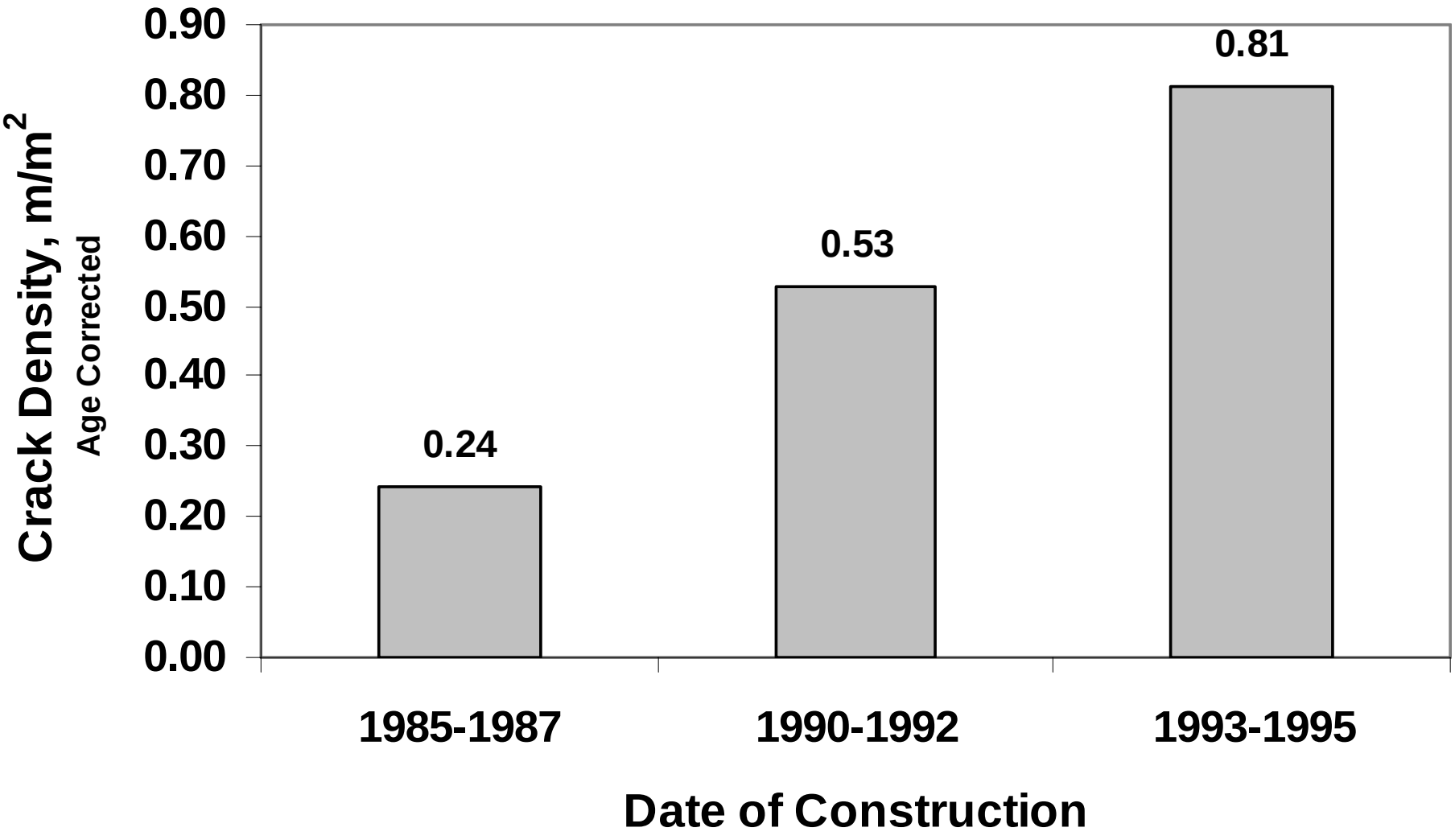
Number of Placements	(4)	(15)	(9)	(4)
Number of Surveys	(8)	(31)	(17)	(9)



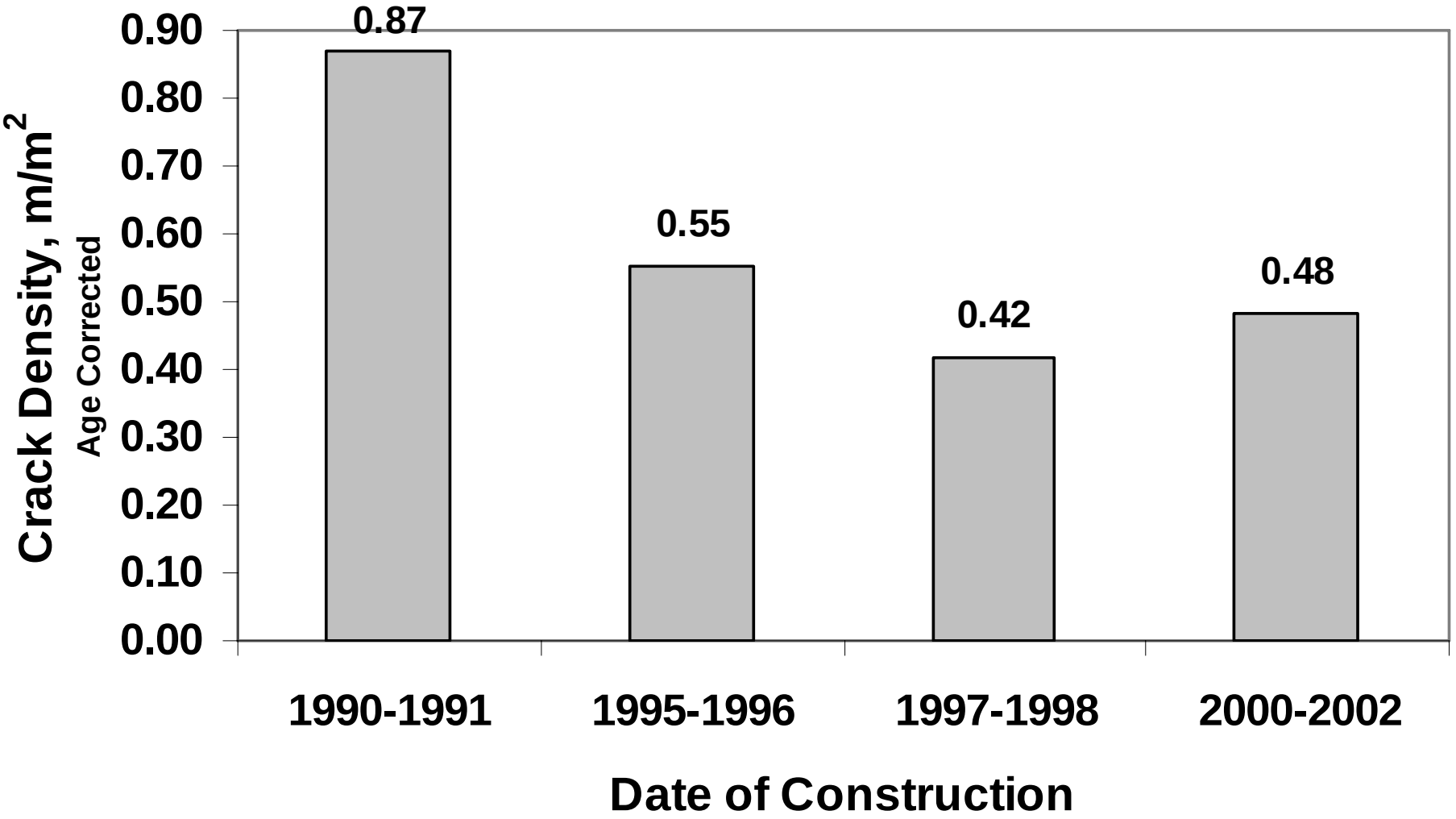
Number of Placements	(2)	(20)	(10)
Number of Surveys	(4)	(42)	(19)

Date of Construction

Number of Bridges	(6)	(7)
Number of Surveys	(12)	(16)

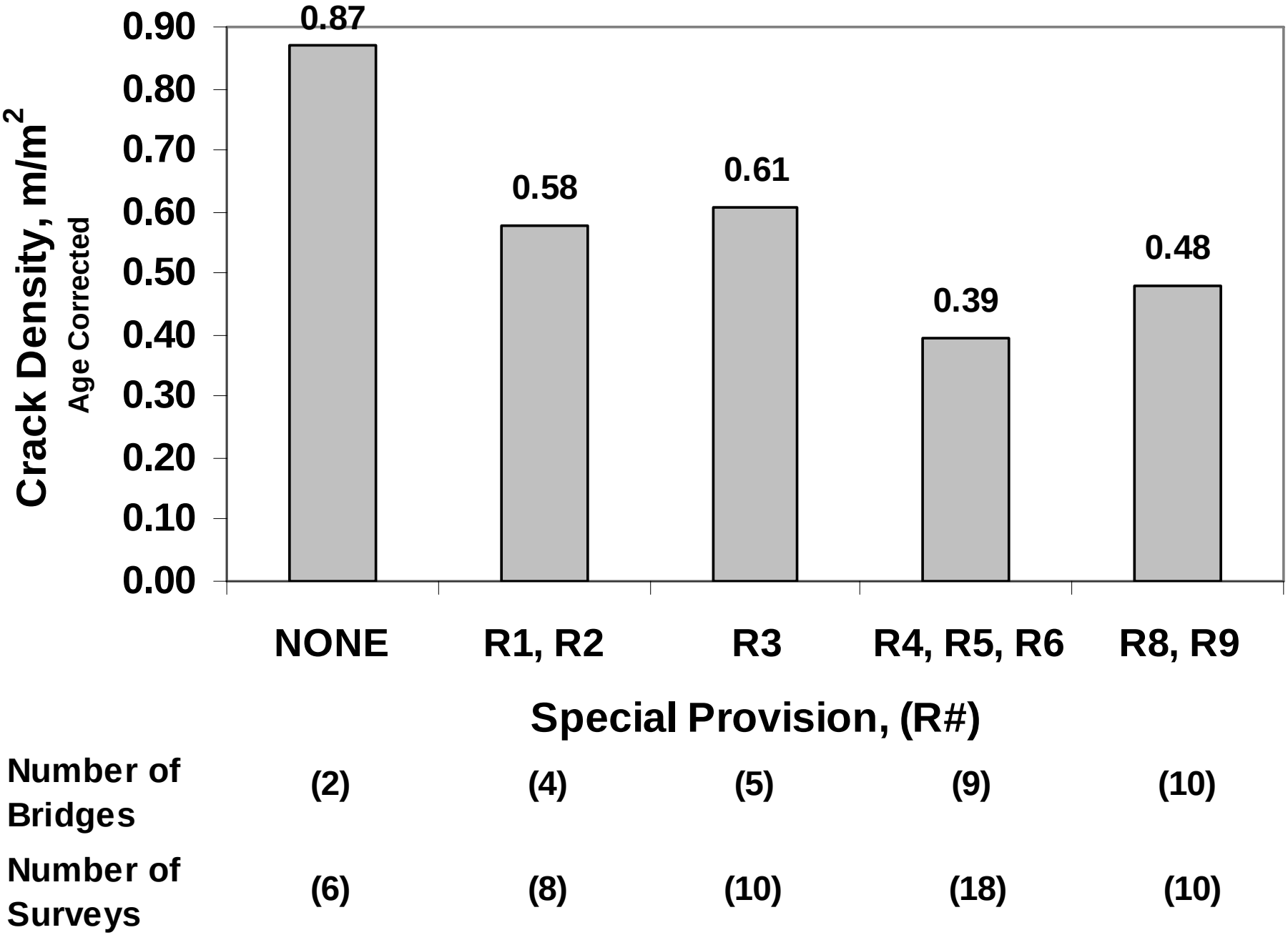


Number of Bridges	(6)	(17)	(3)
Number of Surveys	(6)	(36)	(6)

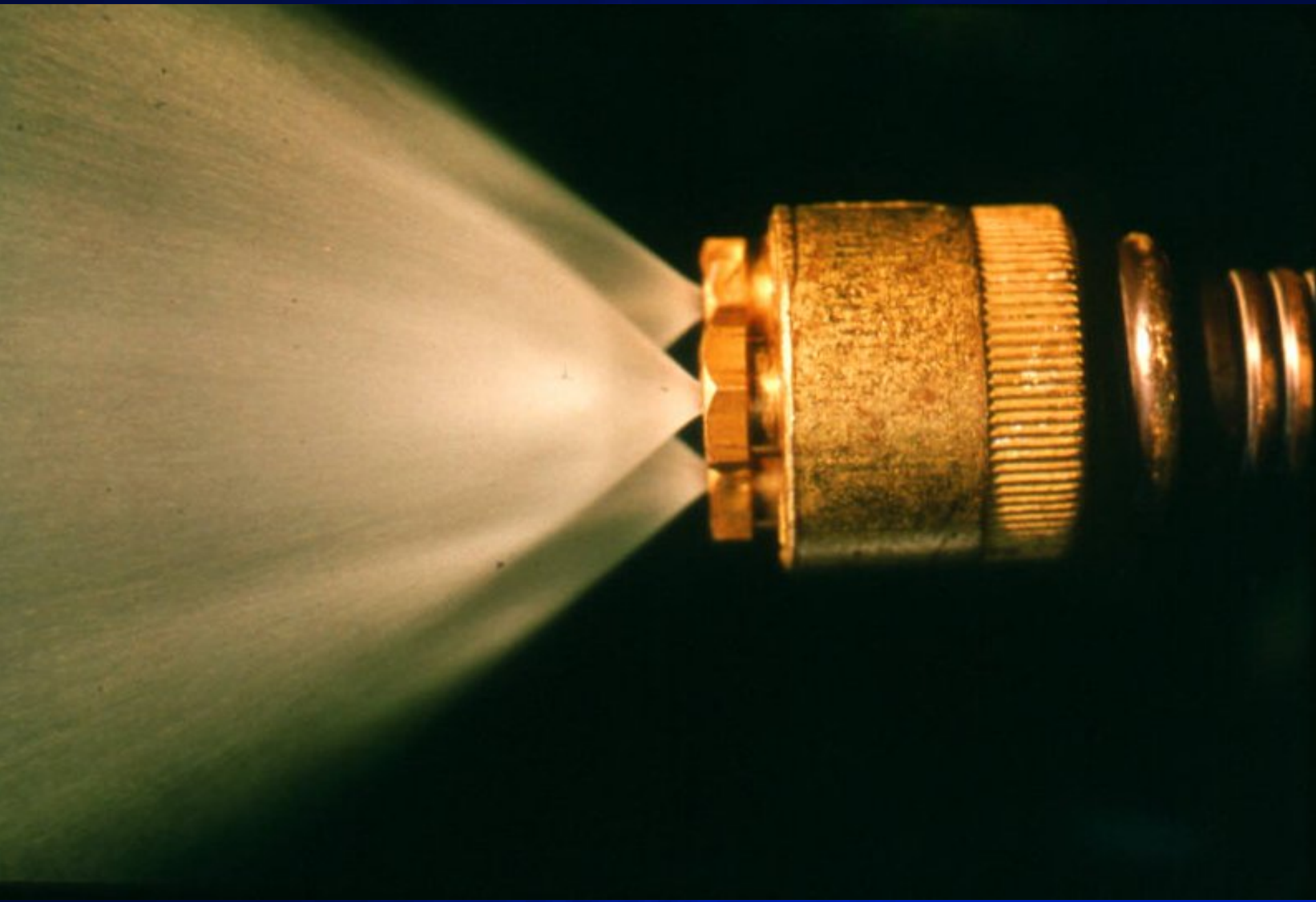


Number of Bridges	(2)	(10)	(8)	(10)
Number of Surveys	(6)	(20)	(16)	(10)

Control of Early Evaporation



Number of Bridges	(2)	(4)	(5)	(9)	(10)
Number of Surveys	(6)	(8)	(10)	(18)	(10)



Overall Approach

- Low cement & water contents
- Low slump
- High strength is not always good
- Low evaporation rate
- Construction methods and materials matter
- More early cracking means more total cracking

LC-HPC

- 1 inch Max Size Aggregate
- Optimized Aggregate Gradation
- Cement Content < 535 lb/yd^3
- Air Content of 8 ±1%
- Max w/c ratio of 0.42
- Improved curing
- Controlled temperature

Thermal Cracking

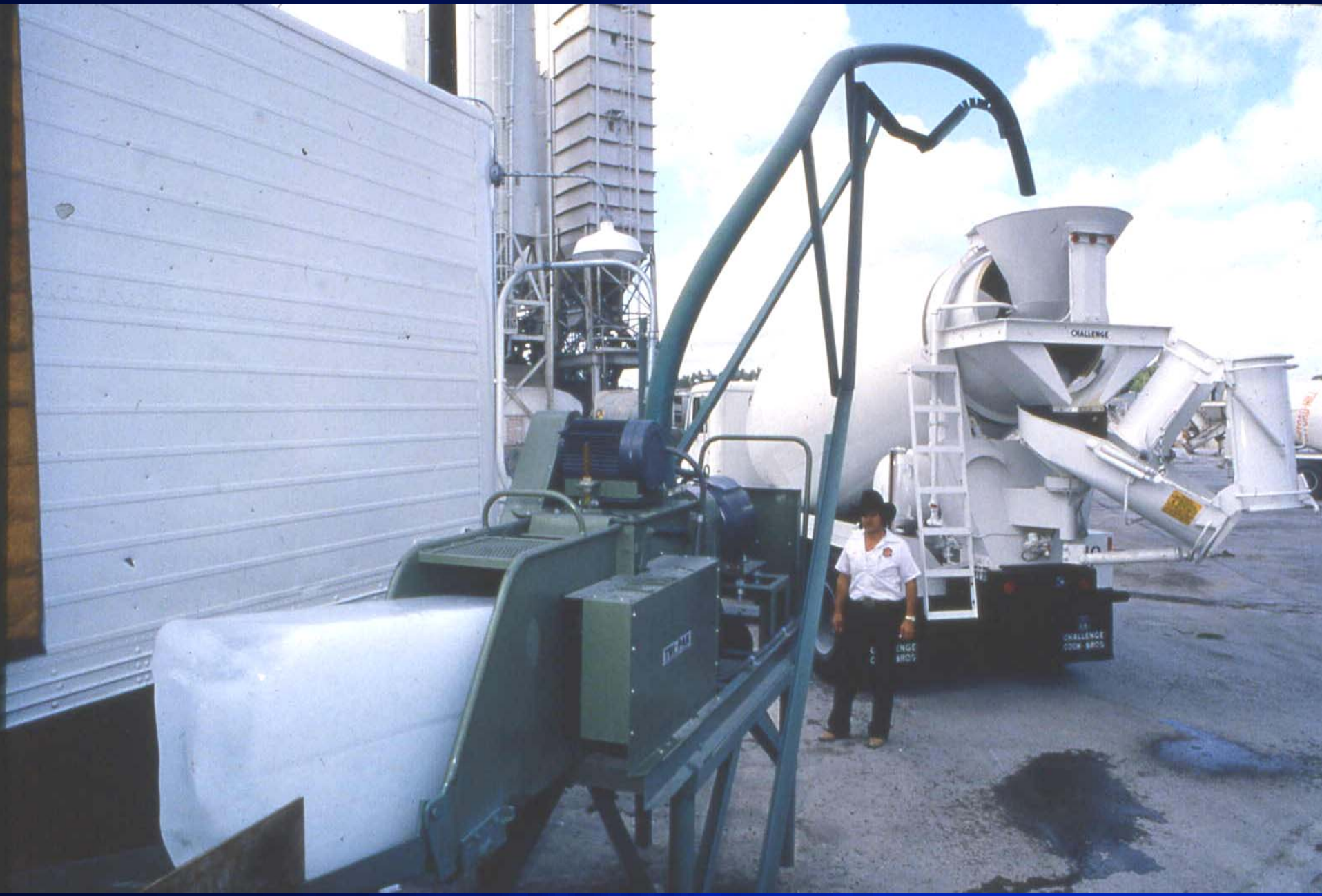
Rule of Thumb: Cracking will result when the temperature of the concrete deck exceeds the temperature of the girders by more than 20° C (36° F).

Thermal Cracking

PennDOT[1] 15° C (27° F)

KDOT 14° C (25° F)

1 Pennsylvania Department of Transportation, “Prevention of Cracks in Concrete Bridge Decks – Summary Report,” Report No. 89-01, March 1996.


CHALLENGE

Alternatives to Pumping

- Concrete Buckets
- Conveyor Belts


ADVANCE

Consolidation Requirements

Vertically mounted internal gang vibrators

Finishing

Machine Fogging

Machine Fogging

Supplemented by Hand Fogging

Early Wet Burlap Cure

Curing

- 14 days wet cure with burlap, soaker hoses, and plastic
- Followed by curing compound to slow the rate of evaporation

Qualification Slab

To demonstrate implementation of the specialized process and address problems before bridge deck casting.

- Process
- Contractor
- Ready Mix Plant
- Inspectors

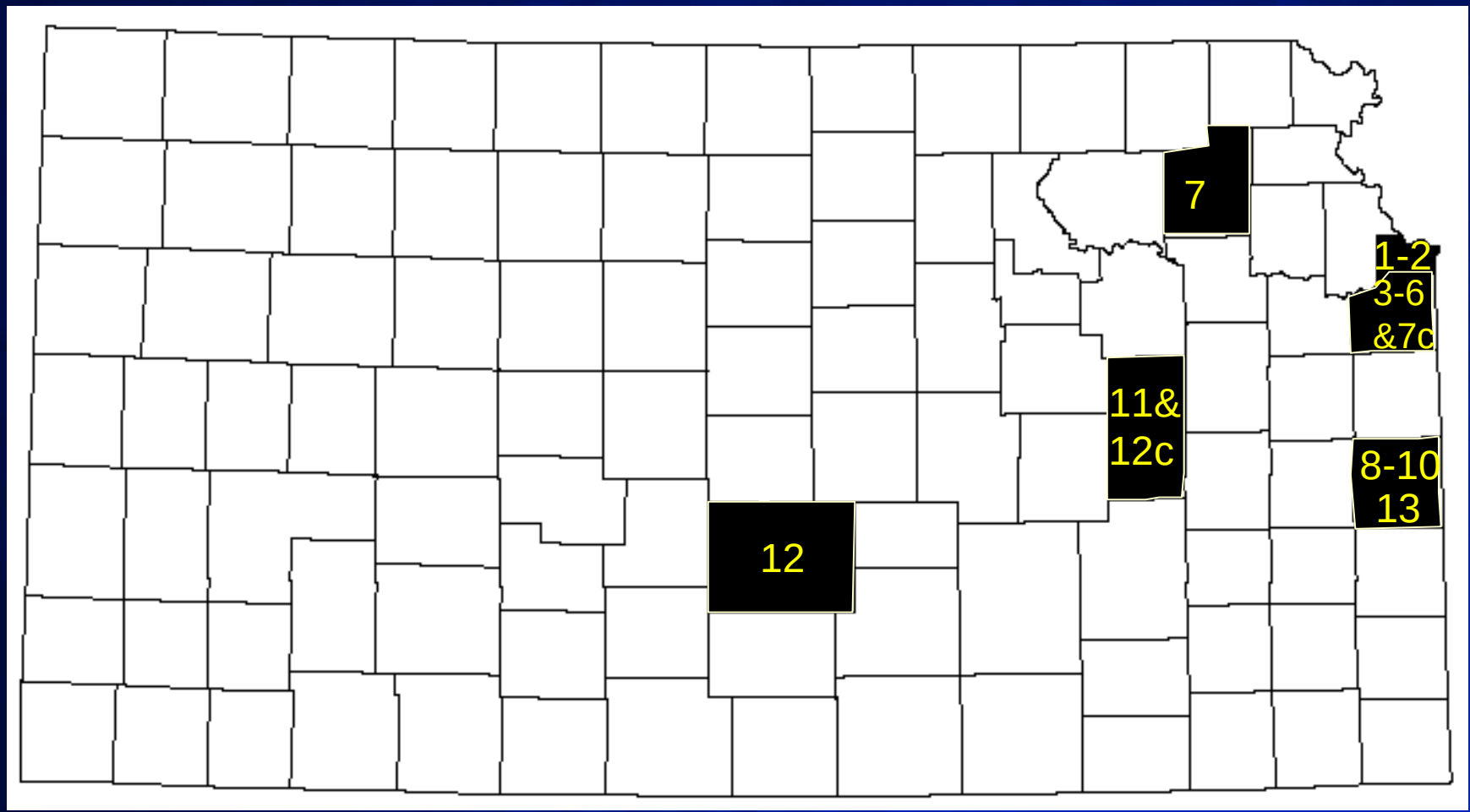
NO SUPRISES

Selection of Contractors

- Prequalified
- Multiple bridge contracts (to gain from experience)

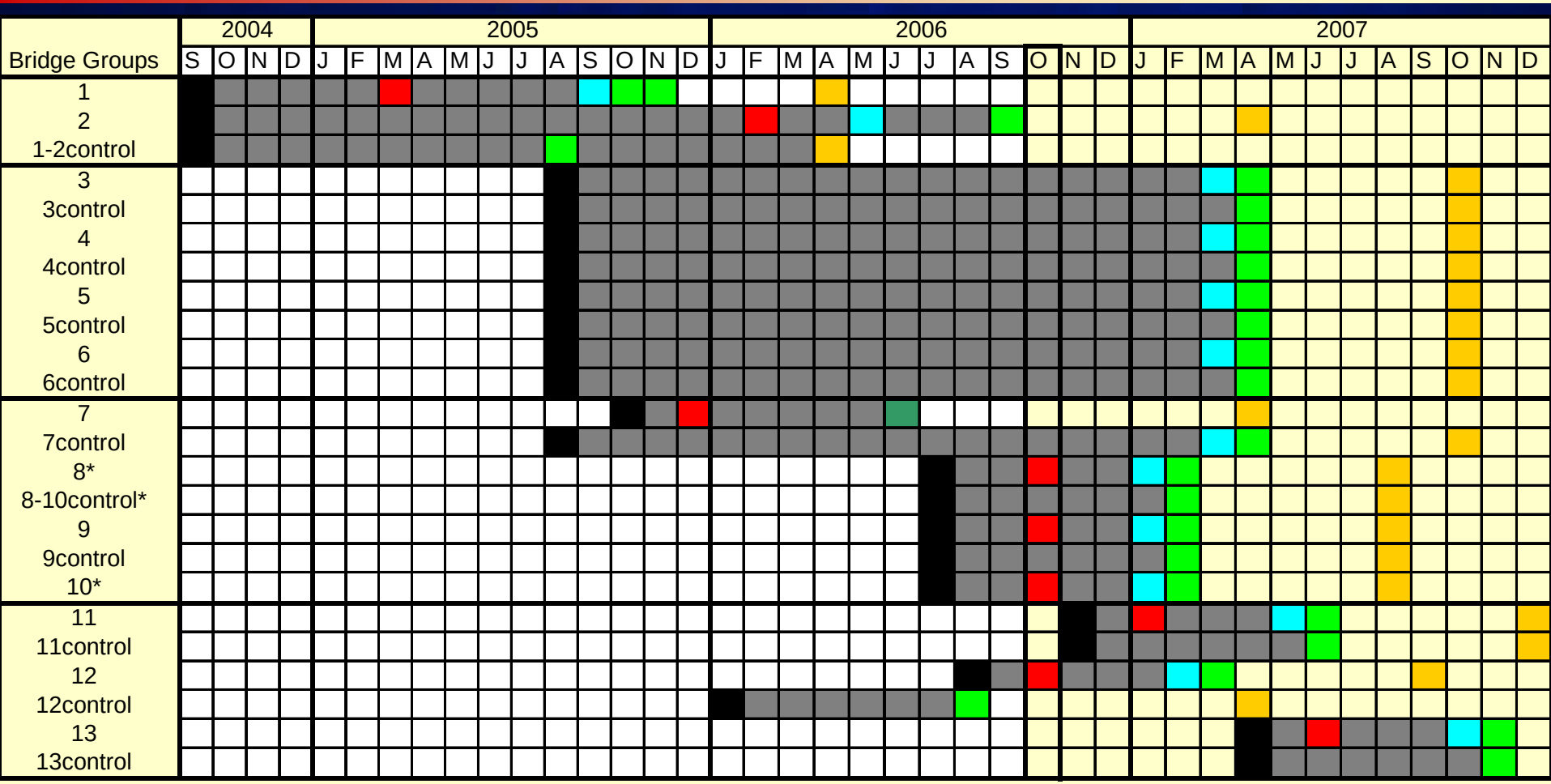
Experiences

Kansas Bridges



Unless specifically noted, all control bridges are in the same county as LC-HPC bridge.

Kansas Bridges - Timeline



LET Date
Pre-Construction Meeting
Qualification Slab
Cast Deck
1st Crack Survey

* Prestressed-Girder Bridge

Construction experiences

Qualification slabs

- Contractor learned:
  - Could pump mix
  - Need two bridges to place burlap, pre-fold
  - Fogging could not be used as finishing aid (especially in front of roller)
  - Proper use of gang vibrators

Qualification Slabs 1 and 2 – Fall 2005, Spring 2006 - Kansas City Area


WARNING

Burlap placement within 10 min and 10 ft of strike off

Qualification Slab 7 – June 8, 2006 – Topeka, KS

- KsDOT Project Manager: “This proves the value of the trial slab. You can see how much the contractor learned from the beginning to the end of the slab.”

Bridge Placements

- Temperature controlled with ice, place at night in mid-summer
- Pumpable even with 1.5-in. slump
- Finishing delayed at end abutments
- Bullfloating worked well, cannot use fogging as finishing aid
- Perfect art of placing burlap, keeping wet
- Cure barriers same as deck
- Careful of cold-weather curing

Bridge Placements

- Bridge superintendent observed that he preferred working with optimized concrete with cement content of 540 lb/yd^3 to traditional mix with cement content of 602 lb/yd^3

Bridge 1: November 2005


GBA

- Cores of deck show that finishing methods leave large coarse aggregate particles close to the upper surface of the deck

Bridge 7 June 24, 2006

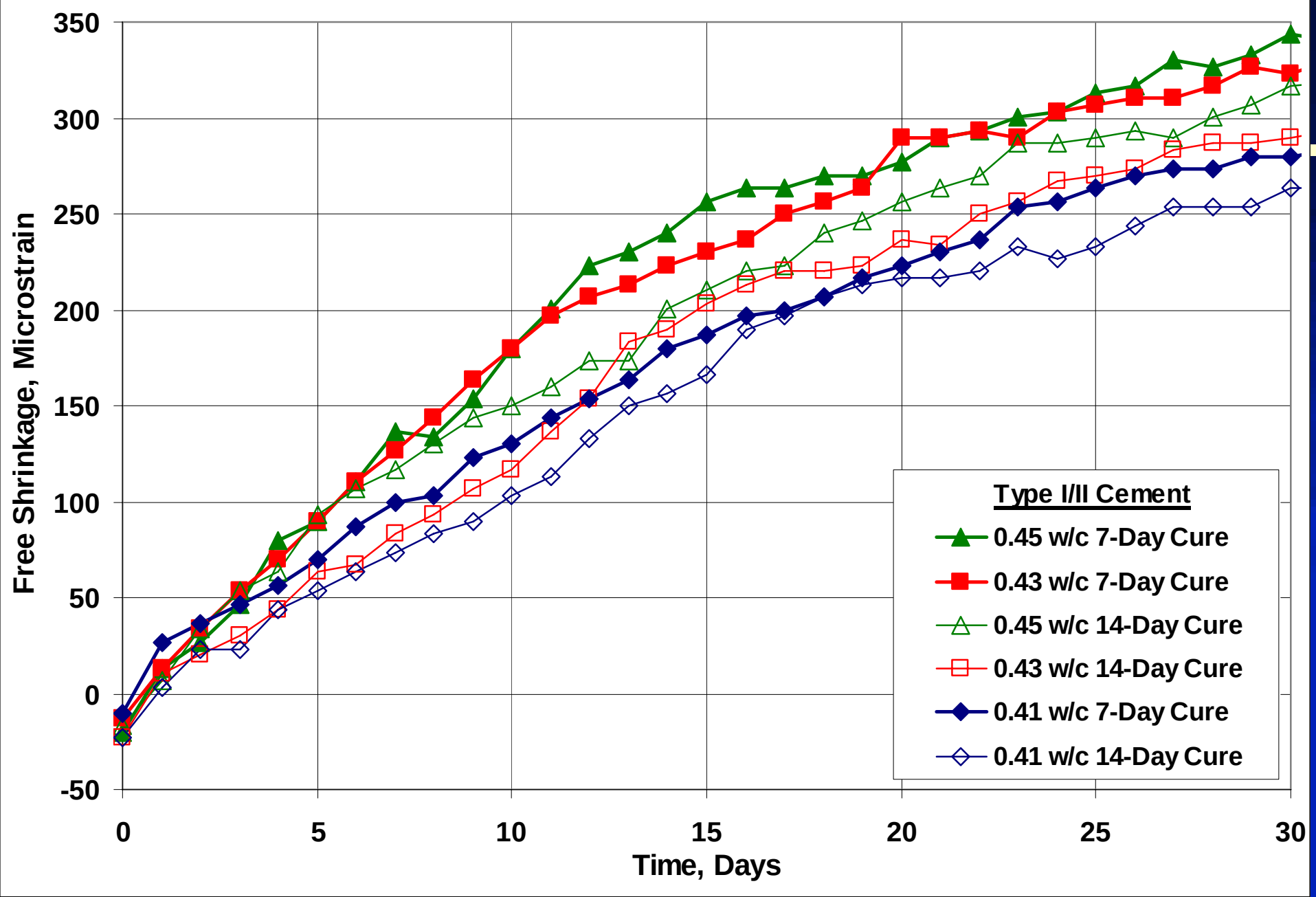

BIDWELL
3600
A CMI TEREX COMPANY
CANTON, SOUTH DAKOTA
(605) 987-2603

Conclusions - Experiences

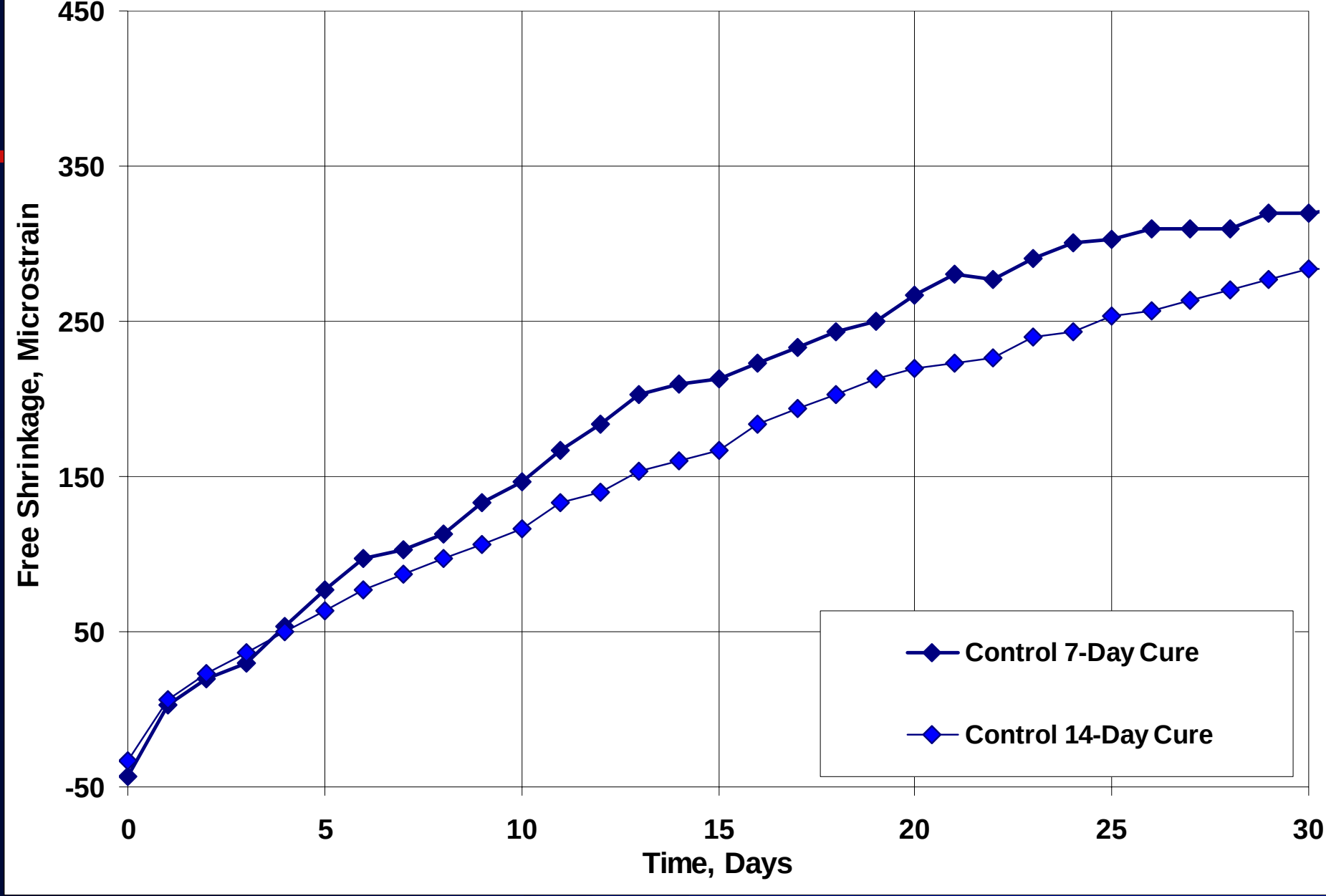
- Optimized concrete mixes with relatively low cement (paste) contents are very pumpable, placeable, and finishable
- Temperature can be controlled using ice

- Techniques can be learned easily and workers can become proficient in a short period of time
- Bid prices are dropping as contractors become more familiar with the methods involved

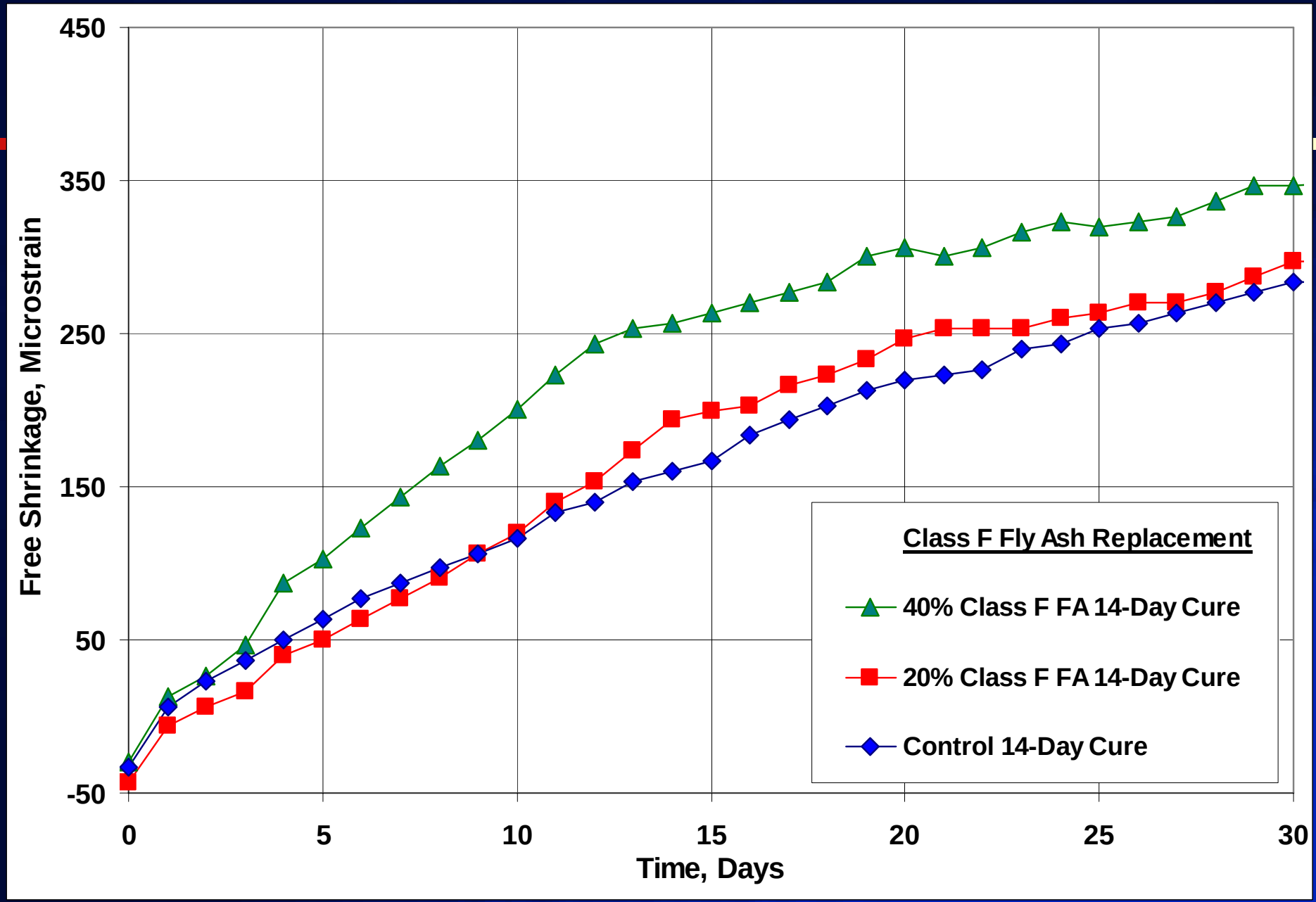
Laboratory Work - Briefly



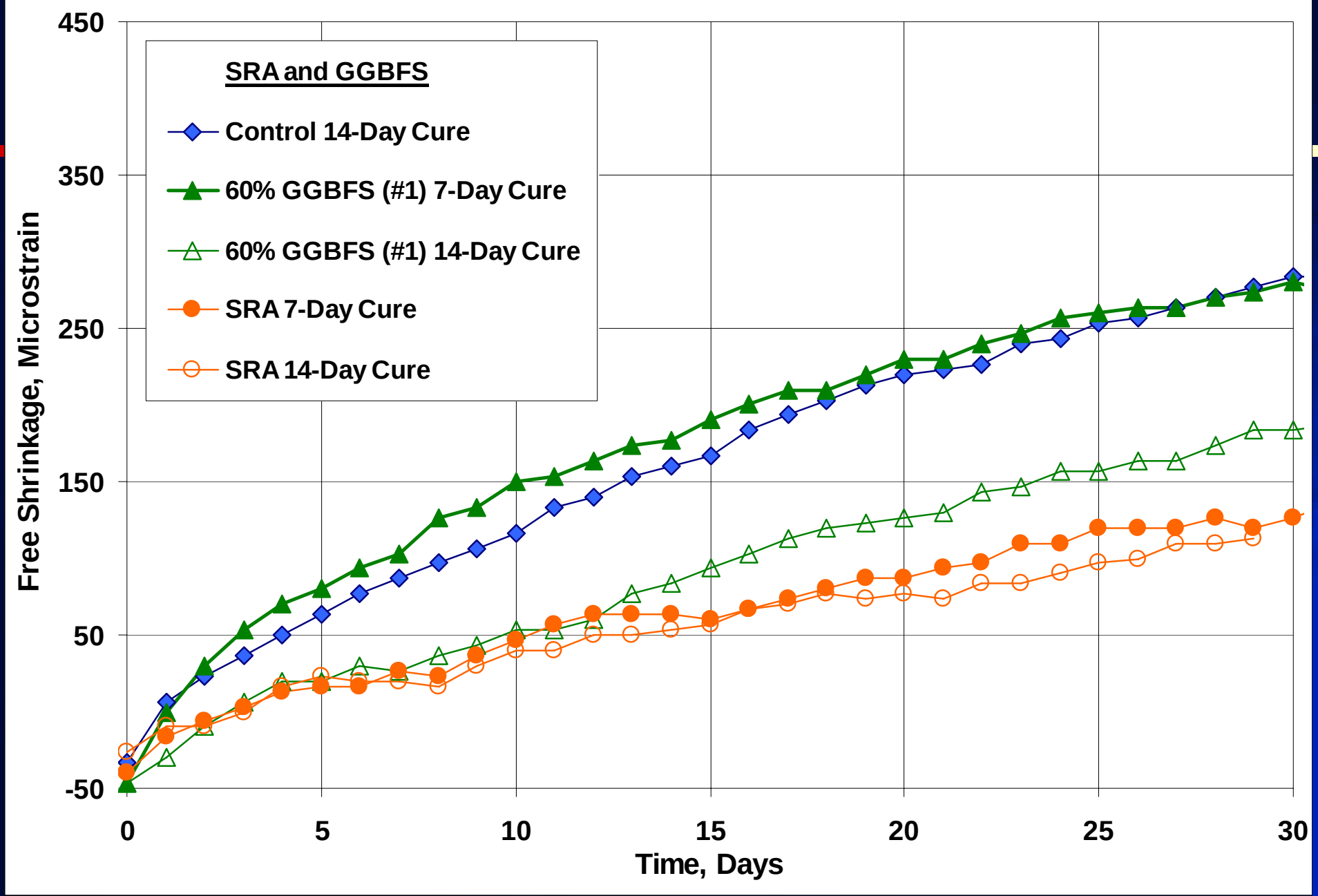
Average Free Shrinkage (Drying Only). 535 lb/yd^3 Type I/II Cement



Average Free Shrinkage (Drying Only). 535 lb/yd^3 Type I/II Cement
***w/cm* = 0.42, 23.26% paste**



Average Free Shrinkage (Drying Only). *w/cm* = 0.42, 23.26% paste



Average Free Shrinkage (Drying Only). *w/cm* = 0.42, 23.26% paste

Summary

Background

Experiences

Laboratory Work – in brief

Questions?

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Costs

- Qualification Slabs 1 & 2
  - $4205/yd^3
- Bridges 1 & 2
  - $1741 & $1698/yd^3
- Control Bridge 1 & 2
  - $770/yd^3

Costs

- Qualification Slabs 3 – 6
  - $995-$1154/yd^3
- Bridges 3 – 6
  - $655-$751/yd^3
- Control Bridges 3 – 6
  - $608-$656/yd^3

Costs

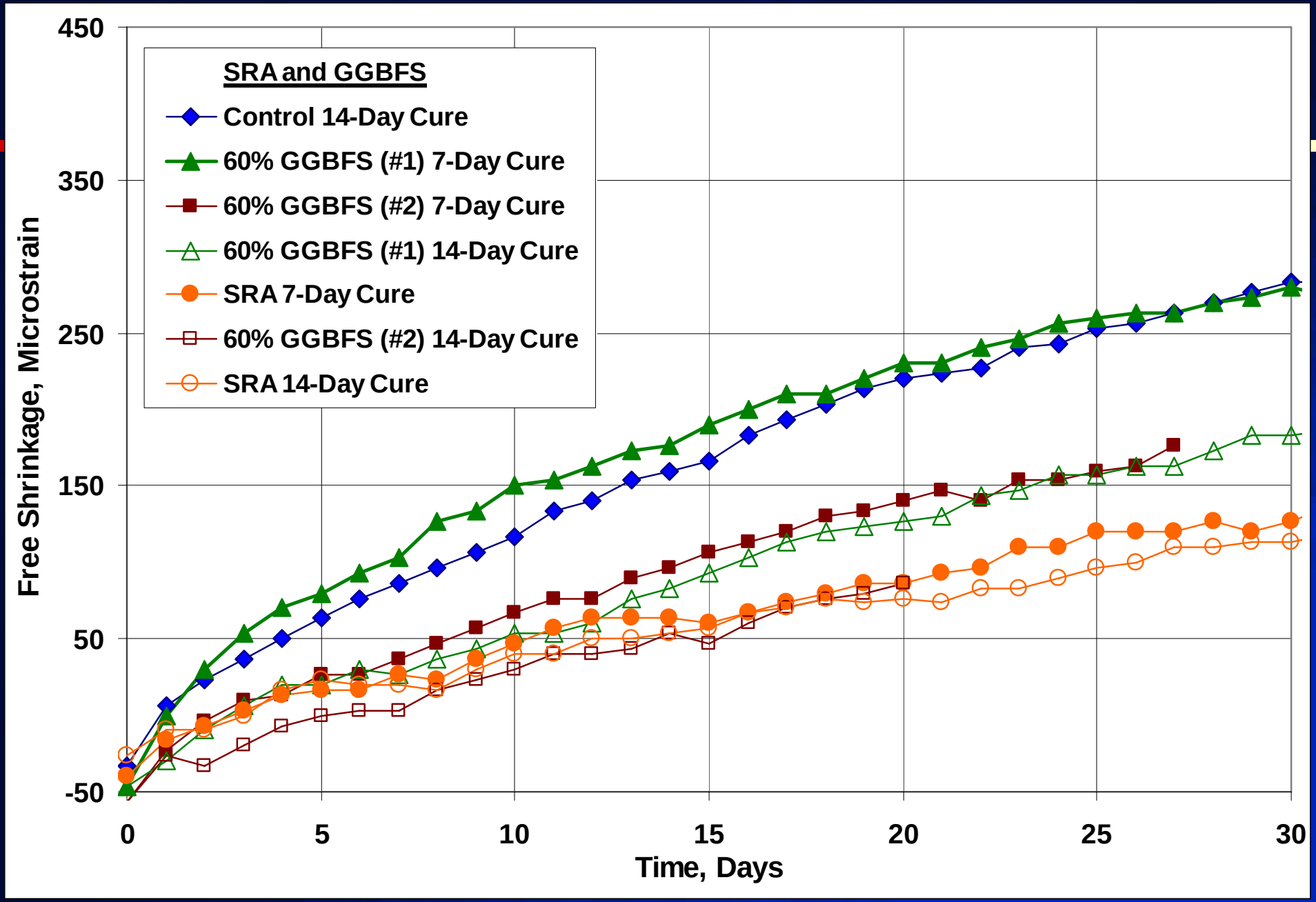
- Qualification Slab 7
  - $573/yd^3
- Bridge 7
  - $623/yd^3
- Control Bridge 7
  - $725/yd^3

Costs

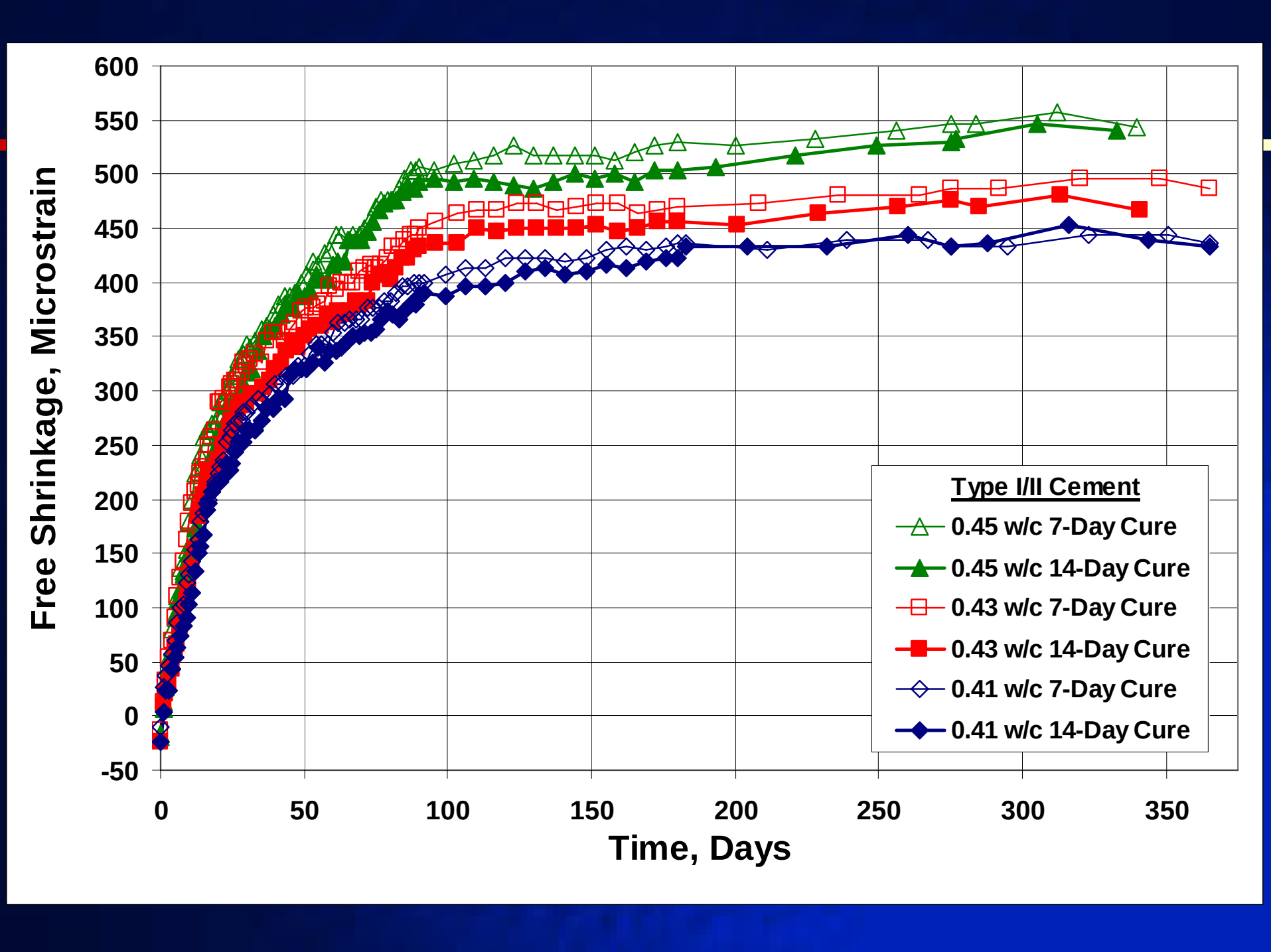
- Qualification Slab 8-10
  - $906-956/yd^3
- Bridge 8-10
  - $569-774/yd^3
- Control Bridge 8-10
  - $371/yd^3

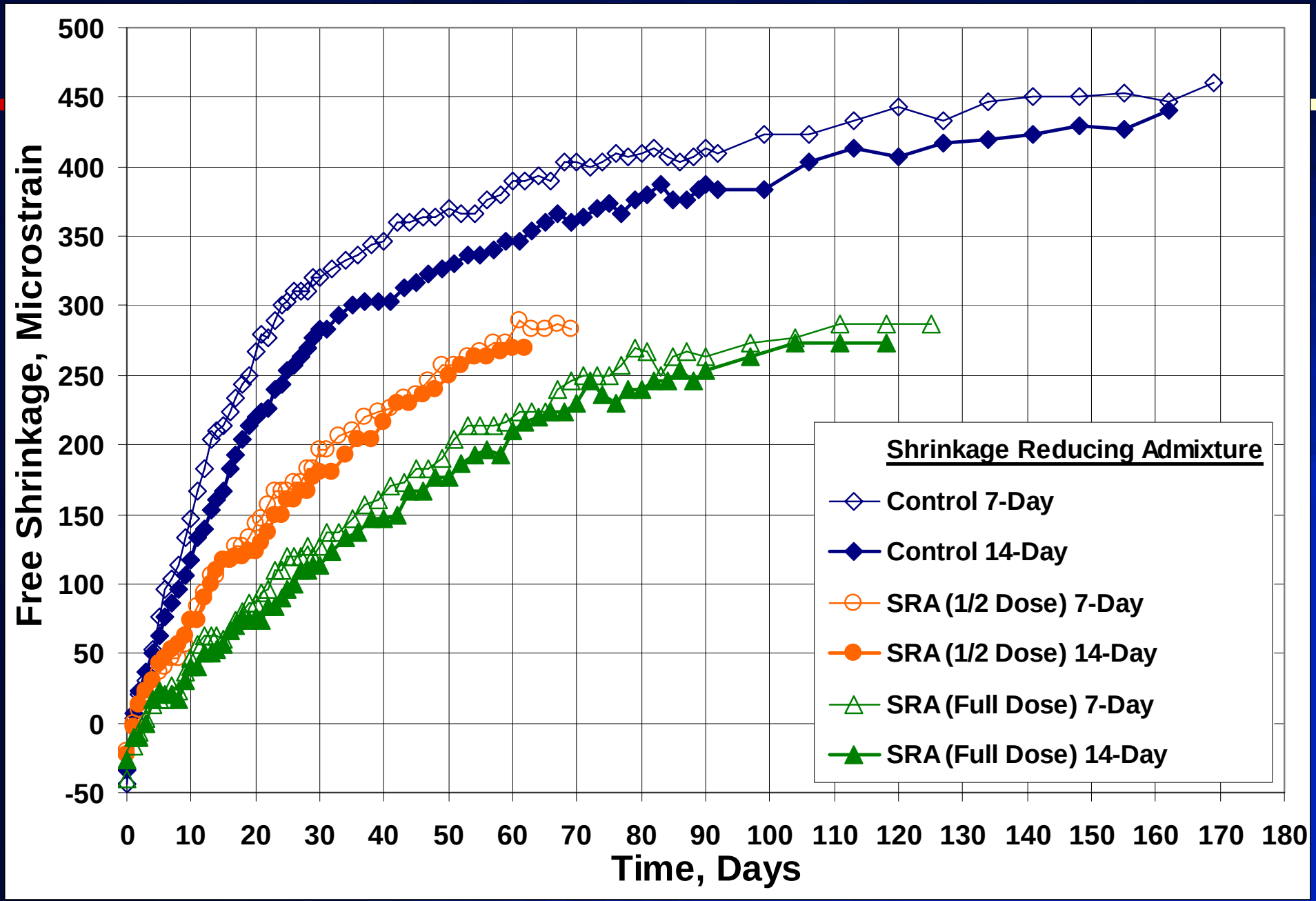
Costs

- Qualification Slab 12
  - $1070/yd^3
- Bridge 12
  - $1275/yd^3
- Control Bridge 12
  - $401/yd^3

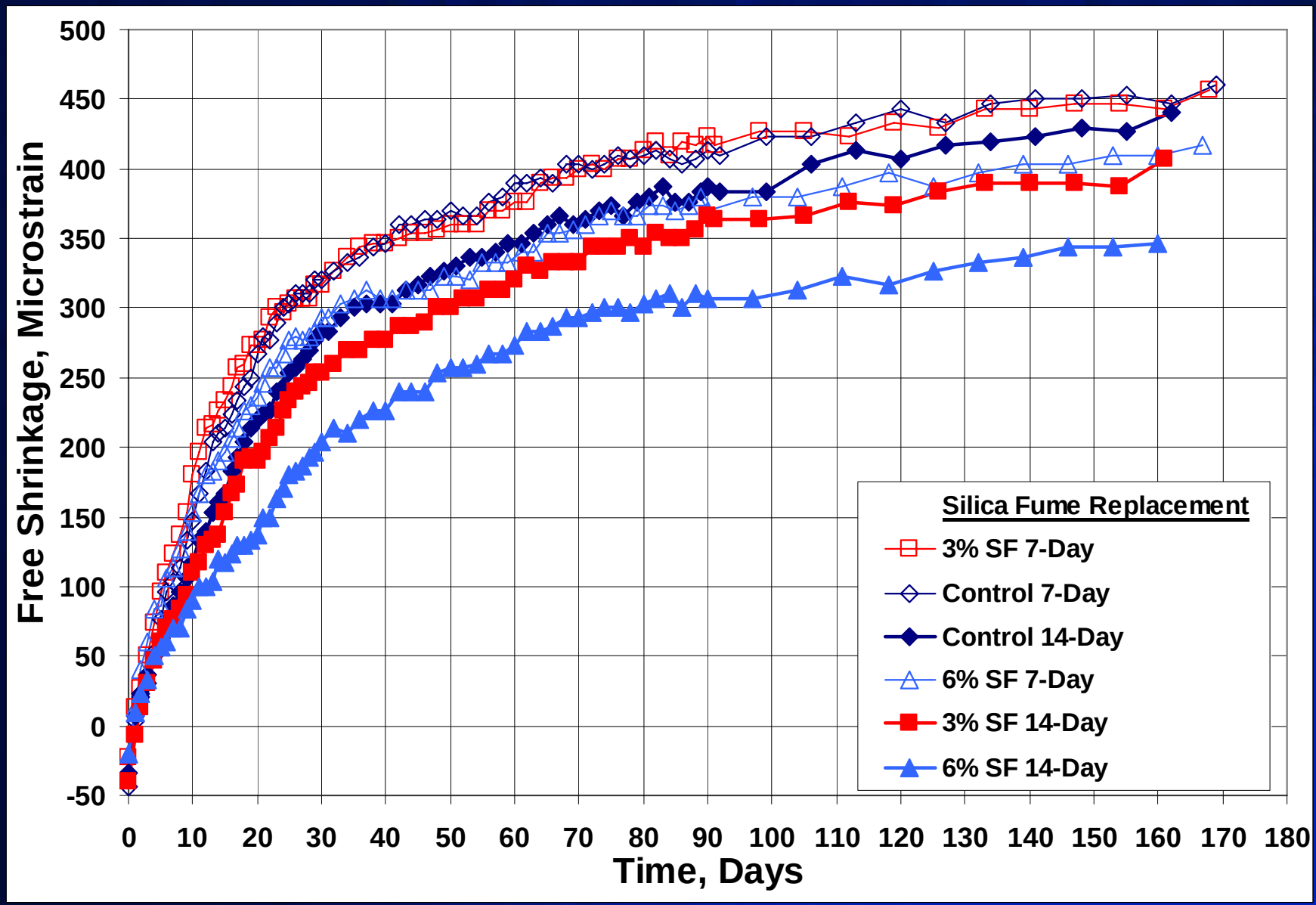


Average Free Shrinkage (Drying Only). *w/cm* = 0.42, 23.26% paste

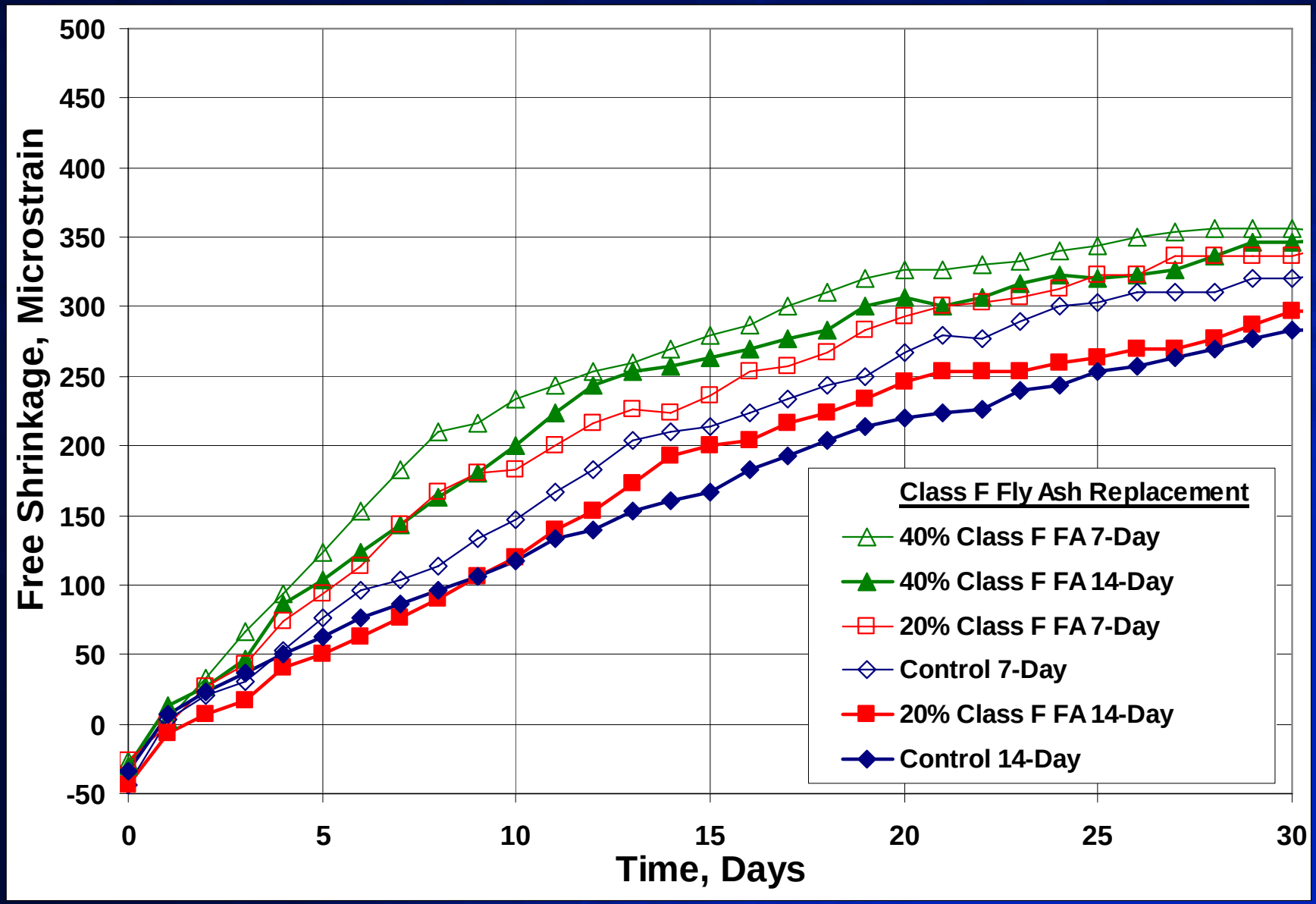

Free Shrinkage, Microstrain
600
550
500
450
400
350
300
250
200
150
100
50
0
-50
0
50
100
150
200
250
300
350
Time, Days
Type I/II Cement
0.45 w/c 7-Day Cure
0.45 w/c 14-Day Cure
0.43 w/c 7-Day Cure
0.43 w/c 14-Day Cure
0.41 w/c 7-Day Cure
0.41 w/c 14-Day Cure


Free Shrinkage, Microstrain
500
450
400
350
300
250
200
150
100
50
0
-50
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Time, Days
Shrinkage Reducing Admixture
Control 7-Day
Control 14-Day
SRA (1/2 Dose) 7-Day
SRA (1/2 Dose) 14-Day
SRA (Full Dose) 7-Day
SRA (Full Dose) 14-Day

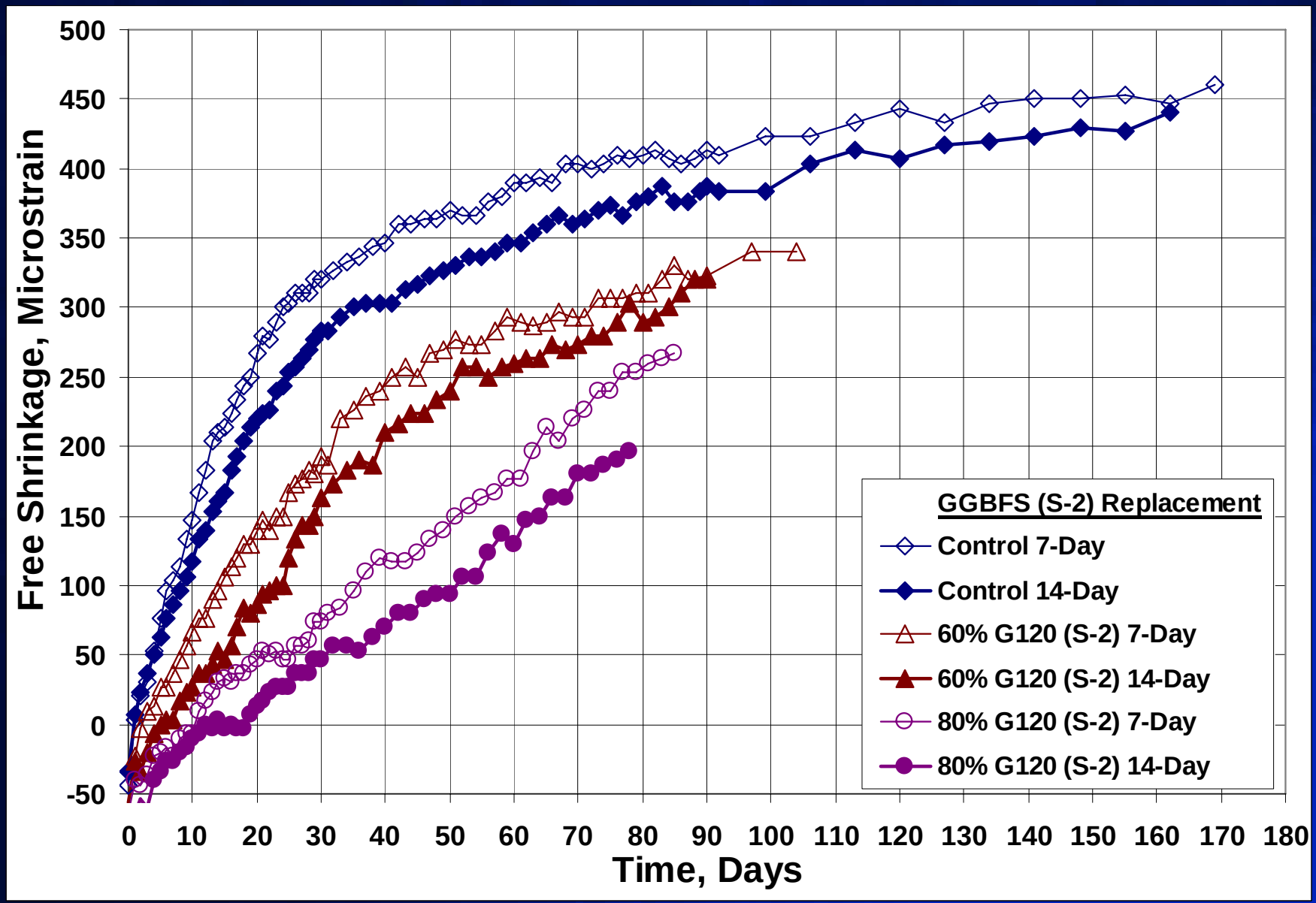
Silica Fume


Free Shrinkage, Microstrain
500
450
400
350
300
250
200
150
100
50
0
-50
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Time, Days
Silica Fume Replacement
3% SF 7-Day
Control 7-Day
Control 14-Day
6% SF 7-Day
3% SF 14-Day
6% SF 14-Day

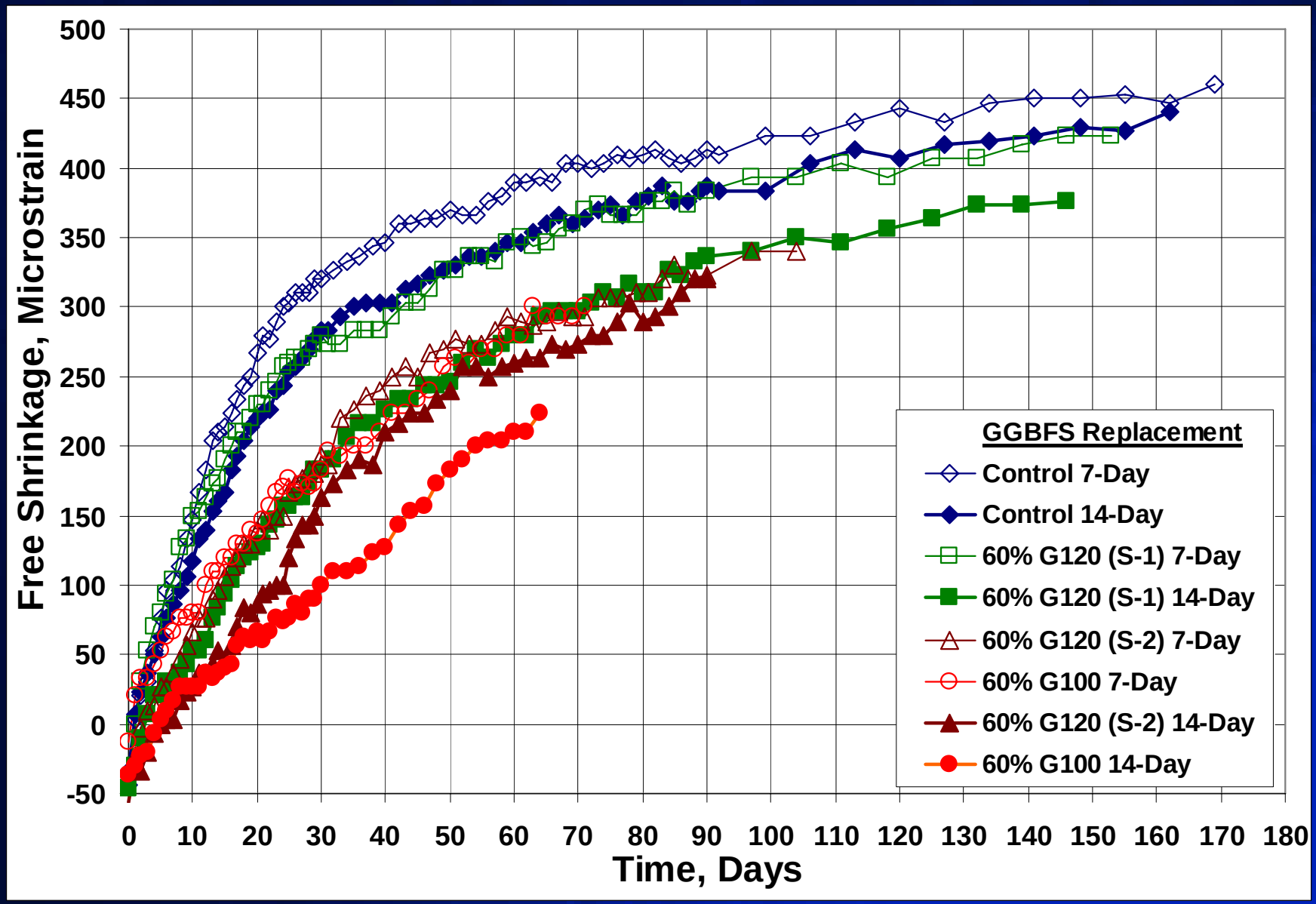
Class F Fly Ash



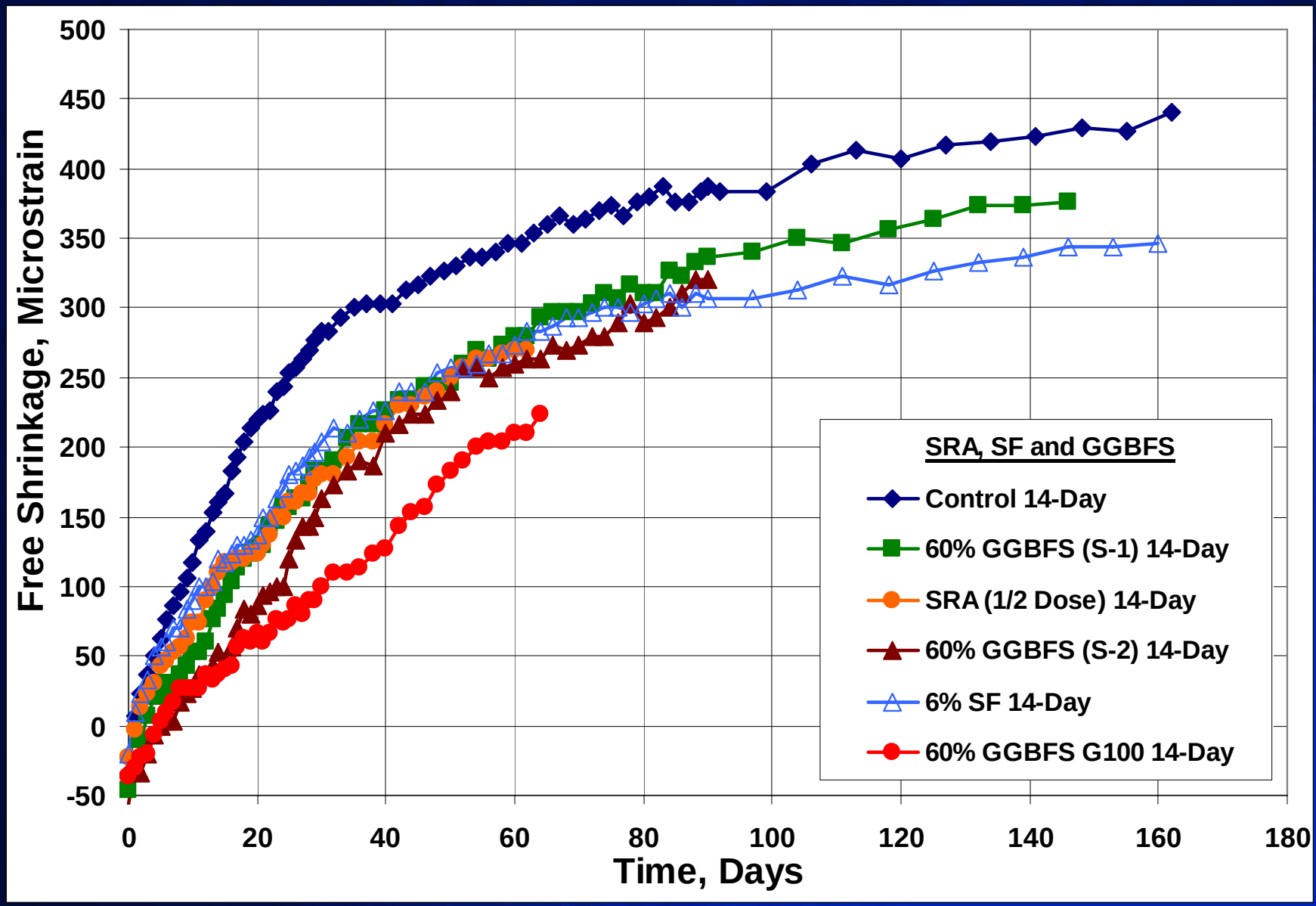
Ground Granulated Blast Furnace Slag



Ground Granulated Blast Furnace Slag



GGBFS, SF and SRA



Work in Progress

- Ternary Mixtures with Reduced Paste Content
  - CF 273 kg/m^3 (460 lb/yd^3)
  - 60% - 80% GGBFS
  - 6% Silica Fume
- Aggregate type
- Permeability testing of mineral admixture batches
- Scaling tests for slag mixes