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INVESTIGATION OF EARLY-AGE CRACKING IN CONCRETE BRIDGE CURBS

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INVESTIGATION OF EARLY-AGE CRACKING IN CONCRETE BRIDGE CURBS

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ABSTRACT

INVESTIGATION OF EARLY-AGE CRACKING IN CONCRETE BRIDGE CURBS

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In recent years a number of newly constructed curbs on New Hampshire Department of Transportation (NHDOT) single-span roadway bridges have suffered from cracking within one year after placement. The cracking that occurs in bridge curbs may provide easy ingress of water and chloride ions into the curb which could accelerate deterioration. An additional concern is that cracks in the curb could extend into the bridge deck. Ideally, bridge curbs and bridge decks are replaced at the same time in an effort to reduce the frequency of lane closures and frequency of mobilizing a crew to perform repeated rehabilitation. Potential accelerated deterioration related to early-age cracking would likely mean that curb and deck replacement would not be done at the same time, leading to increased agency costs and inconvenience to the driving public. This thesis focuses on the survey and analysis of data collected at several bridges in an effort to find ways to reduce cracking in bridge curbs. Seventeen existing bridges that had been placed in the past eleven years, in addition to six bridges placed during the study, were examined for curb cracking. Four of the bridges had variables applied to one of the curbs to try and identify which items could contribute to crack reduction. Results indicate that longer bridges experience a greater amount of cracking per foot than shorter bridges. There is also a relationship between the amount of cracking and location on the curb relative to the ends of the curb. Pairs of curbs suggest longer wet cure durations and lower cementitious content PCC mixes reduce cracking.

CHAPTER 1: INTRODUCTION

1.1 Overview

Cracking in concrete provides a pathway for water, chlorides, and other debris to travel deeper into concrete elements. While cracking is unsightly, the greater concerns are typically how cracking affects the performance of the structure or how the crack will affect the durability of the concrete member. In climates like New Hampshire, which are subjected to freeze-thaw cycles, water that has entered into the concrete may freeze. The expansion related to water freezing can cause stresses leading to further cracking and damage. Corrosion of reinforced concrete becomes an additional concern as the process is accelerated by the presence of chlorides found in road salts. The expansion of steel as it corrodes places additional stresses on concrete. By reducing cracking in concrete there is the potential to reduce the amount of freeze-thaw and corrosion damage a concrete element experiences. The desire to extend the life of structures and reduce their life cycle costs makes cracking in concrete an important research topic. This thesis will focus on concrete cracking in single-span, roadway, concrete bridge curbs in New Hampshire.

1.2 Motivation and Objectives of Research

This research was conducted as part of New Hampshire Department of Transportation's (NHDOT) project 26962P, *Reducing Cracking in New Bridge Curbs*. The Bureau of Bridge Maintenance (BoBM) at NHDOT has been experiencing early-age cracking on several bridge curbs as shown in Figure 1. Some cracking has been documented in as little as a few days after placement. For the purpose of this research, early-age cracks are those that form within one year following placement. NHDOT's BoBM performs maintenance and rehabilitation work on many

Figure 1: Crack in a bridge curb 5 days after placement.

New Hampshire state-owned bridges. The Bureau also does a fair amount of replacement work for smaller, single span bridges. The preference is to replace the bridge curbs at the same time as the bridge deck. By replacing both at the same time there is a cost savings from not having to mobilize workers and equipment multiple times. Same time replacement also means fewer lane closures and disruptions to the traveling public.

Bridge curbs that experience large amounts of cracking, particularly at an early age, may facilitate accelerated deterioration of the curb. This results in a curb replacement that needs to be conducted before the deck replacement. The early-age cracking that has been seen by the BoBM has been noticed, in some cases, as soon as three days after placement.

The goal of the project, *Reducing Cracking in New Bridge Curbs*, was created to investigate the problem of cracking in bridge curbs and find cost-effective, easy to implement procedures or material changes that will reduce the amount of cracking in bridge curbs. This thesis will primarily focus on the investigation procedure developed to document curb cracking and the analysis of several existing bridge curbs as well as new curbs placed during the research project. Many of the curbs reconstructed during the project also had modifications to mix design or construction practices. These variables will also be discussed further in the thesis.

1.3 Bridge Curb Sites

Over the course of the research project 23 bridges had curbs investigated. Of all the curbs investigated, six were placed during the project and 17 were existing prior to the start of the research project.

The existing bridge sites were selected in two different groupings. The first set included bridges that had curb reconstruction in 2010 or more recently. This set had also a broad range of bridge spans and were taken from various counties throughout the state. The second set of bridge curbs investigated belonged to bridges constructed in 2008 or more recently. This set of bridges were of two different structure types: concrete slab or steel I-beam with concrete deck. These are two common bridge types used by the BoBM. The bridge sites were selected based on bridge length in order to have bridges of the two different types but lengths.

Bridge curbs constructed during the research project were visited as they were reconstructed. This means that the number of new curbs investigated was limited to those being constructed by the BoBM during the construction period. A map of all the sites investigated during the project are shown in Figure 2.

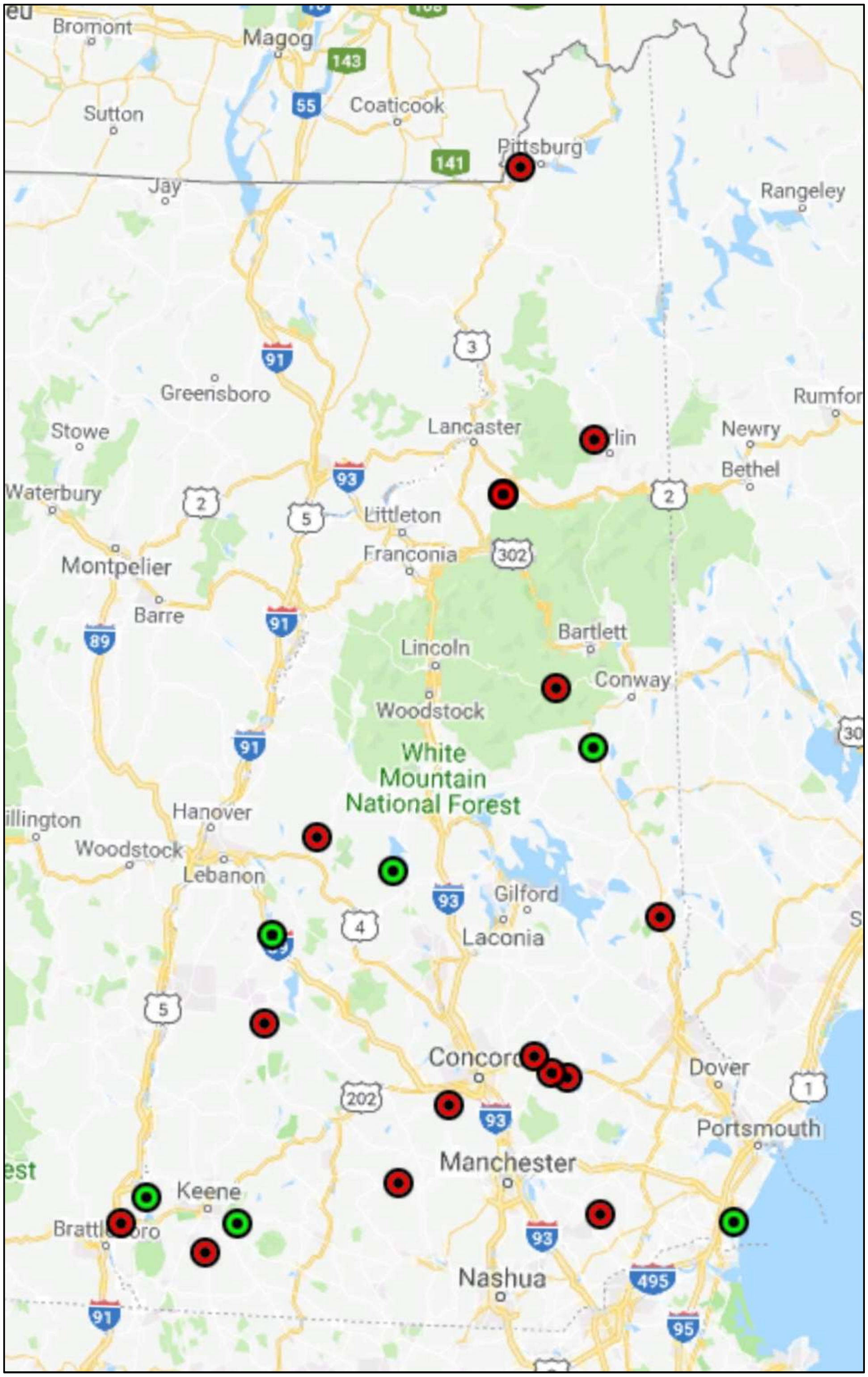


Figure 2: Google image of surveyed sites. Sites with curbs placed before the study are in red. Sites with curb placement during the study are in green.

1.4 Research Background

1.4.1 Curb Function and Replacement

Bridge curbs, similar to the one in Figure 3, provide a place for guardrail to be mounted as well as provide drainage characteristics to the bridge. As vehicles drive over the bridge dust and debris may be deposited on the roadway. When it rains, water flows down from the center of the roadway to the edges parallel to the direction of travel. The curbs prevent runoff, which can be

Figure 3: Example of a concrete bridge curb. This curb is approximately 29 feet long and is located on NH 113 in Grantham, NH.

carrying debris, from flowing directly off the side into the roadway or waterbody below. Runoff moves down toward the ends of the bridge or is intercepted by a drainage system implemented in the bridge. Debris that collects at the edge of the curb can then be cleaned up by maintenance personnel.

The curb also provides a place where the guardrail post can rest while providing space below for the guardrail post anchoring system. The curb also allows room for additional longitudinal and hoop reinforcement to help secure the guardrail anchoring system.

Replacement frequently includes the replacement of the entire longitudinal ends of the bridge deck, as shown in Figure 4, and not simply removing only the visible few inches of the

Figure 4: Exposed rebar extending out from a bridge deck after the former curb had been demolished.

curb rising above the deck. The figure also shows the steel beam and shear studs that were once buried underneath the old curb concrete. Once the curb has been demolished new reinforcement can be installed and tied to the existing deck reinforcement as shown in Figure 5. The guardrail anchor systems are also placed with the reinforcement. Additional hoop reinforcement is placed near the guardrail post locations to provide additional strength in case of a vehicle collision with guardrail. The additional reinforcement and anchor system can be seen in Figure 6.

Figure 5: Curb formwork and reinforcement on a curb replacement project.

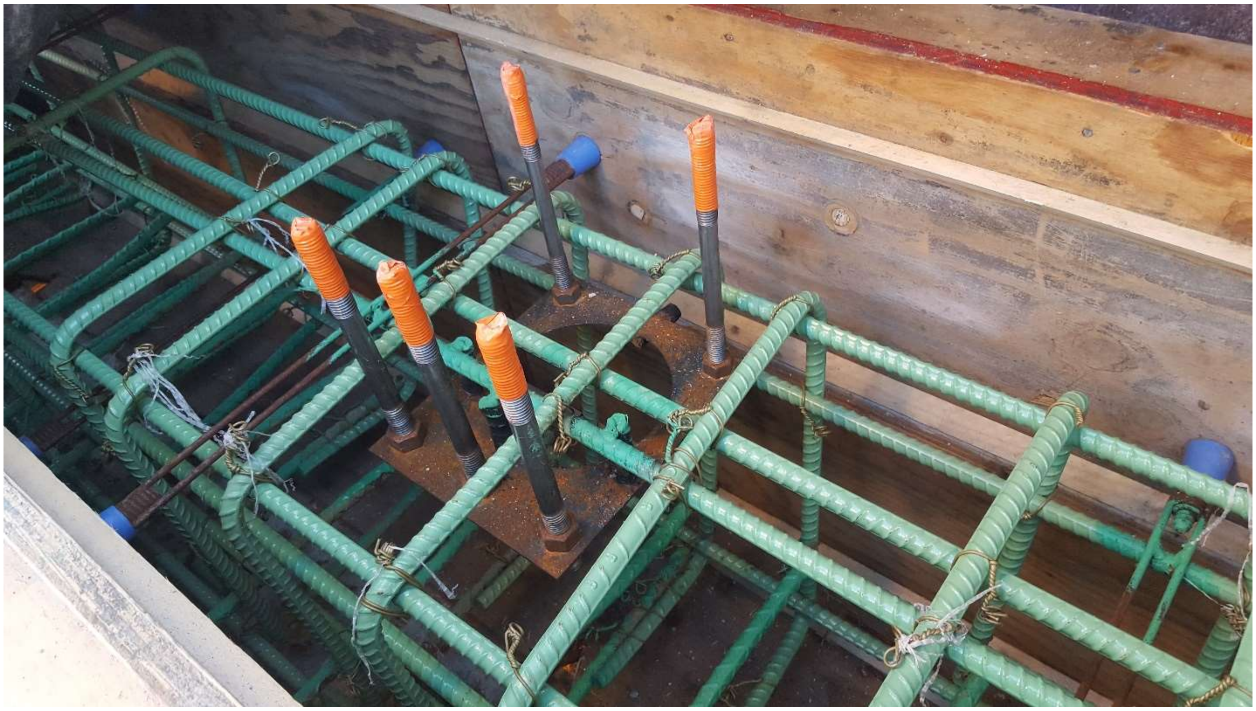


Figure 6: Guardrail anchorage and reinforcement in curb formwork. Tape on the top of the anchoring system keeps threads clean during concrete placement.

Once the reinforcement and guardrail anchoring system has been installed concrete can be placed in the forms and left to cure. Wet curing typically lasts about five to seven days and involves wet burlap being placed over the curb. This changes slightly in the winter as heat must be applied to the wet curb to prevent freezing of the concrete and water. This is commonly done by one or two methods. One method, show in Figure 7, involves using insulated wraps that are placed over the wet burlap. Hot air is blown underneath the wraps. The second method involves construction of a heated enclosure like the one shown in Figure 8. Heating is often performed by propane heaters. Heating adds an additional cost so the wet curing period is often shorter in the winter. It should be noted that NHDOT Standard Specifications calls for a minimum wet cure of 7 days but the BoBM is not required to adhere to the Standard Specifications and often take advantage of this in an effort to expedite construction.'

Figure 7: Insulated wrap and heaters on a bridge curb after cold weather placement.

Figure 8: A heated enclosure constructed over a bridge to prevent concrete from freezing during curing.

1.4.2 Concrete Material Requirements

The concrete used for bridge curb construction is typically the same as the concrete used in bridge decks. The requirements for bridge deck concrete correspond to NHDOT Concrete Class AA which can be seen in Table 1. Concrete that is to be used on a project must have the mix design submitted to NHDOT for approval (New Hampshire Department of Transportation, 2016).

Table 1: NHDOT concrete classification. Adapted from NHDOT Standard Specifications for Road and Bridge Construction.

Concrete Class	Minimum Expected 28 Day Compressive Strength (psi)	Maximum Water/Cement Ratio	Percent Entrained Air	Permeability Value (kΩ-cm)
AAA	5000	0.444	5 to 9	20
AA	4000	0.444	5 to 9	20
A	3000	0.464	4 to 7	10

Along with the approval, there must be a laboratory report on the reactivity of the aggregates used. In lieu of an aggregate reactivity report a means of mitigating reactivity must be shown. The mitigation method is often used over providing a mineral report. Frequently the mitigation requirement is met by substituting, by weight, a minimum of 50% of the cement content with ground granulated blast furnace slag, GGBFS, or 25% of the cement content with fly ash. In addition, the aggregates must also be graded appropriately. The gradation requirements for Concrete Classes A, AA, and AAA require a nominal maximum aggregate size of 3/4 inch.

1.4.3 Cracking Mechanisms in Concrete

Cracking in concrete occurs when tensile stresses exceed the tensile strength of the concrete. Concrete is well known for the behavior of being good in compression but poor in tension. Concrete is difficult to test in direct tension so often indirect tension or flexure tests are used to estimate concrete tensile strength. Often a rule of thumb for normal strength concrete is that the tensile strength is approximately 10% of is compressive strength. Design codes recognize this and provide estimates for the tensile strength of concrete based on its compressive strength. For example, ACI 318 uses the following equation to estimate concrete's modulus of rupture which can represent tensile strength (ACI Committee 318, 2014):

$$f_r = 7.5 \cdot \lambda\sqrt{f'c} \qquad \text{Eq. 1.1}$$

Where:

$$f_r = Modulus\ of\ Rupture, psi$$

$$\lambda = Modification\ Factor\ for\ Concrete\ Weight, 1\ for\ normalweight$$

$$f'c = Specified\ Concrete\ Compressive\ Strength, psi$$

Some common ways that tensile stresses may develop in bridge curbs are from loading, changes in temperature, and the volumetric instability of concrete. The following paragraphs will discuss how the previously mentioned crack-causes may manifest in curbs. First, a brief overview of the concrete microstructure as it relates to cracking will be discussed. One of the most important concrete characteristics that relates to cracking in concrete is the interfacial transition zone, ITZ.

The ITZ is still not fully understood but is considered the weak link in the concrete matrix. The ITZ is the name given to the thin layer that develops on the boundary between aggregate and bulk cement paste. During concrete placement, hydration products have difficulty packing closely to the aggregate. This is termed the "wall effect". This inefficiency in packing means there is a higher porosity in the ITZ. This high porosity along with local bleeding leads to a higher water-cement ratio (Ollivier, Maso, & Bourdette, 1995). The higher water-cement ratio at the interface leads to a reduction in the amount of Calcium silicate hydrate, C-S-H, relative to the rest of the concrete. Since C-S-H contributes the most to concrete strength, areas that are low in C-S-H tend to be weaker. The high water content encourages the production of Calcium hydroxide or ettringite in place of C-S-H (Mindness, Young, & Darwin, 2003).

The reduced strength near the ITZ means that cracks can form more easily in these areas than others. Additionally, the ITZ is more fragile earlier in hydration then later after hydration products have sufficiently developed. This is a concern because microscopic cracks, referred to as microcracks, can form early in the ITZ at stresses well below a concretes anticipated tensile strength. A crack that has started in the ITZ may easily grow as the tip of the crack creates an area of stress concentration. As a microcrack grows it intercepts other microcracks. Over time these microcracks can develop into a crack visible to the naked eye, a macrocrack.

Microcracks can form from any of the reasons mentioned earlier in this section. Loading concrete in tension is likely the most obvious way a tensile crack develops. Direct tensile loads on the bridge curb are probably much less common than tensile loads created due to bending. The bridges visited for this research are all single span bridges. From a structural analysis point of view it would be expected that the top fiber of the bridge curb would be entirely in compression except for the ends of the span where fixity and connection to the substructure may create areas of negative moments. Another possible scenario where tension may be developed in the curb is due to vibrations from passing traffic. A passing vehicle or truck may cause an excitation of the bridge. This excitation may create tensile strains before the bridge returns to its static condition.

A second source of potential cracking is due to temperature effects. If a concrete curb is cast along with the deck then the entire concrete structure will expand and contract together. If the curb is cast separately from the deck then there is the opportunity for tension to form due to changes in temperature. For example, if a deck has a surface temperature that is well below freezing and concrete is cast with a temperature above freezing then as the curb begins to cool, either from hydration slowing down or heated curing stopping, it will want to contract. The contraction is restricted due to the concrete deck. This will cause tensile stresses to develop within the curb that may contribute to curb cracking. Additionally there may be thermal compatibility issues between steel and concrete or between concretes of varying aggregate types.

Another potential source of tensile stresses include the volumetric instability of concrete. As concrete cures it undergoes plastic shrinkage. Plastic shrinkage occurs as a result of the products of the hydration reaction occupying less space than the reactants. This reduction in volume causes shrinkage in the volume occupied by concrete. Additionally, water consumed for the hydration reaction can also produce small voids, which depending on the concrete rigidity, reduces the concretes volume.

Drying shrinkage is also a concern. As concrete dries, the smaller amounts of water in the concrete retreats to narrower and narrower sections of the pores. This increases capillary forces within the pores that create tension and pull on the concrete which manifests as shrinkage. When dry concrete is introduced to excess moisture the amount of drying shrinkage will decrease and could possibly lead to some swelling as well.

The volume instability of concrete is not a concern providing the concrete element is allowed to freely expand and contract. This is not the case for bridge curbs which are fixed to the deck. As a newly placed curb concrete tries to shrink, it is restrained by the deck. This creates tensile stresses in the curb which may lead to cracking.

1.4.4 Effects of Freeze-thaw Damage and Steel Corrosion

While damage due to freeze-thaw action and steel corrosion could be discussed at length the topic here will remain limited. The importance of understanding these effects on bridges curbs is to understand that they accelerate the deterioration of concrete and severely reduce concrete durability. Damage from freeze-thaw and corrosion work by the same mechanism: expansion.

Freeze-thaw damage is associated with the expansion of water as it turns to ice in the concrete structure. The freezing of water results in approximately 9% increase in volume. This expansion places stresses on concrete and aggregates that can lead to further deterioration of the concrete. Water that is present in the cracks of concrete will expand upon freezing which may result in the crack becoming wider or pieces of concrete becoming removed from the rest of the concrete structure. By reducing initial cracking in bridge curbs there is less opportunity for freeze-thaw damage to cause further cracking or durability issues.

Rebar in concrete is fairly stable. The high pH, or alkaline environment, of concrete produces a passive layer over the rebar that reduces the opportunity for corrosion to take place. This passive layer is removed in the presence of chloride ions. If the passive layer is removed corrosion may begin. Iron oxide, or rust, occupies a greater volume then the steel that it originated from. This expansion puts stress on concrete that can lead to concrete deterioration. It can be understood why in New Hampshire, where road salts containing chlorides are used, curb cracks are a concern. Another common problem associated with deicing salts on roadways is that they can cause salt crystals to grow in concrete creating expansive forces as well as pulling nearby water through capillaries in the concrete creating high osmotic pressures (Kosmatka &

Wilson, 2016) A crack in reinforced concretes used on roadways provides an easy ingress for water and chlorides to enter and start the corrosion process.

1.4.5 Previously Conducted Research

The following paragraphs are a literature review of previously conducted research. The studies were largely gathered from the Transportation Research Board's Transportation Research Database, TRID. The studies focus on early-age concrete cracking in both bridge decks and bridge parapets. Most of the literature available was concerned with bridge decks. A limited amount of research was reviewed that dealt with restrained concrete shrinkage.

Fatigue in concrete often manifests itself in the form of cracking, spalling, scaling, pop outs, crazing, or delamination. Frequently fatigue is often the result of prolonged exposure to weather, stresses due to traffic, chemical processes within concrete, improper construction practices, or a combination of the previous items.

Construction practices that effect durability include improper reinforcement, mix design, placement, and curing. If concrete is inadequately reinforced tensile stresses in concrete may develop and cause cracking. Mix designs have many variables that need to be adjusted and tested prior to the use of the mix. Often durability problems resulting from an improper mix design is caused by a water-cement ratio that is not appropriate. A high water-cement ratio may lead to a more porous concrete which allows more water to penetrate into the structure leading to reduced durability. Placement of concrete may reduce durability if there is poor consolidation of material around reinforcement and formwork, segregation of aggregates and cement paste, incorrect curing practices, or improper finishing techniques that may reduce the amount of air entrained in the concrete. Cracking may also be the result of concrete shrinkage.

A similar issue was faced by the Ohio Department of Transportation, or ODOT. Bridges operated by ODOT were experiencing cracking at intervals over bridges. One finding was that the frequency of parapet cracks increased near bridge piers. Traffic loading created negative moment areas near bridge piers which placed tensile stresses on the concrete parapets leading to cracks. In order to combat uncontrolled cracking researchers recommended using saw cuts in parapets at regular intervals to encourage cracking at those locations. By encouraging cracking at specific locations maintenance crews are more able to manage, monitor, and maintain cracks. Saw cuts were recommended to be done while concrete was less than a day old as concrete may begin developing cracks in the first few days after pouring (Kalabon, Hedges, & DeLatte, 2015).

Similar cracking problems with bridge decks are also frequently researched. Premature cracking in bridge decks can be the result of negative-moment areas, non-uniform concrete curing, and thermal gradients in curing concrete creating tensile stresses in the deck (Subramaniam, 2016). Research conducted on bridge decks in New York that were experiencing early-age cracking concluded that cracks form in concrete during the period when the cement matrix was weak within the first 48 hours after placement. The study also concluded that the cracking was the result of shrinkage and thermal stresses (Subramaniam, 2016). The magnitude of the stresses also depend on the restraint between the bridge deck and bridge structure. Recommendations from this study include keeping air content above 6% (preferably around 8%), having a maximum water-to-cementitious material ratio, w/cm, of 0.42, and a maximum cement content of 534 lb/yd^3 (Subramaniam, 2016).

Shrinkage compensating concrete has also been evaluated at reducing cracking in bridge decks however shrinkage compensating concrete also comes with increased cost, increased attention during placement, and may not be readily available (Nair, Ozyildirim, & Sprinkel, 2016). A study on bridge deck cracking in Florida found that cracking in bridge decks may be increased by the use of integral abutments as well as using concrete with larger compressive strengths. The study used finite element analysis and identified the causes of cracking to be largely associated with shrinkage, thermal effects, and truck loading (ElSafty, Abdel-Mohti, Jackson, Lasa, & Parades, 2013).

The recommendations made by previously mentioned studies are also echoed by a PennDOT study that recommended limiting cementitious material content to 620 lb/yd^3 and using SCMs, excluding silica fume, to reduce heat of hydration and reduce concrete stiffness. Limiting concrete compressive strength to 4000 psi and 5000 psi at 7 and 28 days respectively was also advised. The study also encouraged wet curing for 14 days and not letting evaporation exceed 0.10 lbs/(ft^2·hr) (Hopper, Manafpour, Radlinska, & et al., 2015).

A report from the National Research Council Canada described the problem of transverse cracking in bridge barrier walls only a few days after concrete placement (in as little as one and a half days in some cases). Many cracks observed in this study had a fairly regular spacing of about 0.8 meters and extended fully through barrier wall. This study used a combination of field data, finite element analysis, and strain gauges to try to determine the causality of cracking. When it came to traffic vibrations the researchers noted that peak strains in the upper portion of the barrier wall were recorded during off peak hours likely due to higher vehicle speeds. One recorded peak in strain resulted in a compressive strain of 44με followed by a tensile strain of 17με. The study concluded that the main contributor of cracking in barrier walls was due to thermal gradients in the wall resulting in tensile stresses to develop. To remedy these researchers recommended keeping formwork on longer then one day as well as reducing the cement content in concrete. A higher w/cm was also encouraged to decrease the effects of autogenous cracking which was considered a significant contributor to the problem. The cement content used in the study was 758 lb/yd^3 and the w/cm was 0.36. The study also stated that vibrations induced by traffic may have also led to crack formation particularly in the early stages of curing (Cusson & Repette, 2000).

An article published in 2007 on the subject of reducing cracking in bridge decks stated that no single method of crack reduction is likely to work on its own but must be used in conjunction with multiple reduction methods. Some of the methods mentioned in the article include keeping the w/cm between 0.40 and 0.45 and trying to reduce the amount of cement content per cubic yard. The mix should also include SCMs in order to reduce the heat of hydration. Other modifications to the type of concrete used include specifying the lowest compressive strength that is acceptable for the project as well as using a minimum of a 7 day wet cure. Another suggestion by the article included using shrinkage compensating concrete (Russell, 2017).

A University of Kansas study funded by multiple DOTs to explore how to reduce cracking in bridge decks was published in 2017. The study used Low-Cracking High-Performance Concrete, LC-HPC, developed by KDOT and tested it on various bridge decks with a control. LC-HPC uses cementitious material content between 500 lb/yd^3 and 563 lb/yd^3 of concrete and a w/cm of 0.42-0.45.The mixture also had air contents between 6% and 9.5%. The study concluded that the LC-HPC was superior in reducing cracking in most cases compared to the control decks (Darwin, Khajehdehi, Alhmood, & et al., 2017). The study also concluded that using lower cementitious material, restricting maximum compressive strength, minimizing finishing operations, controlling temperature in concrete, and placing limits on maximum slump can reduce cracking in bridge decks.

While many different theories and conclusions were made about the mechanisms of early-age concrete cracking in the literature review some general mechanisms appear to be working in many of them.

Traffic loading can cause a bridge to flex at constraints or piers creating negative moment areas which place concrete in tension. When the tensile stresses are large enough the concrete will crack. This cracking can also be caused by traffic traveling over the bridge creating vibrations that propagate through the bridge structure and can cause rapid strains which may lead to cracking.

Thermal stresses caused by expansion and contraction as well as thermal gradients created during placement can create tensile stresses in concrete which lead to cracking. Thermal issues may also develop due to non-uniform curing as heat is generated during the hydration process. Additionally, as concrete hydrates and dries the concrete may begin to shrink which also induces tensile forces in concrete leading to cracks.

Some recommendations posed by the studies include limiting cement content (preferably below 534 $lb./yd^3$), using SCMs (except silica fume), limiting compressive strength to the lowest acceptable value, using a w/cm between 0.40 and 0.45, performing saw-cuts to promote cracking in specific areas, and using an air content greater than 6%. These modifications aim at increasing flexibility in concrete as well as reducing the amount of shrinkage experienced by the concrete elements.

CHAPTER 2: STUDY VARIABLES AND RESEARCH APPROACH

2.1 Research Methodology

In order to find potential reasons for the cracking on curbs, several bridges were visited. The curbs can be lumped into two groups. One group are existing curbs that were placed prior to the study and the second group are curbs placed during the study. The curbs that were placed before the study provide data on cracking conditions several years after placement whereas the curbs placed during the study provide data on early-age cracking.

During the study when bridge curbs were replaced on a bridge, one curb would be built using the BOBM standard construction procedures and mix while the other curb would have a variable applied to the construction practice or mix design. These variables will be discussed in following sections. These curbs were surveyed multiple times over the following year after construction with the visits concentrated in the first month after placement. Due to construction dates, weather, and availability not all sites were visited the same amount. The data from site visits was collected in order to search for similarities between cracking and curb attributes or construction. The investigation procedure is discussed in the following section.

2.2 Curb Survey Procedure

In order to facilitate easy data acquisition a simple curb survey procedure was developed. The procedure starts before visiting the site by getting data that already exists on the NHDOT website. This information includes bridge span length, type of bridge, and year constructed or rebuilt. For new bridge curbs, the year constructed is replaced with the date the curb was placed. For the first visit to a particular site, general photos are taken of the bridge, its structure, the curb, and its location. At future site visits these photos are often not taken unless a feature of interest needs to be documented.

A tape measure is extended the length of one of the curbs after photos are taken. The location of each guardrail post, relative to the curb end, is measured. The total length of the curb is also recorded. Once the guardrail post locations are identified the crack survey may begin.

Using the same tape measure laid out to record post locations, each visible crack's location on the curb is recorded. Cracks are documented on the side of the curb the traveled way is on. This was done as a safety precaution to prevent the surveyor from having to lean over the railing while investigating cracks. It is important that for all future visits the tape measure is pulled from the same side to prevent crack location data from being misrepresented. Additionally, each crack is given two index values based on its length and width. These values are discussed later. A crack comparator is used to determine crack width. The widest portion of the crack is used to determine the index value. An image of the crack comparator being used can be seen in Figure 9. It should be stated that cracks were only evaluated if visible. On several occasions cracks that were visible during a previous survey were no longer visible or appeared shorter or thinner than before. This could be due to dust and debris covering the crack, changes in humidity, changes in temperature, or a combination of the three. Recording of the crack location can be done in any way that is convenient to the surveyor. Initially during this study, photos of every crack were taken. While this method is beneficial when creating a visual record of the cracks it is much more time consuming, requires a significant amount of data storage, and on cold days may become difficult as batteries tend to lose their charge quickly without being kept warm. A common method used in this study was to use a voice recorder to verbally note crack location, width, and length.

Figure 9: Crack comparator used to aid in crack width determination.

2.3 Selection of Curb Variables

As mentioned earlier, on new curbs placed during the study, one curb on a bridge was left as a control, built using the traditional methods and materials used by BoBM. The second curb would have a variable changed in order to compare if any improvement would result. Several variables were initially discussed at the beginning of the project. Due to the limited amount of curbs reconstructed during the period only two of the variables were selected to implement. These two variables will be discussed in the following paragraphs along with some of the variables that were not selected and the reasoning they were not chosen.

The first variable that was selected was a 14-day wet cure duration. The reason increasing the wet cure duration was selected was to reduce the effects of drying shrinkage on concrete that may not have realized an appropriate strength to resist cracking. Another benefit to this was that it was easy for the BoBM to implement and only added a small inconvenience to scheduling. With that said, BoBM is more reluctant to try a 14-day wet cure during the winter season as it increases fuel costs required to maintain warmer curb temperatures during curing.

The second variable selected was mix design. NHDOT's concrete classification system means each concrete producer's mix is slightly different. The BoBM prefers to use mixes that have made it through the NHDOT approval process. During the early portion of the study, researchers recognized that some facilities that were producing NHDOT AA mix, which has a required 28 day compressive strength of 4000 psi, with 28 day compressive strengths in excess of 6000 psi. This high compressive strength may mean the concrete is more brittle. In order to see the effects of a concrete with a lower compressive strength, variable curbs using NHDOT A mix were placed. This mix has a specified compressive strength requirement of at least 3000 psi. An argument could also be made that the higher compressive strength concrete would achieve a higher earlier strength and thus be less likely to crack under the same conditions of a weaker curb. If either of these effects would be true or are significant they would manifest themselves in cracking on the curbs. Again, one reason this variable was selected was that it was simple for BoBM to implement and only required coordination with the concrete producer.

While many variables were initially discussed, a lot were not easy to implement. These included trying to decouple the curb from the bridge deck, using precast curbs, modifications to guardrail post assemblies, preventing traffic during construction, and altering concrete mix to reduce thermal expansion. Again, many of these were more difficult to implement. Additionally, safety was a concern on a number of the items.

2.4 Cracking Indices

Due to the nature of concrete's volume instability, a crack's visible width and length can be effected by moisture, temperature, and degree of hydration. When it comes to a cracks length it becomes difficult to discern where a macrocrack ends and a microcrack begins, and where the crack entirely ends. In addition to concrete's inherent volume instability there are environmental considerations when looking at cracking in the field. These considerations include lighting and presence of moisture on the concrete curb which may make cracks more or less visible. Additionally, road salt and debris collecting on the curb can further hide the true details of a concrete crack. These reasons make it difficult to determine the "true" characteristics of a concrete crack. Since the true crack characteristics are difficult to determine, several crack indices were created to aid the project investigators and researchers by creating an easy to use identification system that can provide a general idea of crack characteristics. The metrics can be divided into two groups: one group used in the field and another group calculated after the survey. Each of these values will be discussed in the following sections.

2.4.1 Average Uncracked Length

One difficulty when comparing the number of cracks in one curb compared to another is that the curbs are often different lengths. For example, knowing that curb X has 5 cracks and curb Y has 10 cracks does not provide enough information on the relative amount of cracking in each curb. Simply looking at the number of cracks would indicate that curb Y is worse. But if curb Y is 60 feet long and curb X is 20 feet long than it becomes clearer that the amount of cracking is actually worse on curb X even though it has fewer cracks then curb Y. This is the reason for developing the average uncracked length for a curb which can be described by equation 2.1 below.

$$Average\ Uncracked\ Length = \frac{Curb\ Length}{Number\ of\ Cracks + 1} \qquad \text{Eq. 2.1}$$

Since the location of each visible crack along the curb is recorded, the average uncracked length is really a measure of the distance between cracks on a curb, or the end of the curb, if they were equally distributed along its length. This can be seen in Figure 10. It is important to note that a larger average uncracked length indicates a curb with less frequent cracking then one with a small average uncracked length. As cracks become fewer, the average uncracked length approaches the original curb length. When no visible cracking is present on a curb the average uncracked length is equivalent to the curbs length.

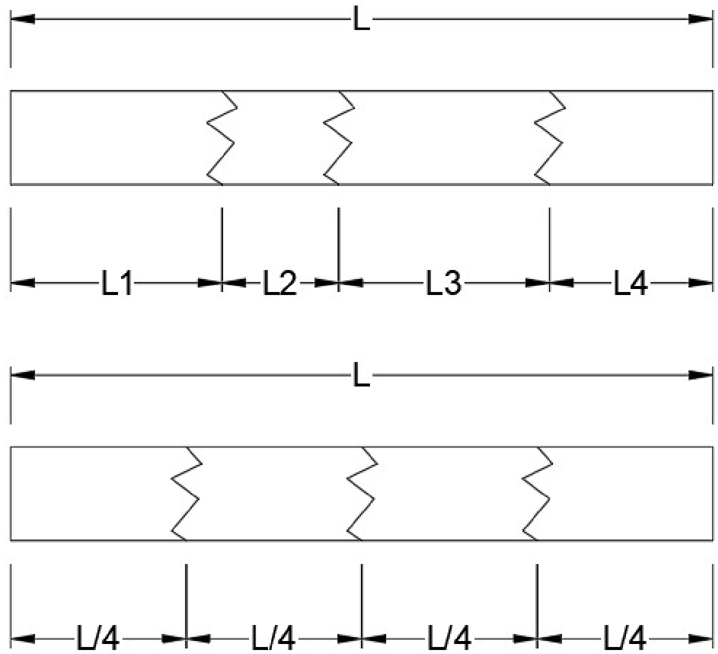


Figure 10: Comparison of actual length between cracks (top) and average uncracked length (bottom).

2.4.2 Length Index

As mentioned earlier, it is difficult to determine the true properties of a crack in concrete. In order to address part of this issue the length index was created. The length index allows for general classification of a visible cracks length. There are three different values for the length index: 1, 2, and 3. Examples of the three index values can be seen in Figure 11.

A crack with a length index of 1 is defined as having partial or limited cracking on one or two sides of the curb. Again, for safety reasons, this is frequently the face on the traveled way and the upper face. The example shown in Figure 11 shows a typical length index 1 crack which extends only a few inches along the top face and into the chamfer of the front face.

A length index of 2 indicates a crack that has nearly full cracking on one face and partial cracking on another face. The example of a length index 2 crack in Figure 11 shows a fine crack that extends more than halfway along the upper face of the curb and only extends down the front face to the chamfer.

Length Index 1 | Length Index 2 | Length Index 3

Figure 11: Examples of the three different length index values.

A length index 3 crack, as show in Figure 11, is defined as having full cracking along at least two faces or extending fully from the front face into a guardrail post. This guardrail consideration is to account for being uncertain as to exactly how the crack travels underneath the guardrail post.

2.4.3 Intensity Index

The intensity index is used to categorize the cracks width into one of three categories, similar to the length index. The values for the intensity index were developed from recommendations in ACI 224R-01. ACI 224R-01 contains a table of reasonable crack widths for concrete structures subject to flexure exposed to different environmental conditions. Since NH bridge curbs are placed on structures that are exposed to deicing chemicals, using ACI's table of reasonable crack widths indicates cracks 0.007 inches and smaller are reasonable. For concrete that is in dry air or has a protective membrane the reasonable crack width becomes 0.016 inches or smaller (ACI Committee 224, 2001).

The intensity index was developed with these limitations in mind. A crack width less than 0.007 inches was given an intensity index of 1. This means the crack is reasonable by ACI standards. An intensity index of 3 corresponds to a crack that greater than or equal to 0.016 inches in width. This value means the crack is likely unacceptable in most concrete structures, particularly those exposed to deicing chemicals. An intensity index of 2 simply means the crack is between the values established for an intensity 1 and 3 crack. An intensity value of 2 likely indicates that the crack is of concern on a bridge curb where concrete is exposed to deicing salts.

Another important consideration is that an intensity index value of 1 does not mean the crack does not adversely affect the curb. Furthermore, a crack that has an initial intensity of index of 1 may very well become an intensity 2 or 3 at a later date. An example of the crack intensities can be shown in Figure 12.

Intensity Index 1 Intensity Index 2 Intensity Index 3

Figure 12: Examples of the three different crack intensity index values.

2.4.4 Severity Index

Since the length index and intensity index describe two different qualities of a crack, a single term was created in order to combine the characteristics of the crack into a single value. This value is called the severity index and can be described by equation 2.2. The severity index is a range of values from 1 to 3. A severity index 3 crack will generally be considered a worse crack compared to a crack with a slower severity index.

$$Severity\ Index = \sqrt{(Length\ Index) * (Intensity\ Index)} \qquad \text{Eq. 2.2}$$

2.4.5 Curb Cracking Index

Once the severity index has been determined for each crack, the average severity index of all the cracks on a single curb is determined. The average severity value provides an average of the characteristics of each crack on the curb. This can be used with the average uncracked length, which represents the average spacing of cracks on a curb, to create a single metric that describes the quality of the curb in terms of cracking. This metric is the Curb Cracking Index, or CCI. The CCI is described by equation 2.3. From the equation it can be shown that a curb with a high CCI is in better condition than one with a low CCI.

$$Curb\ Cracking\ Index = \frac{Average\ Uncracked\ Length}{Average\ Severity\ Index} \qquad \text{Eq. 2.3}$$

2.5 Post-processing and Analysis

After a site visit all the recorded data was entered into a spreadsheet. The spreadsheet would automatically calculate severity index, average severity index, average uncracked length, and curb cracking index. The location and severity index of each crack was plotted on a graph to serve as a visual representation of cracking along the curb. This can be seen in Figure 13. At this point, data can be collected from this curb along with other curbs in order to do statistical analysis.

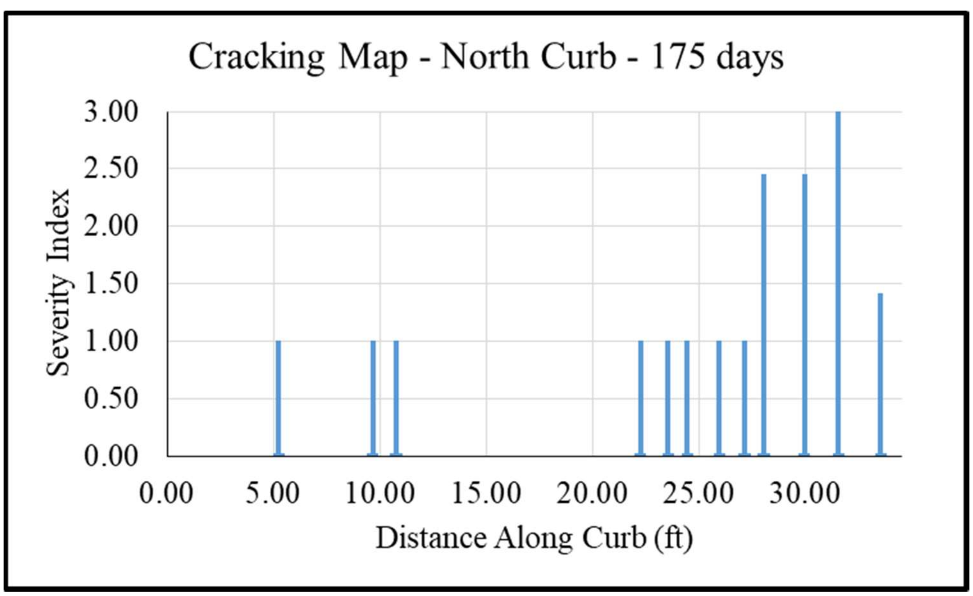


Figure 13: Graph showing crack location and severity index.

Analysis was generally conducted through the use of t-tests and Pearson's correlations. For t-tests, analysis was conducted using Excel's data analysis function for two samples while assuming unequal variances in the samples. A significance level of 0.05 was selected for rejecting the null-hypothesis. Any deviations or details for a particular analysis will be discussed in the appropriate section in Chapter 3. Additionally, most of the analysis was conducted looking for differences in the average uncracked length, length index, and intensity index.

CHAPTER 3: RESULTS AND DISCUSSION

3.1 Introduction

The following sections in this chapter describe many of the results from tests conducted during the experiment. It should be noted that the some results contain data from all bridges looked at during the study and others only show bridges constructed during the study. The bridge data set used will be described in the appropriate results section.

3.2 Bridge Locations and Attributes

A total of 23 bridges investigated during the study were used in preparing results in this report. Some bridges surveyed only have one curb that was included in the analysis of the results. This could be for a variety of reasons. For example, the bridge in Marlborough only had one curb replaced at the time of the investigation and the other curb was untouched during reconstruction.

A list of the bridges surveyed, along with some general information about each bridge, can be seen in Table 2. The table distinguishes between those that were constructed or rebuilt during the study and those that were constructed or rebuilt before the study. Test variables for curbs placed during the study are also listed. One note is that the Hampton 207/094 bridge was undergoing construction at the start of the project so no variables were applied to the curbs at that site.

Table 2: List of sites surveyed during the study.

Town	Bridge ID	Existing or Constructed During Study	Bridge Length, feet	Bridge Type*	Date Constructed or Reconstructed	ADT (% Trucks)	Test Variables
Albany	080/148	Existing	72.8	IB-C	2015	670 (4)	-
Alexandria	174/146	Study	29	CS	2017	880 (10)	Curing
Alstead	107/130	Existing	31.9	CS	2012	1600 (5)	-
Berlin	194/070	Existing	12	CS	2016	2700 (7)	-
Bow	052/140	Existing	31	IB-C	2014	9400 (4)	-
Canaan	178/141	Existing	47	IB-C	2011	1200 (4)	-
Chesterfield	080/120	Existing	41	IB-C	2010	370 (10)	-
Chichester	130/100	Existing	15	CS	2013	6400 (7)	-
Epsom	160/111	Existing	21	CS	2010	2800 (4)	-
Epsom**	117/120	Existing	39	IB-C	2008	680 (4)	-
Goshen**	105/129	Existing	40.67	CS	2013	110 (4)	-
Grantham	140/069	Study	27.5	CS	2018	1500 (10)	Curing
Hampton	207/094	Study	126	IB-C	2017	8500 (7)	-
Jefferson	087/096	Existing	84	IB-C	2011	840 (10)	-
Jefferson	089/090	Existing	27.6	CS	2015	840 (10)	-

Continued on next page

Marlborough	090/127	Study	10	CB	2018	7900 (7)	-
New Boston	045/131	Existing	17.4	CS	2015	1500 (7)	-
Pittsburg	070/032	Existing	94	IB-C	2014	1000 (4)	-
Sandown	082/103	Existing	26	CS	2013	4300 (4)	-
Swanzey	143/087	Existing	31.5	IB-C	2013	3000 (4)	-
Tamworth	095/162	Study	22	CS	2018	1700 (4)	PCC
Wakefield	245/066	Existing	52	IB-C	2012	8600 (7)	-
Westmoreland	111/072	Study	24	CB	2019	1700 (4)	PCC
*Bridge Types CS: Concrete Slab IB-C: Steel I-Beam with Concrete Deck CB: Concrete Box							
**Municipality Owned							

3.3 Distribution of Crack Length and Intensity

One important consideration when looking at cracking is the distribution of the length and intensity indices for all the cracks. This distribution can be seen in Figure 14. A distribution like the one shown helps demonstrate the need to address cracking on bridge curbs. According to the ACI guidelines discussed earlier and used to establish the intensity index, a crack intensity of one is a reasonable crack width. By recognizing a crack width of one as reasonable, it can be seen that 83.0% of the cracking on the documented bridge sites do not currently need to be addressed by ACI 224R standards. It is important to note that although a crack width of 0.007 inches is considered acceptable ACI points out that this is a general rule of thumb and should not be taken as a guarantee due to the variable nature of cracking in concrete. In fact, the table listing acceptable values has the following footnote:

> "It should be expected that a portion of the cracks in the structure will exceed these values. With time, a significant portion can exceed these values. These are general guidelines for design to be used in conjunction with sound engineering judgement." ACI 224R-01

So although 83.0% of the cracks documented in this study pass ACI acceptability, this does not necessarily mean they will remain a reasonable size for the life of the curb.

One observation when looking at the total values for intensity index is that the total number of cracks decreases significantly from an index value of one to three. In fact, only 0.9% of cracks documented have an intensity of 3. While this does demonstrate the widest cracks are infrequent compared to the total amount of cracking, it still shows that cracks exceeding even ACI's loosest acceptance criteria still occur.

Unlike intensity index, the length index does not have a decreasing pattern but instead demonstrates a decrease in the amount of length index two cracking compared to either length index one or three cracks. This may be due to a length index of one and three being a more stable state for a crack and that a crack length of two is simply a crack in transition to a length three crack.

Figure 15 depicts the change in a curbs average severity index compared to the curbs average uncracked length. From the figure, it can be seen that a large number of curbs have an average uncracked length less than 5 ft. A t-test was conducted and the results are shown in Table 3. The results indicate there is a significance in the severity index between curbs with smaller average uncracked lengths compared to those with longer average uncracked lengths. The curbs with an average uncracked length greater than 5 ft had an average severity index of 1.11 compared to those with an average uncracked length less than 5 ft which had an average severity index of 1.26. The same procedure was conducted but instead using an average uncracked length

		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	

		Length Index			
		1	2	3	Total
Intensity Index	1	**61.8**	**7.5**	**13.7**	83.0
	2	**2.6**	**1.6**	**11.8**	16.0
	3	**0.0**	**0.0**	**0.9**	0.9
	Total	64.4	9.2	26.4	

Figure 14: Distribution of cracking by length and intensity index. Total cracking, top, and percent of total cracking, bottom.

normalized to the length of the curb. This can be seen graphically in Figure 16. A t-test was also conducted sing this data with the boundary being point with a normalized average uncracked length less than or equal to 0.1 in one group and those greater than 0.1 in another group. The result of the t-test are shown in Table 3 and reaffirm the idea that average severity index is significantly different on curbs with smaller average uncracked lengths.

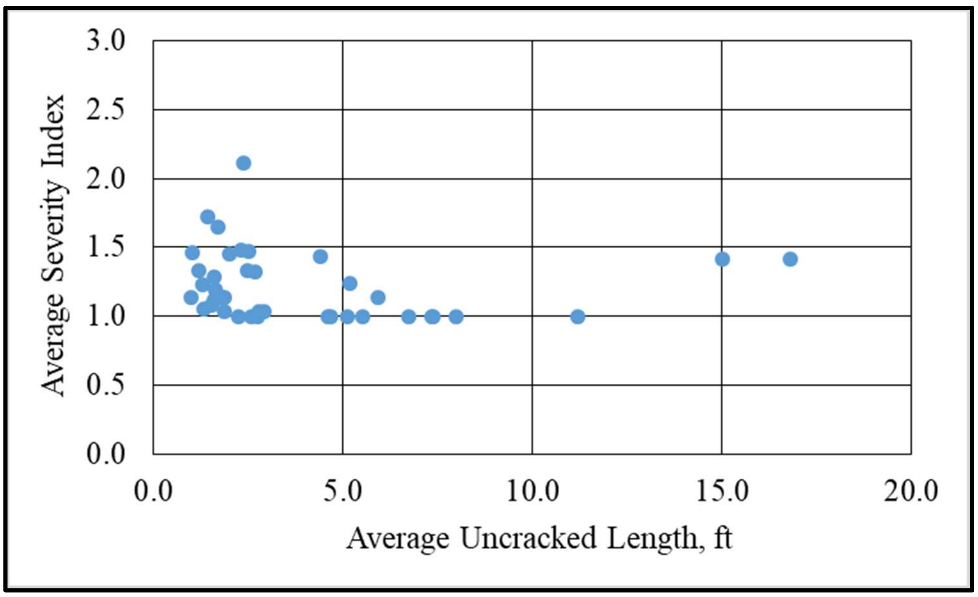


Figure 15: Comparison of the average uncracked length of a curb to the average severity index.

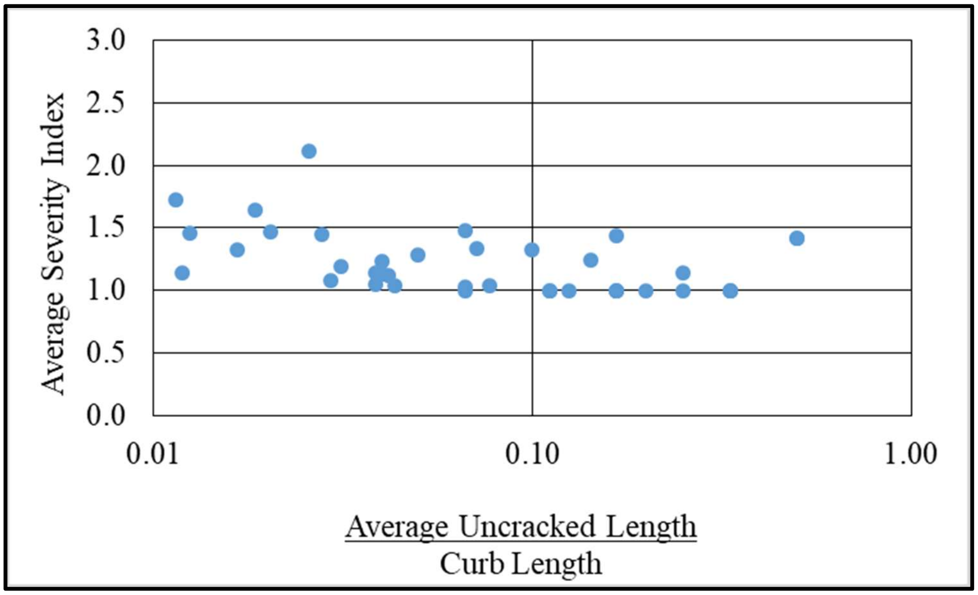


Figure 16: Comparison of the average uncracked length of a curb to the average severity index.

Table 3: t-test conducted on the average severity index on curbs with different average uncracked lengths.

t-test	**p-value** **α < 0.05**	**Outcome**
Average Severity Index Average Uncracked Length <5 ft & >5 ft	0.047	Average severity index of a curb is significantly different on curbs with an average uncracked length of less than 5 ft compared to those greater than 5 ft.
Average Severity Index Normalized Average Uncracked Length <0.1 & >0.1	0.00001	Average severity index of a curb is significantly different on curbs with a normalized average uncracked length of less than 0.1 compared to those greater than 0.1.

3.4 Bridge Length

This section describes the results from analysis on bridge length. Bridge length was determined from data published by NHDOT. The FHWA defines structure length as the distance of roadway that is supported by the structure and is either measured from paving notch to paving notch or is the distance between the backs of the abutment backwalls. Early analysis of bridge data suggested that there was a difference in cracking behavior for longer bridges compared to shorter bridges. In order to analyze the difference between longer bridges and shorter bridges a length of 40 ft was selected as a location of approximate change in cracking characteristics. This boundary, although guided from the data, is still not refined and fairly arbitrary. This boundary is used in other parts of this thesis to separate data. All recent site survey data was used in the bridge length analysis.

The effect of bridge length on the average uncracked length of the curb can be seen in Figure 17. It can be seen that curbs less than approximately 35 ft exhibit a larger range of values for average uncracked length. The high average uncracked length is attributed to minimal

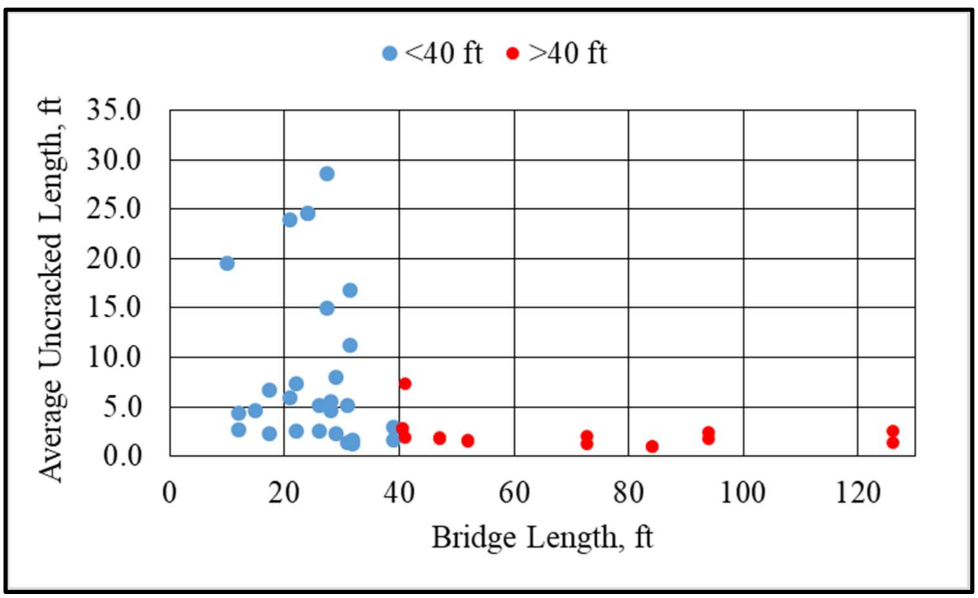


Figure 17: Effect of bridge length on average uncracked length.

cracking. Even ignoring data points that have an average uncracked length greater than 10 ft, the remaining shorter bridge curbs tend to have a higher average uncracked length compared to bridges over 40 ft in length. Performing a t-test on average uncracked length, see Table 4, indicates that the difference between shorter and longer bridges is significant.

When looking at the distribution of average length index compared to bridge length, Figure 18, there seems to be clusters of higher length index values on both sides the 40 ft mark. The trend on curbs over 40 ft appears to indicate an increase in the average length index at increasing bridge lengths. A t-test conducted suggests the average length index is not significantly different between curbs over 40 ft and less than 40 ft. This may hold true for the division line of 40 ft but perhaps the effects of bridge length on the average length index do not become significant until 60 ft or greater. Further investigation of this is required.

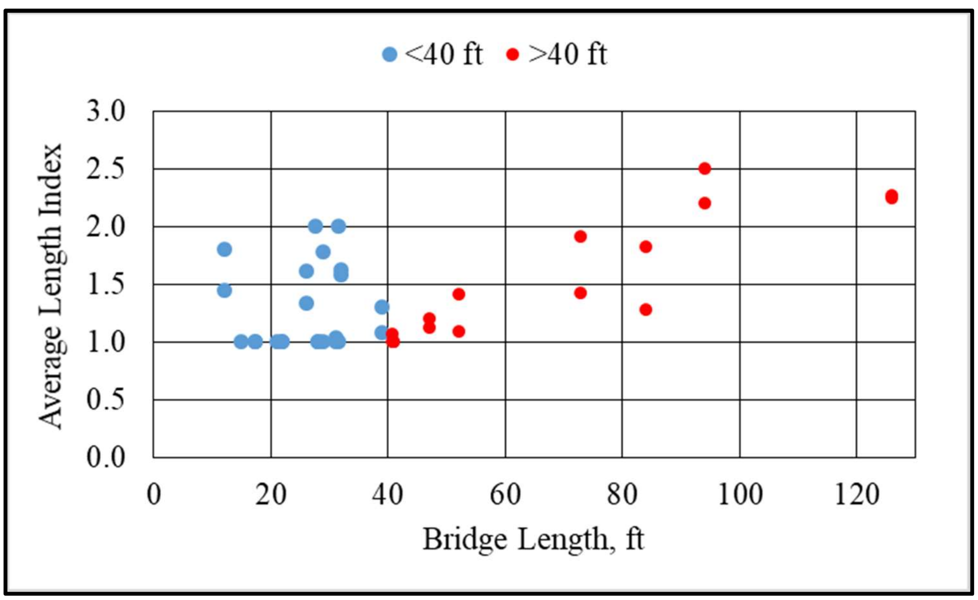


Figure 18: Effect of bridge length on average length index.

The average intensity index for curbs tends to be flatter than the average length index graphs. This can be seen in Figure 19. Again, it appears that there may be a slight upward trend in average intensity index with increasing bridge length. The results of a t-test, Table 4, currently indicate that there is no significant difference in average intensity index for curbs on bridges less than 40 feet in length compared to those greater than 40 ft in length.

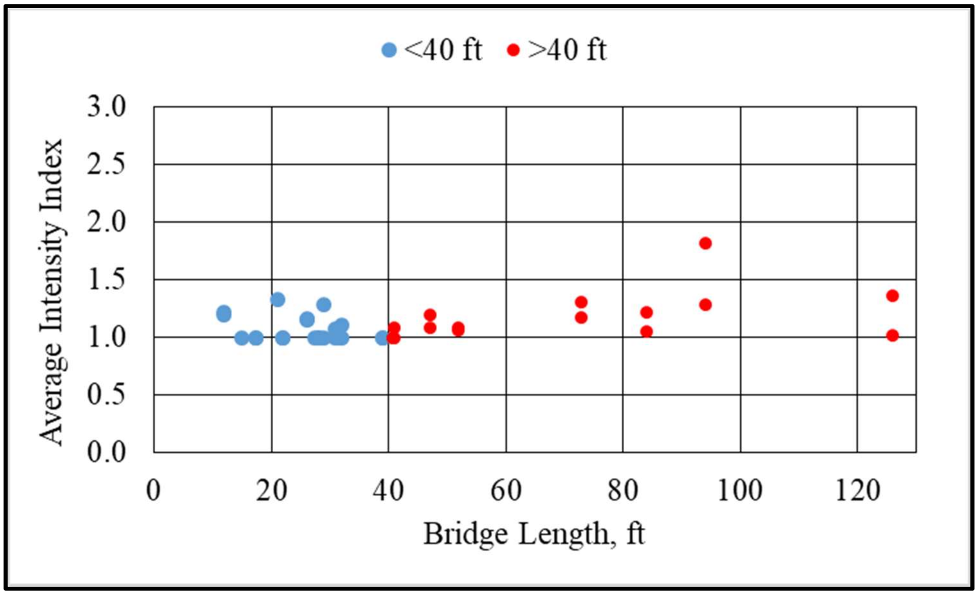


Figure 19: Effect of bridge length on average intensity index.

Table 4: Curb t-tests comparing variations between bridges less than 40 ft in length and greater than 40 ft in length.

t-test	p-value $\alpha < 0.05$	Outcome
Average Length Index Bridge Length <40 ft & >40 ft	0.119	Average length index of a curb does not significnatly differ for bridges under 40 ft and bridge over 40 ft.
Average Intensity Index Bridge Length <40 ft & >40 ft	0.077	Average intensity index of a curb does not significnatly differ for bridges under 40 ft and bridge over 40 ft.
Average Uncracked Length Bridge Length <40 ft & >40 ft	0.0004	Average uncracked length of a curb is significnatly differerent for bridges under 40 ft and bridge over 40 ft.

3.5 Steel I-Beam with Concrete Deck and Concrete Slab Construction

One thing to consider in addition to the length of the bridge effecting cracking is the type of bridge structure the curb is on. The majority of the bridge curbs surveyed in this study were either concrete slab, CS, bridges or steel I-beam with concrete deck, IB-C, bridges. Typically, for shorter spans the concrete slab bridge structure, Figure 20, is used. As bridge spans become larger there is a tendency to use steel I-beams, Figure 21, for the structure.

Figure 20: Concrete slab bridge structure example in Alexandria, NH.

This trend can be seen in Figure 22 and Figure 23. Early in the study it was noticed that longer bridge lengths tended to have a smaller average uncracked length. It was observed that this change appeared to happen around 40 feet. When looking at Figure 22, this change in cracking appears to coincide with around the same bridge length that CS bridge types are abandoned in favor of IB-C types. It can be seen that there are some CS bridge types in areas dominated by IB-C types. The CS types near 40 ft also exhibit a low average uncracked length.

Unfortunately, there are very few longer CS bridge and shorter IB-C bridges that have been built within the last decade in New Hampshire. This makes it difficult to determine if the decreased average uncracked length is strictly related to bridge length, or bridge type, or both.

Figure 21: Steel I-beam with concrete deck bridge structure example in Wakefield, NH.

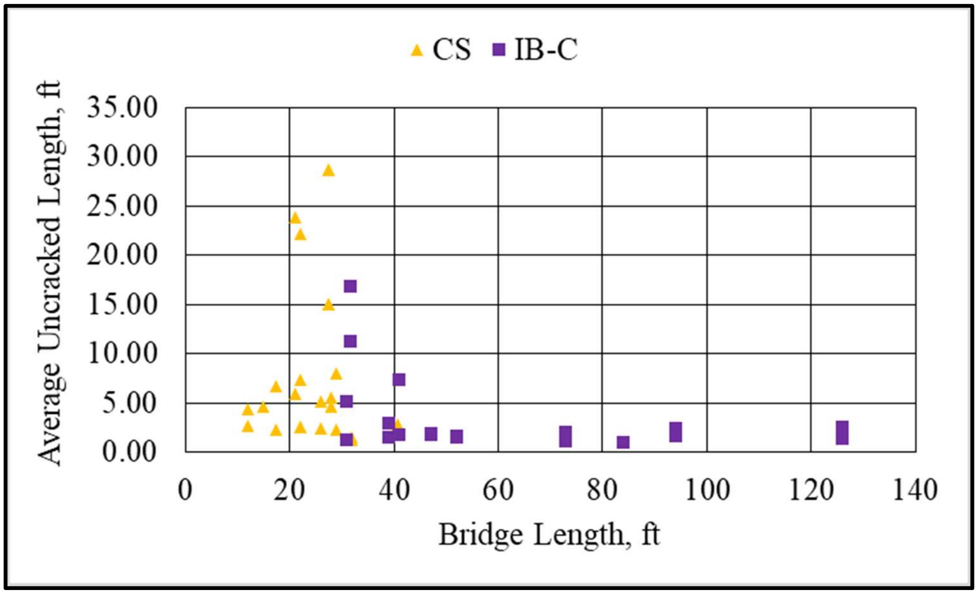


Figure 22: Average uncracked length compared to bridge length separated by bridge type.

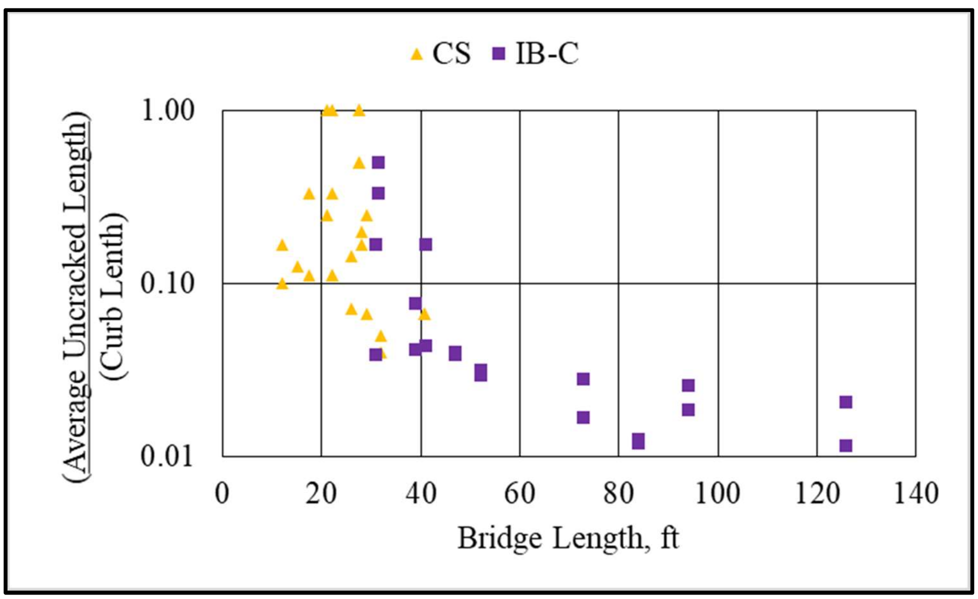


Figure 23: Ratio of average uncracked length to curb length compared to bridge length separated by bridge type.

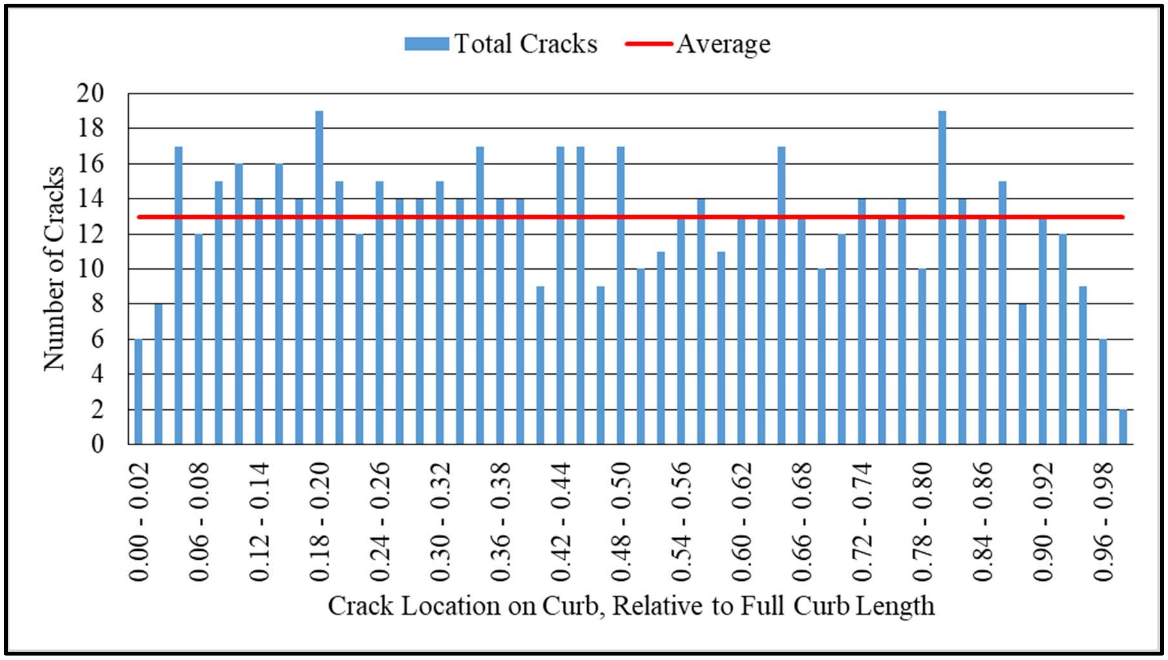
3.6 Location on Curb

There was a concern that cracking may vary at different locations along the bridge. In order to see if there were any areas with abnormal cracking compared to the rest of the curb all the crack locations for curbs on bridges over 40 ft were plotted into several categories that represented two percent sections of the entire curb. The total cracking in each section can be seen in Figure 24.

From Figure 24, it appears that there is less cracking occurring at the ends of the curb. To further investigate the effect of curb location, each crack was given a value from 0 to 1 corresponding to its distance relative to the center of the curb. A crack that was located at the center of the curb would be given a location value of 0. A crack that was located halfway between the middle of the curb and the curb end would be given a location value of 0.5. This is shown in Figure 25.

Each crack was then categorized into one of five sections. Each section corresponds to one-fifth of the curbs length. The sections are: 0 to 0.2, 0.2 to 0.4, 0.4 to 0.6, 0.6 to 0.8, and 0.8 to 1.0. By placing cracks into each section t-tests could be conducted to determine if there was a significant difference in cracking behavior along the curb. Paired t-tests were conducted for the number of cracks in each section since each section comes out of the same curb. For length and intensity index, unpaired t-tests were conducted since some curb sections experienced no cracking and thus the length and intensity index of that section would not be applicable. The t-tests were conducted on all the most recent bridge investigations.

Figure 24: Cracking at curb sections on bridges over 40 feet in length.



The results of the t-tests can be seen in Table 5. It can be seen that the length index or intensity index does not change significantly from one section to another. It will be noted that the end section of the bridge, furthest for midspan, experiences a lower average uncracked length than the rest of the curb. The difference in the amount of cracking can be seen in Figure 26.

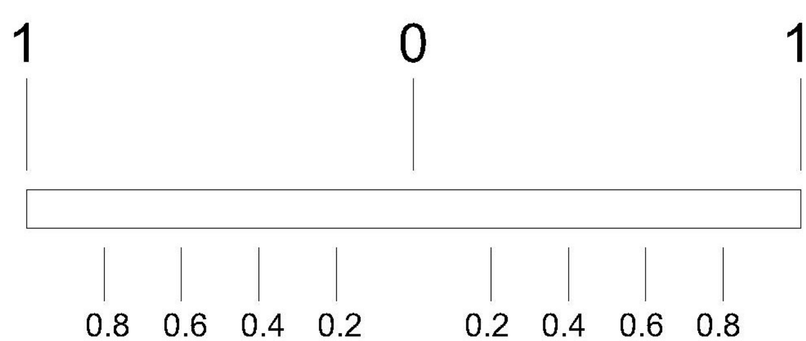


Figure 25: Crack location boundaries along a bridge curb for analysis.

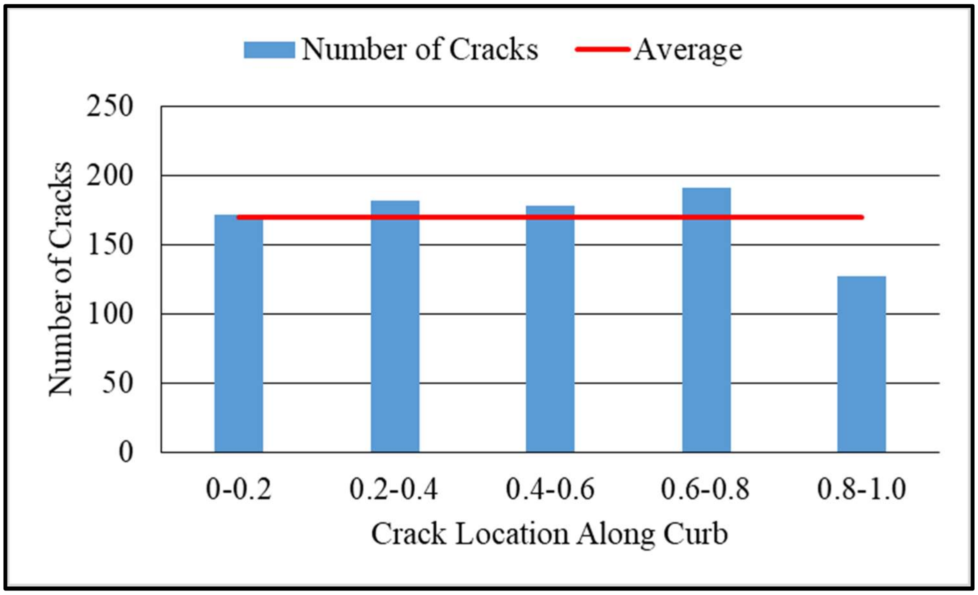


Figure 26: Amount of cracking at various sections along the curb. Zero refers to the center of the span and one to the ends of the curb.

The ends of curbs tend to have significantly less cracking when compared to the other parts of the curb. The difference between the sections may be due to the end of the curb being less restricted by shrinkage than the rest of the curb or a potential structural response. For curbs less than 40 ft, the end fifth of the curb deviates from the average of the curbs by 32.8%. For curbs longer than 40 ft the deviation is 23.0%.

Two bar charts were created to compare the average uncracked length of curbs to the distance of the first crack in from each end of a curb. If the shape of the plot of average uncracked length matches the shape of the plot of the distance to the first crack, it would suggest that there is no difference in cracking at the ends of the curb. By looking at Figure 27, it can be seen that the majority of curbs over 40 ft have an average uncracked length between 1 ft and 2 ft. This differs from Figure 28 which does not have as prominent of a peak at the 1 ft to 2 ft mark.

The greater distance from the end of the curb to the first crack compared to the average uncracked length further suggests cracking is less frequent at the end of the curb. It should also be noted that although each curb has only one average uncracked length, two entries are made for the first crack since both ends of the curb can be used.

Table 5: Resulting p-values for cracking behavior based on curb location. A red cell background indicates significance and green indicates lack of significance.

Number of Cracks, α = 0.05

	0.0 to 0.2	0.2 to 0.4	0.4 to 0.6	0.6 to 0.8	0.8 to 1.0
0.0 to 0.2		0.313	0.634	0.163	0.009
0.2 to 0.4			0.736	0.408	0.002
0.4 to 0.6				0.329	0.005
0.6 to 0.8					0.001
0.8 to 1.0					

Length Index, α = 0.05

	0.0 to 0.2	0.2 to 0.4	0.4 to 0.6	0.6 to 0.8	0.8 to 1.0
0.0 to 0.2		0.920	0.343	0.697	0.420
0.2 to 0.4			0.389	0.770	0.367
0.4 to 0.6				0.557	0.102
0.6 to 0.8					0.245
0.8 to 1.0					

Intensity Index, α = 0.05

	0.0 to 0.2	0.2 to 0.4	0.4 to 0.6	0.6 to 0.8	0.8 to 1.0
0.0 to 0.2		0.886	0.814	0.672	0.283
0.2 to 0.4			0.682	0.756	0.303
0.4 to 0.6				0.474	0.186
0.6 to 0.8					0.416
0.8 to 1.0					

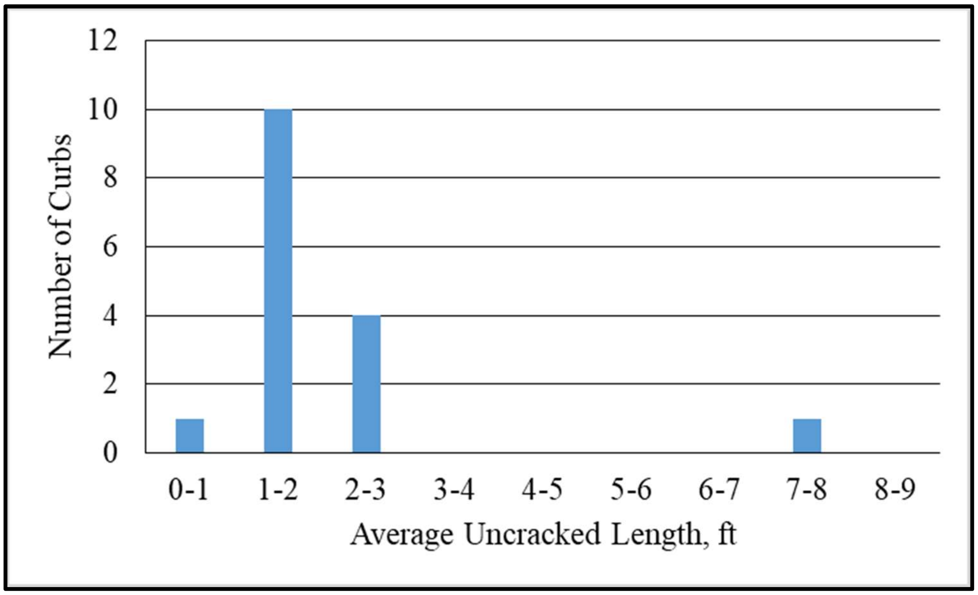


Figure 27: Frequency distribution of average uncracked length of curbs on bridges over 40 ft.

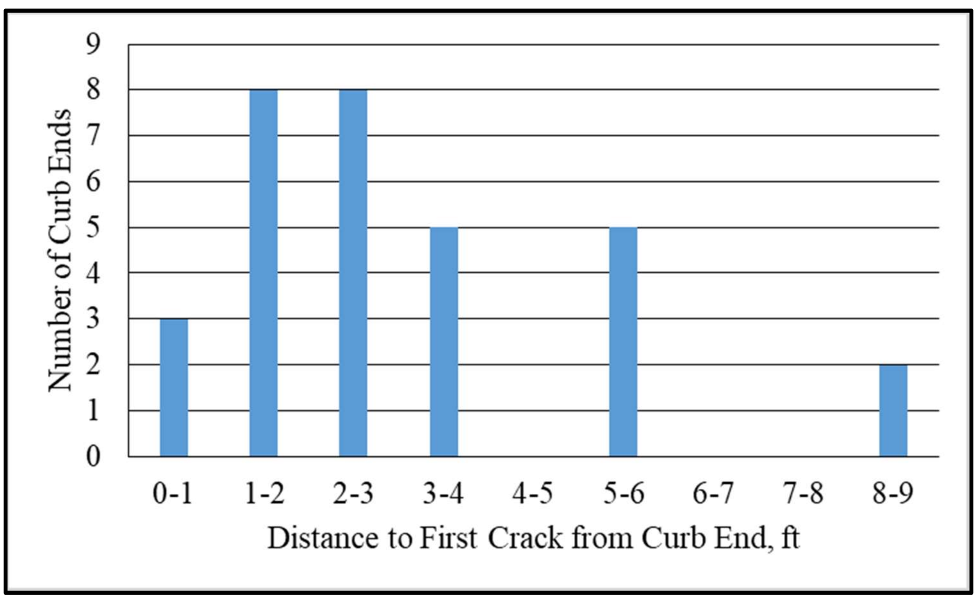


Figure 28: Frequency distribution of where the first curb crack on a bridge over 40 ft in length occurs from the end of the curb.

3.7 Curing Duration

A paired t-test was conducted for curbs that were placed with different wet cure durations. Due to the lack of newly constructed bridge curbs there were only two bridge sites that could be compared. One of which had a curb with no cracking. No cracking means the t-test on length index and intensity index would only have one data point to compare against and does not produce a valid t-test. The results of the t-test, shown in Table 6, indicate that wet cure duration does not have a significant effect on the average uncracked length.

Table 6: t-test of average uncracked length on different wet cure durations.

t-test	p-value $\alpha < 0.05$	Outcome
Average Uncracked Length Wet Cure Duration 7-day & 14-day	0.247	Average uncracked length of a curb does not significnatly differ for curbs on bridges with 7-day wet cures and 14-day wet cures.

In order to see the effects of curing on all the curbs studied, not just the ones that had variable wet cures, three graphs were created. The graphs show wet cure duration against average uncracked length, average length index, or average intensity index. The average uncracked length plot, Figure 29, appears to be lacking a clear trend. It should be noted as well that this graph does not separate bridges under and over 40 ft in length. The length influence may exist here as two of the three data points with an average uncracked length below 5 ft are curbs on bridges over 40 feet. Additionally, the pairs of curbs that are on the same bridge and were subject to different wet cures as shown connected by a dashed line. From the paired curbs it may be inferred that longer wet cure durations produce curbs with a greater average uncracked length.

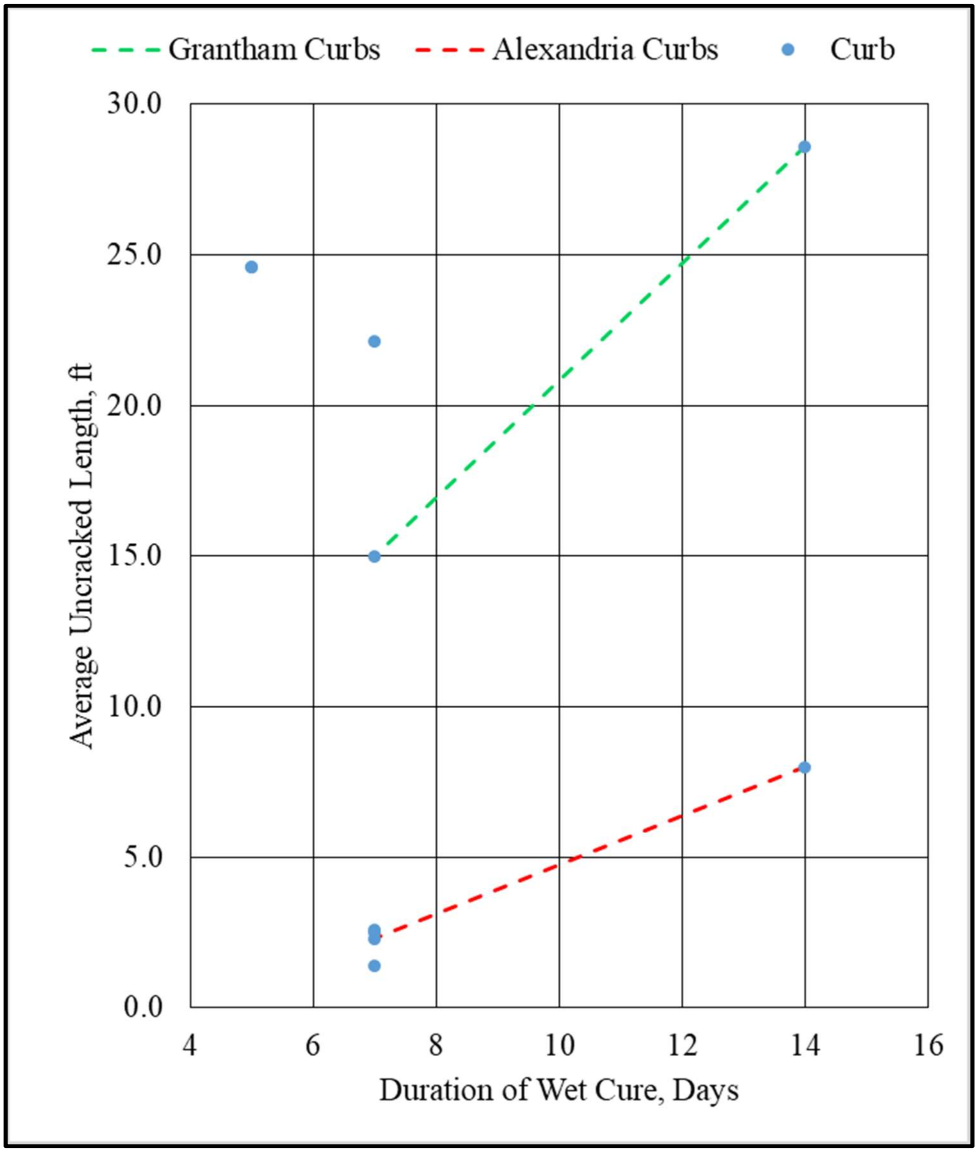


Figure 29: Average uncracked length and wet cure duration.

Wet cure duration may have an effect on average crack length and width as can be seen in Figure 30 and Figure 31. In both figures the average index value is lower for the curb placed with a 14-day wet cure compared to those with 7 day wet cures. Again, these graphs show only curbs that have experienced any cracking at all. The difference in wet cure duration is more pronounced for the average length index compared to the average intensity index.

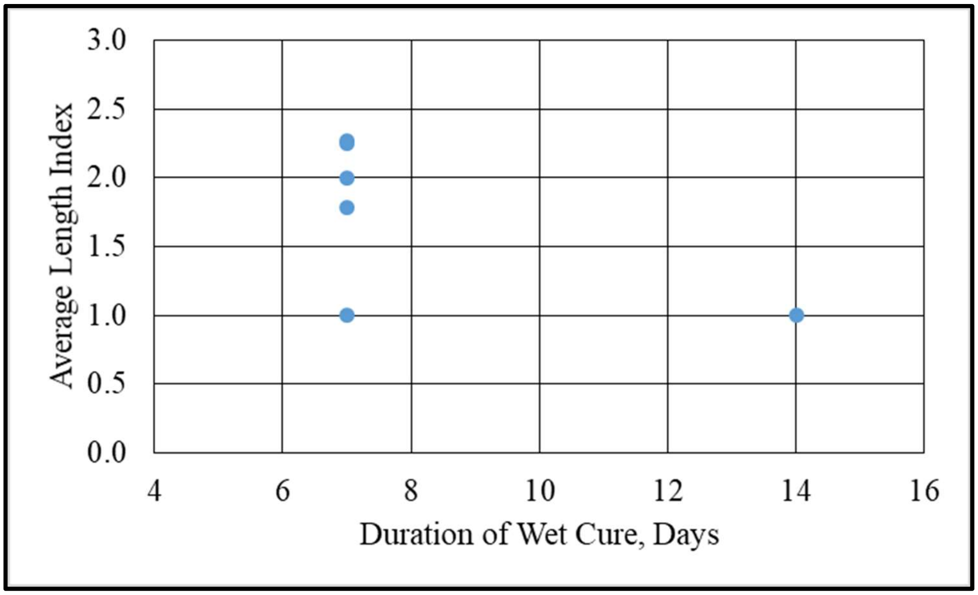


Figure 30: Average length index compared to wet cure duration.

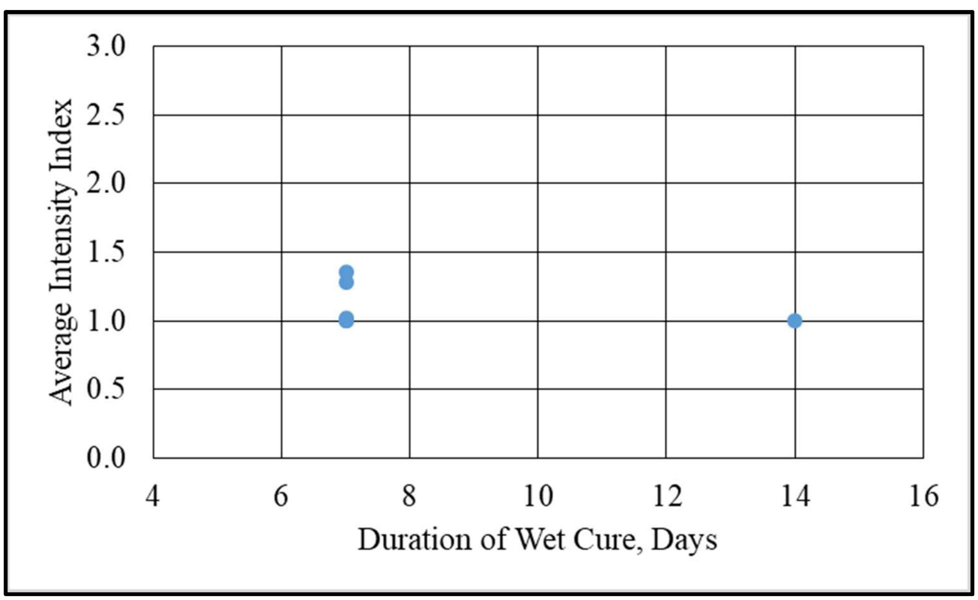


Figure 31: Average intensity index compared to wet cure duration.

Additional concerns with curing, particularly cold weather curing in New Hampshire, is the internal temperature of the curing concrete. This study placed thermocouples in four curbs to see how the internal temperature of the curbs varied during curing. Two curbs were placed during the winter and two were placed during warmer weather in spring and summer. The thermocouple results for a curb placed in the winter can be seen in Figure 32.

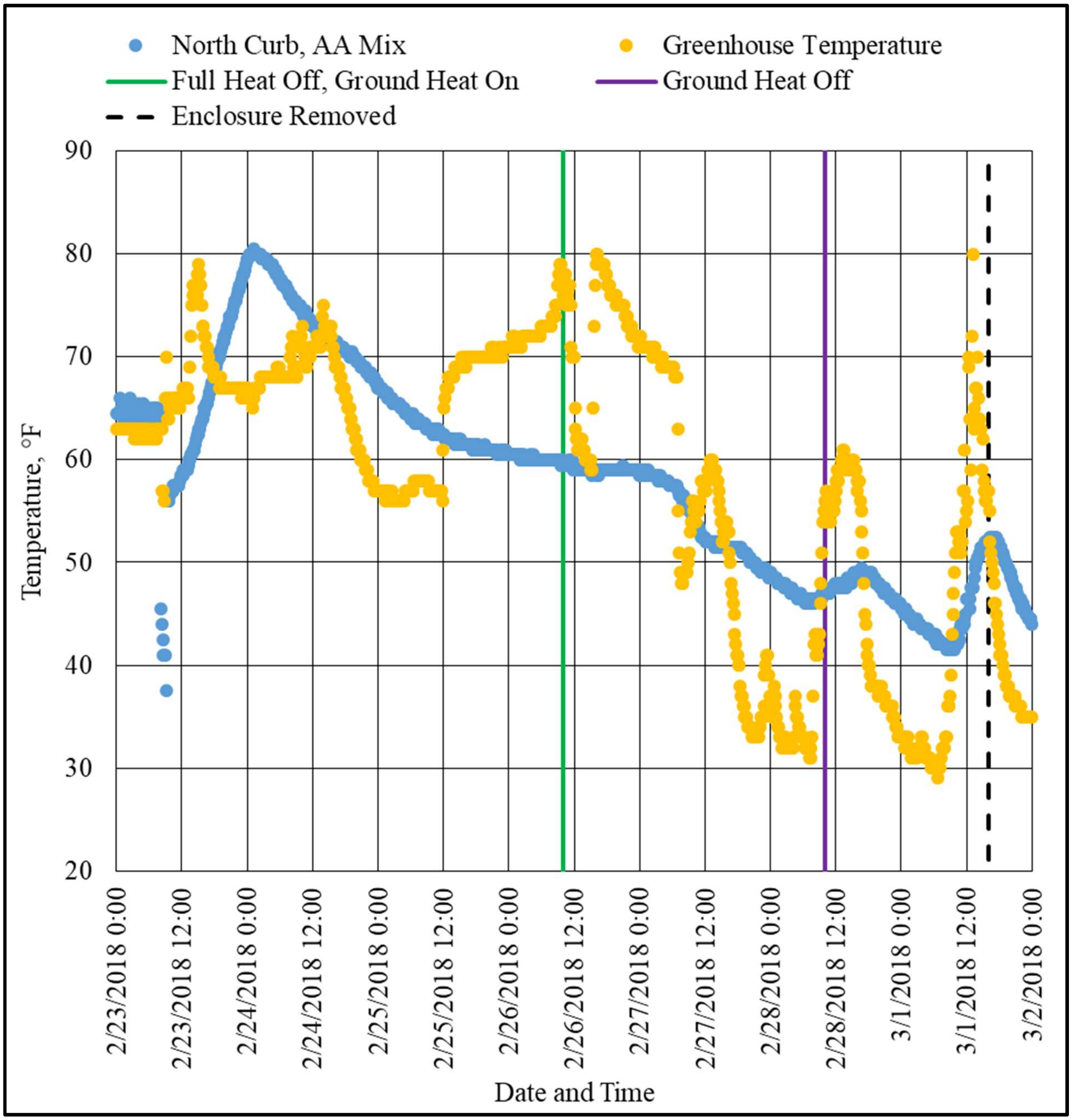


Figure 32: Thermocouple temperature measurements from inside a curb placed in the winter inside of an enclosure.

The curb in Figure 32 was placed in a "greenhouse" constructed by NHDOT to keep concrete from freezing as well as provide a working space for personnel. The greenhouse was heated by gas heaters in the enclosure as well as ground heaters underneath the deck. Both heaters were kept on until the solid green line in the graph when the enclosure heat was turned off and the ground heat was kept on. The purple vertical line indicates when all heat was shut off. The dashed black line indicates when the enclosure was removed and the curb was then exposed to environmental conditions. The temperature within the greenhouse can be seen by the yellow data points. The internal curb temperature can be seen by the blue data points. The point when cold concrete touches the thermocouples during placement can be seen by the sudden drop in temperature on 2/23/2018. After the drop, the temperature rises as concrete begins to cure. The graph appears to indicate that the winter curing practice of the NHDOT is sufficient to prevent the concrete from freezing early after placement.

One of the curbs placed in warmer weather is shown in Figure 33. Thermocouples measured the internal temperature of the curb near the two ends of the curb and at the center of the curb. From the image it can be seen that the middle portion of the curb experiences a higher temperature then the two ends but still below temperatures that may be detrimental to the concrete. It should be noted that the high for the day on the placement of this curb was 73°F.

The instrumented curbs suggest that nothing unordinary is happening with respect to the curb temperature that would be of a concern. Again, there has only been a limited about of internal temperature data collected and further investigation may reveal excessively high or low temperatures early in curing.

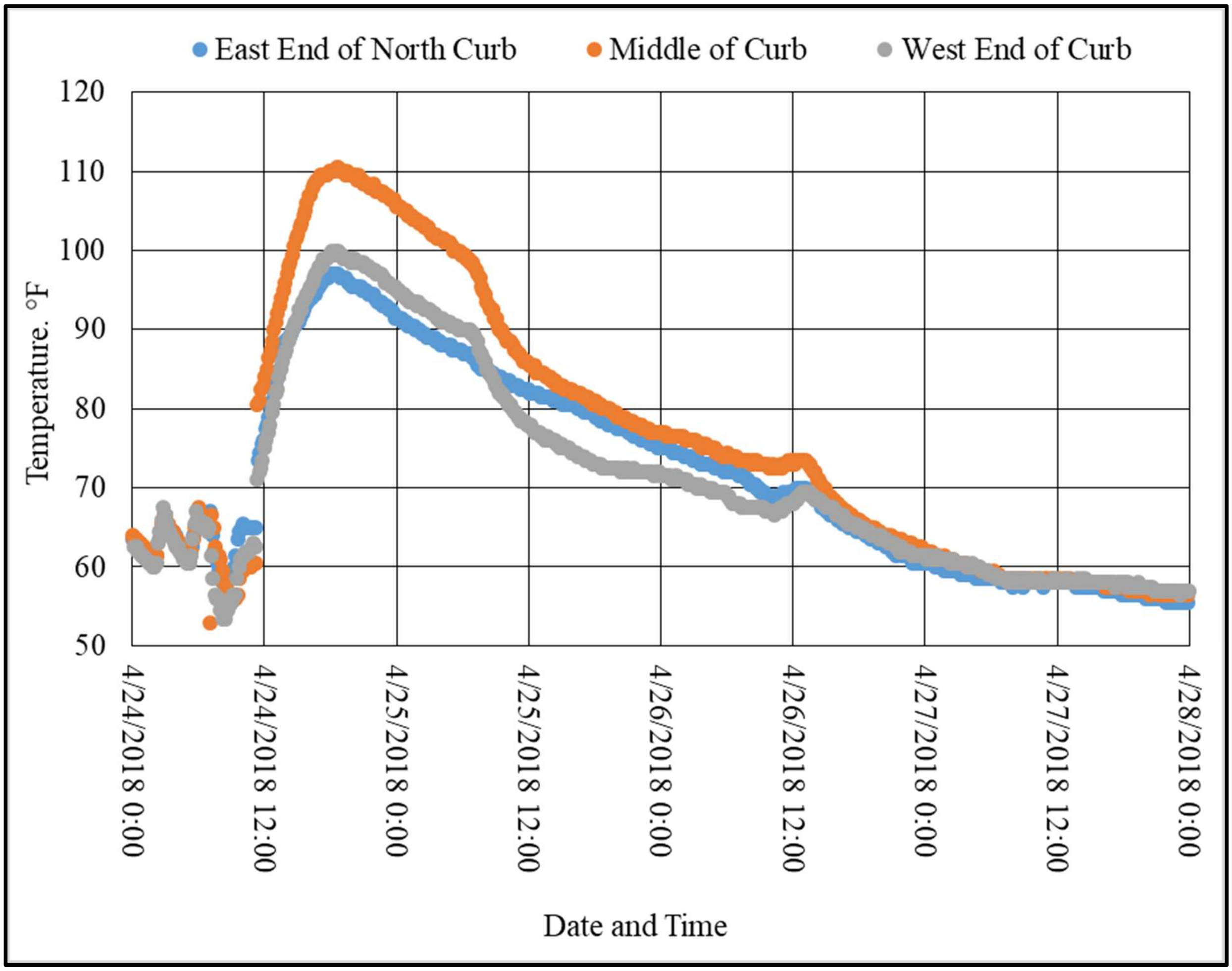


Figure 33: Thermocouple temperature measurements from inside a curb placed on a day with a high of 73°F.

3.8 Cementitious Content

Similar to wet cure duration, a paired t-test was conducted on two bridges that had variations in PCC mix design. On each bridge, one curb was placed using NHDOT AA mix and the other was placed using NHDOT A mix. The results of the paired t-test can be seen in Table 7. The p-value is not below the value required for significance. The two NHDOT AA mix curbs had average uncracked lengths less than 3 ft whereas the curbs constructed of NHDOT A mix had average uncracked lengths in excess of 20 ft. The average length and intensity indices had no t-tests performed since the one of the NHDOT A mix curbs experienced no cracking which prevents a valid t-test from being conducted.

Table 7: t-test results for curbs placed with NHDOT AA mix with that of NHDOT A mix.

t-test	p-value α < 0.05	Outcome
Average Uncracked Length PCC Mix NHDOT AA & A	0.500	Average uncracked length of a curb does not significnatly differ for curbs constructed with NHDOT AA or NHDOT A mixes.

Graphs on all curbs placed during the study with known w/cm were created. t-tests were not conducted on w/cm since no clear separation in the graphically expressed data existed t-tests were not conducted on w/cm. This can be seen in Figure 34. The graph does not appear to have a linear trend but may have a trend corresponding to a second order polynomial function with a w/cm of about 0.39 corresponding to the greatest average uncracked length. The graph of the average length index, Figure 36, only consists of six data points and lack a clear trend. If the

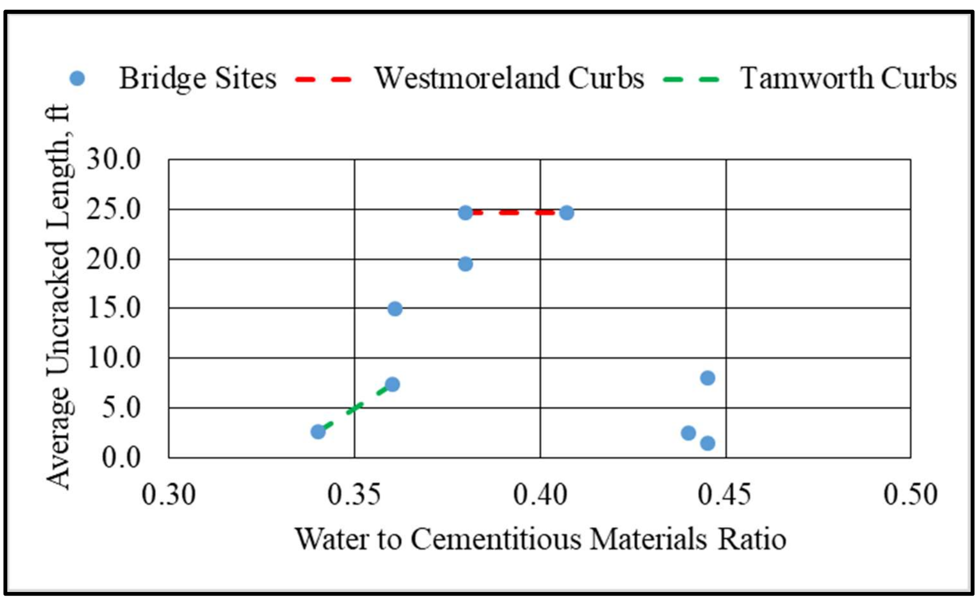


Figure 34: Average uncracked length compared to w/cm.

general shape of a second order function is overlaid over Figure 36 it may hypothesized that a pessimum for the average length index of the curb corresponds to the optimum w/cm of average uncracked length. When looking at the average intensity index compared to w/cm, Figure 37, it appears that different w/cm do not produce large variations in the average intensity index.

The total cementitious material content per cubic yard of several curbs placed during the study were compared to cracking. When the total cementitious content is compared against average uncracked length, as shown in Figure 35, no trend is apparent. Further data is required in order to determine if the lower average uncracked lengths between 620 lbs/yd^3 and 640 lbs/yd^3 are significant or are the result from other factors. When comparing curbs placed on the same bridge, curbs with a higher cementitious content tend to exhibit a smaller average uncracked length.

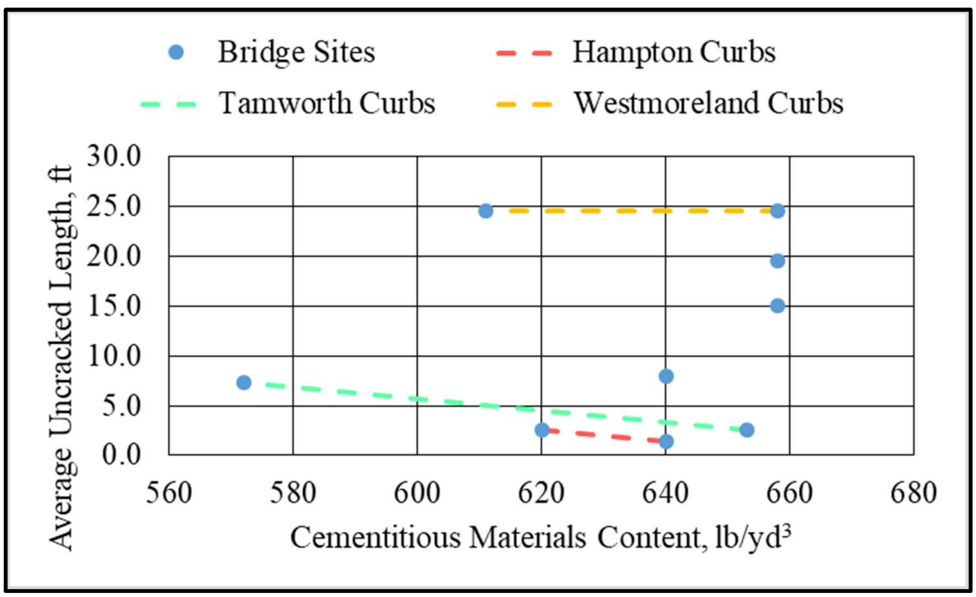


Figure 35: Cementitious content compared to average uncracked length.

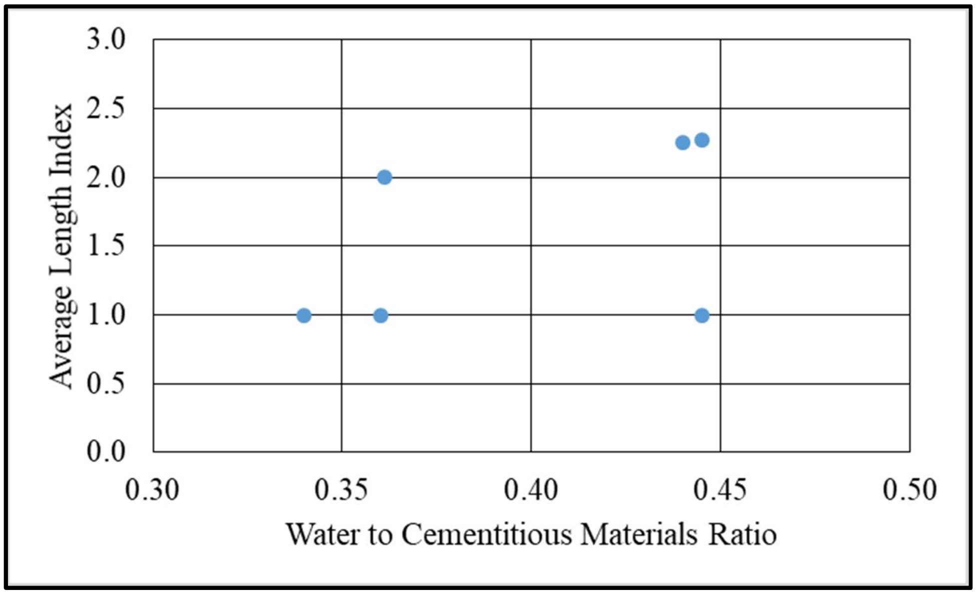


Figure 36: Average length index compared to w/cm.

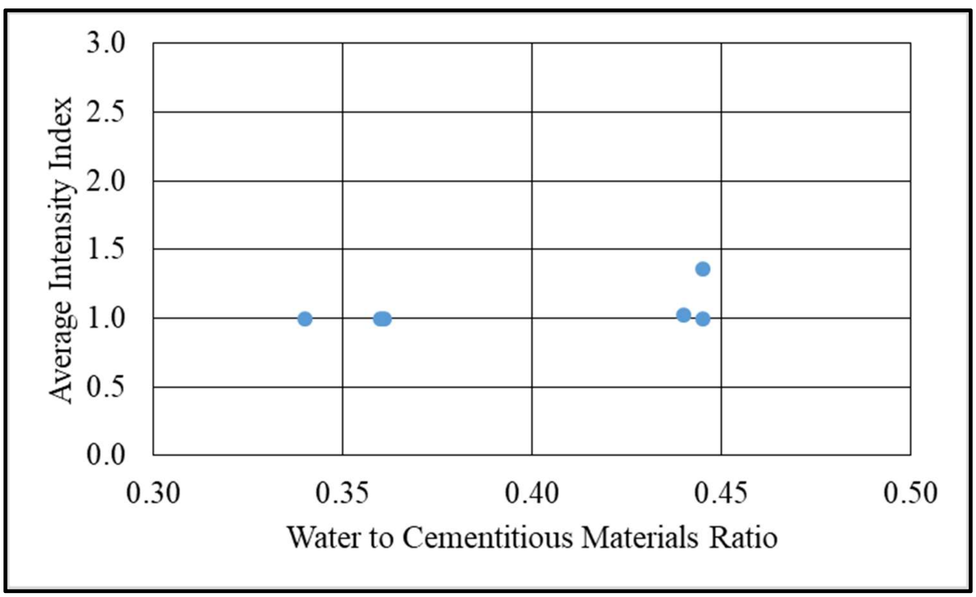


Figure 37: Average intensity index compared to w/cm.

The distribution of average length and average intensity index indicates there is likely no connection between crack characteristics and cement content. This can be seen in Figure 38 and Figure 39. Pearson correlations were also conducted on both the w/cm and the total cementitious content of concrete per cubic yard. The results suggest that there is no correlation between the average uncracked length and either the cementitious content or w/cm of PCC. The actual Pearson correlation coefficients are shown in Table 8.

Table 8: Pearson correlations for cementitious content and w/cm.

Pearson Correlation	r	Outcome
w/cm, Average Uncracked Length	-0.295	The average uncracked length of a curb has a weak negative correlation with w/cm
2*Log(w/cm), Log(Average Uncracked Length)	-0.232	
Cementitious Content, Average Uncracked Length	-0.520	The average uncracked length of a curb has a weak negative correlation with cementitious content
2*Log(Cementitious Content), Log(Average Uncracked Length)	-0.497	

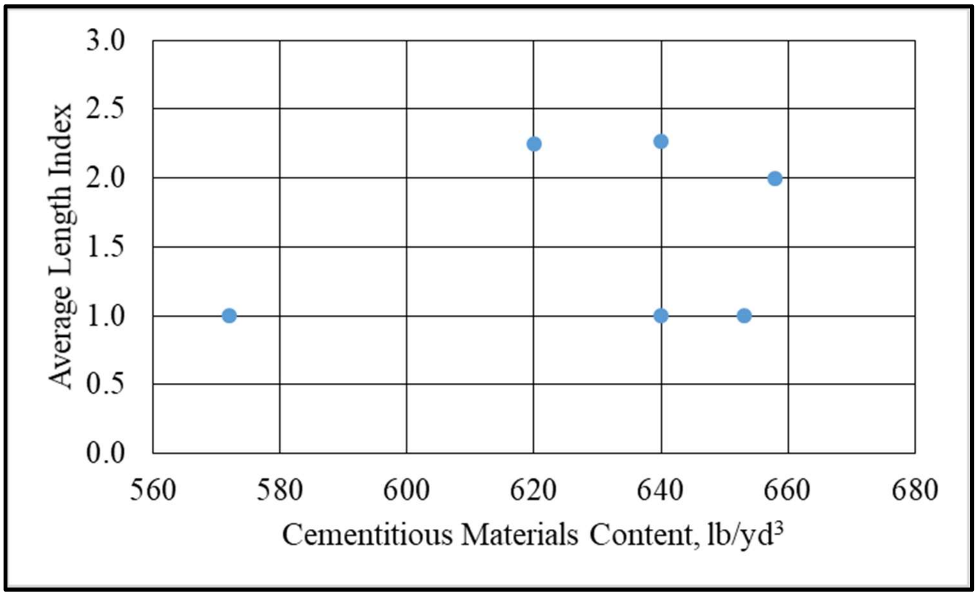


Figure 38: Cementitious content compared to average length index.

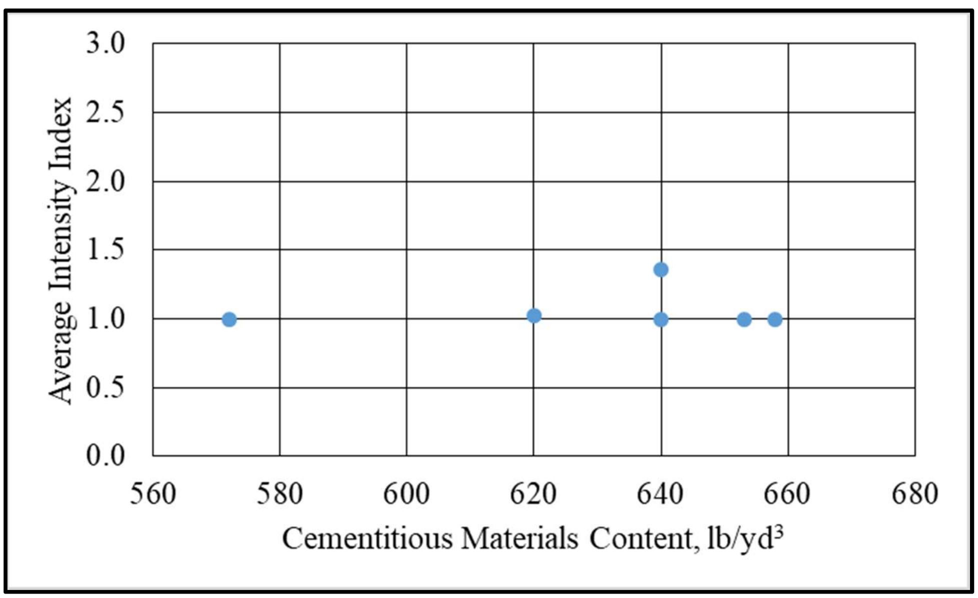


Figure 39: Cementitious content compared to average intensity index.

3.9 Compressive Strength

Compressive strength is often used as an indicator of concrete durability. Curbs placed during the study had samples taken to undergo compressive strength tests. The compressive strength test data used in this paragraph were all conducted at 28-days. Cylinders were not taken on placement days when personnel was limited. The curbs that had compressive strengths tested at 28-days can be shown in Table 9 and are the only curbs used for the results in this section. All the most recent data, excluding the most recent Tamworth survey, is used in the following analyses.

Table 9: Curbs with 28-day compressive strength data.

Bridge	Town	Side	Bridge Length (ft)	28-day Compressive Strength (psi)
174/146	Alexandria	North	29	4013
140/069	Grantham	North	27.5	5194
140/069	Grantham	South	27.5	5094
207/094	Hampton	South	126	5919
207/094	Hampton	North	126	5772
090/127	Marlborough	North	10	6325
095/162	Tamworth	North	22	6032
095/162	Tamworth	South	22	4596
111/072	Westmoreland	East	24	4460

In order to create t-tests for the data set, two categories needed to be determined for comparison. A value of 5,500 psi was selected as the boundary of the data set in order to have a similar amount of data points in each group. It should be noted that the two longest curbs in the study are placed in the same group. The same 5,500 psi requirement was used for t-tests conducted using average length index and average intensity index. For the average length and average intensity indices, only curbs that had experienced any cracking were used. This was done to avoid characterizing cracks that do not exist on the curb. The downside to removing these values from the data set is that the sample size is reduced to five curbs. The comparisons of the average length index and average intensity index to compressive strength can be seen in Figure 41 and Figure 42 respectively.

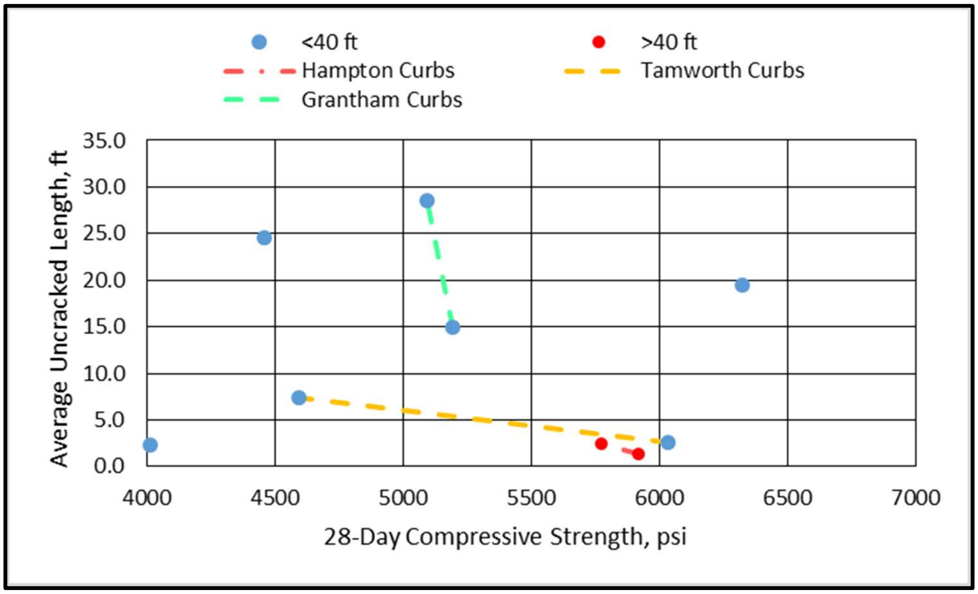


Figure 40: Average uncracked length compared to 28-day compressive strength.

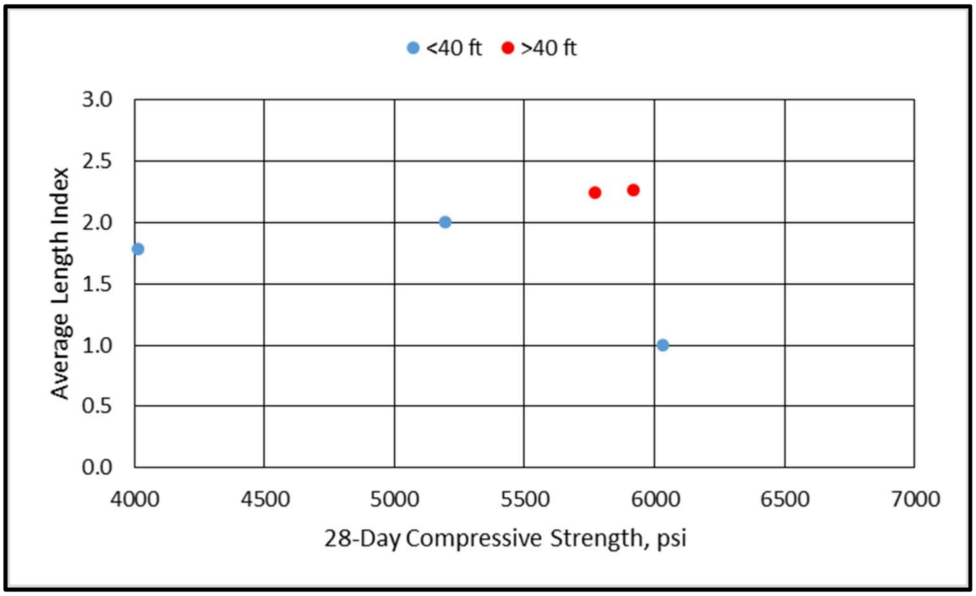


Figure 41: Average length index compared to 28-day compressive strength.

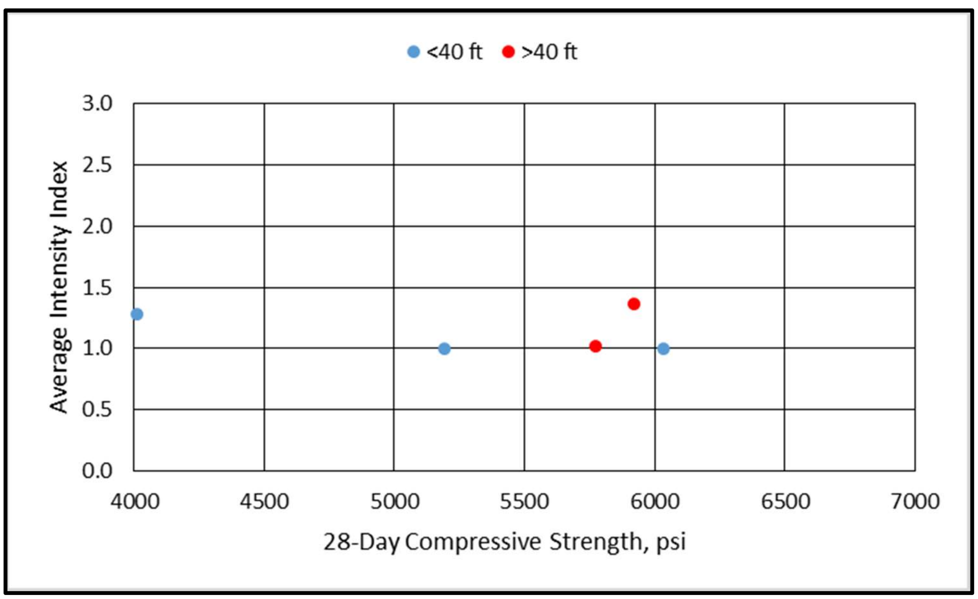


Figure 42: Average intensity index compared to 28-day compressive strength.

The results of the t-tests conducted on compressive strength appears to indicate that the compressive strength of concrete does not significantly affect the amount of cracking on a curb nor does it affect the length or width of the cracks that form on the curb. This can be seen in Table 10. It can be seen from the p-values of the t-tests that both length and intensity indices are not significant. The average uncracked length also does not significantly change between curbs with compressive strengths over 5,500 psi and curbs with compressive strengths under 5,500 psi.

Since tensile strength of concrete is often described as a function of the compressive strength of concrete, it might be expected that as compressive strength increased there would be a reduction in the amount and severity of cracking in the concrete element. This may further indicate that the macrocracks seen in curbs are simply the evolution of microcracks that formed early in the concretes life when tensile strengths are low regardless of the 28-day compressive strength.

Table 10: t-tests conducted on compressive strength.

t-test	p-value $\alpha < 0.05$	Outcome
Average Length Index 28-Day Compressive Strength <5500 psi & >5500 psi	0.219	Average length index of a curb does not significnatly differ for curbs on bridges with 28-Day strengths below 5500 psi compared to those above 5500 psi.
Average Intensity Index 28-Day Compressive Strength <5500 psi & >5500 psi	0.662	Average intensity index of a curb does not significnatly differ for curbs on bridges with 28-Day strengths below 5500 psi compared to those above 5500 psi.
Average Uncracked Length 28-Day Compressive Strength <5500 psi & >5500 psi	0.843	Average uncracked length of a curb does not significnatly differ for curbs on bridges with 28-Day strengths below 5500 psi compared to those above 5500 psi.

A Pearson correlation was conducted on the 28-day compressive strength of the curbs compared to the average uncracked length of the curbs. The near zero values in Table 11 indicate that there is not a linear or second order polynomial relationship between compressive strength and the average uncracked length of a curb.

Table 11: Pearson correlations for 28-day compressive strength.

Pearson Correlation	r	Outcome
28-day strength, Average Uncracked Length	-0.132	The average uncracked length of a curb does not correlate well with the concrete w/cm.
2*Log(28-day strength), Log(Average Uncracked Length)	-0.138	

3.10 Guardrail Posts

Early in the study it was suggested by BoBM personnel that cracking appeared to happen more frequently at guardrail post locations. The study analyzed cracking at guardrail post locations by looking at the relative amount and severity of cracking within 1.5 ft of the guardrail post compared to the entirety of the curb. The data was broken into two separate categories: bridges less than 40 ft in length and those greater than 40 ft in length. This was done to separate the effects of bridge length discussed in a previous section.

In order to determine if the quantity of cracking near guardrail posts is greater than a purely random distribution, a graph was produced and can be seen in Figure 43. In the figure, if cracking were perfectly random, the percent of cracking near guardrail posts would match the percent of the curb that is near guardrail posts. For example, if cracking were perfectly random, a curb with 40% of its length within 1.5 ft of guardrail posts would have 40% of all of its cracking also within 1.5 ft of the guardrail posts. This "perfectly random" line can be seen in Figure 43 as

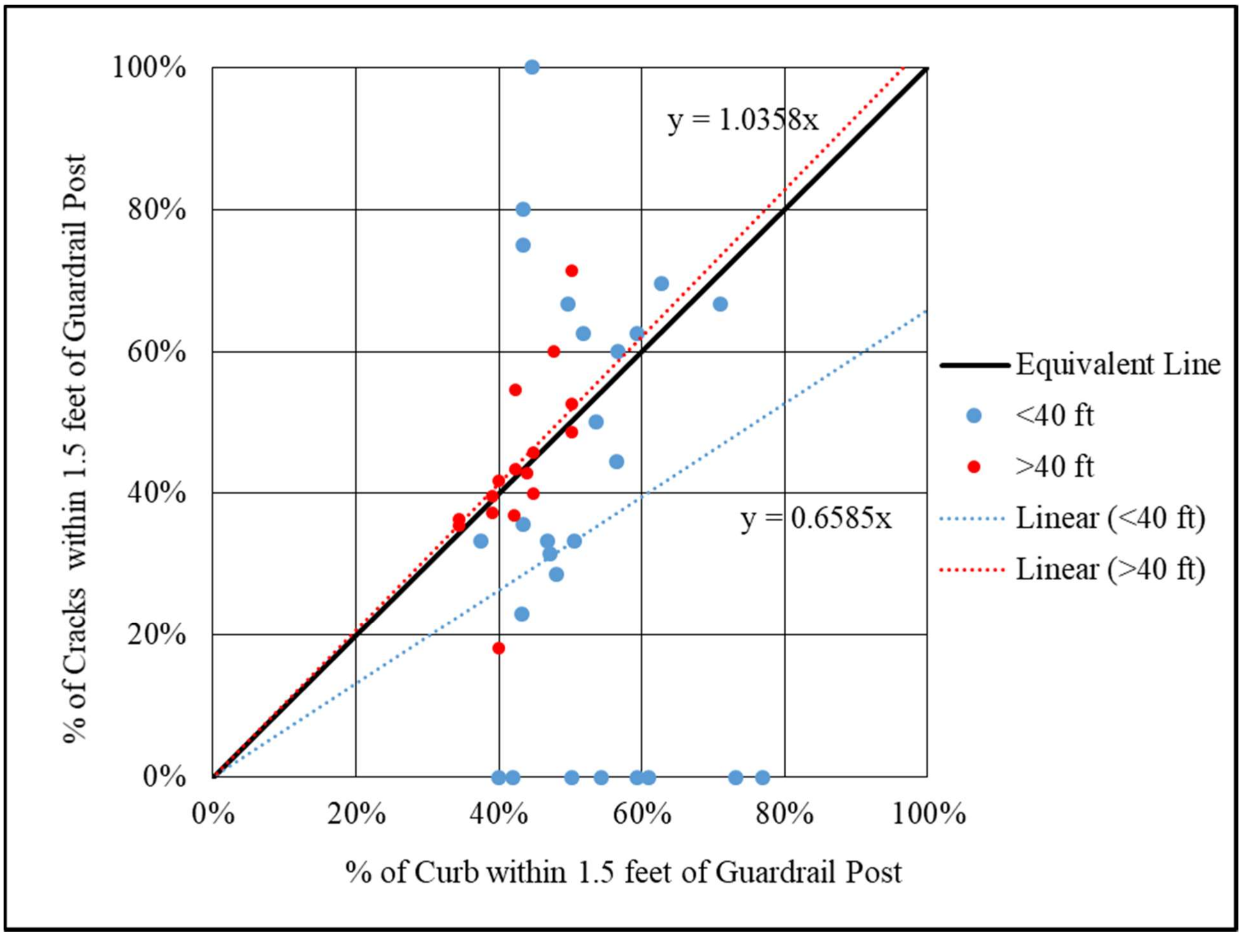


Figure 43: Comparison of the percent of near-post cracking compared to the percent of the curb that is near-post.

a solid black line. A trend of points being plotted below the black line indicates that less cracking is occurring near the guardrail posts compared to the rest of the curb. A trend of points above the black line would indicate that more cracking is occurring at guardrail posts.

A trend line is plotted for both curbs on bridges that are greater than 40 ft and curbs that are less than 40 ft. For bridge lengths above 40 ft, cracking near bridge curbs appears to be random; that is a linear trend line plotted through the origin of the graph yields a line with a slope of nearly one.

For curbs less than 40 feet it appears that cracking is less frequent near guardrail posts. The less frequent cracking near posts on shorter bridges may be due to the increased percentage of the curb near guardrail posts in conjunction with the smaller amount of cracking generally seen on shorter bridges. This smaller amount cracking would mean, when a crack does or does not occur near a post, it has a greater weight on the percentage of cracking compared to a curb with a greater amount of cracking. The cracking near guardrail posts on the shorter curbs more closely resembles a completely random crack distribution when the curbs with no cracking are removed as shown in Figure 44.

A variety of unpaired t-tests were completed on the guardrail metrics and can be seen in Table 12. The t-tests used a confidence value of 0.05 and assumed unequal variances. For testing, the values of the entire curb were compared to those of the portion of the curb near guardrail posts. For average length and intensity index t-tests, curbs with no cracking at all were ignored. Table 12 indicates that there is not an increase in the amount or severity of cracking that occurs near the guardrail posts.

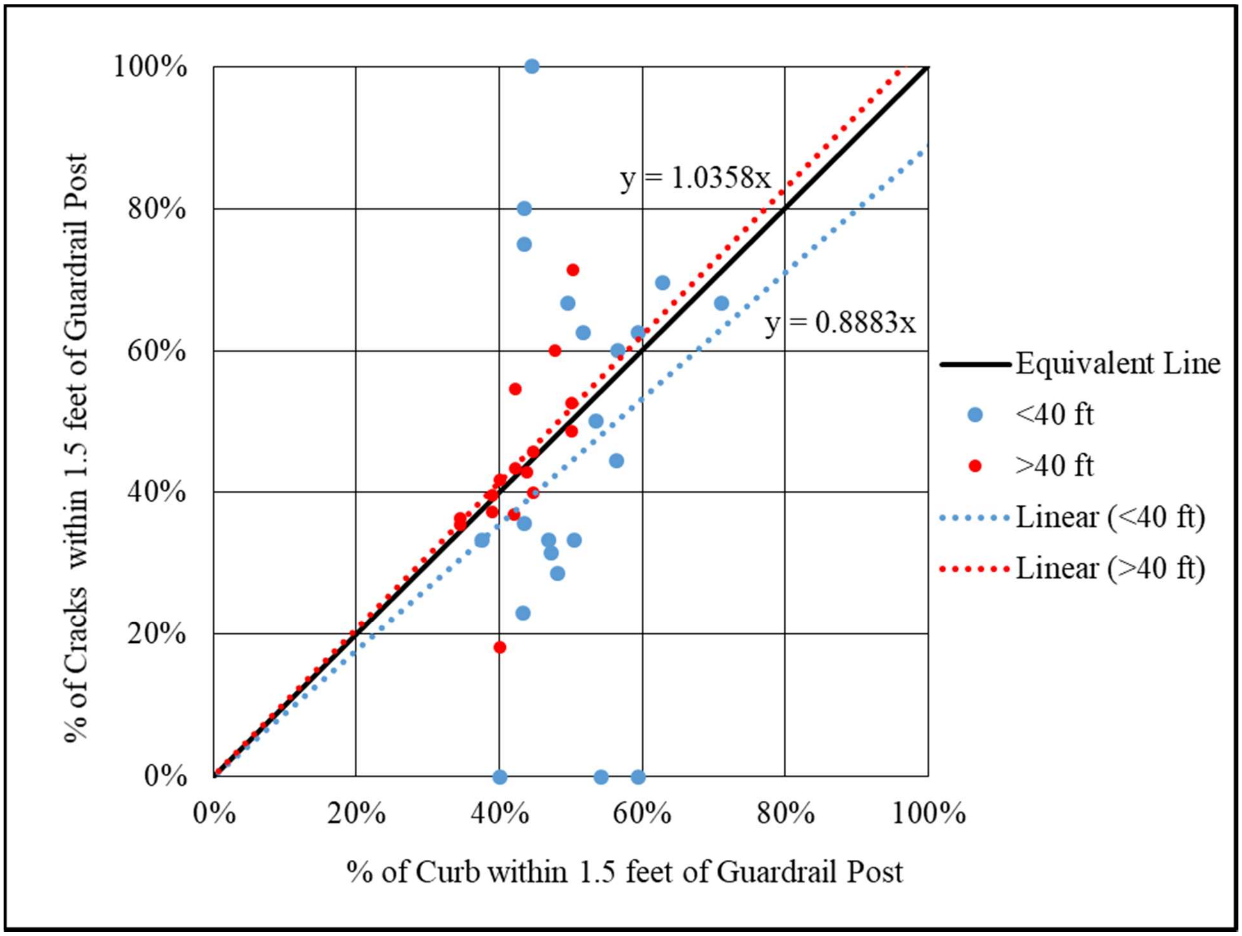


Figure 44: Comparison of the percent of near-post cracking compared to the percent of the curb that is near-post. Curbs with no cracking removed.

Table 12: t-test for cracking near guardrail posts compared to the entire curb.

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.

3.11 Weather after Placement

One theory for a contribution to curb cracking was a concern with temperature effects from the weather. Cold temperatures with improper curing practices could result in concrete that freezes before it has had sufficient strength development. High external temperatures coupled with internal heat of hydration could also cause additional drying shrinkage and reduced strength which may contribute to cracking. There also exists the possibility that large changes in temperatures may cause thermal gradients in the concrete as well as differential expansion and contraction between the curb and the deck.

The following section contains comparisons of temperature during the first week after placement compared to cracking performance. Since only the construction dates of curbs placed during the study are known, none of the existing bridge curbs were included in this data. All the most recent data, excluding the most recent Tamworth survey, is used in the following analyses. The results presented in this section are from the most recent investigations only and do not include the information collected from each site visit. For length and intensity indices, if no cracking had been reported the index values were omitted since no cracking exists to have the characteristics quantified.

Several graphs and t-tests were conducted when looking for patterns in cracking related to the weather following placement. Since there is limited data on the number of new curbs placed during the study there is also a limited number of known temperatures during curb placement. The data that is known is graphed in Figure 45, Figure 46, and Figure 47. The three figures show the length index, intensity index, and average uncracked length plotted against the average of all the low temperatures for each day for seven days after placement. These sets of graphs are fairly similar to different variations of x-axis values. For example, the average high for the seven days after placement resembles the average low graph except shifted to the right. For this reason, only the week average low graphs are shown.

Again, in the graphs, bridges are separated in two separate groups: those longer than 40 feet and those shorter than 40 feet. In Figure 45, it can be seen that the bridges with over 40 feet have curbs with a greater length index which makes it difficult to tell if there is a contribution from the cold weather affecting cracking.

Figure 46 shows average low temperatures for the week after placement compared to the curbs average intensity index. Here the range of the values is quiet low which may suggest that the average cold temperature for the week after placement may not have a large effect on the average intensity index.

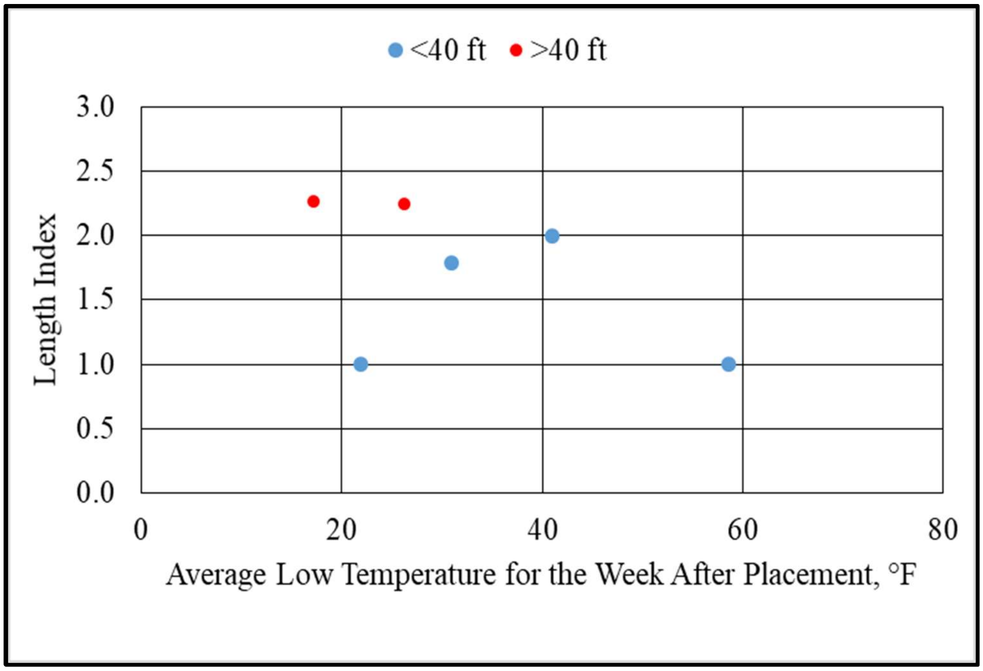


Figure 45: Average low temperature for the week after placement compared to average length index of curb.

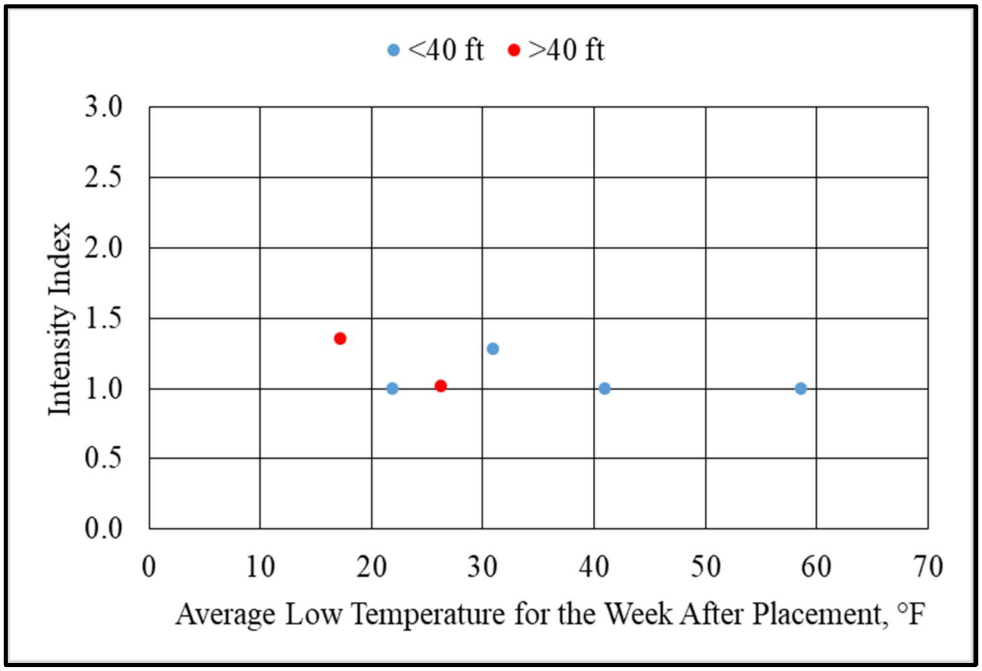


Figure 46: Average low temperature for the week after placement compared to average intensity index of curb.

When looking at the average uncracked length of a curb compared to the average low temperature for the week after placement, there is a much greater variation. This is likely do to many of the curbs surveyed having no cracking which makes the average uncracked length of the curb the full length of the curb which can be a much larger number compared to the same curb with only a few cracks. The data collected over the study for average uncracked length can be seen in Figure 47.

Concrete freezing after placement in the winter before sufficient strength gain is a concern in winter. A t-test was conducted by separating the data into two categories: placement day lows less than or equal to 32°F and those with placement day lows above 32°F. The results from these t-tests can be seen in Table 13. The reason the t-tests were conducted using the placement day's low and not the average weekly low was that concrete is more susceptible to freezing damage during and shortly after placement.

It is also important to note the sample size for the t-tests is also small. Only curbs with cracking were used for the average length and intensity index t-tests. This means that only four curbs were included in the data set below 32°F and two in the data set above 32°F. Additionally, for the t-test regarding average uncracked length, there are nine curbs placed below 32°F and only three placed above 32°F.

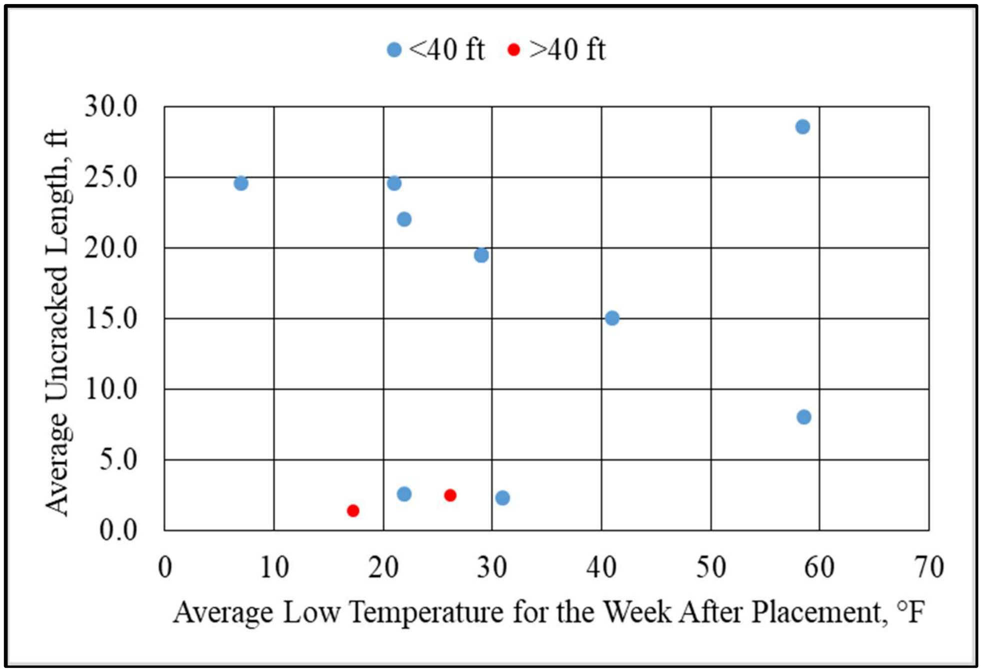


Figure 47: Average low temperature for the week after placement compared to average uncracked length of curb

3.12 Average Daily Traffic

Concerns with flexure in the bridge causing areas of tension and cracking in the curb could be instigated by areas with greater amounts of traffic. The hypothesis being that fresh concrete with a very low tensile strength may be exposed to significant tensile stresses in the ITZ from excitations of passing trucks. This may mean that the more traffic a bridge sees the greater amount of loading cycles microcracks may see. The more frequent loading cycles may translate to more visible cracking.

Table 13: t-tests conducted on placement day low temperatures compared to curb cracking.

t-test	p-value α < 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 significnatly 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 significnatly 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 significnatly differ for curbs placed below 32°F compared to those placed above 32°F.

The average uncracked length was plotted against the average daily traffic, ADT, for the bridge. This can be seen in Figure 48. This graph includes data from the most recent survey of all bridge sites. The data set appears to be fairly dichotimous with traffic either being above or below 5000 ADT. Again, a higher average uncracked length indicates a bridge with less cracking. Figure 48, along with the other figures in this section also differentiate between bridge lengths less than or greater than 40 ft. Visually, it is difficult to see any potential affects ADT has on the average uncracked length of a curb.

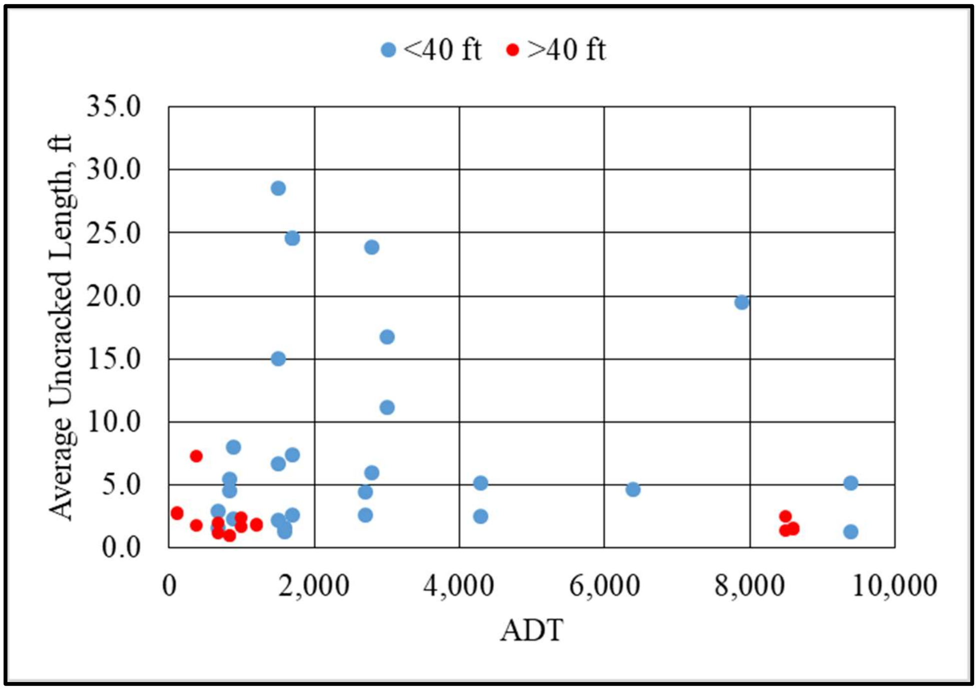


Figure 48: Average uncracked length compared to average daily traffic, ADT.

Similarly, the relationship of any effect of ADT on length index and inensity index is difficult to see as shown in Figure 49 and Figure 50. Again, the variability of the cluster of data points at both ends of the graph make it difficult to see any qualititative relationship between ADT and cracking behavior. In addition to ADT, the estimated amount of daily truck traffic was determined from ADT and the percent truck traffic. The range in percent truck traffic for each bridge varied from 4% to 10%. The truck traffic experienced on bridges fell in two clusters: the estimated number of trucks being less than or greater than 300. Coincidentally, the data points that were in each cluster matched the ADT groupings. Since the relative locations of the data did not vary greatly from the ADT graphs, the estimated number of truck graphs were omitted in this section.

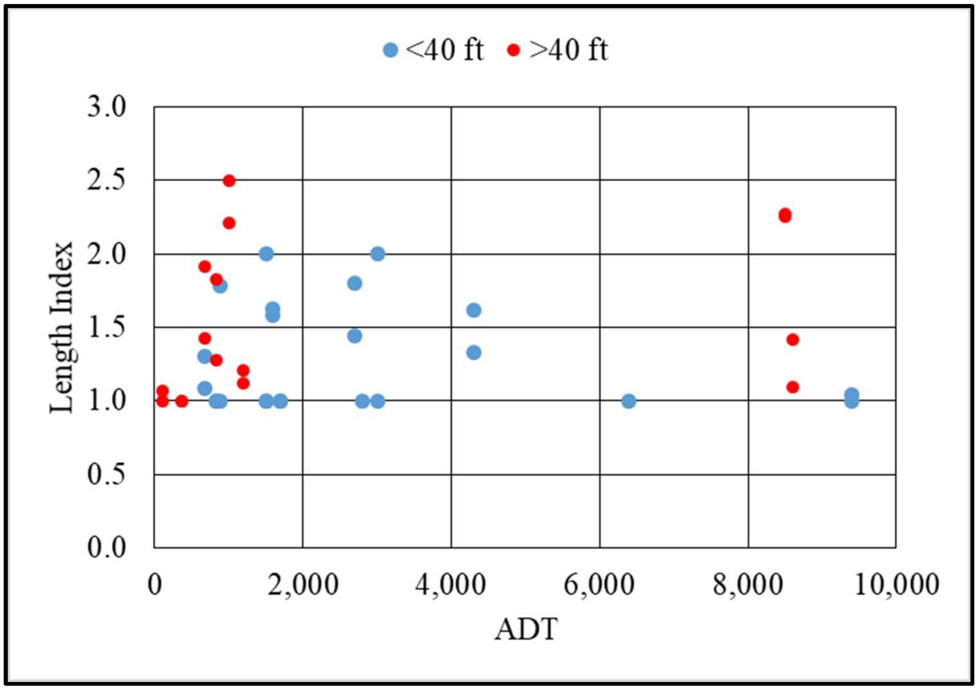


Figure 49: Average daily traffic plotted against the average length index of a curb.

Results for t-tests conducted for traffic can be seen in Table 14. The t-tests conducted for this study separated the ADT data into two groups: ADT less than 5,000 and ADT greater than 5,000. Again, when the estimated number of trucks was seperated into two groups the same data points in each group matched the ones in the ADT groups. Performing t-tests for ADT and number of trucks would be redundant. The results from the t-tests suggest that traffic does not have a significant affect on curb cracking.

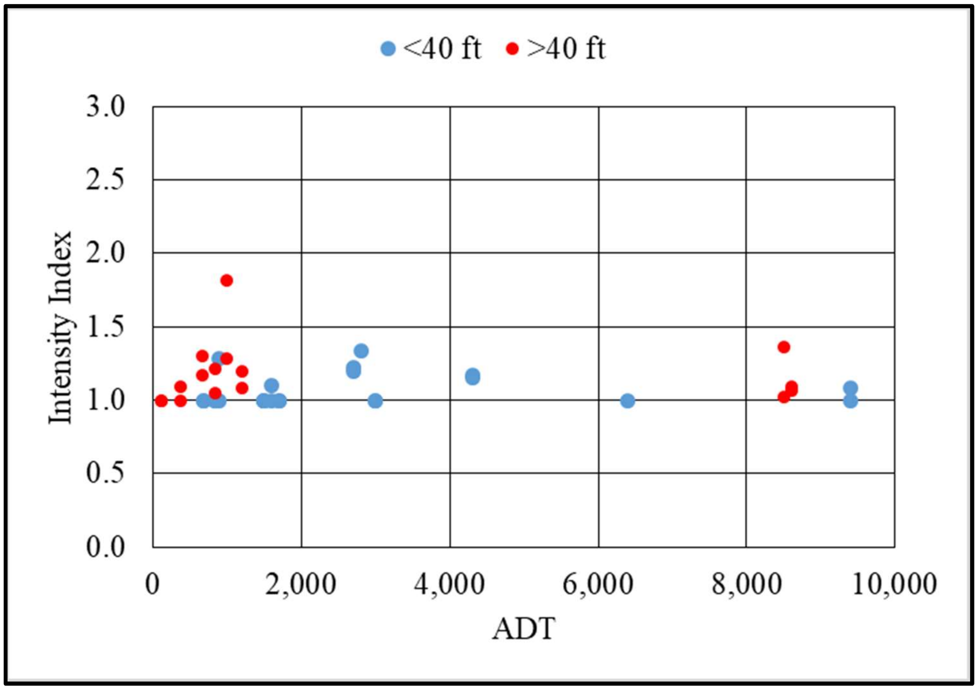


Figure 50: Average daily traffic plotted against average intensity index.

Table 14: t-tests conducted on ADT compared to curb cracking.

t-test	p-value α < 0.05	Outcome
Average Length Index Average Daily Traffic <5000 & >5000	0.803	Average length index of a curb does not significnatly differ for curbs on bridges with ADT below 5000 compared to those with ADT above 5000.
Average Intensity Index Average Daily Traffic <5000 & >5000	0.642	Average intensity index of a curb does not significnatly differ for curbs on bridges with ADT below 5000 compared to those with ADT above 5000.
Average Uncracked Length Average Daily Traffic <5000 & >5000	0.456	Average uncracked length of a curb does not significnatly differ for curbs on bridges with ADT below 5000 compared to those with ADT above 5000.

3.13 Monitoring of Curb Cracking with Time

An important part of this study was to look at the early age cracking behavior of cracking in bridge curbs. This early age cracking is of a concern since it exposes the inside of the curb to the elements early in the curbs life. In order to look at the early life of cracking in concrete bridge curbs, several graphs were created to show how cracking developed over time in curbs placed during the study. The average uncracked length of a bridge curb over time can be seen in Figure 51. As time passes, more cracks tend to form and the average uncracked length decreases. Note that at certain times the average uncracked length increases. This is a result of the visual survey. Cracks that may have existed during one survey may be covered up by dust and debris

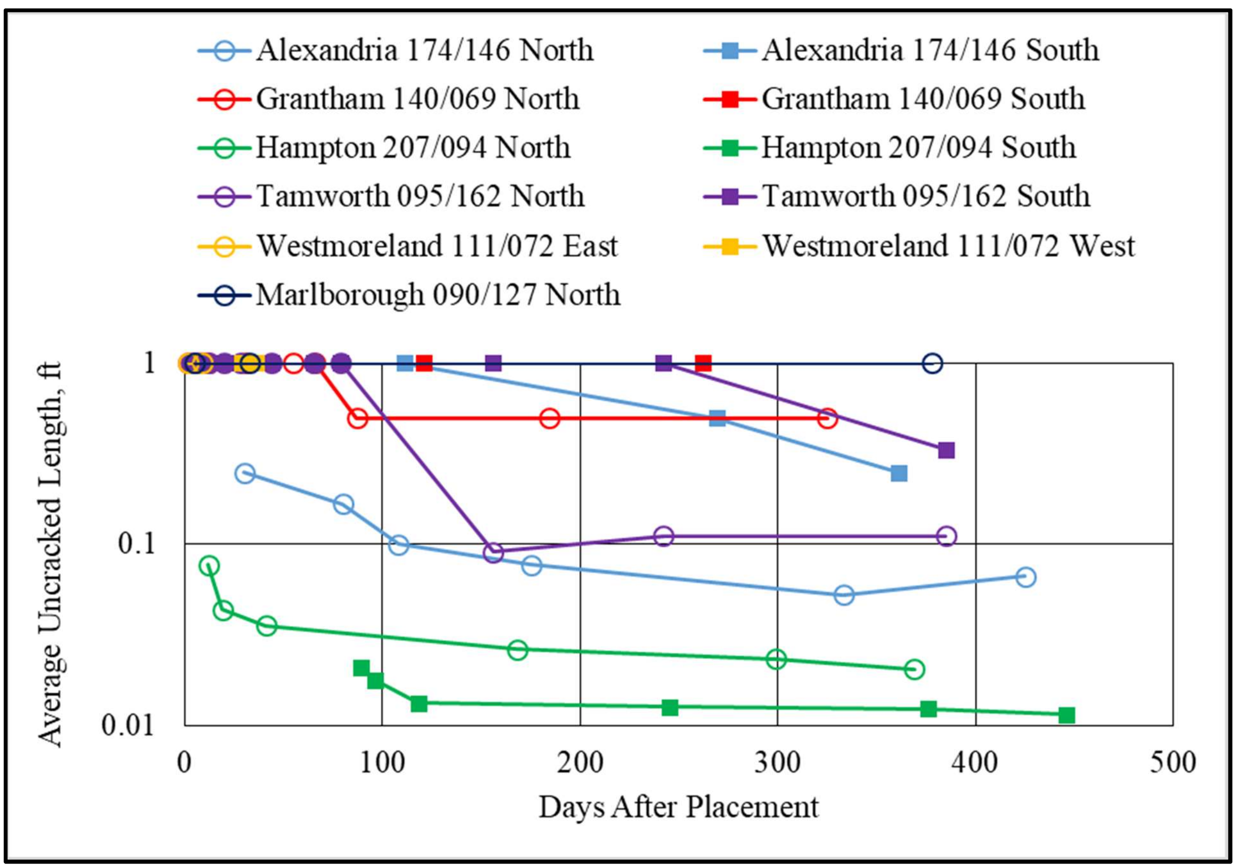


Figure 51: Average uncracked length for bridges placed during the study over time after placement.

during another survey and went unnoticed visually. Additionally, changes in temperature and humidity will effect crack width.

The average crack characteristics over time can be seen in Figure 52 and Figure 53. These graph show the length and intensity index, respectively, over time after placement. Here, changes in the average index values are not as easily explained. A curb with a single long and wide crack can quickly have reductions in the average length and intensity index values as new, smaller cracks form. Another possibility is that a stable number of small cracks exist and over time they become longer or wider, increasing index values over time. It should be noted that when no cracking on the curb exists the length and intensity index is plotted as zero.

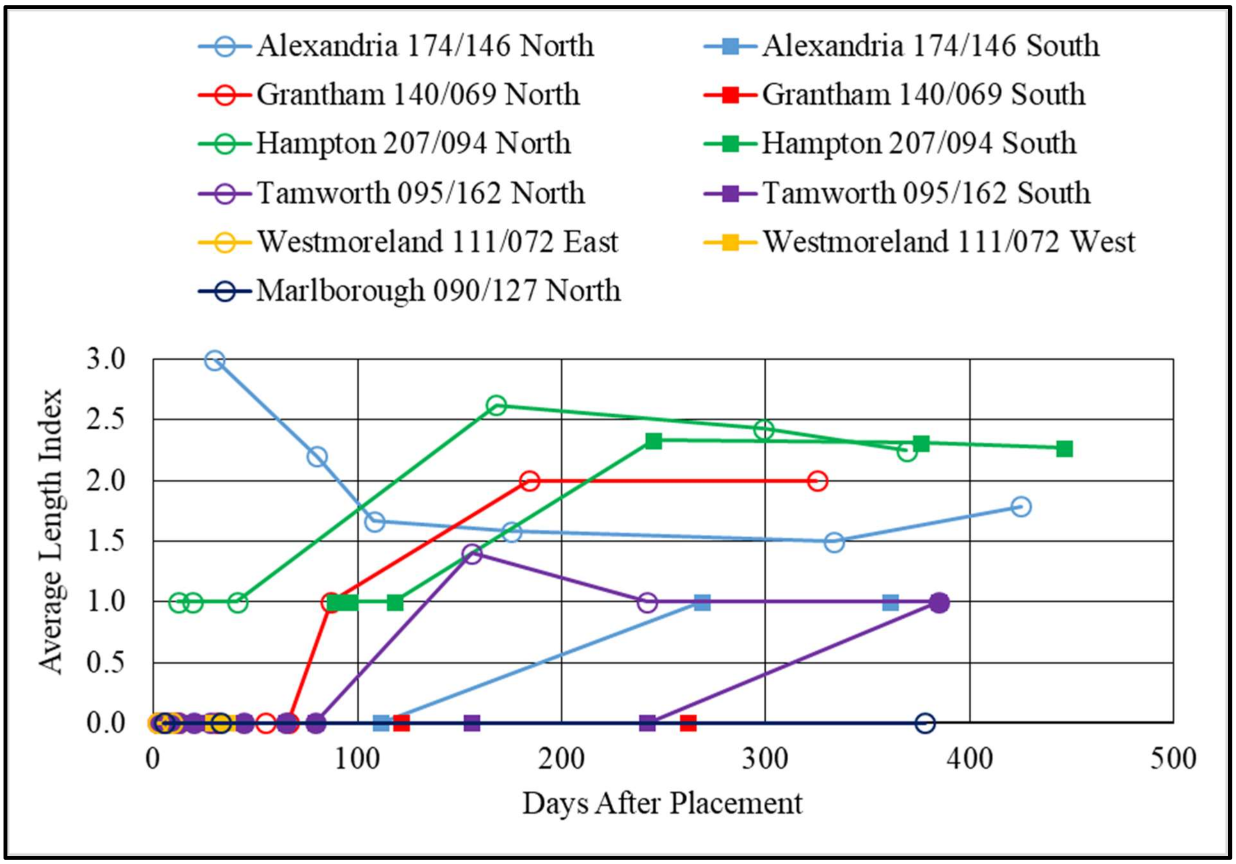


Figure 52: Average length index for bridges placed during the study over time after placement.

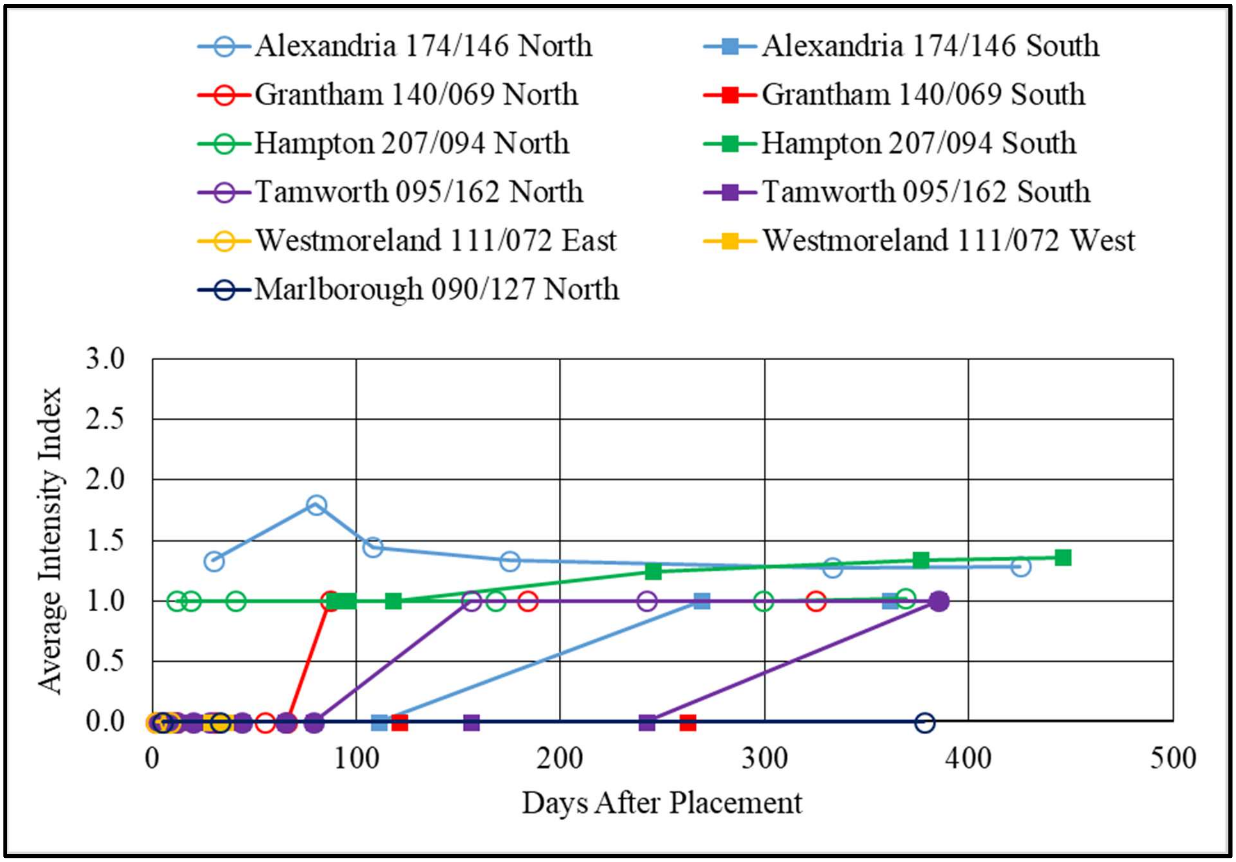


Figure 53: Average intensity index for bridges placed during the study over time after placement.

3.14 Relative Crack Volume

Although the severity index combines a cracks length and width into a single term it may be beneficial to describe a crack in term of its volume. Since only a cracks length index and intensity index were recorded during the study determining an absolute volume of a crack is difficult. However, an approximate method can be used.

This involves prescribing a typical crack width for each intensity index. This value can be seen in Table 15 and were selected based on typical crack widths seen during field observations.

Similarly a cracked cross-sectional area of the curb is approximated for each length index. These typical values were also estimated from field observations on average crack lengths and widths for various length and intensity index values.

The cracked area is estimated by applying boundaries around the exterior of the curb that correspond to a typical crack of a certain length index. Additionally, the depth of the crack is assumed to be linear between the two crack tips. The crack is then assigned an area value corresponding to the relative size of the curbs cross-section. This can be seen in Table 16. The development of the approximate crack area values were created by assuming a 5.5 inch thick curb with a width of 18 inch. For a length index 1 crack the two crack faces were assumed to extend 2.75 inch along each face. For a length index 2 crack the front face was assumed to be fully cracked at 5.5 inch and the top face was assumed to be 1/3 cracked, or 6 inch. The length index 3 crack was assumed fully cracked along two faces. The cracked areas in the shape of triangles were determined, divided by the curb cross-section area, and converted to a fraction to be used on curbs with various dimensions.

Table 15: Corresponding intensity index values and assigned width values.

Intensity Index	Assigned Width inch
1	0.005
2	0.012
3	0.017

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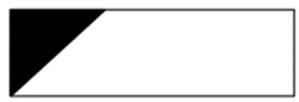
Table 16: Corresponding length index values and assigned area values.

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

Once the length and intensity indices have been converted to assigned areas and assigned widths respectively, the estimated total volume of each crack can be determined and all the cracks along the curb added together to get an estimate of the total crack volume along a curb. This estimate can be described by the following equation:

$$Total\ Cracked\ Volume = \sum (A_w * A_A * d * b)$$

Where:

$$A_w = Assigned\ Width$$

$$A_A = Assigned\ Area$$

$$d = Curb\ Depth$$

$$b = Curb\ Width$$

Once the estimated total cracked volume along the curb is known it needs to be compared to the overall volume of the curb in order to account for variation in curb sizes. This normalization can be described by the following equation:

$$Normalized\ Crack\ Volume = \frac{Total\ Cracked\ Volume}{Curb\ Volume} = \frac{\sum(A_w * A_A * d * b)}{d * b * L} = \frac{\sum(A_w * A_A)}{L}$$

Where:

$$L = Curb\ Length\ in\ inches$$

Note that the values in the above equation assume that the curb width and depth is constant over the length of the curb. Additionally, the curb length is in inches in order to keep the normalized crack volume a unitless value in the event this method were to be adapted to SI units.

While the use of this volume method was not explored in depth during this study a graph was generated comparing bridge length to normalized crack volume and can be seen in Figure 54. A similar pattern to that of bridge length and the average uncracked length emerges. The benefit of using the normalized crack volume is that it can take into account an approximate volume of all the cracks instead of relying on looking at the severity index and average uncracked length separately. What can also be seen in Figure 54 is that even the most severely cracked bridges less than 40 ft in length have nearly 1/3 of the crack volume per unit curb volume compared to the most severely cracked bridges over 40 ft in length.

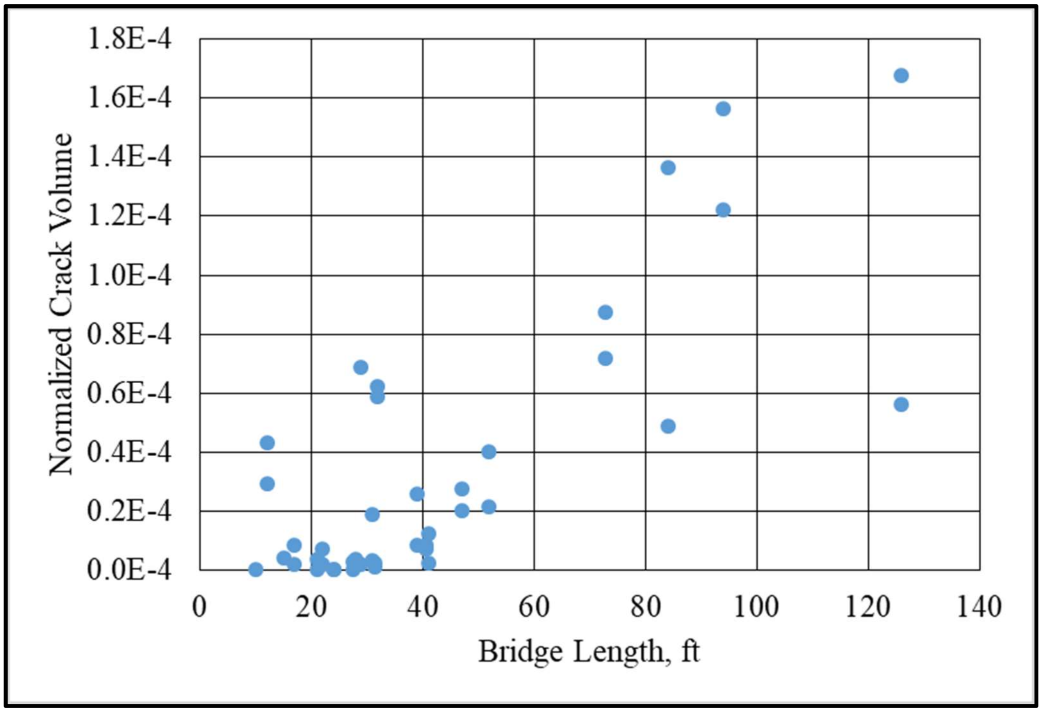


Figure 54: Bridge length compared to normalized crack volume.

3.15 Summary of Results

The results in this chapter have highlighted some of the potential relationships that exist between cracking and curb and bridge characteristics. These relationships are briefly highlighted in Table 17. The findings in this research indicate that bridge length and the location along the curb have a significant effect on cracking, particularly, the curbs average uncracked length. Additional surveys may help further prove significance in other categories, particularly those with relatively few curbs surveyed.

Table 17: Summary table of cracking relationships.

	Average Uncracked Length	Length Index	Intensity Index
Bridge Length	Significant	Not Significant, Trend may exist for longer bridges	Nearly Significant
Location on Curb	Significant	Not Significant	Not Significant
Curing Duration	Not Significant, Curb Pairs Suggest Differences		
PCC Mix	Not Significant		
Water/Cementitious Materials Ratio	No Correlations		
Cementitious Material Content	Weak Correlation, Curb Pairs Suggest Differences		
28-day Compressive Strength	Not Significant, Curb Pairs Suggest Differences	Not Significant	Not Significant
Guardrail Post Bridge <40 ft	Not Significant	Not Significant	Not Significant
Guardrail Post Bridge >40 ft	Not Significant	Not Significant	Not Significant
Weather After Placement	Not Significant	Not Significant	Not Significant
Average Daily Traffic	Not Significant	Not Significant	Not Significant

CHAPTER 4: SUMMARY AND CONCLUSIONS

4.1 Summary of Research

The goal of the research represented in this paper is to find correlations in early-age cracking of concrete, single span, bridge curbs. The correlations may then be used to provide recommendations to NHDOT on ways to reduce cracking in the curbs or indicate areas that require more study to provide a clearer understanding of the cracking that is occurring.

During this study 23 single span bridges were surveyed. Of the bridges investigated 6 were constructed during the research project and 17 were previously existing bridges constructed after 2008. Most of the bridge curbs constructed during the study had a variable applied to one of the curbs to serve as a comparison to the neighboring curb. The variable was either a change to the curing procedure or PCC mix design. These bridges were of a variety of bride types but were primarily concrete slab and steel I-beam with concrete deck types. The length of bridges in the study varied from 10 feet to 126 feet.

The bridge curbs were evaluated using a method developed for this research project. The method includes recording the location of each crack along with the cracks length index and intensity index. The length index is a measure of the cracks relative length compared to the curb. A length index of one indicates a short crack extending only a few inches. A length index three crack indicates a crack that has extended transversely across most of the curb. A length index of two would fall in between the requirements of a length one and length three crack. The intensity index was developed for crack widths and is also on a scale of one to three. An intensity index of one indicates a narrow crack whereas an intensity index of three indicates a large crack. The widths corresponding to each intensity index value correspond to values listed in ACI 224R-01.

The intensity and length index were used together to develop a severity index which yields a single value for the length and width characteristics of a single crack. The average severity index of all the cracks on a curb can be used to serve as an indicator on the condition of curb cracks. This average severity index can be combined with the average spacing between cracks or the end of the curb to produce a single number to estimate the overall quality of the curb. This curb quality number is referred to as the curb cracking index.

Approximating the volume of an individual crack was conducted by assigning a typical width and cracked area to the crack. The approximated crack width and area correspond to the length and intensity index of that crack. The cracked area is assumed to be triangular in shape with the depth of the crack being linear between the crack tips. The length of each crack was approximated from field observations and each length index had a corresponding crack area relative to the size of the curb.

The approximated volume of all the cracks on a curb can be normalized by the entire curb volume. This allows a direct comparison between different curb sizes since the amount of cracking per volume of curb will account for variations in curb length. Initial observations of the normalized cracking volume on bridge length suggests that the normalized crack volume may be a more suitable and appropriate measure of curb cracking instead of looking at the curb cracking index, average intensity index, average length index, or average uncracked length individually.

4.2 Conclusions

Several conclusions may be drawn based on the results presented in this thesis:

- The distribution of intensity index values on the investigated bridge curbs indicates that 83% of cracking is less than the maximum reasonable size as outlined by ACI 224R-01.

While this demonstrates that most cracking on bridge curbs is not a large concern, it also shows that nearly one in five cracks currently exceed the limits of ACI 224R-01 for concrete exposed to deicing chemicals.

- Bridges that are longer than 40 ft in length have more cracking than bridges less than 40 ft in length. The average severity index of a crack is also slightly greater for curbs with a smaller average uncracked length than curbs with larger average uncracked length.
- The end fifths of the curb experience less cracking compared to the rest of the curb. Although the amount of cracking is less at the ends of the curb, the severity of the cracks at the ends of the curb is not significantly different than the severity of other sections of the curb.
- Limited data on wet cure durations shows that pairs of curbs placed on the same bridge show differences in the average uncracked length when subjected to different wet cures durations. The curb subjected to a longer wet cure tends to have less cracking.
- No general relationship appears to exist between w/cm and cracking behavior. This is also true for cementitious content. The study did find that when comparing pairs of curbs on the same bridge, based on limited data, the curb with a lower cementitious content had the same or less cracking than its neighboring curb. This same relationship also existed when comparing compressive strengths of curb pairs.
- Proximity to guardrail posts, outside air temperature following placement, and ADT have no effect on the cracking behavior of concrete curbs.
- Early age cracking in curbs placed during the study does not necessarily indicate that macrocracking starts within the first few days after placement but may start several

months after placement. Curbs that do experience cracking shortly after placement tend to have the amount of cracking become stable within a year after placement.

- The method of using approximate crack volumes may prove to be more beneficial when comparing cracking between curbs than the curb cracking index or the severity index.

4.3 Recommendations for Future Research

The research presented in this paper helps outline potential sources of cracking in concrete bridge curbs. While it is nearly certain that no single mechanism is responsible for experienced on bridge curbs, further information on many of the previously discussed items is required in addition to other potential cracking sources not surveyed during this study. The following paragraphs will discuss additional research and study that is necessary to form stronger conclusions.

One major difficulty encountered was the lack of new bridge curbs constructed during this study. This limited the amount of trial curbs that could be tested and surveyed. The limited amount of data means that analyses that use only bridges constructed during the study could be highly variable. Additionally, recent data used in the analyses on curbs constructed during the study are of different ages. A future study would benefit from further testing of the two variables discussed in this report. These two variables are wet cure duration and PCC mix design. The study variables tested were often conducted on bridges less than 40 ft. The results from the shorter bridges may not relate well to longer bridges. Another possibility to increase the amount curbs with test variables is to use multiple variable on each curb pair. Additionally, analyzing the data using higher order effects may reveal relationships that were otherwise thought not to exist.

The survey of the new bridge curbs stopped one year after placement. This makes it difficult to determine how cracking at the end of one year correlates to cracking over the life of the curb. Biennial site visits starting one year after placement would allow further monitoring of cracking over time.

The difference in cracking behavior of curbs on longer bridges compared to shorter bridges may suggest that there is a structural or dynamic aspect of cracking. Typically a simply supported bridge is considered to have the top of the bridge entirely in compression. This may not necessarily hold true for the curb at all times. A light curb relative to the weight of the bridge may not place the curb into significant compression. A passing heavy truck over the bridge may cause an excitation in the bridge that could potentially place the top of the curb in tension. Placing strain gauges on the reinforcing steel located in the bridge curb may help prove or disprove this hypothesis. Additionally, a structural analysis should be conducted using a finite element model. The model may provide insight into how the bridge behaves under various loading configurations and if any warping or dishing of the structure creates areas of tension in the curb. The current use of 40 ft as a separation point between longer and shorter curbs is still fairly arbitrary. It may be beneficial to survey more bridges between 30 ft to 80 ft to determine if a more appropriate boundary exists. There may be a bridge length where the two halves of the data set are significantly different for average uncracked length, average length index, and average intensity index.

Material testing should also be conducted on the concrete used on curbs. Determining shrinkage, fracture, and the modulus of elasticity of the concrete materials used may provide data that is valuable in determining the cracking mechanics of the curbs. Determining the contribution of shrinkage to tensile stresses in the curb would help in determining which other mechanisms provide enough energy to cause cracking. Additionally, the results of 28-day compressive strength tests indicate that lower compressive strengths result in fewer cracks. This is likely related more to the stiffness of concrete and less to the compressive strength, since concrete generally behaves stiffer as compressive strength increases. This is an indicator that crack formation in concrete curbs resembles strain-controlled fracture in brittle materials. Concrete that is cracking due to strain would benefit from a lower stiffness. It would be better to determine the elastic modulus directly through testing instead of through the relationship of compressive strength. A stronger relationship may exist between cracking and elastic modulus compared to cracking and compressive strength.

The severity index is an easy to calculate metric to quantify the combined qualities of crack width and length. As it stands, the length index and intensity index of a crack are weighted equally when it comes to crack severity. More work should be done to determine if crack width or length is a greater detriment to the life of the curb. Similarly, the curb cracking index is used to determine the quality of a curb in regards to the amount of cracking it has. The value is a combination of the average uncracked length of the curb and its average severity index. It would likely benefit departments of transportation if several good and bad curbs were identified, their CCI determined, and an evaluation system developed to aid transportation agencies in determining when a curb should receive maintenance or be replaced. Additionally further refinement of the assigned width, assigned length, and normalized crack volume may prove to be beneficial and superior to using the severity index and CCI.

This thesis presented information on all the cracking documented on bridge curbs. If cracks with an intensity index of one are assumed to be acceptable and not a concern then repeating the analyses in this thesis with only cracks with an intensity two or three may prove to be more useful for practitioners when determining if cracking on a curb should be addressed.

4.4 Recommendations for Practitioners

Several recommendations are given in order to aid practitioners in reducing the occurrence of cracking on bridge curbs. These recommendations are a combination of changes from material and construction practices to asset management suggestions.

The first recommendation would be to continue to use the crack survey system developed in this thesis to monitor cracking over time in curbs in an effort to determine when a curb is in need of maintenance, repair, or rehabilitation. Additionally, using the crack survey system on curbs that have reached a terminal condition would assist practitioners on planning when other curbs would need to be replaced in the near future.

Maintenance should also be considered further in the crack survey. Currently, any cracks that were filled with epoxy, specifically at the Hampton site, were still counted as cracks and their length and width determined from what was visible on the curb. For research, it is likely important to count the treated cracks in order to determine the cause of cracking but from an operations standpoint as long as a crack is remedied it likely should not be accounted for in determining the curbs damage.

Based on the higher amount of cracking seen in longer bridges, it may be more beneficial for maintenance crews to prioritize longer bridges over their shorter counterparts. More than 80% of all cracks are acceptable under the ACI recommendations. Even though cracking length and intensity is not significantly different, a longer bridge is likely to have a greater number of cracks with a specific width compared to a shorter bridge. The distribution of crack widths suggests that the majority of cracks on curbs are not a concern according to ACI 224 recommendations.

The change in the rate of new crack formation indicates that crack sealing maintenance on new curbs should be conducted one year after placement in order to seal problem cracks without having to make additional site visits as new cracks develop. Future visits may be required as smaller cracks develop into larger cracks although this is not yet known.

Additionally, reduction in cracking seen on curb pairs suggests a 14-day wet cure would result in less cracking compared to curbs with a 7-day wet cure or less. Similarly when comparing curbs on the same bridge, the curb with the lower cementitious materials content tends to experience less cracking. It is recommended that future curbs be placed using a low cementitious materials content and providing an extended wet cure beyond the traditional 7-day wet cure. Further, placing concrete mixes with higher entrained air amount may lower curb stiffness and improve the curbs resistance to strain-induced cracking.

Although more consideration is required from a construction standpoint, placing contraction joints in the curb could reduce the amount of cracking experienced in curbs. A potential example of this is shown in Figure 55. Cuts placed into concrete curbs can provide locations where cracks can be encouraged to form in locations that are easier to manage. Note that appropriate considerations should be made when determining rebar and saw cut spacing to account for forces placed on the curb from vehicle collisions. The cut faces may act similarly to the ends of the curbs as shrinkage strains cannot be transferred along the top part of the curb where the cut is placed. This may mean, that like the ends of the curbs discussed in this thesis, cracking could be reduced.

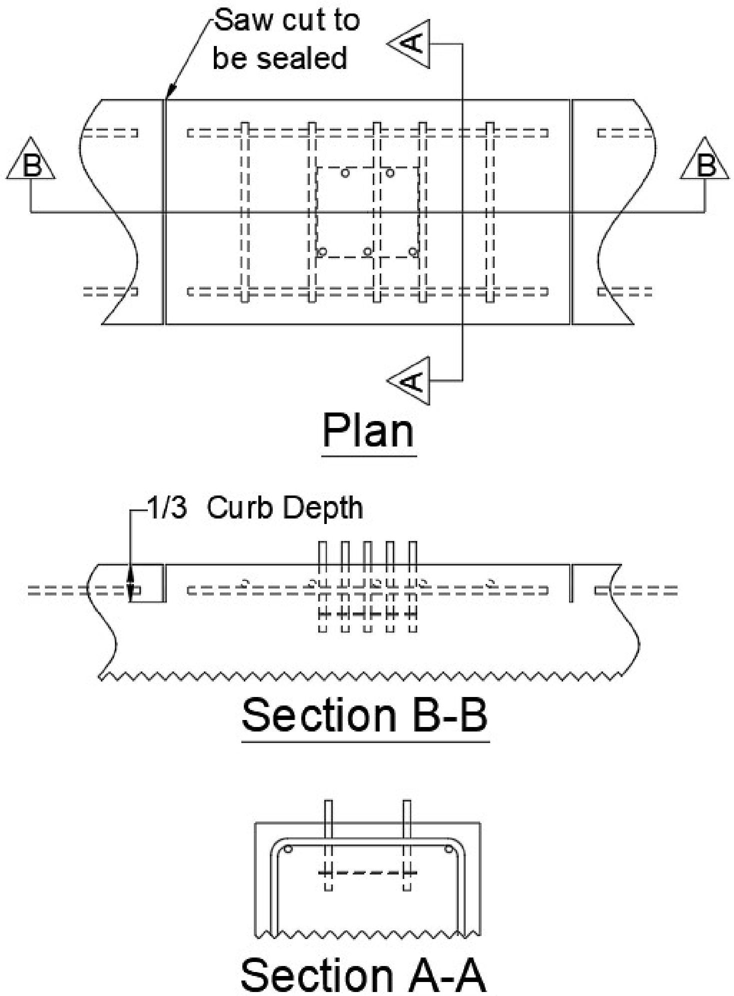


Figure 55: Example of potential rebar layout and saw cuts that may be used to reduce uncontrolled cracking.

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APPENDICIES

Appendix A: Bridge Cracking Heat Maps

Heat maps were constructed to visually show cracking along a bridge curb. Heat maps are constructed by placing a vertical bar at each point along a curb where a crack exists. The height of the bar corresponds to the cracks severity index. Heat maps were produced for all curbs constructed during the study. Some of the heat maps for the Hampton bridge, 207/094, indicate a severity index of one for all cracks, this was because the indexing system was not developed at the time of the first surveys. Curbs with no cracking have their heat maps omitted from the appendix.

4.4.1 Alexandria 174/146

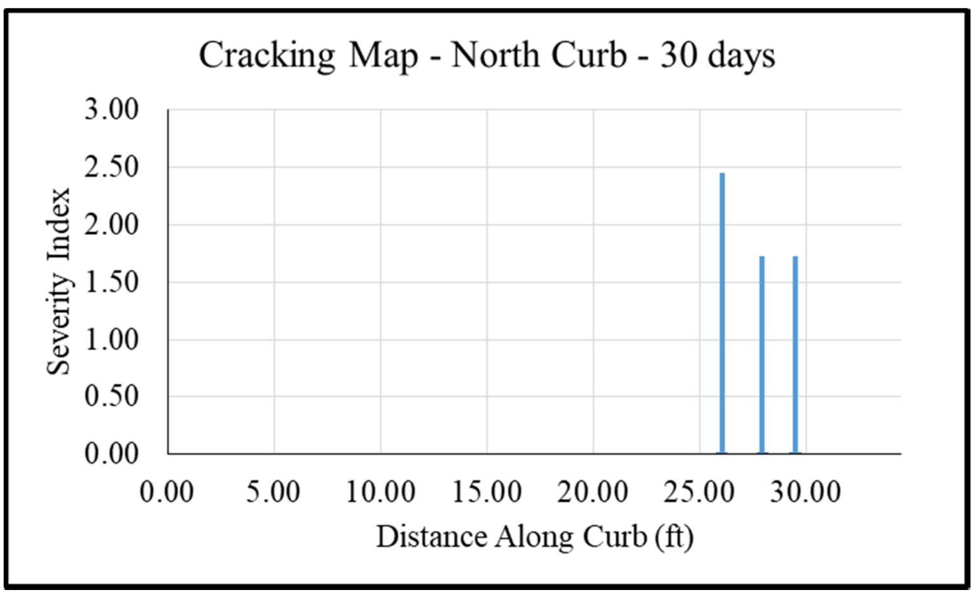

Figure 56: Alexandria north curb heat map at 30 days.

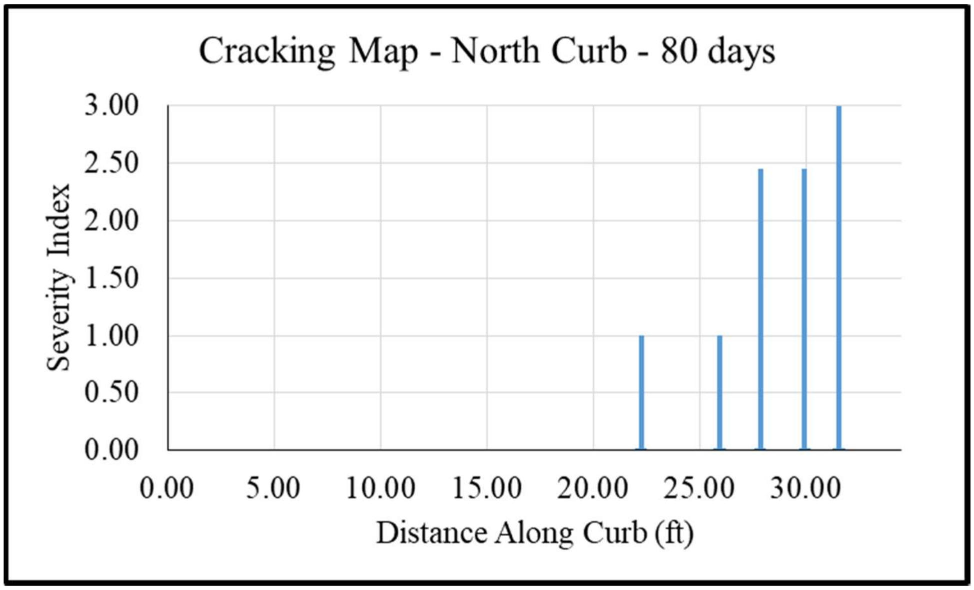

Figure 57: Alexandria north curb heat map at 80 days.

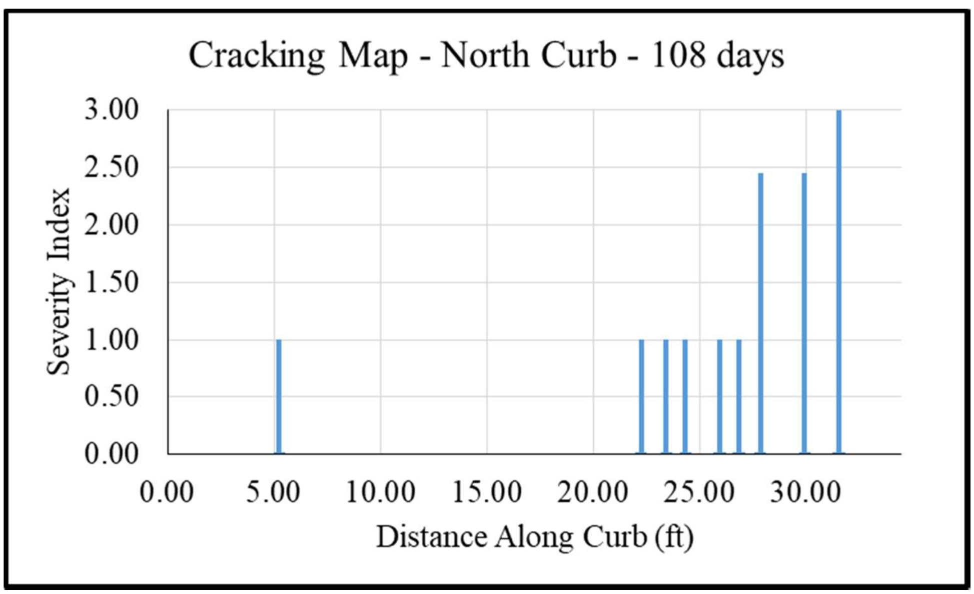

Figure 58: Alexandria north curb heat map at 108 days.

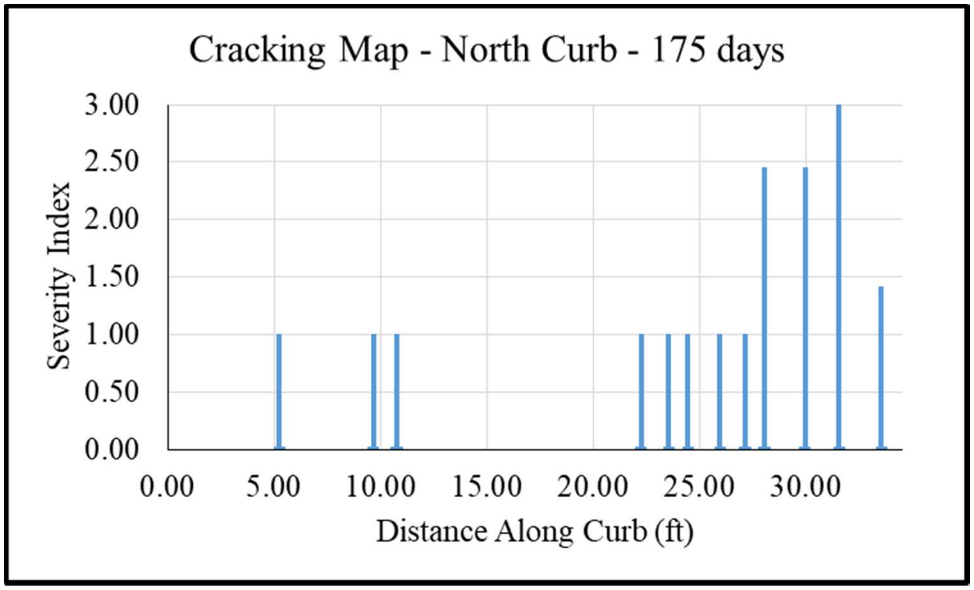

Figure 59: Alexandria north curb heat map at 175 days.

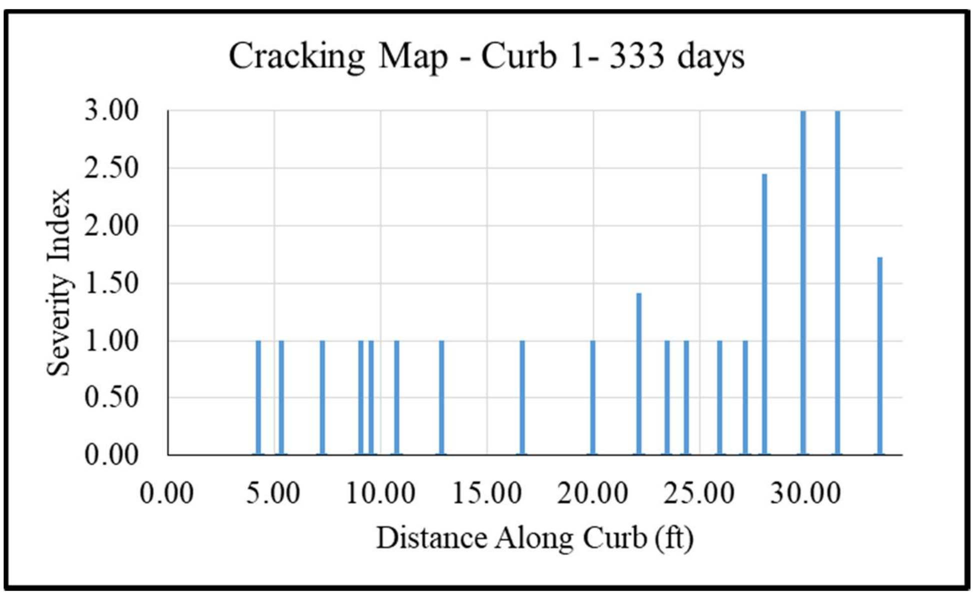

Figure 60: Alexandria north curb heat map at 333 days.

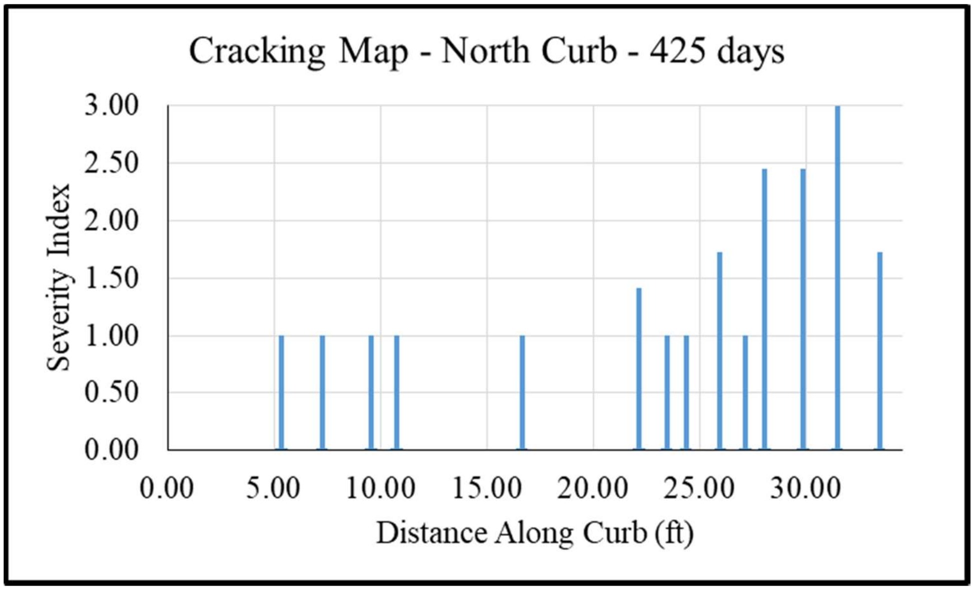

Figure 61: Alexandria north curb heat map at 425 days.

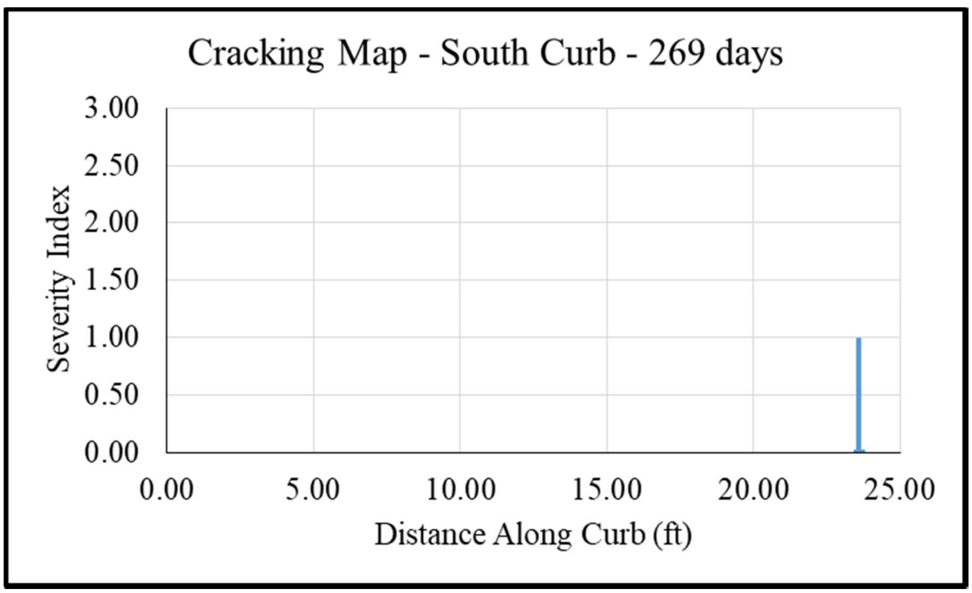

Figure 62: Alexandria south curb heat map at 269 days.

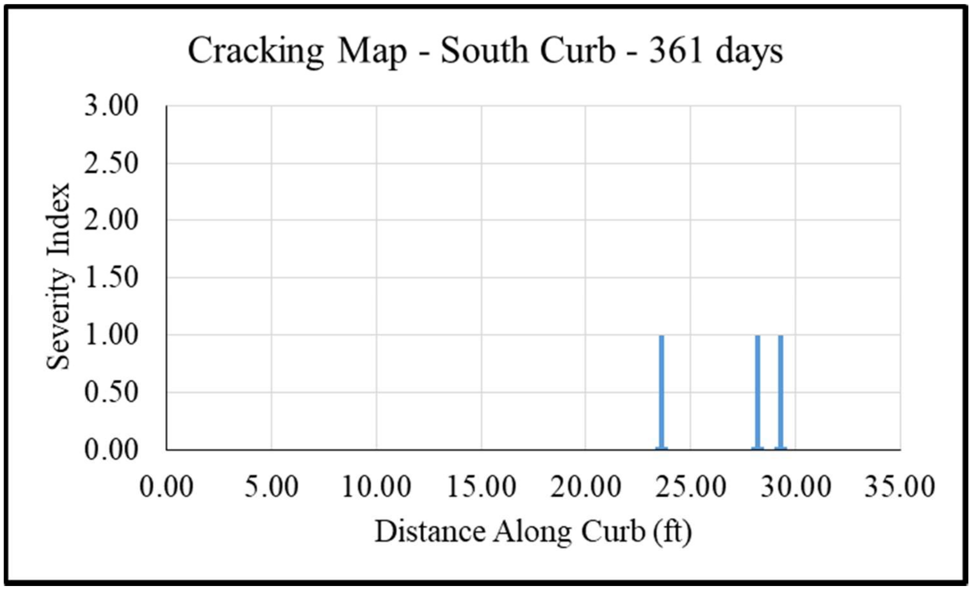

Figure 63: Alexandria south curb heat map at 361 days.

4.4.2 Hampton 207/094

To repeat a statement made earlier, the severity index values on the first few heat maps for Hampton should be ignored as the index values had not been developed at the time of the survey. Thus, Hampton heat maps with all cracks at a severity of one should only be used as a reference to crack location and not the cracks length and width characteristics.

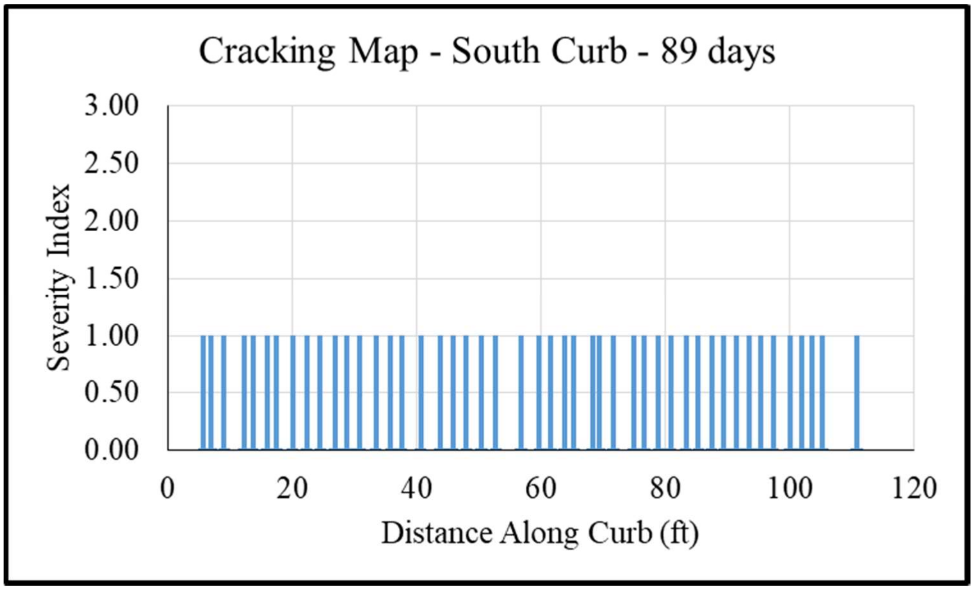

Figure 64: Hampton south curb heat map at 89 days.

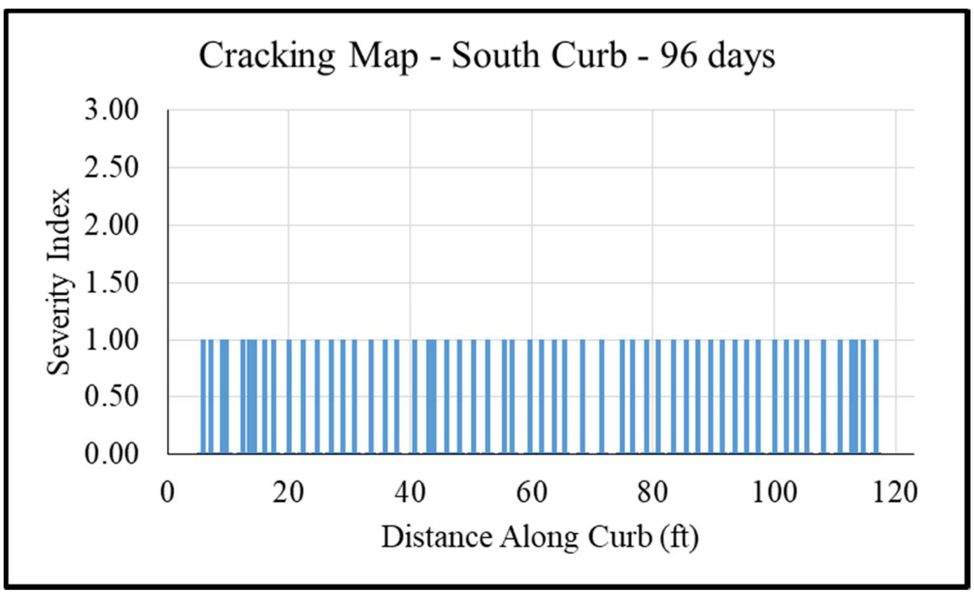

Figure 65: Hampton south curb heat map at 96 days.

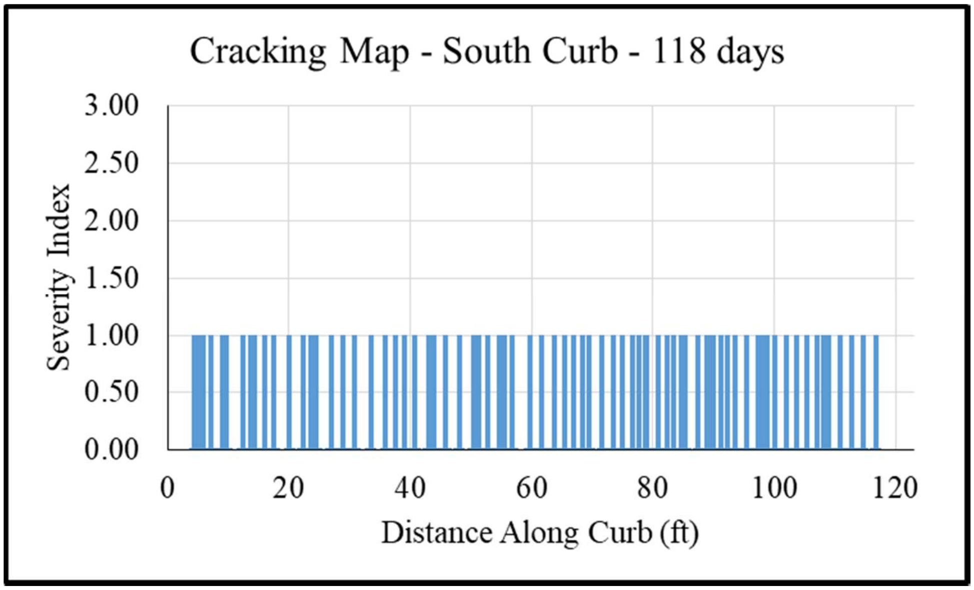

Figure 66: Hampton south curb heat map at 118 days.

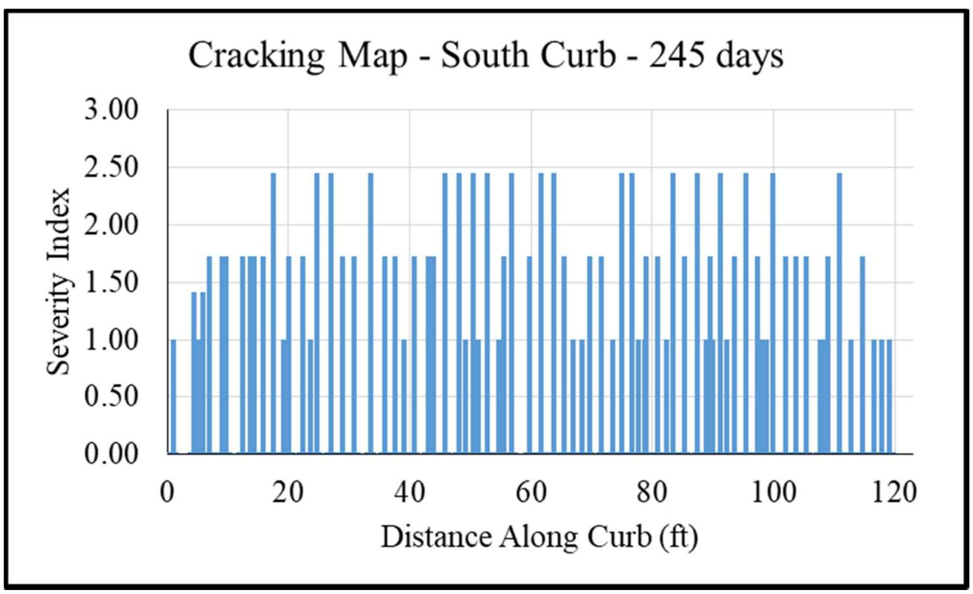

Figure 67: Hampton south curb heat map at 245 days.

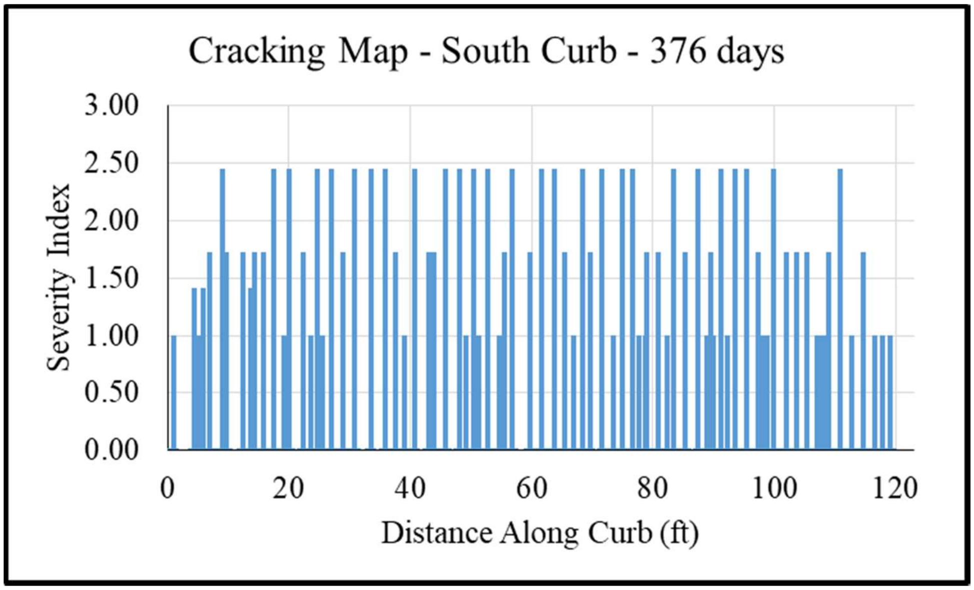

Figure 68: Hampton south curb heat map at 376 days.

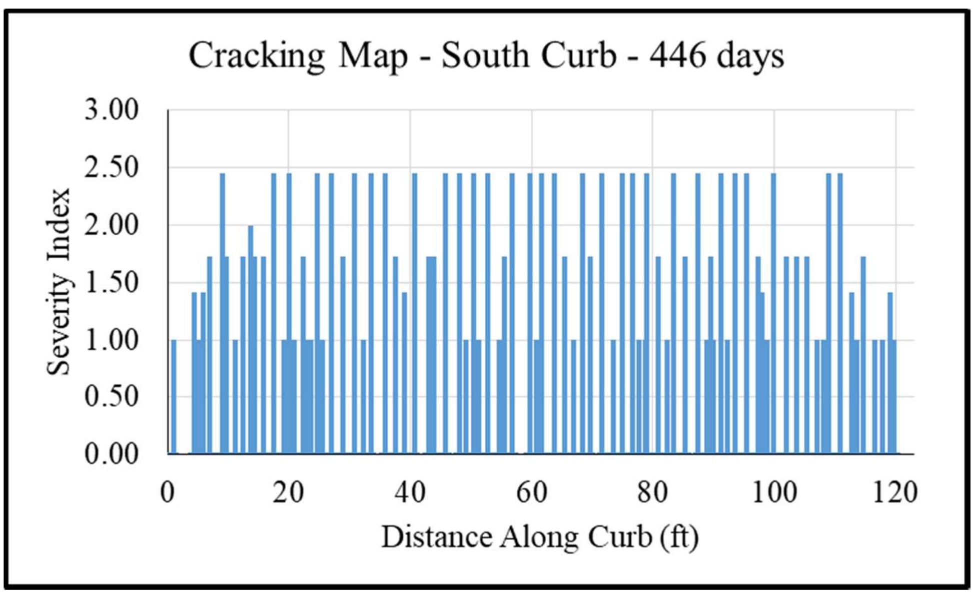

Figure 69: Hampton south curb heat map at 446 days.

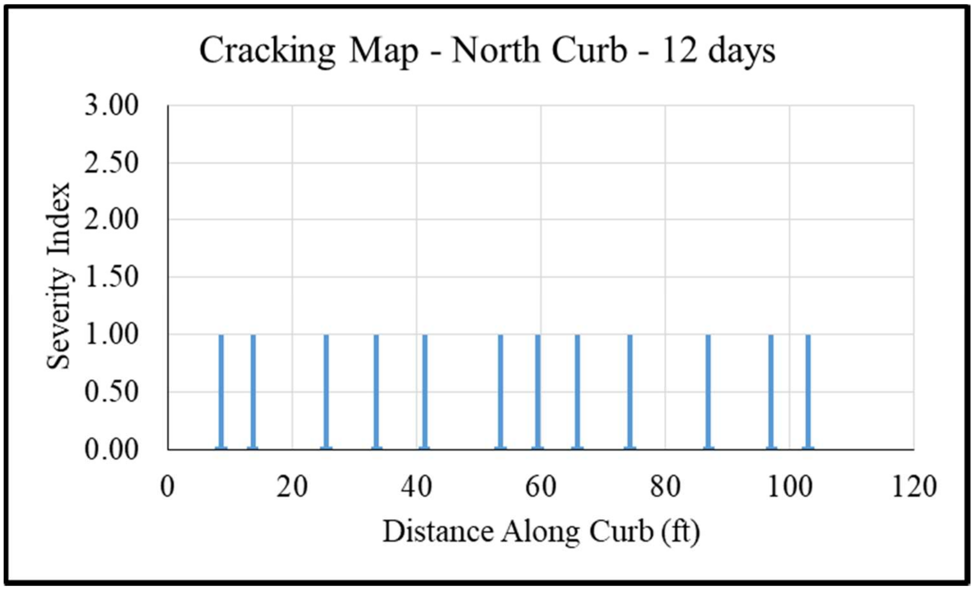

Figure 70: Hampton north curb heat map at 12 days.

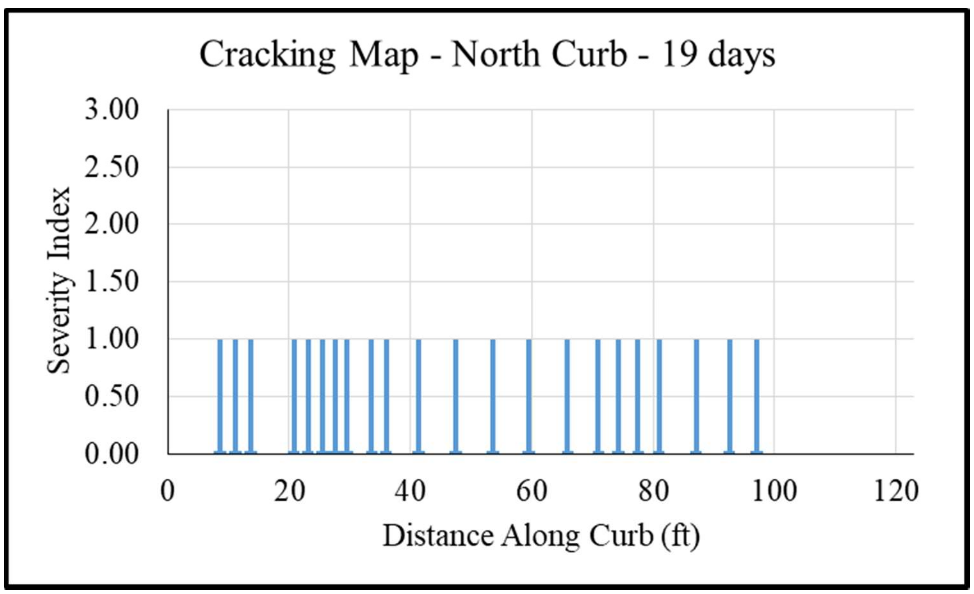

Figure 71: Hampton north curb heat map at 19 days.

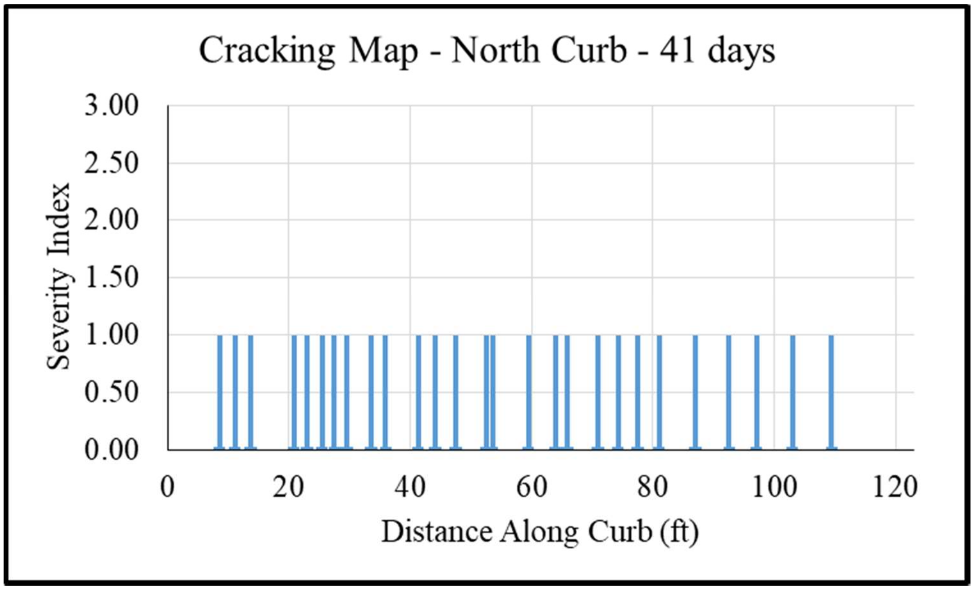

Figure 72: Hampton north curb heat map at 41 days.

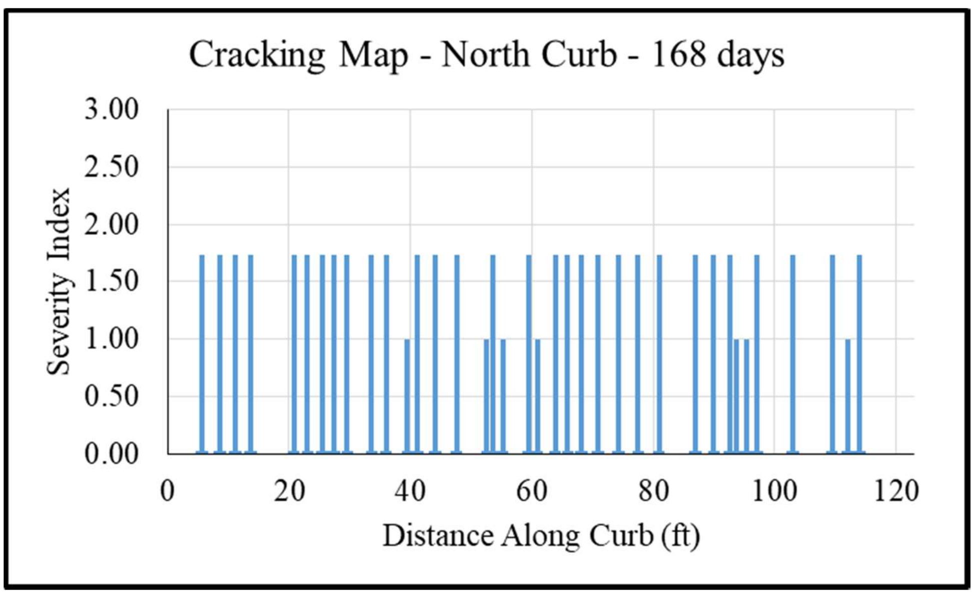

Figure 73: Hampton north curb heat map at 168 days.

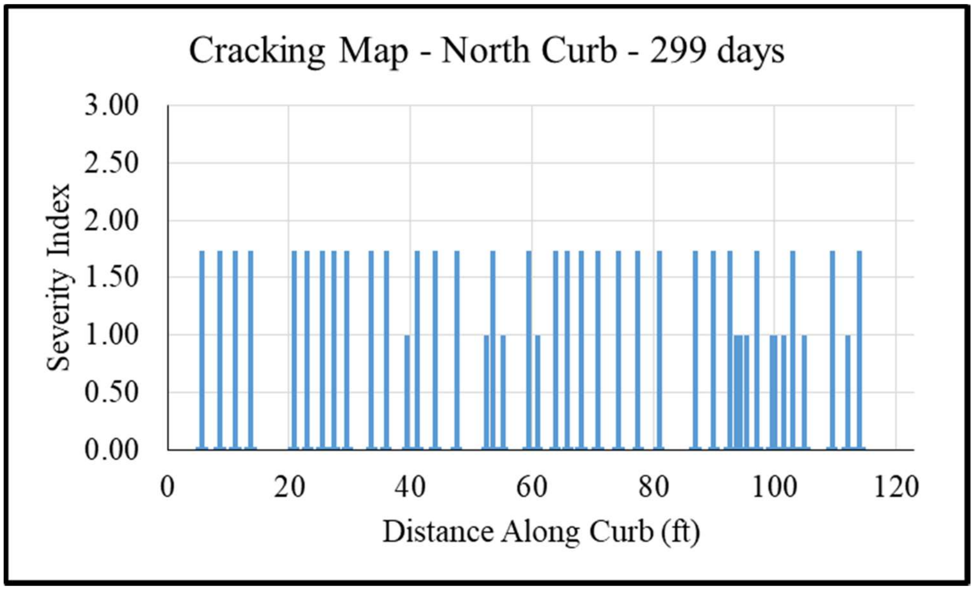

Figure 74: Hampton north curb heat map at 299 days.

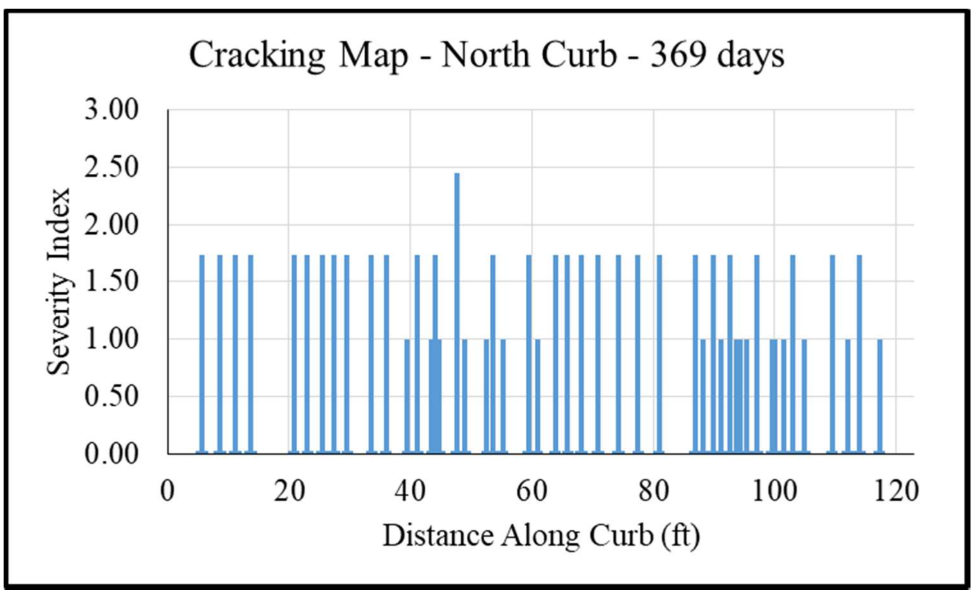

Figure 75: Hampton north curb heat map at 369 days.

4.4.3 Tamworth 095/162

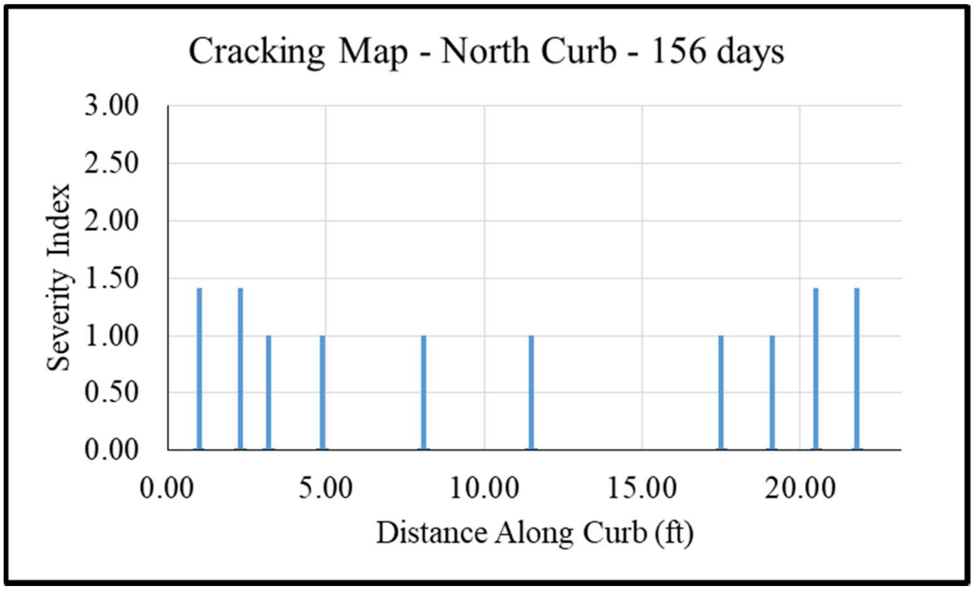

Figure 76: Tamworth north curb heat map at 156 days.

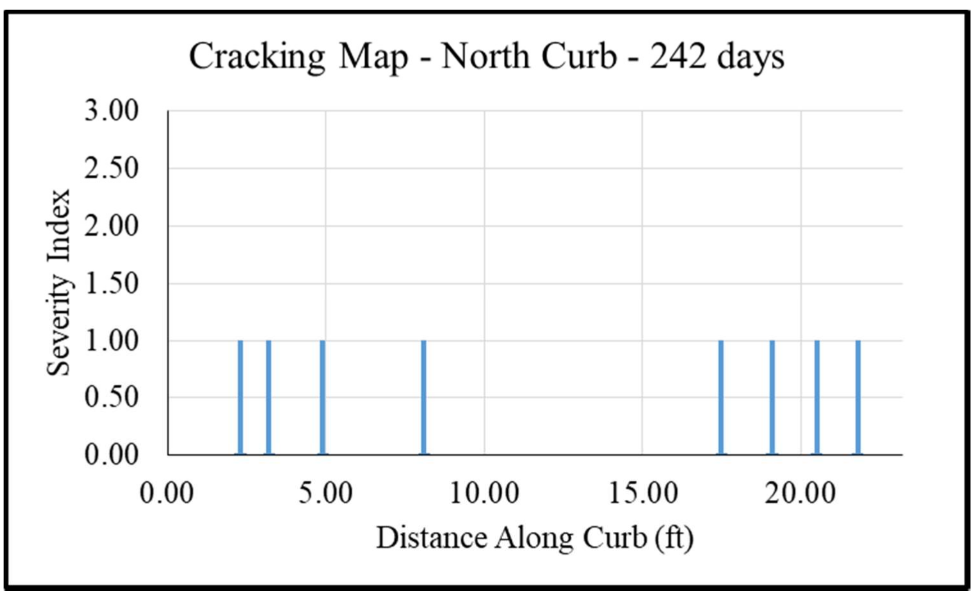

Figure 77: Tamworth north curb heat map at 242 days.

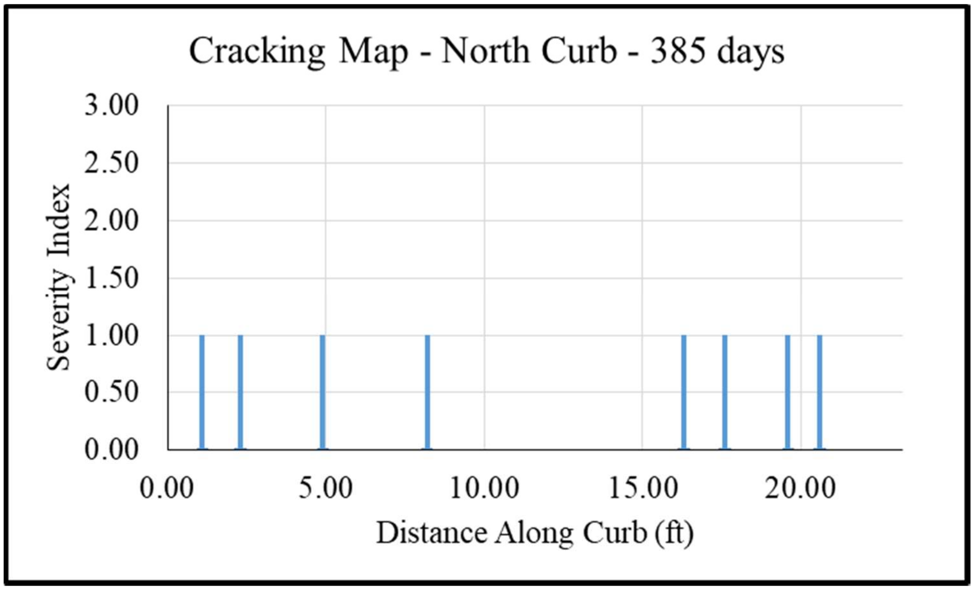

Figure 78: Tamworth north curb heat map at 385 days.

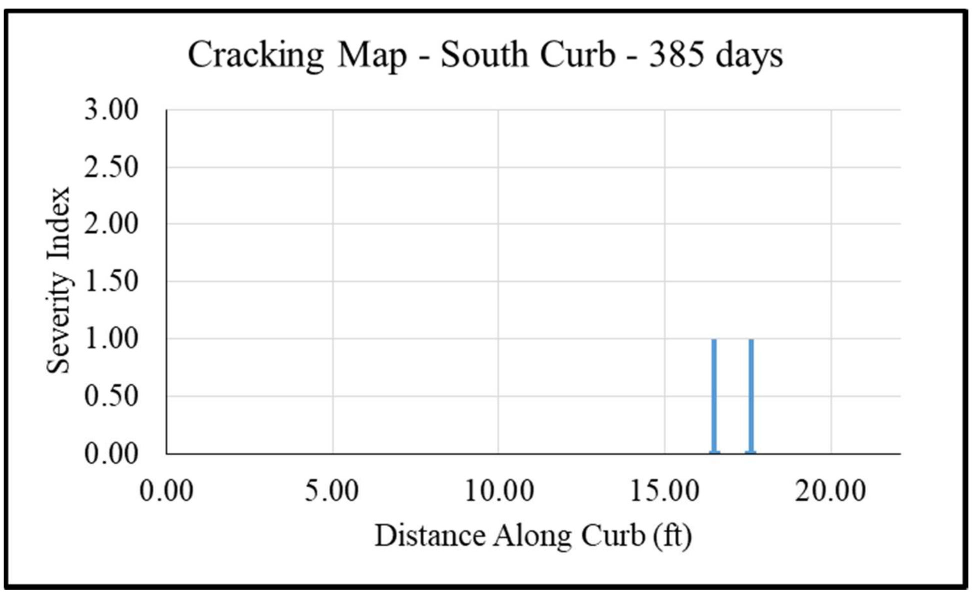

Figure 79: Tamworth north curb heat map at 385 days.

4.4.4 Grantham 140/069

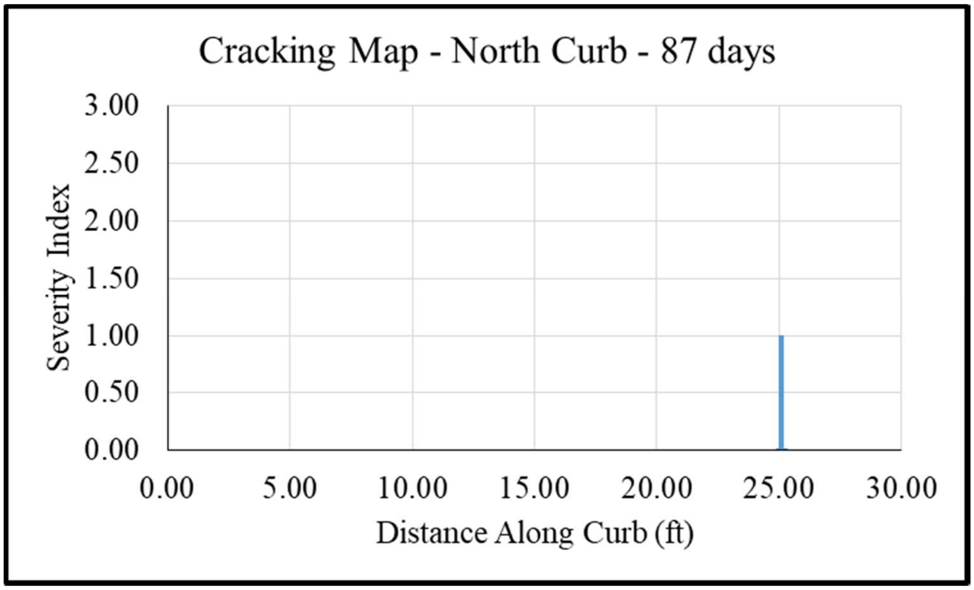

Figure 80: Grantham north curb heat map at 87 days.

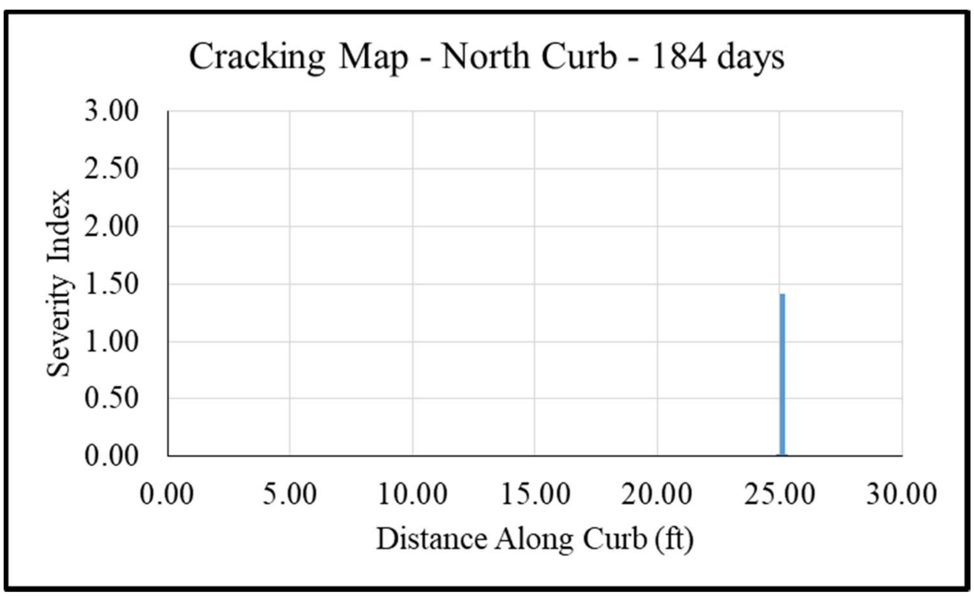

Figure 81: Grantham north curb heat map at 184 days.

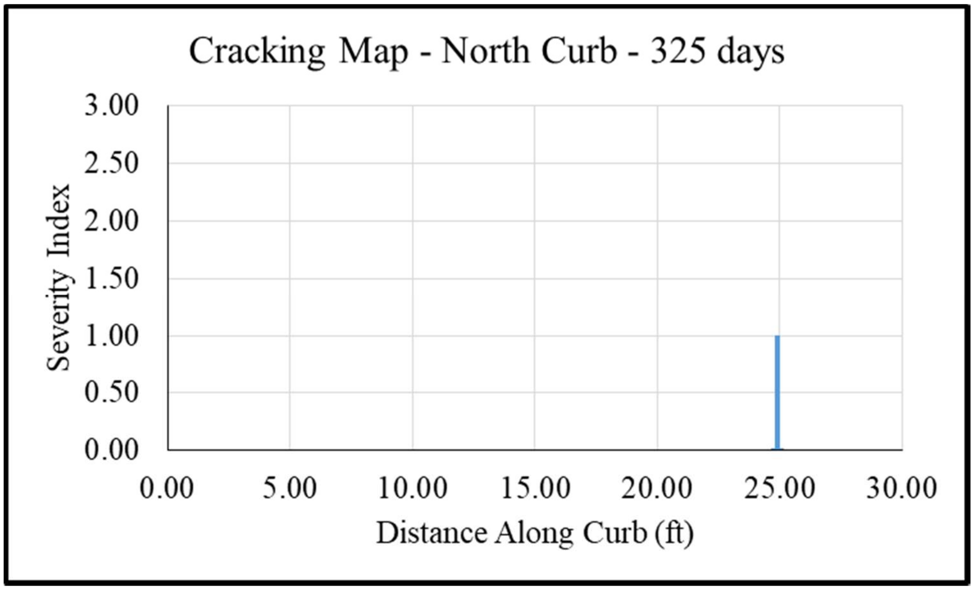

Figure 82: Grantham north curb heat map at 325 days.

4.4.5 Westmoreland 111/072

No visible cracking has been seen on the Westmoreland curb at the time of the last survey.

4.4.6 Marlborough 090/127

No visible cracking has been seen on the Marlborough curb at the time of the last survey.

Appendix B: Analysis Data

The following is a collection of data used in this report. This information does not include specific location along curb, length index, or intensity index values for each curb but is the aggregate information for each curbs site visit.

Table 18: Data used in thesis analysis.

Basic Information									
Bridge	Town	Side	Super Structure	Cast	Age (Days)	Bridge Length (ft)	Curb Length	Number of Posts	% of curb within 1.5' of posts
070/032	Pittsburg	South	Steel	2014	-	94	92.6	13	42%
070/032	Pittsburg	North	Steel	2014	-	94	92.3	13	42%
194/097	Berlin	South	Concrete	2016	-	12	26.5	5	57%
194/097	Berlin	North	Concrete	2016	-	12	26.6	5	56%
087/096	Jefferson (Israel River)	East	Steel	2011	-	84	82.4	11	40%
087/096	Jefferson (Israel River)	West	Steel	2011	-	84	82.4	11	40%
089/090	Jefferson (Cherry Mill)	North	Concrete	2015	-	28	27.6	4	43%
089/090	Jefferson (Cherry Mill)	South	Concrete	2015	-	28	27.6	4	43%
178/141	Canaan	East	Steel	2011	-	47	46.9	7	45%
178/141	Canaan	West	Steel	2011	-	47	46.9	7	45%
080/148	Albany	South	Steel	2015	-	72.8	71.8	12	50%
080/148	Albany	North	Steel	2015	-	72.8	71.8	12	50%
230/057	Wakefield	West	Steel	2012	-	52	52.2	6	34%
230/057	Wakefield	East	Steel	2012	-	52	52.2	6	34%
160/111	Epsom	West	Concrete	2010	-	21	23.9	4	50%
160/111	Epsom	East	Concrete	2010	-	21	23.75	4	51%
130/100	Chichester	East	Concrete	2013	-	15	37.4	6	48%
052/140	Bow	North	Steel	2014	-	31	34.1	6	53%
052/140	Bow	South	Steel	2014	-	31	30.75	6	59%
080/120	Chesterfield	West	Steel	2010	-	41	44	7	48%
080/120	Chesterfield	East	Steel	2010	-	41	42.6	6	42%
045/131	New Boston	North	Concrete	2015	-	17.4	20.2	4	59%
045/131	New Boston	South	Concrete	2015	-	17.4	20.2	4	59%
174/146	Alexandria	North	Concrete	5/31/2017	30	29	34.5	5	43%
174/146	Alexandria	North	Concrete	5/31/2017	80	29	34.5	5	43%
174/146	Alexandria	South	Concrete	8/3/2017	16	29	32	5	47%
174/146	Alexandria	North	Concrete	5/31/2017	108	29	34.5	5	43%
174/146	Alexandria	South	Concrete	8/3/2017	44	29	32	5	47%
174/146	Alexandria	North	Concrete	5/31/2017	175	29	34.5	5	43%
174/146	Alexandria	South	Concrete	8/3/2017	111	29	32	5	47%
174/146	Alexandria	North	Concrete	5/31/2017	333	29	34.5	5	43%
174/146	Alexandria	South	Concrete	8/3/2017	269	29	32	5	47%
174/146	Alexandria	North	Concrete	5/31/2017	425	29	34.5	5	43%
174/146	Alexandria	South	Concrete	8/3/2017	361	29	32	5	47%
140/069	Grantham	North	Concrete	4/24/2018	2	27.5	30	4	40%
140/069	Grantham	North	Concrete	4/24/2018	5	27.5	30	4	40%
140/069	Grantham	North	Concrete	4/24/2018	9	27.5	30	4	40%
140/069	Grantham	North	Concrete	4/24/2018	12	27.5	30	4	40%
140/069	Grantham	North	Concrete	4/24/2018	31	27.5	30	4	40%
140/069	Grantham	North	Concrete	4/24/2018	55	27.5	30	4	40%
140/069	Grantham	North	Concrete	4/24/2018	66	27.5	30	4	40%
140/069	Grantham	South	Concrete	6/26/2018	3	27.5	28.6	4	42%
140/069	Grantham	North	Concrete	4/24/2018	87	27.5	30	4	40%
140/069	Grantham	South	Concrete	6/26/2018	24	27.5	28.6	4	42%
140/069	Grantham	North	Concrete	4/24/2018	184	27.5	30	4	40%
140/069	Grantham	South	Concrete	6/26/2018	121	27.5	28.6	4	42%
140/069	Grantham	North	Concrete	4/24/2018	325	27.5	30	4	40%
140/069	Grantham	South	Concrete	6/26/2018	262	27.5	28.6	4	42%

Basic Information									
Bridge	Town	Side	Super Structure	Cast	Age (Days)	Bridge Length (ft)	Curb Length	Number of Posts	% of curb within 1.5' of posts
207/094	Hampton-Ignore Index Values	South	Steel	1/5/2017	89	126	123	16	39%
207/094	Hampton-Ignore Index Values	North	Steel	3/23/2017	12	126	123	16	39%
207/094	Hampton-Ignore Index Values	South	Steel	1/5/2017	96	126	123	16	39%
207/094	Hampton-Ignore Index Values	North	Steel	3/23/2017	19	126	123	16	39%
207/094	Hampton-Ignore Index Values	South	Steel	1/5/2017	118	126	123	16	39%
207/094	Hampton-Ignore Index Values	North	Steel	3/23/2017	41	126	123	16	39%
207/094	Hampton	South	Steel	1/5/2017	245	126	123	16	39%
207/094	Hampton	North	Steel	3/23/2017	168	126	123	16	39%
207/094	Hampton	South	Steel	1/5/2017	376	126	123	16	39%
207/094	Hampton	North	Steel	3/23/2017	299	126	123	16	39%
207/094	Hampton	South	Steel	1/5/2017	446	126	123	16	39%
207/094	Hampton	North	Steel	3/23/2017	369	126	123	16	39%
090/127	Marlborough	North	Concrete	3/1/2018	5	10	19.5	5	77%
090/127	Marlborough	North	Concrete	3/1/2018	33	10	19.5	5	77%
090/127	Marlborough	North	Concrete	3/1/2018	378	10	19.5	5	77%
095/162	Tamworth	North	Concrete	2/23/2018	3	22	23.2	4	52%
095/162	Tamworth	South	Concrete	2/23/2018	3	22	22.1	4	54%
095/162	Tamworth	North	Concrete	2/23/2018	7	22	23.2	4	52%
095/162	Tamworth	South	Concrete	2/23/2018	7	22	22.1	4	54%
095/162	Tamworth	North	Concrete	2/23/2018	12	22	23.2	4	52%
095/162	Tamworth	South	Concrete	2/23/2018	12	22	22.1	4	54%
095/162	Tamworth	North	Concrete	2/23/2018	20	22	23.2	4	52%
095/162	Tamworth	South	Concrete	2/23/2018	20	22	22.1	4	54%
095/162	Tamworth	North	Concrete	2/23/2018	28	22	23.2	4	52%
095/162	Tamworth	South	Concrete	2/23/2018	28	22	22.1	4	54%
095/162	Tamworth	North	Concrete	2/23/2018	44	22	23.2	4	52%
095/162	Tamworth	South	Concrete	2/23/2018	44	22	22.1	4	54%
095/162	Tamworth	North	Concrete	2/23/2018	65	22	23.2	4	52%
095/162	Tamworth	South	Concrete	2/23/2018	65	22	22.1	4	54%
095/162	Tamworth	North	Concrete	2/23/2018	79	22	23.2	4	52%
095/162	Tamworth	South	Concrete	2/23/2018	79	22	22.1	4	54%
095/162	Tamworth	North	Concrete	2/23/2018	156	22	23.2	4	52%
095/162	Tamworth	South	Concrete	2/23/2018	156	22	22.1	4	54%
095/162	Tamworth	North	Concrete	2/23/2018	242	22	23.2	4	52%
095/162	Tamworth	South	Concrete	2/23/2018	242	22	22.1	4	54%
095/162	Tamworth	North	Concrete	2/23/2018	242	22	23.2	4	52%
095/162	Tamworth	South	Concrete	2/23/2018	242	22	22.1	4	54%
111/072	Westmoreland	West	Concrete	1/2/2019	29	24	24.6	5	61%
111/072	Westmoreland	East	Concrete	1/29/2019	2	24	24.6	6	73%
111/072	Westmoreland	West	Concrete	1/2/2019	36	24	24.6	5	61%
111/072	Westmoreland	East	Concrete	1/29/2019	9	24	24.6	6	73%
107/130	Alstead	North	concrete	2012	-	31.9	32	4	38%
107/130	Alstead	South	concrete	2012	-	31.9	31.8	5	47%
082/103	Sandown	East	Concrete	2013	-	26	34.7	5	43%
082/103	Sandown	West	Concrete	2013	-	26	36.3	6	50%
117/120	Epsom	West	Steel	2008	-	39	38.2	8	63%
117/120	Epsom	East	Steel	2008	-	39	38	9	71%
105/129	Goshen	East	Concrete	2013	-	40.67	41	6	44%
105/129	Goshen	West	Concrete	2013	-	40.67	41.8	7	50%
143/087	Swanzey	East	Steel	2013	-	31.5	33.6	5	45%
143/087	Swanzey	West	Steel	2013	-	31.5	33.6	6	54%

Bridge	Town	Side	# of Cracks	# Length 1 Cracks	# Length 2 Cracks	# Length 3 Cracks	# Intensity 1 Cracks	# Intensity 2 Cracks	# Intensity 3 Cracks
070/032	Pittsburg	South	38	8	3	27	12	21	5
070/032	Pittsburg	North	53	19	4	30	39	13	1
194/097	Berlin	South	5	3	0	2	4	1	0
194/097	Berlin	North	9	7	0	2	7	2	0
087/096	Jefferson (Israel River)	East	79	36	21	22	63	15	1
087/096	Jefferson (Israel River)	West	83	65	13	5	79	4	0
089/090	Jefferson (Cherry Mill)	North	5	5	0	0	5	0	0
089/090	Jefferson (Cherry Mill)	South	4	4	0	0	4	0	0
178/141	Canaan	East	24	20	3	1	22	2	0
178/141	Canaan	West	25	22	3	0	20	5	0
080/148	Albany	South	35	18	2	15	29	6	0
080/148	Albany	North	59	45	3	11	41	18	0
230/057	Wakefield	West	33	31	1	1	30	3	0
230/057	Wakefield	East	31	23	3	5	29	2	0
160/111	Epsom	West	0	0	0	0	0	0	0
160/111	Epsom	East	3	3	0	0	2	1	0
130/100	Chichester	East	7	7	0	0	7	0	0
052/140	Bow	North	25	24	1	0	23	2	0
052/140	Bow	South	5	5	0	0	5	0	0
080/120	Chesterfield	West	5	5	0	0	5	0	0
080/120	Chesterfield	East	22	22	0	0	20	2	0
045/131	New Boston	North	8	8	0	0	8	0	0
045/131	New Boston	South	2	2	0	0	2	0	0
174/146	Alexandria	North	3	0	0	3	2	1	0
174/146	Alexandria	North	5	2	0	3	2	2	1
174/146	Alexandria	South	0	0	0	0	0	0	0
174/146	Alexandria	North	9	6	0	3	6	2	1
174/146	Alexandria	South	0	0	0	0	0	0	0
174/146	Alexandria	North	12	8	1	3	9	2	1
174/146	Alexandria	South	0	0	0	0	0	0	0
174/146	Alexandria	North	18	13	1	4	15	1	2
174/146	Alexandria	South	1	1	0	0	1	0	0
174/146	Alexandria	North	14	8	1	5	11	2	1
174/146	Alexandria	South	3	3	0	0	3	0	0
140/069	Grantham	North	0	0	0	0	0	0	0
140/069	Grantham	North	0	0	0	0	0	0	0
140/069	Grantham	North	0	0	0	0	0	0	0
140/069	Grantham	North	0	0	0	0	0	0	0
140/069	Grantham	North	0	0	0	0	0	0	0
140/069	Grantham	North	0	0	0	0	0	0	0
140/069	Grantham	North	0	0	0	0	0	0	0
140/069	Grantham	South	0	0	0	0	0	0	0
140/069	Grantham	North	1	1	0	0	1	0	0
140/069	Grantham	South	0	0	0	0	0	0	0
140/069	Grantham	North	1	0	1	0	1	0	0
140/069	Grantham	South	0	0	0	0	0	0	0
140/069	Grantham	North	1	0	1	0	1	0	0
140/069	Grantham	South	0	0	0	0	0	0	0

Bridge	Town	Side	# of Cracks	# Length 1 Cracks	# Length 2 Cracks	# Length 3 Cracks	# Intensity 1 Cracks	# Intensity 2 Cracks	# Intensity 3 Cracks
207/094	Hampton-Ignore Index Values	South	47	47	0	0	47	0	0
207/094	Hampton-Ignore Index Values	North	12	12	0	0	12	0	0
207/094	Hampton-Ignore Index Values	South	55	55	0	0	55	0	0
207/094	Hampton-Ignore Index Values	North	22	22	0	0	22	0	0
207/094	Hampton-Ignore Index Values	South	74	74	0	0	74	0	0
207/094	Hampton-Ignore Index Values	North	27	27	0	0	27	0	0
207/094	Hampton	South	78	25	2	51	59	19	0
207/094	Hampton	North	37	7	0	30	37	0	0
207/094	Hampton	South	80	26	3	51	53	27	0
207/094	Hampton	North	42	12	0	30	42	0	0
207/094	Hampton	South	86	28	7	51	55	31	0
207/094	Hampton	North	48	18	0	30	47	1	0
090/127	Marlborough	North	0	0	0	0	0	0	0
090/127	Marlborough	North	0	0	0	0	0	0	0
090/127	Marlborough	North	0	0	0	0	0	0	0
095/162	Tamworth	North	0	0	0	0	0	0	0
095/162	Tamworth	South	0	0	0	0	0	0	0
095/162	Tamworth	North	0	0	0	0	0	0	0
095/162	Tamworth	South	0	0	0	0	0	0	0
095/162	Tamworth	North	0	0	0	0	0	0	0
095/162	Tamworth	South	0	0	0	0	0	0	0
095/162	Tamworth	North	0	0	0	0	0	0	0
095/162	Tamworth	South	0	0	0	0	0	0	0
095/162	Tamworth	North	0	0	0	0	0	0	0
095/162	Tamworth	South	0	0	0	0	0	0	0
095/162	Tamworth	North	0	0	0	0	0	0	0
095/162	Tamworth	South	0	0	0	0	0	0	0
095/162	Tamworth	North	0	0	0	0	0	0	0
095/162	Tamworth	South	0	0	0	0	0	0	0
095/162	Tamworth	North	0	0	0	0	0	0	0
095/162	Tamworth	South	0	0	0	0	0	0	0
095/162	Tamworth	North	10	6	4	0	10	0	0
095/162	Tamworth	South	0	0	0	0	0	0	0
095/162	Tamworth	North	8	8	0	0	8	0	0
095/162	Tamworth	South	0	0	0	0	0	0	0
095/162	Tamworth	North	8	8	0	0	8	0	0
095/162	Tamworth	South	0	0	0	0	0	0	0
111/072	Westmoreland	West	0	0	0	0	0	0	0
111/072	Westmoreland	East	0	0	0	0	0	0	0
111/072	Westmoreland	West	0	0	0	0	0	0	0
111/072	Westmoreland	East	0	0	0	0	0	0	0
107/130	Alstead	North	24	16	1	7	24	0	0
107/130	Alstead	South	19	13	1	5	17	2	0
082/103	Sandown	East	13	8	2	3	11	2	0
082/103	Sandown	West	6	5	0	1	5	1	0
117/120	Epsom	West	23	17	5	1	23	0	0
117/120	Epsom	East	12	11	1	0	12	0	0
105/129	Goshen	East	14	14	0	0	14	0	0
105/129	Goshen	West	14	13	1	0	14	0	0
143/087	Swanzey	East	1	0	1	0	1	0	0
143/087	Swanzey	West	2	2	0	0	2	0	0

			Entire Curb				
Bridge	Town	Side	Average Uncracked Length (ft)	Average Crack Length	Average Crack Intensity	Average Crack Severity	CCI
070/032	Pittsburg	South	2.37	2.50	1.82	2.11	1.12
070/032	Pittsburg	North	1.71	2.21	1.28	1.65	1.04
194/097	Berlin	South	4.42	1.80	1.20	1.44	3.08
194/097	Berlin	North	2.66	1.44	1.22	1.32	2.01
087/096	Jefferson (Israel River)	East	1.03	1.82	1.22	1.46	0.71
087/096	Jefferson (Israel River)	West	0.98	1.28	1.05	1.14	0.86
089/090	Jefferson (Cherry Mill)	North	4.60	1.00	1.00	1.00	4.60
089/090	Jefferson (Cherry Mill)	South	5.52	1.00	1.00	1.00	5.52
178/141	Canaan	East	1.88	1.21	1.08	1.14	1.65
178/141	Canaan	West	1.80	1.12	1.20	1.14	1.58
080/148	Albany	South	1.99	1.91	1.17	1.45	1.37
080/148	Albany	North	1.20	1.42	1.31	1.33	0.90
230/057	Wakefield	West	1.54	1.09	1.09	1.08	1.42
230/057	Wakefield	East	1.63	1.42	1.06	1.19	1.37
160/111	Epsom	West	23.90	0.00	0.00	0.00	23.90
160/111	Epsom	East	5.94	1.00	1.33	1.14	5.22
130/100	Chichester	East	4.68	1.00	1.00	1.00	4.68
052/140	Bow	North	1.31	1.04	1.08	1.05	1.25
052/140	Bow	South	5.13	1.00	1.00	1.00	5.13
080/120	Chesterfield	West	7.33	1.00	1.00	1.00	7.33
080/120	Chesterfield	East	1.85	1.00	1.09	1.04	1.78
045/131	New Boston	North	2.24	1.00	1.00	1.00	2.24
045/131	New Boston	South	6.73	1.00	1.00	1.00	6.73
174/146	Alexandria	North	8.63	3.00	1.33	1.97	4.38
174/146	Alexandria	North	5.75	2.20	1.80	1.98	2.90
174/146	Alexandria	South	32.00	0.00	0.00	0.00	32.00
174/146	Alexandria	North	3.45	1.67	1.44	1.54	2.23
174/146	Alexandria	South	32.00	0.00	0.00	0.00	32.00
174/146	Alexandria	North	2.65	1.58	1.33	1.44	1.84
174/146	Alexandria	South	32.00	0.00	0.00	0.00	32.00
174/146	Alexandria	North	1.82	1.50	1.28	1.37	1.33
174/146	Alexandria	South	16.00	1.00	1.00	1.00	16.00
174/146	Alexandria	North	2.30	1.79	1.29	1.48	1.55
174/146	Alexandria	South	8.00	1.00	1.00	1.00	8.00
140/069	Grantham	North	30.00	0.00	0.00	0.00	30.00
140/069	Grantham	North	30.00	0.00	0.00	0.00	30.00
140/069	Grantham	North	30.00	0.00	0.00	0.00	30.00
140/069	Grantham	North	30.00	0.00	0.00	0.00	30.00
140/069	Grantham	North	30.00	0.00	0.00	0.00	30.00
140/069	Grantham	North	30.00	0.00	0.00	0.00	30.00
140/069	Grantham	North	30.00	0.00	0.00	0.00	30.00
140/069	Grantham	South	28.60	0.00	0.00	0.00	28.60
140/069	Grantham	North	15.00	1.00	1.00	1.00	15.00
140/069	Grantham	South	28.60	0.00	0.00	0.00	28.60
140/069	Grantham	North	15.00	2.00	1.00	1.41	10.61
140/069	Grantham	South	28.60	0.00	0.00	0.00	28.60
140/069	Grantham	North	15.00	2.00	1.00	1.41	10.61
140/069	Grantham	South	28.60	0.00	0.00	0.00	28.60

			Entire Curb				
Bridge	Town	Side	Average Uncracked Length (ft)	Average Crack Length	Average Crack Intensity	Average Crack Severity	CCI
207/094	Hampton-Ignore Index Values	South	2.56	1.00	1.00	1.00	2.56
207/094	Hampton-Ignore Index Values	North	9.46	1.00	1.00	1.00	9.46
207/094	Hampton-Ignore Index Values	South	2.20	1.00	1.00	1.00	2.20
207/094	Hampton-Ignore Index Values	North	5.35	1.00	1.00	1.00	5.35
207/094	Hampton-Ignore Index Values	South	1.64	1.00	1.00	1.00	1.64
207/094	Hampton-Ignore Index Values	North	4.39	1.00	1.00	1.00	4.39
207/094	Hampton	South	1.56	2.33	1.24	1.66	0.94
207/094	Hampton	North	3.24	2.62	1.00	1.59	2.03
207/094	Hampton	South	1.52	2.31	1.34	1.72	0.88
207/094	Hampton	North	2.86	2.43	1.00	1.52	1.88
207/094	Hampton	South	1.41	2.27	1.36	1.72	0.82
207/094	Hampton	North	2.51	2.25	1.02	1.47	1.70
090/127	Marlborough	North	19.50	0.00	0.00	0.00	19.50
090/127	Marlborough	North	19.50	0.00	0.00	0.00	19.50
090/127	Marlborough	North	19.50	0.00	0.00	0.00	19.50
095/162	Tamworth	North	23.20	0.00	0.00	0.00	23.20
095/162	Tamworth	South	22.10	0.00	0.00	0.00	22.10
095/162	Tamworth	North	23.20	0.00	0.00	0.00	23.20
095/162	Tamworth	South	22.10	0.00	0.00	0.00	22.10
095/162	Tamworth	North	23.20	0.00	0.00	0.00	23.20
095/162	Tamworth	South	22.10	0.00	0.00	0.00	22.10
095/162	Tamworth	North	23.20	0.00	0.00	0.00	23.20
095/162	Tamworth	South	22.10	0.00	0.00	0.00	22.10
095/162	Tamworth	North	23.20	0.00	0.00	0.00	23.20
095/162	Tamworth	South	22.10	0.00	0.00	0.00	22.10
095/162	Tamworth	North	23.20	0.00	0.00	0.00	23.20
095/162	Tamworth	South	22.10	0.00	0.00	0.00	22.10
095/162	Tamworth	North	23.20	0.00	0.00	0.00	23.20
095/162	Tamworth	South	22.10	0.00	0.00	0.00	22.10
095/162	Tamworth	North	23.20	0.00	0.00	0.00	23.20
095/162	Tamworth	South	22.10	0.00	0.00	0.00	22.10
095/162	Tamworth	North	2.11	1.40	1.00	1.17	1.81
095/162	Tamworth	South	22.10	0.00	0.00	0.00	22.10
095/162	Tamworth	North	2.58	1.00	1.00	1.00	2.58
095/162	Tamworth	South	22.10	0.00	0.00	0.00	22.10
095/162	Tamworth	North	2.58	1.00	1.00	1.00	2.58
095/162	Tamworth	South	22.10	0.00	0.00	0.00	22.10
111/072	Westmoreland	West	24.60	0.00	0.00	0.00	24.60
111/072	Westmoreland	East	24.60	0.00	0.00	0.00	24.60
111/072	Westmoreland	West	24.60	0.00	0.00	0.00	24.60
111/072	Westmoreland	East	24.60	0.00	0.00	0.00	24.60
107/130	Alstead	North	1.28	1.63	1.00	1.23	1.04
107/130	Alstead	South	1.59	1.58	1.11	1.29	1.23
082/103	Sandown	East	2.48	1.62	1.15	1.33	1.86
082/103	Sandown	West	5.19	1.33	1.17	1.24	4.18
117/120	Epsom	West	1.59	1.30	1.00	1.12	1.42
117/120	Epsom	East	2.92	1.08	1.00	1.03	2.83
105/129	Goshen	East	2.73	1.00	1.00	1.00	2.73
105/129	Goshen	West	2.79	1.07	1.00	1.03	2.71
143/087	Swanzey	East	16.80	2.00	1.00	1.41	11.88
143/087	Swanzey	West	11.20	1.00	1.00	1.00	11.20

				Near Post					
Bridge	Town	Side	% of Cracks within 1.5' of posts	# of Cracks	Average Length	Average Intensity	Average Crack Severity	Average Uncracked Length	CCI
070/032	Pittsburg	South	36.84%	14.00	2.64	1.86	2.20	2.60	1.18
070/032	Pittsburg	North	43.40%	23.00	2.043478261	1.217391304	1.54	1.63	1.05
194/097	Berlin	South	60.00%	3.00	2.33	1.33	1.73	3.75	2.17
194/097	Berlin	North	44.44%	4.00	2.333333333	1.666666667	1.97	3.00	1.53
087/096	Jefferson (Israel River)	East	41.77%	33.00	1.97	1.33	1.59	0.97	0.61
087/096	Jefferson (Israel River)	West	18.07%	15.00	1.45	1.10	1.24	2.06	1.66
089/090	Jefferson (Cherry Mill)	North	80.00%	4.00	1.00	1.00	1.00	2.40	2.40
089/090	Jefferson (Cherry Mill)	South	75.00%	3.00	1.00	1.00	1.00	3.00	3.00
178/141	Canaan	East	45.83%	11.00	1.27	1.09	1.17	1.75	1.50
178/141	Canaan	West	40.00%	10.00	1.10	1.10	1.40	1.91	1.36
080/148	Albany	South	48.57%	17.00	1.88	1.12	1.41	2.00	1.42
080/148	Albany	North	52.54%	31.00	1.45	1.32	1.35	1.13	0.83
230/057	Wakefield	West	36.36%	12.00	1.00	1.17	1.07	1.38	1.30
230/057	Wakefield	East	35.48%	11.00	1.18	1.00	1.08	1.50	1.39
160/111	Epsom	West	-	0.00	0.00	0.00	0.00	12.00	12.00
160/111	Epsom	East	33.33%	1.00	1.00	1.00	1.00	6.00	6.00
130/100	Chichester	East	28.57%	2.00	1.00	1.00	1.00	6.00	6.00
052/140	Bow	North	44.00%	11.00	1.00	1.00	1.00	1.50	1.50
052/140	Bow	South	40.00%	2.00	1.00	1.00	1.00	6.00	6.00
080/120	Chesterfield	West	60.00%	3.00	1.00	1.00	1.00	5.25	5.25
080/120	Chesterfield	East	54.55%	12.00	1.00	1.08	1.03	1.38	1.34
045/131	New Boston	North	62.50%	5.00	1.00	1.00	1.00	2.00	2.00
045/131	New Boston	South	0.00%	0.00	0.00	0.00	0.00	12.00	12.00
174/146	Alexandria	North	33.33%	1.00	3.00	1.33	1.97	7.50	3.80
174/146	Alexandria	North	20.00%	1.00	1.00	1.00	1.00	7.50	7.50
174/146	Alexandria	South	-	0.00	0.00	0.00	0.00	15.00	15.00
174/146	Alexandria	North	33.33%	3.00	1.00	1.00	1.00	3.75	3.75
174/146	Alexandria	South	-	0.00	0.00	0.00	0.00	15.00	15.00
174/146	Alexandria	North	41.67%	5.00	1.20	1.00	1.08	2.50	2.31
174/146	Alexandria	South	-	0.00	0.00	0.00	0.00	15.00	15.00
174/146	Alexandria	North	33.33%	6.00	1.33	1.00	1.12	2.14	1.91
174/146	Alexandria	South	100.00%	1.00	1.00	1.00	1.00	7.50	7.50
174/146	Alexandria	North	35.71%	5.00	1.80	1.00	1.29	2.50	1.93
174/146	Alexandria	South	33.33%	1.00	1.00	1.00	1.00	7.50	7.50
140/069	Grantham	North	-	0.00	0.00	0.00	0.00	12.00	12.00
140/069	Grantham	North	-	0.00	0.00	0.00	0.00	12.00	12.00
140/069	Grantham	North	-	0.00	0.00	0.00	0.00	12.00	12.00
140/069	Grantham	North	-	0.00	0.00	0.00	0.00	12.00	12.00
140/069	Grantham	North	-	0.00	0.00	0.00	0.00	12.00	12.00
140/069	Grantham	North	-	0.00	0.00	0.00	0.00	12.00	12.00
140/069	Grantham	North	-	0.00	0.00	0.00	0.00	12.00	12.00
140/069	Grantham	South	-	0.00	0.00	0.00	0.00	12.00	12.00
140/069	Grantham	North	0.00%	0.00	0.00	0.00	0.00	12.00	12.00
140/069	Grantham	South	-	0.00	0.00	0.00	0.00	12.00	12.00
140/069	Grantham	North	0.00%	0.00	0.00	0.00	0.00	12.00	12.00
140/069	Grantham	South	-	0.00	0.00	0.00	0.00	12.00	12.00
140/069	Grantham	North	0.00%	0.00	0.00	0.00	0.00	12.00	12.00
140/069	Grantham	South	-	0.00	0.00	0.00	0.00	12.00	12.00

				Near Post					
Bridge	Town	Side	% of Cracks within 1.5' of posts	# of Cracks	Average Length	Average Intensity	Average Crack Severity	Average Uncracked Length	CCI
207/094	Hampton-Ignore Index Values	South	31.91%	17.00	1.00	1.00	1.00	2.67	2.67
207/094	Hampton-Ignore Index Values	North	50.00%	7.00	1.00	1.00	1.00	6.00	6.00
207/094	Hampton-Ignore Index Values	South	30.91%	20.00	1.00	1.00	1.00	2.29	2.29
207/094	Hampton-Ignore Index Values	North	40.91%	9.00	1.00	1.00	1.00	4.80	4.80
207/094	Hampton-Ignore Index Values	South	29.73%	26.00	1.00	1.00	1.00	1.78	1.78
207/094	Hampton-Ignore Index Values	North	37.04%	11.00	1.00	1.00	1.00	4.00	4.00
207/094	Hampton	South	37.18%	29.00	2.31	1.31	1.70	1.60	0.94
207/094	Hampton	North	35.14%	15.00	2.47	1.00	1.54	3.00	1.95
207/094	Hampton	South	37.50%	30.00	2.27	1.40	1.75	1.55	0.88
207/094	Hampton	North	40.48%	17.00	2.29	1.00	1.47	2.67	1.81
207/094	Hampton	South	37.21%	32.00	2.25	1.41	1.75	1.45	0.83
207/094	Hampton	North	39.58%	19.00	2.16	1.05	1.46	2.40	1.64
090/127	Marlborough	North	-	0.00	0.00	0.00	0.00	15.00	15.00
090/127	Marlborough	North	-	0.00	0.00	0.00	0.00	15.00	15.00
090/127	Marlborough	North	-	0.00	0.00	0.00	0.00	15.00	15.00
095/162	Tamworth	North	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	South	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	North	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	South	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	North	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	South	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	North	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	South	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	North	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	South	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	North	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	South	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	North	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	South	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	North	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	South	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	North	50.00%	5.00	1.80	1.00	1.33	2.00	1.50
095/162	Tamworth	South	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	North	50.00%	4.00	1.00	1.00	1.00	2.40	2.40
095/162	Tamworth	South	-	0.00	0.00	0.00	0.00	12.00	12.00
095/162	Tamworth	North	50.00%	4.00	1.00	1.00	1.00	2.40	2.40
095/162	Tamworth	South	-	0.00	0.00	0.00	0.00	12.00	12.00
111/072	Westmoreland	West	-	0.00	0.00	0.00	0.00	15.00	15.00
111/072	Westmoreland	East	-	0.00	0.00	0.00	0.00	18.00	18.00
111/072	Westmoreland	West	-	0.00	0.00	0.00	0.00	15.00	15.00
111/072	Westmoreland	East	-	0.00	0.00	0.00	0.00	18.00	18.00
107/130	Alstead	North	33%	8.00	1.38	1.00	1.14	1.33	1.17
107/130	Alstead	South	32%	6.00	1.83	1.33	1.55	2.14	1.38
082/103	Sandown	East	23%	3.00	1.67	1.00	1.24	3.75	3.01
082/103	Sandown	West	67%	4.00	1.50	1.25	1.36	3.60	2.64
117/120	Epsom	West	70%	16.00	1.31	1.00	1.12	1.41	1.26
117/120	Epsom	East	67%	8.00	1.13	1.00	1.05	3.00	2.85
105/129	Goshen	East	43%	6.00	1.00	1.00	1.00	2.57	2.57
105/129	Goshen	West	71%	10.00	1.10	1.00	1.04	1.91	1.83
143/087	Swanzey	East	100%	1.00	2.00	1.00	1.41	7.50	5.30
143/087	Swanzey	West	50%	1.00	1.00	1.00	1.00	9.00	9.00

			0<=x<0.2				0.2<=x<0.4			
Bridge	**Town**	**Side**	**# of Cracks**	**Average Length**	**Average Intensity**	**Average Severity**	**# of Cracks**	**Average Length**	**Average Intensity**	**Average Severity**
070/032	Pittsburg	South	7.00	2.57	2.14	2.34	10.00	2.80	2.00	2.33
070/032	Pittsburg	North	9.00	2.22	1.56	1.85	11.00	2.27	1.45	1.78
194/097	Berlin	South	2.00	1.00	1.00	1.00	0.00	-	-	-
194/097	Berlin	North	2.00	1.00	1.00	1.00	2.00	1.00	1.00	1.00
087/096	Jefferson (Israel River)	East	16.00	2.00	1.38	1.62	19.00	2.00	1.26	1.56
087/096	Jefferson (Israel River)	West	17.00	1.53	1.00	1.21	17.00	1.53	1.06	1.25
089/090	Jefferson (Cherry Mill)	North	0.00	-	-	-	0.00	-	-	-
089/090	Jefferson (Cherry Mill)	South	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
178/141	Canaan	East	6.00	1.00	1.00	1.00	3.00	1.33	1.33	1.33
178/141	Canaan	West	6.00	1.17	1.33	1.21	7.00	1.14	1.29	1.20
080/148	Albany	South	8.00	1.88	1.13	1.42	7.00	2.14	1.43	1.68
080/148	Albany	North	10.00	1.90	1.60	1.69	14.00	1.29	1.21	1.21
230/057	Wakefield	West	8.00	1.25	1.00	1.09	8.00	1.00	1.13	1.05
230/057	Wakefield	East	8.00	1.75	1.13	1.33	7.00	1.43	1.14	1.27
160/111	Epsom	West	0.00	-	-	-	0.00	-	-	-
160/111	Epsom	East	0.00	-	-	-	0.00	-	-	-
130/100	Chichester	East	1.00	1.00	1.00	1.00	2.00	1.00	1.00	1.00
052/140	Bow	North	5.00	1.00	1.00	1.00	6.00	1.00	1.17	1.07
052/140	Bow	South	3.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
080/120	Chesterfield	West	1.00	1.00	1.00	1.00	2.00	1.00	1.00	1.00
080/120	Chesterfield	East	5.00	1.00	1.20	1.08	5.00	1.00	1.00	1.00
045/131	New Boston	North	4.00	1.00	1.00	1.00	2.00	1.00	1.00	1.00
045/131	New Boston	South	0.00	-	-	-	0.00	-	-	-
174/146	Alexandria	North	0.00	-	-	-	0.00	-	-	-
174/146	Alexandria	North	0.00	-	-	-	1.00	1.00	1.00	1.00
174/146	Alexandria	South	0.00	-	-	-	0.00	-	-	-
174/146	Alexandria	North	0.00	-	-	-	2.00	1.00	1.00	1.00
174/146	Alexandria	South	0.00	-	-	-	0.00	-	-	-
174/146	Alexandria	North	0.00	-	-	-	3.00	1.00	1.00	1.00
174/146	Alexandria	South	0.00	-	-	-	0.00	-	-	-
174/146	Alexandria	North	2.00	1.00	1.00	1.00	4.00	1.25	1.00	1.10
174/146	Alexandria	South	0.00	-	-	-	0.00	-	-	-
174/146	Alexandria	North	1.00	1.00	1.00	1.00	3.00	1.33	1.00	1.14
174/146	Alexandria	South	0.00	-	-	-	0.00	-	-	-
140/069	Grantham	North	0.00	-	-	-	0.00	-	-	-
140/069	Grantham	North	0.00	-	-	-	0.00	-	-	-
140/069	Grantham	North	0.00	-	-	-	0.00	-	-	-
140/069	Grantham	North	0.00	-	-	-	0.00	-	-	-
140/069	Grantham	North	0.00	-	-	-	0.00	-	-	-
140/069	Grantham	North	0.00	-	-	-	0.00	-	-	-
140/069	Grantham	North	0.00	-	-	-	0.00	-	-	-
140/069	Grantham	South	0.00	-	-	-	0.00	-	-	-
140/069	Grantham	North	0.00	-	-	-	0.00	-	-	-
140/069	Grantham	South	0.00	-	-	-	0.00	-	-	-
140/069	Grantham	North	0.00	-	-	-	0.00	-	-	-
140/069	Grantham	South	0.00	-	-	-	0.00	-	-	-
140/069	Grantham	North	0.00	-	-	-	0.00	-	-	-
140/069	Grantham	South	0.00	-	-	-	0.00	-	-	-

			0<=x<0.2				0.2<=x<0.4			
Bridge	Town	Side	# of Cracks	Average Length	Average Intensity	Average Severity	# of Cracks	Average Length	Average Intensity	Average Severity
207/094	Hampton-Ignore Index Values	South	10.00	1.00	1.00	1.00	11.00	1.00	1.00	1.00
207/094	Hampton-Ignore Index Values	North	3.00	1.00	1.00	1.00	2.00	1.00	1.00	1.00
207/094	Hampton-Ignore Index Values	South	10.00	1.00	1.00	1.00	12.00	1.00	1.00	1.00
207/094	Hampton-Ignore Index Values	North	4.00	1.00	1.00	1.00	5.00	1.00	1.00	1.00
207/094	Hampton-Ignore Index Values	South	15.00	1.00	1.00	1.00	17.00	1.00	1.00	1.00
207/094	Hampton-Ignore Index Values	North	6.00	1.00	1.00	1.00	6.00	1.00	1.00	1.00
207/094	Hampton	South	15.00	2.33	1.33	1.73	17.00	2.41	1.29	1.73
207/094	Hampton	North	9.00	2.33	1.00	1.49	7.00	2.71	1.00	1.63
207/094	Hampton	South	15.00	2.47	1.47	1.87	17.00	2.41	1.35	1.77
207/094	Hampton	North	9.00	2.33	1.00	1.49	7.00	2.71	1.00	1.63
207/094	Hampton	South	16.00	2.38	1.50	1.86	17.00	2.47	1.41	1.84
207/094	Hampton	North	9.00	2.33	1.00	1.49	10.00	2.20	1.10	1.51
090/127	Marlborough	North	0.00	-	-	-	0.00	-	-	-
090/127	Marlborough	North	0.00	-	-	-	0.00	-	-	-
090/127	Marlborough	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	1.00	1.00	1.00	1.00
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	1.00	1.00	1.00	1.00
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
111/072	Westmoreland	West	0.00	-	-	-	0.00	-	-	-
111/072	Westmoreland	East	0.00	-	-	-	0.00	-	-	-
111/072	Westmoreland	West	0.00	-	-	-	0.00	-	-	-
111/072	Westmoreland	East	0.00	-	-	-	0.00	-	-	-
107/130	Alstead	North	5.00	2.00	1.00	1.38	5.00	1.00	1.00	1.00
107/130	Alstead	South	6.00	1.33	1.17	1.24	4.00	2.00	1.00	1.37
082/103	Sandown	East	1.00	1.00	1.00	1.00	4.00	1.50	1.00	1.18
082/103	Sandown	West	2.00	1.00	1.00	1.00	2.00	1.00	1.00	1.00
117/120	Epsom	West	6.00	1.17	1.00	1.07	6.00	1.33	1.00	1.14
117/120	Epsom	East	5.00	1.00	1.00	1.00	2.00	1.00	1.00	1.00
105/129	Goshen	East	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
105/129	Goshen	West	1.00	1.00	1.00	1.00	2.00	1.50	1.00	1.21
143/087	Swanzey	East	0.00	-	-	-	0.00	-	-	-
143/087	Swanzey	West	0.00	-	-	-	1.00	1.00	1.00	1.00

			0.4<=x<0.6				0.6<=x<0.8			
Bridge	Town	Side	# of Cracks	Average Length	Average Intensity	Average Severity	# of Cracks	Average Length	Average Intensity	Average Severity
207/094	Hampton-Ignore Index Values	South	11.00	1.00	1.00	1.00	10.00	1.00	1.00	1.00
207/094	Hampton-Ignore Index Values	North	4.00	1.00	1.00	1.00	2.00	1.00	1.00	1.00
207/094	Hampton-Ignore Index Values	South	11.00	1.00	1.00	1.00	13.00	1.00	1.00	1.00
207/094	Hampton-Ignore Index Values	North	8.00	1.00	1.00	1.00	3.00	1.00	1.00	1.00
207/094	Hampton-Ignore Index Values	South	15.00	1.00	1.00	1.00	17.00	1.00	1.00	1.00
207/094	Hampton-Ignore Index Values	North	8.00	1.00	1.00	1.00	5.00	1.00	1.00	1.00
207/094	Hampton	South	15.00	2.47	1.33	1.78	18.00	2.44	1.17	1.65
207/094	Hampton	North	11.00	2.64	1.00	1.60	5.00	3.00	1.00	1.73
207/094	Hampton	South	16.00	2.38	1.50	1.86	19.00	2.32	1.21	1.64
207/094	Hampton	North	12.00	2.50	1.00	1.55	9.00	2.11	1.00	1.41
207/094	Hampton	South	17.00	2.35	1.47	1.84	20.00	2.25	1.30	1.67
207/094	Hampton	North	14.00	2.29	1.00	1.47	9.00	2.11	1.00	1.41
090/127	Marlborough	North	0.00	-	-	-	0.00	-	-	-
090/127	Marlborough	North	0.00	-	-	-	0.00	-	-	-
090/127	Marlborough	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	2.00	1.00	1.00	1.00	3.00	1.33	1.00	1.14
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	2.00	1.00	1.00	1.00	3.00	1.00	1.00	1.00
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
095/162	Tamworth	North	2.00	1.00	1.00	1.00	3.00	1.00	1.00	1.00
095/162	Tamworth	South	0.00	-	-	-	0.00	-	-	-
111/072	Westmoreland	West	0.00	-	-	-	0.00	-	-	-
111/072	Westmoreland	East	0.00	-	-	-	0.00	-	-	-
111/072	Westmoreland	West	0.00	-	-	-	0.00	-	-	-
111/072	Westmoreland	East	0.00	-	-	-	0.00	-	-	-
107/130	Alstead	North	6	1.33	1.00	1.12	7.00	2.14	1.00	1.42
107/130	Alstead	South	2	2.50	1.50	1.93	6.00	1.33	1.00	1.12
082/103	Sandown	East	3	1.00	1.00	1.00	4.00	2.25	1.50	1.80
082/103	Sandown	West	1	3.00	2.00	2.45	0.00	-	-	-
117/120	Epsom	West	4	1.75	1.00	1.29	4.00	1.25	1.00	1.10
117/120	Epsom	East	1	1.00	1.00	1.00	2.00	1.50	1.00	1.21
105/129	Goshen	East	2	1.00	1.00	1.00	5.00	1.00	1.00	1.00
105/129	Goshen	West	1	1.00	1.00	1.00	5.00	1.00	1.00	1.00
143/087	Swanzey	East	1	2.00	1.00	1.41	0.00	-	-	-
143/087	Swanzey	West	1	1.00	1.00	1.00	0.00	-	-	-

			0.8<=x<=1				
Bridge	**Town**	**Side**	**# of Cracks**	**Average Length**	**Average Intensity**	**Average Severity**	**X-Day Wet Cure**
070/032	Pittsburg	South	6.00	1.67	1.33	1.48	-
070/032	Pittsburg	North	9.00	1.44	1.11	1.24	-
194/097	Berlin	South	0.00	-	-	-	-
194/097	Berlin	North	2.00	1.00	1.00	1.00	-
087/096	Jefferson (Israel River)	East	13.00	1.38	1.08	1.20	-
087/096	Jefferson (Israel River)	West	10.00	1.20	1.00	1.07	-
089/090	Jefferson (Cherry Mill)	North	4.00	1.00	1.00	1.00	-
089/090	Jefferson (Cherry Mill)	South	2.00	1.00	1.00	1.00	-
178/141	Canaan	East	5.00	1.60	1.20	1.37	-
178/141	Canaan	West	3.00	1.00	1.00	1.00	-
080/148	Albany	South	2.00	3.00	1.00	1.73	-
080/148	Albany	North	10.00	1.00	1.00	1.00	-
230/057	Wakefield	West	4.00	1.00	1.00	1.00	-
230/057	Wakefield	East	2.00	1.00	1.00	1.00	-
160/111	Epsom	West	0.00	-	-	-	-
160/111	Epsom	East	1.00	1.00	2.00	1.41	-
130/100	Chichester	East	0.00	0.00	0.00	0.00	-
052/140	Bow	North	3.00	1.00	1.00	1.00	-
052/140	Bow	South	0.00	-	-	-	-
080/120	Chesterfield	West	1.00	1.00	1.00	1.00	-
080/120	Chesterfield	East	3.00	1.00	1.00	1.00	-
045/131	New Boston	North	1.00	1.00	1.00	1.00	-
045/131	New Boston	South	0.00	-	-	-	-
174/146	Alexandria	North	0.00	-	-	-	7
174/146	Alexandria	North	1.00	3.00	3.00	3.00	7
174/146	Alexandria	South	0.00	-	-	-	14
174/146	Alexandria	North	1.00	3.00	3.00	3.00	7
174/146	Alexandria	South	0.00	-	-	-	14
174/146	Alexandria	North	2.00	2.50	2.00	2.21	7
174/146	Alexandria	South	0.00	-	-	-	14
174/146	Alexandria	North	2.00	3.00	2.00	2.37	7
174/146	Alexandria	South	0.00	-	-	-	14
174/146	Alexandria	North	2.00	3.00	2.00	2.37	7
174/146	Alexandria	South	1.00	1.00	1.00	1.00	14
140/069	Grantham	North	0.00	-	-	-	7
140/069	Grantham	North	0.00	-	-	-	7
140/069	Grantham	North	0.00	-	-	-	7
140/069	Grantham	North	0.00	-	-	-	7
140/069	Grantham	North	0.00	-	-	-	7
140/069	Grantham	North	0.00	-	-	-	7
140/069	Grantham	North	0.00	-	-	-	7
140/069	Grantham	South	0.00	-	-	-	14
140/069	Grantham	North	0.00	-	-	-	7
140/069	Grantham	South	0.00	-	-	-	14
140/069	Grantham	North	0.00	-	-	-	7
140/069	Grantham	South	0.00	-	-	-	14
140/069	Grantham	North	0.00	-	-	-	7
140/069	Grantham	South	0.00	-	-	-	14

			0.8<=x<=1				
Bridge	Town	Side	# of Cracks	Average Length	Average Intensity	Average Severity	X-Day Wet Cure
207/094	Hampton-Ignore Index Values	South	5.00	1.00	1.00	1.00	7
207/094	Hampton-Ignore Index Values	North	1.00	1.00	1.00	1.00	7
207/094	Hampton-Ignore Index Values	South	9.00	1.00	1.00	1.00	7
207/094	Hampton-Ignore Index Values	North	2.00	1.00	1.00	1.00	7
207/094	Hampton-Ignore Index Values	South	10.00	1.00	1.00	1.00	7
207/094	Hampton-Ignore Index Values	North	2.00	1.00	1.00	1.00	7
207/094	Hampton	South	13.00	1.92	1.08	1.40	7
207/094	Hampton	North	5.00	2.60	1.00	1.59	7
207/094	Hampton	South	13.00	1.92	1.15	1.46	7
207/094	Hampton	North	5.00	2.60	1.00	1.59	7
207/094	Hampton	South	16.00	1.88	1.13	1.42	7
207/094	Hampton	North	6.00	2.33	1.00	1.49	7
090/127	Marlborough	North	0.00	-	-	-	-
090/127	Marlborough	North	0.00	-	-	-	-
090/127	Marlborough	North	0.00	-	-	-	-
095/162	Tamworth	North	0.00	-	-	-	7
095/162	Tamworth	South	0.00	-	-	-	7
095/162	Tamworth	North	0.00	-	-	-	7
095/162	Tamworth	South	0.00	-	-	-	7
095/162	Tamworth	North	0.00	-	-	-	7
095/162	Tamworth	South	0.00	-	-	-	7
095/162	Tamworth	North	0.00	-	-	-	7
095/162	Tamworth	South	0.00	-	-	-	7
095/162	Tamworth	North	0.00	-	-	-	7
095/162	Tamworth	South	0.00	-	-	-	7
095/162	Tamworth	North	0.00	-	-	-	7
095/162	Tamworth	South	0.00	-	-	-	7
095/162	Tamworth	North	0.00	-	-	-	7
095/162	Tamworth	South	0.00	-	-	-	7
095/162	Tamworth	North	0.00	-	-	-	7
095/162	Tamworth	South	0.00	-	-	-	7
095/162	Tamworth	North	3.00	2.00	1.00	1.41	7
095/162	Tamworth	South	0.00	-	-	-	7
095/162	Tamworth	North	2.00	1.00	1.00	1.00	7
095/162	Tamworth	South	0.00	-	-	-	7
095/162	Tamworth	North	2.00	1.00	1.00	1.00	7
095/162	Tamworth	South	0.00	-	-	-	7
111/072	Westmoreland	West	0.00	-	-	-	5
111/072	Westmoreland	East	0.00	-	-	-	5
111/072	Westmoreland	West	0.00	-	-	-	-
111/072	Westmoreland	East	0.00	-	-	-	-
107/130	Alstead	North	1.00	1.00	1.00	1.00	-
107/130	Alstead	South	1.00	1.00	1.00	1.00	-
082/103	Sandown	East	1.00	2.00	1.00	1.41	-
082/103	Sandown	West	1.00	1.00	1.00	1.00	-
117/120	Epsom	West	3.00	1.00	1.00	1.00	-
117/120	Epsom	East	2.00	1.00	1.00	1.00	-
105/129	Goshen	East	5.00	1.00	1.00	1.00	-
105/129	Goshen	West	5.00	1.00	1.00	1.00	-
143/087	Swanzey	East	0.00	-	-	-	-
143/087	Swanzey	West	0.00	-	-	-	-

Bridge	Town	Side	NHDOT Mix	w/cm	28-day fc (psi)	% Air	Cement Content (lbs/yd)	SCM Content (lbs/yd)
070/032	Pittsburg	South	-	-	-	-	-	-
070/032	Pittsburg	North	-	-	-	-	-	-
194/097	Berlin	South	-	-	-	-	-	-
194/097	Berlin	North	-	-	-	-	-	-
087/096	Jefferson (Israel River)	East	-	-	-	-	-	-
087/096	Jefferson (Israel River)	West	-	-	-	-	-	-
089/090	Jefferson (Cherry Mill)	North	-	-	-	-	-	-
089/090	Jefferson (Cherry Mill)	South	-	-	-	-	-	-
178/141	Canaan	East	-	-	-	-	-	-
178/141	Canaan	West	-	-	-	-	-	-
080/148	Albany	South	-	-	-	-	-	-
080/148	Albany	North	-	-	-	-	-	-
230/057	Wakefield	West	-	-	-	-	-	-
230/057	Wakefield	East	-	-	-	-	-	-
160/111	Epsom	West	-	-	-	-	-	-
160/111	Epsom	East	-	-	-	-	-	-
130/100	Chichester	East	-	-	-	-	-	-
052/140	Bow	North	-	-	-	-	-	-
052/140	Bow	South	-	-	-	-	-	-
080/120	Chesterfield	West	-	-	-	-	-	-
080/120	Chesterfield	East	-	-	-	-	-	-
045/131	New Boston	North	-	-	-	-	-	-
045/131	New Boston	South	-	-	-	-	-	-
174/146	Alexandria	North	AA	-	4013	-	-	-
174/146	Alexandria	North	AA	-	4013	-	-	-
174/146	Alexandria	South	AA	0.45	-	-	320	320
174/146	Alexandria	North	AA	-	4013	-	-	-
174/146	Alexandria	South	AA	0.45	-	-	320	320
174/146	Alexandria	North	AA	-	4013	-	-	-
174/146	Alexandria	South	AA	0.45	-	-	320	320
174/146	Alexandria	North	AA	-	4013	-	-	-
174/146	Alexandria	South	AA	0.445	-	-	320	320
174/146	Alexandria	North	AA	-	4013	-	-	-
174/146	Alexandria	South	AA	0.445	-	-	320	320
140/069	Grantham	North	AA	0.36	5194	-	329	329
140/069	Grantham	North	AA	0.36	5194	-	329	329
140/069	Grantham	North	AA	0.36	5194	-	329	329
140/069	Grantham	North	AA	0.36	5194	-	329	329
140/069	Grantham	North	AA	0.36	5194	-	329	329
140/069	Grantham	North	AA	0.36	5194	-	329	329
140/069	Grantham	North	AA	0.36	5194	-	329	329
140/069	Grantham	South	AA		5094	-	-	-
140/069	Grantham	North	AA	0.36	5194	-	329	329
140/069	Grantham	South	AA		5094	-	-	-
140/069	Grantham	North	AA	0.36	5194	-	329	329
140/069	Grantham	South	AA		5094	-	-	-
140/069	Grantham	North	AA	0.36	-	-	329	329
140/069	Grantham	South	AA	-	-	-	-	-

Bridge	Town	Side	NHDOT Mix	w/cm	28-day fc (psi)	% Air	Cement Content (lbs/yd)	SCM Content (lbs/yd)
207/094	Hampton-Ignore Index Values	South	AA	0.45	5919	-	416	224
207/094	Hampton-Ignore Index Values	North	AA	0.44	5772	-	403	217
207/094	Hampton-Ignore Index Values	South	AA	0.45	5919	-	416	224
207/094	Hampton-Ignore Index Values	North	AA	0.44	5772	-	403	217
207/094	Hampton-Ignore Index Values	South	AA	0.45	5919	-	416	224
207/094	Hampton-Ignore Index Values	North	AA	0.44	5772	-	403	217
207/094	Hampton	South	AA	0.45	5919	-	416	224
207/094	Hampton	North	AA	0.44	5772	-	403	217
207/094	Hampton	South	AA	0.45	5919	-	416	224
207/094	Hampton	North	AA	0.44	5772	-	403	217
207/094	Hampton	South	AA	0.45	5919	-	416	224
207/094	Hampton	North	AA	0.44	5772	-	403	217
090/127	Marlborough	North	AA	0.38	6325	-	329	329
090/127	Marlborough	North	AA	0.38	6325	-	329	329
090/127	Marlborough	North	AA	0.38	6325	-	329	329
095/162	Tamworth	North	AA	0.34	6032	7.2	455	198
095/162	Tamworth	South	A	0.36	4596	5.8	400	172
095/162	Tamworth	North	AA	0.34	6032	7.2	455	198
095/162	Tamworth	South	A	0.36	4596	5.8	400	172
095/162	Tamworth	North	AA	0.34	6032	7.2	455	198
095/162	Tamworth	South	A	0.36	4596	5.8	400	172
095/162	Tamworth	North	AA	0.34	6032	7.2	455	198
095/162	Tamworth	South	A	0.36	4596	5.8	400	172
095/162	Tamworth	North	AA	0.34	6032	7.2	455	198
095/162	Tamworth	South	A	0.36	4596	5.8	400	172
095/162	Tamworth	North	AA	0.34	6032	7.2	455	198
095/162	Tamworth	South	A	0.36	4596	5.8	400	172
095/162	Tamworth	North	AA	0.34	6032	7.2	455	198
095/162	Tamworth	South	A	0.36	4596	5.8	400	172
095/162	Tamworth	North	AA	0.34	6032	7.2	455	198
095/162	Tamworth	South	A	0.36	4596	5.8	400	172
095/162	Tamworth	North	AA	0.34	6032	7.2	455	198
095/162	Tamworth	South	A	0.36	4596	5.8	400	172
095/162	Tamworth	North	AA	0.34	6032	7.2	455	198
095/162	Tamworth	South	A	0.36	4596	5.8	400	172
095/162	Tamworth	North	AA	0.34	6032	7.2	455	198
095/162	Tamworth	South	A	0.36	4596	5.8	400	172
111/072	Westmoreland	West	AA	-	-	-	-	-
111/072	Westmoreland	East	A	-	4460	-	-	-
111/072	Westmoreland	West	AA	0.38	-	-	329	329.00
111/072	Westmoreland	East	A	0.407	4460	-	306	305.00
107/130	Alstead	North	-	-	-	-	-	-
107/130	Alstead	South	-	-	-	-	-	-
082/103	Sandown	East	-	-	-	-	-	-
082/103	Sandown	West	-	-	-	-	-	-
117/120	Epsom	West	-	-	-	-	-	-
117/120	Epsom	East	-	-	-	-	-	-
105/129	Goshen	East	-	-	-	-	-	-
105/129	Goshen	West	-	-	-	-	-	-
143/087	Swanzey	East	-	-	-	-	-	-
143/087	Swanzey	West	-	-	-	-	-	-

Bridge	Town	Side	Placement Day Low	Placement Day High	Placement Week Low	Placement Week High	Week Avg. High	Week Avg. Low
070/032	Pittsburg	South	-	-	-	-	-	-
070/032	Pittsburg	North	-	-	-	-	-	-
194/097	Berlin	South	-	-	-	-	-	-
194/097	Berlin	North	-	-	-	-	-	-
087/096	Jefferson (Israel River)	East	-	-	-	-	-	-
087/096	Jefferson (Israel River)	West	-	-	-	-	-	-
089/090	Jefferson (Cherry Mill)	North	-	-	-	-	-	-
089/090	Jefferson (Cherry Mill)	South	-	-	-	-	-	-
178/141	Canaan	East	-	-	-	-	-	-
178/141	Canaan	West	-	-	-	-	-	-
080/148	Albany	South	-	-	-	-	-	-
080/148	Albany	North	-	-	-	-	-	-
230/057	Wakefield	West	-	-	-	-	-	-
230/057	Wakefield	East	-	-	-	-	-	-
160/111	Epsom	West	-	-	-	-	-	-
160/111	Epsom	East	-	-	-	-	-	-
130/100	Chichester	East	-	-	-	-	-	-
052/140	Bow	North	-	-	-	-	-	-
052/140	Bow	South	-	-	-	-	-	-
080/120	Chesterfield	West	-	-	-	-	-	-
080/120	Chesterfield	East	-	-	-	-	-	-
045/131	New Boston	North	-	-	-	-	-	-
045/131	New Boston	South	-	-	-	-	-	-
174/146	Alexandria	North	52	69	41	75	54	31
174/146	Alexandria	North	52	69	41	75	54	31
174/146	Alexandria	South	55	86	44	86	78	59
174/146	Alexandria	North	52	69	41	75	54	31
174/146	Alexandria	South	55	86	44	86	78	59
174/146	Alexandria	North	52	69	41	75	54	31
174/146	Alexandria	South	55	86	44	86	78	59
174/146	Alexandria	North	52	69	41	75	54	31
174/146	Alexandria	South	55	86	44	86	78	59
174/146	Alexandria	North	52	69	41	75	54	31
174/146	Alexandria	South	55	86	44	86	78	59
140/069	Grantham	North	28	73	28	73	59	41
140/069	Grantham	North	28	73	28	73	59	41
140/069	Grantham	North	28	73	28	73	59	41
140/069	Grantham	North	28	73	28	73	59	41
140/069	Grantham	North	28	73	28	73	59	41
140/069	Grantham	North	28	73	28	73	59	41
140/069	Grantham	North	28	73	28	73	59	41
140/069	Grantham	South	41	80	41	98	85	58
140/069	Grantham	North	28	73	28	73	59	41
140/069	Grantham	South	41	80	41	98	85	58
140/069	Grantham	North	28	73	28	73	59	41
140/069	Grantham	South	41	80	41	98	85	58
140/069	Grantham	North	28	73	28	73	59	41
140/069	Grantham	South	41	80	41	98	85	58

Bridge	Town	Side	Placement Day Low	Placement Day High	Placement Week Low	Placement Week High	Week Avg. High	Week Avg. Low
207/094	Hampton-Ignore Index Values	South	25	33	25	46	31	17
207/094	Hampton-Ignore Index Values	North	14	36	50	14	38	26
207/094	Hampton-Ignore Index Values	South	25	33	25	46	31	17
207/094	Hampton-Ignore Index Values	North	14	36	50	14	38	26
207/094	Hampton-Ignore Index Values	South	25	33	25	46	31	17
207/094	Hampton-Ignore Index Values	North	14	36	50	14	38	26
207/094	Hampton	South	25	33	25	46	31	17
207/094	Hampton	North	14	36	50	14	38	26
207/094	Hampton	South	25	33	25	46	31	17
207/094	Hampton	North	14	36	50	14	38	26
207/094	Hampton	South	25	33	25	46	31	17
207/094	Hampton	North	14	36	50	14	38	26
090/127	Marlborough	North	-	-	-	-	-	-
090/127	Marlborough	North	-	-	-	-	-	-
090/127	Marlborough	North	-	-	-	-	-	-
095/162	Tamworth	North	15	34	9	68	45	22
095/162	Tamworth	South	15	34	9	68	45	22
095/162	Tamworth	North	15	34	9	68	45	22
095/162	Tamworth	South	15	34	9	68	45	22
095/162	Tamworth	North	15	34	9	68	45	22
095/162	Tamworth	South	15	34	9	68	45	22
095/162	Tamworth	North	15	34	9	68	45	22
095/162	Tamworth	South	15	34	9	68	45	22
095/162	Tamworth	North	15	34	9	68	45	22
095/162	Tamworth	South	15	34	9	68	45	22
095/162	Tamworth	North	15	34	9	68	45	22
095/162	Tamworth	South	15	34	9	68	45	22
095/162	Tamworth	North	15	34	9	68	45	22
095/162	Tamworth	South	15	34	9	68	45	22
095/162	Tamworth	North	15	34	9	68	45	22
095/162	Tamworth	South	15	34	9	68	45	22
095/162	Tamworth	North	15	34	9	68	45	22
095/162	Tamworth	South	15	34	9	68	45	22
095/162	Tamworth	North	15	34	9	68	45	22
095/162	Tamworth	South	15	34	9	68	45	22
095/162	Tamworth	North	15	34	9	68	45	22
095/162	Tamworth	South	15	34	9	68	45	22
111/072	Westmoreland	West	20	31	13	41	35	21
111/072	Westmoreland	East	23	34	-10	59	32	7
111/072	Westmoreland	West	20	31	13	41	35	21
111/072	Westmoreland	East	23	34	-10	59	32	7
107/130	Alstead	North	-	-	-	-	-	-
107/130	Alstead	South	-	-	-	-	-	-
082/103	Sandown	East	-	-	-	-	-	-
082/103	Sandown	West	-	-	-	-	-	-
117/120	Epsom	West	-	-	-	-	-	-
117/120	Epsom	East	-	-	-	-	-	-
105/129	Goshen	East	-	-	-	-	-	-
105/129	Goshen	West	-	-	-	-	-	-
143/087	Swanzey	East	-	-	-	-	-	-
143/087	Swanzey	West	-	-	-	-	-	-

Appendix C: Curb Survey Dates

The following tables list the bridge sites surveyed during the study along with the dates of the survey. For curbs placed during the study the date of curb placement for each curb is given in addition to the dates of each survey.

Table 19: List of survey dates for curbs that were placed before the beginning of the study.

Constructed Before Study		
Town	**Bridge ID**	**Date Surveyed**
Albany	080/148	6/17/2017
Alstead	107/130	2/13/2019
Berlin	194/097	7/9/2017
Bow	052/140	6/9/2017
Canaan	178/141	6/30/2017
Chesterfield	080/120	6/9/2017
Chichester	130/100	6/9/2017
Epsom	160/111	6/11/2017
Jefferson	089/090	7/7/2017
Jefferson	087/096	7/7/2017
New Boston	045/131	6/9/2017
Pittsburg	070/032	7/7/2017
Wakefield	245/066	6/17/2017
Sandown	082/103	3/14/2019
Swanzey	143/087	3/14/2019
Epsom	117/120	3/15/2019
Goshen	105/129	3/15/2019

Table 20: List of survey dates for curbs that were placed during the study. Alphabetical A-G.

Constructed During Study			
Town	**Bridge ID**	**Date of Curb Placement**	**Dates Surveyed**
Alexandria	174/146	5/31/2017 8/30/2017	
			6/30/2017
			8/19/2017
			9/16/2017
			11/22/2017
			4/29/2018
			7/30/2018
Grantham	140/069	4/24/2018 6/26/2018	
			4/26/2018
			4/29/2018
			5/3/2018
			5/6/2018
			5/25/2018
			6/18/2018
			6/29/2018
			7/20/2018
			10/25/2018
			3/15/2019

Table 21: List of survey dates for curbs that were placed during the study. Alphabetical H-Z.

Town	Bridge ID	Date of Curb Placement	Dates Surveyed
Hampton	207/094	1/5/2017 3/23/2017	
			4/4/2017
			4/11/2017
			5/3/2017
			9/7/2017
			1/16/2018
			3/27/2018
Marlborough	090/127	3/1/2018	
			3/6/2018
			4/3/2018
			3/14/2019
Tamworth	095/162	2/23/2018 2/23/2018	
			2/26/2018
			3/2/2018
			3/7/2018
			3/15/2018
			3/23/2018
			4/8/2018
			4/29/2018
			5/13/2018
			7/29/2018
			10/23/2018
			3/15/2019
Westmoreland	111/072	1/2/2019 1/29/2019	
			1/31/2019
			2/7/2019