



*Reducing Cracks in New Bridge
Curbs*

2019 NESMEA

Eric Caron and Eshan V. Dave
University of New Hampshire



University of
New Hampshire



Outline

- **Background**
 - **Curb Construction**
 - **Research Problem**
 - **Research Goals**
- **Research Methodology**
- **Results and Discussion**
- **Summary and Conclusions**
- **Recommendations**



Background: Research Need

- NHDOT Bureau of Bridge Maintenance (BoBM)
- Purpose:
 - Supports guardrail
 - Provides drainage characteristics to the bridge
 - Non-structural
- NHDOT Standard Specifications for Road and Bridge Construction



Background: Curb Construction

- Prefer to replace deck and curb at the same time
- Typically replace one side at a time



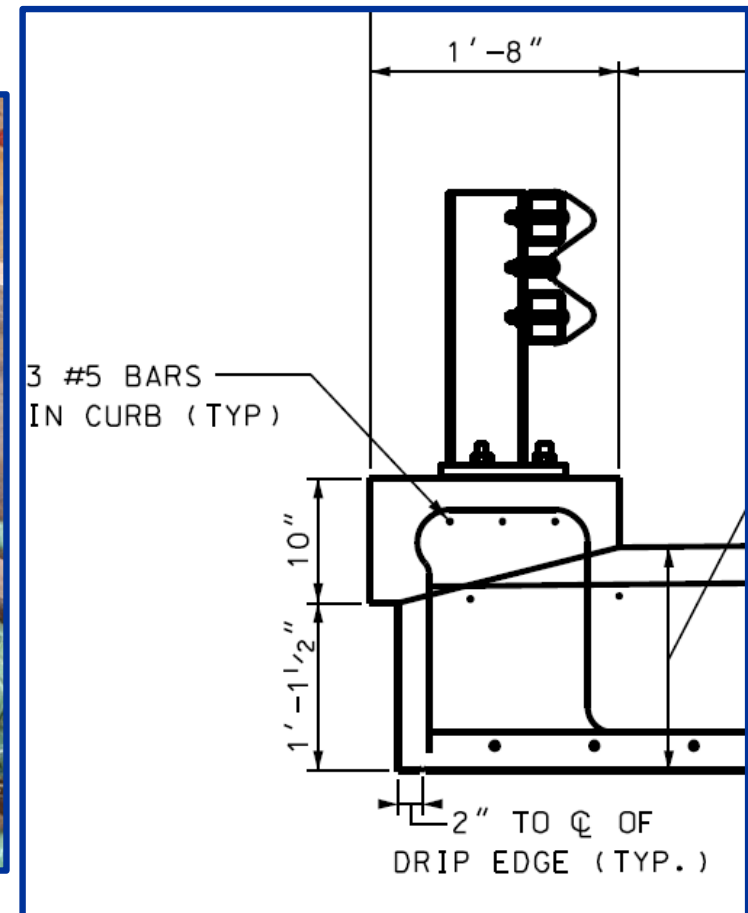
Background: Curb Construction

- Curb removal



Background: Curb Construction

- Reinforcement and formwork installed
 - Guardrail post assemblies installed
 - Additional reinforcement around guardrail posts



Background: Curb Construction

- PCC on curbs is typically same as that used on deck (NHDOT AA class)

Concrete Class	Minimum Expected 28 Day Compressive Strength (psi)	Maximum Water/Cement Ratio	Percent Entrained Air	Permeability Value (kΩ-cm)
AAA	5,000	0.444	5 to 9	20
AA	4,000	0.444	5 to 9	20
A	3,000	0.464	4 to 7	10

Adapted from NHDOT Standard Specifications for Road and Bridge Construction 2016



Background: Curb Construction

- Wet Cure

- PCC is wet cured 5 to 7 days
- Curbs are often placed in winter
- Winter wet cure duration is often shortened



Background: Research Goals

- Develop a cracking index to quantify early-age cracking in curbs
- Use cracking index to document cracking on newly constructed bridge curbs with controls and various remedial variables
- Analyze cracking results and recommend changes to material specifications and construction and maintenance practices



Outline

- Background
- **Research Methodology**
 - Investigation Procedure
 - Cracking Indices
 - Data Organization
 - Site Variables
 - Investigation Challenges
 - Data Analysis
- Results and Discussion
- Summary and Conclusions
- Recommendations



Research Methodology: Investigation Procedure

- Investigation Process

- 1) Pre-visit site research
- 2) Site visits
- 3) Additional data collection (batch slips, compressive strength etc.)
- 4) Post-processing



Research Methodology: Cracking Indices (1/5)

- Length Index (LI)

Length Index

- 1 Partial or limited cracking on one or two faces.
- 2 Nearly full cracking along one face with partial cracking along another.
- 3 Full cracking along at least two faces or extending from guardrail post to roadway.



Research Methodology: Cracking Indices (2/5)

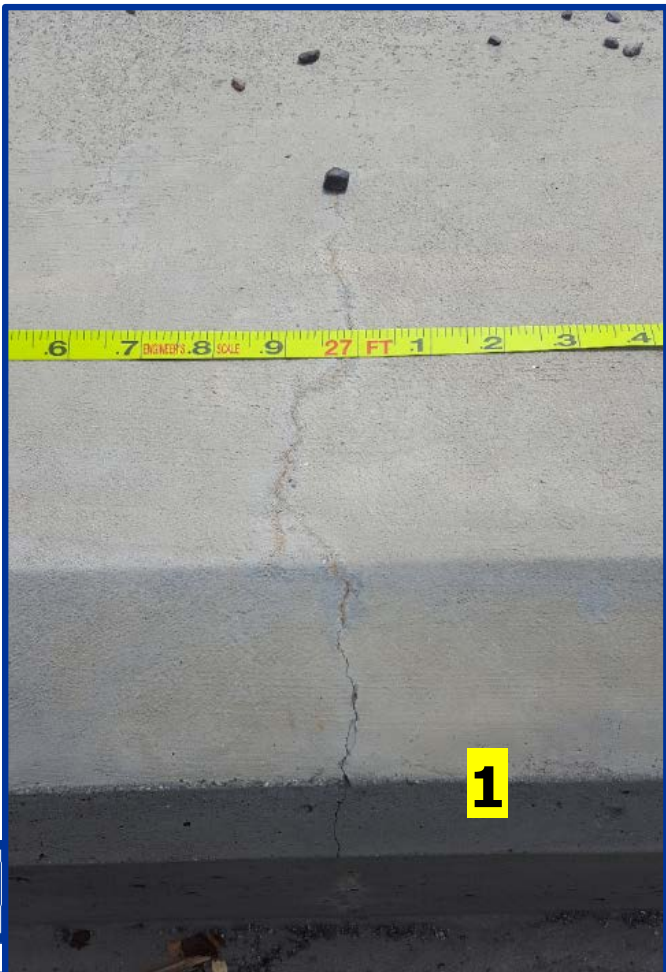
- Intensity Index (II)

ACI 224R-01 Table 4.1

0.007" for Deicing Chemicals

0.016" Dry Air

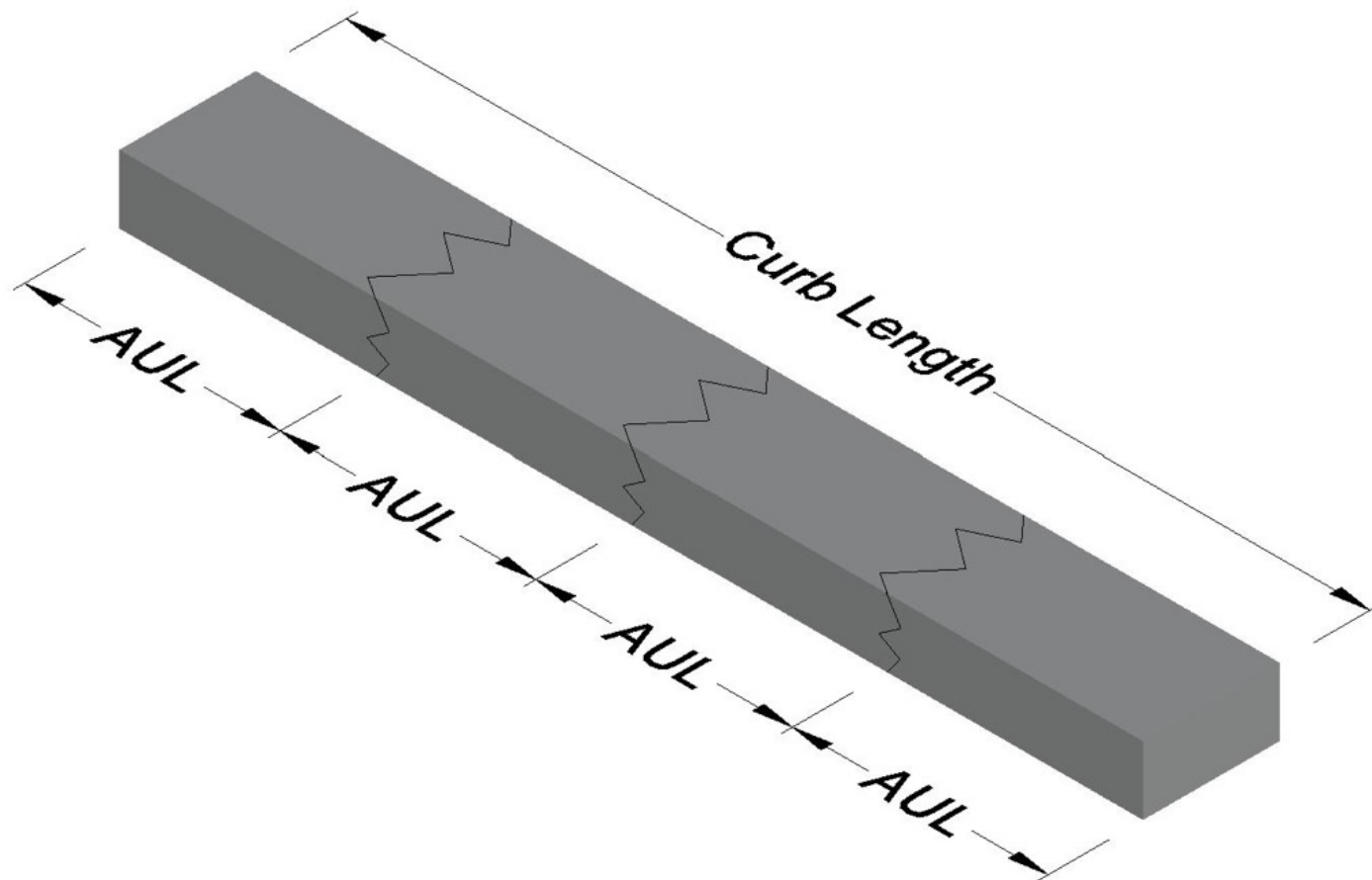
Intensity Index	
1	Crack width < 0.007 "
2	Crack width ≥ 0.007 " but < 0.016 "
3	Crack width ≥ 0.016 "



Research Methodology: Cracking Indices (3/5)

- Average Uncracked Length (AUL)

$$= \frac{\text{Curb Length}}{1 + (\# \text{ Cracks})}$$



Research Methodology: Cracking Indices (4/5)

- Severity Index (SI)

$$= \sqrt{(LI) * (II)}$$

- Curb Cracking Index, CCI




$$= \frac{\text{Average Uncracked Length}}{\text{Average Severity Index}}$$



Research Methodology: Cracking Indices (5/5)

Crack Volume

- Crack width and cracked area based on index values
- Determine the estimated volume of each crack
- Determine the total estimated volume of all the cracks on a curb
- Ratio of cracked volume to curbs volume

Length Index	Sketch of Cracked Cross-Section	Approximate Crack Area
1		1/26
2		1/6
3		1/2

Intensity Index	Assigned Width inch
1	0.005
2	0.012
3	0.017

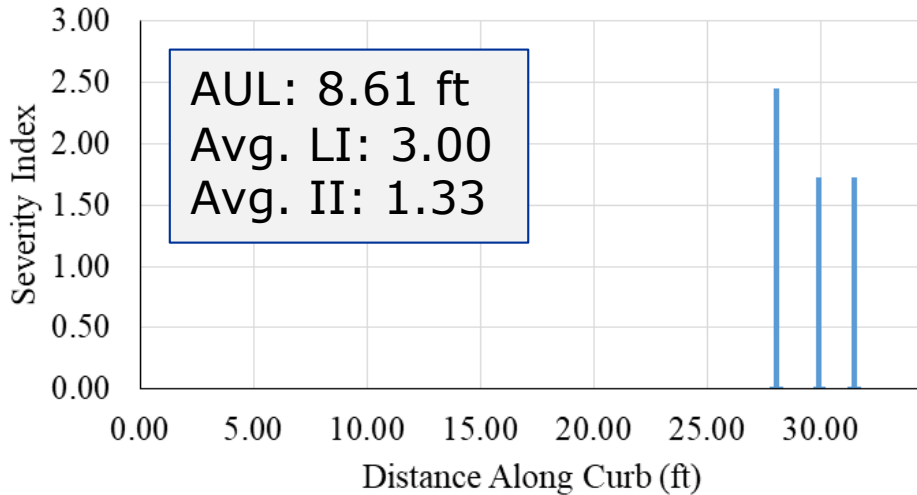
$$\text{Normalized Crack Volume} = \frac{\text{Total Cracked Volume}}{\text{Curb Volume}}$$



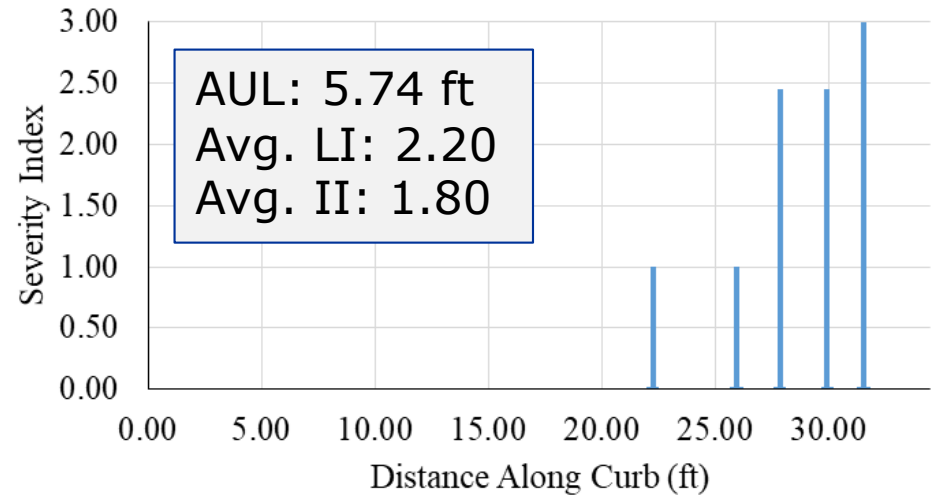
Research Methodology: Data Organization

Alexandria (174/146) Cracking Maps:

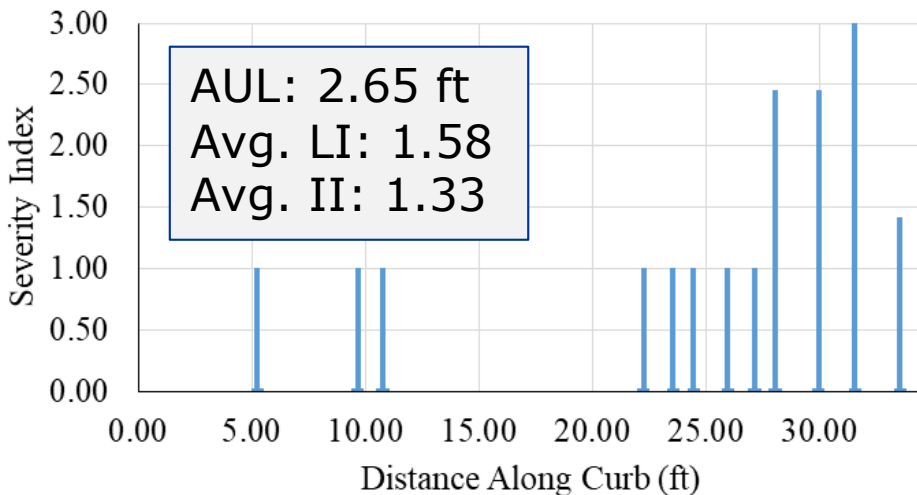
Cracking Map - North Curb - 30 days



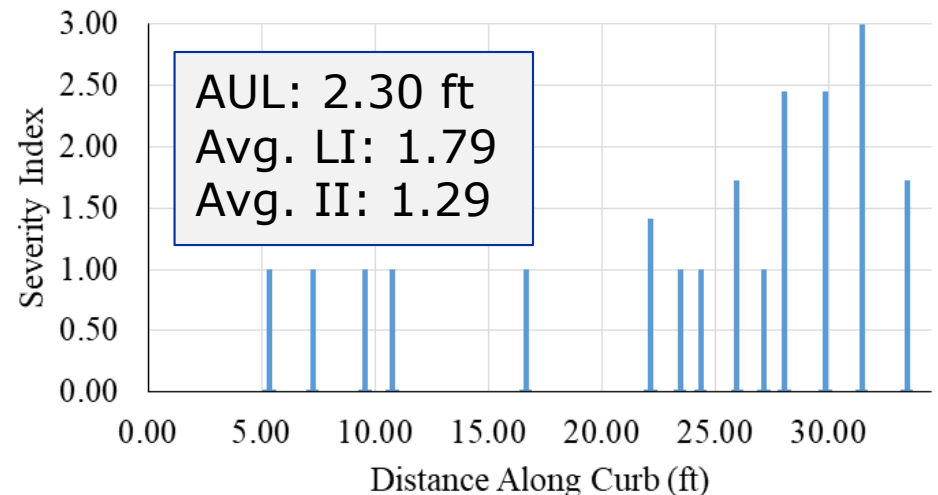
Cracking Map - North Curb - 80 days



Cracking Map - North Curb - 175 days



Cracking Map - North Curb - 425 days



Research Methodology: Site Variables

- Bridge curb pairs replaced during the study had a variable applied to one of the curbs
- Tested variables
 - 14-day wet cure compared to traditional 5 to 7-day wet cure
 - PCC mix, NHDOT A mix compared to NHDOT AA mix



Research Methodology: Data Analysis

1. Graphical comparisons

- Cracking maps
- Cracking indices

2. t-tests

- Statistical significance testing

3. Pearson's correlation

- Describes how well the data matches a linear trend



Outline

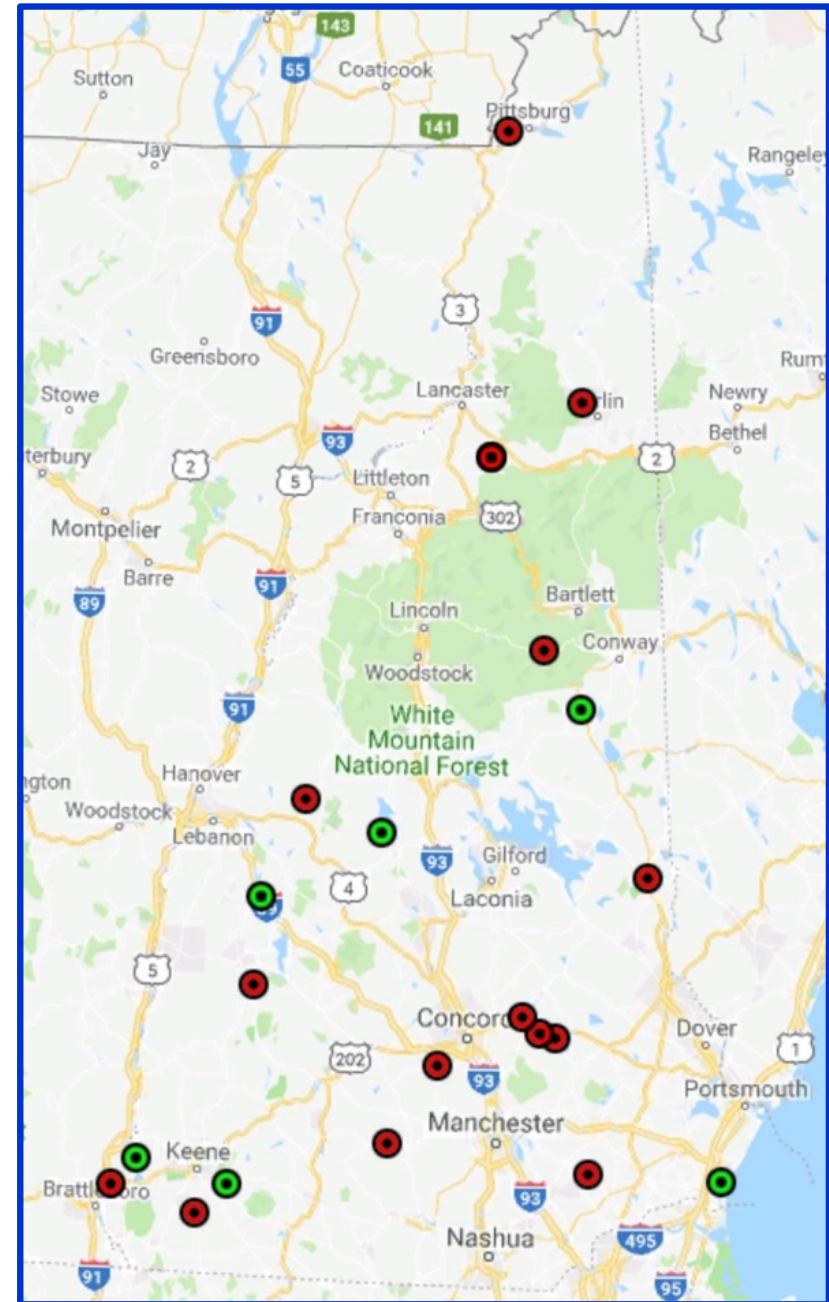
- Background
- Research Methodology
- **Results and Discussion**
 - Crack Distribution
 - Bridge Length
 - Location Along Curb
 - Wet Cure Duration
 - PCC Composition
 - Proximity to Guardrail Posts
 - Crack Evolution with Time
- Summary and Conclusions
- Recommendations



Results and Discussion

23 Bridges Surveyed

- Existing Bridge Curbs (red)
 - 17 bridges visited constructed after 2008
 - Survey previous bridges and see if correlations exist
- New Bridge Curbs (green)
 - 8 new bridges



Results and Discussion

- New Bridge Curb Sites and Variables
 1. **Hampton** – No variable
 2. **Alexandria** – 14-day wet cure
 3. **Tamworth** – ‘A’ mix
 4. **Marlborough** – No variable, one curb replaced
 5. **Grantham** – 14-day wet cure
 6. **Westmoreland-1** – ‘A’ mix
 7. **Westmoreland-2** – 14-day wet cure and ‘A’ mix
 8. **Meredith** – 14-day wet cure and ‘A’ mix

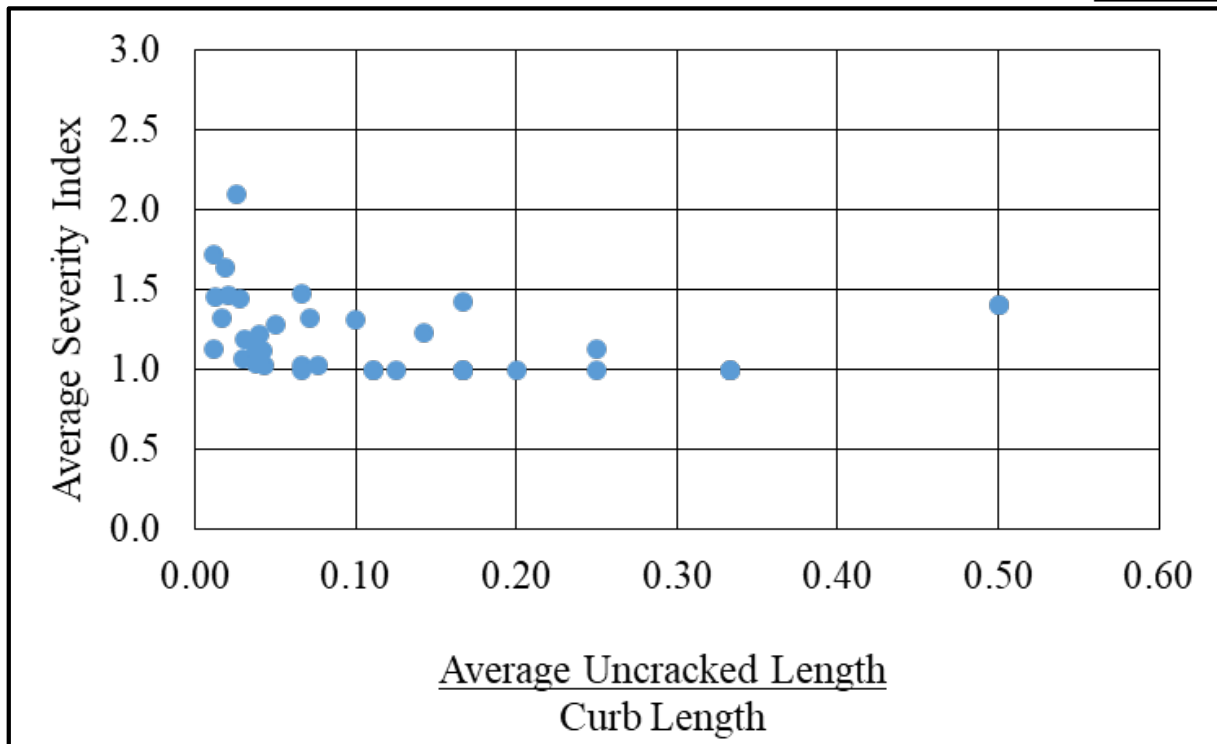


Results and Discussion

Distribution of Cracks

- 83% are of reasonable width
- Shorter AUL, higher SI

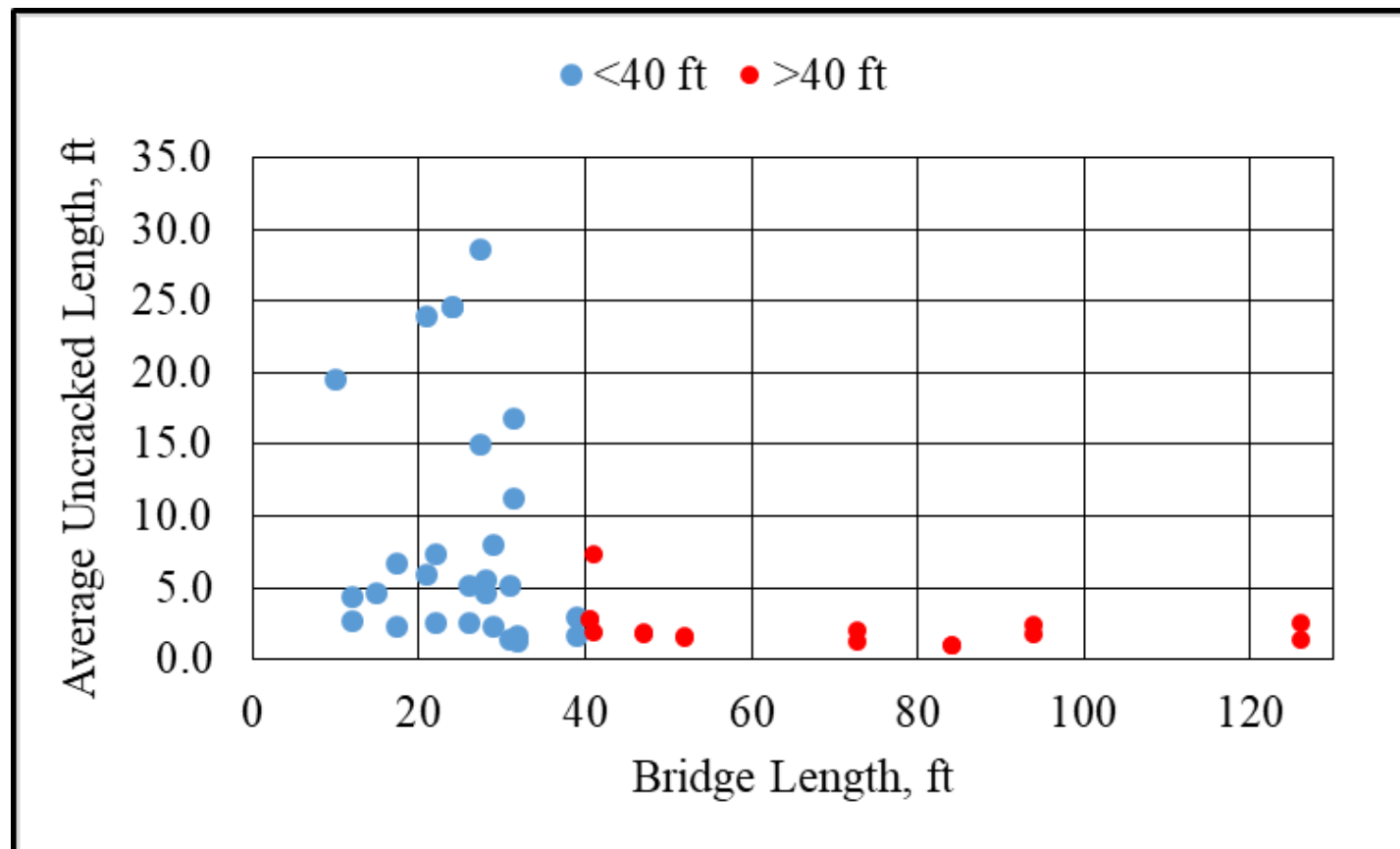
		Length Index			Total
		1	2	3	
Intensity Index	1	525	64	116	705
	2	22	14	100	136
	3	0	0	8	8
Total		547	78	224	



Results and Discussion

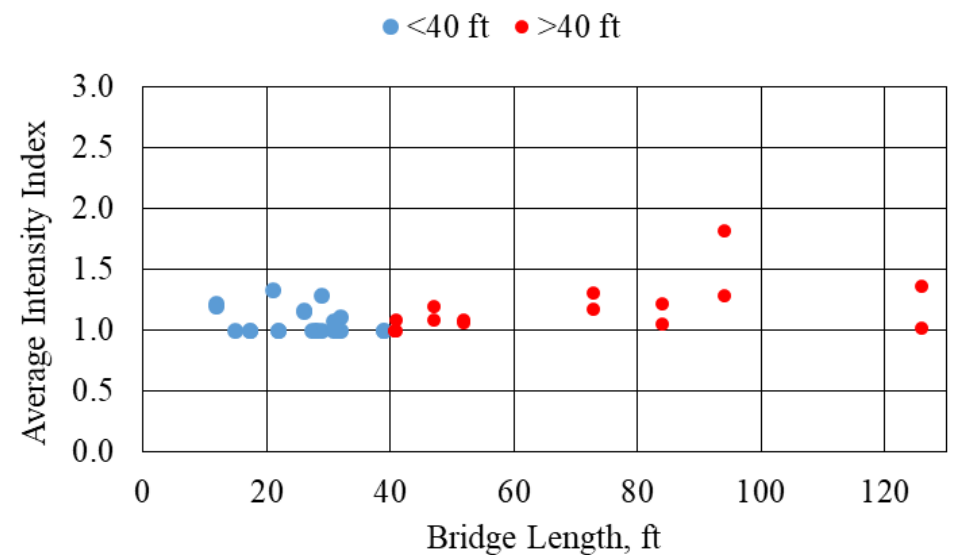
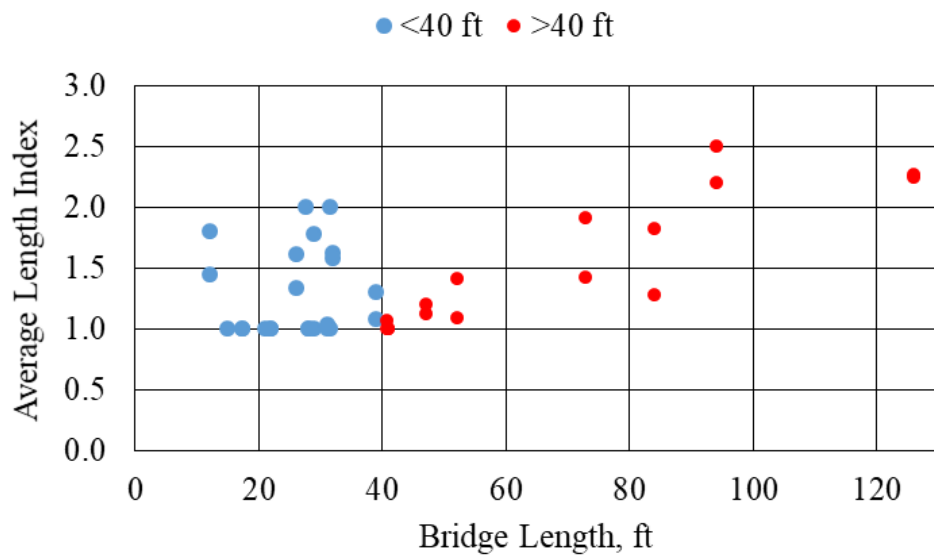
Bridge Length

- Noticeable change near 40 ft in length
- Around 30-40 ft concrete slab structures are switched to steel I-beams with concrete deck



Results and Discussion

Bridge Length

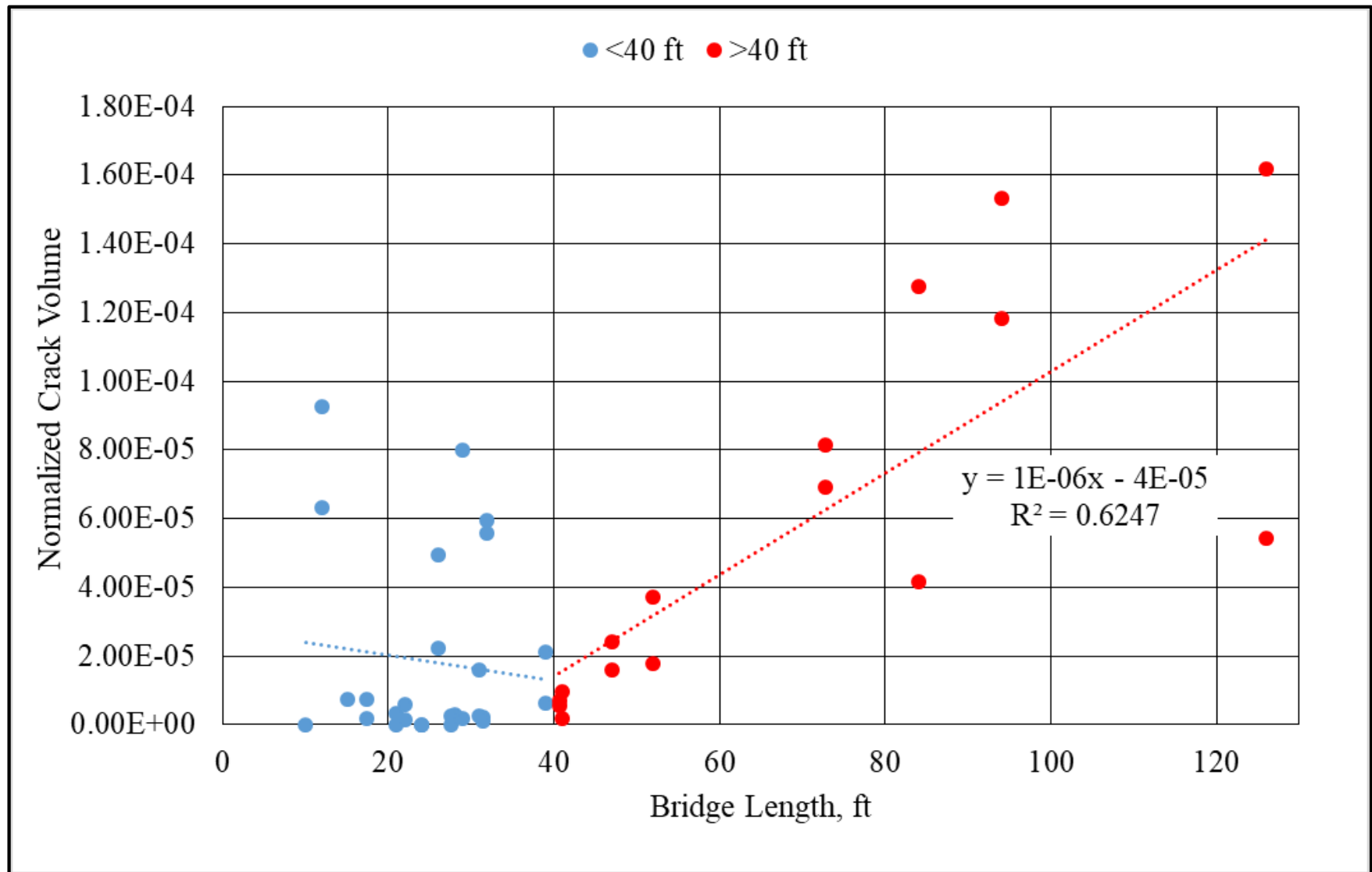


t-test <40 ft & >40 ft	p-value $\alpha < 0.05$	Outcome
Average Length Index	0.119	Not Significant
Average Intensity Index	0.077	Not Significant
Average Uncracked Length	0.0004	Significant



Results and Discussion

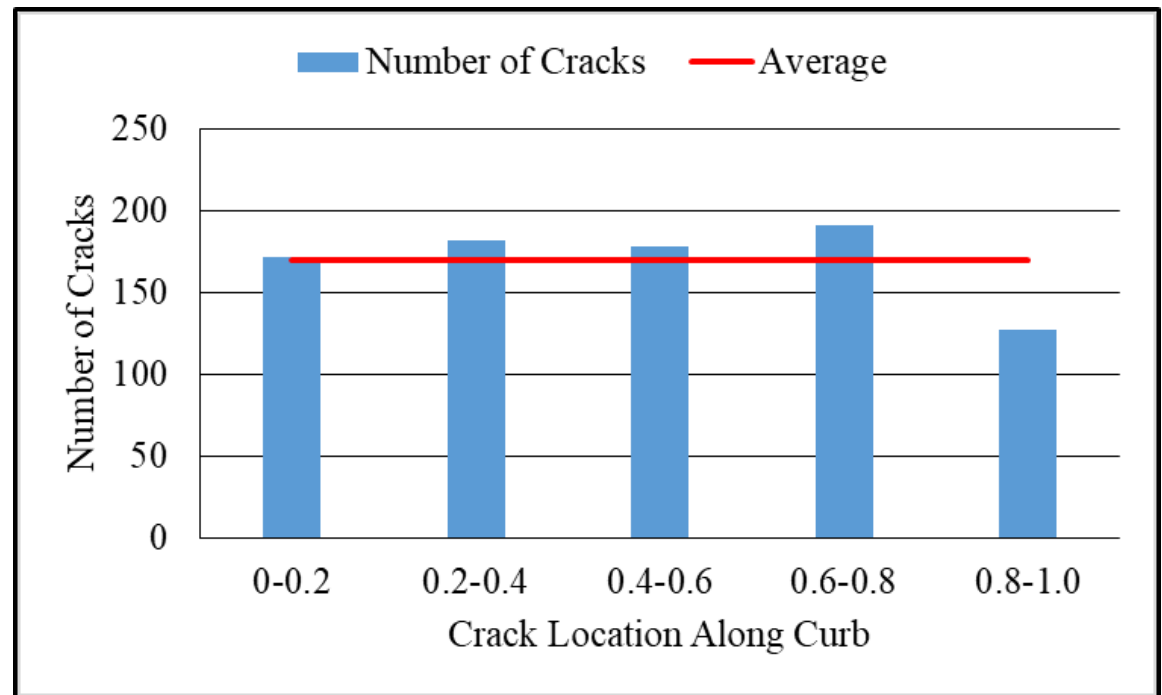
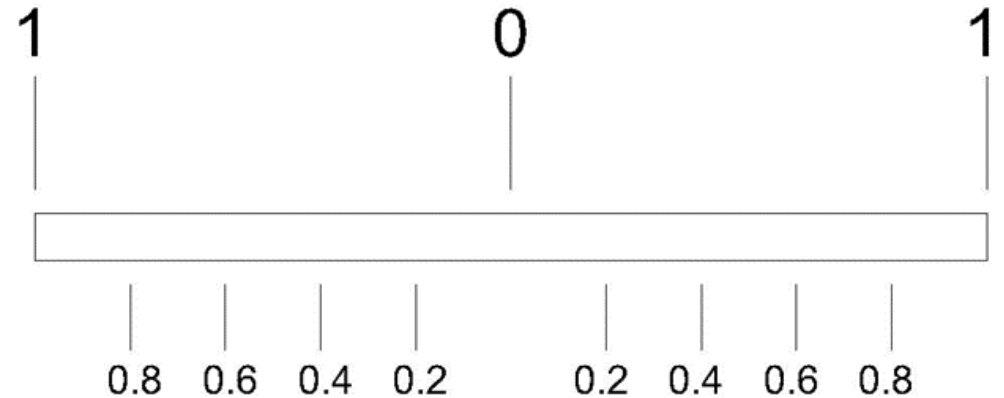
Bridge Length – Volume Method



Results and Discussion

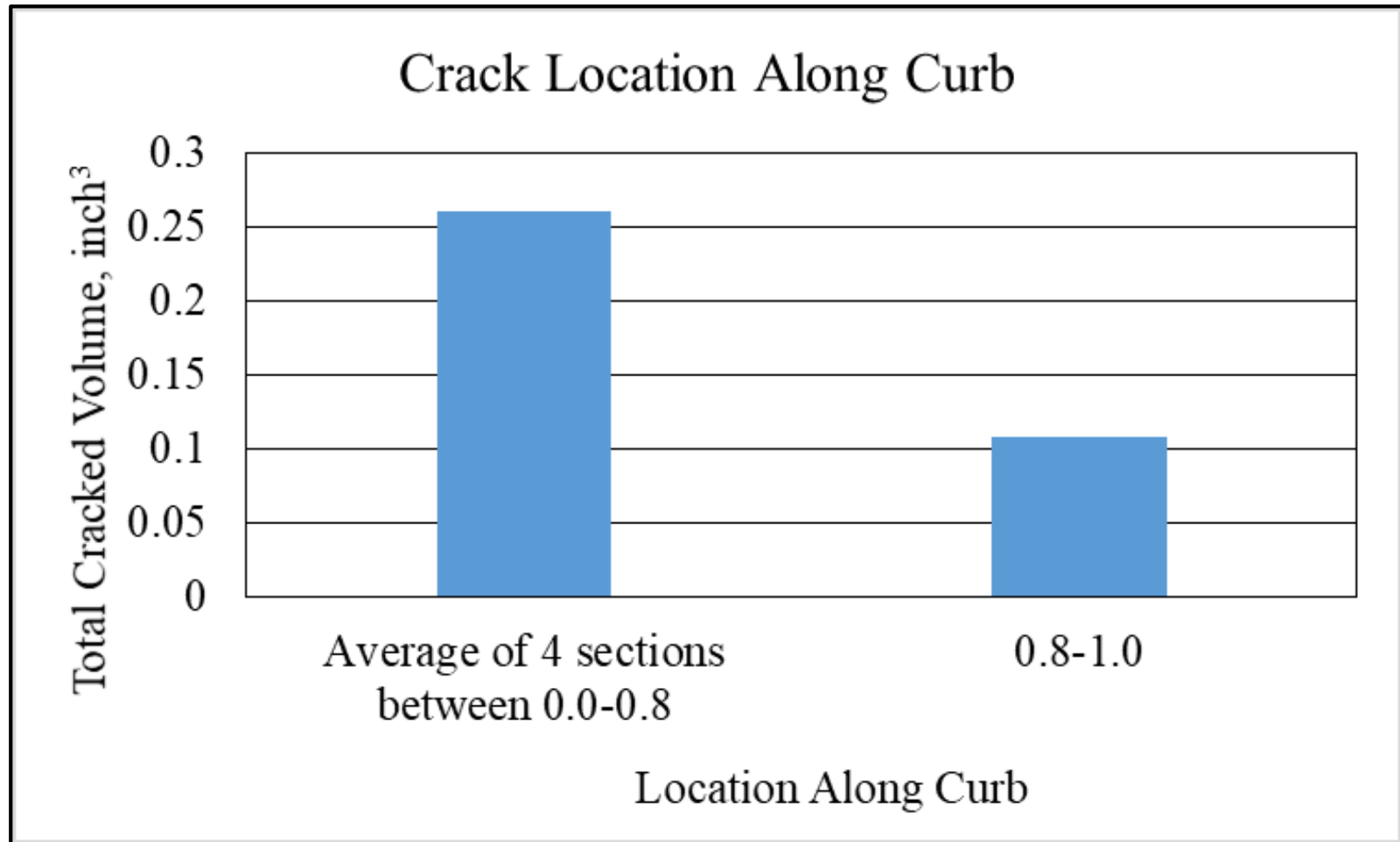
Location Along Curb

- Each crack assigned a value of 0 to 1
 - 0 corresponds to center of curb
 - 1 corresponds to end of curb
- Less cracking at the ends of the curb
- Statistical testing confirms these findings



Results and Discussion

Location Along Curb – Volume Method

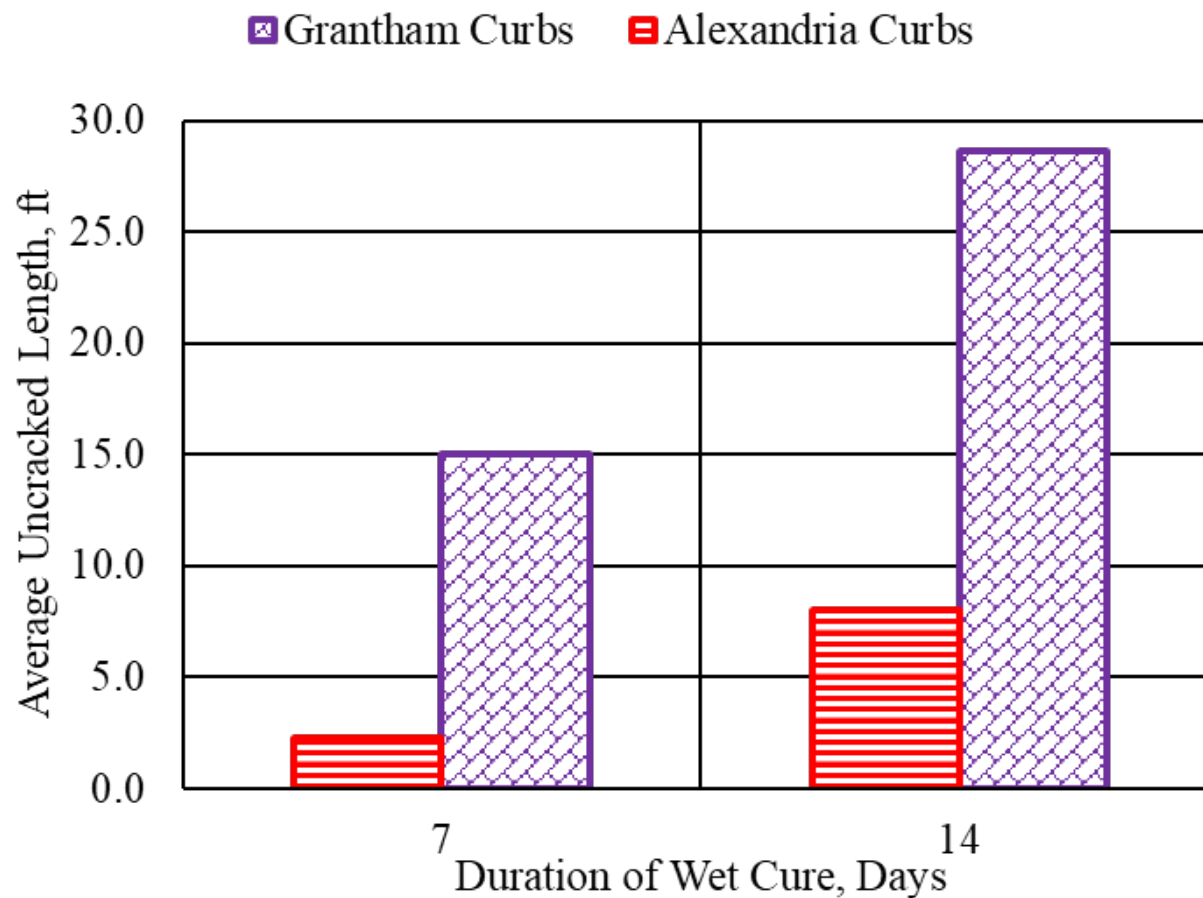




Results and Discussion

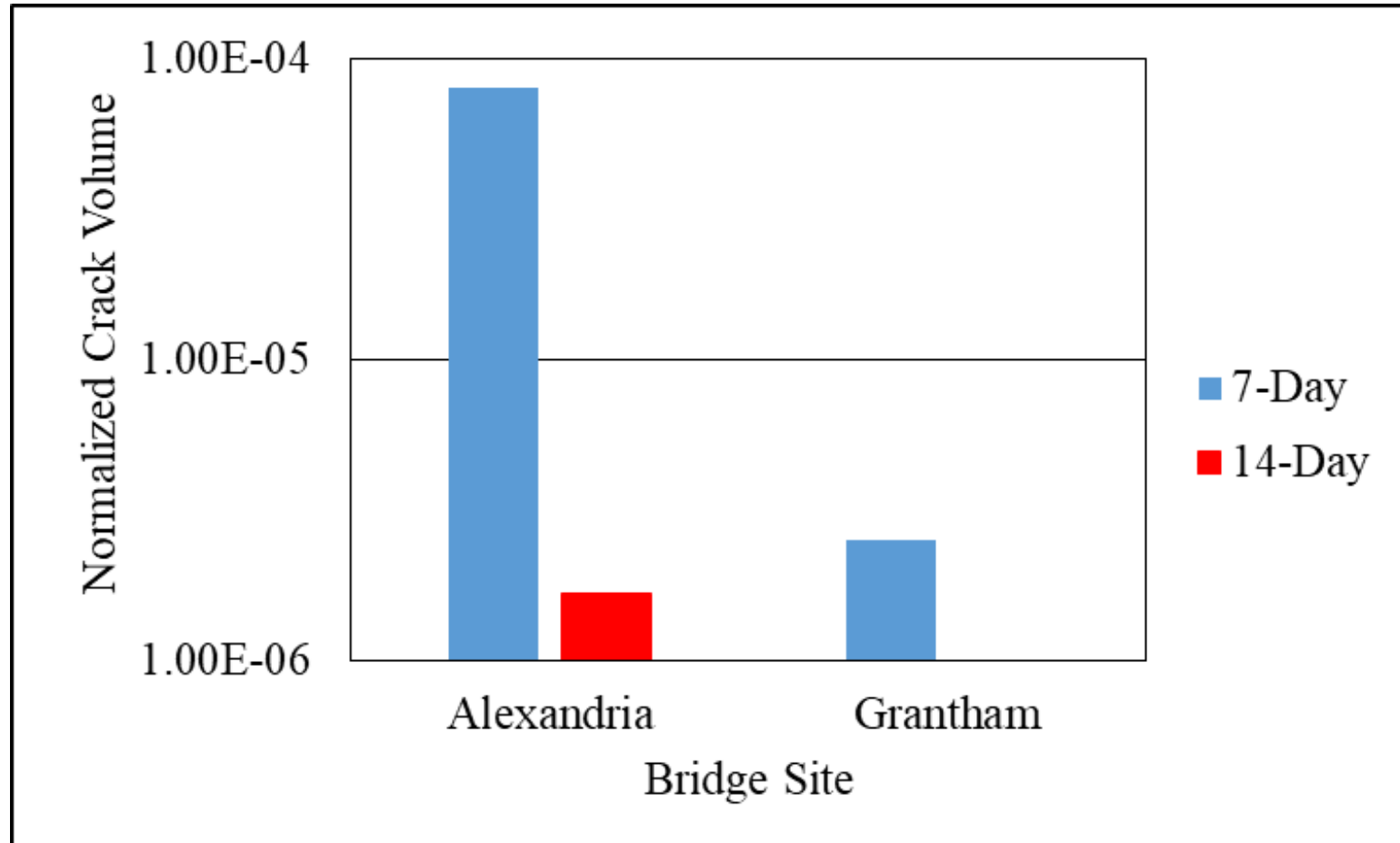
Wet Cure Duration

- t-tests do not indicate significance (all data)
- Curb pairs indicate 14-day wet cure reduces the amount of cracking compared to 7-day



Results and Discussion

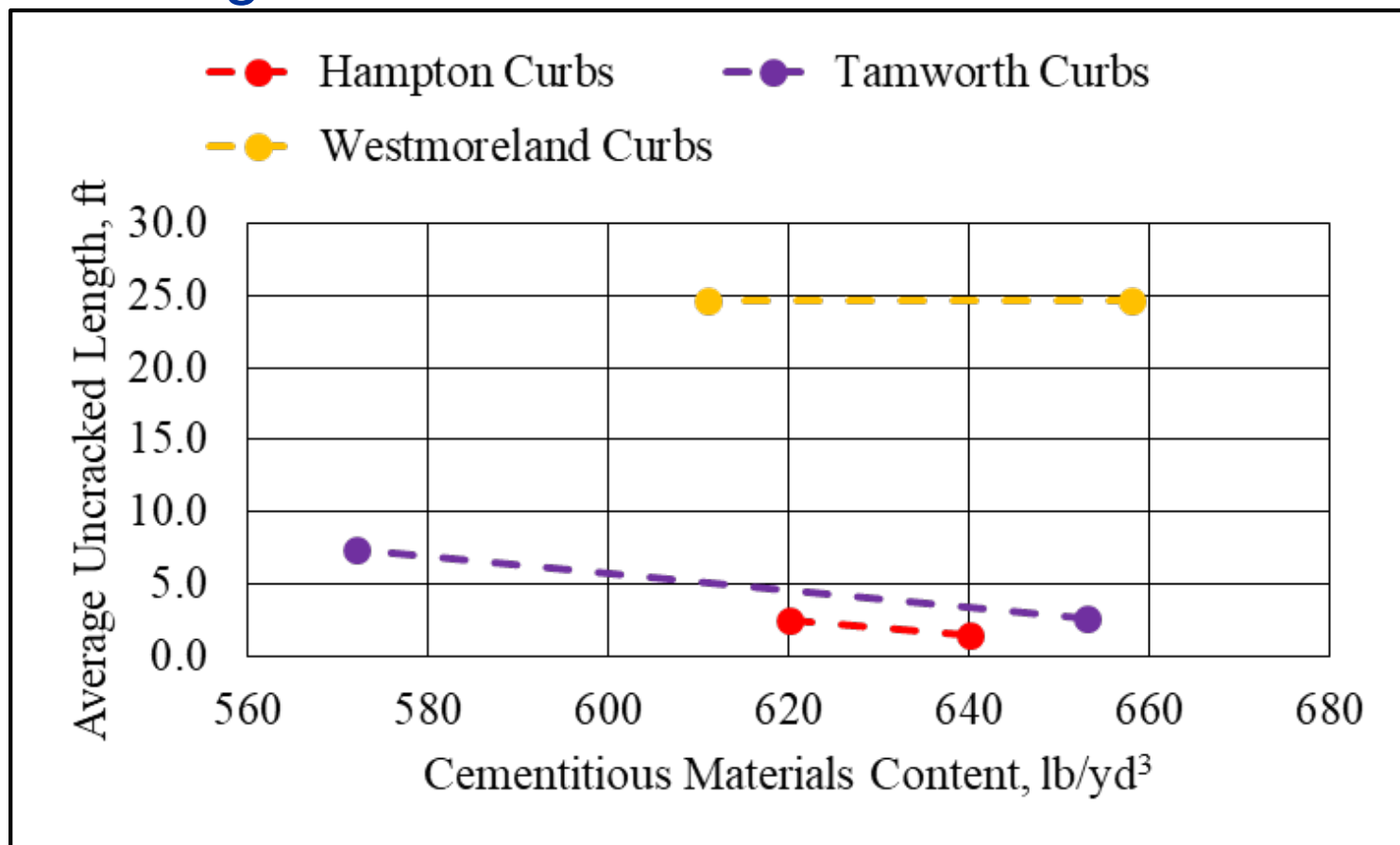
Wet Cure Duration – Volume Method



Results and Discussion

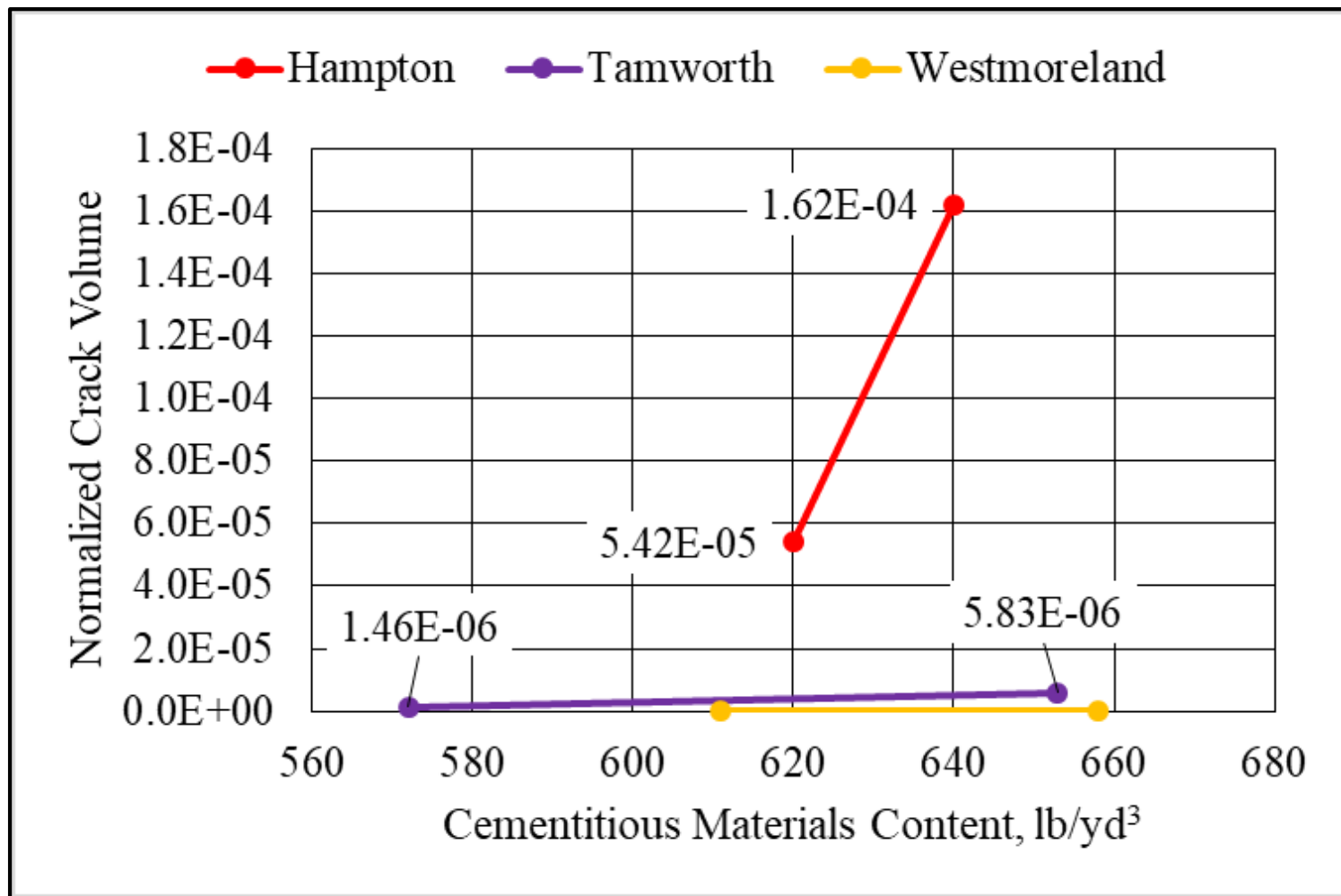
Cementitious Materials Content

- Not significant according to t-tests
- Curb pairs indicate lower cementitious content produces curbs with a greater AUL



Results and Discussion

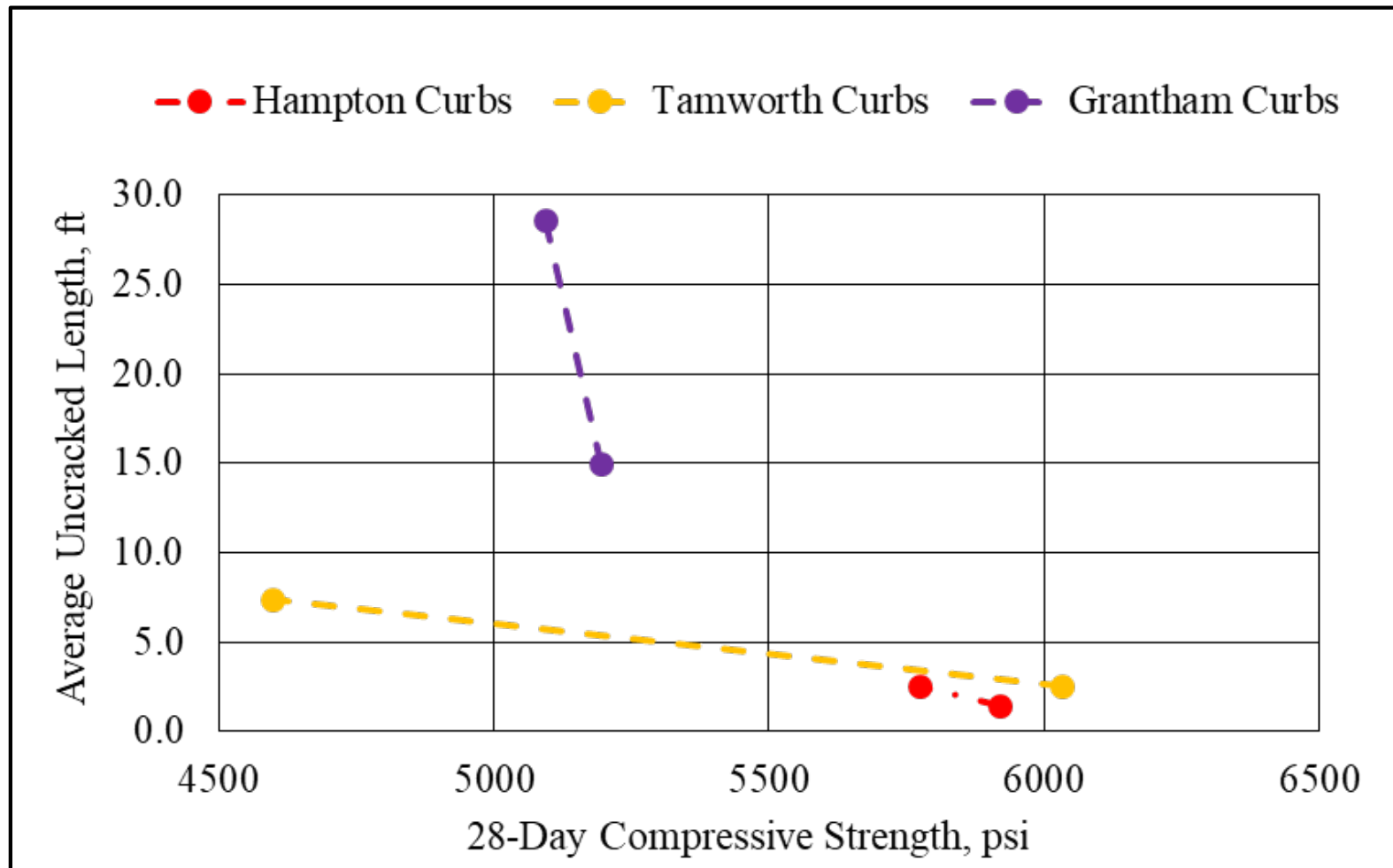
Cementitious Materials Content – Volume Method



Results and Discussion

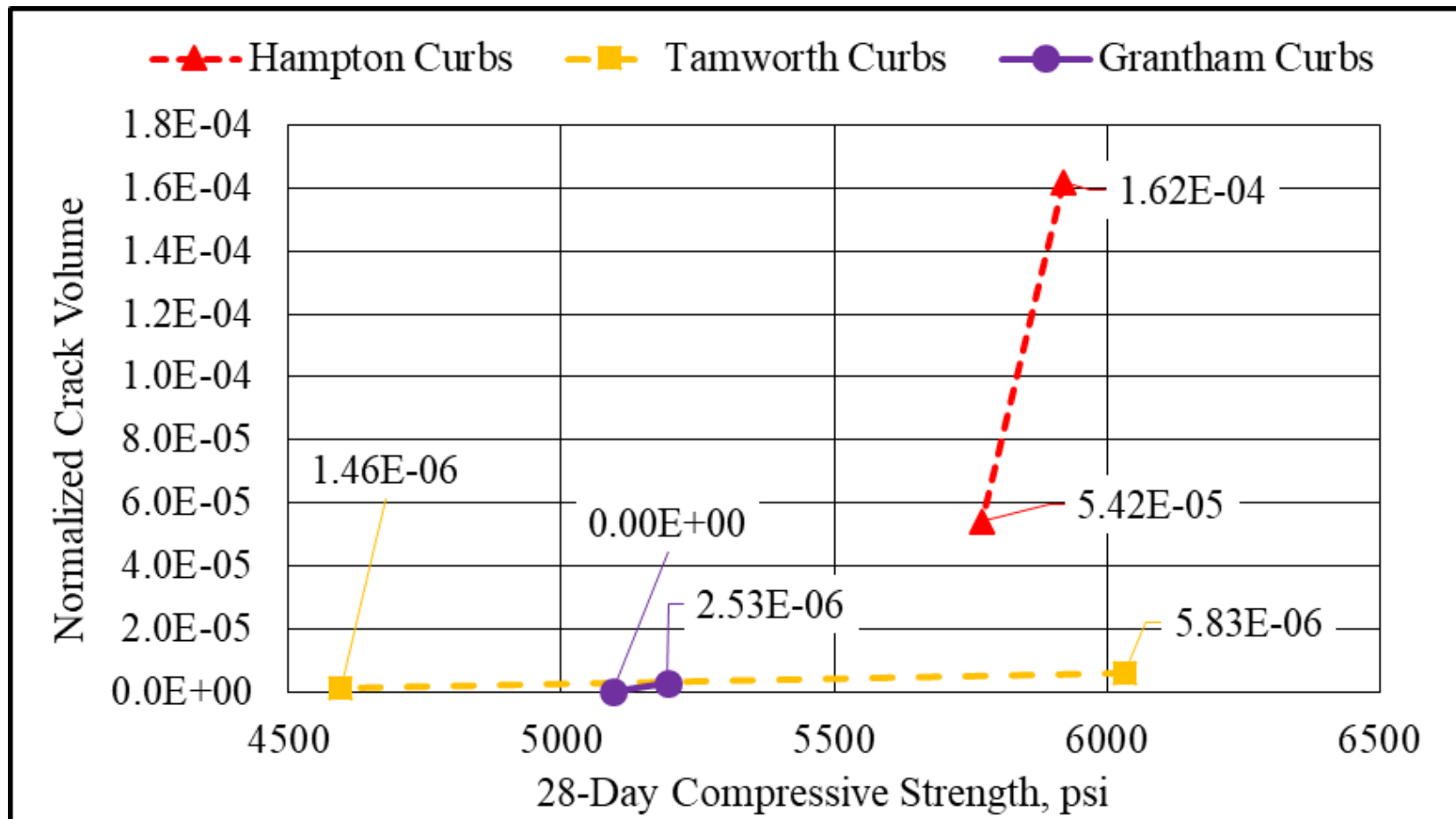
28-day Compressive Strength

- Curb pairs indicate higher compressive strength leads to shorter AULs



Results and Discussion

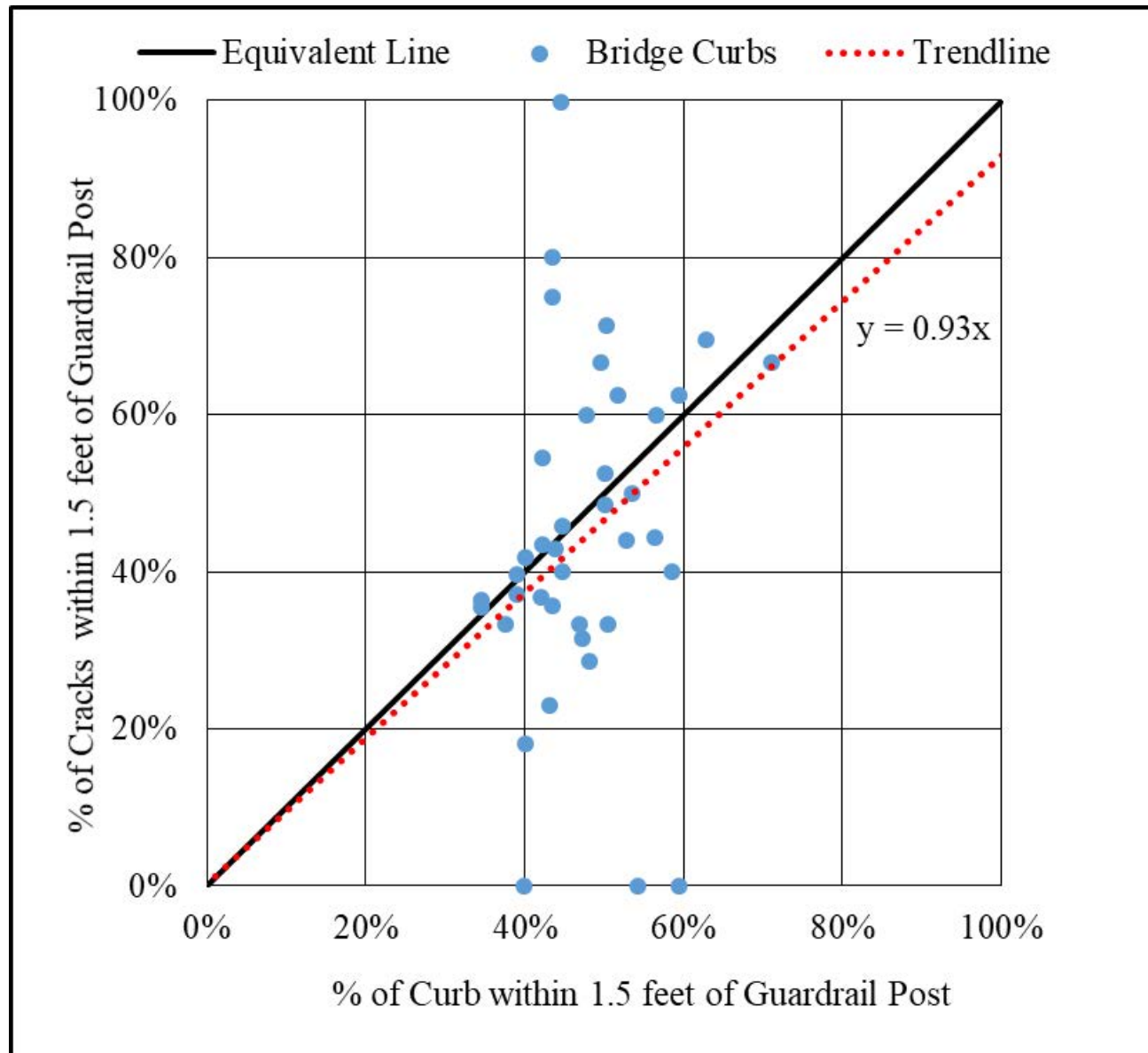
28-day Compressive Strength – Volume Method





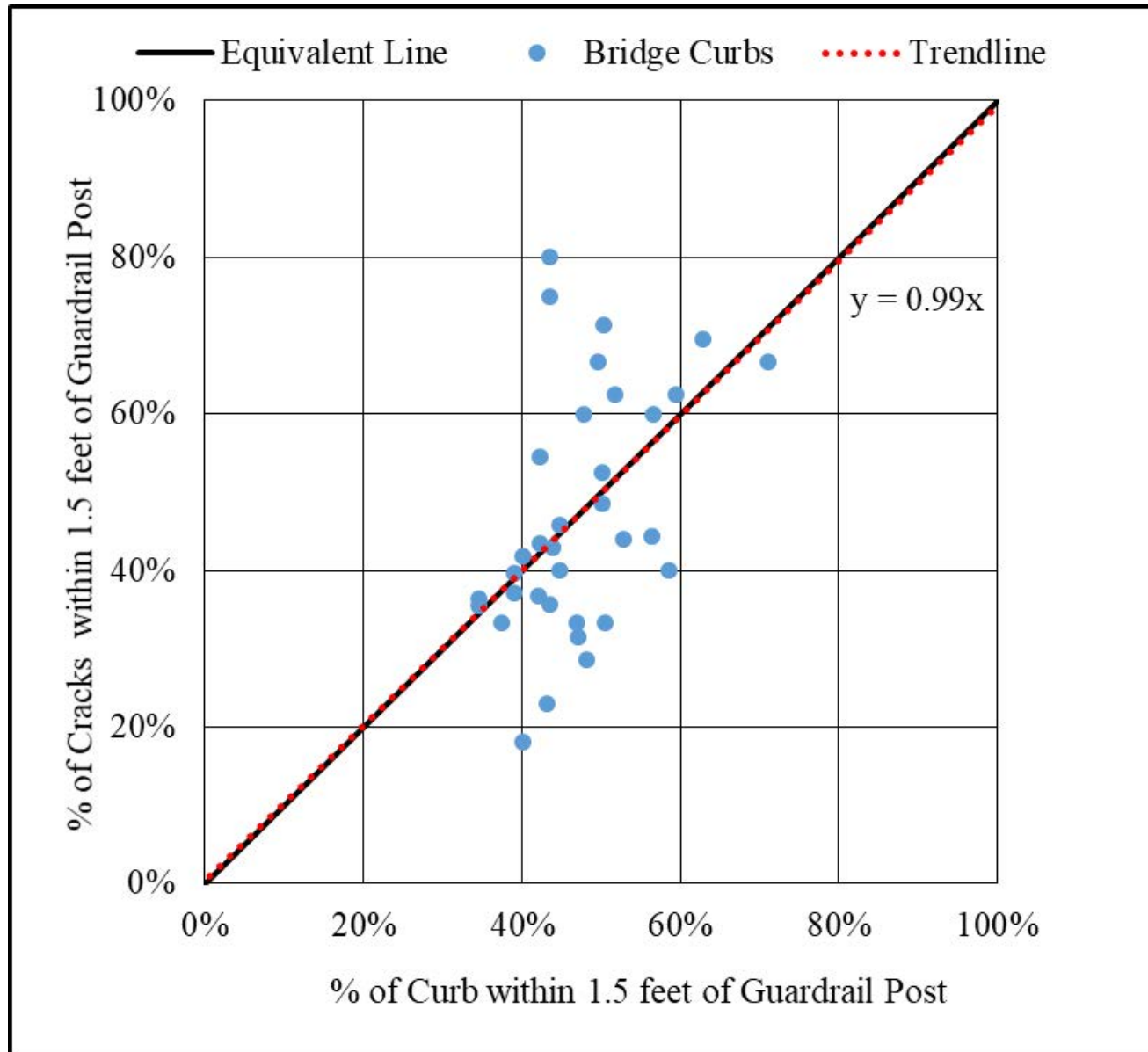
Results and Discussion

Proximity to Guardrail Posts



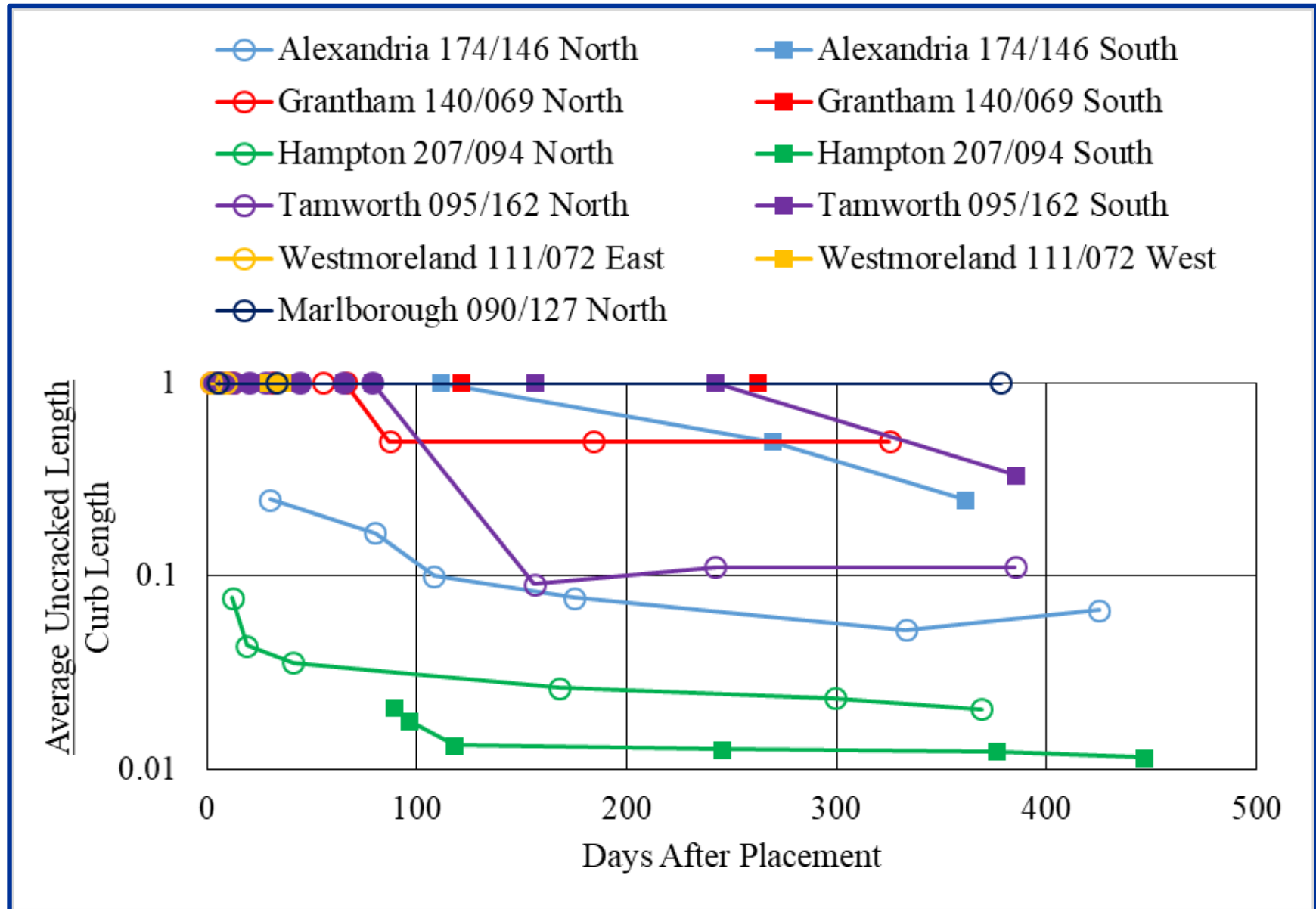
Results and Discussion

Proximity to Guardrail Posts (Curbs with more than 2 Cracks)



Results and Discussion

Cracking Over Time: AUL



Overview

- Background
- Research Methodology
- Results and Discussion
- **Summary and Conclusions**
- Recommendations



Summary

- 25 Bridges Surveyed: 8 placed during the study
- 2 Variables tested:
 - Wet Cure Duration
 - PCC Mix
- Cracks were assigned two index values (scale: 1 – 3) depending on length and width
- The amount of cracking on a curb was related to the average length between cracks or the curb face to account for variations in curb lengths
- Approximated crack volumes were compared between curbs



Summary and Conclusion

Summary of Results

	Average Uncracked Length (AUL)	Length Index (LI)	Intensity Index (II)
Bridge Length	Red	Yellow	Yellow
Location on Curb	Red	Green	Green
Curing Duration	Yellow	Black	
PCC Mix	Green		
Water/Cementitious Materials Ratio	Green		
Cementitious Content	Yellow		
28-day Compressive Strength	Yellow	Green	Green
Guardrail Post	Green	Green	Green
Weather After Placement	Green	Green	Green
Average Daily Traffic	Green	Green	Green



Conclusions (1 of 2)

- 83% of curb cracks are less than the maximum reasonable width as outlined by ACI 224R-01
- Curbs with more cracking tend to have more severe cracking
- Curbs on bridges over 40 ft. in length tend to have more cracking
- Less cracking occurs at the ends of curbs compared to the rest of the curb



Conclusions (2 of 2)

- Curbs with a 7-day wet cure have more cracking as compared to their neighboring curb wet cured for 14-days
- Curbs placed with a higher cementitious content have more cracking compared to their neighboring curb
- Curbs with a higher compressive strength have more cracking compared to their neighboring curb
- Proximity to guardrail post have minimal effect on cracking behavior



Overview

- Background
- Research Methodology
- Results and Discussion
- Summary and Conclusions
- **Recommendations**
 - **Practice Changes**
 - **Future Research**



Recommendations: Practice Changes

- Prioritize maintenance on longer bridges
- Wait one year after placement before sealing problem cracks or make sure to revisit after 1 year
- Increase the wet cure duration from 7-days to 14-days
- Use PCC with a lower cementitious content and lower 28-day compressive strengths
 - Specify NHDOT “A” mix



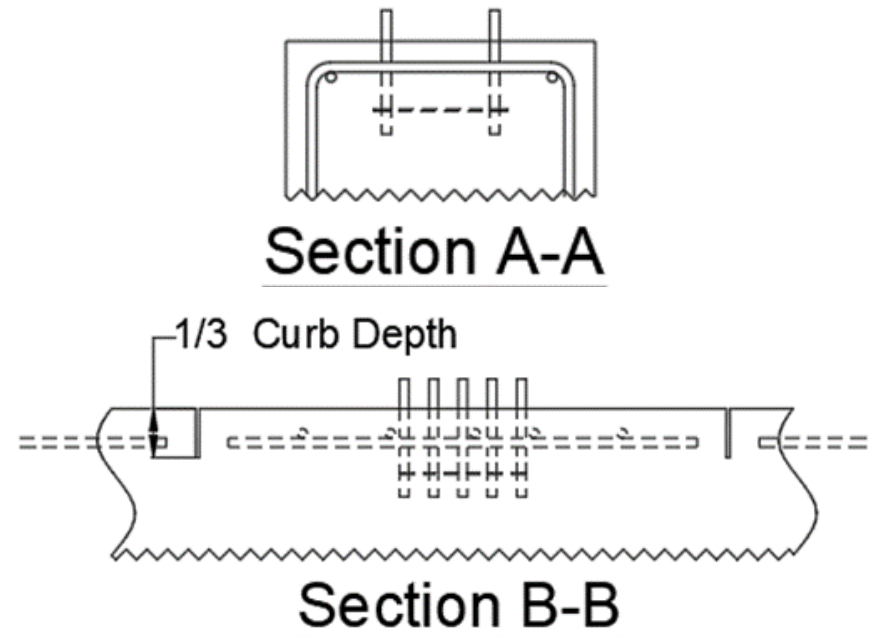
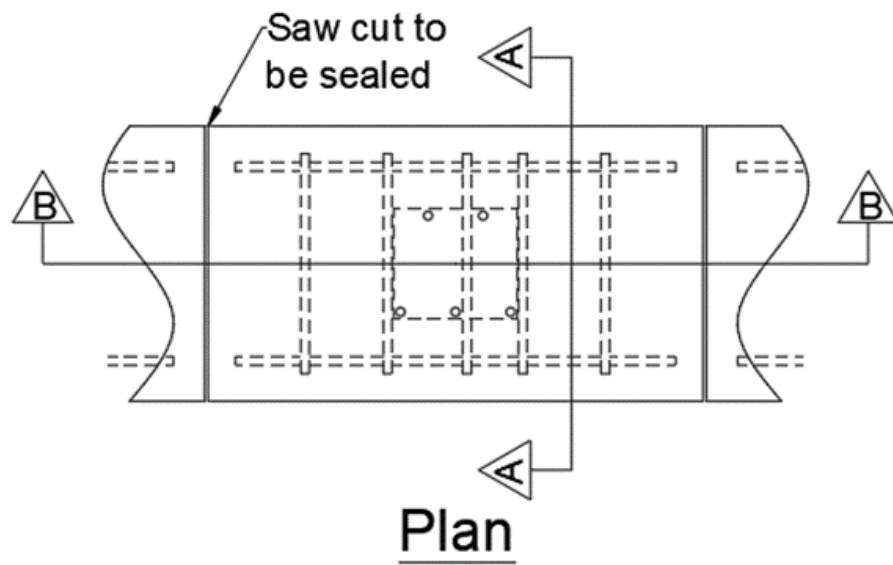
Recommendations: Future Research

- Refinement of Field Data Analysis
 - Further develop the volume method and determine normalized crack volumes that correspond to curbs in good, fair, and poor condition
 - Revisit the study looking at only cracks with an intensity index of 2 or 3
- Structural Analysis
 - Further investigation of relationship between cracking and bridge length
 - Investigate structural and dynamic aspects of loading on curbs
 - Use of strain gauges in curb reinforcement and concrete maturity measurements



Recommendations: Future Research

- Contraction Joints at Guardrail Posts



Thank you for your attention!
Questions?

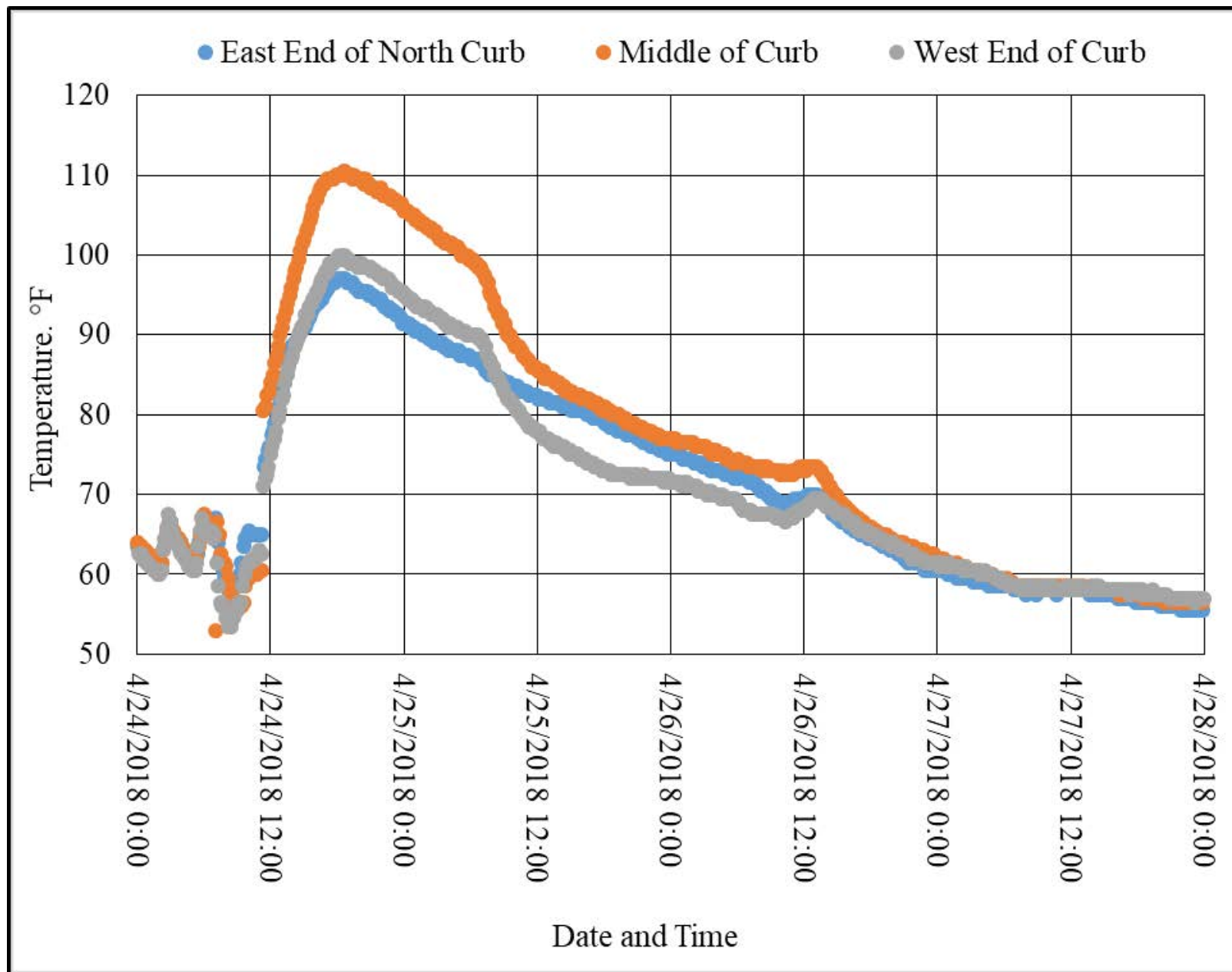


Research Methodology: Investigation Challenges

- Cracks are only documented when visible
- Crack expansion and contraction
- Dust, road salt, and polymers in cracks
- Ice and snow



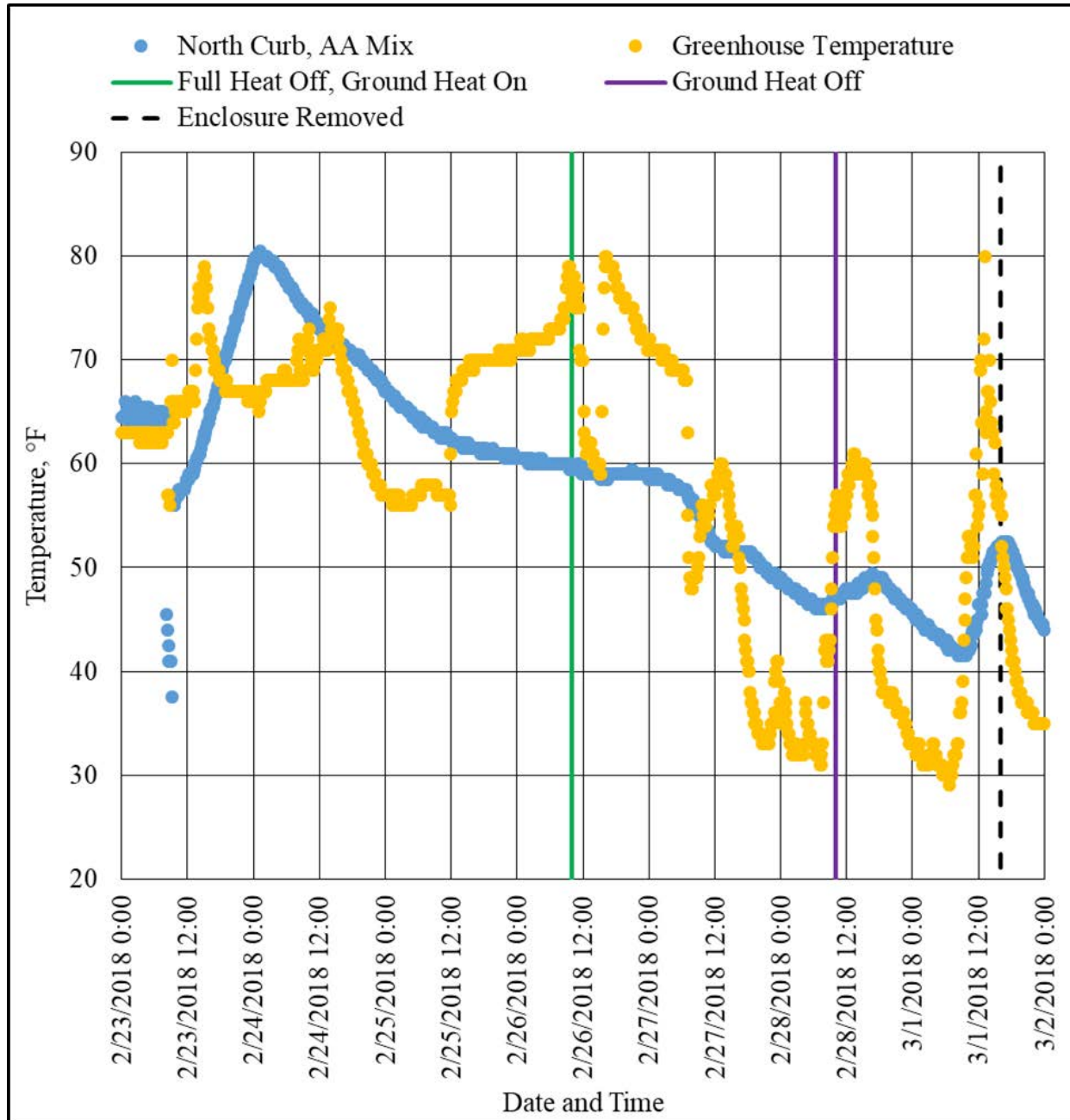
Appendix – Curing Temperature



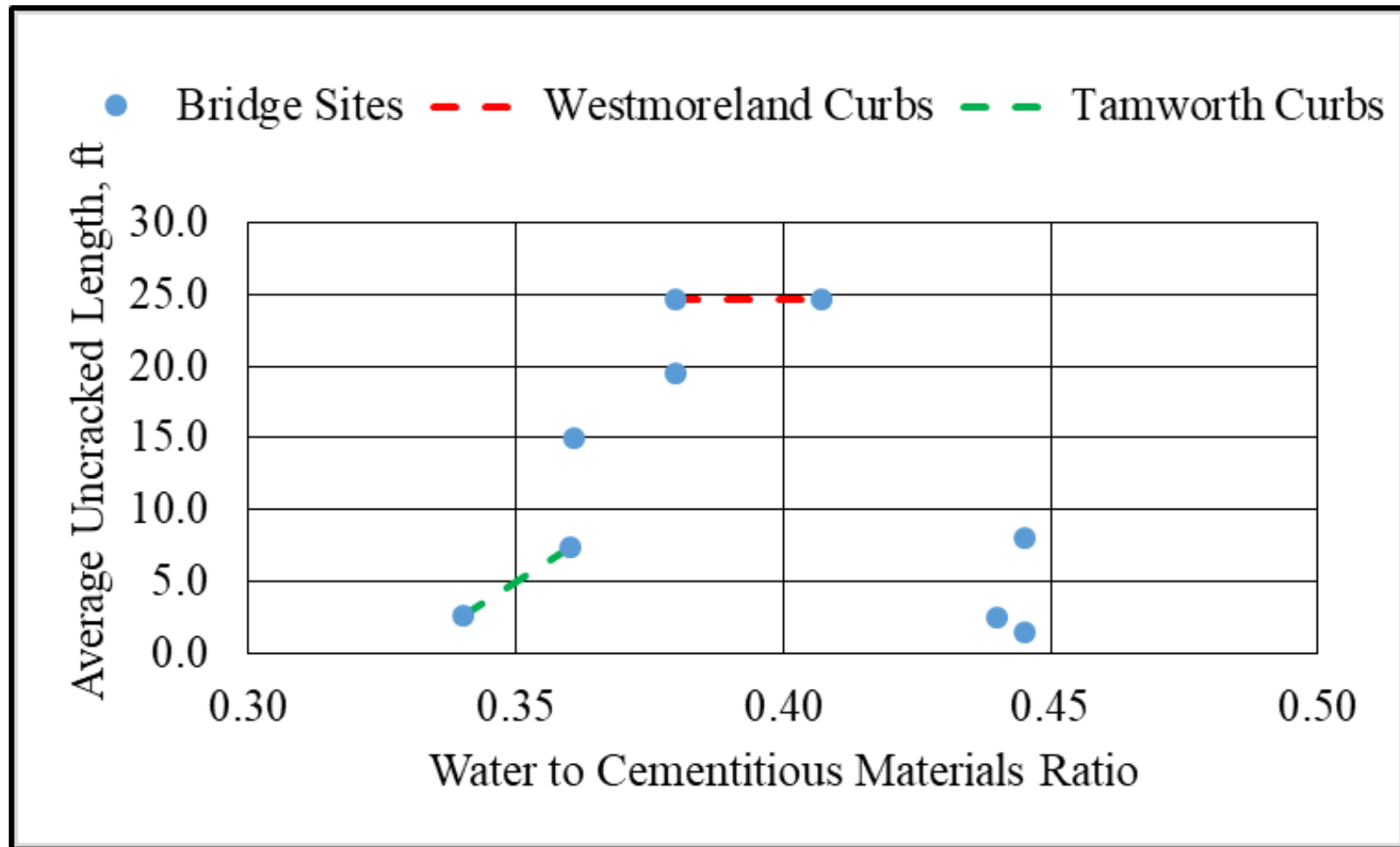
Results and Discussion

Curing Temperature

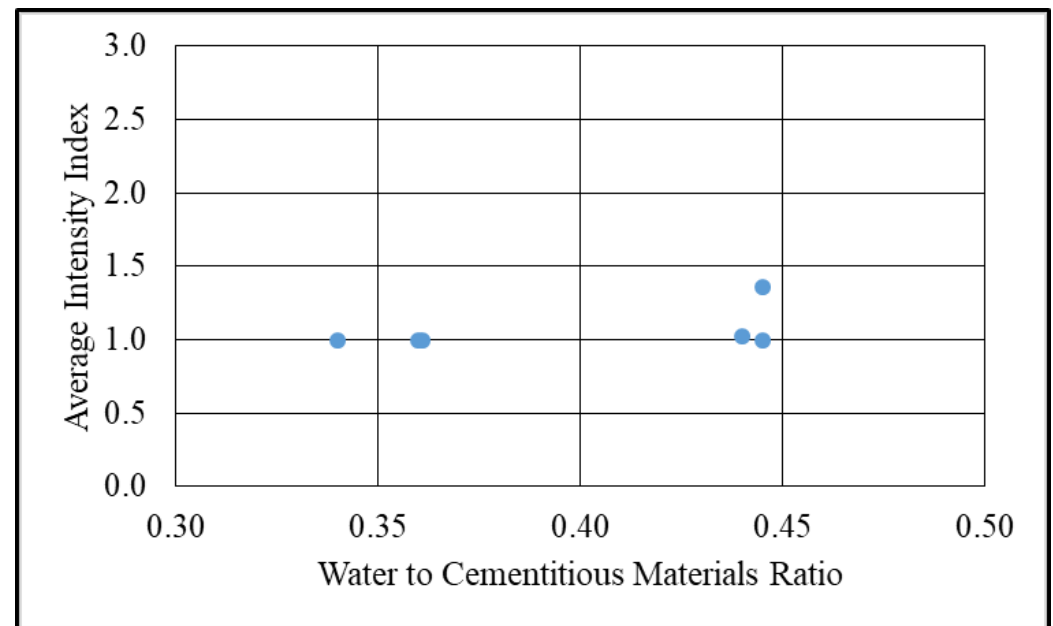
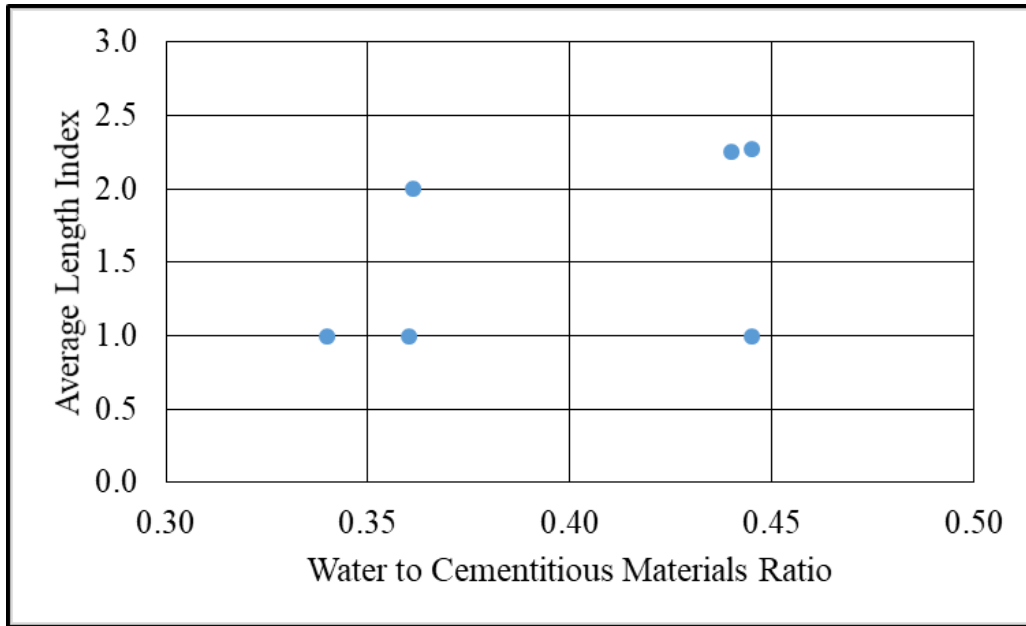
- Indicates curing procedure prevents concrete freezing or becoming too hot at an early age.



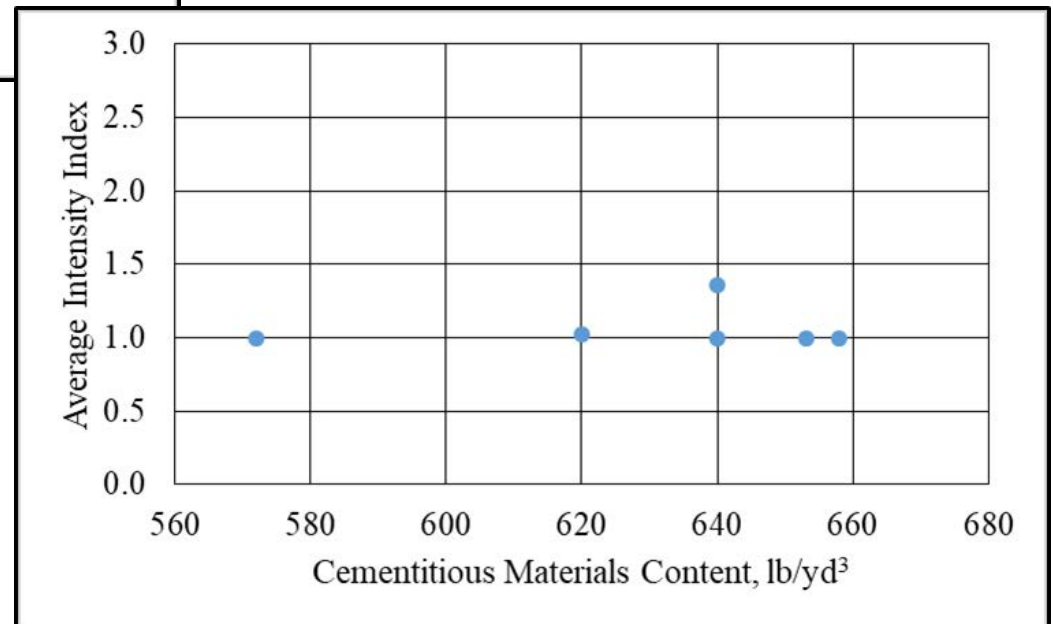
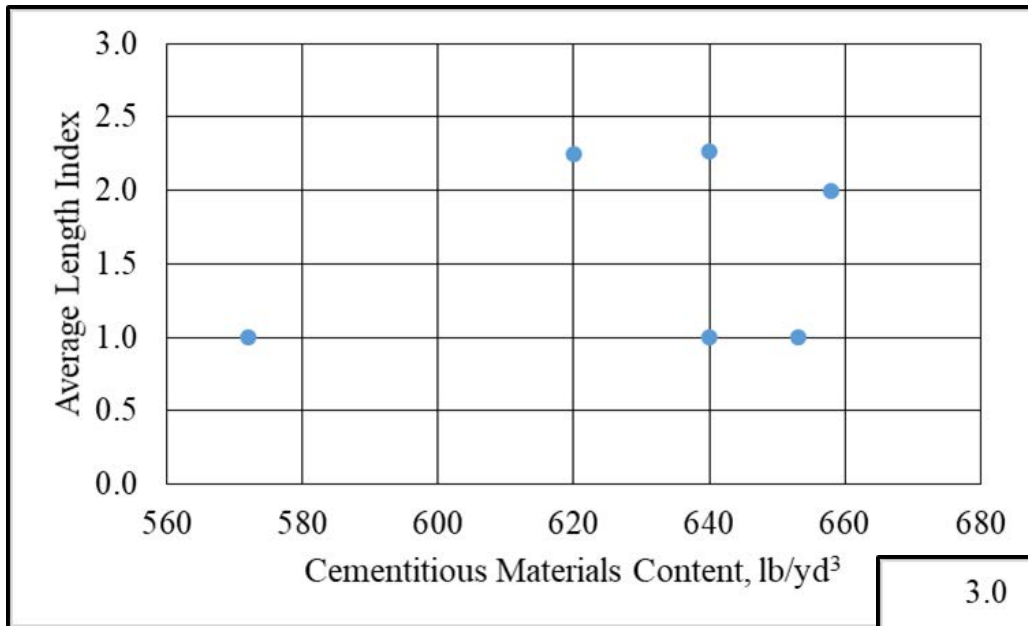
Appendix – w/cm



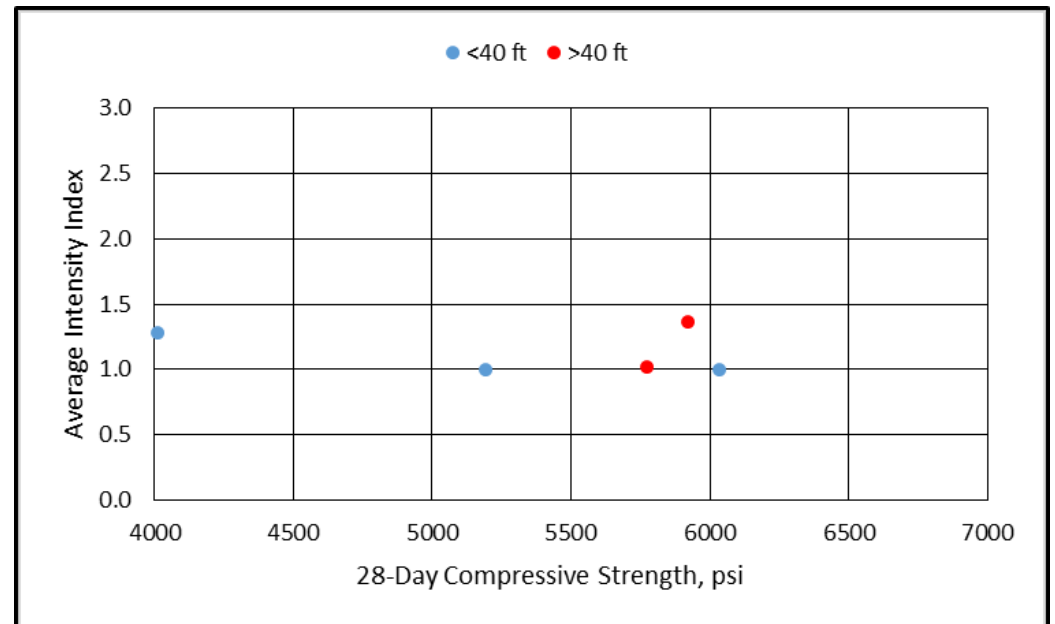
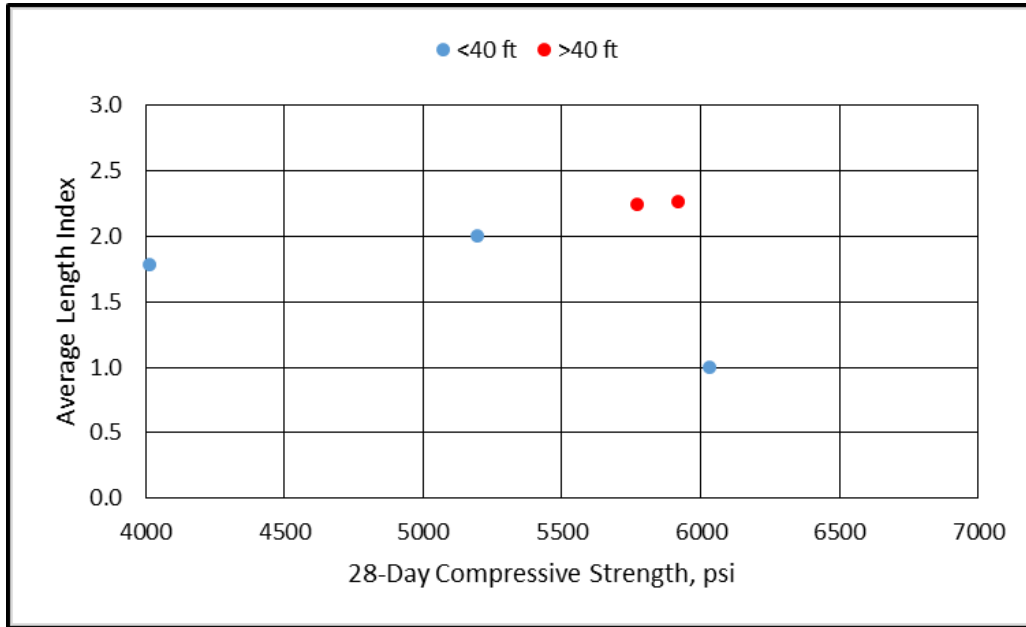
Appendix – w/cm



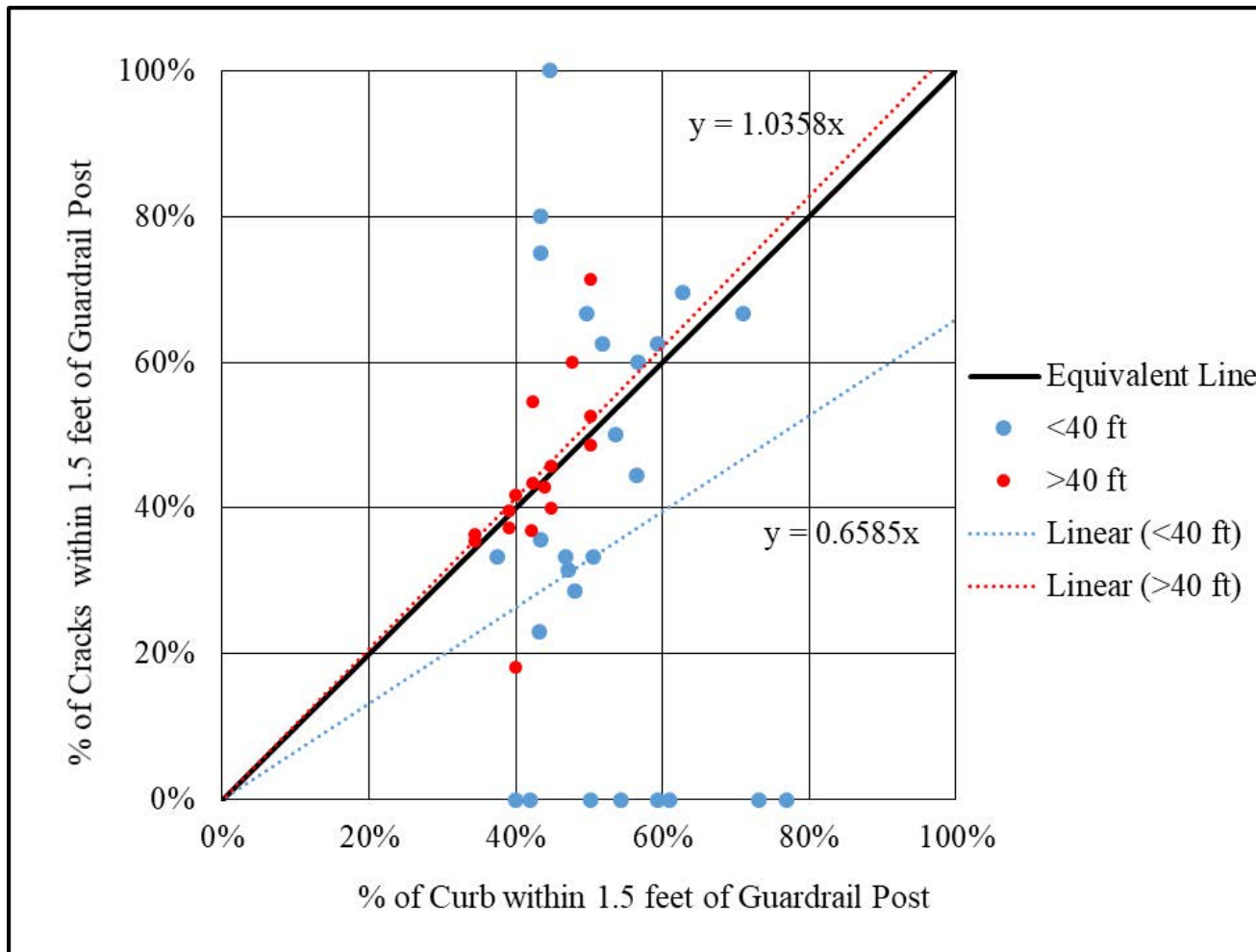
Appendix – Cementitious Content



Appendix – Compressive Strength



Appendix – Guardrail Posts

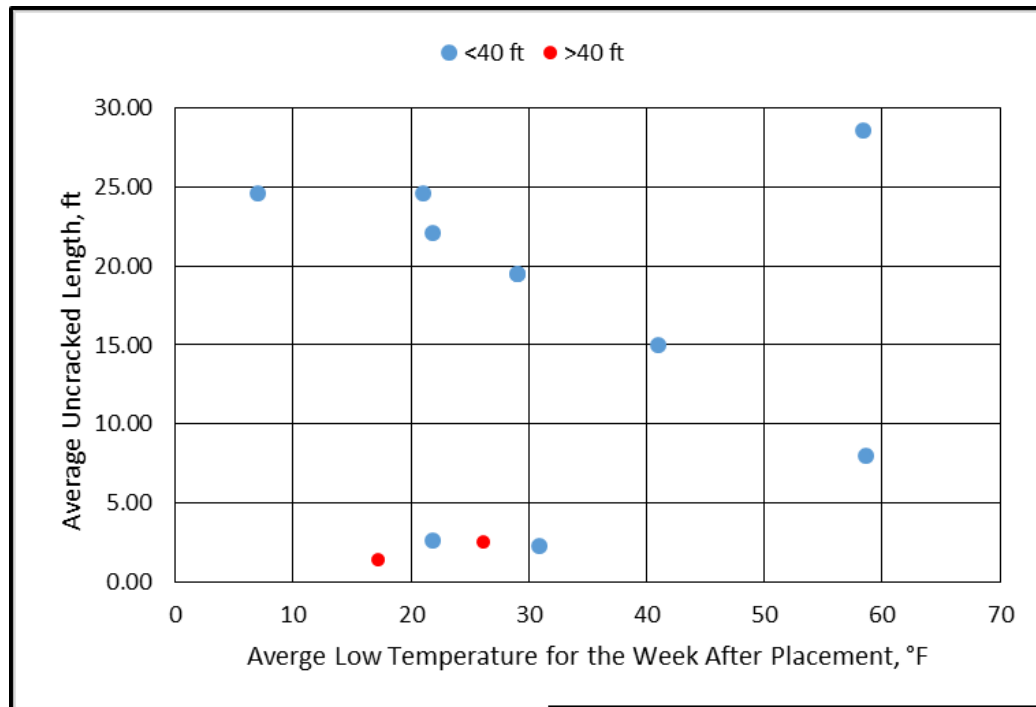


Appendix – Guardrail Posts

t-test	p-value $\alpha < 0.05$	Outcome
Average Uncracked Length, Bridge Length <40 feet	0.256	Uncracked length near posts does not significantly differ than that of the entire curb.
Average Uncracked Length, Bridge Length >40 feet	0.691	Uncracked length near posts does not significantly differ than that of the entire curb.
Average Length Index, Bridge Length <40 feet	0.514	Crack length near posts does not significantly differ than that of the entire curb.
Average Length Index, Bridge Length >40 feet	0.981	Crack intensity near posts does not significantly differ than that of the entire curb.
Average Intensity Index, Bridge Length <40 feet	0.72	Crack intensity near posts does not significantly differ than that of the entire curb.
Average Intensity Index, Bridge Length >40 feet	0.934	Crack intensity near posts does not significantly differ than that of the entire curb.



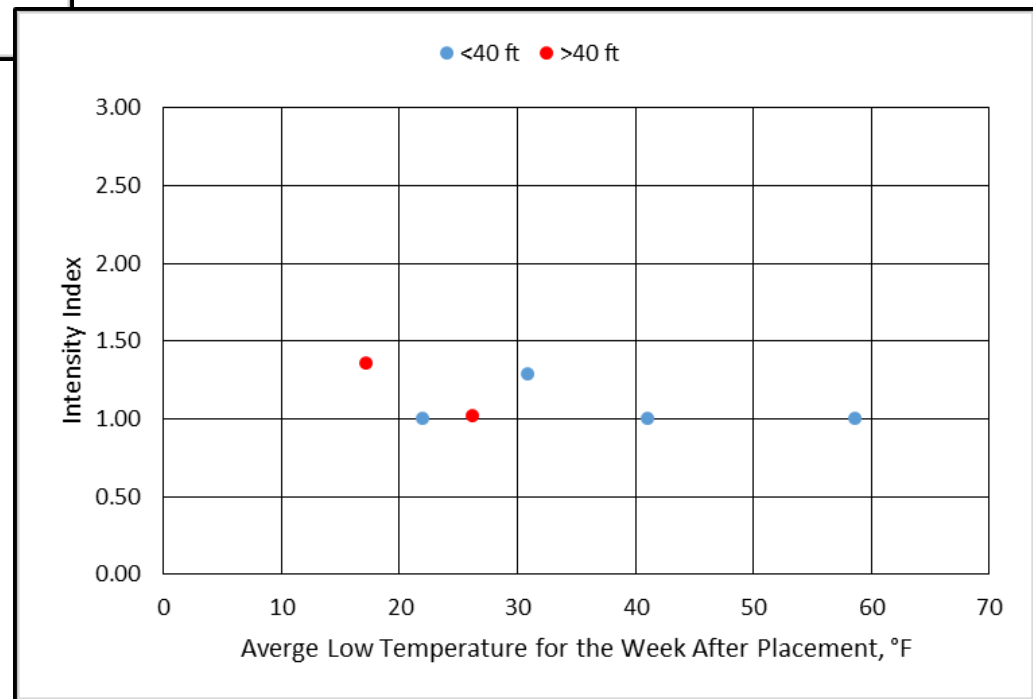
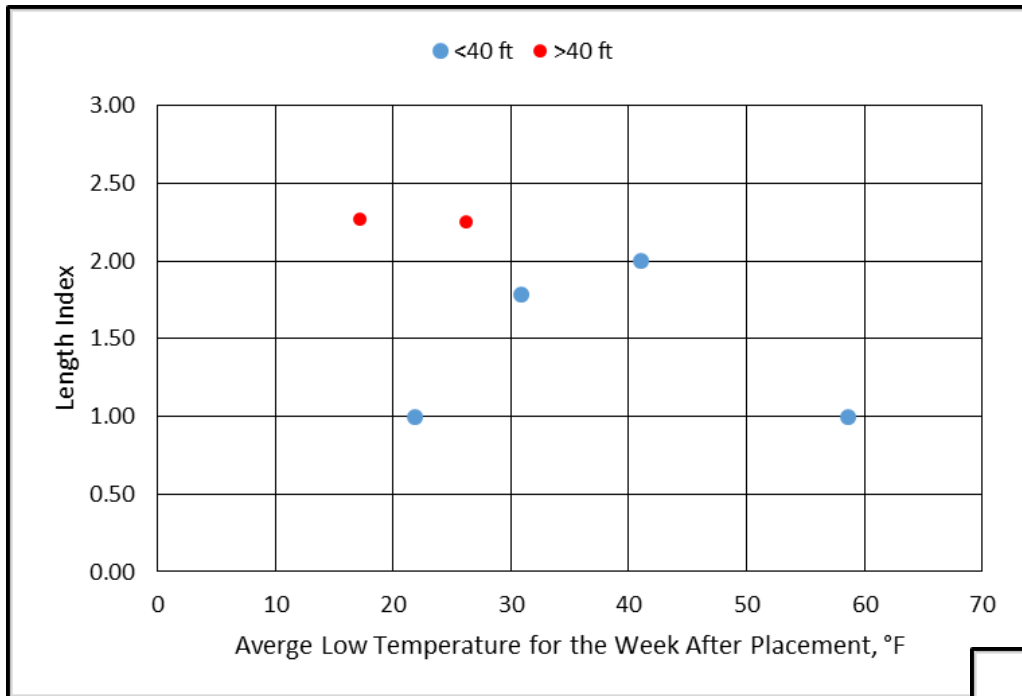
Appendix – Weather After Placement



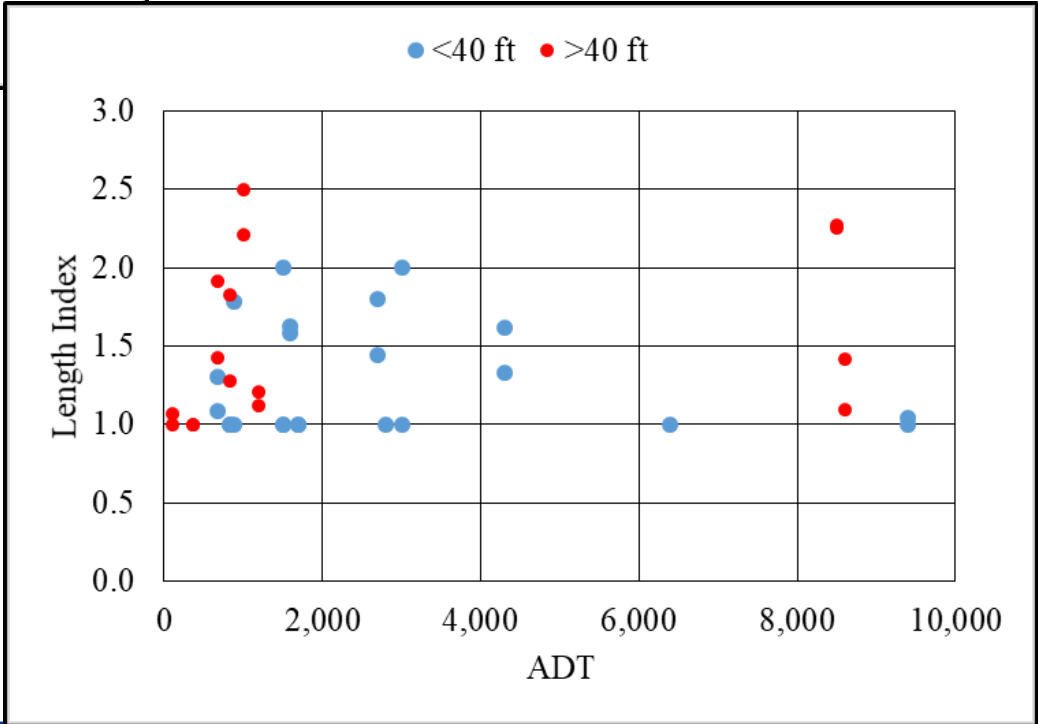
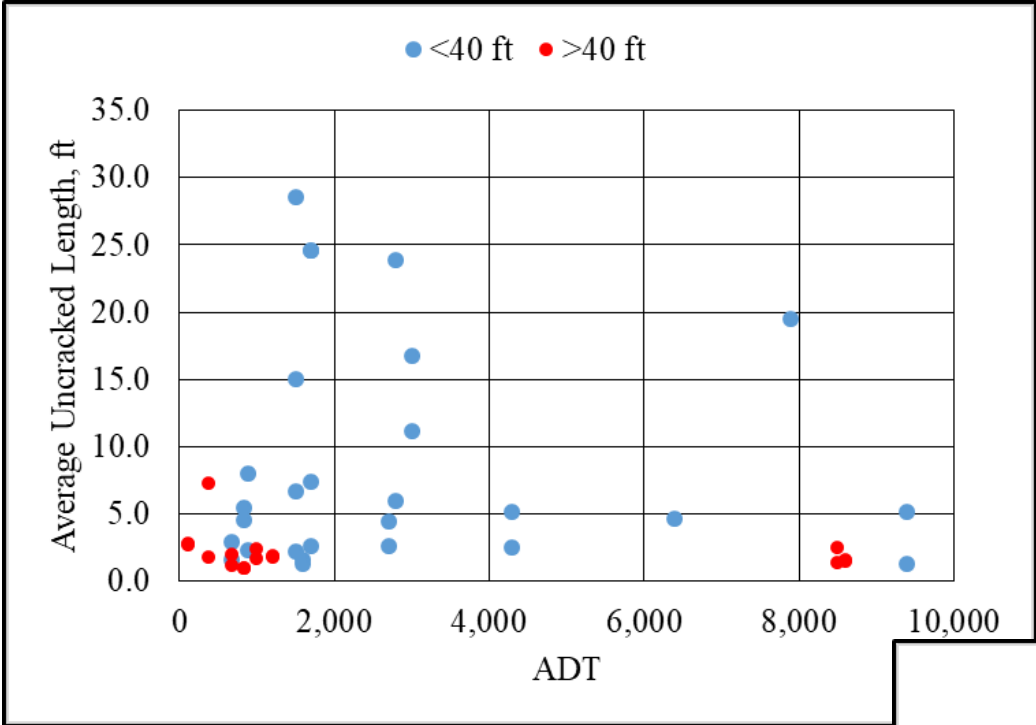
t-test	p-value $\alpha < 0.05$	Outcome
Average Length Index Daily Low on Day of Placement <32°F & >32°F	0.428	Average length index of a curb does not significantly differ for curbs placed below 32°F compared to those placed above 32°F.
Average Intensity Index Daily Low on Day of Placement <32°F & >32°F	0.804	Average intensity index of a curb does not significantly differ for curbs placed below 32°F compared to those placed above 32°F.
Average Uncracked Length Daily Low on Day of Placement <32°F & >32°F	0.858	Average uncracked length of a curb does not significantly differ for curbs placed below 32°F compared to those placed above 32°F.



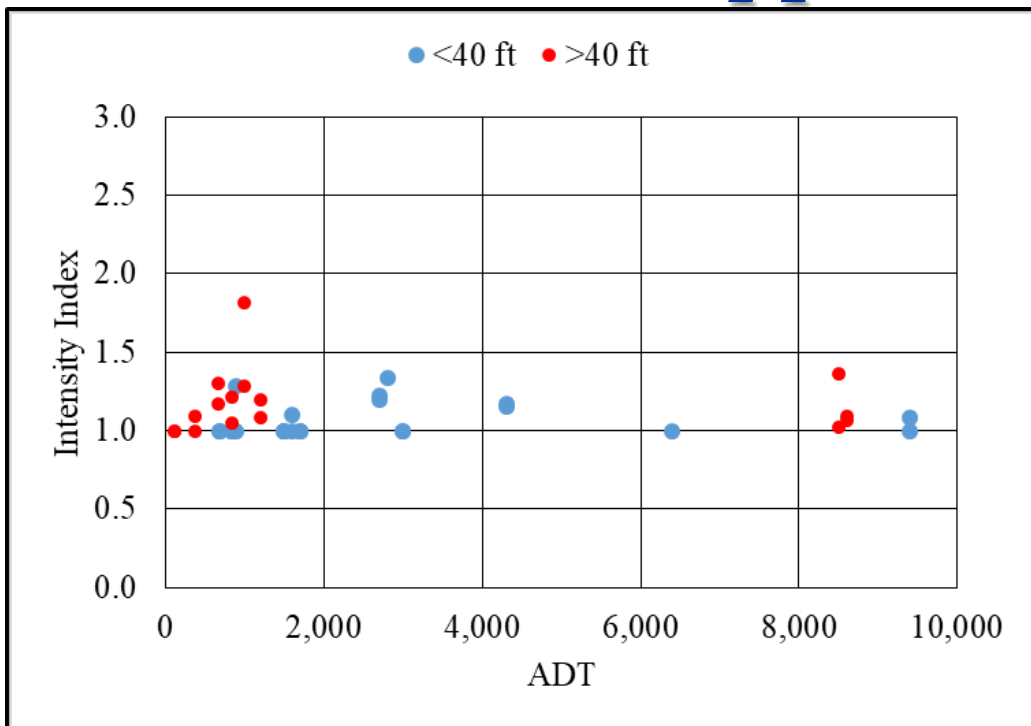
Appendix – Weather After Placement



Appendix – ADT



Appendix – ADT



Results and Discussion

Cementitious Materials Content

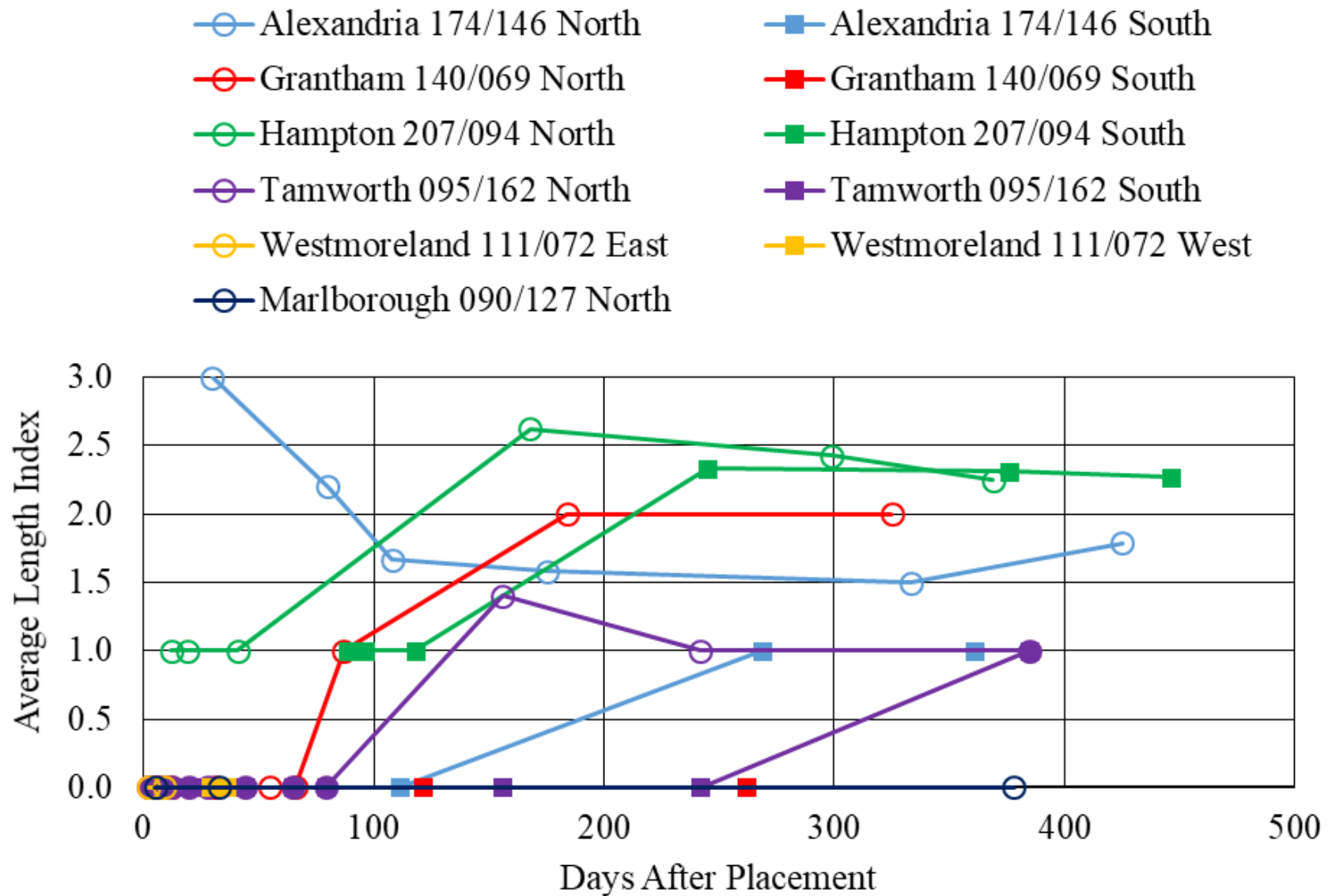
Water-Cement Ratio, w/cm

Pearson Correlation	r	Outcome
w/cm, Average Uncracked Length	-0.295	w/cm: Weak negative correlation
Cementitious Content, Average Uncracked Length	-0.520	Cementitious Content: Weak negative correlation



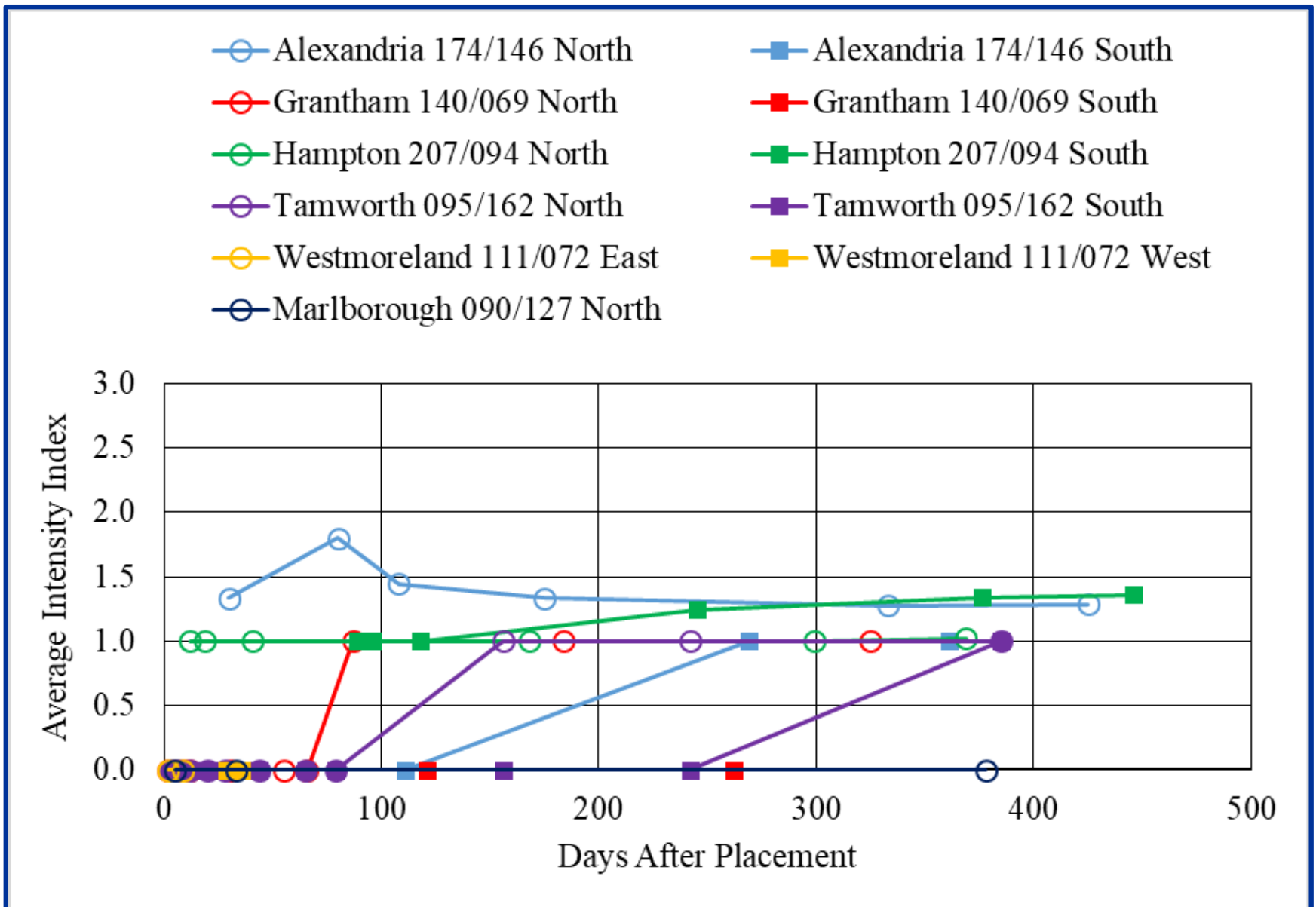
Results and Discussion

Cracking Over Time: Length Index



Results and Discussion

Cracking Over Time: Intensity Index



Results and Discussion

Cracking Over Time: Normalized Crack Volume

