NHDOT SPR2 PROGRAM
RESEARCH PROGRESS REPORT

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a progress report at least every three months during the project duration. Reports are due the 5th of the month following the end of the quarter. Please provide a project update even if no work was done during this reporting period.

Project # 26962P		**Report Period** Year: 2019 ☐Q1 (Jan-Mar) ☒Q2 (Apr-Jun) ☐Q3 (Jul-Sep) ☐Q4 (Oct-Dec)
Project Title: Reducing Cracking in New Bridge Curbs		
Project Investigator: Eshan Dave **Phone: 603-862-5268**		**E-mail: eshan.dave@unh.edu**
Research Start Date: December 1, 2016	**Research End Date:** September 30, 2019	**Project schedule status:** ☒ On schedule ☐ Ahead of schedule ☐ Behind schedule[1]

Brief Project Description: In recent years a number of newly constructed concrete curbs on NHDOT bridges have suffered from premature, early-age cracking. This project focuses on proposing necessary changes to the materials specifications as well as construction and maintenance practices to lower the propensity for early age cracking. The scope of the project involves developing a crack measurement system to quantify cracking in curbs, using the measurement system on a number of newly constructed curbs with different concrete mixes (varying cementitious material amounts, water amounts etc.), construction practices, and curing strategies. Analysis of results from field trials and development of recommendations will also be completed.

Progress this Quarter (include meetings, installations, equipment purchases, significant progress, etc.):
Major effort during this past quarter was spent on analysis of the field data that has been collected over the course of this study. A new approach towards quantification of the curb cracking performance called "normalized crack volume" was developed and used to analyze various study variables. Results for the normalized crack volume measure of the study curbs is shown in Figure 1.

The analysis conducted in the reported quarter continued to support the hypothesis that use of 14-day wet cure has high potential for lowering the propensity of early age cracking in the curbs (an example is shown in Figure 2). Total cementitious content also shows to be a factor in increasing the potential for curb cracking (Figure 3).

Initial recommendations form this study have been developed and they were presented to NHDOT in May at a TAG meeting. The presentation slides from the TAG meeting are attached with this report as an appendix. Primary recommendations for practice change are as following:

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

As with other quarters, several site visits were made to curbs placed during the study in the reported quarter. Site visits to these curbs also included training of new student researcher who will continue the site visits for remaining duration of the project.

Items needed from NHDOT (i.e., Concurrence, Sub-contract, Assignments, Samples, Testing, etc…):
Continued cooperation from NHDOT regarding construction dates and coordination of test variables is required in the

[1] Task 2 is delayed slightly due to delay in curb construction. Overall project is expected to be on time.

following months. NHDOT will need to work with researchers on making arrangements to have variables procedures applied to test curbs. Following curb placement, NHDOT will need to send batch slips and concrete strength data to UNH researchers.

Anticipated research next 3 months:
The following key topics will be undertaken by the research team during next 3 months:

(1) Continued visits to Westmoreland and Meredith bridge sites.
(2) Further analysis and refinement of gathered data with the addition of data from Westmoreland and Meredith.
(3) Development of the draft final report and refinement of recommendations.

Circumstances affecting project: Describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope, and budget, along with recommended solutions to those problems.
One bridge is currently planned to be constructed during the study, this bridge is Meredith will begin in early July 2019. This means that Task 2 of the research project will extend longer than initially indicated. The extension of Task 2 means that Task 3 may be delayed as well. Fortunately, a significant portion of the analysis in Task 4 has already been completed and will just need to be updated based on information from the new bridge sites. This means the research project can still be completed on schedule providing there are no large delays in curb reconstruction. Some preliminary analysis on the curbs has been conducted for Task 4 and may help keep the project on the original timeline although newly collected data will still need to be analyzed.

Tasks (from Work Plan)	Planned % Complete	Actual % Complete
1. Review of Current Practices	**100**	**100**
2. Construction of Concrete Curbs	**100**	**95**[2]
3. Survey of Concrete Curbs for Cracking Performance	**95**	**95**
4. Analysis of Results and Recommendation Development	**40**	**75**

[2] * Actual percent completed was determined assuming a total of 5 bridges will be constructed during the study. The current bridges constructed include Alexandria, Tamworth, Marlborough, Grantham, and Westmoreland (111/072). Marlborough is counted as only half a bridge since only one curb was replaced.

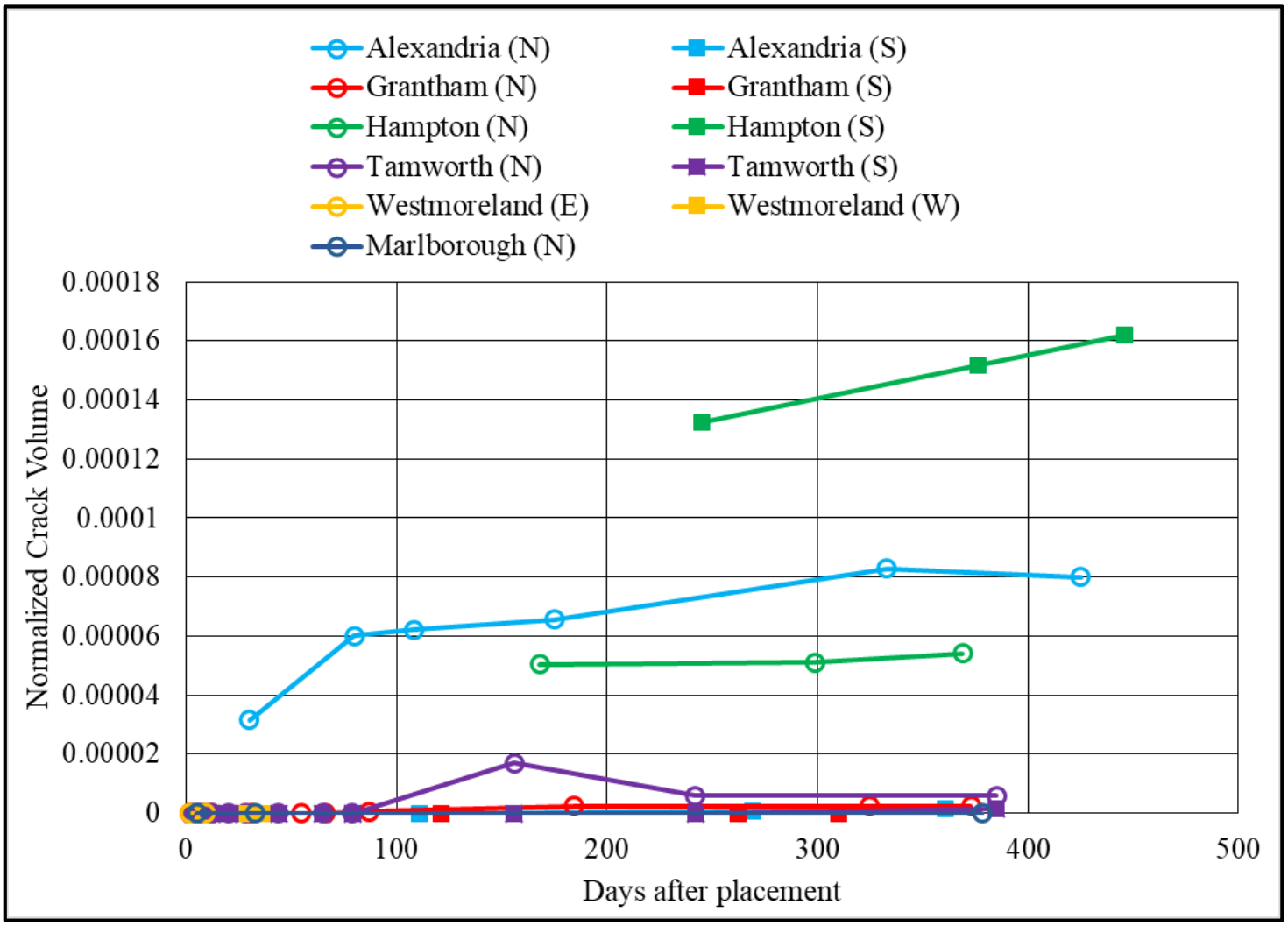

Figure 1 Normalized Crack Volume for Study Curbs.

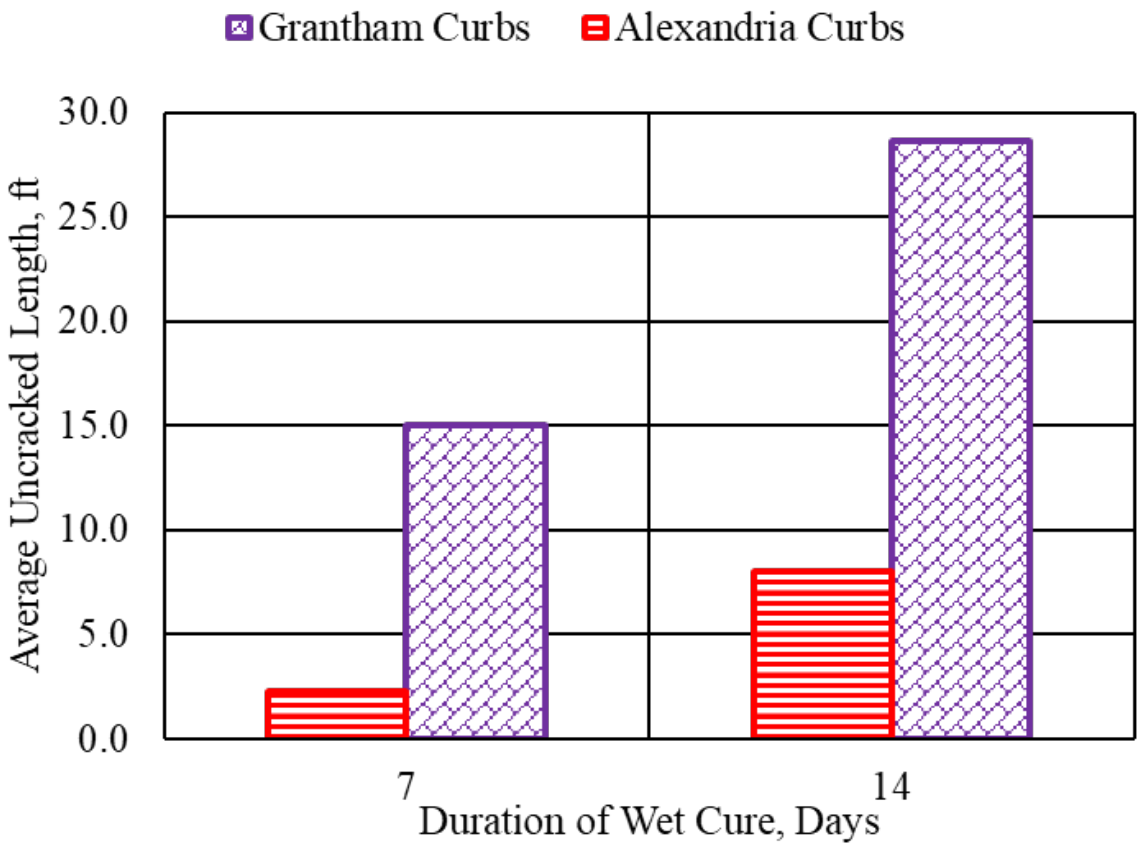

Figure 2: Comparisons of the amount of cracking (in terms of uncracked lengths) on companion curbs from two bridges with different curing durations.

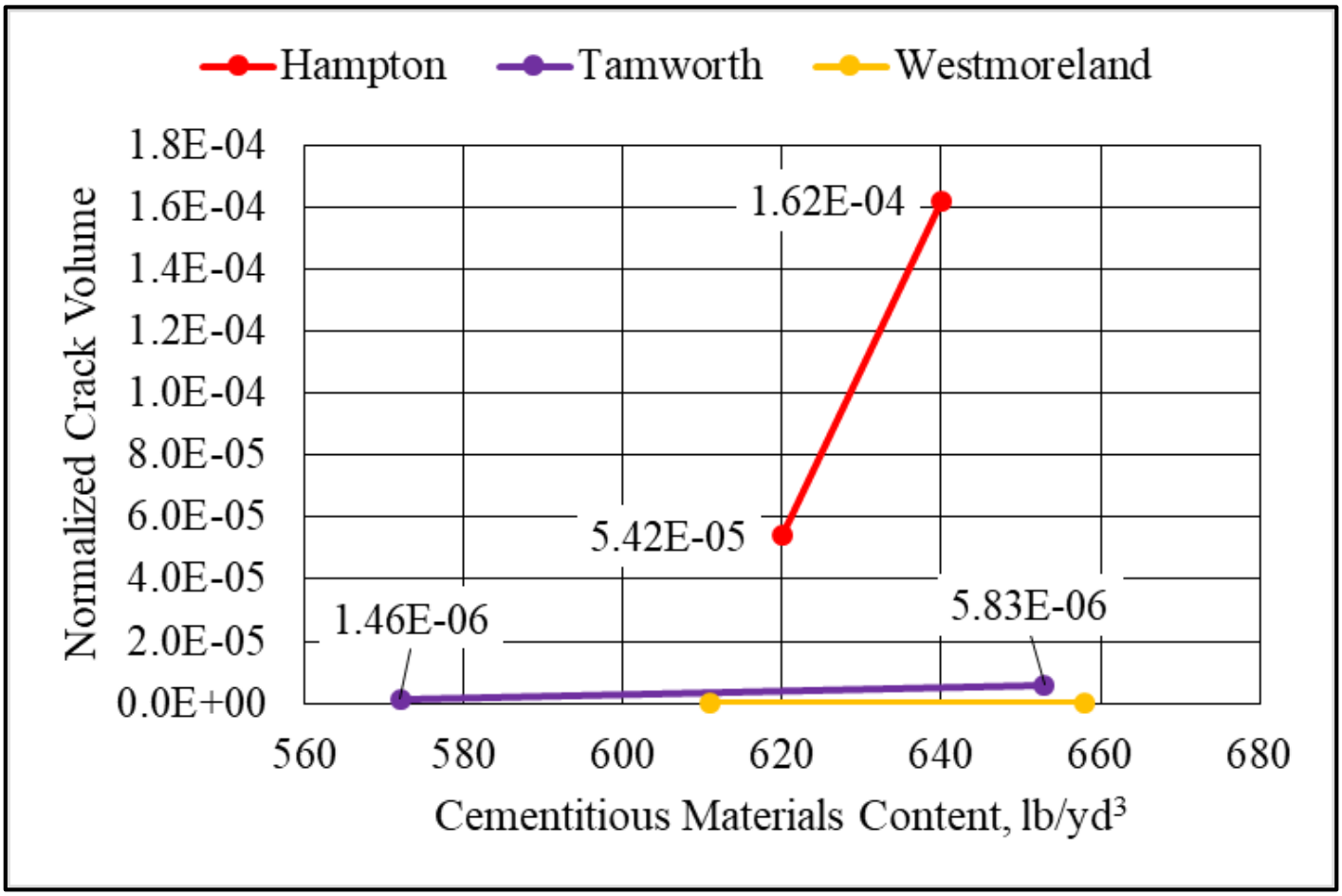

Figure 3: Comparisons of the curb cracking performance (in terms of normalized crack volume) on companion curbs from three bridges with different cementitious material contents.

NHDOT Research Project 26962P

Reducing Cracks in New Bridge Curbs

May 9th 2019 TAG Meeting

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University of New Hampshire

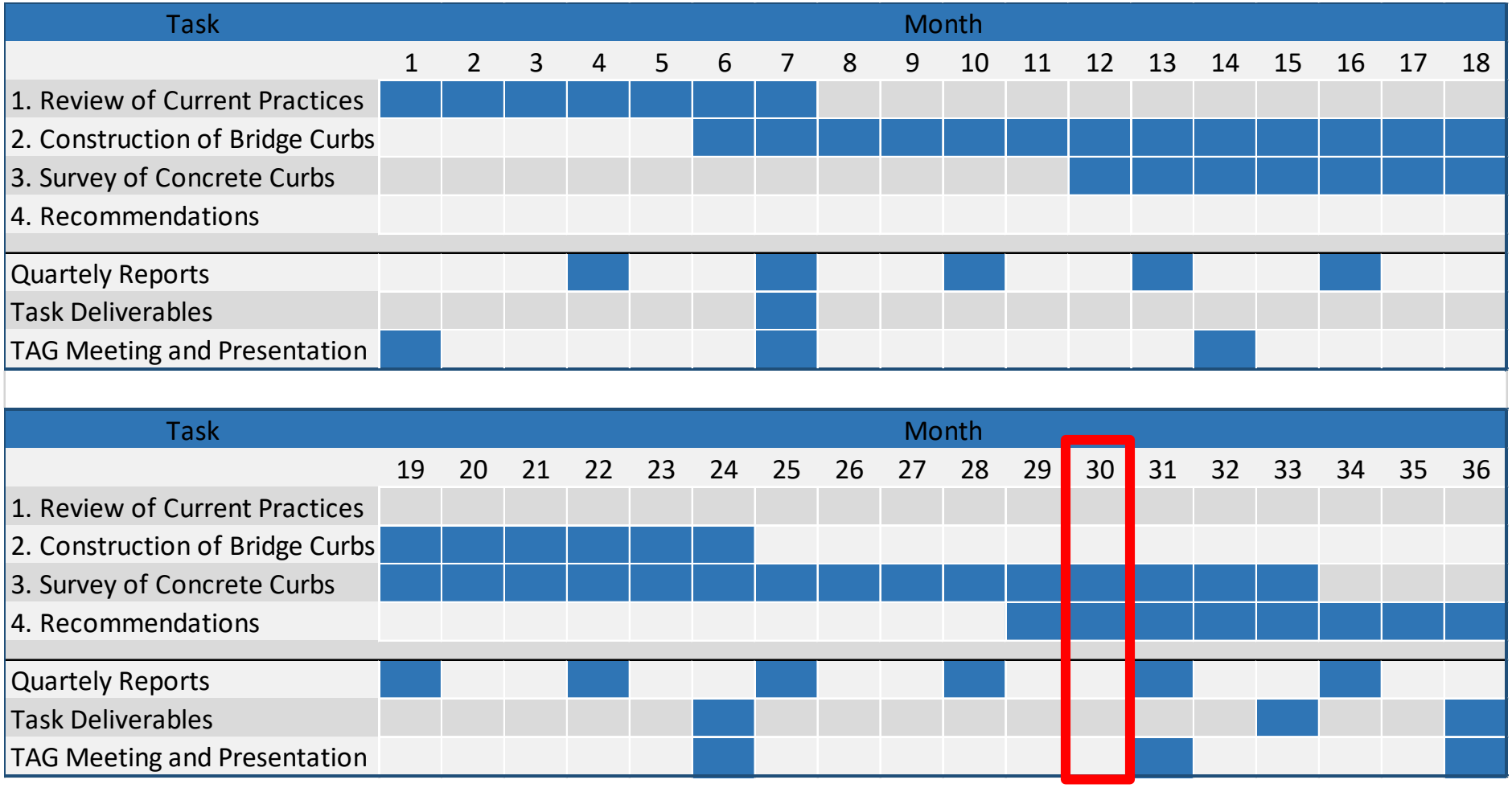
University of New Hampshire

New Hampshire DOT Department of Transportation

Outline

- **Background**
  - **Project Schedule**
  - **Research Goals**
- Research Methodology
- Results and Discussion
- Summary and Conclusions
- Recommendations and Future Tasks

Background: Project Schedule



Background: Research Goals

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

Outline

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

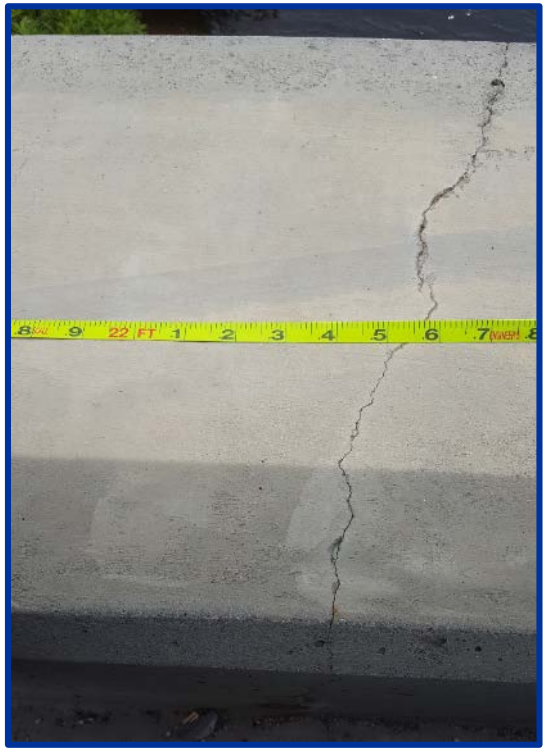
Research Methodology: Cracking Indices

- 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.

1

2



3

Research Methodology: Cracking Indices

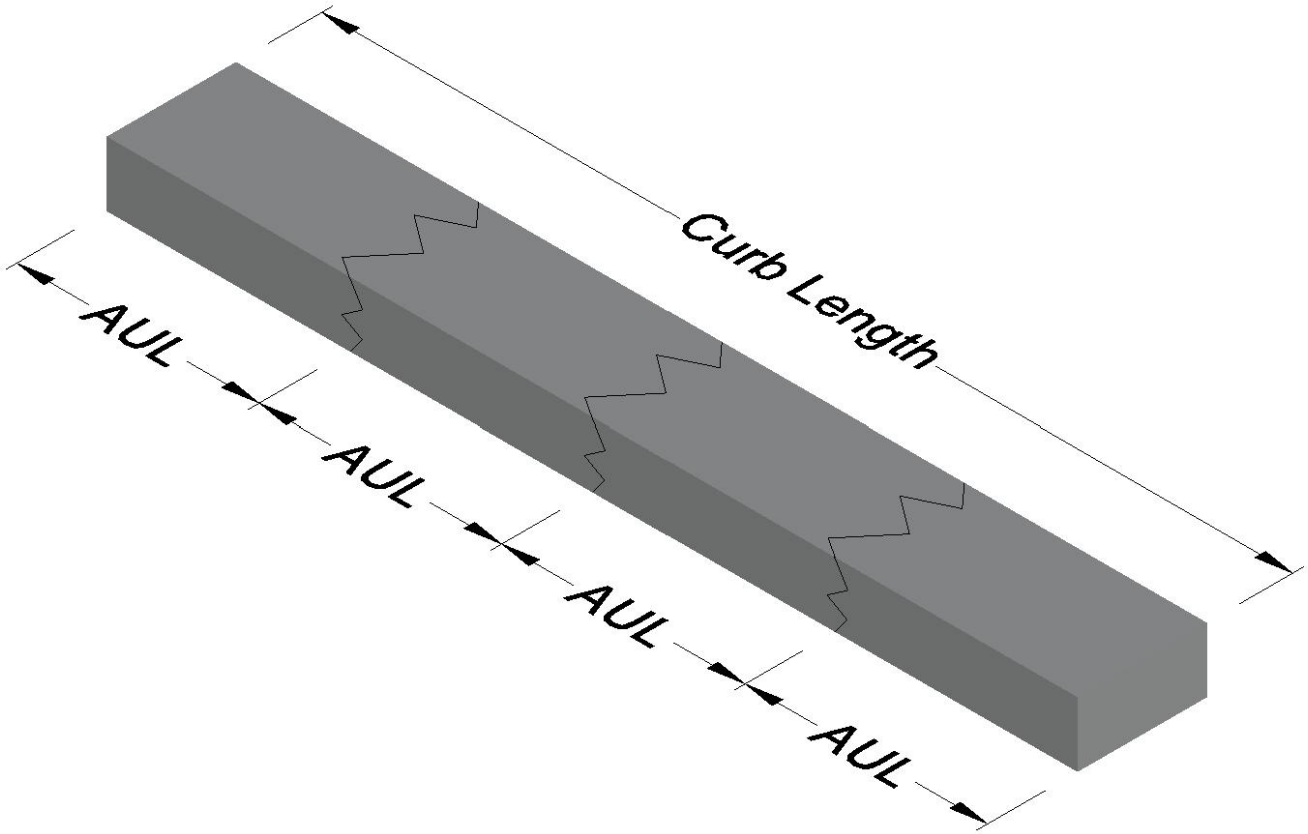
- Intensity Index (II)
  - ACI 224R-01 Table 4.1
  - 0.007” for Deicing Chemicals
  - 0.016” Dry Air

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

Research Methodology: Cracking Indices

- Average Uncracked Length (AUL)

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



Research Methodology: Cracking Indices

- Severity Index (SI)

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

- Curb Cracking Index, CCI

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

Crack Volume

- Assign each crack a typical 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
- Divide by the curbs total volume to adjust for different curb lengths.

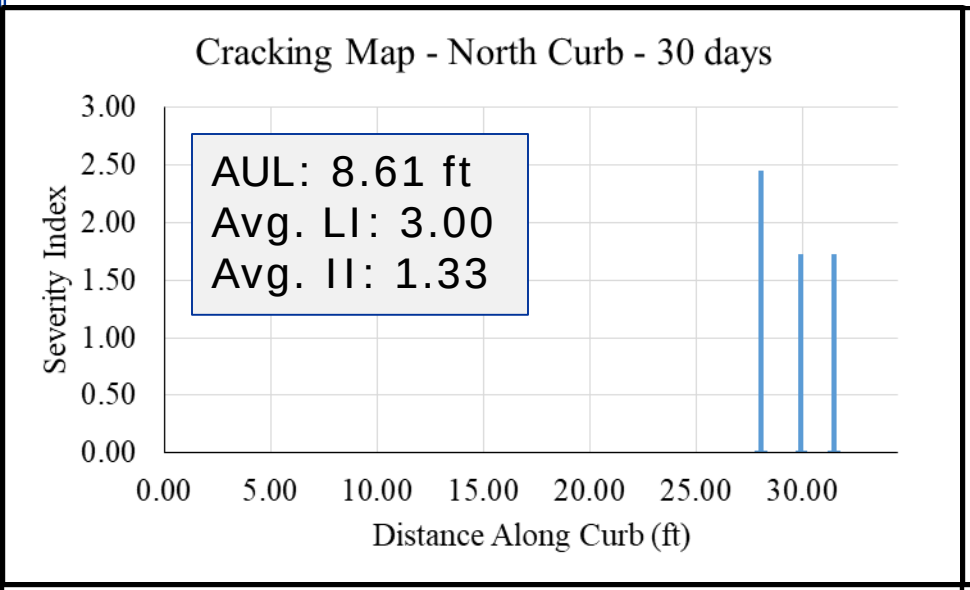
Length Index	Sketch of Cracked Cross-Section	Approximate Crack Area
1		1/26
2		1/6
3		1/2

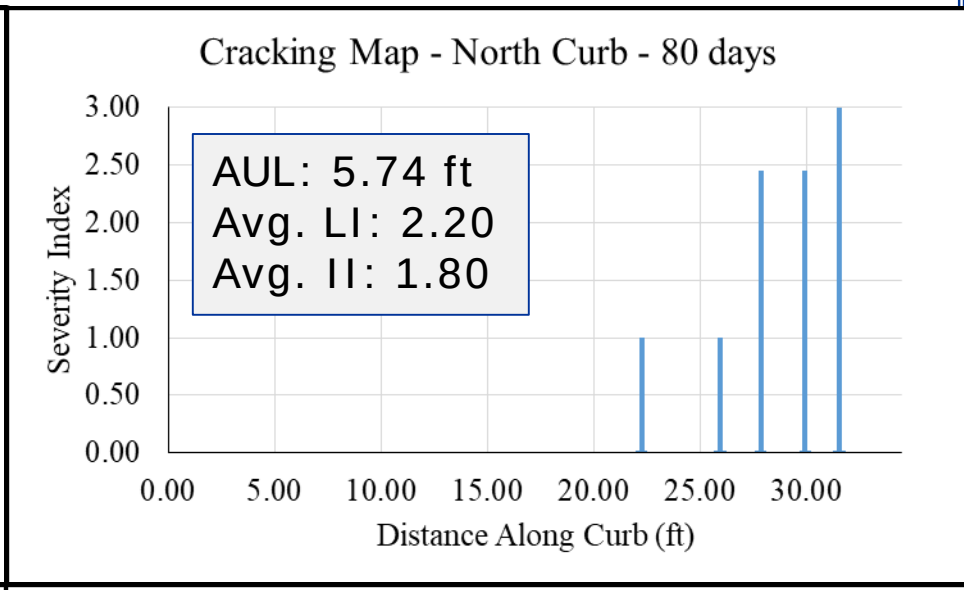
Intensity Index	Assigned Width inch
1	0.005
2	0.012
3	0.017

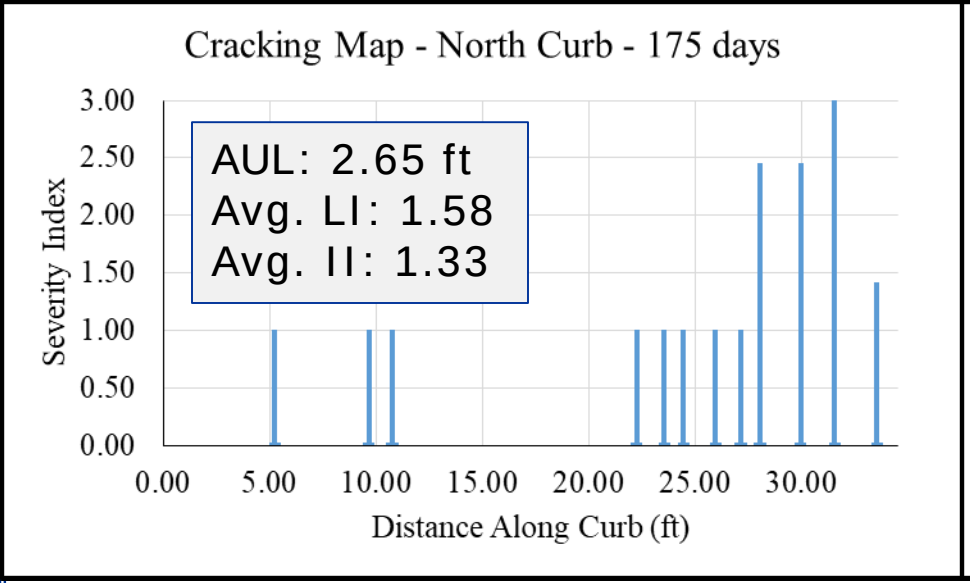
$$Normalized\ Crack\ Volume = \frac{Total\ Cracked\ Volume}{Curb\ Volume}$$

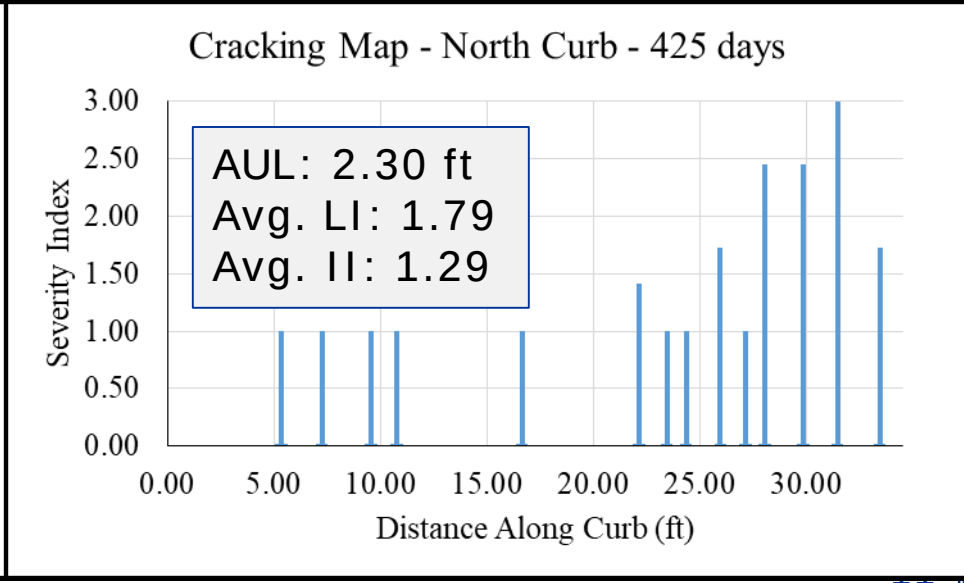
Research Methodology: Data Organization

- Alexandria (174/146) Cracking Maps:









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: Investigation Challenges

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

Research Methodology: Data Analysis

1. Graphical comparisons

2. t-tests
   - Compare two sets of data
   - Determines the likelihood the differences between the data are by chance
   - Described by a significance value, α, and a p-value which ranges from 0 to 1

3. Pearson's correlation
   - Describes how well the data matches a linear trend

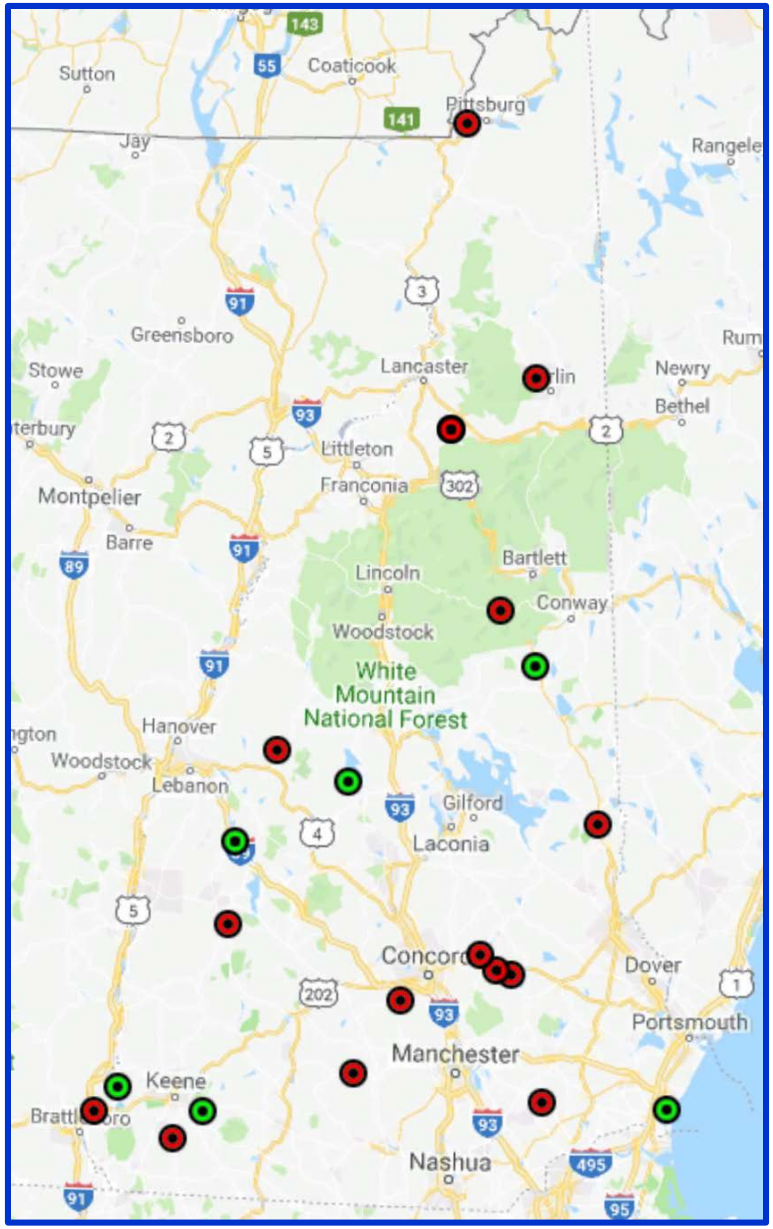
Outline

- 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 and Future Tasks

Results and Discussion

23 Bridges Visited

- Existing Bridge Curb Visits (red)
  - 17 bridges visited constructed after 2008
  - Look at previous bridges and see if correlations exist
- New Bridge Curb Visits (green)
  - 6 new bridges visited



Results and Discussion

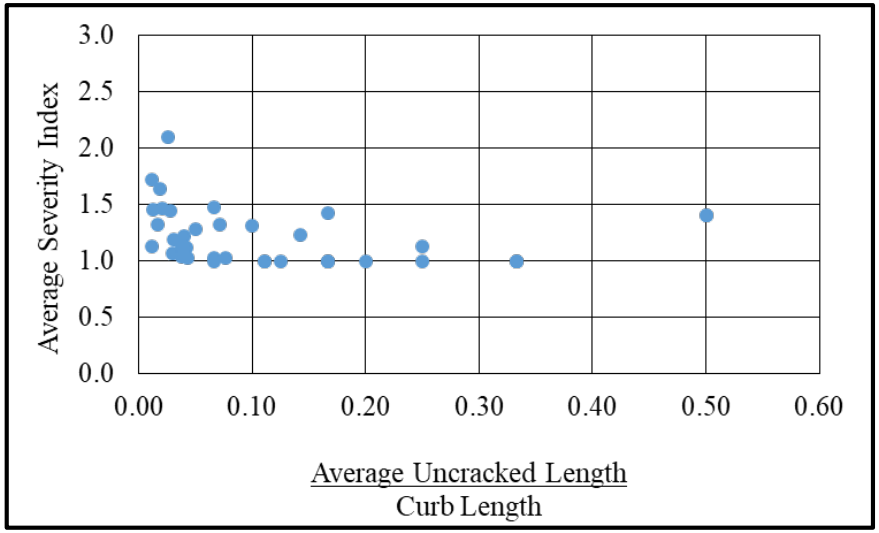
- New Bridge Curb Sites and Variables
  - **Hampton** – No variable
  - **Alexandria** – 14-day wet cure
  - **Tamworth** – ‘A’ mix
  - **Marlborough** – No variable, one curb replaced
  - **Grantham** – 14-day wet cure
  - **Westmoreland** – ‘A’ mix

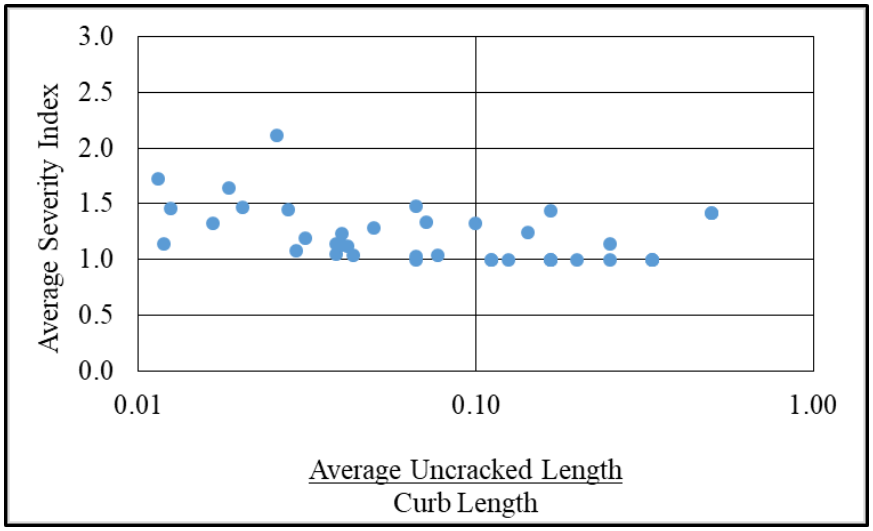
Results and Discussion

Distribution of Cracks

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

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

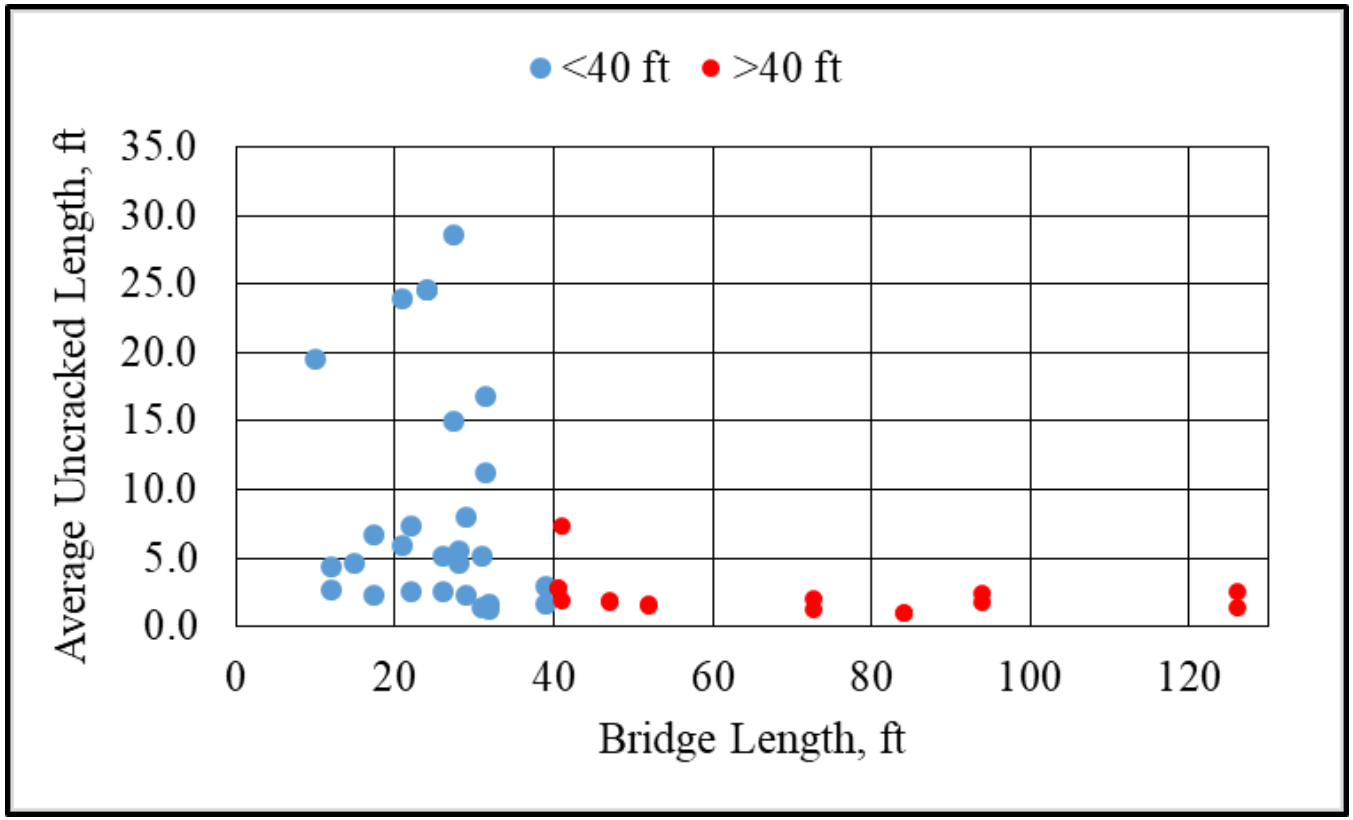




Results and Discussion

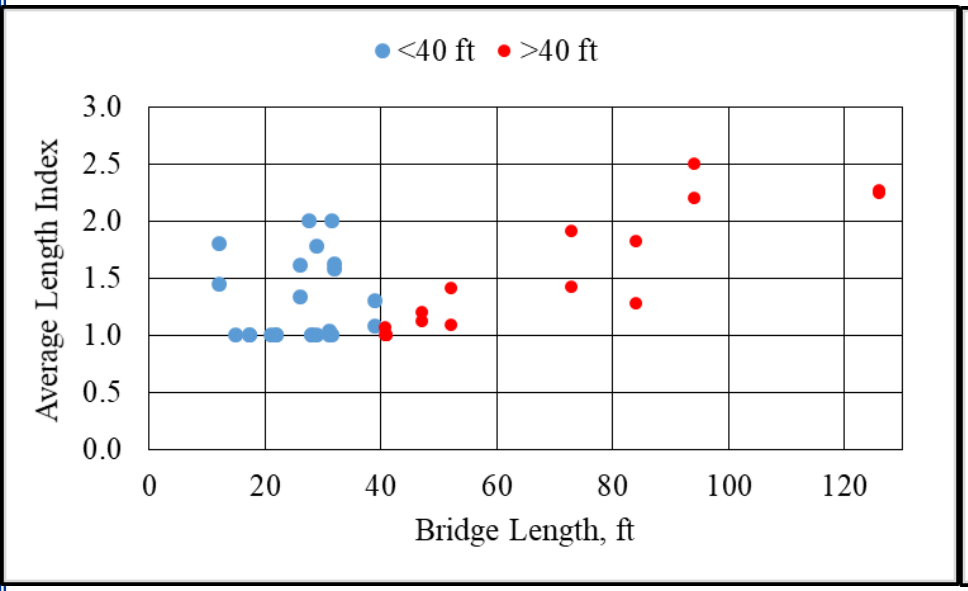
Bridge Length

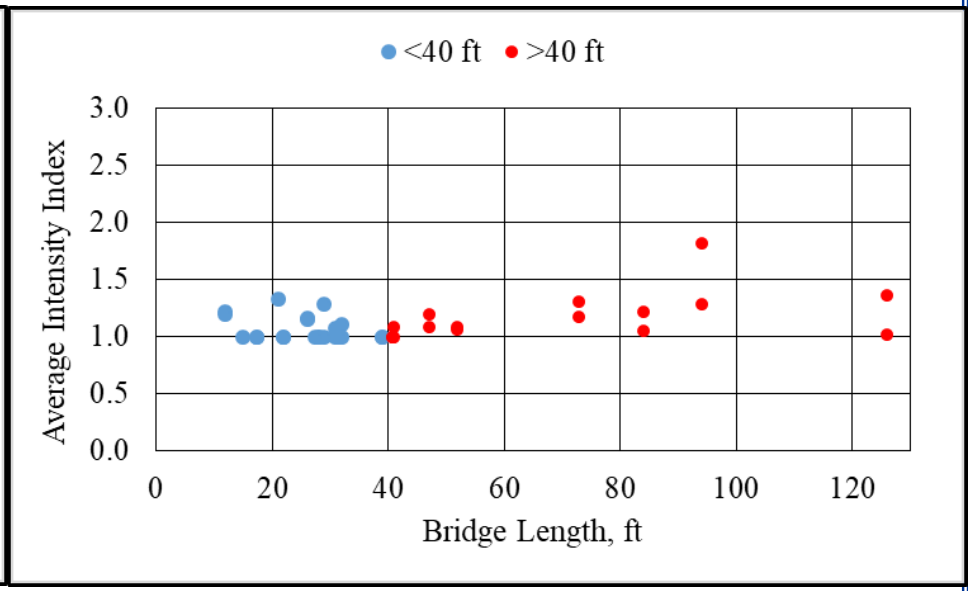
- Noticeable change near 40 ft in length
- Around 30-40 ft concrete slab structures are switched to steel I-beams with concrete deck



Results and Discussion

Bridge Length

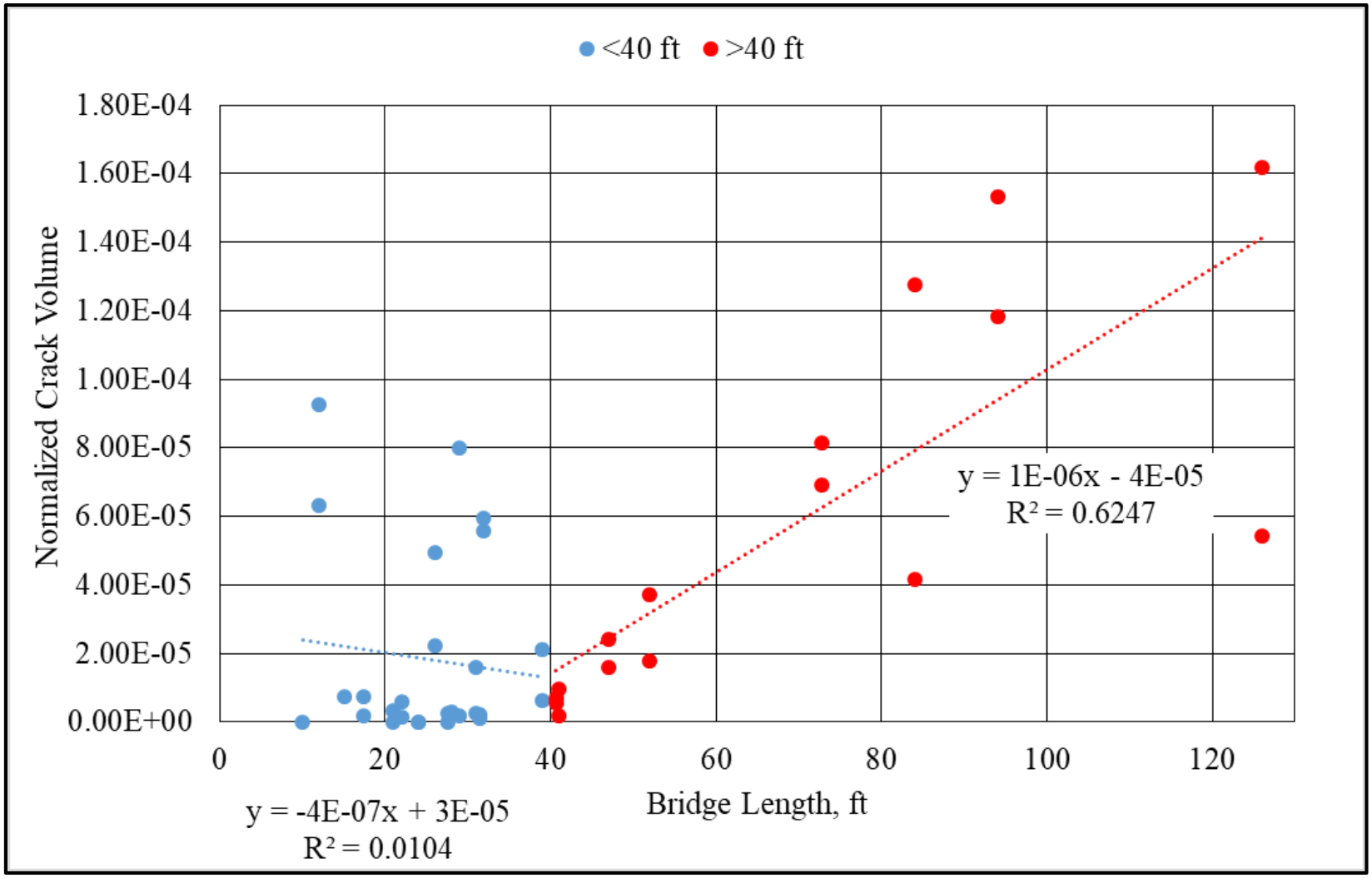




t-test <40 ft & >40 ft	p-value $\alpha < 0.05$	Outcome
Average Length Index	0.119	Not Significant
Average Intensity Index	0.077	Not Significant
Average Uncracked Length	0.0004	Significant

Results and Discussion

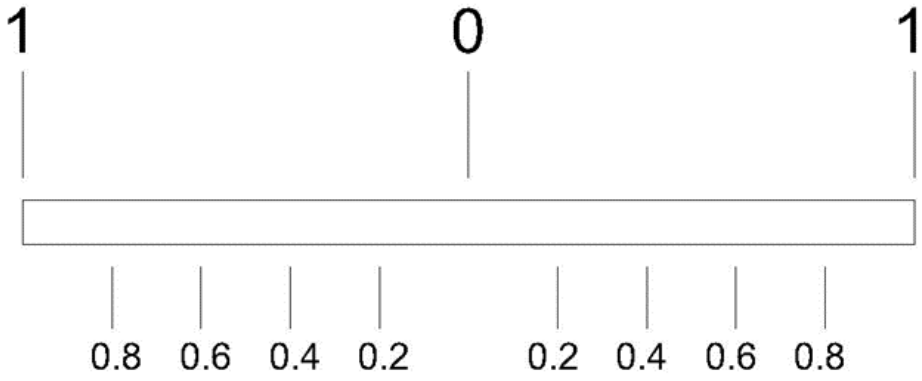
Bridge Length – Volume Method

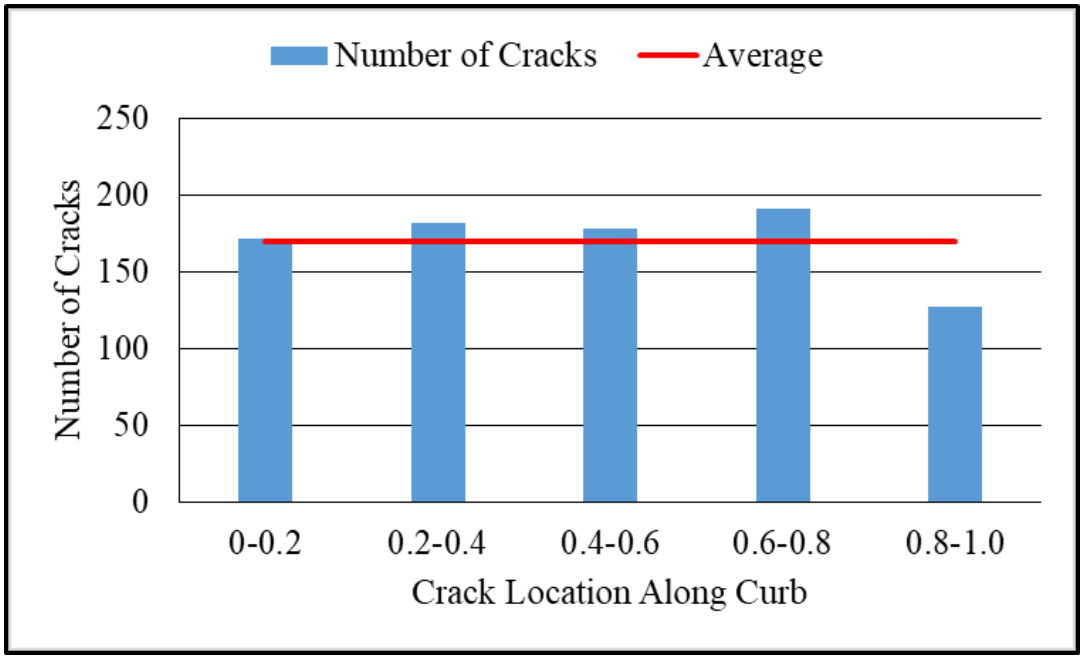


Results and Discussion

Location Along Curb

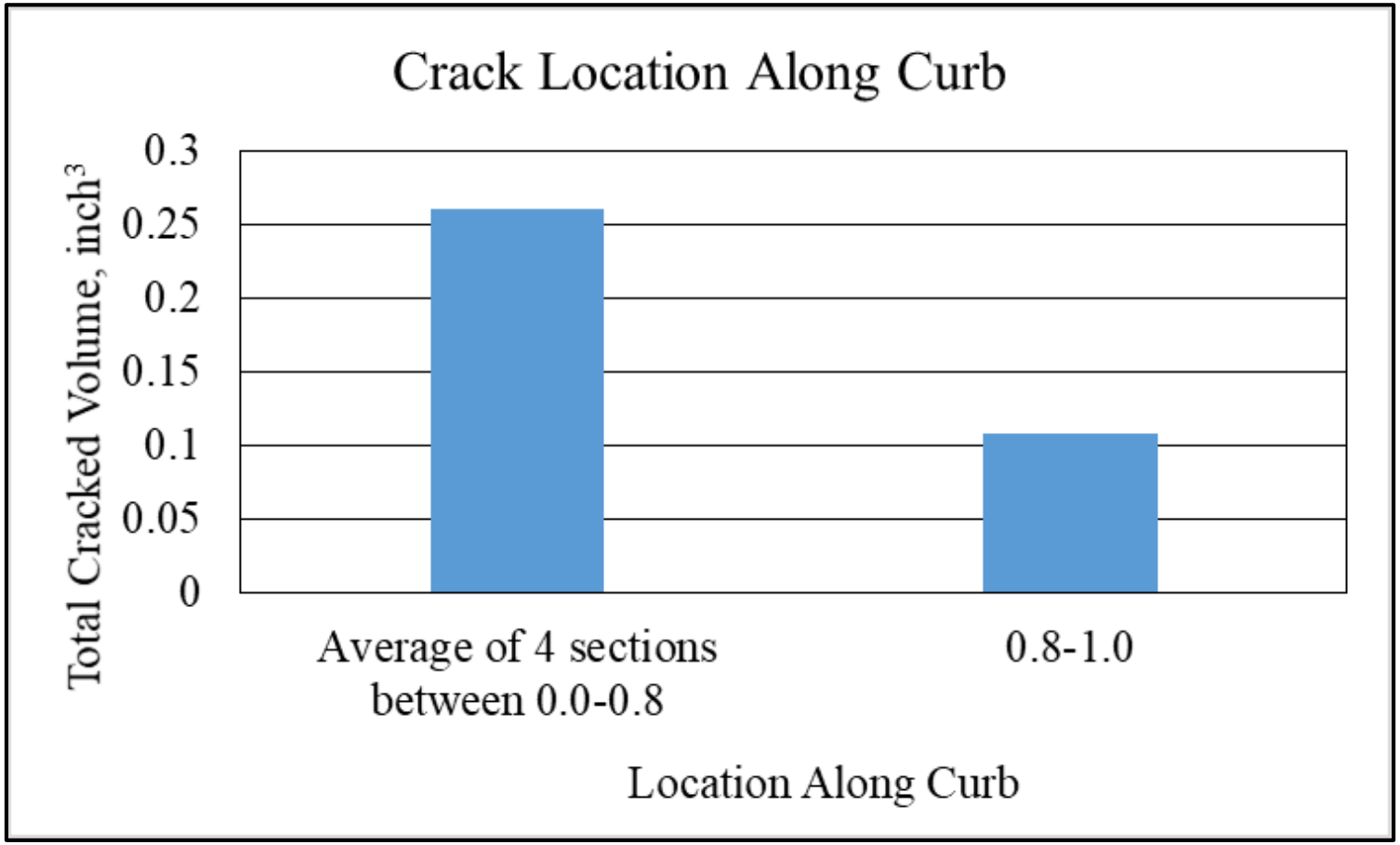
- Each crack assigned a value of 0 to 1
  - 0 corresponds to center of curb
  - 1 corresponds to end of curb
- Less cracking at the ends of the curb
- Statistical testing confirms these findings





Results and Discussion

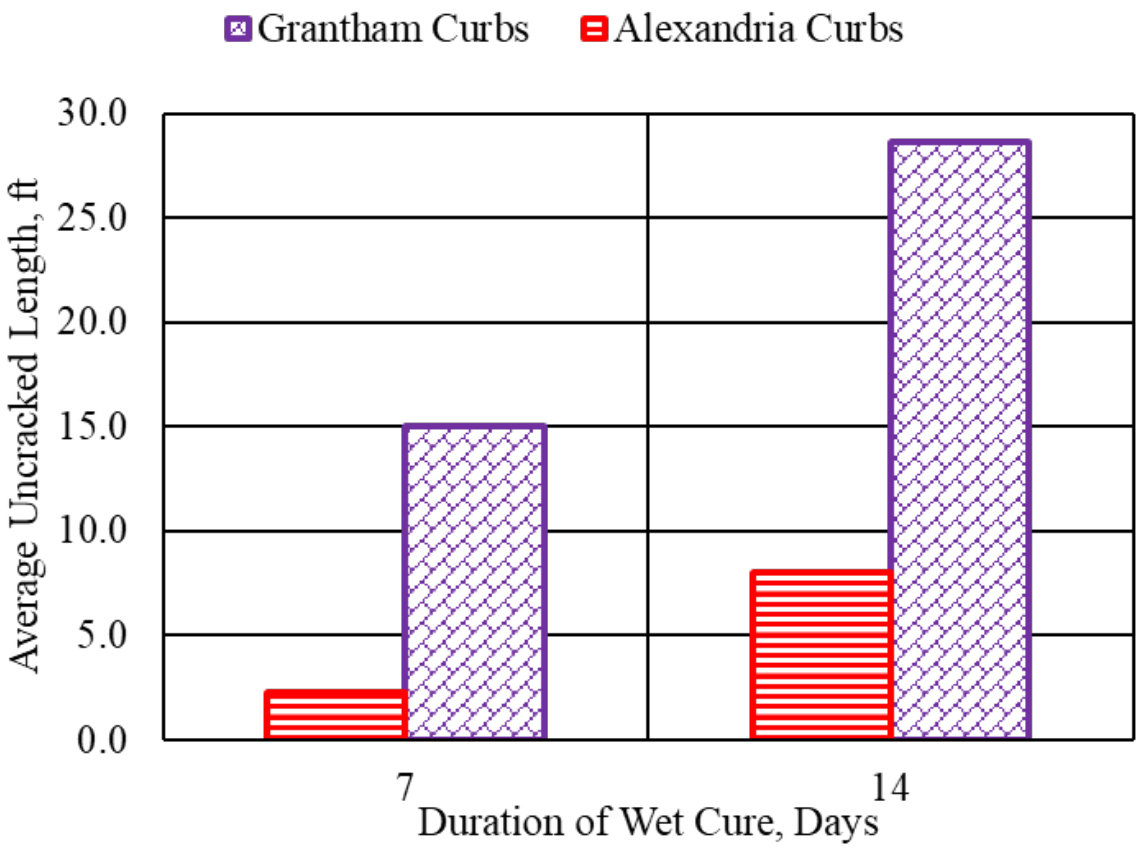
Location Along Curb – Volume Method



Results and Discussion

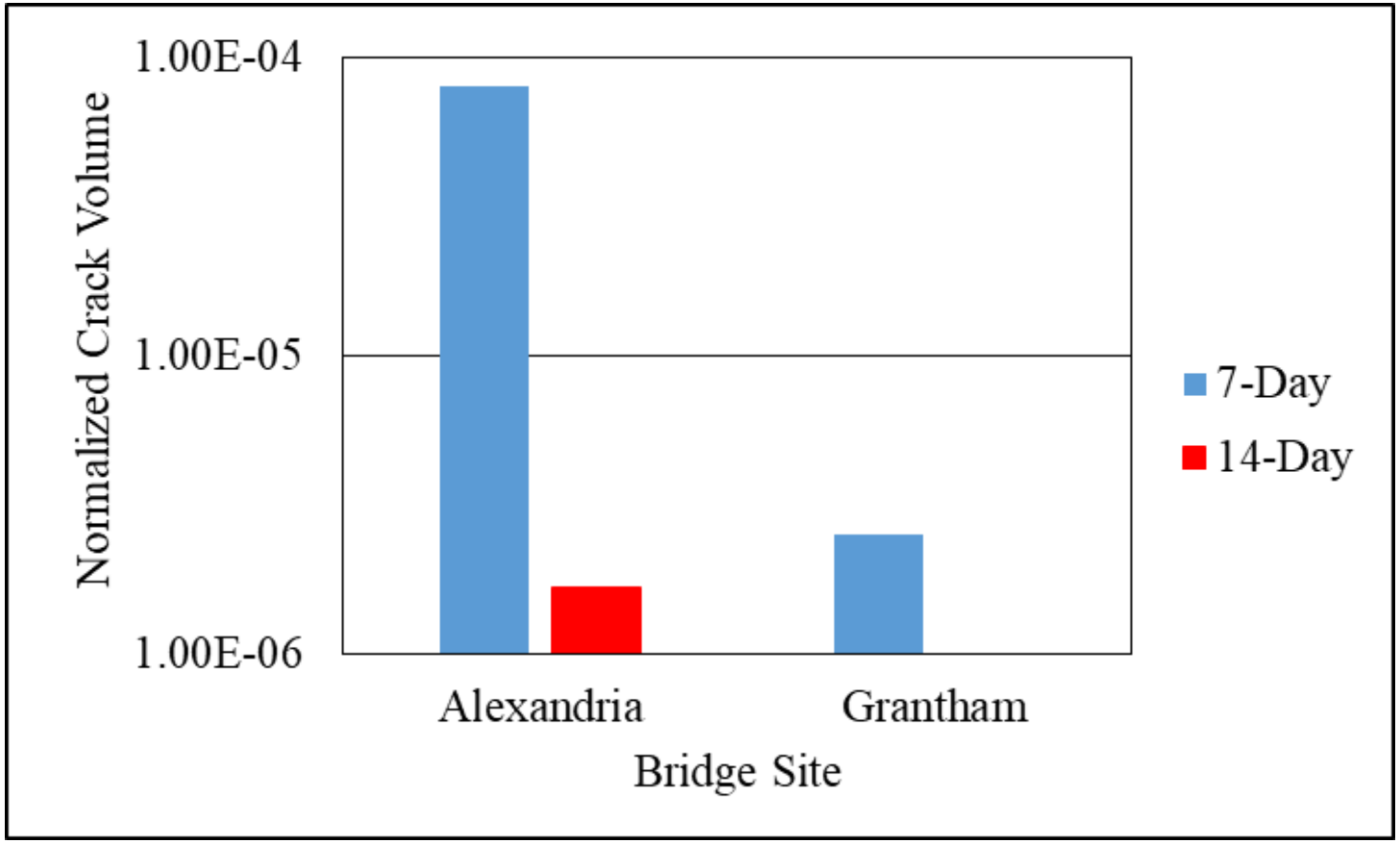
Wet Cure Duration

- 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

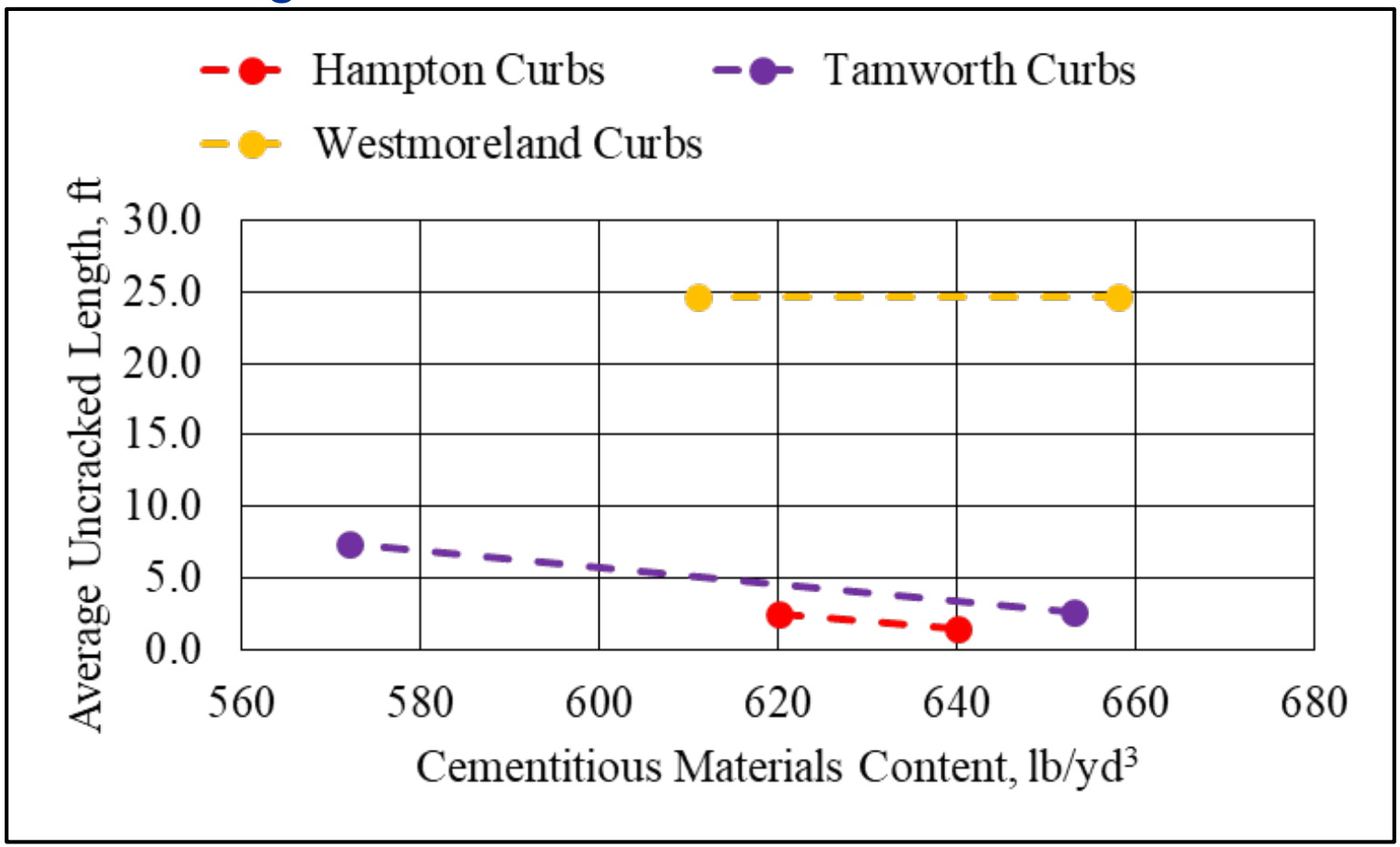
Wet Cure Duration – Volume Method



Results and Discussion

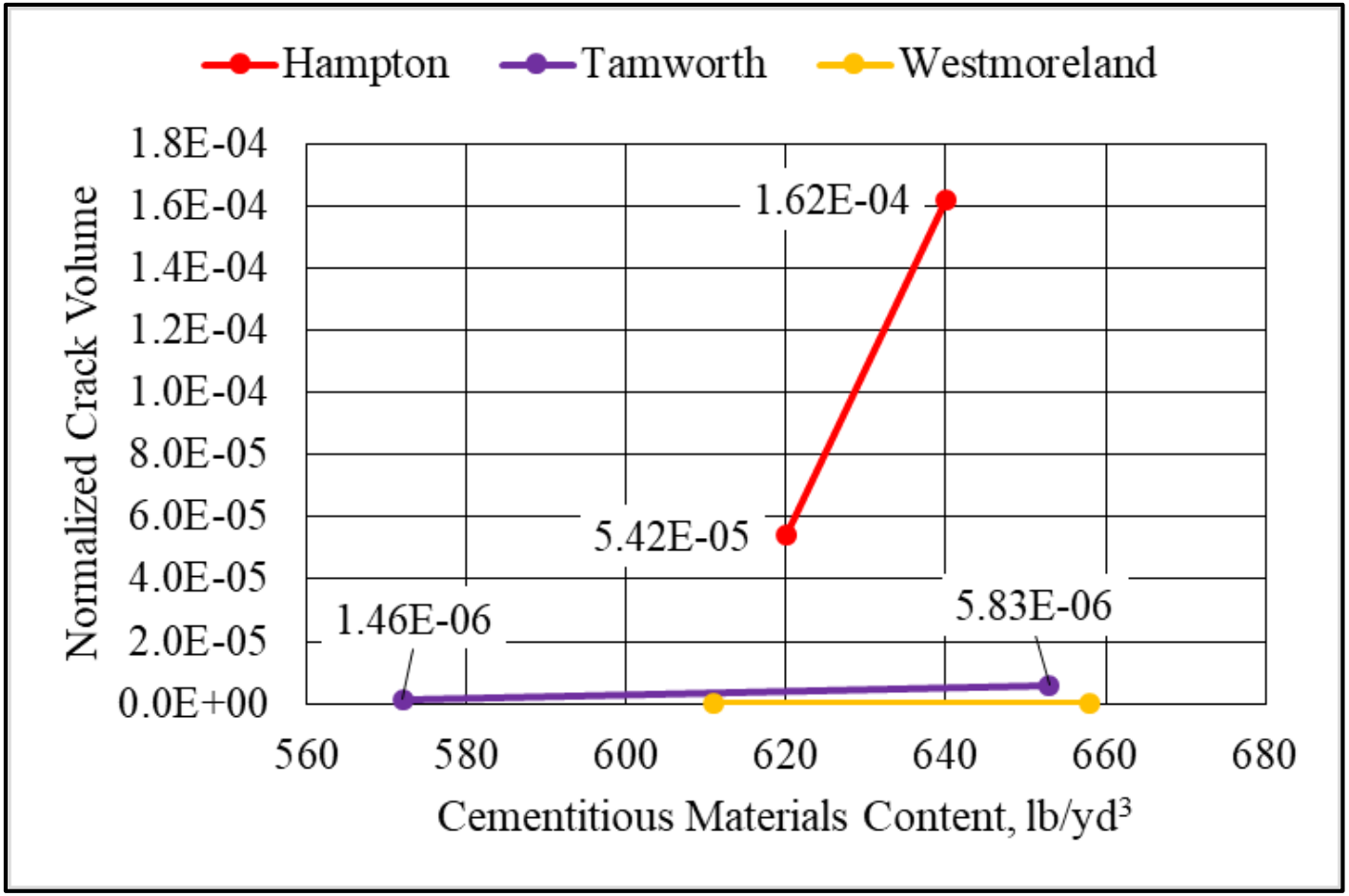
Cementitious Materials Content

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



Results and Discussion

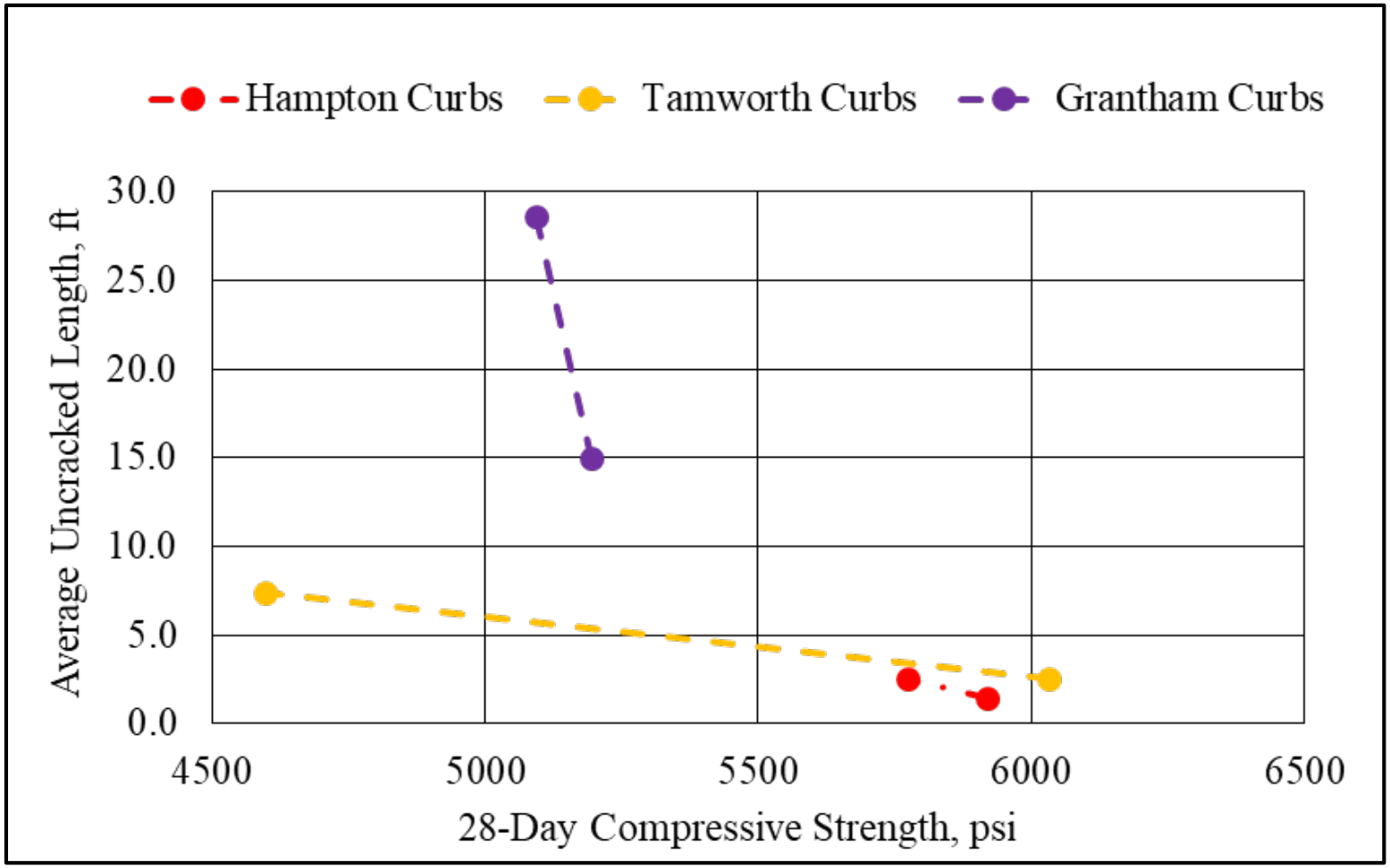
Cementitious Materials Content – Volume Method



Results and Discussion

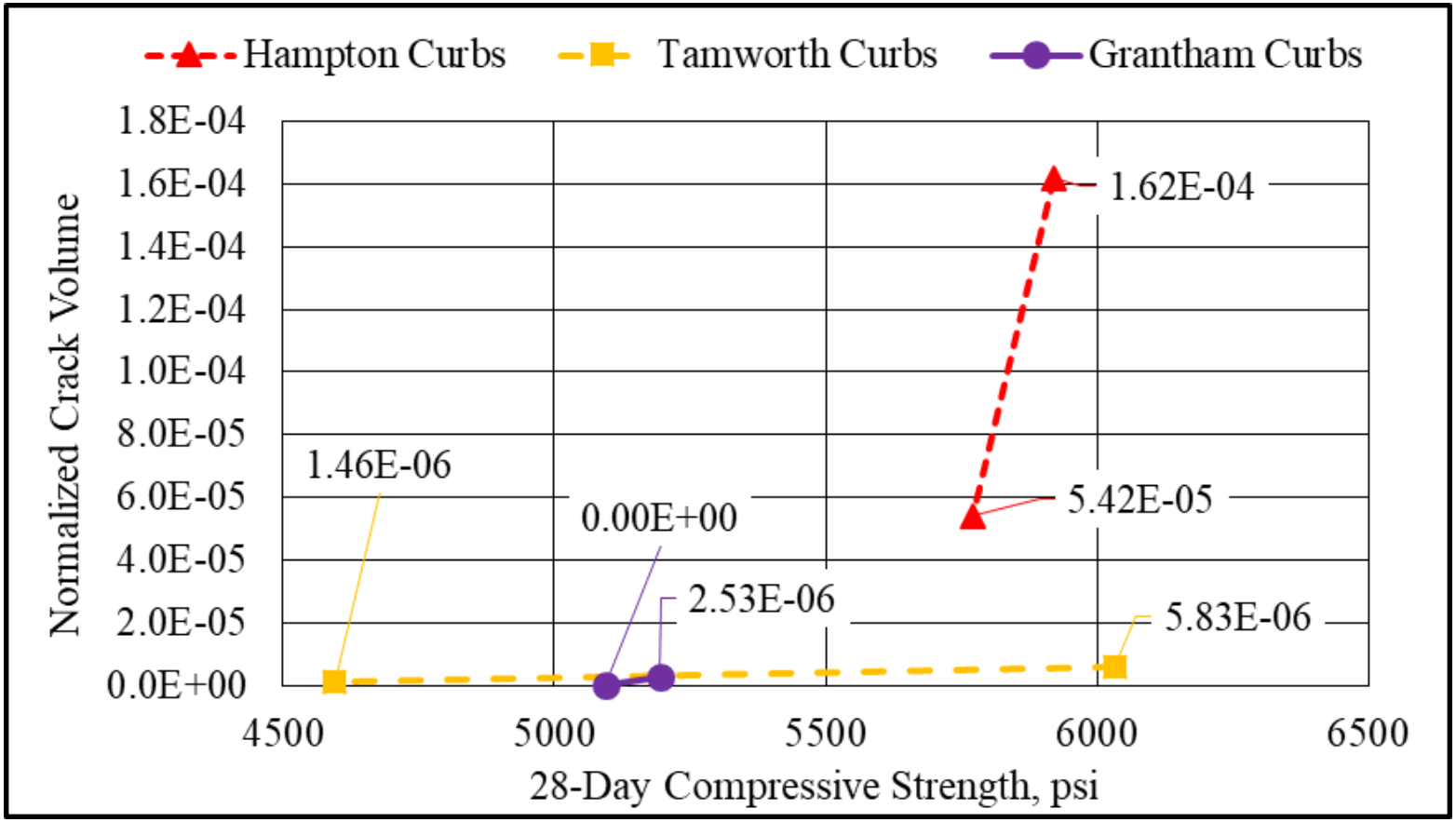
28-day Compressive Strength

- Curb pairs indicate higher compressive strength leads to shorter AULs



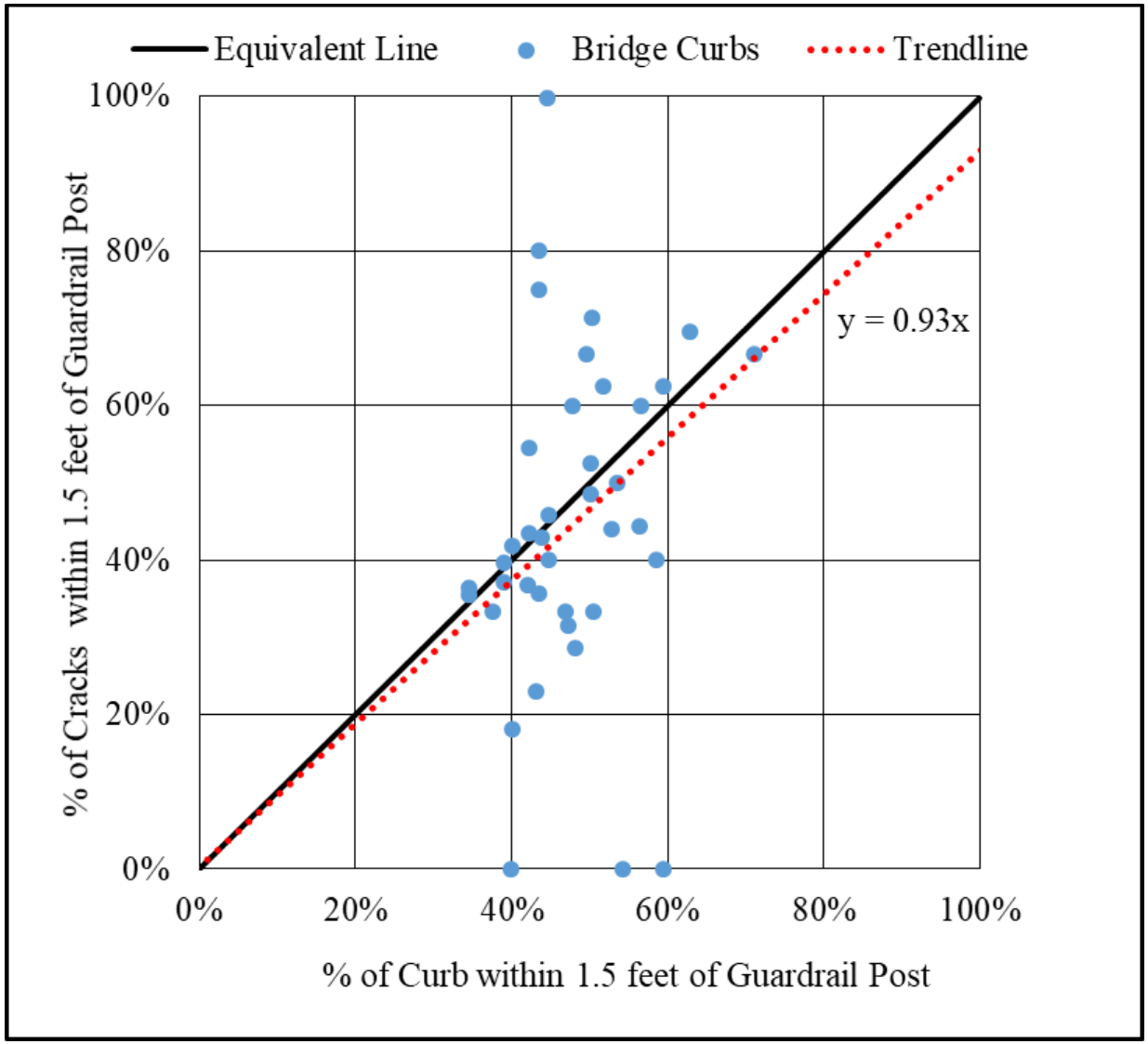
Results and Discussion

28-day Compressive Strength – Volume Method



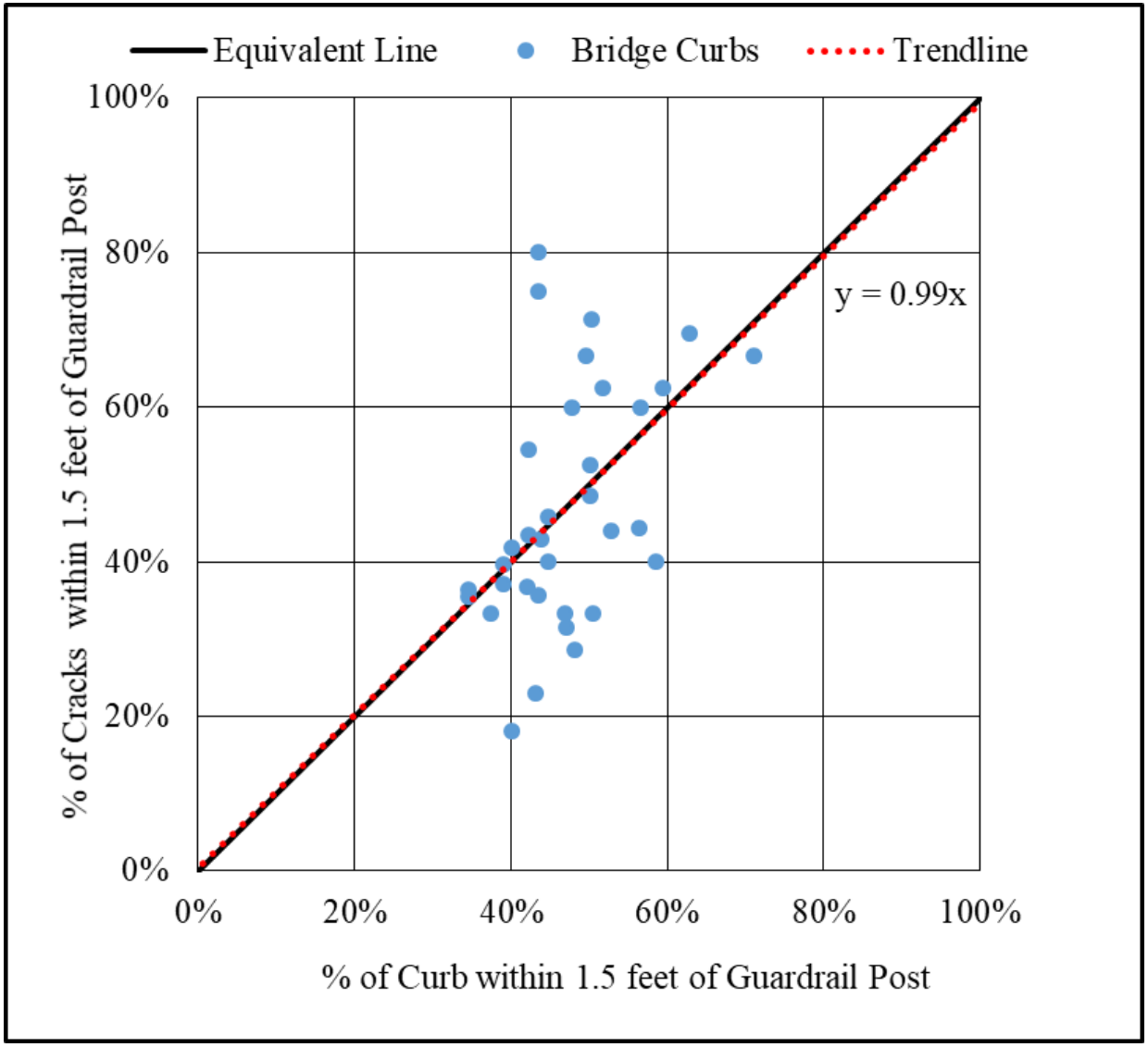
Results and Discussion

Proximity to Guardrail Posts



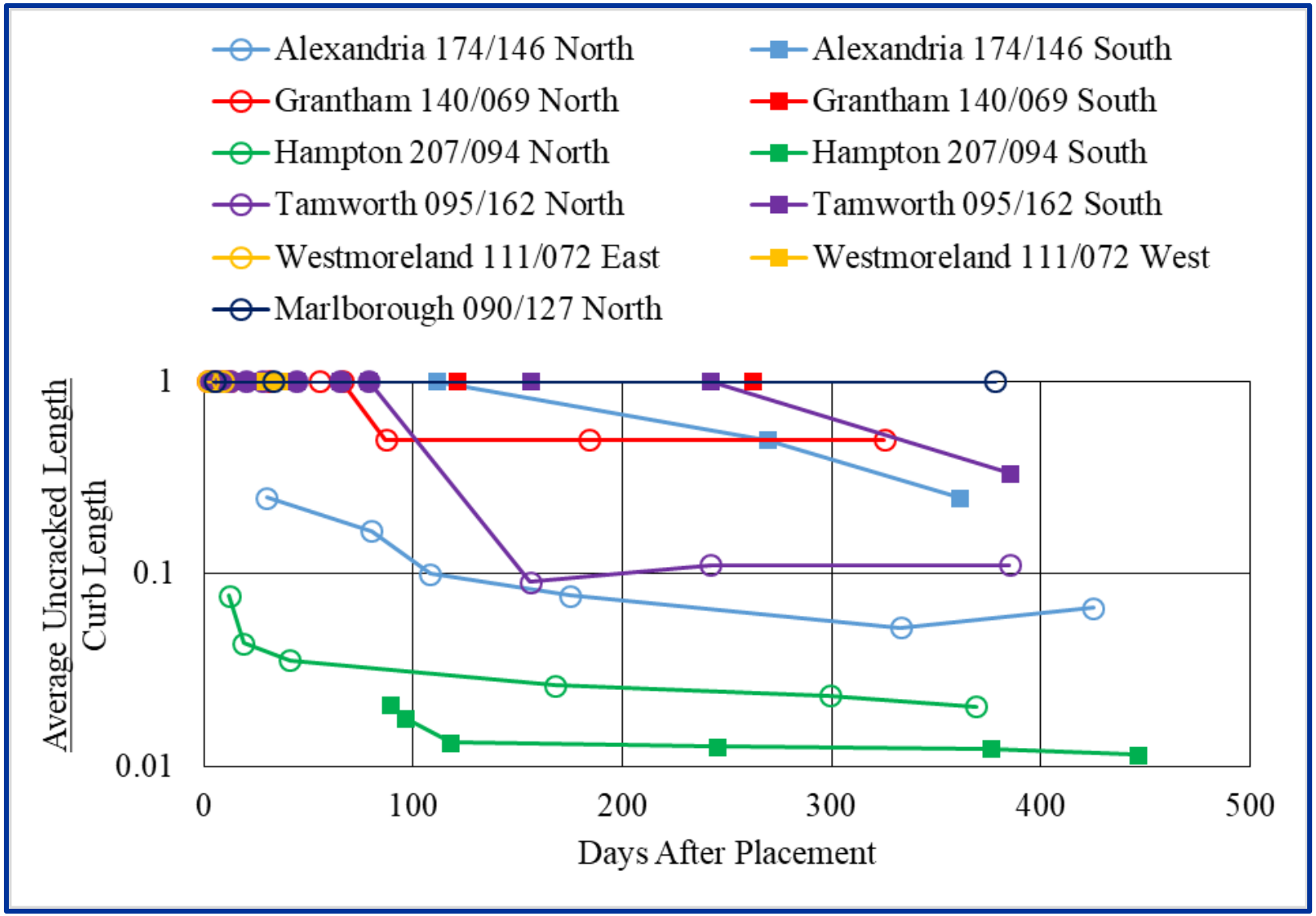
Results and Discussion

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



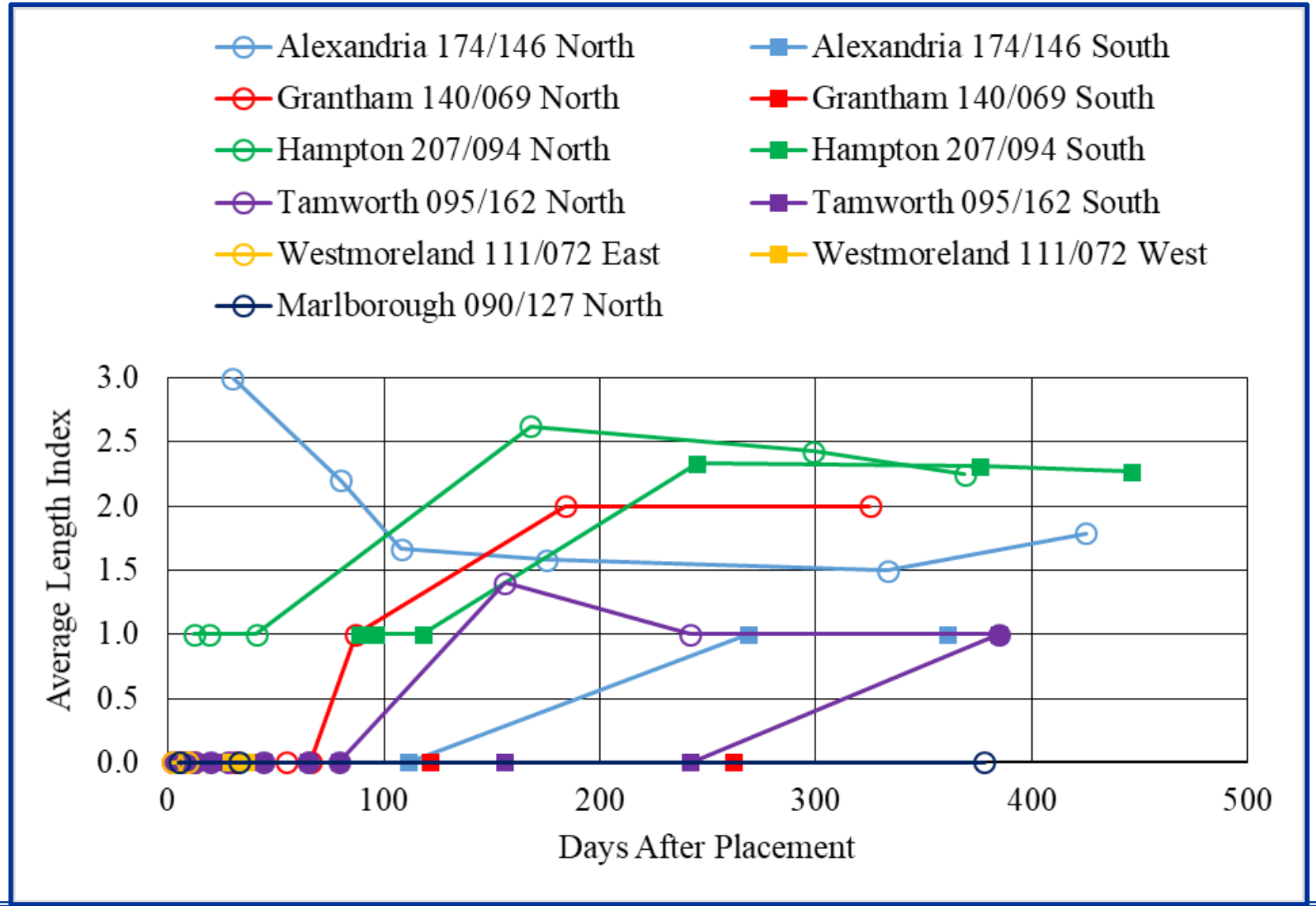
Results and Discussion

Cracking Over Time: AUL



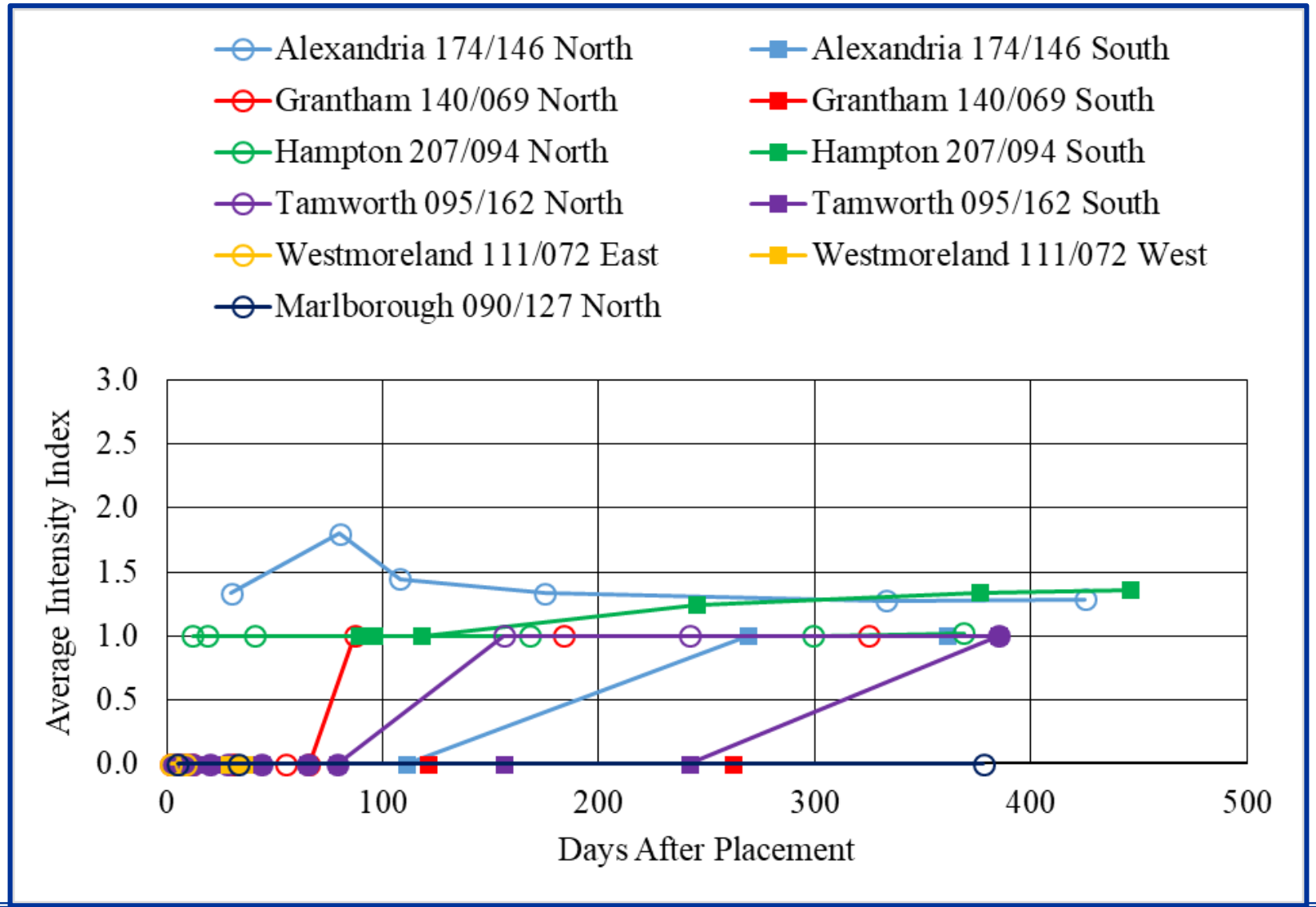
Results and Discussion

Cracking Over Time: Length Index



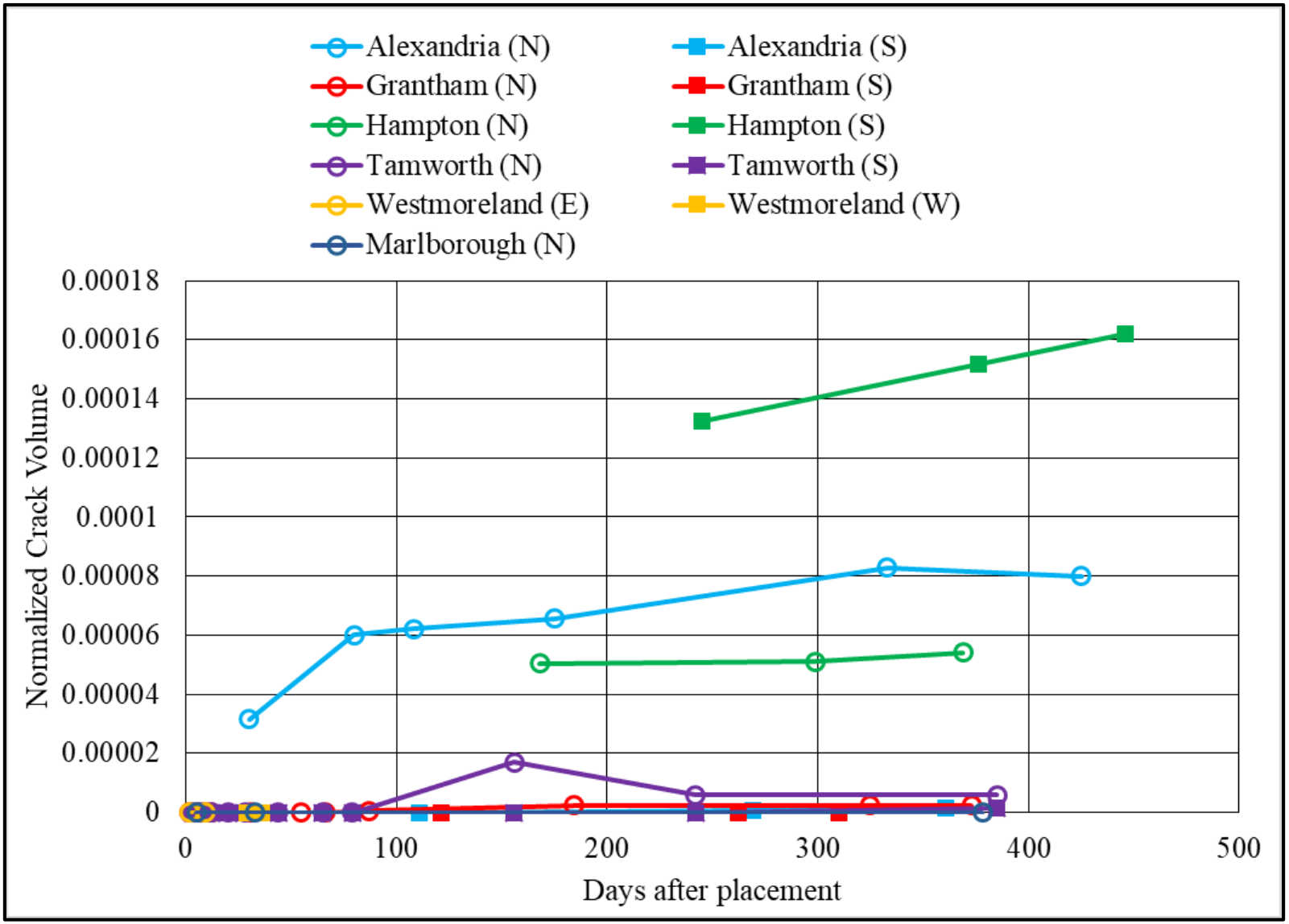
Results and Discussion

Cracking Over Time: Intensity Index



Results and Discussion

Cracking Over Time: Normalized Crack Volume



Overview

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

Summary

- 23 Bridges Surveyed: 6 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			
Location on Curb			
Curing Duration			
PCC Mix			
Water/Cementitious Materials Ratio			
Cementitious Content			
28-day Compressive Strength			
Guardrail Post			
Weather After Placement			
Average Daily Traffic			

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
- Guardrail posts have minimal effect on cracking behavior

Overview

- Background
- Research Methodology
- Results and Discussion
- Summary and Conclusions
- **Recommendations and Future Tasks**
  - **Practitioners**
  - **Future Research**

Recommendations: Practitioners

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

On-going Work (until project ends)

- Additional Site Visits
  - Visit and monitor additional new curbs using same variables
  - Analyzing data for all curbs at 1 year of age
  - Monitoring of curbs on a biennial basis after 1 year
- Additional Curbs
  - Westmoreland
  - Meredith
- Final Report

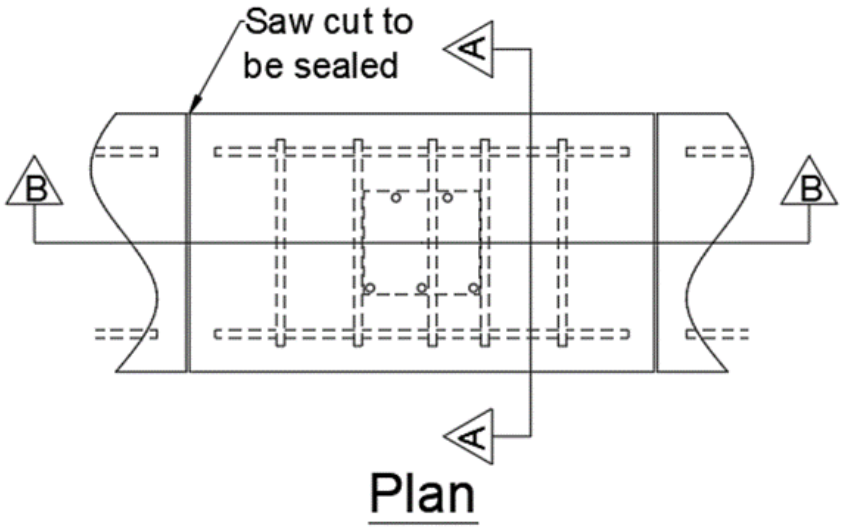
Recommendations: Future Research

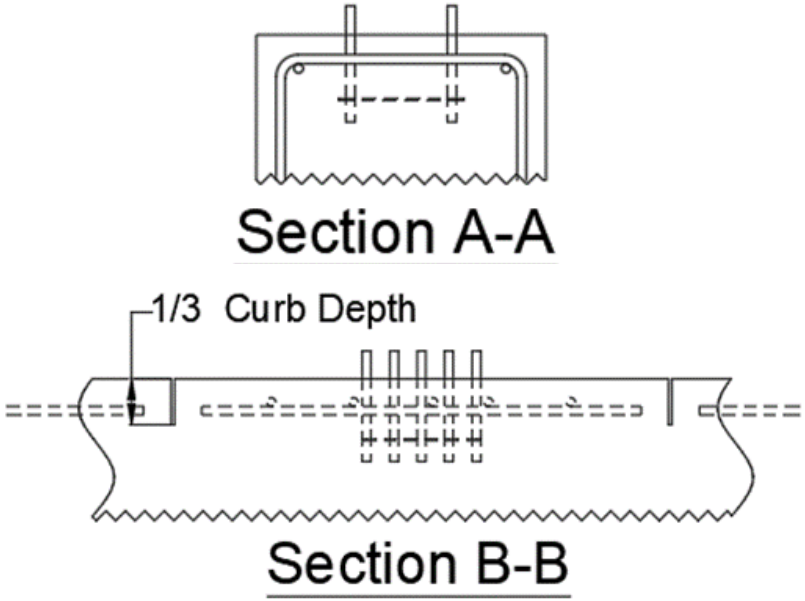
- Refinement of Field Data Analysis
  - Further develop the volume method and determine normalized crack volumes that correspond to curbs in good, fair, and poor condition
  - Revisit the study looking at only cracks with an intensity index of 2 or 3

- 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

- Research Contraction Joints at Guardrail Posts





Thank you for
your attention!
Questions?

References

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