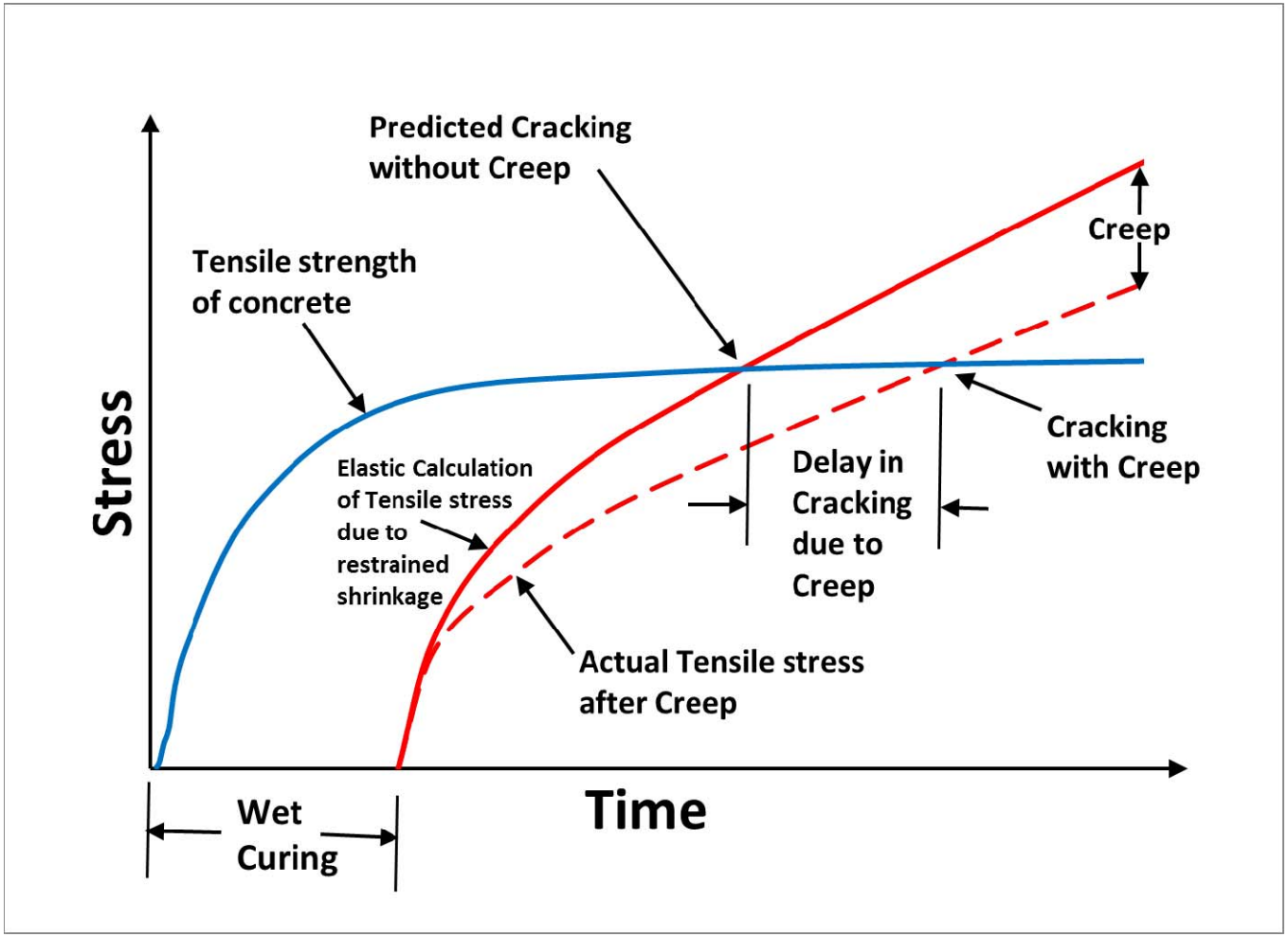
Type K Engineered Expansive Cements

Boyd's Hollow Bridge

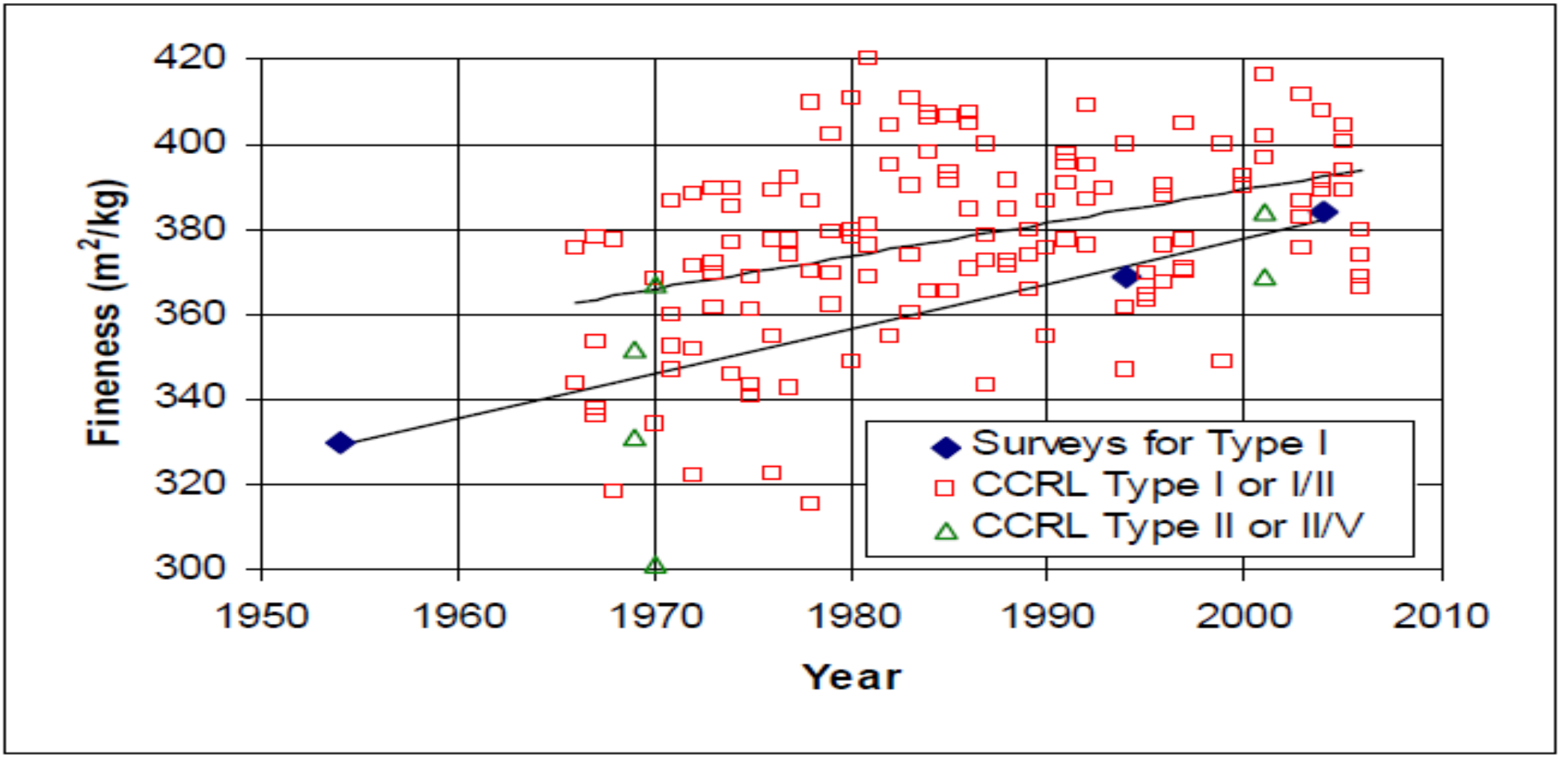
Chris Ramseyer Ph.D., P.E

Very Typical Cracks in PCC

Portland Concrete



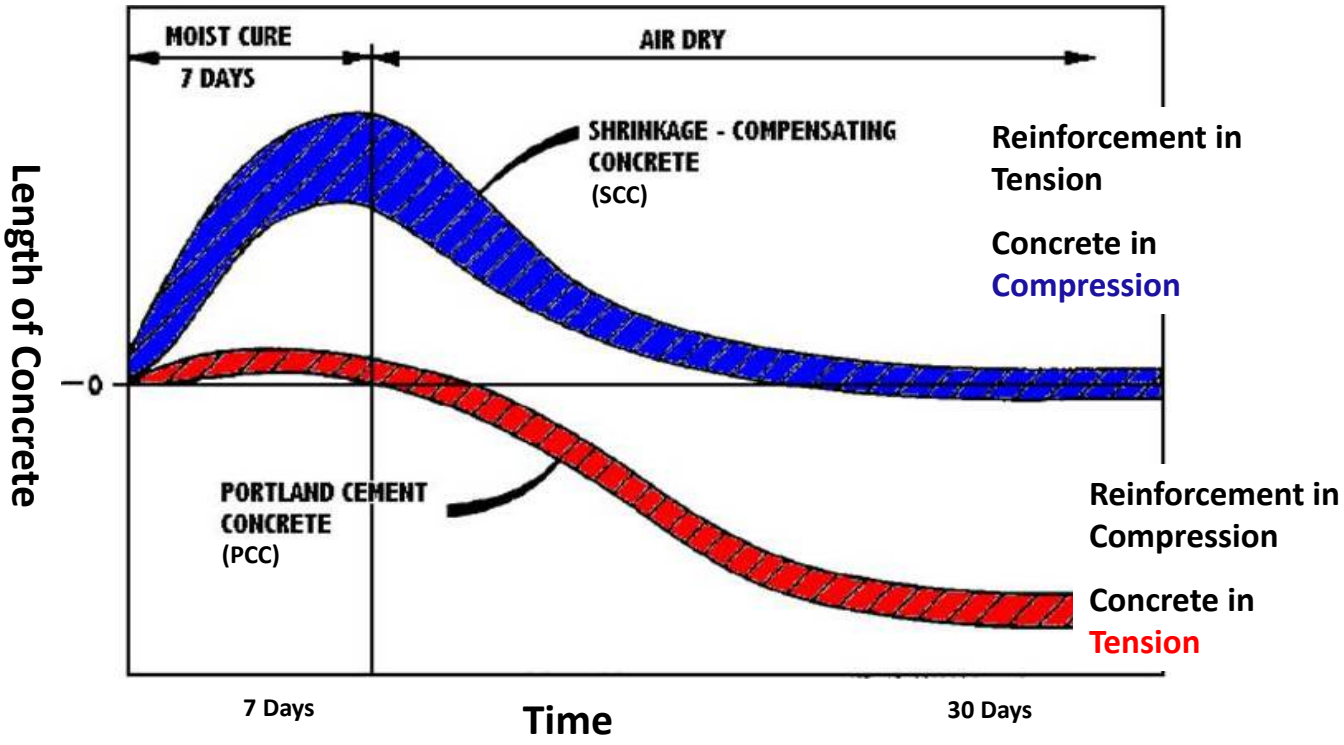
Why we are here- Trends in Portland cement



MANUFACTURING

- Patents for Klein's compound were applied for in 1963
- First full-scale manufacture of Shrinkage Compensating Concrete (Type K) was Kaiser Cement Company
- Caltrans places an order for 2 miles of highway in 1963

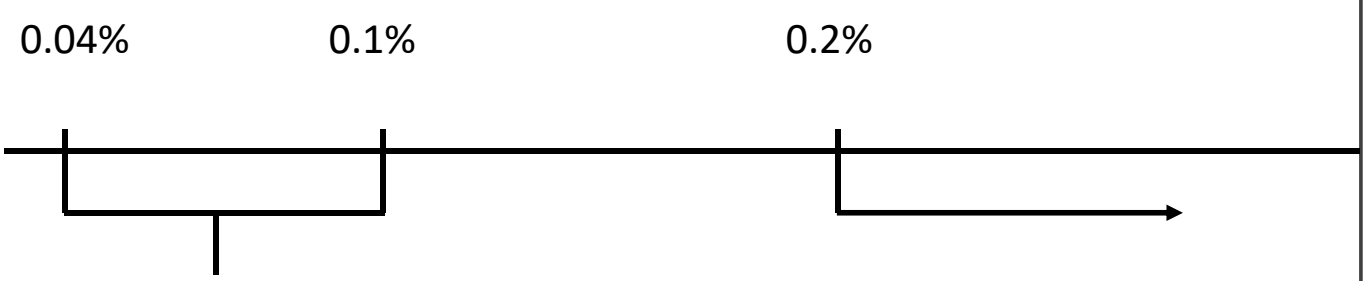
ACI 223: Figure 2.5.3



ACI 223 Standard Practice for the use of Shrinkage Compensating Concrete

DEFINING THE MATERIAL

ASTM C845 **Defines expansion at 7 days**



Shrinkage Compensating Concrete

Expansion at 28 days not to exceed 0.15%

Chemical Prestressed Concrete

DEFINING THE MATERIAL

Why were these limits chosen?

- For Shrinkage Compensated Concrete (0.04%-0.1%)
  - Ability to substitute Type K Shrinkage Compensating Cement for any concrete structure without changing the reinforcing or joint detail
- For Chemical Pre-Stressed Concrete (> 0.2%)
  - To create a clear difference between Shrinkage Compensated and Chemical Pre-stressed concrete

PCC & SCC Decks (2012)
20 yrs old, Grand Rapids, MI

Ohio Turnpike

Ohio Turnpike Authority Director

Type K Shrinkage Compensating Concrete Addresses Many Concerns from Safety to Ride Characteristics.

Ohio Turnpike Authority Director

“We don’t even think about cracks or crack maintenance on our Shrinkage Compensating Concrete Decks”

1. **Deck Condition**
2. **Wearing Surface**
3. **Approaches**
4. **Safety Barriers**

Ohio Turnpike Authority Director

“We don’t even think about cracks or crack maintenance on our Shrinkage Compensating Concrete Decks”

1. ~~**Deck Condition**~~
2. **Wearing Surface**
3. **Approaches**
4. **Safety Barriers**

Ohio Turnpike Bridge Replacement Program 1983 – 1989

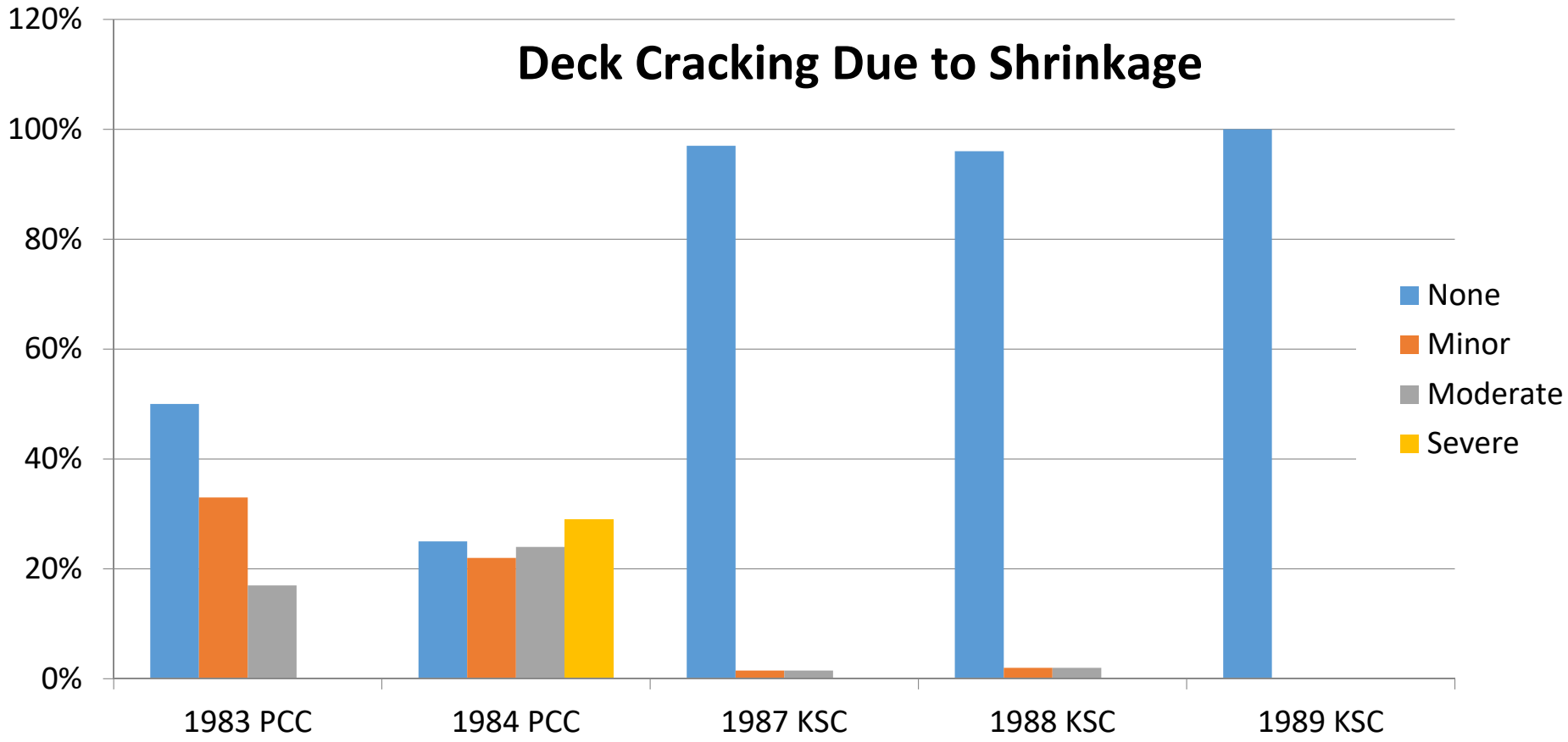
Deck Cracking Due to Drying Shrinkage						
		Degree of Cracking			% of decks with crack	
Year	None	Minor	Moderate	Severe	Total Bridges Replac	
1983	50%	33%	17%	0%	50%	PCC
	3	2	1	0	6	
1984	25%	22%	24%	29%	75%	PCC
	17	15	16	19	67	
1985	87%	10%	3%	0%	13%	KSC
	33	4	1	0	38	
1986	96%	4%			4%	KSC
	43	2			45	
1987	97%	1.5%	1.50%		3%	KSC
	72	1	1		74	
1988	96%	2%	2%		4%	KSC
	57	1	1		59	
1989	100%				0%	KSC
	53				53%	
1984	2 Bridges Used Type K Concrete no drying shrinkage					
1885 to Date	All bridge decks are specified with Type K Concrete					

1984 thru 1989
95% Crack Free

1985 thru 1989
97.8% Crack Free

Less than 3% Minor and no Moderate or Severe

Ohio Performance with Type K



Ohio Turnpike Authority

When asked the question;

“How does this effect maintenance costs?

The Answer Is Quite Simple:

- **Very Low Cost to Maintain the Actual Shrinkage Compensating Concrete Decks**
- **No Deck Delaminations, Spalls or Steel Corrosion**

Ohio Turnpike Experience

Equipment, mixes, design, conditions

- **SCC - Use Same Production, Pumping, Placing Equipment**
- **Water Cement Ratio Required .44 to .55**
  - **(5 to 6” Slump) No Bleed - No Water of Convenience**
- **Can Use Traditional Design and Reinforcing**
- **Can Place Outside and During Daylight**
- **Same Hot or Cold Weather Practices as PCC**

Myths Than Can Be Dismissed

- **ASTM C-845 Type K Cement Concrete is Not New in Bridge Design**
  - **In Ohio Since 1968**
  - **Type K Cement Listed in FHWA**
  - **Established - Lowers Permeability and Limits Shrinkage Cracks**
  - **Over 600 Bridges in the US**

Sustainability

- **A Total of 13 LEED Point Are Available With ASTM C-845 Type K Komponent Cement**
- **Low CO_2 Output in Production**

Mixes

	30%	19%	17%	15%
PC Type I	406	470	481	493
Komponent	174	110	99	87
Total Cementitious	580	580	580	580
Rock	1776	1776	1786	1780
Sand	1377	1383	1392	1369
Water	275	275	256	287
W/C Ratio	0.5	0.5	0.5	0.5

(Lbs. per cubic yard)

Mixes

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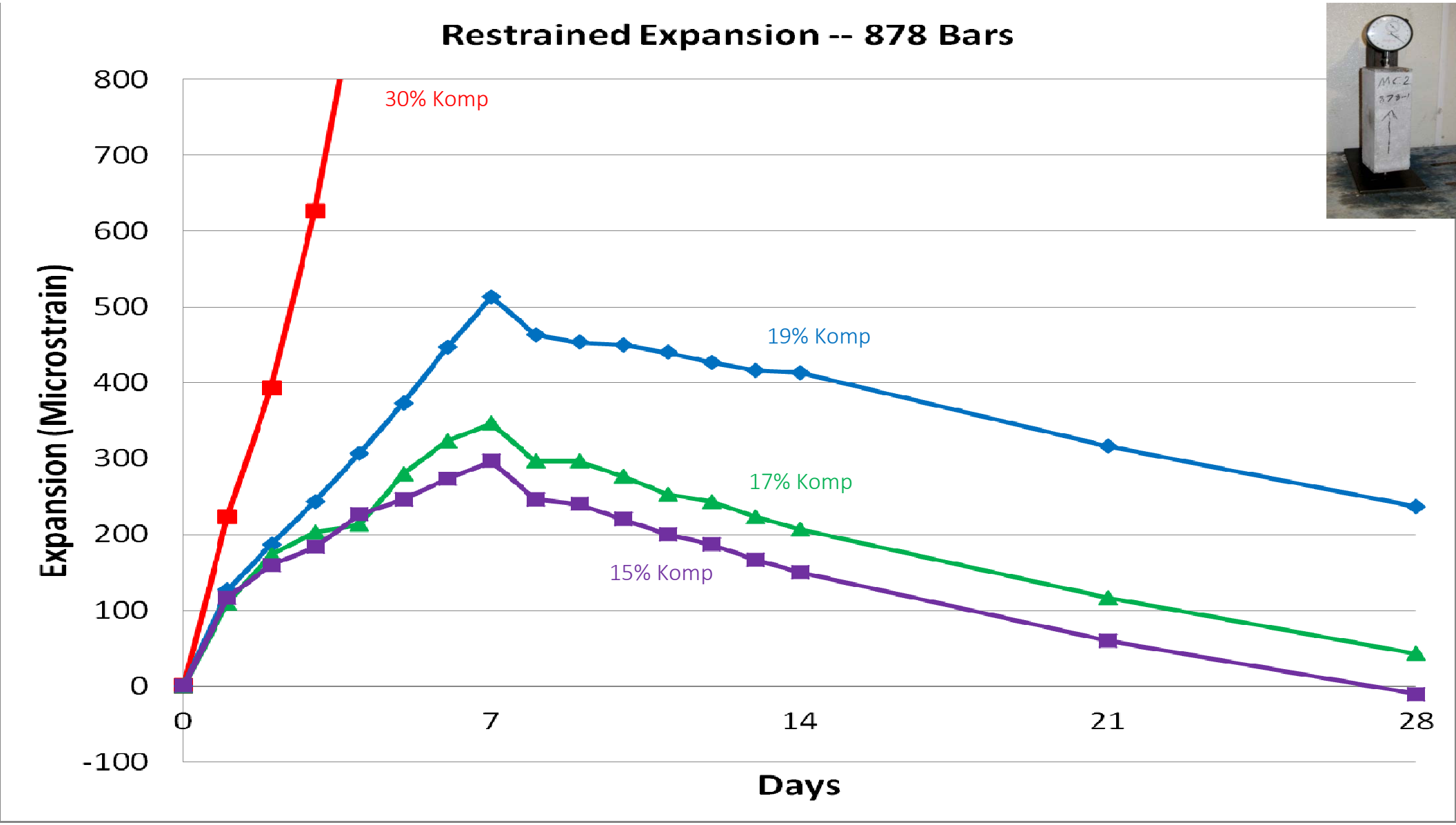
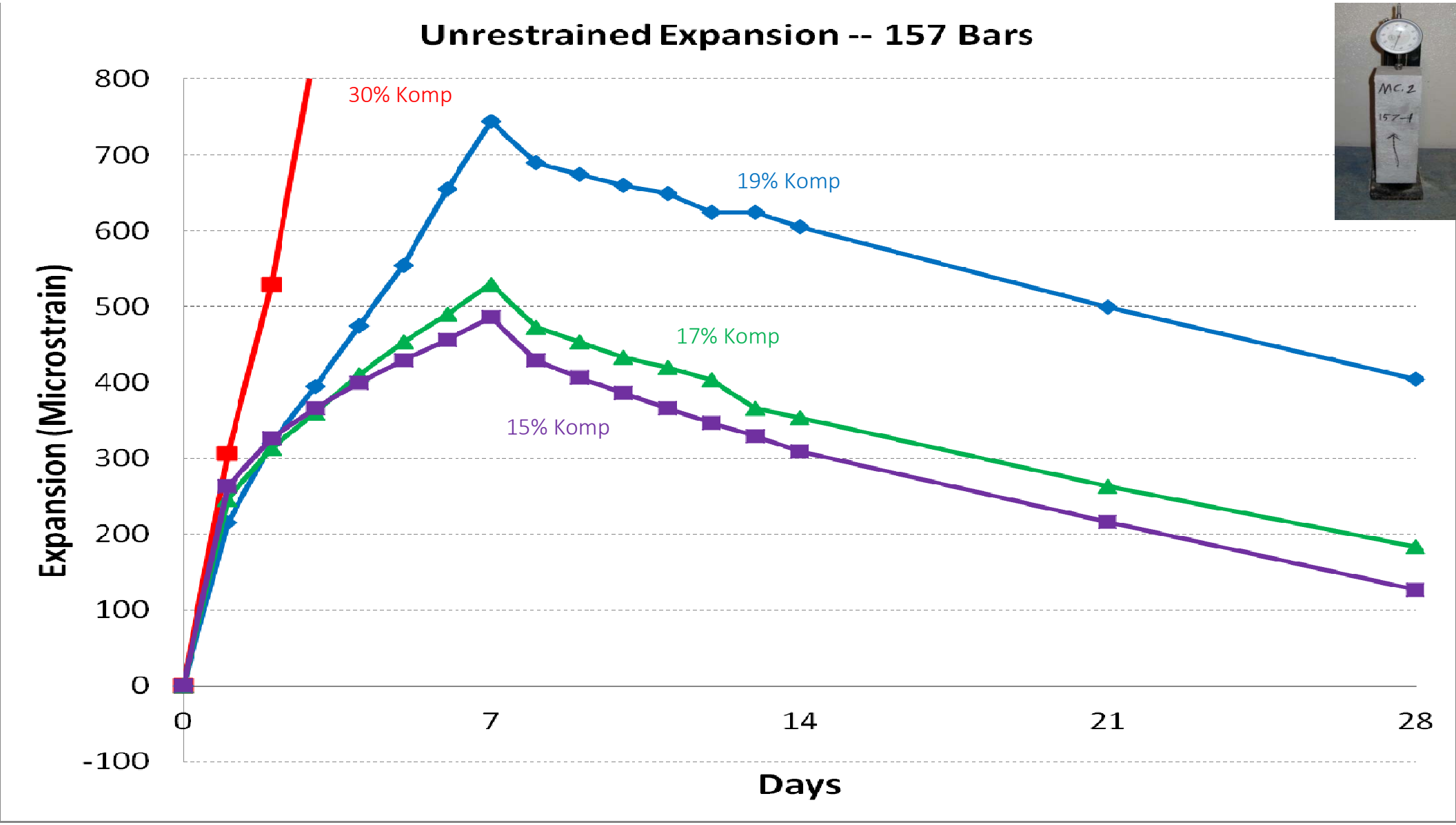

Restrained Expansion -- 878 Bars
800
700
600
500
400
300
200
100
0
-100
Expansion (Microstrain)
0
7
14
21
28
Days
30% Komp
19% Komp
17% Komp
15% Komp

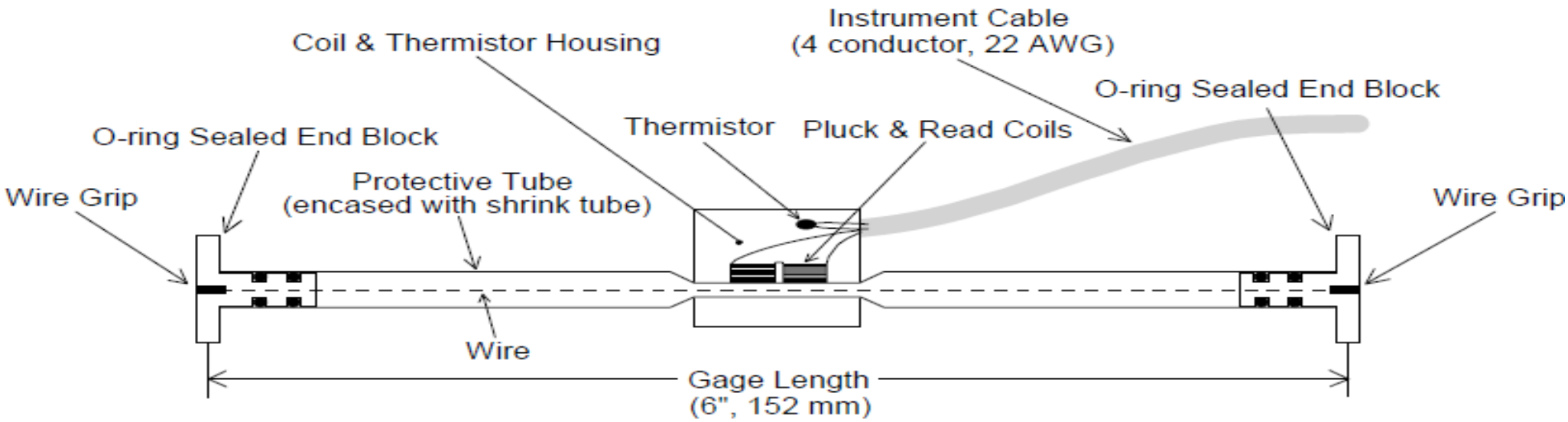

Unrestrained Expansion -- 157 Bars
800
700
600
500
400
300
200
100
0
-100
Expansion (Microstrain)
0
7
14
21
28
Days
30% Komp
19% Komp
17% Komp
15% Komp

Instrumentation

- GeoKon VWSG:

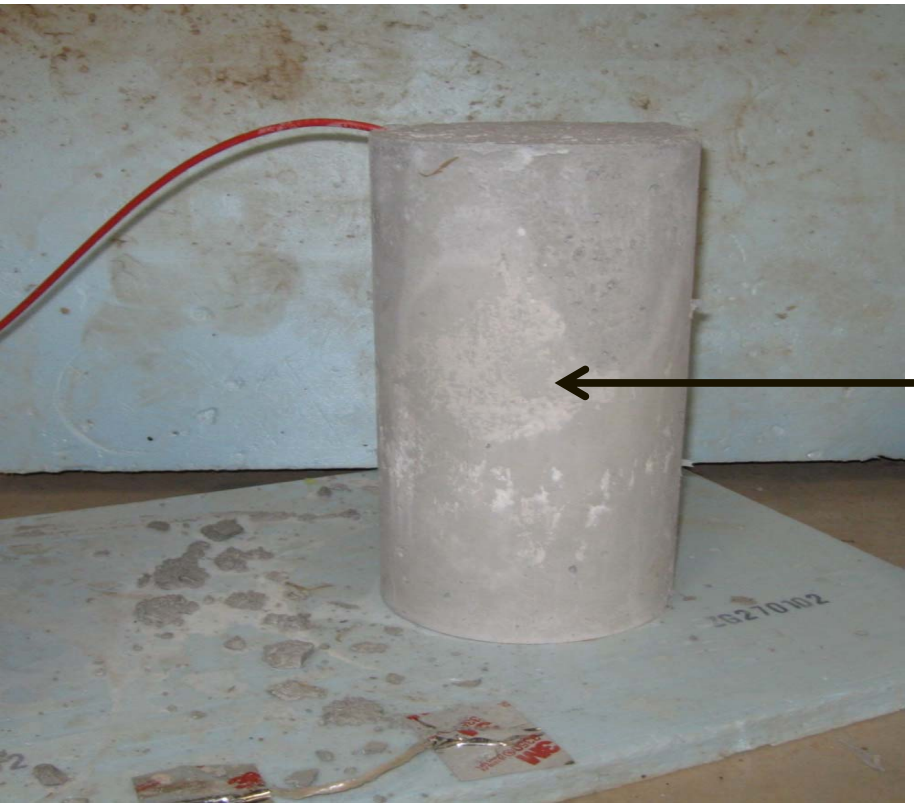
Equipment

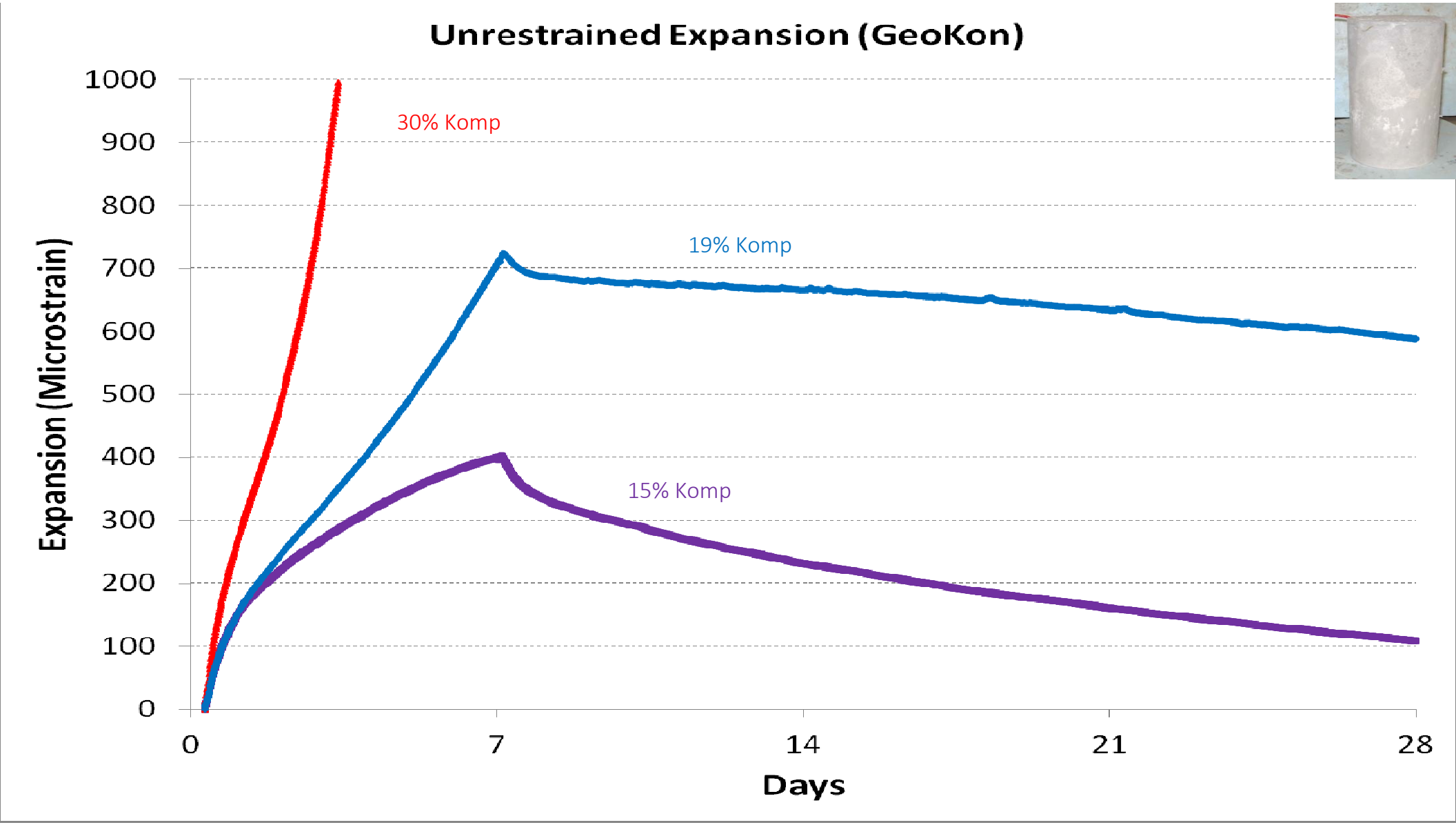
- Geokon Vibrating Wire Strain Gages
  - Model 4200 (with 100’ of cable)
    - Measures microstrains
    - Measures temperature

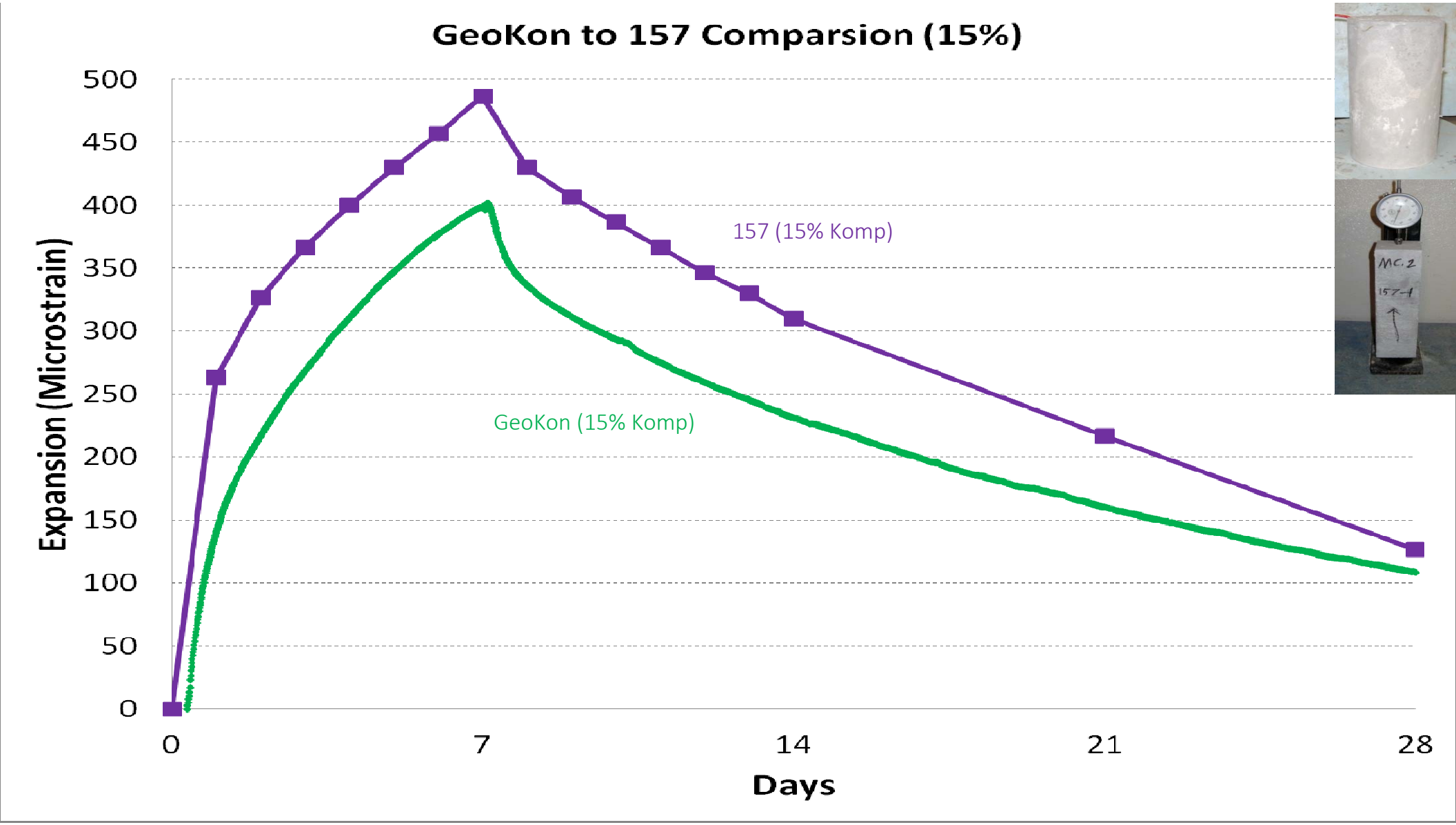


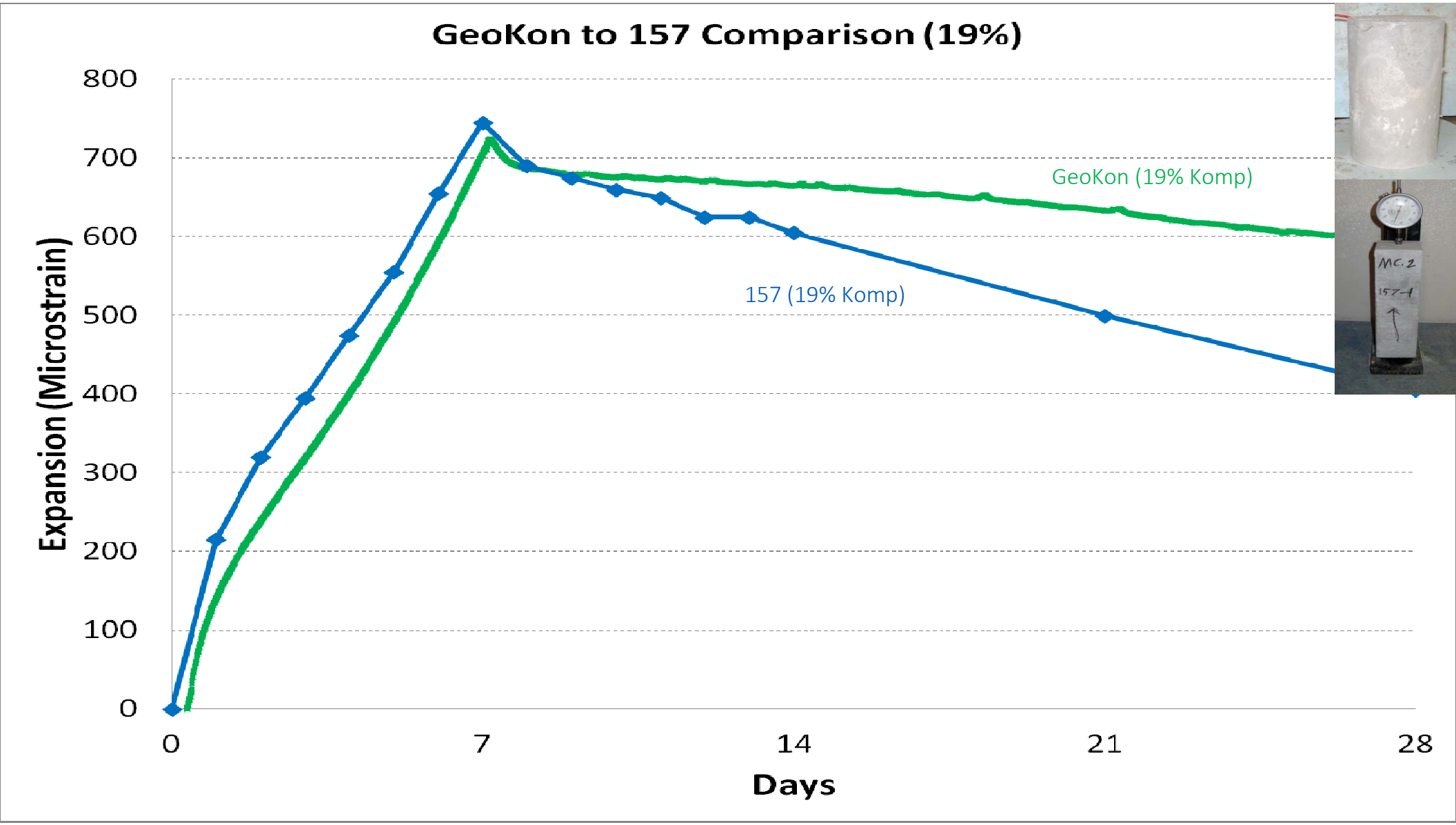
Unrestrained 6x12 Cylinder

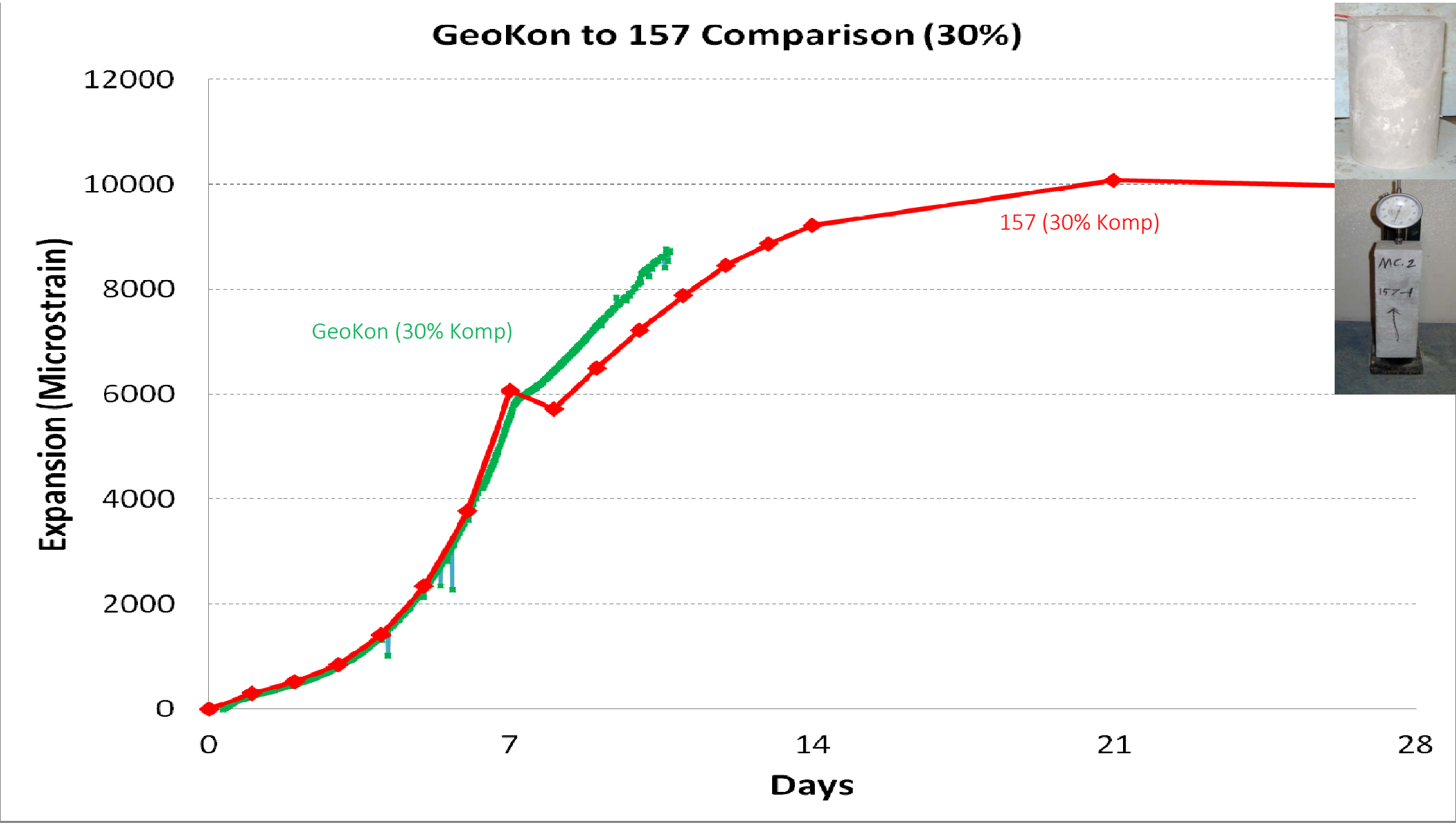
- GeoKon VWSG imbedded in center:




Unrestrained Expansion (GeoKon)
Expansion (Microstrain)
1000
900
800
700
600
500
400
300
200
100
0
30% Komp
19% Komp
15% Komp
0
7
14
21
28
Days


GeoKon to 157 Comparsion (15%)
Expansion (Microstrain)
500
450
400
350
300
250
200
150
100
50
0
0
7
14
21
28
Days
157 (15% Komp)
GeoKon (15% Komp)

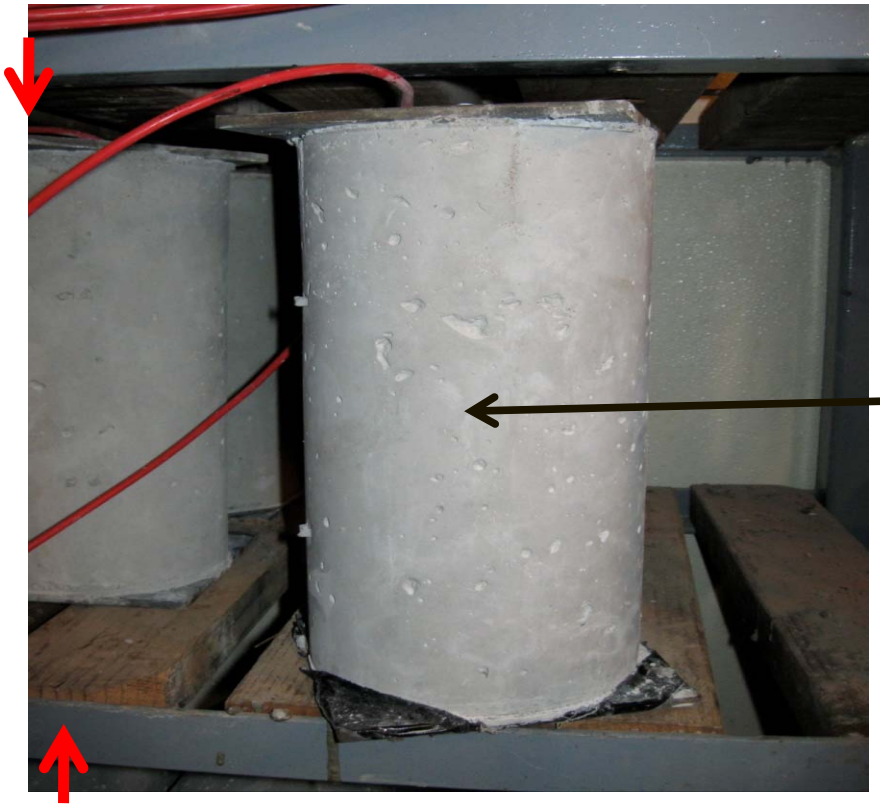

GeoKon to 157 Comparison (19%)
Expansion (Microstrain)
800
700
600
500
400
300
200
100
0
0
7
14
21
28
Days
GeoKon (19% Komp)
157 (19% Komp)

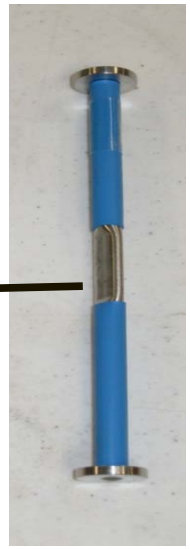

GeoKon to 157 Comparison (30%)
12000
10000
8000
6000
4000
2000
0
Expansion (Microstrain)
0
7
14
21
28
Days
GeoKon (30% Komp)
157 (30% Komp)

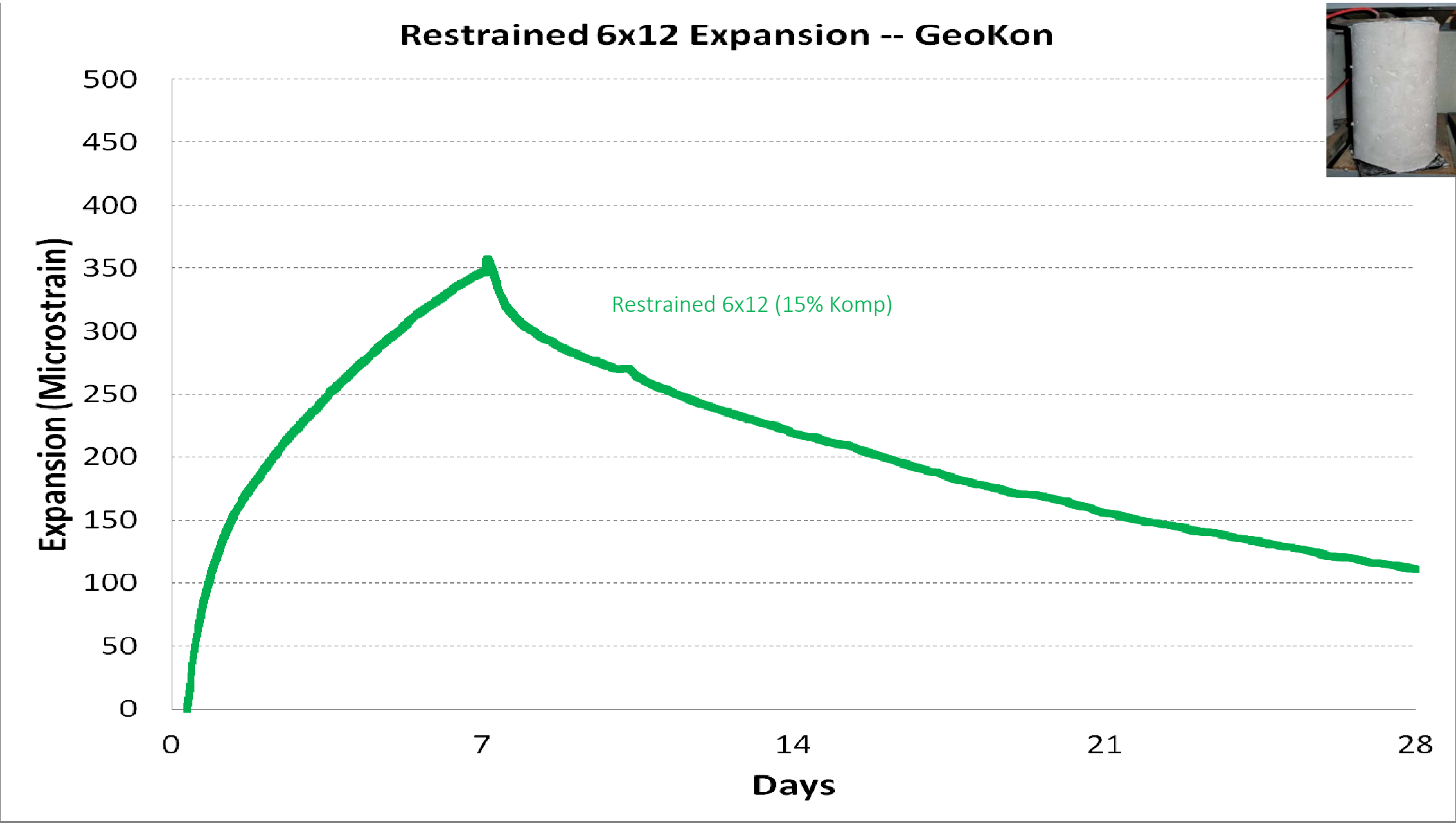
Restrained 6x12 Cylinder

- GeoKon VWSG imbedded in center:

$\rho_{cylinder} = \rho_{878} = 0.17\%$






Restrained 6x12 Expansion -- GeoKon
Expansion (Microstrain)
500
450
400
350
300
250
200
150
100
50
0
0
7
14
21
28
Days
Restrained 6x12 (15% Komp)

GeoKon to 878 Comparsion

Expansion (Microstrain)

500
450
400
350
300
250
200
150
100
50
0

Restrained 6x12 (15% Komp)

878 (15% Komp)

0
7
14
21
28

Days

Test Frames

Somat eDAQ

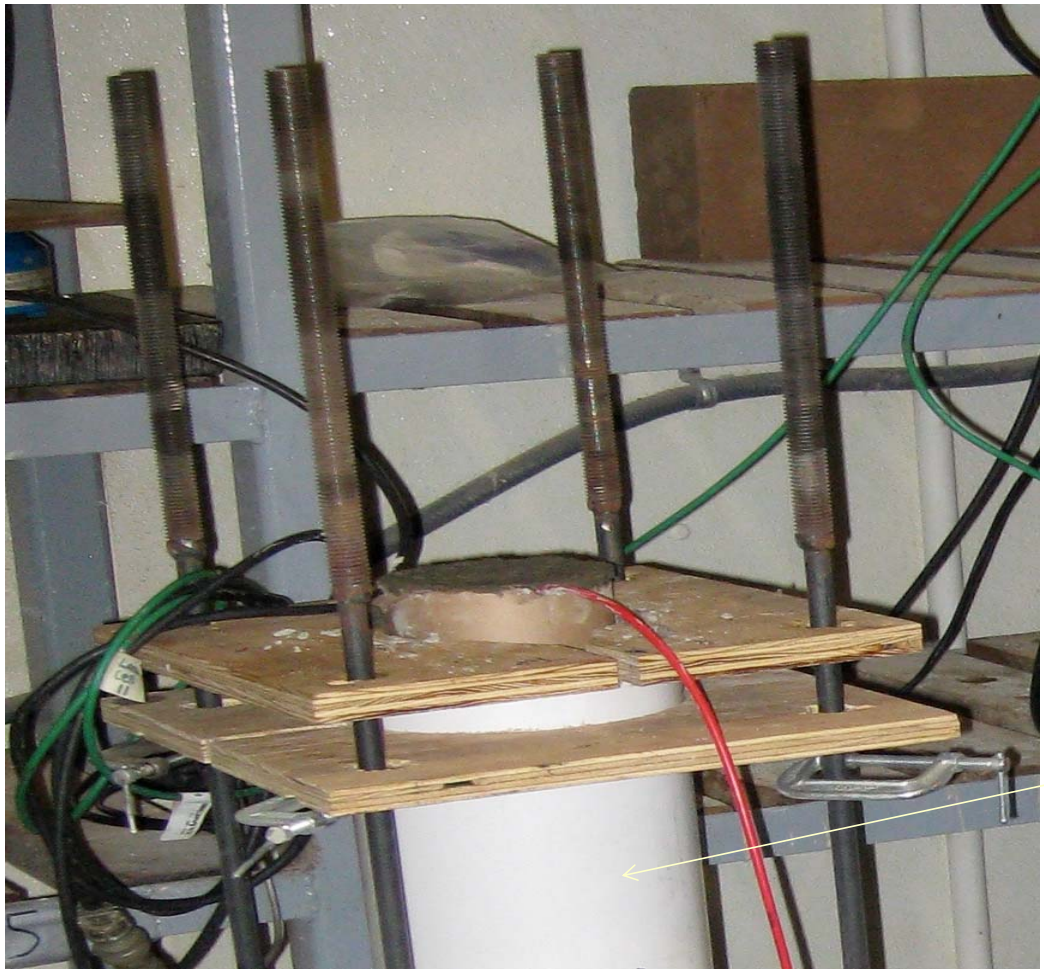
1/2” Frame

5/8” Frame

3/4” Frame

GeoKon Loggers

Wet Curing Condition



PVC Water Jacket

Wet Curing Condition

Columns Curing with PVC Water Jackets

Dry Curing Condition

Water Jackets Removed

Column Load (15%)

Load (lbs.)

3500
3000
2500
2000
1500
1000
500
0
-500

0
7
14
21
28

Days

Increase in load with
increasing rod stiffness

3/4 in.
5/8 in.
1/2 in.

Column Load (17%)
Load (lbs.)
3500
3000
2500
2000
1500
1000
500
0
-500
0
7
14
21
28
Days
1/2 in.
3/4 in.
5/8 in.

Column Load (19%)
Load (lbs.)
3500
3000
2500
2000
1500
1000
500
0
-500
0
7
14
21
28
Days
3/4 in.
1/2 in.
5/8 in.

Column Load (1/2 in. -- All Mixes)
Load (lbs.)
3500
3000
2500
2000
1500
1000
500
0
-500
0
7
14
21
28
Days
30% Komp
17% Komp
19% Komp
15% Komp

Column Expansion (15%)

Column Expansion (19%)
Expansion (Microstrain)
500
450
400
350
300
250
200
150
100
50
0
-50
-100
0
7
14
21
28
Days
3/4 in. (360 lb)
1/2 in. (392 lb)
5/8 in. (340 lb)

Column Expansion (5/8 in. -- All Mixes)

Instrumentation Conclusions

- GeoKon VWSG converges consistently with ASTM-standardized tests
- VWSG generates smoother, more complete data sets than length-comparator tests
- Overall behavior better characterized due to finer interval of readings

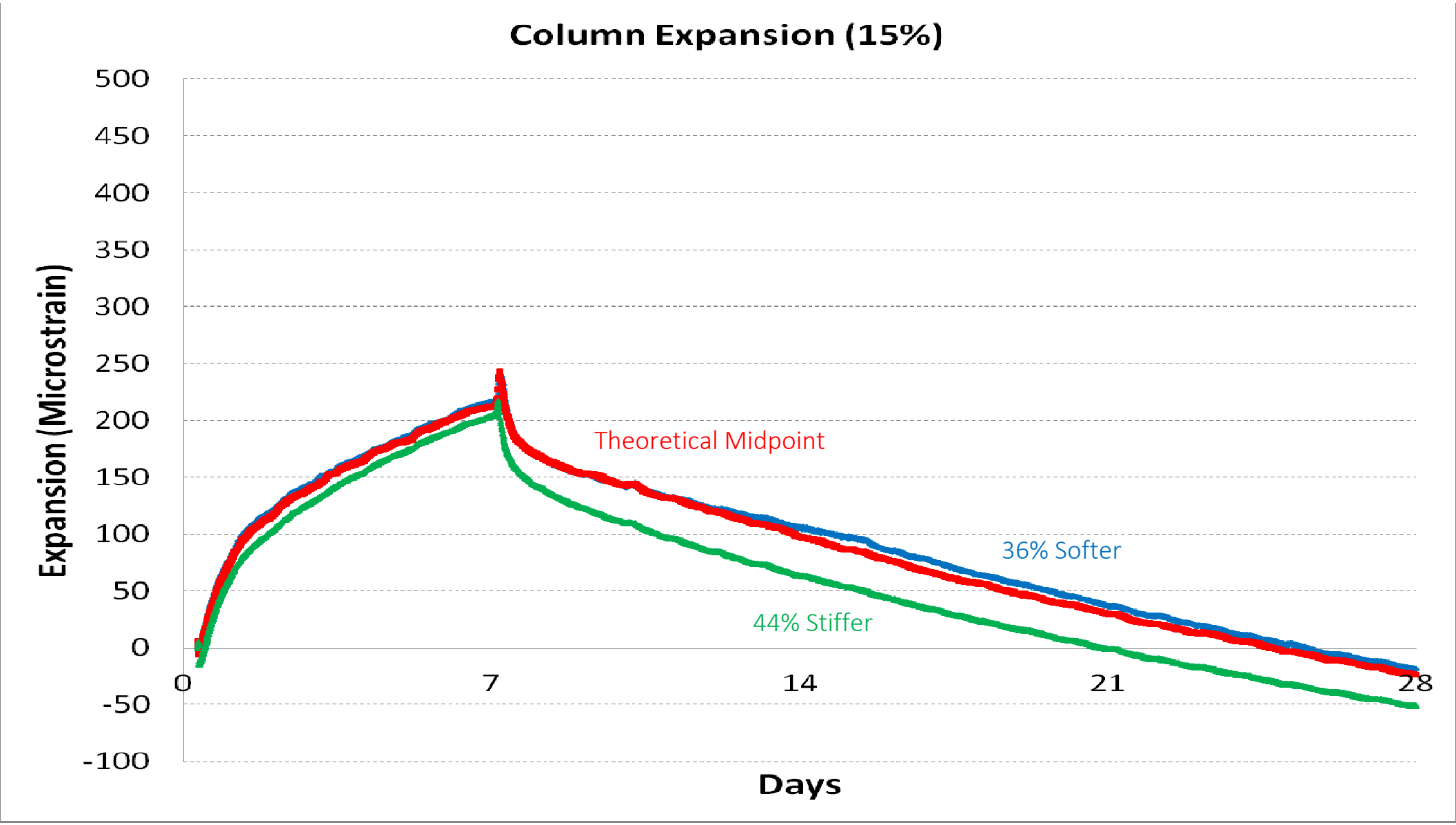
Instrumentation Conclusions

- VWSG 6x12 specimens less vulnerable to environmental variation:
  - Higher thermal mass than ASTM bar tests
  - Lower surface-area-to-volume ratio than ASTM bar tests

Material Conclusions

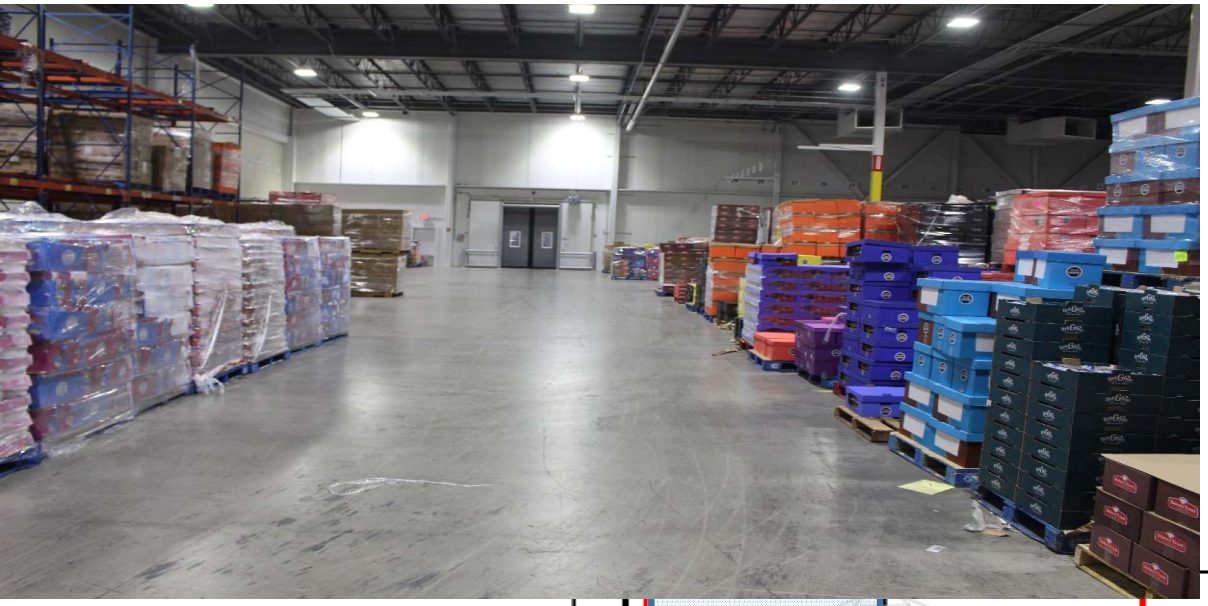
- Bracketing of stiffness problem:

Frame Size:	½”	→	5/8”	→	¾”
Stiffness Variance:		36%		44%	


Column Expansion (15%)
Expansion (Microstrain)
500
450
400
350
300
250
200
150
100
50
0
-50
-100
0
7
14
21
28
Days
Theoretical Midpoint
36% Softer
44% Stiffer

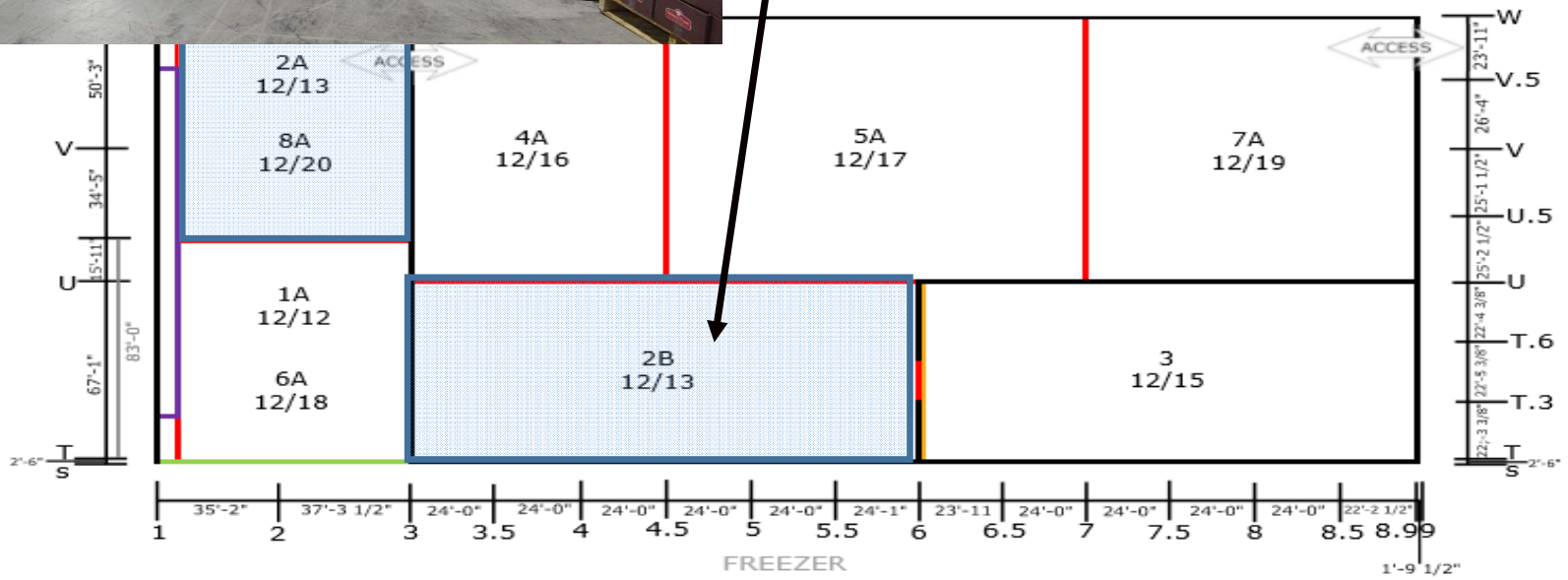
Material Conclusions

- Large increase in restraint stiffness does not cause a large gap in shrinkage compensation
  - All column expansion data sets are tightly clustered
- A very stiff boundary condition will not prevent shrinkage-compensating expansion
  - Type K shrinkage compensating concrete is not sensitive to a mature concrete boundary condition

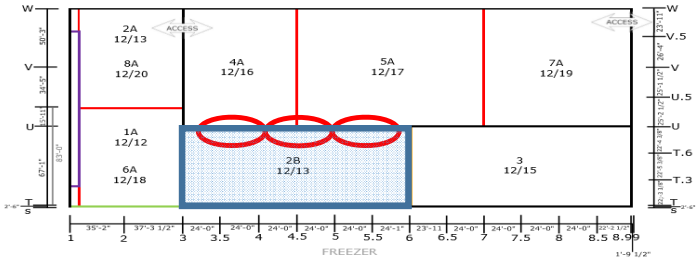


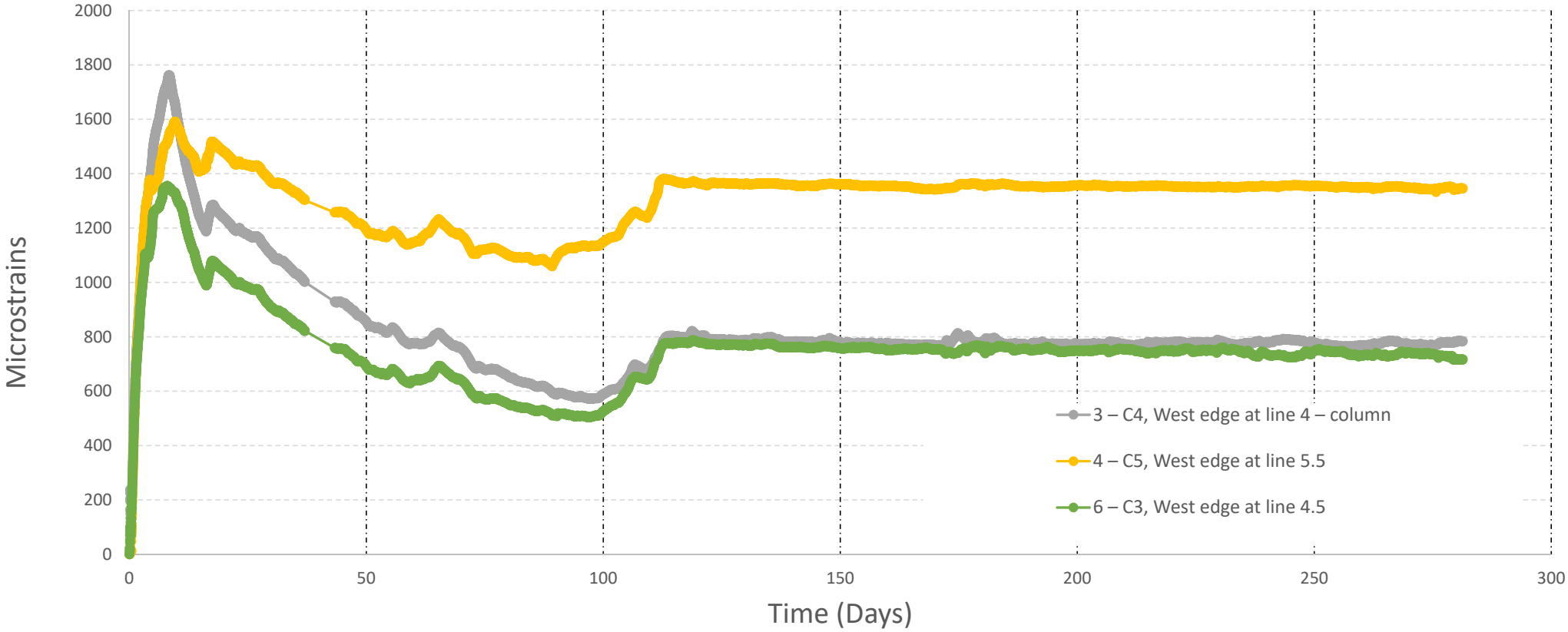
Aldi Freezer

44 m x 25 m slab



Freezer - West Edge



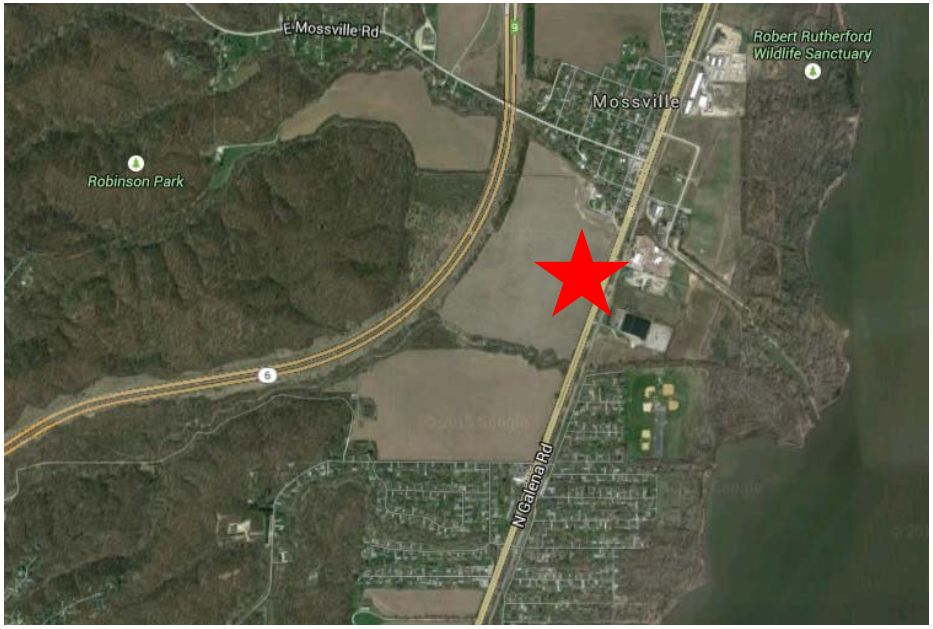


Boyd’s Hollow Bridge

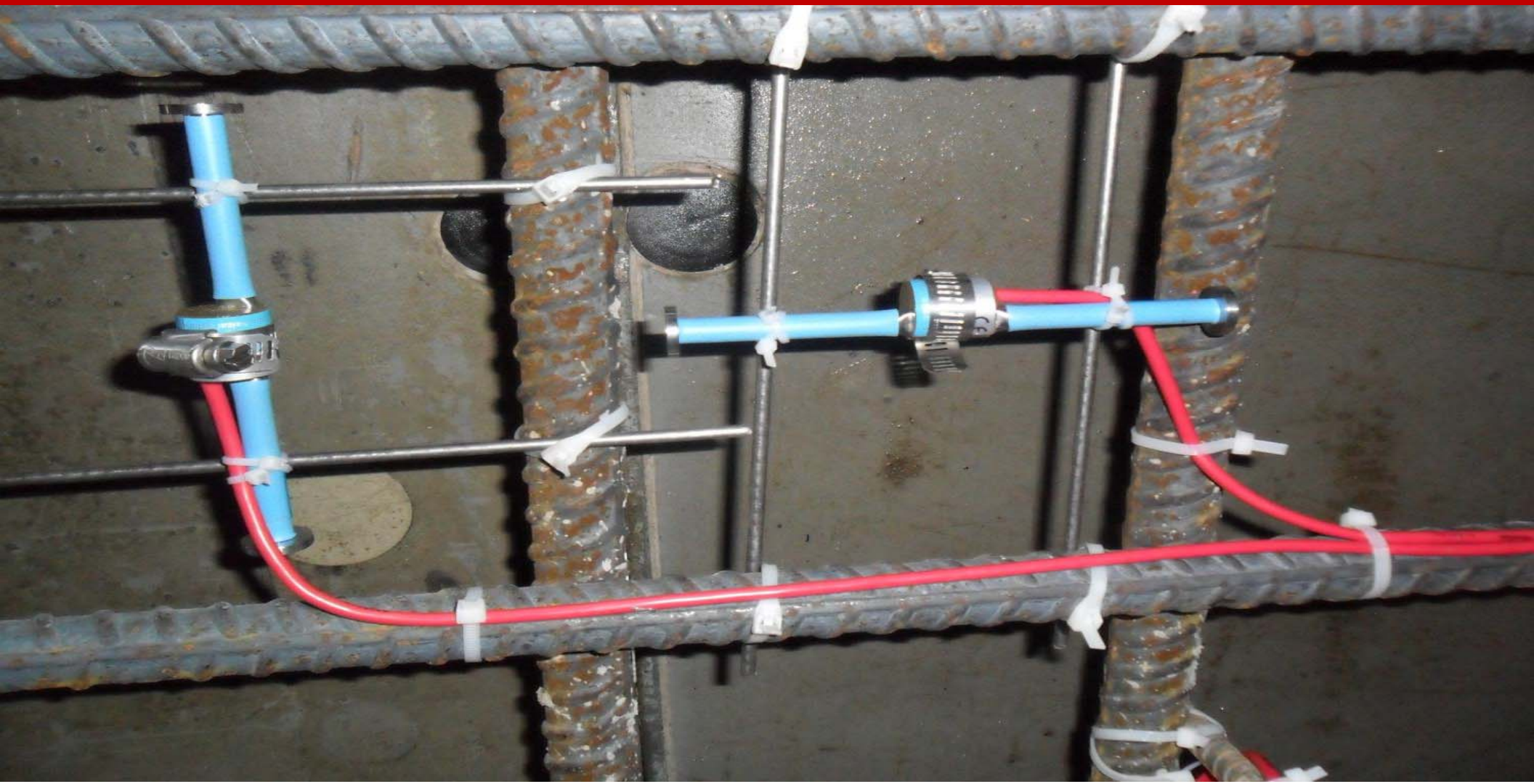
Fears Lab

Background

- 61 feet by 84 feet
- Peoria County
- Route IL 29
- Bar Spacing
  - Top Reinforcement – Longitudinal 12” Transverse 8”
  - Bottom Reinforcement – Longitudinal 11” Transverse 8”

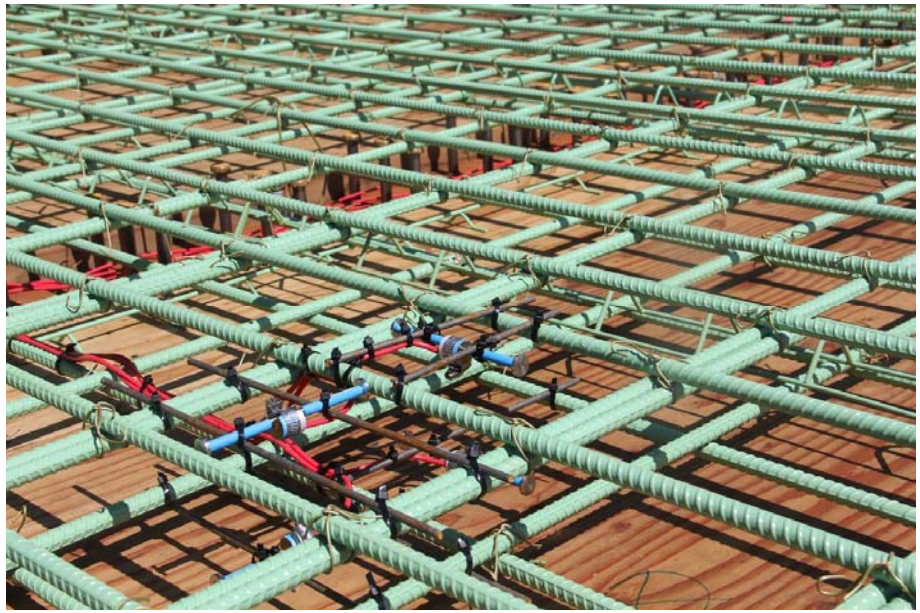


- strain gages isolated from rebar – method 1

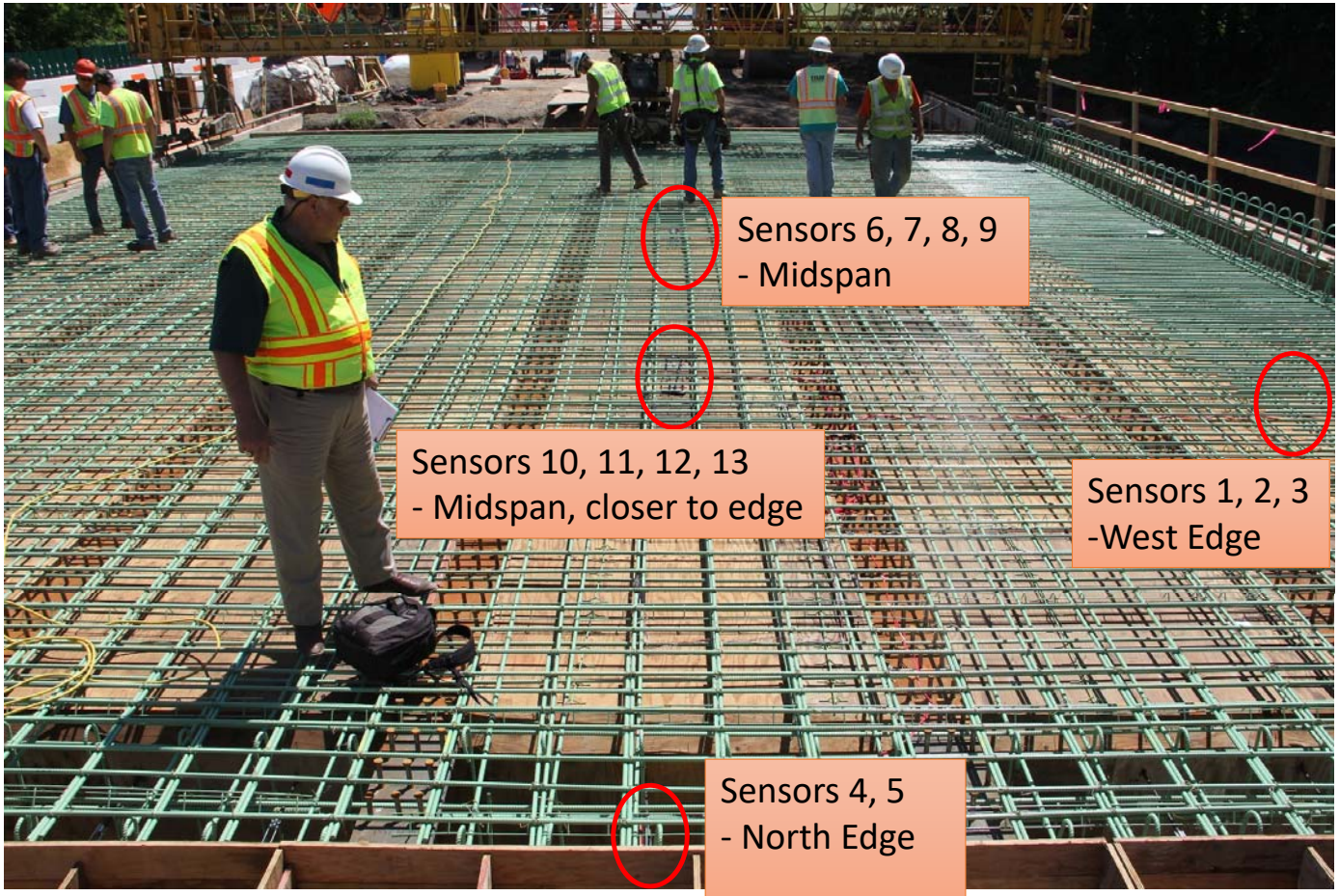


Instrumentation

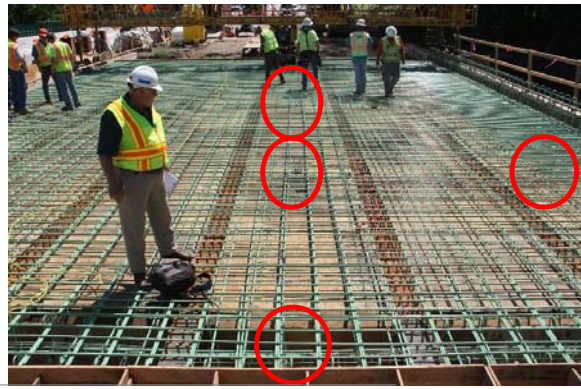
- Vibrating Wire Strain Gages
  - Total of 15

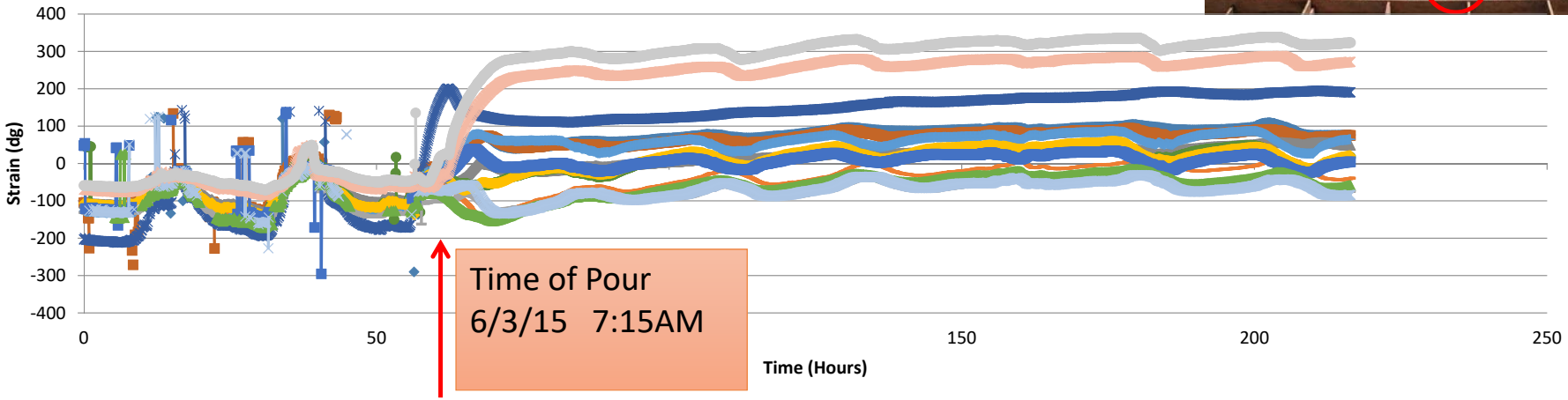


Bridge Deck Layout



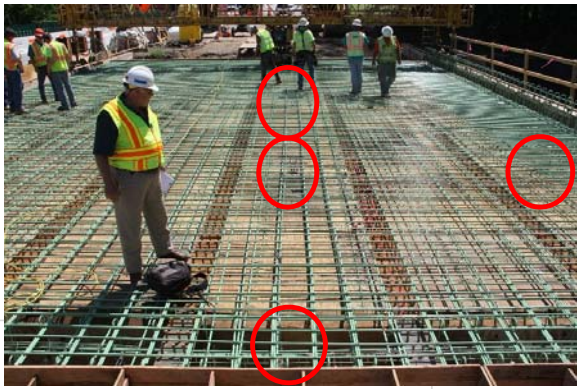
All Strain Readings-Raw Data

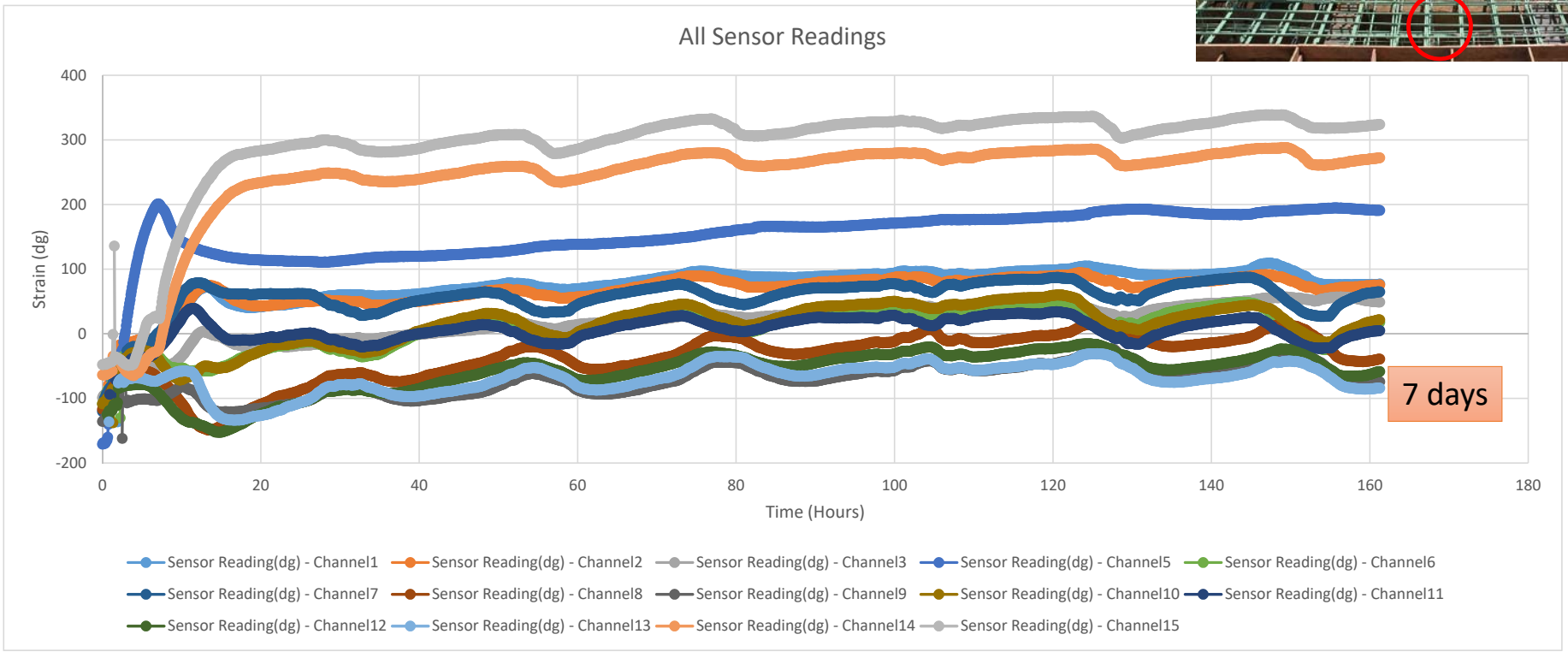




Sensor Reading(dg) - Channel1 West Edge, Transverse
Sensor Reading(dg) - Channel2 West Edge, Transverse
Sensor Reading(dg) - Channel3, West Edge, Longitudinal
Sensor Reading(dg) - Channel5, North Edge
Sensor Reading(dg) - Channel6, Midspan, Top, Longitudinal
Sensor Reading(dg) - Channel7, Midspan, Top, Transverse
Sensor Reading(dg) - Channel8, Midspan, Bottom, Longitudinal
Sensor Reading(dg) - Channel9, Midspan, Bottom, Transverse
Sensor Reading(dg) - Channel10, Midspan closer to edge, Top, Longitudinal
Sensor Reading(dg) - Channel11, Midspan closer to edge, Top, Transverse
Sensor Reading(dg) - Channel12, Midspan closer to edge, Bottom, Longitudinal
Sensor Reading(dg) - Channel13, Midspan closer to edge, Bottom, Transverse
Sensor Reading(dg) - Channel14, Cylinder
Sensor Reading(dg) - Channel15, Cylinder

All Strain Readings-Raw, Zeroed





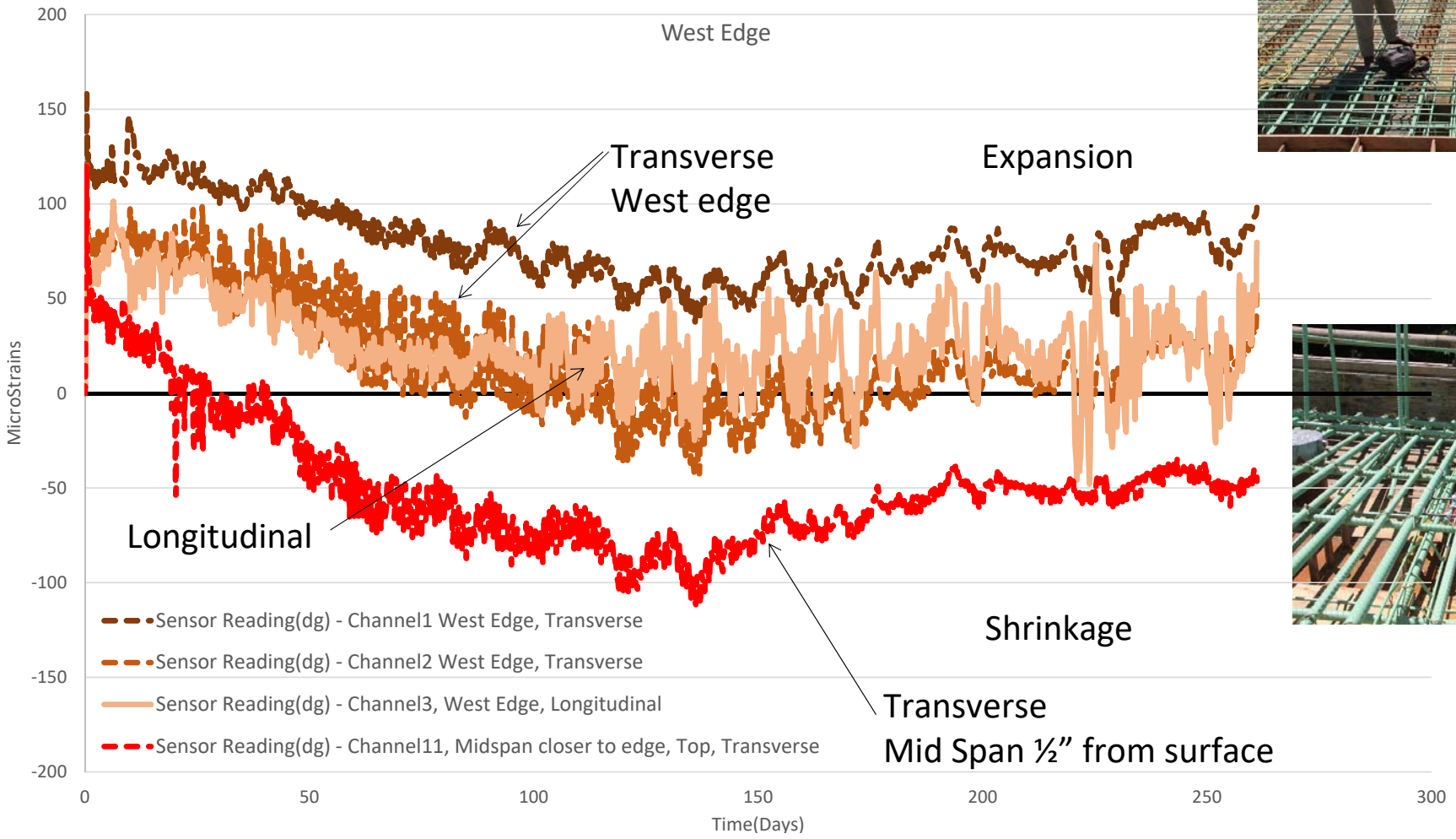
Adjustment

- All of the raw data needed to be adjusted with the thermal coefficient of Shrinkage Komp only

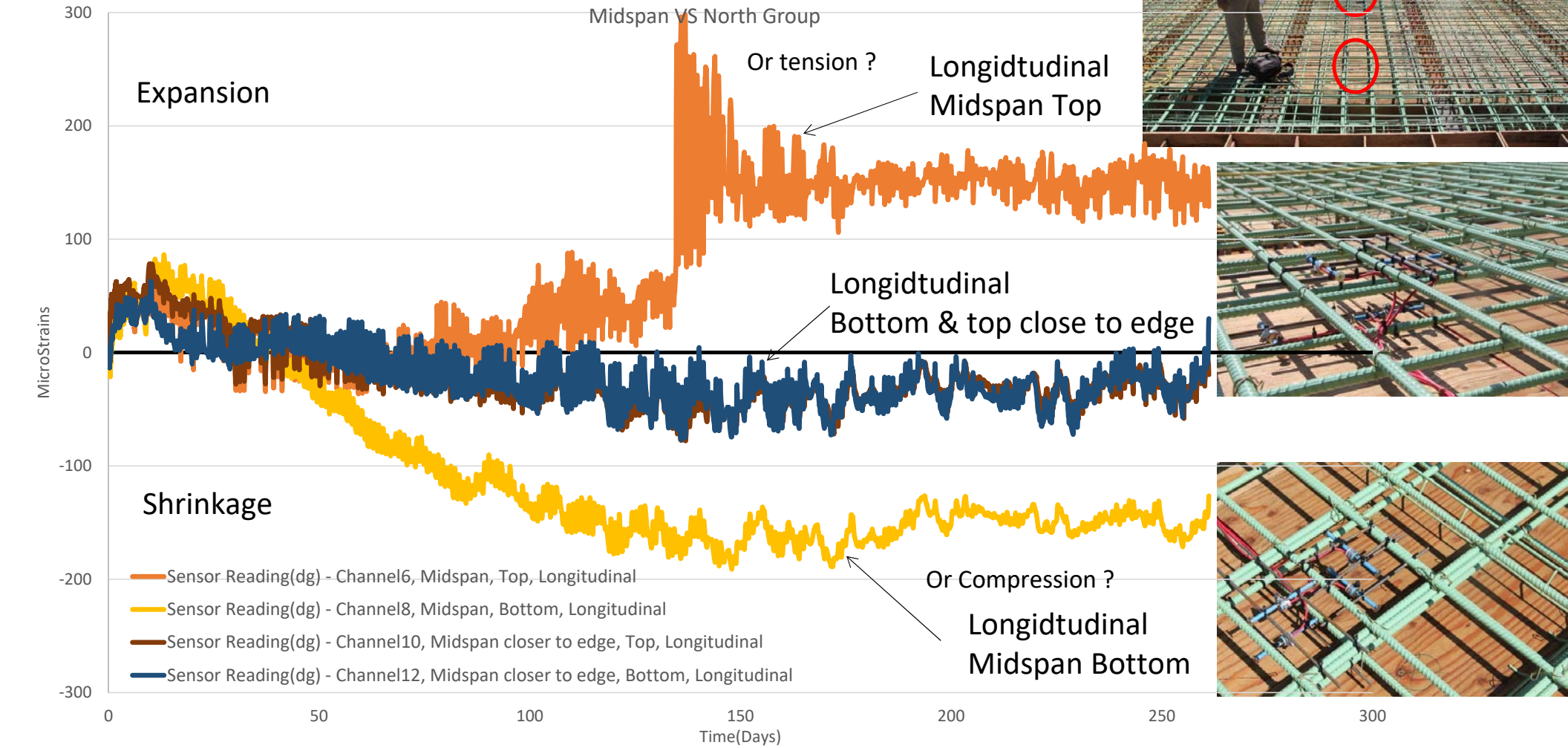
- $\mu_{load} = (R_1 - R_0)B + (T_1 - T_0)(C_1 - C_2)$

- The following slides, the graphs shown are with data adjusted

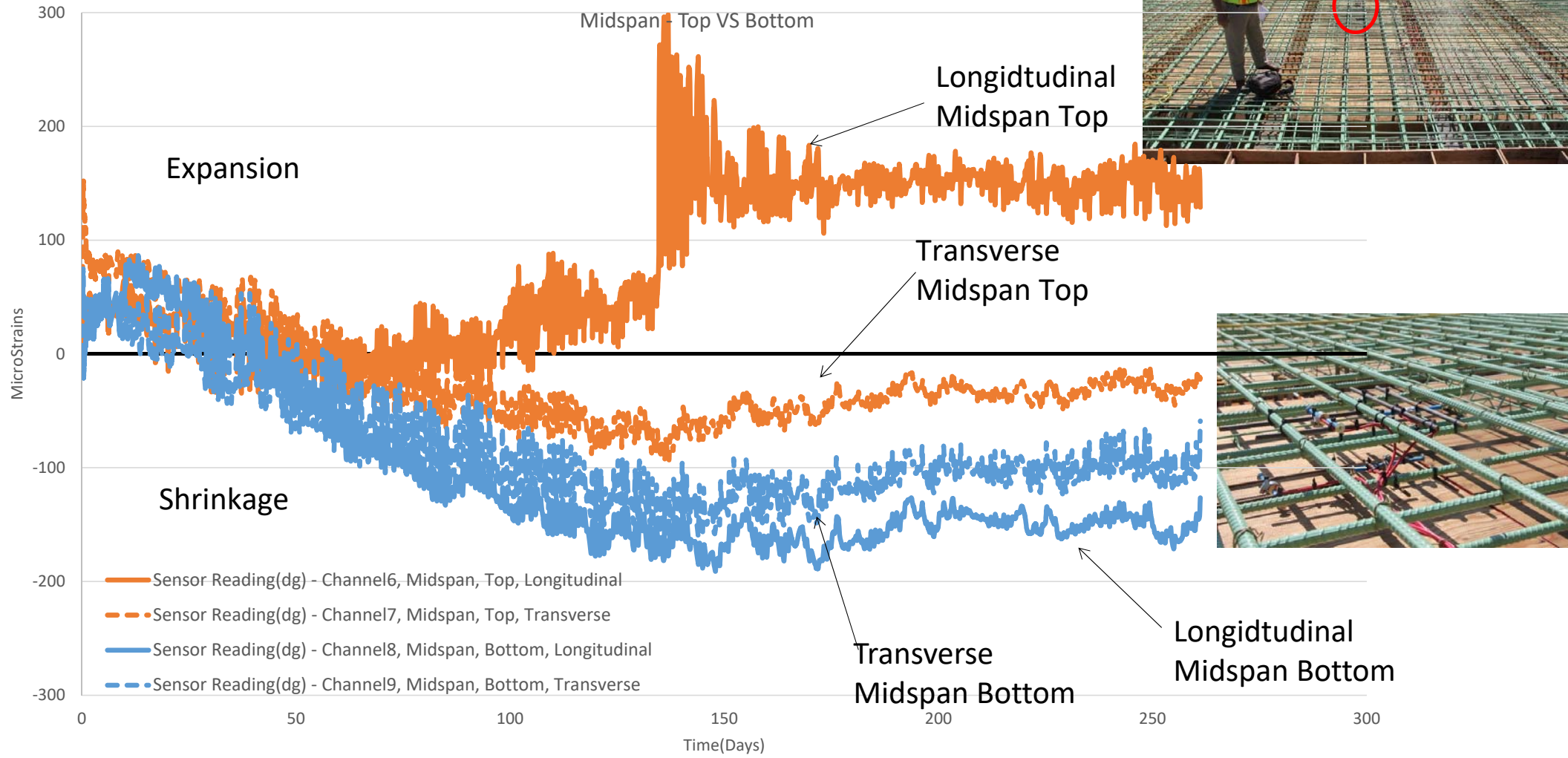
West Edge


West Edge
200
150
100
50
0
-50
-100
-150
-200
MicroStrains
0
50
100
150
200
250
300
Time(Days)
Transverse
West edge
Expansion
Longitudinal
Shrinkage
Transverse
Mid Span ½" from surface
Sensor Reading(dg) - Channel1 West Edge, Transverse
Sensor Reading(dg) - Channel2 West Edge, Transverse
Sensor Reading(dg) - Channel3, West Edge, Longitudinal
Sensor Reading(dg) - Channel11, Midspan closer to edge, Top, Transverse

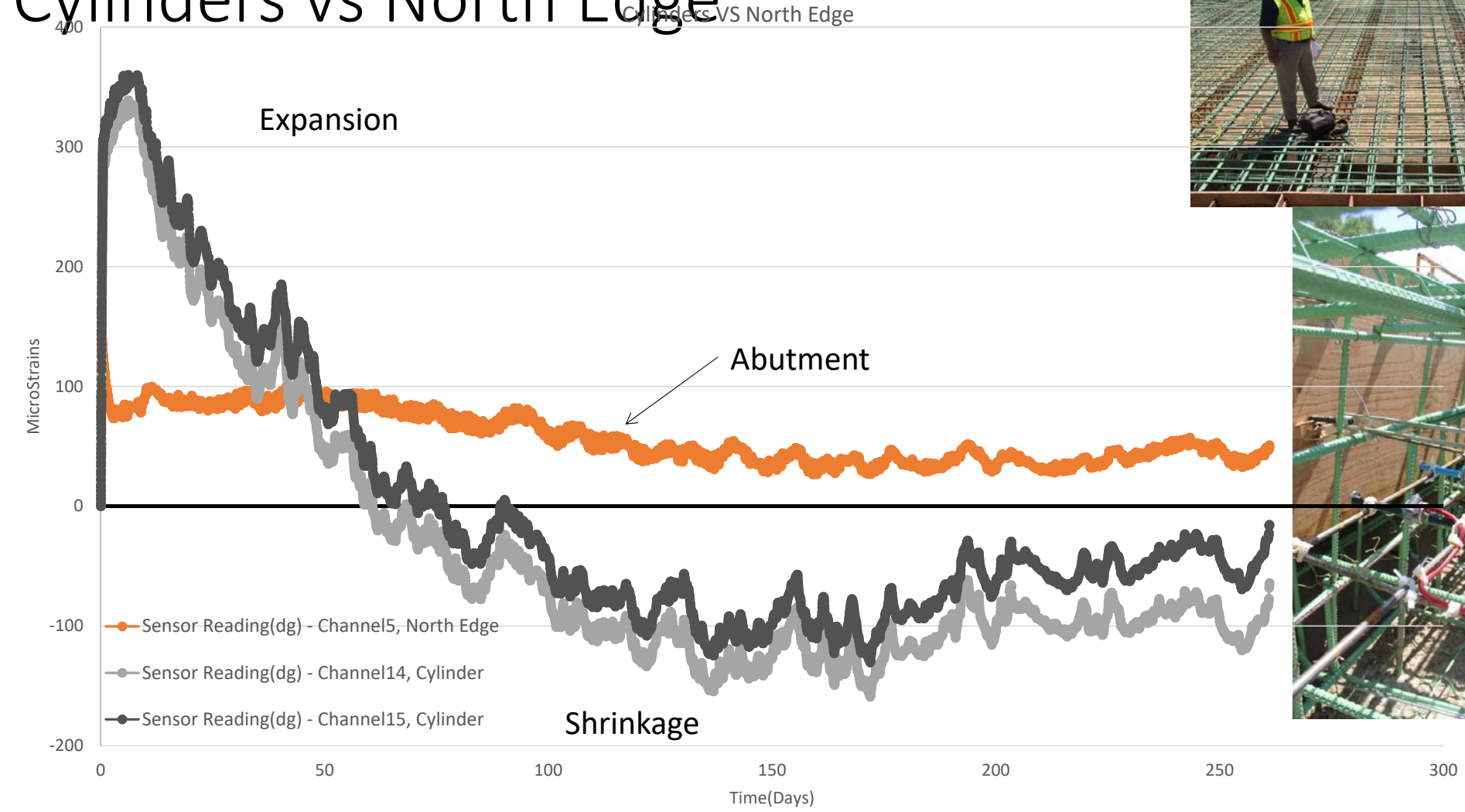
Midspan vs North Group

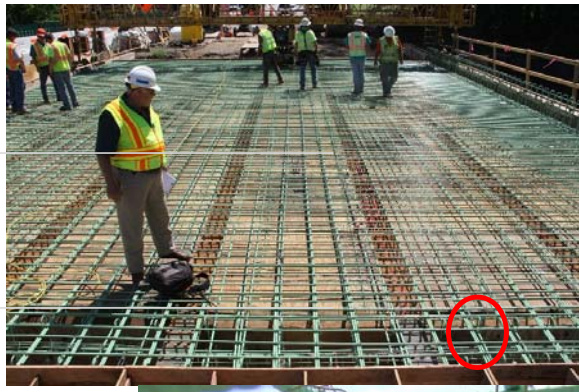


Midspan – Top vs Bottom



Cylinders vs North Edge





Conclusion

- More restraint causes less expansion/shrinkage
- Longitudinal sensors expanded less than the transverse sensors.
  - Possibly due to transverse steel more tightly spaced than longitudinal steel.
- Top bar sensors expanded more than bottom sensors.
  - Possibly due to top concrete having more access to water during curing stage.
- Based on the strain readings in the top and bottom sensors, it was found that the entire slab is experiencing flexure.

Questions?

Concrete Mix Design
Phase III

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

Materials (per cubic yard)	SRA#1	SRA#2	PCC	HPC	CTS Shrinkage Compensating	
					#1	#2
Komp I	-	-	-	-	120	120
PC	356	355	355	543	370	370
Flyash	88	88	88	180	-	-
Rapid Set Cement	-	-	-	-	-	-
Citric Acid	-	-	-	-	-	-
Course Aggregate 57	1850	1850	1850	1850	1750	1750
Sand	1463	1463	1463	1196	1315	1315
Water	266	266	266	264	269.5	271.5
MR (Polyheed (oz))	-	-	-	-	17.3	17.5
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

Concrete Mix Designs

PCC with Shrinkage Reducing Admixtures

Materials (per cubic yard)	SRA#1	SRA#2	PCC	HPC	CTS Shrinkage Compensating	
					#1	#2
Komp I	-	-	-	-	120	120
PC	356	355	355	543	370	370
Flyash	88	88	88	180	-	-
Rapid Set Cement	-	-	-	-	-	-
Citric Acid	-	-	-	-	-	-
Course Aggregate 57	1850	1850	1850	1850	1750	1750
Sand	1463	1463	1463	1196	1315	1315
Water	266	266	266	264	269.5	271.5
MR (Polyheed (oz))	-	-	-	-	17.3	17.5
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

Concrete Mix Designs

PCC and HPC

Materials (per cubic yard)	SRA#1	SRA#2	PCC	HPC	CTS Shrinkage Compensating	
					#1	#2
Komp I	-	-	-	-	120	120
PC	356	355	355	543	370	370
Flyash	88	88	88	180	-	-
Rapid Set Cement	-	-	-	-	-	-
Citric Acid	-	-	-	-	-	-
Course Aggregate 57	1850	1850	1850	1850	1750	1750
Sand	1463	1463	1463	1196	1315	1315
Water	266	266	266	264	269.5	271.5
MR (Polyheed (oz))	-	-	-	-	17.3	17.5
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

Concrete Mix Designs

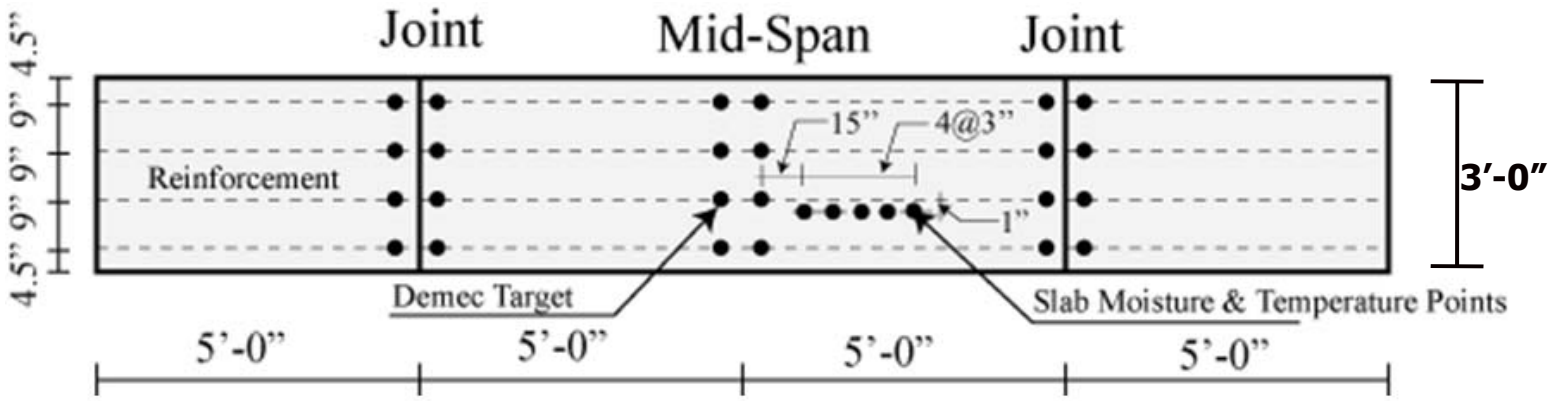
Type K Shrinkage Compensating Cement

Materials (per cubic yard)	SRA#1	SRA#2	PCC	HPC	CTS Shrinkage Compensating	
					#1	#2
Komp I	-	-	-	-	120	120
PC	356	355	355	543	370	370
Flyash	88	88	88	180	-	-
Rapid Set Cement	-	-	-	-	-	-
Citric Acid	-	-	-	-	-	-
Course Aggregate 57	1850	1850	1850	1850	1750	1750
Sand	1463	1463	1463	1196	1315	1315
Water	266	266	266	264	269.5	271.5
MR (Polyheed (oz))	-	-	-	-	17.3	17.5
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

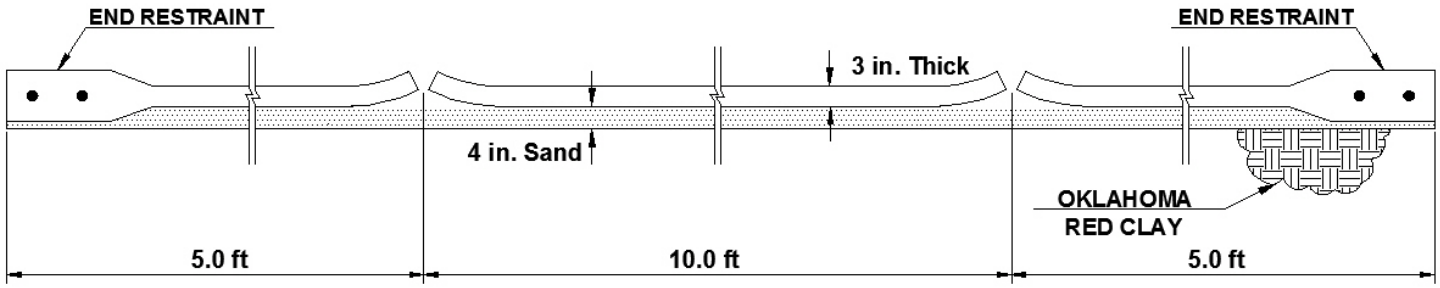
Slab Specimens Located on Grade

(Top surface exposed to the Controlled Environment)

Slab Plan View

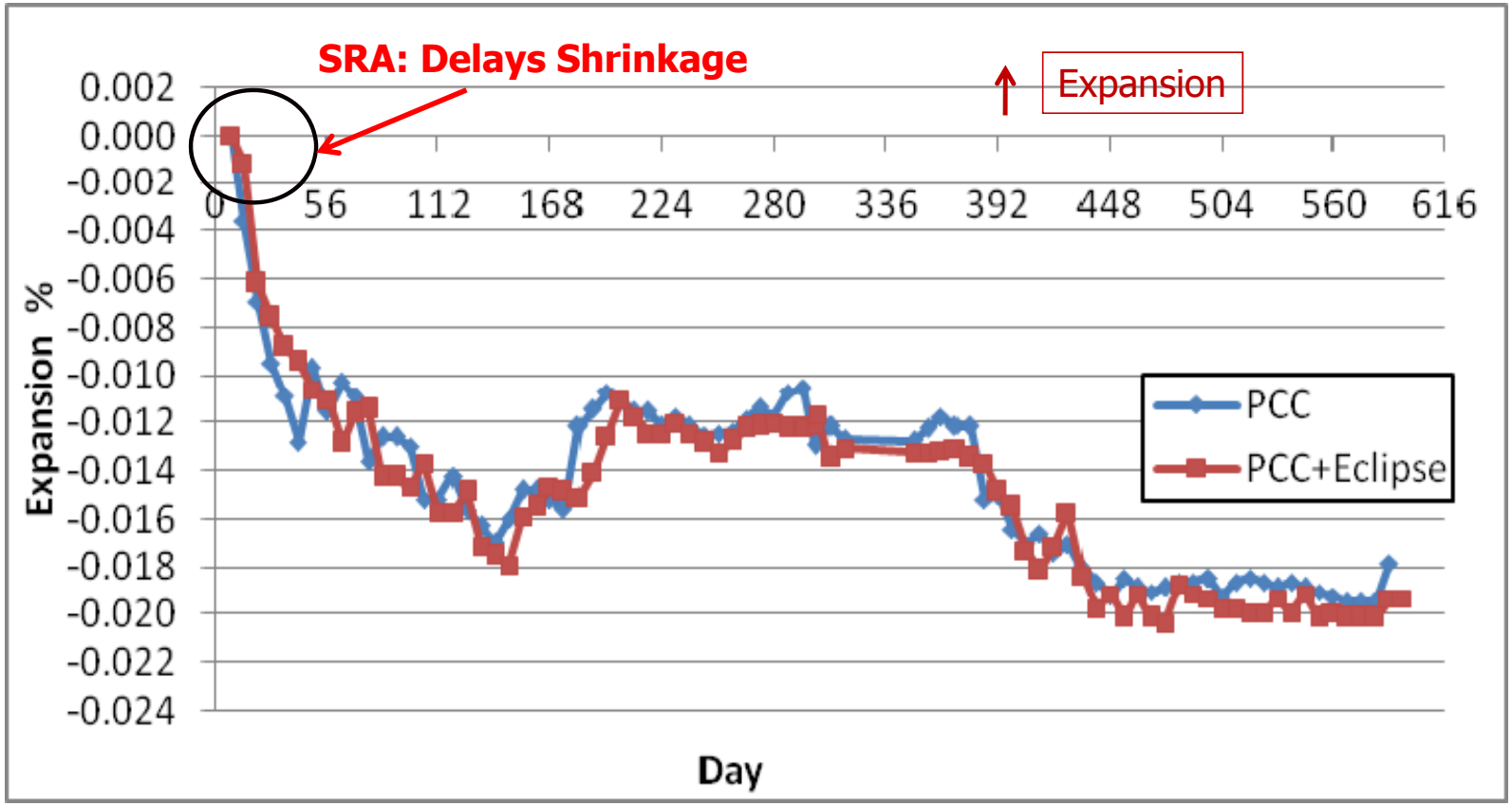


Profile of Slab Deformation Due to Warping



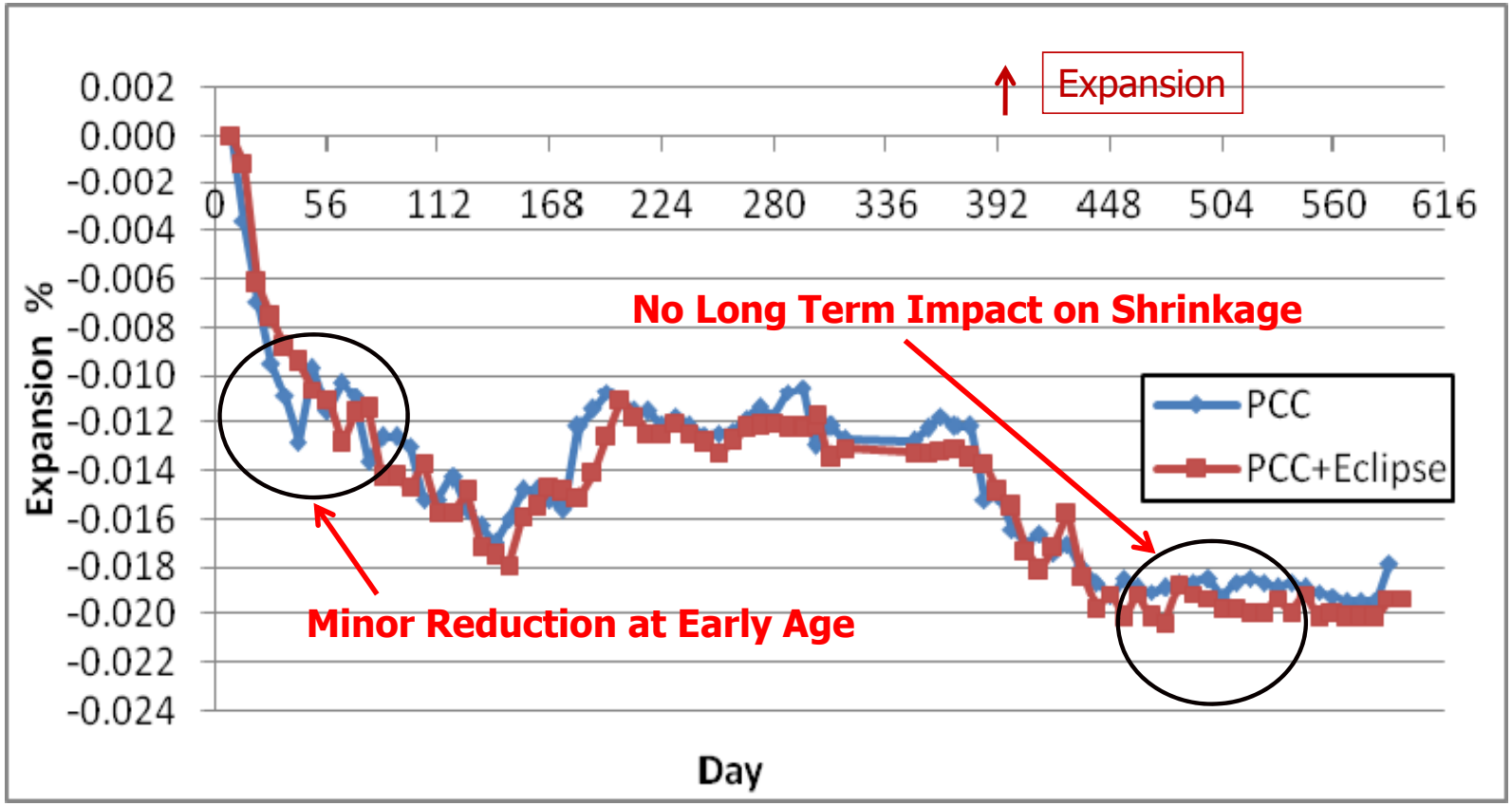
SLAB TEST RESULTS

Shrinkage of PCC vs. Eclipse (SRA) (Mid-Span)



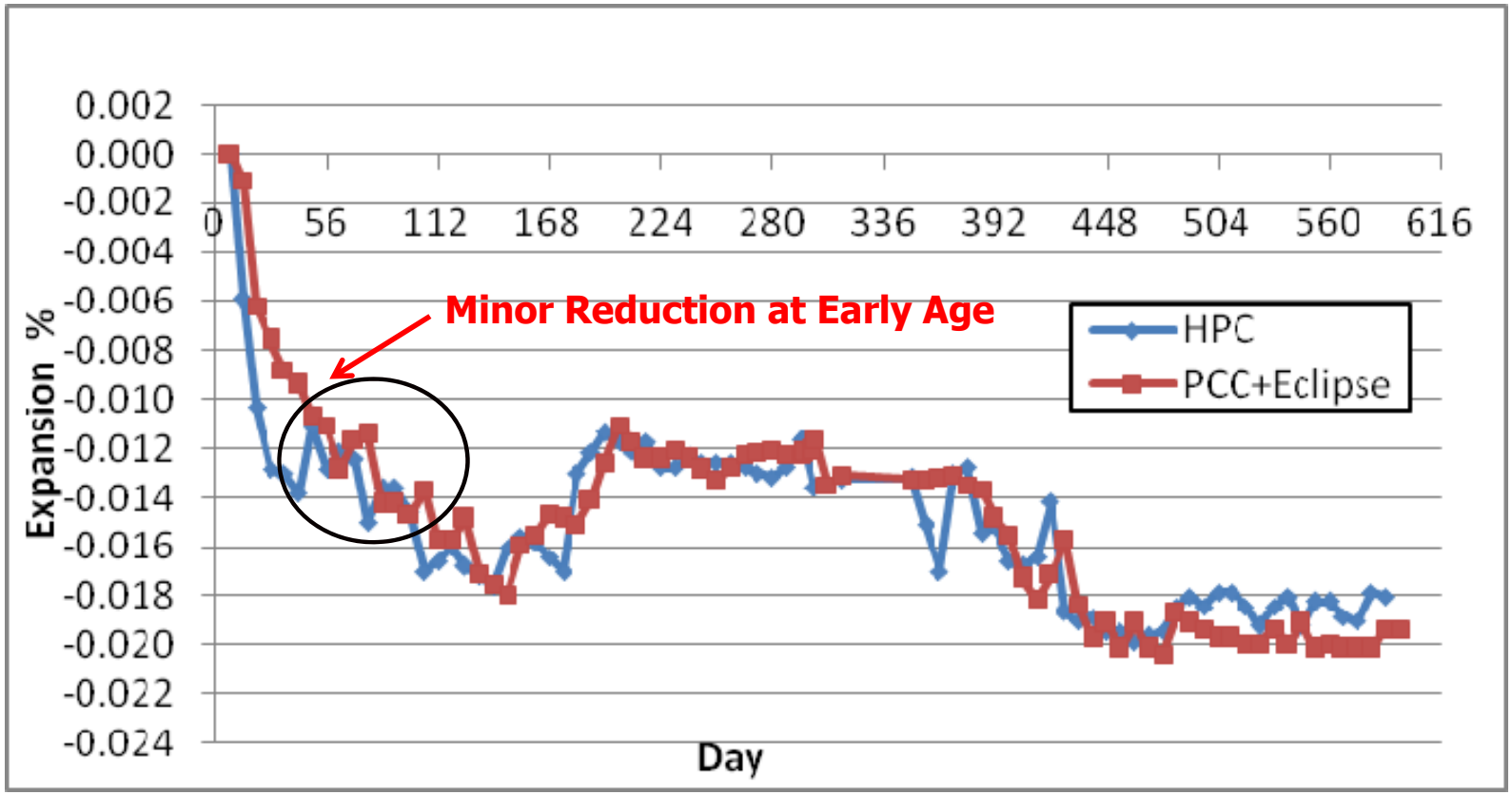
SLAB TEST RESULTS

Shrinkage of PCC vs. Eclipse (SRA) (Mid-Span)



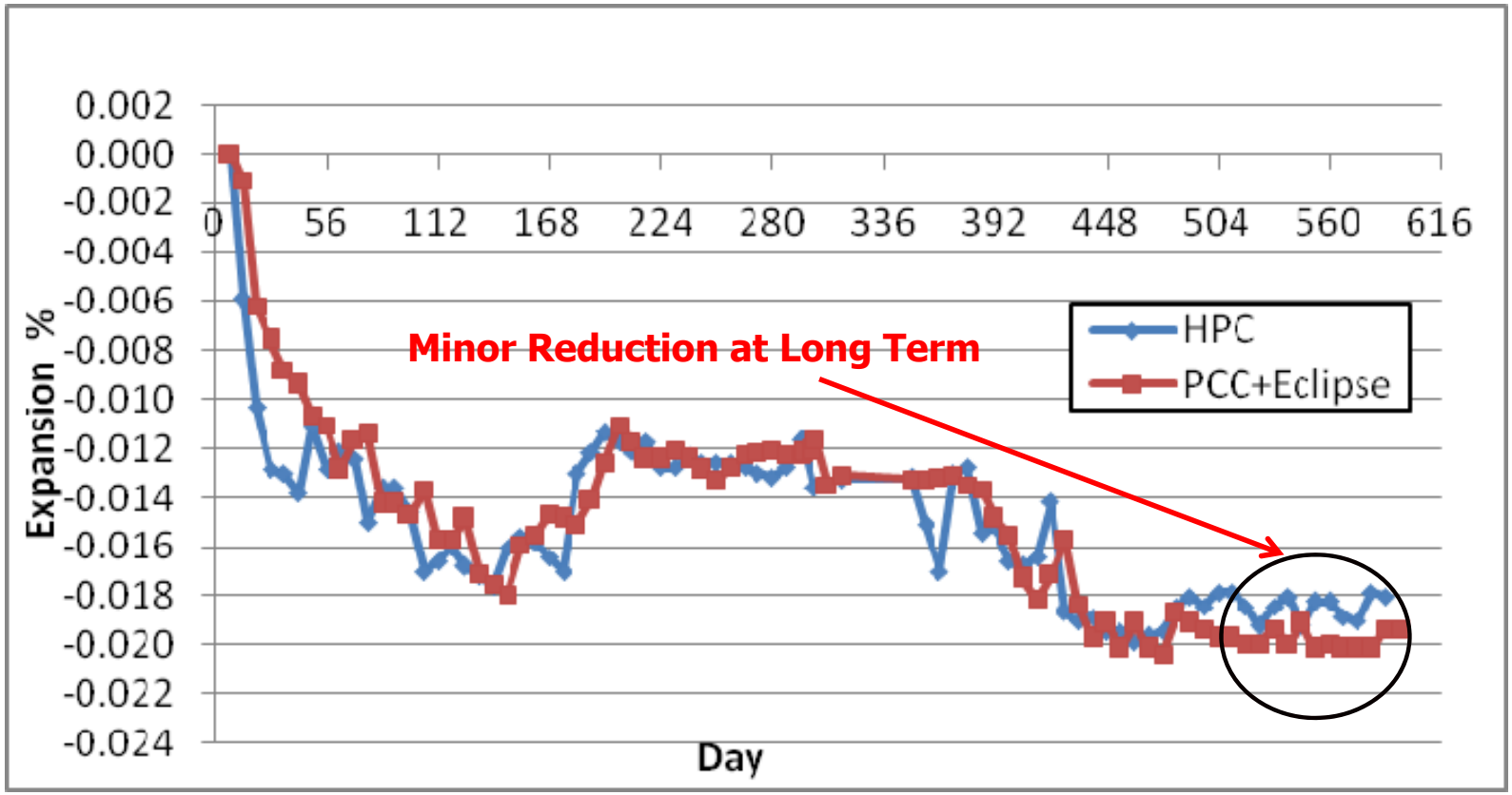
SLAB TEST RESULTS

Shrinkage of HPC vs. Eclipse (SRA) (Mid-Span)



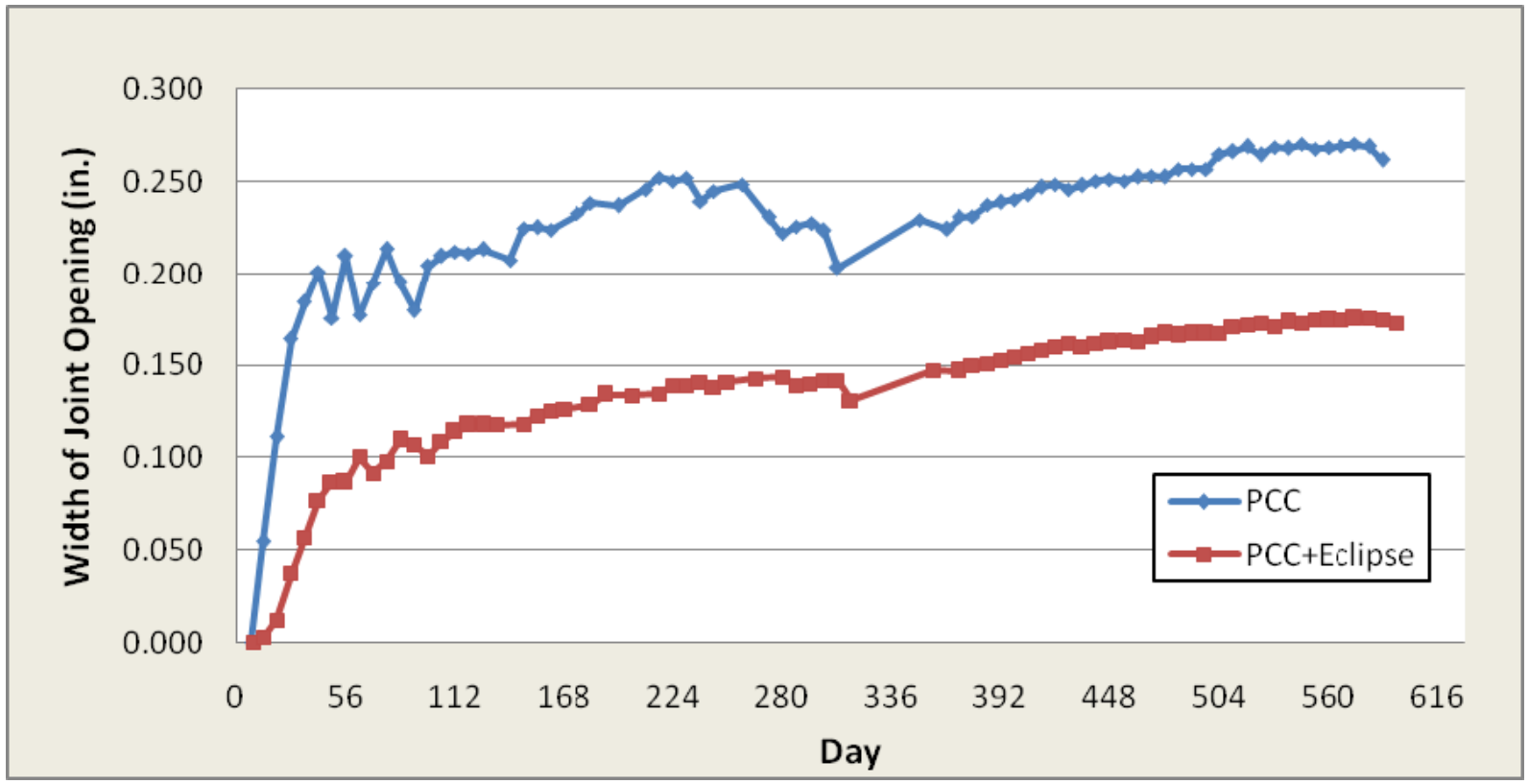
SLAB TEST RESULTS

Shrinkage of HPC vs. Eclipse (SRA) (Mid-Span)



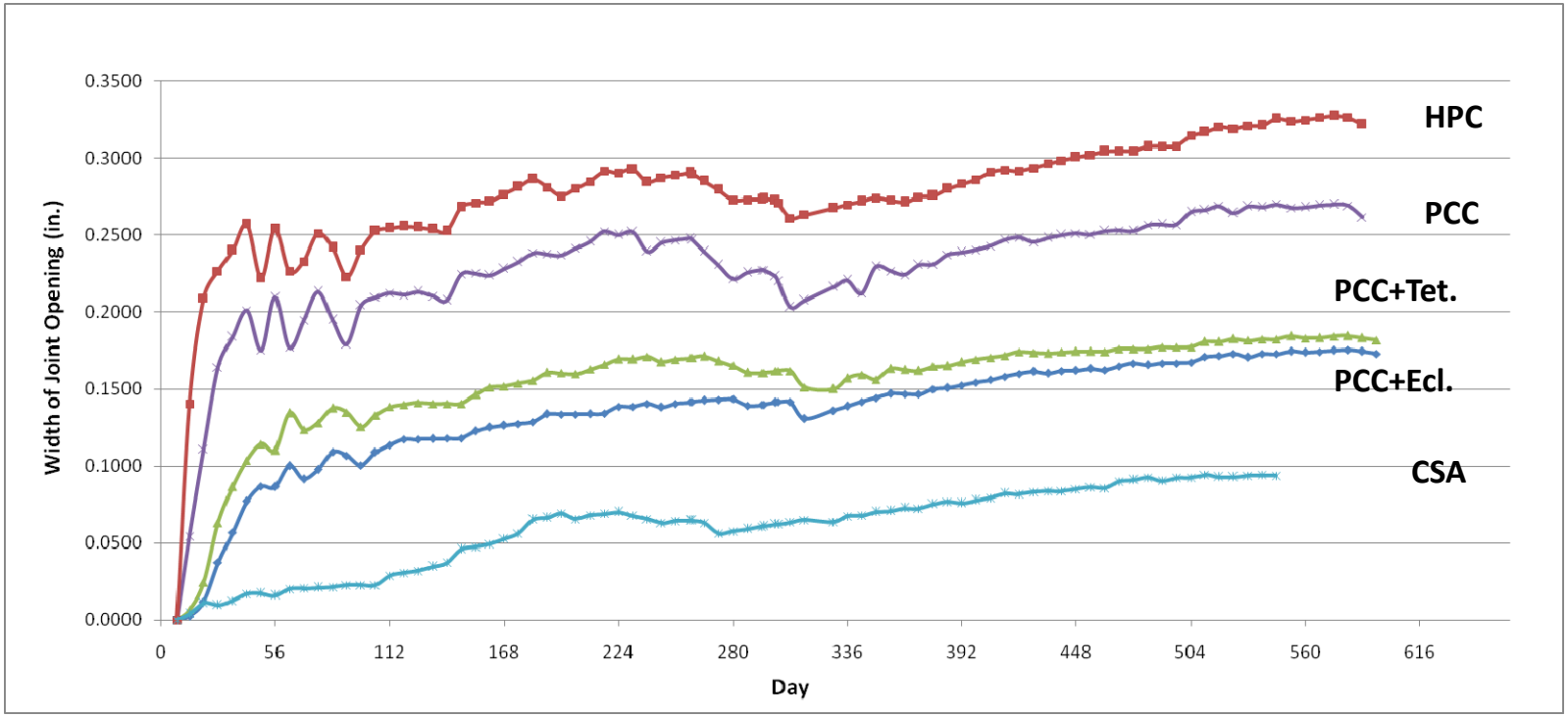
SLAB TEST RESULTS

Demec Strain (Crack or Expansion)
PCC vs. (PCC+Eclipse (SRA))

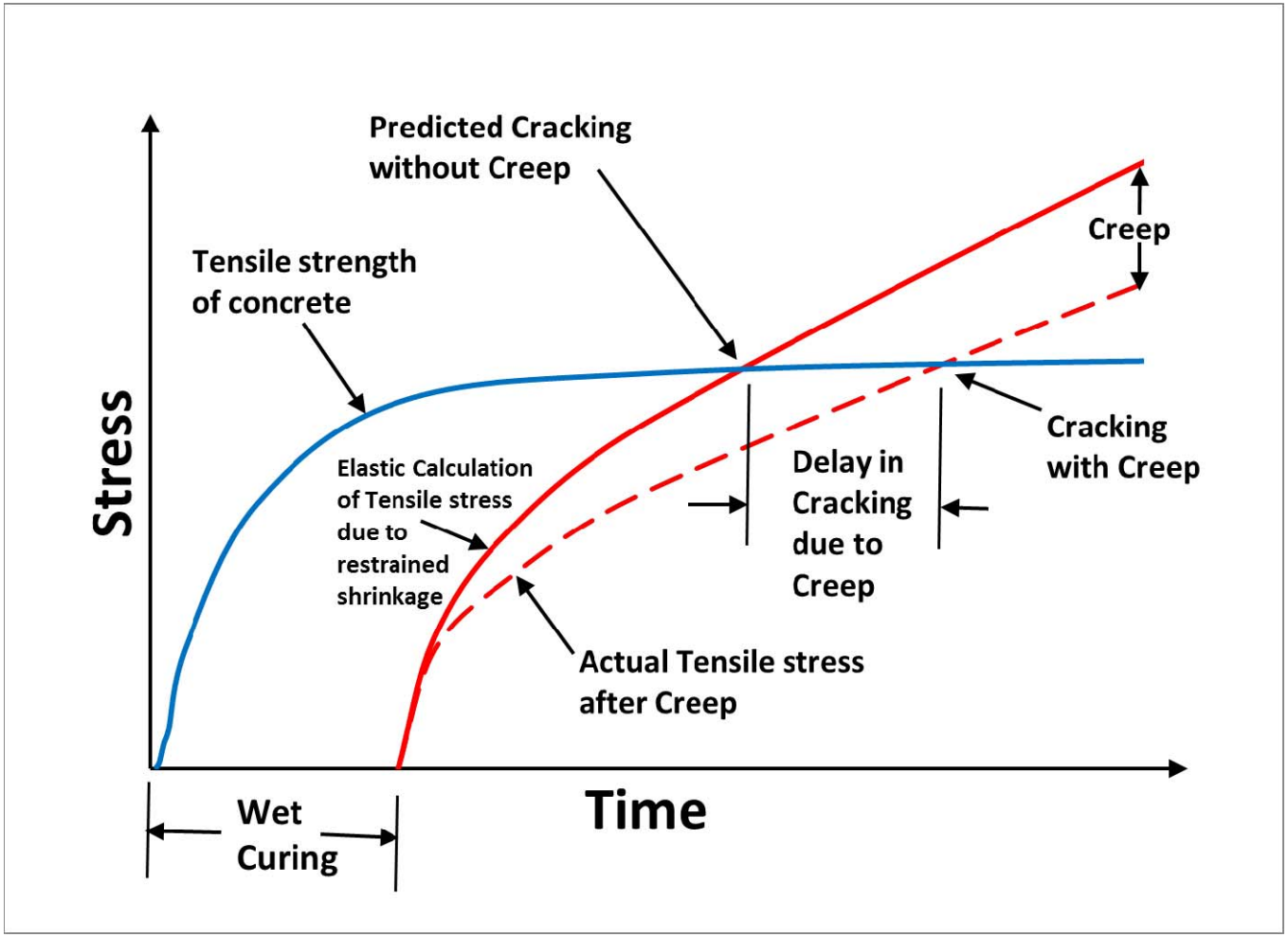


SLAB TEST RESULTS

Joint Opening (Crack or Expansion) for All the Slabs



Portland Concrete



Portland Concrete with Shrinkage Reducing Admixtures