EVALUATION OF SAW-CUT SEALANTS FOR THE PREVENTION OF REFLECTIVE CRACKING IN HOT MIX ASPHALT

(A CASE STUDY ON NORTH CAPITOL STREET, NW)

DRAFT FINAL REPORT

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10. Abstract Reflective cracking, a common distress that affects composite pavements is caused by cyclical movements in the underlying concrete base that is overlaid with hot-mix-asphalt in reaction to climate and traffic conditions. In an attempt to prevent or control reflective cracking, the saw and seal method, which involves making saw cuts in the overlaying asphalt across and along the direction of travel and sealing with a compressible rubberized low modulus sealant, was studied for its effectiveness in composite pavements in Washington, DC. In the 4 ½ year field study, the widths of the fifteen transverse and seven longitudinal saw-cut measurement points in the hot-mix-asphalt overlay were measured quarterly since 2006. Statistical tests of significance were conducted to determine the statistical relationship between the changes in mean daily air temperature, average daily traffic, pavement age and the variations of the saw-cut widths. The interactions of changes in mean daily air temperature and average daily traffic (ADT) had a statistically significant impact on variations in transverse and longitudinal saw-cut widths accounting for 95.7% and 91.4% of variations respectively. In addition, a visual condition comparison with the adjacent untreated pavement section showed that the saw and seal method effectively controlled reflective cracking in the composite pavement.				
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1.0 EXECUTIVE SUMMARY

Reflective cracking is cracking that occurs predominantly in composite pavements and is visible in the Hot-mix-asphalt (HMA) overlay above the locations of the underlying concrete joints and cracks as they react to temperature and traffic loading by expanding, contracting and vertically shifting. Reflective cracking is a major problem for the District Department of Transportation (DDOT) and state agencies nationwide because it leads to a decrease in the intended service lives of pavements and thus proves very costly to maintain the afflicted pavements. The saw and seal method was implemented on the southbound section of North Capitol Street at Irving Street, northwest Washington DC to evaluate its effectiveness in preventing or mitigating the effects of reflective cracking in composite pavements. The saw and seal method involves cutting uniformly spaced joints (spaces – transverse or longitudinal) at approximately half of an inch in width in the HMA overlay directly above the joints or cracks in the underlying concrete and sealing them with rubberized modified asphalt. The intended purpose of this method is to accommodate the concrete’s movement caused by its expansion and contraction in response to temperature changes. Sealing of the joints prevent the intrusion of moisture and incompressible materials, which could otherwise lead to pavement distresses such as rutting.

Field observations were conducted approximately every three months for 4 ½ years where the widths of saw-cuts were measured at fifteen transverse and seven longitudinal points. The points of measurement along the saw-cuts were spray painted during each field observation to maintain consistency in measurements. Visual assessments of the treated and untreated sections were conducted and compared per field visit. Visual assessments involved recording the physical conditions of the pavements by estimated crack counts, location and severity of cracks such as joint raveling, potholes, and “blow-ups”. Photographs of both pavement sections were taken during each field visit.

The effectiveness of the saw and seal method on North Capitol Street was determined by a two-step evaluation process consisting of data analyses in conjunction with visual assessment comparisons between treated and untreated pavement sections. The statistical analyses comprised multiple regression analyses and the use of the student's t-test to determine if there is a relationship between the changes in saw-cut widths and the combination of mean daily air temperature and average daily traffic (ADT) and to determine the strength of this relationship based on the magnitude of the proportion of variance R^2, if a relationship exists.

The results of the statistical analyses shows that there is a significant relationship (p-values less than 0.05) between changes in saw-cut widths and the combination of mean daily air temperature and ADT, which indicates that the saw-cuts are controlling reflective cracking by accommodating the transverse and longitudinal movements associated with it. The multiple regression analyses results showed that the proportions of variance (R^2) of saw-cut widths accounted for by the combination of mean daily air temperature and ADT were 95.7% and 91.4% for transverse and longitudinal saw-cut widths respectively. In addition, the sawed and sealed pavement section vastly outperformed the untreated pavement section in physical condition throughout the experiment. The untreated section underwent severe transverse and longitudinal cracking throughout the section studied, which led to the development potholes. Comparison, the sawed and sealed section developed only two low severity cracks.

Based on the results of the experiment, the saw and seal method effectively controlled reflective cracking and therefore presents a feasible method for further use at segments in the District of Columbia where reflective cracking is dominant.

2.0 BACKGROUND ON REFLECTIVE CRACKING

Reflective cracking is a type of pavement distress that is prevalent in pavements consisting of an underlying concrete base overlaid with hot-mix-asphalt (HMA). In reaction to thermal and traffic loading, concrete - the pavement's base - inherently expands, contracts, and vertically shifts, resulting in lateral and vertical movements, which consequently ruptures the bonded overlaying HMA at pavement joints. Reflection cracking normally starts at the interface and spreads to the surface, causing early pavement deterioration and failure. The combination of traffic loading and freeze-thaw cycles accelerate the deterioration of the pavement surface condition after the reflective cracks penetrate the asphalt layer. The deteriorated pavement condition affects the durability of the pavement itself as well as the ride quality and safety. The District Department of Transportation (DDOT) of the Government of the District of Columbia is looking into the feasibility of innovative strategies for obtaining longer lasting pavements by either reducing or preventing reflective cracking.

A variety of procedures, methods, and materials have been developed to prevent or minimize reflective cracking, with varying results. Some of these commonly used mitigation techniques to prevent reflective cracking include the reinforcement of the HMA overlay with geosynthetic material, placing new asphalt directly on the distressed pavement, resurfacing with increased the asphalt thickness, varying the viscosity of the asphalt, installing interlayer stress-absorbing composite (ISAC) materials between overlay and concrete, milling and overlaying the asphalt surface, and full-depth reclamation. The recurring themes of the experiences in using these methods is that success in reflective crack mitigation varies by location and no method exists that is effective under all conditions. One potential solution to overcome the problem of reflection cracking is by the use of transverse and longitudinal joints in the new hot-mix asphalt (HMA) layer. In recent years, some state Departments of Transportation (e.g., New York and New Jersey) have experimented with the sawing and sealing of the HMA overlay directly above the underlying concrete joints in an attempt to extend the service life of the pavement. The aim of this method is for the HMA overlay to accommodate the movements of the underlying concrete base by moving along with it instead of cracking at these joint locations. Despite the difficulty in accurately implementing sawed and sealed HMA joints, the results of the experiments conducted indicate remarkable success in significantly reducing reflective cracking in new composite pavements [4]. The saw and seal method has been explored as early as the 1960s and despite reasonable success in Minnesota, New York, Louisiana, and North Dakota, it has not achieved widespread implementation or evaluation. New York, which has been identified as the pioneer of the saw and seal method, has used it as their predominantly chosen method for crack prevention [1]. Minnesota, Louisiana, and North Dakota have also found it to be very effective in minimizing the effects of reflective cracking. However, the drawbacks of applying this method is the low success on older roadways, requirement of saw-cuts in the HMA to be located exactly above the joints in the underlying concrete base, and requirement of a strong concrete foundation. The greatest disadvantage identified by state agencies is the difficulty associated with accurately locating the underlying concrete's joints. Implementation of the saw and seal method while being unsure about the joints' locations could be wasteful and costly.

With temperature, traffic volume, and pavement age recognized as the major factors that cause reflective cracking, the main objective of this study is to evaluate the saw and seal method in controlling reflective cracking by developing relationships between these factors and the changes of the saw-cut widths in the HMA overlay over a period of time.

3.0 PROBLEM STATEMENT

Typical pavement maintenance procedures such as crack routing and sealing, as well as slurry sealing have been used by the District Department of Transportation (DDOT) in attempts to extend the service life of its pavements and maintain suitable ride quality for drivers. However, similar to the experience of several states, these typical measures merely delay cracking and may not increase service life of the pavement. In an attempt to find a successful strategy to minimize or prevent reflective cracking in composite pavements, the District Department of Transportation (DDOT) implemented the saw and seal method on a section of North Capitol Street using a sealant that meets the criteria of ASTM D6690 Type 2. Due to continuous frequent maintenance that merely increases the short service lives of composite pavements in the District of Columbia, as well as the non-transferability of mitigation methods used in other regions of the country, the effectiveness of the saw and seal method in controlling reflective cracking is investigated in this research. Success of mitigation methods are not transferrable across regions due to the variations of local conditions such as soil type, climate, quality of pavement design, and construction quality that influence reflective cracking.

4.0 RESEARCH OBJECTIVES

The objectives of the research are to:

- Determine if the proposed saw cuts with the sealant in the HMA overlay will reduce or not cause the propagation of reflective cracking through the designed HMA overlay through 2011.
- Determine the impact of ADT and air temperature on the transverse and longitudinal saw cuts.

5.0 LITERATURE REVIEW

5.1 Overview

Various procedures, methods, and materials have been developed to prevent or minimize reflective cracking; however, taken altogether, these procedures have varying results. As a result, studies to develop reflective crack mitigation techniques are ongoing. Some well-documented reflective cracking mitigation techniques are:

1. Crack control via the saw and seal Method
2. Modify or strengthen existing pavement surface layer
3. Use of stress-absorbing Interlayers
4. Cushion between pavement layers
5. Reinforcement of HMA layer

The major reasons for varying success in mitigating reflective cracking across the United States are: differences in environmental conditions from one location to another, inappropriate application of mitigation strategy for existing pavement conditions, and bad construction practices [2]. However, as a result of several studies, there have been significant advances in the understanding of the phenomenon of reflective cracking. The objectives of this literature review are to synthesize the outcomes of several methods to mitigate reflective cracking, compile information on characteristics of reflective cracking, and to gain an understanding of various pavement characteristics and experience in using the saw and seal method.

5.2 Mechanisms of Reflective Cracking

Reflective cracking may occur in composite pavements as well as flexible pavements. However, reflective cracking in composite pavements is more frequent and is more widely researched and documented. While this is recognized, the mechanisms of reflective cracking described in this literature review are more applicable to composite pavements.

Reflective cracking are classified into two categories [8]:

1. Cracks caused by underlying joints in the concrete slab base
2. Cracks caused by underlying cracks either in the concrete base or old HMA overlay.

Reflective cracks occur due to a coupled effect of repetitive horizontal and vertical deflections at the underlying joints in composite (jointed) pavements or at the underlying cracks in original HMA layer that has been overlaid with additional HMA [9]. Figure 1 depicts the commonly accepted mechanisms of reflective cracking [8].

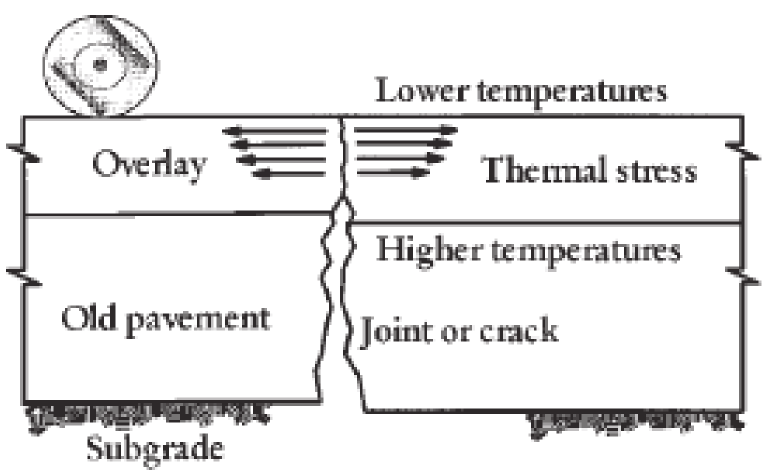


Figure 1: Tensile Stresses due to Traffic loading and Temperature Variation
Source: Owusu-Antwi, et al. [6]

5.2.1 Horizontal Displacement

Horizontal movements are caused by the expansion and contraction of the Portland Concrete Cement (PCC) slabs that are concentrated at the joints and cracks, while vertical movements occur due to traffic loading. The most documented cause or initiation of reflective cracking is horizontal movements, which results in transverse cracking. Contraction and expansion of the PCC slab, which occurs due to changes in temperature, cause the opening and closing of joints or cracks and consequently induces horizontal stresses in the HMA overlay [2]. When these horizontal stresses exceed the horizontal tensile strength of the HMA overlay a crack is formed at the interface of the PCC slab and HMA overlay [8, 10]. Continuous horizontal movements over time result in upward crack propagation that becomes visible at the driving surface as a transverse reflective crack. Reflective cracking caused by such temperature cycling is referred to as thermally-induced cracking. It must be noted that the extent of contraction and expansion of the PCC slab (the underlying concrete base) is based on its coefficient of thermal expansion (CTE). Even though horizontal movements are the most documented cause for reflective cracking, several other factors help in crack progression [2]. Slab geometry, properties of the HMA overlay, curling and warping of the slab during curing after placement, gauge length across the joint or crack are all factors to be considered in evaluating environmental effects on HMA overlays.

5.2.2 Vertical Displacement

The second major cause of reflective cracking is the vertical deflection across joints or cracks in the concrete slab or existing pavement. Reflective cracking caused by vertical deflections are due to traffic loading and are referred to as traffic-induced cracking. Vertical deflections in the pavements are caused by the shear and bending stresses that occur at the joints of adjacent PCC slabs – where one slab ends and the other begins – and at crack openings when wheel loadings occur [6]. The magnitude of vertical movements is influenced by the load transfer efficiency (LTE) at the underlying PCC joints, quality of aggregate interlock at crack openings, the magnitude of the wheel load, and the sub-grade support under the slab [2]. LTE at joints are affected by whether dowels are used and the quality of dowels used. Dowels are used in JPCP's to achieve high LTE at the joints in a PCC slab. Without dowels, poor load transfer would occur as vehicles pass over the joint locations, resulting in high differential vertical movement at each joint (Figure 2).

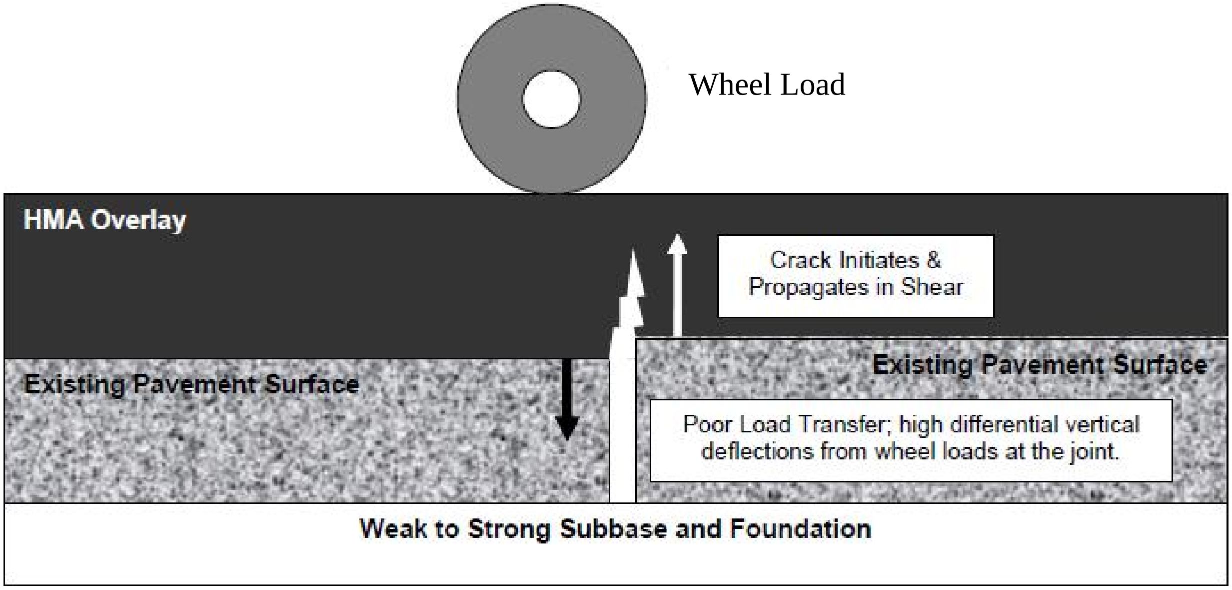


Figure 2: Vertical Deflection at a Joint without a Dowel
Source: Von Quintos, et al. (2009) [2]

In addition to dowels and aggregate interlock, which determines LTE at the joints and cracks, the presence of voids in the subgrade support under the slab (where a joint or crack is located) also influences the magnitude of shear and bending stress concentrations. Voids allow for high displacement to occur at the joints because there is less support under the slab enabling loads to depress one end of a slab relative to the other. Such vertical movement creates shear or bending stresses in the HMA overlay across the joints and ultimately causes reflective cracking to occur. Turo, et al (2009) found that vertical displacements were greater in thinner HMA overlays than in thicker ones and deflections vary along the same joint across different lanes [9]. Von Quintos, et al. (2009) found that an HMA overlay of at least four inches is required to significantly reduce the rate of crack progression in pavements that experience vertical deflections of more than 0.008 inches [2].

5.3 Saw and Seal Method

Saw and seal is a reflective crack mitigation technique that involves the incision of uniformly spaced joints (spaces – transverse or longitudinal) at approximately half of an inch in width in a bituminous overlay and sealing them with rubberized modified asphalt (Figure 3). These joints in the bituminous overlay are located directly over the joints or reflective cracks in the underlying concrete base in an attempt to accommodate the concrete's movement caused by its expansion and contraction in response to temperature changes. Sealing of the joints prevent the intrusion of moisture and incompressible materials, which could otherwise lead to pavement distresses such as rutting. The sealant's main characteristic is to be flexible in order to retain its adhesion to the walls of the joints during pavement expansion and contraction.

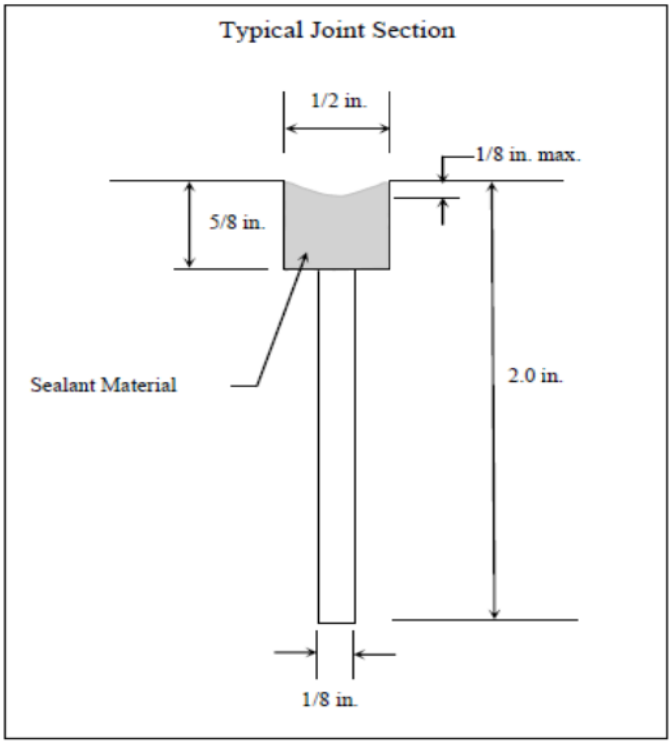


Figure 3: Detail of a Typical Saw-Cut Joint

If the underlying joint or crack movements cannot be accommodated by the overlay, the tensile stresses developed at the interface of the bituminous overlay and concrete base overcomes the tensile strength of the bituminous overlay and a crack is initiated. The frequency of these cracks throughout a concrete slab depends on the HMA overlay stiffness, traffic loading, and the friction properties at the interface between the overlay and underlying pavement layer [8]. The smaller joint spacing (slab length) suitably accommodates the stresses in the pavement and is generally more effective than longer ones. In New York, joint spacing distances as low as fifteen feet has been used with high levels of success in preventing reflective cracking and in Minnesota thirty to fifty feet is the optimal joint spacing distance for the saw and seal method to be effective [1, 8].

From the experiment conducted in Minnesota and New York, it was reported that the depth of the saw cut needs to be depth of at least 5/8th inches in order for the underlying reflective cracks to coincide with the HMA overlay joints [8].

Deep saw cuts ensure that there is a sufficiently weak plane for cracks to coincide with the joints, otherwise the cracks may not form at the HMA overlay joints. The consensus of the literature is that joint depths should be at least one-third the thickness of the HMA overlay [8]. The joint's depth is also of particular importance because it determines the joint's shape factor, which influences the sealants ability to stretch without losing its bond to the joint walls. The shape factor is the ratio of the joint width to depth and a joint's shape factor depends on the slab length. As a slab length increases so does the required shape factor. Table 1 presents the saw cut dimensions for the saw and seal method recommended by New York DOT.

Table 1: HMA Overlay Saw Cut Joint Dimensions Recommended by the New York DOT

Source: Janisch and Turgeon (1996) [8]

Slab Length (feet)	**Width** (inches)	**Depth** (inches)	**Shape Factor**
50 ft or less	1/2	5/8	0.80
51 - 62	5/8	5/8	1
63 - 75	3/4	5/8	1.2
76 - 87	7/8	3/4	1.16
87 - 100	1	7/8	1.14

Success with the saw and seal method has been experienced by the DOT's of New York, Minnesota, North Dakota, and Kansas. In a summary of the practices of how HMA's are designed and evaluated by state highway agencies (SHAs) throughout the US, it was found that only 8 of the 26 states that were involved in the survey use the saw and seal method in transverse joints, while only 3 of the 26 states used the method in longitudinal joints [21]. State agencies were mainly concerned with properly locating the underlying joints especially on second and third generation HMA overlays. However, most of the states that have used the saw and seal method found it to be successful in mitigating reflective cracking.

In a study conducted in New York only 174 of 683 saw cuts were properly aligned with the underlying joints, which indicate a major challenge in successfully implementing the saw and seal method [2]. Most of the literature suggests that saw cuts in the HMA overlay must be made within one inch of the underlying joint or crack in order for the reflective crack to coincide with the overlay saw cut joint [1]. It is suggested that the saw and seal method is most suitable for JRCP with longer slab lengths. It was suggested that shorter slab lengths require more sawing and sealing and thus may not be cost-effective. However, it was suggested that shorter slab lengths, which more easily withstands thermal stresses due to slab movement and thus prevent mid-slab cracking [1].

5.4 Case Studies of Saw and Seal Method

This section presents the results of studies performed using the saw and seal method on pavements that have varying pavement characteristics. The impacts on reflective cracking by several factors such as; traffic volume, HMA overlay thickness; joint spacing, temperature, foundation strength, and age of pavement were investigated from those studies.

5.4.1 Minnesota Saw and Seal Study

Beginning in the late 1960's the City of Minnesota conducted a study that spanned over thirty years on more than fifty roadway test sections that utilized the method of sawing and sealing joints in the HMA overlay to reduce reflective cracking [8]. Three pavement types were used in the study; HMA overlay on existing JCP's, new HMA on new JCP's, and HMA overlays on HMA pavements. The variables of this study were the depth of saw cut, width of the saw cut, distances between saw cuts in a test section, and the location of the saw cuts in the HMA overlay in relation to that of the joints in the underlying concrete base.

The study found that the saw and seal method was very successful with a success rate of seventy-six percent and currently all new roadway construction in Minnesota utilizes this method. The results of the study indicated that most of the unsuccessful test sections were as a result of misalignment of the underlying joints in the concrete base or where sawing in the HMA overlay was done at uniform spacing with no consideration of the underlying cracks' location in HMA on HMA overlay pavements. The success rate was determined by dividing the total number of joints in a test section by the sum of the number of joints and the number of cracks in the test section. The study found that in new composite pavements the depths of saw cuts must be at least one third the thickness of the HMA overlay or 2.5 inches, whichever is greater and that the distances between joints must be thirty to forty feet to be effective. Longer distances between saw cuts will result in cracks between consecutive joints. The study also found that the saw and seal method must only be used in HMA on HMA overlays when there are a small number of cracks and the cracks are neat and in a straight horizontal direction. For HMA overlays on JCP's, sawing and sealing the HMA was successful where no mid-panel (between joints in the concrete) cracks were present in the underlying concrete base because these cracks easily reflected through to the surface. The study also found that adhesion failure between the sealant and the sidewalls were prevalent, causing raveling to occur at the edges of the joints in the overlay. This problem was attributed to either fatigue of the sealant due to the repetition of contraction and expansion during temperature cycling or a chemical reaction between the silicone sealant and the asphalt in the HMA mixture. The study also found that in JCP's the sawed joint in the HMA overlay must be located within one inch of the underlying joint in the concrete base to be effective, otherwise a reflective crack will reflect through to the surface in very close proximity to the joint in the HMA overlay, which is then deemed as a static overlay joint.

5.4.2 Louisiana Saw and Seal Study

In Louisiana, the saw and seal method used on 15 composite pavements were evaluated for their cost-effectiveness and effectiveness in reducing reflective cracking [25]. The sections, monitored for a period of six to fifteen years, experienced average annual daily traffic (AADT) ranging from 1,800 to 50,250 along with varying climate conditions. In the northern part of the state temperatures varied between 18°F and 106°F in the winter, and in the southern part of the state, temperatures varied between 46°F and 100°F. Saw cuts made in the HMA overlay were both transverse and longitudinal.

The study found that the saw and seal method was an overall success in increasing the service life of the pavement [25]. Seven test sections indicated an increase in service life ranging from 4 to 12 years and six of the test sections indicated an increase in service life of 3 years resulting in an expected average increase in service life of 4 years. The study also found that the saw and seal method is a cost effective technique but is most cost-effective on pavements that experience low to medium traffic volumes.

5.4.3 North Dakota Saw and Seal Study

In North Dakota, a study on a composite pavement test section that consisted of 54 sawed and sealed joints were conducted to determine its effect on controlling reflective cracking [26]. That study began in 1994 and yearly evaluations were performed until 2001. The pavement consisted of an underlying concrete base that had very little transverse and longitudinal cracking with a four-inch thick HMA overlay. Joints in the HMA overlay were sawed directly over the joints in the concrete base at twenty-eight feet apart and some joints were purposely overfilled and squeegeed and some were filled and sealed to the exact roadway surface level without being squeegeed. Evaluations of the test sections indicated that each year since 1995 the test sections experienced no reflective cracking, even though 15 percent of the shoulders showed reflective cracking after one year. The study found that all joints were in good condition and they experienced no adhesion failure between the sealant and the sidewalls of the joints despite extreme temperature cycling [26]. The findings also suggested that the saw and seal method is effective when joints in the HMA overlay are located within one inch of the underlying concrete joint. Coring was performed at various joints, which showed that all but one joint in the HMA overlay was within one inch of the underlying joint in the concrete base. The saw and seal method was found to be successful due to the fact that after seven years, the test section experienced no cracking even though 59 percent of the shoulders at the joints experienced reflective cracking.

5.4.4 Interlayer and Design Considerations to Retard Reflective Cracking

Blankenship et al., (2004) completed an 8-year, 12-project, multi-climate study in 2004 of a method for protecting HMA-overlaid pavements by addressing the multiple forces (tension, shear and bending forces) that contribute to reflective cracking [27]. The main method that was tested in that study was a reflective-crack relief interlayer system that is placed between the cracked underlying concrete base and the HMA overlay with the purpose of, not only withstanding the forces that contribute to reflective cracking, but also protecting the underlying concrete base from air and moisture [27]. Two auxiliary studies were also conducted, which comprised the saw and seal method and increasing overlay thickness. Laboratory flexural fatigue testing and field testing were conducted for comparison of results.

Based on the results of the field tests, the interlayer has the ability to withstand the forces associated with reflective cracking by remaining intact but within five years, at least 50% of the cracks from the underlying concrete base reflect through to the overlay. The results showed that there was a 52% improvement in average crack rate per year from control sections to sections that used the interlayer. It was also indicated that a highly flexible asphalt-rich HMA interlayer that has passed a flexural beam fatigue requirement overlaid on a strong concrete base will delay reflective cracking. Of the twelve experimental test sections, five had strong concrete bases and consequently experienced significantly lower average cracking rate per year (%/yr) than the remaining seven test sections.

The study found that traffic volume had no significant impact on crack rate but on one project (Decorah, Iowa) cracks immediately reflected through to the HMA overlay during critically low temperatures. In addition the results showed that reflective cracking increased mainly during the winter and spring seasons but little or no increase in reflective cracking occurred during the summer and fall months [27]. Increase in overlay thickness did not retard the progression of reflective cracking but this finding may have been as a result of weak underlying concrete bases. The proportion of variance between overlay thickness and average crack rate was only 2%.

Though no detailed report was included in the report, the saw and seal method was used on one project (Beto Junction, Kansas) and after year 2 was the most effective method in slowing reflective cracking (Blankenship, et al, 2004).

5.4.5 New York City Multiple Testing Methods

The effectiveness of eight reflective crack mitigation techniques were investigated on a 3,800 ft. experimental roadway section in Queens, New York over a period of 6 ½ years [1]. The objectives of the study were to document the causes of reflective cracking and to determine the most cost-effective crack-control techniques. The following are the methods that were investigated:

1. Standard NYC design utilizing an 18-inch membrane placed at each joint in the underlying concrete base.
2. Saw and Seal the HMA overlay.
3. Polypropylene fabric: NYCDDC standard fabric
4. Alternative Paveprep fabric
5. Heavy-duty membrane interlayer
6. ISAC fabric
7. Fiberglass grid (two types)

The operative variables of the study were the treatment type, joint spacing or distance between joints, and pavement age.

For the most part, field surveys were conducted twice per year and the results revealed that the saw and seal control method was the most effective method in slowing reflective cracking. The saw and seal method outperformed all crack-control methods in the short-term and throughout the long-term. The heavy-duty membrane interlayer, fiberglass grids, alternative fabric, and ISAC composite did not significantly reduce the amount of reflective cracking in comparison with the control sections. In fact, the control sections outperformed the fiberglass and geosynthetics on the 15-ft. joint spacing sections [1]. An important observation of this experiment was a significantly lower percentage of cracking of all severities in almost all the methods at the 15-ft. joint spacing sections.

5.5 Summary of Literature Review

Based on the literature review, there is no method that completely eliminates reflective cracking in pavements under all conditions. A recurring theme is that a reflective crack mitigation method that is successful in one location will not necessarily be successful in other locations due to the huge variations in conditions. The major factors that influence reflective cracking are climate, traffic volume, asphalt thickness, and the existing structural capacity of a composite pavement's concrete base. It is evident however, that most methods have a higher degree of success in warm to mild climates than in cold climates with freeze-thaw cycles, indicating that of all factors temperature potentially has the most significant impact on reflective cracking. The distress in pavements due to reflective cracking generally increases in severity during critically low temperatures but slightly increases while experiencing higher temperatures during the summer and fall months.

All studies that vary HMA overlay thickness have shown that reflective cracking is significantly delayed with increased HMA overlay thickness. Overlay thicknesses, as low as one inch, have experienced reflective cracking in a relatively short time but thicker overlays delay reflective cracking for a longer time. Two combined principles characterize the effectiveness of increasing overlay thicknesses; (1) reduction of damage associated with traffic loads because it facilitates better load transfer across cracks and joints in the concrete base; (2) increased insulation of the concrete base resulting in reduction of the upward curling generally experienced during freeze-thaw cycles. However, the effectiveness of increased asphalt thickness is dependent on traffic volume and loading that it supports and the climate it experiences thus increased thickness must be determine based on the localized conditions and used in conjunction with other reflective crack mitigation methods. Traffic volume influences the effectiveness of all reflective crack mitigation methods. A common trend is that several mitigation methods are successful on low traffic volume roads and only a few such as the saw and seal method and ISAC are successful on medium level traffic volumes. Despite the mitigation methods used, heavy traffic volumes greatly reduce their effectiveness. The level of influence of traffic volume on the effectiveness of a reflective crack mitigation method greatly depends on the design and structural capacity of the pavement. Asphalt mixture configuration, asphalt thickness, and strength of the concrete base are the typical pavement characteristics on which the influence of traffic volume depends.

Reflective cracking is impacted by temperature variations, traffic volume, overlay thickness, and age of pavement. The combined effect poses the greatest challenge in finding a suitable technique to mitigate or prevent reflective cracking. A review of the literature suggests that since mitigation methods are not effectively transferrable across locations, it is imperative that reflective cracking be addressed at the local level, thus the District of Columbia should develop its own application for reflective crack prevention. In doing so, the effectiveness of the saw and seal method was explored and evaluated.

6.0 SITE DESCRIPTION

North Capitol Street is a three-lane divided roadway oriented in the north to south direction and separates the Northwest and Northeast quadrants of Washington DC. It is a heavily traveled arterial roadway that links eastern downtown area of Washington DC to the northeastern suburbs of Maryland, and accommodates an ADT of approximately 30,000 vehicles.

The experimental section shown in Figure 4 is located along the southbound direction of North Capitol Street NW at the interchange with Irving St. It is approximately 150 feet long and consists of fifteen transverse saw-cuts and seven longitudinal saw-cuts respectively. The transverse saw cuts cover all three lanes and are equally spaced at 30 feet and placed directly above the transverse underlying concrete joints. The longitudinal saw-cuts are located directly above the longitudinal joints between the concrete slabs, which coincides with the dashed white lines that separate each lane in the HMA overlay. The HMA saw-cuts are neatly filled with sealant to the exact level of the pavement.

Figure 4: Experimental Pavement Section showing Sawed and Sealed HMA Saw-Cuts with Sealants

The adjacent northbound section, constructed at the same time as the experimental section but without sawing and sealing, was used for visual comparison purposes. It was assumed that the ADT for both the northbound and experimental sections was the same.

7.0 RESEARCH METHODOLOGY

7.1 Variables

Based on the literature reviewed climate apparently had the most significant impact on reflective cracking. Almost all studies that were conducted in warmer climates produced more effective results than the studies conducted in areas that experienced drastic temperature variations [2, 7]. Similarly, studies conducted in Louisiana, Nevada, Massachusetts, and Virginia indicated that traffic volume influenced the progression of reflective cracking. Considering these observations, changes in air temperature (measured in degrees Fahrenheit) and ADT were chosen as two of three variables to be used in evaluating the effectiveness of the saw and seal method in preventing reflective cracking on the test segment. The method of interpolation and extrapolation of traffic volume data between 2005 and 2008 was used to estimate the ADT of the period. Pavement age was selected as the third variable based on the fact that reflective cracking generally occurs at random ages of pavements.

7.2 Data Collection and Extraction

Three types of data were collected and obtained on a quarterly basis quarter; HMA saw-cut widths (transverse and longitudinal), average daily traffic; mean daily air temperature, and pavement age, based on field observations and data extrapolation. The final data collection was conducted on March 28, 2011. DDOT provided traffic control during the field observations and data collection. Spot photographs of the pavement conditions throughout the experimental and control sections were taken with all the photographs of the saw-cuts taken from a consistent height of 4.3 feet above the pavement surface. The points along the sawed and sealed joints where saw cut widths were measured were the same for all the previous data collection in order maintain consistency in data analysis procedures. The widths of the saw-cuts, both transverse and longitudinal, were marked at these reference points on sheets of paper from which the actual measurements were extracted. Fifteen transverse and seven longitudinal saw-cuts were observed. Figure 5 shows the locations of the transverse and longitudinal saw cuts in the experimental roadway section. On each field observation day the mean air temperature for Washington DC was obtained from the National Climatic Data Center.

Visual observations of the roadway test section and the adjacent northbound roadway section were conducted at each field visit. Distress to the pavement surfaces of both sections was noted and photographs of each pavement section were taken. During each field data collection the points of measurement of each saw-cut were spray-painted to provide consistent measurement location throughout the project's duration.

7.3 Data Reduction

Saw-cuts made in the HMA overlay were 0.40, 0.50, or 0.60 inches in initial widths at the beginning of the project in May 2006. An average of the fifteen initial transverse saw-cut widths and an average of the seven initial longitudinal saw-cut widths were obtained and used as initial observation values for transverse and longitudinal saw-cut widths respectively. That procedure was repeated each quarter using the raw observation values that were collected and the resulting averages comprised the data set for observed HMA saw-cuts each quarter. Average HMA saw-cut widths were calculated from observed raw saw-cut widths collected from the field were reduced to the variable, changes in HMA saw-cut widths. That was achieved by subtracting the average initial saw-cut widths from each average saw-cut value corresponding to each data collection period. Tables 2 and 3 show the reduced saw cut widths. Daily mean temperature in degrees Fahrenheit for each data collection day was reduced to the variable, changes in daily mean air temperature by subtracting the initial air temperature of the beginning day of the project from temperatures recorded for each data collection day.

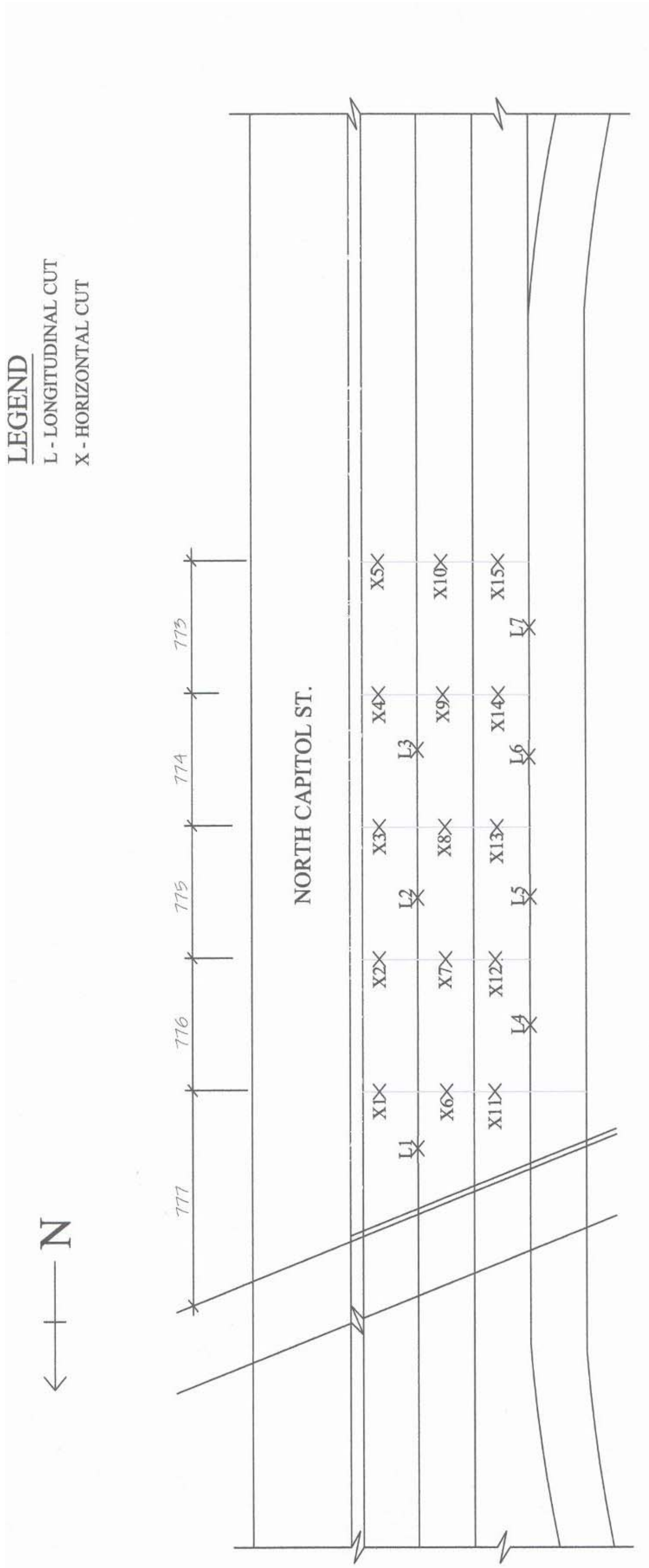


Figure 5. Saw-Cut Locations on North Capitol Street

7.4 Traffic Volume Interpolation and Extrapolation

The Average Daily Traffic (ADT) of the pavement test section for each quarter was estimated by extrapolating from a linear relationship created between previous traffic data counts that were performed in 2005 and 2008 for the District of Columbia Department of Transportation (DDOT). The traffic data counts were recorded in 15-minute increments for 24 hours on 5 consecutive weekdays (Monday to Friday) of both years. An estimated ADT for each year (2005 and 2008) was determined by finding the average of the total traffic recorded for all five days after which a scatter plot of both points and their subsequent relationship was developed (Figure 6).

The ADT corresponding to each data collection period was then determined by substituting the number of cumulative days since the saw-cuts were installed into the linear regression equation

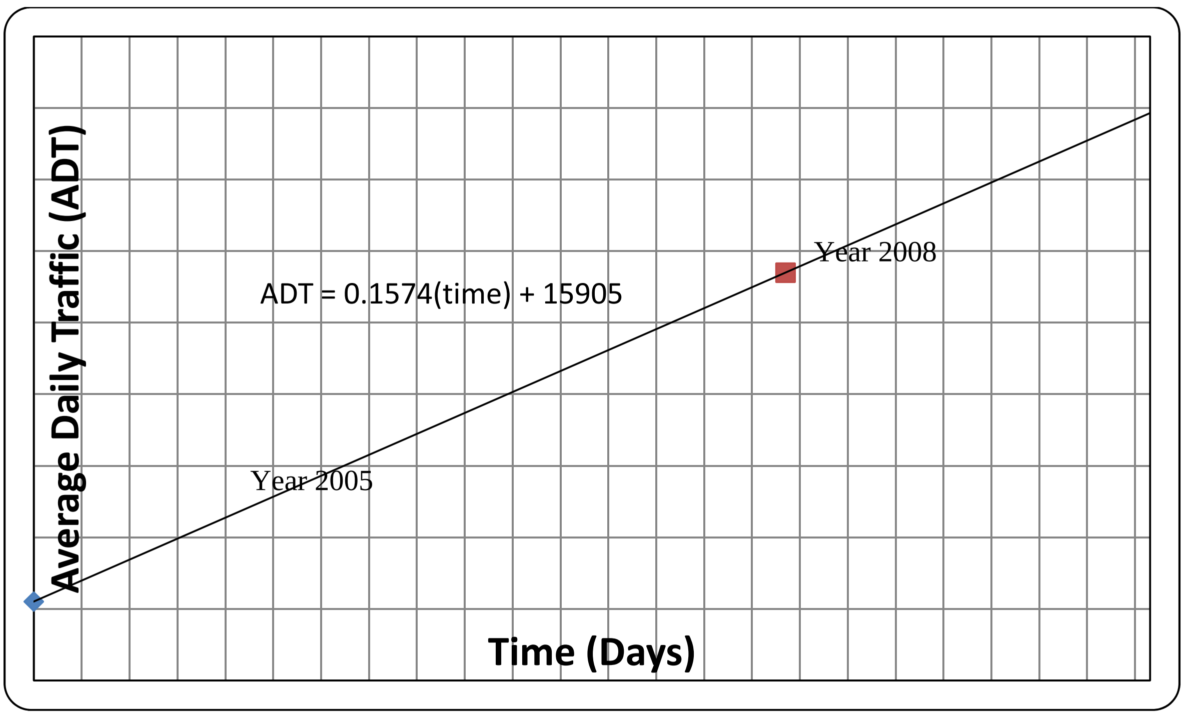


Figure 6: Relationship between ADT and Time between Years 2005 and Projected Year 2010

Table 2: Reduced Data Saw-Cut Widths used for Regression Analysis

Date	Changes in Average Transverse Saw-Cut Widths (inches)	Changes in Average Longitudinal Saw-Cut Widths (inches)	Changes in Daily Mean Air Temperature (°F)	Pavement Age (months)	Average Daily Traffic
May 1, 2006	0	0.0000	0	0	15905
August 4, 2006	0.1353	0.0629	28.6	3	15920
November 6, 2006	0.142	0.0686	-13.4	6	15935
February 6, 2007	0.218	0.0529	-42.2	9	15949
May 15, 2007	0.1553	0.0471	11.5	12	15965
August 7, 2007	0.2007	0.0914	27.8	15	15978
November 19, 2007	0.1673	0.0929	-13.1	18	15994
May 13, 2008	0.1173	0.0471	0.3	23	16022
September 12, 2008	0.174	0.1071	16.2	27	16041
February 6, 2009	0.1693	0.0400	-31.8	32	16064
December 10, 2009	0.2313	0.0871	-14.4	42	16113
April 1, 2010	0.204	0.0871	1.3	46	16130
June 10, 2010	0.2007	0.0871	20.3	48	16141
September 13, 2010	0.2187	0.1157	11.7	51	16156
December 9, 2010	0.2955	0.1250	-28	54	16170
March 28, 2011	0.2360	0.1057	-19	57	16249

Note: Changes in average saw cut widths represent the difference between the average observed saw-cut width and the average initial saw-cut width at the beginning of the project in May 2006.

Note: Changes in daily mean air temperature represent the difference between the daily mean air temperature on the data collection day and the daily mean air temperature at the beginning of the project in May 2006

8.0 RESULTS

A multiple regression analysis and an independent samples t-test were conducted to determine if a relationship exist between changes in daily mean air temperature and ADT, and to determine if pavement movements at the transverse and longitudinal joints are similar. The multiple regression analysis produced test statistics such as the proportion of variance of changes in HMA saw-cut widths accounted for by ADT and daily mean air temperature change, and ANOVA F-ratios. The statistical significance of the multiple regression analysis was then determined by the probability value (p-value). A *p*-value of less than 0.05 indicates statistical significance and thus would be accepted and developed into a linear equation format. An independent samples t-test, also called the student's *t*-test, tests for a difference between the means of two samples of independent but identical distributed data. The independent samples t-test was used to determine not only if there was a significant difference between changes in average transverse saw cut widths and changes in average longitudinal saw cut widths but also if one is significantly greater than the other. The probability of the difference between means not occurring by chance alone (*p*-value) is computed by the statistical software, SPSS based on the area under the normal distribution curve after which this *t*-value is compared to the selected criterion probability value of 0.05. A *p*-value that is less than 0.05 indicates that there is a significant difference between the means of both samples.

An independent samples *t*-test conducted on the data sets presented in Table 4 shows that changes in average transverse HMA saw-cut widths are significantly greater than the changes in longitudinal saw cut widths. Predominantly, the changes in transverse saw-cut widths are twice the magnitude of the changes in longitudinal saw cut widths (Figure 7). Figure 7 shows that the changes in average transverse saw-cut widths were contained within the range of 0 to 0.29 inches, which is more than twice the range of 0 to 0.13 inches within which the changes in longitudinal saw-cut widths were contained. This indicates that pavement movements at transverse joints due to temperature changes and traffic volume are of greater concern than movements undergone by the pavement at the longitudinal joints.

Table 3.1: Transverse Saw-Cut Widths in HMA Overlay on North Capitol Street Experimental Section (May 2006 to November 2007)

Transverse Saw-Cut Locations	05/01/06	08/04/06	11/06/06	02/06/07	05/15/07	08/07/07	11/19/07
1	0.40	0.59	0.63	0.70	0.61	0.75	0.57
2	0.40	0.65	0.67	0.73	0.75	0.69	0.75
3	0.40	0.61	0.59	0.79	0.73	0.72	0.69
4	0.40	0.65	0.65	0.63	0.67	0.69	0.69
5	0.40	0.55	0.55	0.55	0.59	0.56	0.57
6	0.40	0.47	0.47	0.55	0.63	0.71	0.63
7	0.50	0.67	0.65	0.75	0.61	0.75	0.66
8	0.40	0.67	0.47	0.59	0.59	0.63	0.53
9	0.50	0.53	0.55	0.71	0.55	0.56	0.63
10	0.60	0.61	0.63	0.67	0.59	0.65	0.63
11	0.50	0.50	0.59	0.57	0.47	0.53	0.53
12	0.50	0.50	0.51	0.79	0.61	0.56	0.63
13	0.40	0.51	0.67	0.54	0.55	0.56	0.50
14	0.40	0.55	0.47	0.59	0.49	0.56	0.47
15	0.40	0.57	0.63	0.71	0.49	0.69	0.63

Table 3.2: Transverse Saw-Cut Widths in HMA Overlay on North Capitol Street Southbound (May 2008 to December 2010)

Transverse Saw-Cut Locations	05/13/08	09/12/08	02/06/09	12/10/09	04/01/10	06/10/10	09/13/10	12/9/10	03/28/11
X1	0.66	0.66	0.63	0.82	0.47	0.66	0.69	0.72	0.69
X2	0.76	0.63	0.63	0.82	0.50	0.84	0.88	0.94	0.91
X3	0.63	0.82	0.70	0.57	0.75	0.69	0.72	0.97	0.69
X4	0.63	0.85	0.75	0.72	0.85	0.81	0.75	0.75	0.81
X5	0.57	0.60	0.50	0.57	0.57	0.59	0.63	0.78	0.66
X6	0.53	0.47	0.50	0.75	0.63	0.62	0.69	0.75	0.63
X7	0.62	0.72	0.63	0.75	0.63	0.69	0.72	0.88	0.59
X8	0.47	0.57	0.53	0.63	0.57	0.61	0.53	0.59	0.63
X9	0.60	0.53	0.53	0.69	0.60	0.56	0.56	0.69	0.56
X10	0.60	0.66	0.69	0.66	1.00	0.75	0.78	0.78	0.88
X11	0.41	0.50	0.53	0.63	0.57	0.56	0.59	0.59	0.59
X12	0.44	0.57	0.57	0.63	0.60	0.56	0.63	0.63	0.59
X13	0.41	0.60	0.63	0.60	0.60	0.59	0.59	0.66	0.66
X14	0.44	0.50	0.57	0.57	0.57	0.55	0.53	0.63	0.56
X15	0.59	0.53	0.75	0.66	0.75	0.53	0.59	0.69	0.69

Table 3.3: Longitudinal Saw-Cut Widths in HMA Overlay on North Capitol Street Southbound (May 2006 to November 2007)

Longitudinal Saw-Cut Locations	05/01/06	08/04/06	08/04/06	02/06/07	05/15/07	08/07/07	11/19/07
L1	0.50	0.59	0.59	0.51	0.43	0.59	0.50
L2	0.60	0.60	0.55	0.55	0.57	0.56	0.63
L3	0.50	0.57	0.57	0.47	0.53	0.53	0.63
L4	0.60	0.65	0.62	0.55	0.67	0.69	0.69
L5	0.50	0.51	0.59	0.59	0.55	0.63	0.53
L6	0.40	0.53	0.55	.61	0.53	0.61	0.57
L7	0.40	0.49	0.51	0.59	0.55	0.53	0.60

Table 3.4: Longitudinal Saw-Cut Widths in HMA Overlay on North Capitol Street Southbound (May 2008 to December 2010)

Longitudinal Saw-Cut Locations	05/19/08	09/12/08	02/06/09	12/10/09	04/01/10	06/10/10	09/13/10	12/9/10	03/28/11
L1	0.58	0.50	0.57	0.57	0.57	0.59	0.56	0.59	0.59
L2	0.58	0.57	0.57	0.60	0.60	0.56	0.56	0.59	0.56
L3	0.50	0.66	0.57	0.57	0.57	0.63	0.69	0.66	0.69
L4	0.69	0.75	0.63	0.63	0.60	0.59	0.59	0.63	0.59
L5	0.48	0.57	0.50	0.60	0.63	0.58	0.69	0.63	0.59
L6	0.47	0.60	0.50	0.57	0.57	0.58	0.59	0.63	0.59
L7	0.53	0.60	0.44	0.57	0.57	0.58	0.63	0.66	0.63

Table 3.5: Summary of Changes in Average Transverse and Longitudinal HMA Saw-Cut Widths

Date	Changes in Average Transverse Saw-Cut Joint Widths (inches)	Changes in Average Longitudinal Saw-Cut Joint Widths (inches)
May 1, 2006	0	0.0000
August 4, 2006	0.1353	0.0629
November 6, 2006	0.142	0.0686
February 6, 2007	0.218	0.0529
May 15, 2007	0.1553	0.0471
August 7, 2007	0.2007	0.0914
November 19, 2007	0.1673	0.0929
May 13, 2008	0.1173	0.0471
September 12, 2008	0.174	0.1071
February 6, 2009	0.1693	0.0400
December 10, 2009	0.2313	0.0871
April 1, 2010	0.204	0.0871
June 10, 2010	0.2007	0.0871
September 13, 2010	0.2187	0.1157
December 9, 2010	0.2955	0.1250
March 28, 2011	0.2360	0.1057

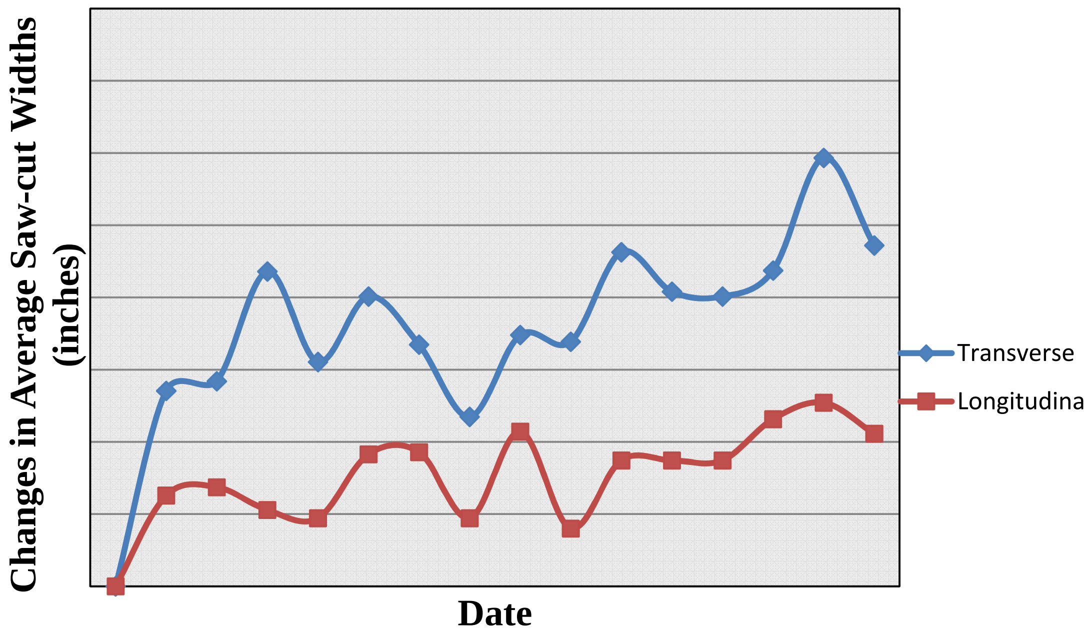


Figure 7 Changes in Average Widths of Saw-Cuts on North Capitol Street Test Section

The results of the multiple regression analyses indicate that there is a statistically significant relationship exists between changes in average *transverse* and *longitudinal* saw-cut widths and the combination of changes in daily mean air temperature and ADT. This indicates that the saw and seal HMA joints are controlling reflective cracking due to their accommodation of the impacts of air temperature changes and traffic volume (depicted by movements of HMA saw cut widths). The multiple regression analysis also showed that the combination of changes in daily mean air temperature and ADT accounted for 95.7% of the variations that occurred in the changes in average *transverse* HMA saw-cut widths and 91.4% of the variations that occurred in the changes in average *longitudinal* HMA saw-cut widths.

9.0 VISUAL ASSESSMENT OF PAVEMENT SECTIONS

9.1. Conditions of Test Section

A final visual inspection of the treated pavement was conducted after fifty-four (54) months, as depicted in Figure 8 it was generally in good physical condition, containing only two cracks. One of these cracks is shown in Figure 9; located approximately one foot away from a transverse saw-cut, is of a low severity, and has an estimated length of five feet.

Figure 8: Condition of the Sawed and Sealed Section

The second crack in the test section, shown in Figure 8, occurred in the center lane and mid-slab between transverse saw cuts. It spanned the entire middle lane with a length of approximately twelve feet. Generally, the test section, with the exception of the two cracks previously described, did not experience reflective cracking.

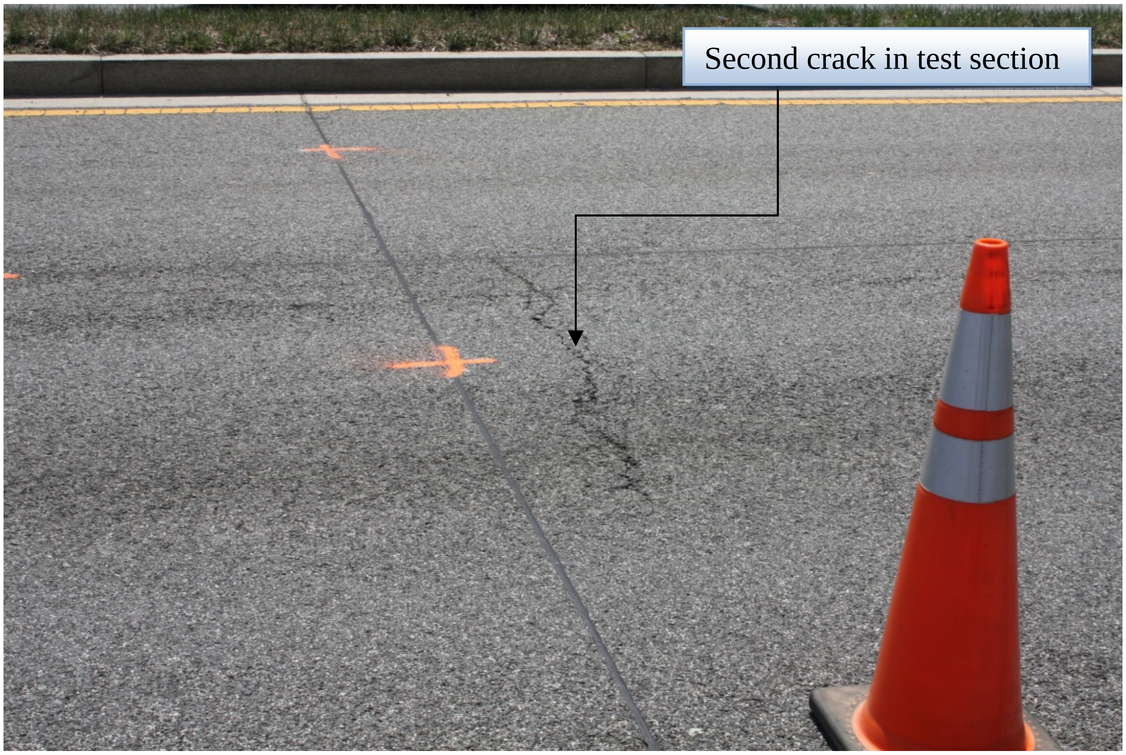


Figure 9: Cracking in Sawed and Sealed Pavement Section in the Vicinity of a Transverse Saw Cut.

No longitudinal cracks were observed in the test section and all longitudinal saw-cuts were in perfect condition. That is, no joint deterioration or sealant adhesion loss was observed in longitudinal saw-cuts. Figure 9 indicates that the test section was predominantly in good condition with the only two noteworthy observations of cracking in the pavement. General asphalt brittleness and typical wearing of the pavement surface have been observed. One case of a minor pavement incision was observed in close proximity to two saw-cuts, which is attributed to snow plowing that occurred during the snow storms in January 2010 and February 2011.

Figure 10 shows the overall condition of the sawed and sealed pavement section. Relative to the conditions of the untreated pavement section shown in Figures 11 and 12, it is apparent that the sawed and sealed section considerably outperformed its counterpart.

Figure 10: Condition of Treated Pavement Section

9.2 Conditions of Untreated Pavement Section

Visual assessments of the control sites showed extensive transverse and longitudinal reflective cracking. Severe longitudinal cracks were present along all lanes and transverse reflective cracking occurred at all transverse joint locations. Figure 11 shows a considerable number of longitudinal and transverse reflective cracks in the untreated section. The severities of these cracks are shown in Figure 12, which provides an example of the damaging effects of reflective crack progression. The untreated pavement at this point (shown in Figure 13) has experienced pavement "blow-up" and stripping. It is expected that, if left untreated, the pavement will experience compromised foundation strength to support traffic loads. Figure 14 provides an example of the inevitability of reflective cracking in a jointed composite pavement, as it represents the condition of the untreated pavement section located at all the transverse joints. The comparison results are magnified by the conditions of the sawed and sealed section and untreated section shown in (Figure 14).

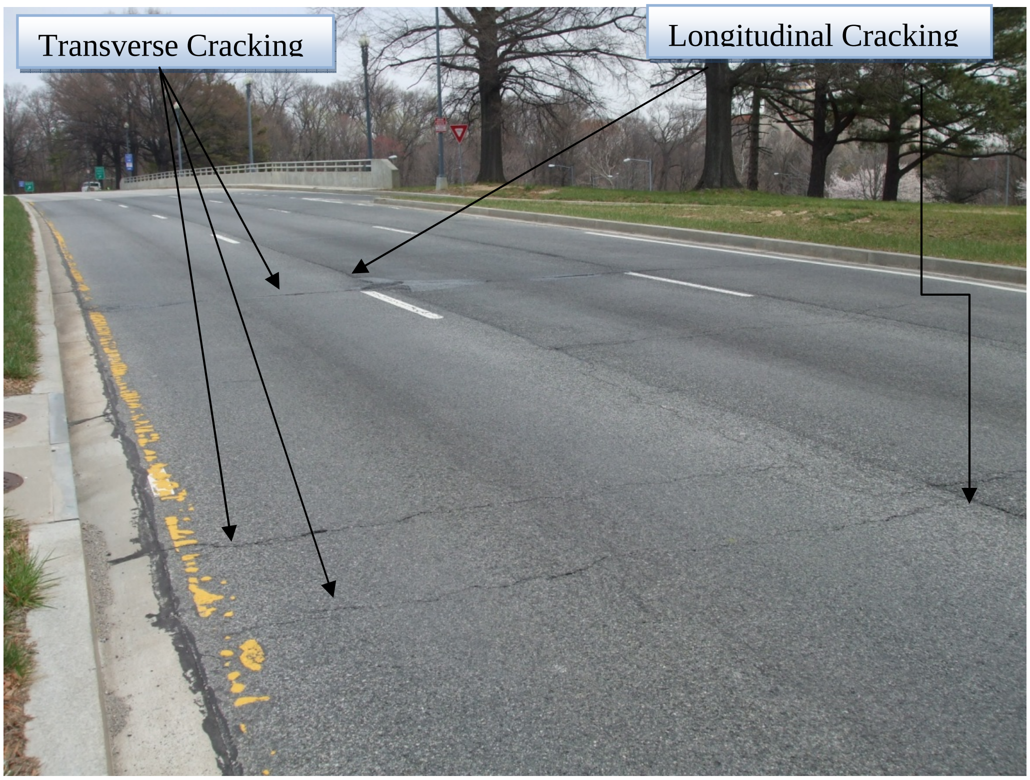


Figure 11: Reflective Cracking Prevalent in Adjacent Untreated Pavement Section

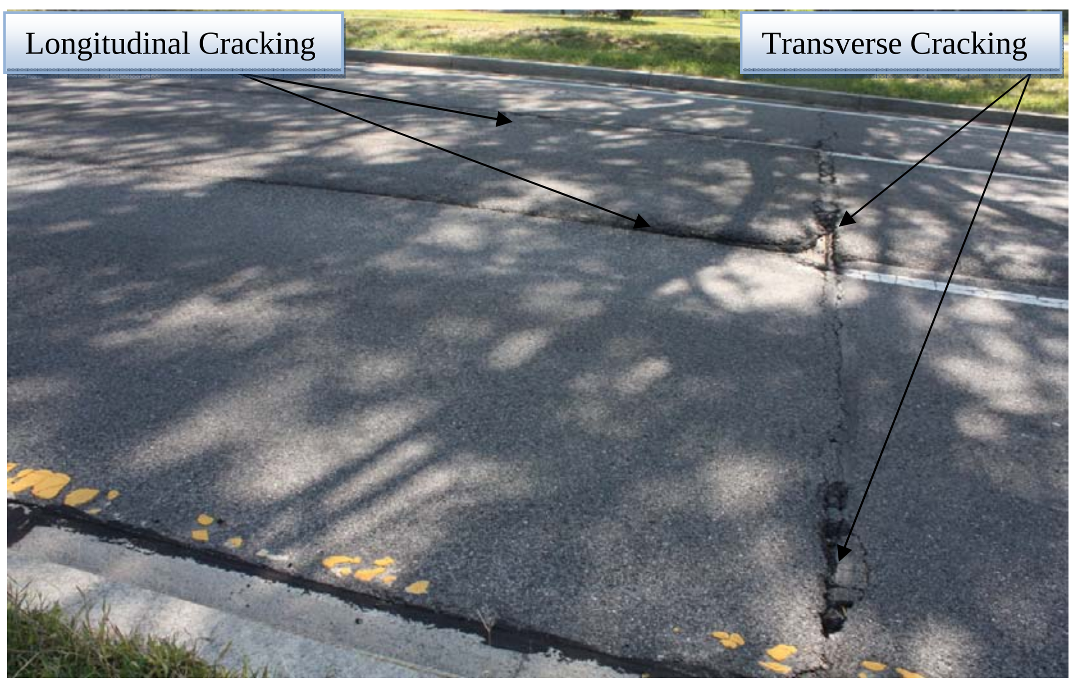


Figure 12: Severe Transverse and Longitudinal Reflective Cracking in Untreated Pavement Section

Figure 13: Major Cracking Area in the Untreated Pavement Section

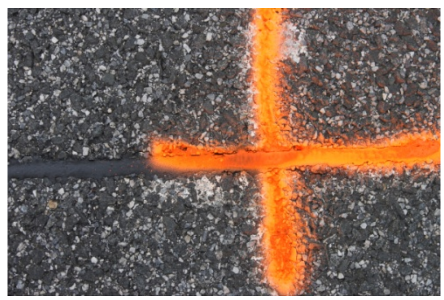
Figure 14: Typical Reflective Cracking Experienced at all Joint Locations in Untreated Pavement Section Adjacent to Corresponding Saw Cuts in Test Section.

9.3 Conditions of the Saw-Cuts

Five of the fifteen transverse saw-cuts, experienced sealant adhesion loss to the saw-cut walls and resealing of the joints are highly recommended in order to avoid “blowups” and potholes in the pavement caused the infiltration of incompressible materials. It is interesting to note that the five saw-cuts that have experienced sealant adhesion loss belong to the same saw-cut joint that spans the entire roadway. Spalling of sealant though was not observed, that is, the sealant has not spread beyond the walls of the saw-cut reservoir boundaries and the saw-cuts (both transverse and longitudinal) were generally still in good condition, which were represented by the still observable neat saw-cut edges. The conditions of the saw-cuts at the last field visit are shown in the following spot photographs.

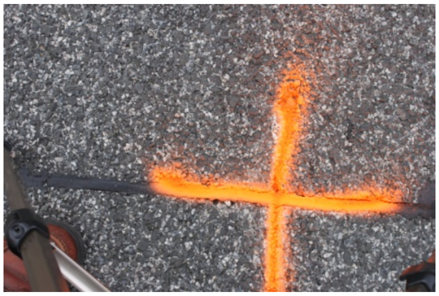
Transverse Saw-Cuts

a) X1

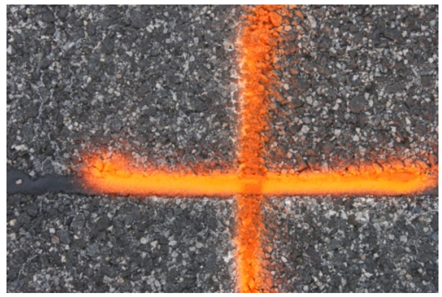


b) X2

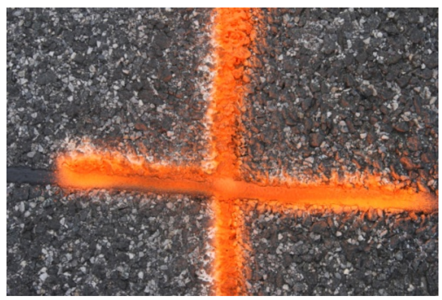
c) X3



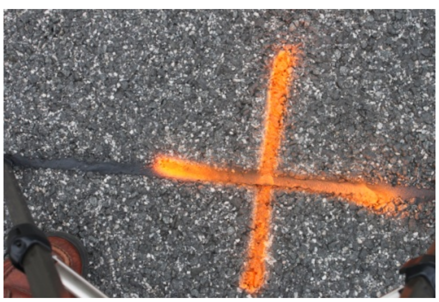
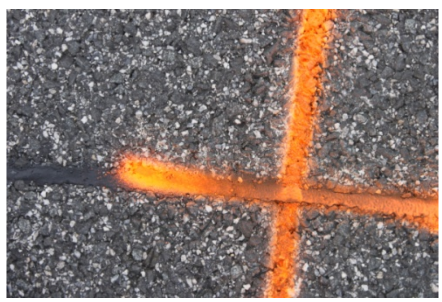

d) X4

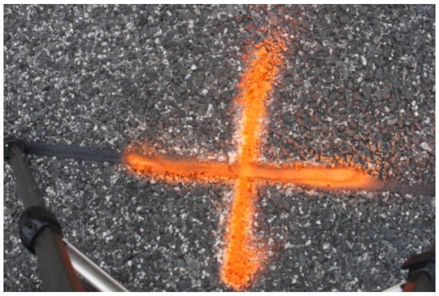
e) X5

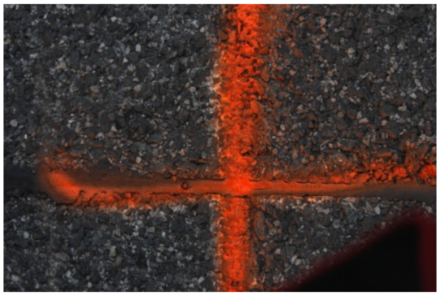
f) X6

g) X7

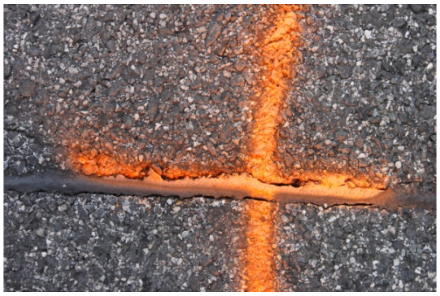



h) X8

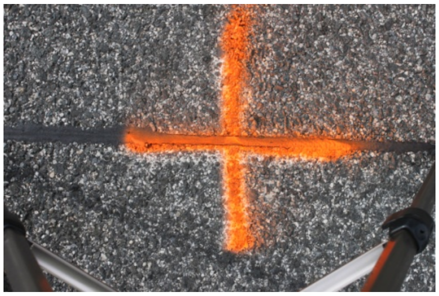



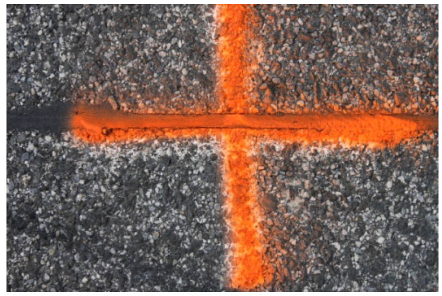
i) X9


j) X10

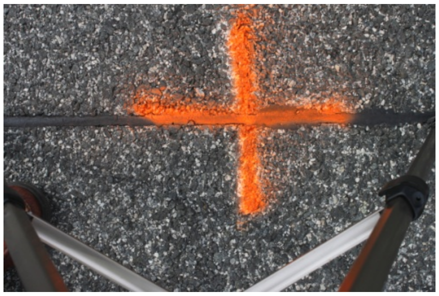



k) X11

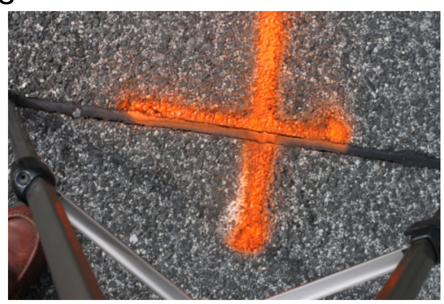




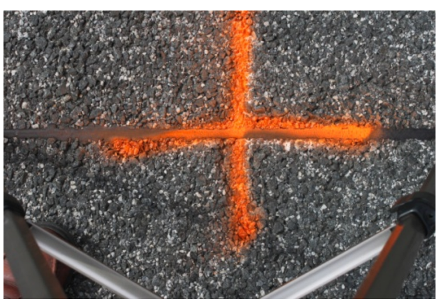
l) X12



m) X13



n) X14



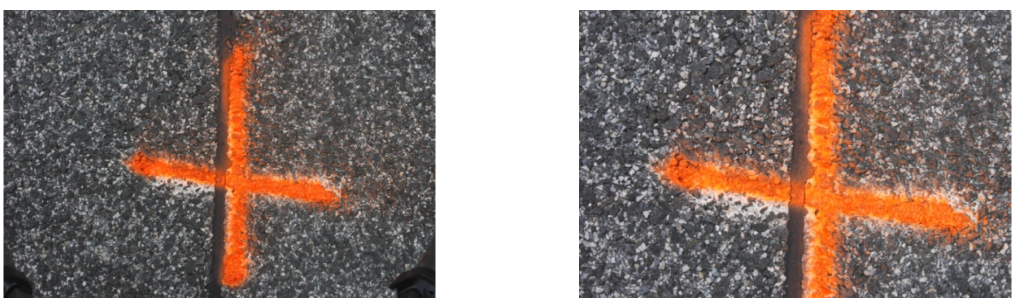
o) X15

Figure 8.9 (a – o): Conditions of HMA Overlay Transverse Saw-Cuts

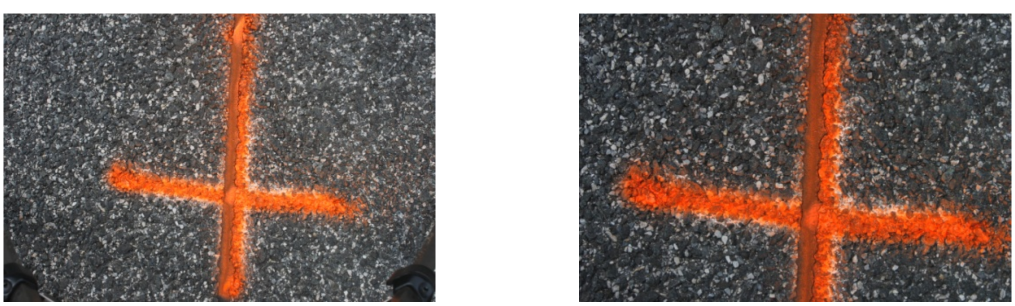
Longitudinal Saw-Cuts

i) L1

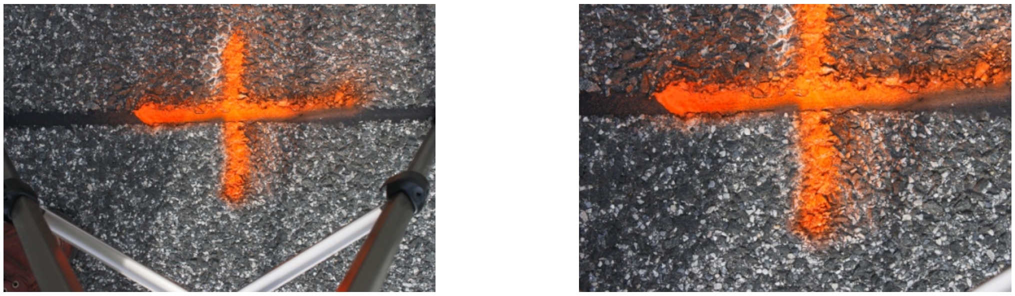
ii) L2



iii) L3

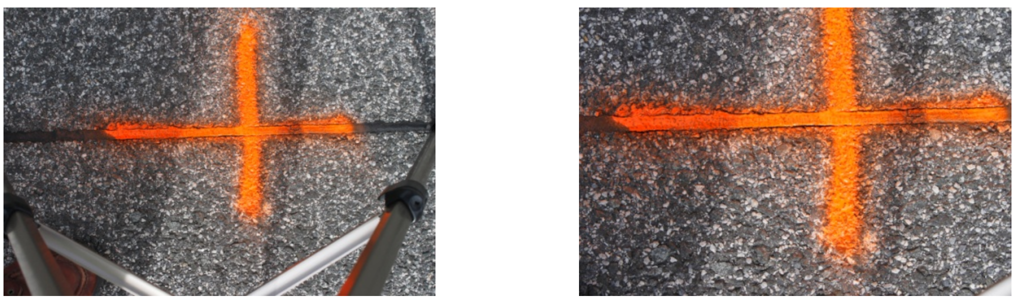


iv) L4



v) L5

vi) L6



vii) L7

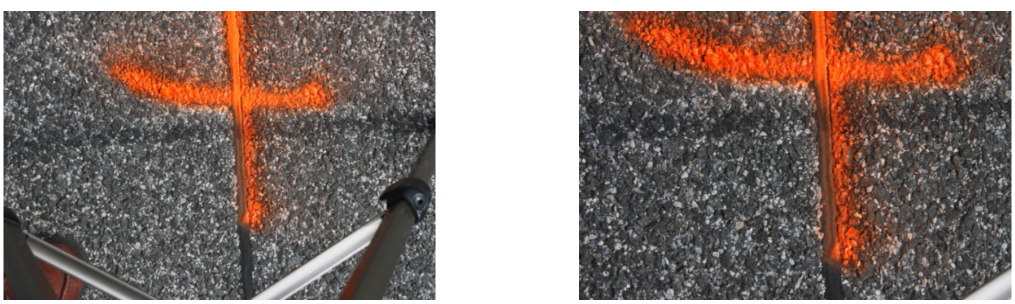


Figure 8.10 (i – vii): Conditions of HMA Overlay Longitudinal Saw-Cuts

10.0 DISCUSSION

Twelve of the fifteen transverse saw-cut widths have decreased and three have increased since the previous data collection on December 10, 2010. These results are consistent with the literature review findings, which indicate that the number of cracks and crack widths increase greatly during warmer climates as a result of underlying slab contraction. The widths of 5 of the 7 longitudinal saw-cuts (L1, L2, L4, L6, and L7) increased and the other two decreased since the previous data collection. Table 8.5 and Figure 8.1 show the quarterly average widths of the saw-cuts. Since the last quarter, the average widths of both the transverse and longitudinal saw-cuts increased by 0.0595 inches and 0.0193 inches respectively representing a change of 20.1% and 15.4%. Such a considerable change in transverse saw-cut widths may suggest that the average air temperature in March data collection was of higher than that of the previous data collection day and traffic volume may have varied considerably throughout the period or a combination of both extreme variations have been experienced at approximately the same time. The largest change in saw-cut width is an increase of 0.28 inches of transverse cut X3. X8 and X13, which are located along the same saw-cut joint both experienced increases in widths of 0.040 and 0.005 inches respectively. Five of the seven longitudinal saw cuts decreased in widths since the last quarter and longitudinal saw-cut widths L1 and L3 remained the same and increased respectively. The cause and progression of longitudinal cracking has several times been hypothesized as being mainly due to traffic loading and the lanes of L1 and L3 may have experienced a considerable difference in traffic volume relative to the other two lanes that contain the remaining longitudinal saw-cuts.

Conditions of the test section have remained same as those observed during the previous data collection period, with only 2 visible transverse cracks in the test section. One transverse crack, which was approximately 10 feet, was located mid slab between saw-cuts and the other was approximately 5 feet and located very close to the X5 saw-cut. General asphalt brittleness and wearing of the pavement surface have been observed. Most of the transverse saw-cuts are experiencing sealant adhesion loss to the saw-cut walls and resealing is currently highly recommended. Saw-cuts X3, X8, X10, X13, and X15 have experienced major sealant adhesion loss and at this point could let in incompressible materials, which could ultimately lead to “blowups” of the pavement and potholes. It is interesting to note that the five saw-cuts that have experienced sealant adhesion loss belong to the same saw-cut joint that spans the entire roadway. X3, X8, and X13 belong to the same transverse joint while X10 and X15 also both belong to the same transverse joint. Spalling of sealant though was not observed, that is, the sealant has not spread beyond the walls of the saw-cut reservoir boundaries and the saw-cuts (both transverse and longitudinal) were generally still in good condition, which were represented by the still observable neat saw-cut edges. Slight raveling of the saw cut, X10 was observed.

The independent samples t-test showed that the changes in transverse saw-cut widths are significantly larger in magnitude than the longitudinal saw-cut widths under the same exact conditions, indicating that the severity of transverse cracks should be greater than the severity of longitudinal cracks on North Capitol Street if the pavement was untreated. It also indicates that transverse joints should be of greater concern due to greater movement and thus if resealing is prioritized among HMA saw-cuts, transverse saw-cuts could be performed prior to resealing of longitudinal saw-cuts. The multiple regression analysis showed that that the combination of air temperature and ADT is significantly related to the changes in HMA saw-cut widths thus indicating that the saw and seal method is controlling reflective cracking in the pavement. In confirmation of this finding, a visual comparison between the test section and the adjacent pavement section - this has the same age and design - shows that the test section is in a significantly better physical condition than the comparison section.

The multiple regression analyses indicate that the interaction of air temperature and ADT has a significant impact on changes in both types of saw-cut widths. Specifically, their interaction explains 95.7% and 91.4% of the changes that occur in the transverse and longitudinal HMA saw-cut widths respectively. Pavement age was originally used in the multiple regression analysis and even though its effect was statistically significant it was excluded from the final model due to a detection of multicollinearity between itself and ADT. The first indication of potential multicollinearity between age and ADT was deduced from their correlation coefficient of 0.851, which was large enough to suspect multicollinearity. In addition to the high correlation, a one-on-one simple linear regression analysis was conducted on ADT and age after suspicion of multicollinearity and their relationship was significant thus indicating multicollinearity.

Air temperature accounts for approximately 12% less variation in longitudinal saw-cut widths than it does in transverse saw-cut widths, indicating that transverse joints is more respondent to temperature changes than are longitudinal joints. In conjunction with the literature, the coefficients of the model show that air temperature had an indirect relationship with the changes in the HMA saw-cut widths and ADT had a positive direct relationship, indicating that drastic falling temperature differences and increasing traffic volume will increase the widths of the HMA saw-cuts. As a result of this, it is suggested that resealing and maintenance procedures be conducted during periods of low temperatures when the saw-cuts are have achieved their widest openings.

11.0 CONCLUSIONS

This research explored the effectiveness of the saw and seal method in preventing or mitigating the impacts of reflectively cracking in a composite pavement. Based on the results of the statistical analyses and the absolute visual assessment of the test and untreated sections the saw and seal method effectively controlled reflective cracking. Confirming this finding is the significant relationship found between the interaction of air temperature, ADT, and the changes in the saw-cut widths. The interaction of air temperature and ADT explained 95.7% and 91.4% of variations in transverse and longitudinal movement at the saw-cuts respectively. This finding indicated that the variations in saw-cuts did not occur by chance but due to the impacts of air temperature and ADT indicating that the saw and seal method is an effective measure in mitigating reflective cracking.

The individual impacts of air temperature and ADT on transverse and longitudinal movements of the saw-cuts were statistically significant. Air temperature and ADT have the greatest individual impact on transverse and longitudinal movements respectively. Air temperature accounts for 54.6 percent and 41.1 percent of variations in transverse and longitudinal movements in the pavement respectively. Pavement age had a significant impact on the saw-cut widths but is highly correlated with ADT, thus indicating the presence of multicollinearity and was excluded from the model. The regression models predict changes in saw-cut widths, which is suitable in determining the optimal conditions under which crack and joint resealing maintenance procedures should be conducted. Crack sealing is generally conducted during largest crack openings thus resealing of the saw-cuts should occur at their largest openings as predicted by the multiple regression model. The statistical relationships developed and represented by both models indicated that transverse movement tends to be of a greater magnitude than longitudinal movement and thus should be of greater concern in composite pavement maintenance. Due to this finding, transverse saw-cuts should require resealing at a considerably earlier time than longitudinal saw-cuts will, thus estimations of funding required for resealing maintenance could be made more accurately. Also, changes in air temperature accounts for 12% more variation in transverse movement than longitudinal movement and thus should be expected to be of greater severity in composite pavements during drastic temperature variations.

Visual assessments of the joint conditions showed adhesion loss in almost half of the total number of the saw-cuts indicating that the sealant may not be able to withstand continuous exposure to extreme conditions of drastic temperature fluctuations and increasing traffic over a long period of time. Based on this, resealing must be performed and done at the optimum time (largest saw-cut width opening) predicted by the regression models.

12.0 REFERENCES

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APPENDIX A

Traffic Volume Data

Table A.1: Daily Traffic Volume in May 2005

VEHICLE VOLUME SUMMARY

District Of Columbia

Department of Transportation

Traffic Services Administration

Station # 96

Location **North Capitol St** Between Michigan Ave NE and Irving St NW

Day	Monday			Tuesday			Wednesday			Thursday			Friday		
Date	5/9/2005			5/10/2005			5/11/2005			5/12/2005			5/13/2005		
Orientation	Dir	Dir	Dir&Dir	Dir	Dir	Dir&Dir	Dir	Dir	Dir&Dir	Dir	Dir	Dir&Dir	Dir	Dir	Dir&Dir
Time of Day	NB	SB	NB&SB	NB	SB	NB&SB	NB	SB	NB&SB	NB	SB	NB&SB	NB	SB	NB&SB
0:00	78	49	127	83	58	141	92	54	146	88	43	131	89	57	146
0:15	55	44	99	58	38	96	60	49	109	58	52	110	64	60	124
0:30	50	26	76	55	30	85	55	28	83	53	24	77	57	31	88
0:45	44	24	68	47	26	73	48	26	74	51	21	72	49	37	86
1:00	40	28	68	45	23	68	47	29	76	48	33	81	49	33	82
1:15	34	25	59	40	26	66	40	30	70	40	24	64	41	42	83
1:30	34	24	58	37	28	65	38	25	63	35	21	56	38	32	70
1:45	32	19	51	34	17	51	34	20	54	34	20	54	36	22	58
2:00	40	12	52	40	13	53	42	15	57	46	13	59	43	24	67
2:15	26	15	41	29	17	46	30	18	48	28	14	42	30	32	62
2:30	17	13	30	20	8	28	20	16	36	20	17	37	19	24	43
2:45	11	14	25	14	12	26	13	17	30	13	16	29	13	19	32
3:00	11	15	26	14	5	19	14	15	29	14	25	39	13	11	24
3:15	12	13	25	15	13	28	14	16	30	14	13	27	14	23	37
3:30	19	18	37	21	19	40	23	20	43	23	15	38	22	23	45
3:45	8	17	25	9	20	29	9	16	25	9	14	23	9	15	24

4:00	9	24	33	10	28	38	10	24	34	10	20	30	10	25	35

Day	**Monday**			**Tuesday**			**Wednesday**			**Thursday**			**Friday**		
Date	5/9/2005			5/10/2005			5/11/2005			5/12/2005			5/13/2005		
Orientation	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**
Time of Day	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**
4:15	17	28	45	17	30	47	18	30	48	18	29	47	18	29	47
4:30	25	36	61	27	39	66	30	34	64	29	27	56	28	37	65
4:45	25	44	69	28	48	76	27	45	72	28	38	66	28	43	71
5:00	26	67	93	25	61	86	27	60	87	27	66	93	27	53	80
5:15	42	73	115	47	69	116	47	81	128	47	74	121	45	92	137
5:30	55	129	184	59	125	184	61	119	180	64	112	176	62	106	168
5:45	72	134	206	80	134	214	87	146	233	84	137	221	84	128	212
6:00	74	128	202	83	153	236	81	139	220	89	114	203	77	133	210
6:15	126	169	295	136	164	300	141	166	307	149	172	321	119	177	296
6:30	131	162	293	149	176	325	145	172	317	155	152	307	129	146	275
6:45	147	241	388	150	231	381	171	228	399	180	245	425	152	202	354
7:00	188	275	463	212	252	464	214	261	475	235	287	522	206	234	440
7:15	180	297	477	203	285	488	206	282	488	226	286	512	181	312	493
7:30	219	327	546	230	314	544	250	318	568	268	308	576	233	348	581
7:45	25	36	620	27	341	617	28	35	641	31	35	669	249	38	638

	9	1		6			4	7		1	8			9	
8:00	256	357	613	268	332	600	278	354	632	314	384	698	261	341	602
8:15	245	367	612	276	333	609	286	355	641	295	365	660	243	384	627
8:30	250	380	630	264	340	604	283	400	683	305	440	745	249	396	645
8:45	244	427	671	272	430	702	292	406	698	310	398	708	257	372	629
9:00	197	277	474	197	301	498	212	294	506	237	288	525	186	298	484
9:15	184	258	442	209	293	502	209	263	472	232	229	461	193	257	450
9:30	155	234	389	178	265	443	178	228	406	198	225	423	161	241	402
9:45	83	220	303	95	242	337	97	234	331	104	201	305	85	231	316
Day	**Monday**			**Tuesday**			**Wednesday**			**Thursday**			**Friday**		
Date	5/9/2005			5/10/2005			5/11/2005			5/12/2005			5/13/2005		
Orientation	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**
Time of Day	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**
10:00	106	210	316	114	207	321	121	209	330	109	206	315	115	203	318
10:15	157	205	362	165	176	341	169	211	380	163	211	374	182	203	385
10:30	167	200	367	175	204	379	180	189	369	177	179	356	180	203	383
10:45	169	193	362	187	191	378	176	196	372	184	182	366	185	201	386
11:00	16	17	340	19	165	357	19	17	366	19	17	368	190	20	398

	7	3		2			0	6		3	5			8	
11:15	152	200	352	166	183	349	170	204	374	156	222	378	178	218	396
11:30	168	192	360	196	173	369	195	191	386	194	205	399	195	223	418
11:45	178	201	379	194	194	388	197	196	393	198	199	397	204	232	436
12:00	157	210	367	185	199	384	193	205	398	183	198	381	197	224	421
12:15	186	204	390	215	204	419	223	201	424	204	191	395	221	231	452
12:30	211	196	407	226	204	430	217	210	427	221	196	417	224	239	463
12:45	194	199	393	213	215	428	206	209	415	213	203	416	212	251	463
13:00	194	205	399	207	186	393	211	207	418	213	221	434	227	221	448
13:15	217	195	412	224	178	402	219	197	416	225	213	438	232	228	460
13:30	185	207	392	193	201	394	211	203	414	190	207	397	208	215	423
13:45	207	225	432	223	208	431	232	224	456	221	222	443	220	243	463
14:00	187	210	397	220	198	418	221	228	449	202	211	413	217	255	472
14:15	210	220	430	214	228	442	235	222	457	233	227	460	228	249	477
14:30	237	196	433	244	168	412	265	204	469	269	210	479	275	223	498
14:45	220	209	429	232	183	415	253	207	460	227	207	434	246	247	493
15:00	225	216	441	249	229	478	241	213	454	261	233	494	266	241	507

15:15	212	205	417	241	212	453	244	218	462	255	204	459	243	239	482
15:30	212	215	427	243	204	447	258	224	482	249	211	460	247	246	493
Day	**Monday**			**Tuesday**			**Wednesday**			**Thursday**			**Friday**		
Date	5/9/2005			5/10/2005			5/11/2005			5/12/2005			5/13/2005		
Orientation	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**
Time of Day	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**
15:45	263	218	481	311	261	572	313	240	553	297	245	542	340	268	608
16:00	377	303	680	400	291	691	421	298	719	420	312	732	355	337	692
16:15	358	222	580	391	275	666	455	240	695	477	172	649	367	290	657
16:30	361	262	623	410	284	694	373	308	681	461	261	722	363	313	676
16:45	379	340	719	374	353	727	371	296	667	438	302	740	382	329	711
17:00	358	298	656	392	301	693	456	306	762	486	251	737	390	273	663
17:15	351	309	660	392	291	683	430	304	734	427	317	744	401	325	726
17:30	335	271	606	371	279	650	356	273	629	380	309	689	357	305	662
17:45	300	289	589	351	313	664	390	305	695	409	228	637	339	378	717
18:00	250	214	464	264	242	506	275	222	497	311	179	490	243	240	483
18:15	254	214	468	250	229	479	280	211	491	298	173	471	252	242	494

18:30	212	198	410	234	193	427	232	206	438	246	192	438	209	207	416
18:45	184	177	361	215	204	419	225	195	420	236	154	390	196	191	387
19:00	193	161	354	200	173	373	210	174	384	232	169	401	195	195	390
19:15	144	165	309	171	163	334	161	173	334	190	174	364	162	221	383
19:30	143	139	282	149	148	297	158	149	307	169	135	304	150	190	340
19:45	131	145	276	148	145	293	153	155	308	176	156	332	132	182	314
20:00	115	126	241	127	131	258	124	131	255	131	126	257	121	162	283
20:15	111	138	249	128	142	270	127	150	277	131	134	265	126	158	284
20:30	117	127	244	135	133	268	126	131	257	137	118	255	135	117	252
20:45	121	100	221	138	114	252	132	114	246	136	102	238	129	137	266
21:00	108	106	214	115	116	231	122	111	233	131	104	235	122	129	251
21:15	134	106	240	149	105	254	153	111	264	149	107	256	145	126	271
Day	**Monday**			**Tuesday**			**Wednesday**			**Thursday**			**Friday**		
Date	5/9/2005			5/10/2005			5/11/2005			5/12/2005			5/13/2005		
Orientation	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**	**Dir**	**Dir**	**Dir&Dir**
Time of Day	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**	**NB**	**SB**	**NB&SB**
21:30	95	112	207	111	116	227	111	115	226	108	108	216	108	116	224

21:45	91	104	195	103	98	201	110	104	214	111	99	210	108	132	240
22:00	104	90	194	103	109	212	113	101	214	116	77	193	111	115	226
22:15	98	98	196	105	110	215	108	104	212	106	84	190	101	134	235
22:30	120	92	212	138	98	236	134	94	228	145	84	229	131	111	242
22:45	138	84	222	144	85	229	149	87	236	153	91	244	141	101	242
23:00	167	89	256	175	100	275	183	102	285	176	85	261	181	133	314
23:15	153	80	233	154	77	231	154	88	242	169	70	239	154	111	265
23:30	130	65	195	137	60	197	139	76	215	148	71	219	150	97	247
23:45	103	47	150	111	56	167	108	63	171	112	43	155	112	113	225

Table A.2: Daily Traffic Volume in November 2008

VEHICLE VOLUME SUMMARY

District Of Columbia

Department of Transportation

Traffic Services Administration

Station # 96

Location **North Capitol St** Between Michigan Ave NE and Irving St NW

Day	Tuesday			Wednesday			Thursday			Friday			Monday		
Date	11/18/2008			11/19/2008			11/20/2008			11/21/2008			11/24/2008		
Orientation	Dir	Dir	Dir&Dir	Dir	Dir	Dir&Dir	Dir	Dir	Dir&Dir	Dir	Dir	Dir&Dir	Dir	Dir	Dir&Dir
Time of Day	NB	SB	NB&SB	NB	SB	NB&SB	NB	SB	NB&SB	NB	SB	NB&SB	NB	SB	NB&SB
0:00	97	47	144	64	41	105	92	61	153	90	46	136	96	48	144
0:15	89	68	157	58	37	95	73	58	131	67	34	101	86	41	127
0:30	67	31	98	37	22	59	59	28	87	58	30	88	73	27	100
0:45	44	47	91	31	25	56	41	19	60	40	38	78	40	28	68
1:00	39	26	65	23	13	36	36	23	59	55	17	72	54	19	73
1:15	54	37	91	32	16	48	33	16	49	39	28	67	44	24	68
1:30	43	22	65	28	18	46	29	16	45	36	19	55	39	20	59
1:45	33	15	48	32	21	53	28	19	47	29	30	59	32	23	55
2:00	39	19	58	20	13	33	20	14	34	39	19	58	26	17	43
2:15	45	25	70	27	12	39	28	16	44	44	12	56	21	15	36
2:30	28	22	50	19	13	32	18	16	34	32	18	50	17	13	30
2:45	23	11	34	15	16	31	25	11	36	27	28	55	20	14	34
3:00	23	21	44	17	9	26	15	23	38	30	10	40	17	7	24
3:15	28	18	46	21	14	35	16	11	27	23	23	46	15	15	30
3:30	14	27	41	16	19	35	23	16	39	27	28	55	14	20	34
3:45	39	40	79	17	23	40	31	36	67	16	29	45	19	24	43
4:00	36	24	60	24	34	58	25	32	57	30	32	62	17	36	53

4:15	24	53	77	21	45	66	25	53	78	25	49	74	24	65	89
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Time of Day	NB	SB	NB&SB	NB	SB	NB&SB	NB	SB	NB&SB	NB	SB	NB&SB	NB	SB	NB&SB
4:30	17	42	59	34	57	91	30	58	88	31	59	90	26	77	103
4:45	34	69	103	37	76	113	40	82	122	38	85	123	49	99	148
5:00	44	89	133	45	108	153	39	137	176	52	116	168	45	149	194
5:15	47	159	206	62	167	229	63	169	232	56	171	227	51	188	239
5:30	59	190	249	78	186	264	62	180	242	78	197	275	69	233	302
5:45	87	172	259	106	218	324	102	210	312	124	213	337	80	231	311
6:00	95	174	269	107	207	314	126	222	348	120	197	317	117	271	388
6:15	125	199	324	155	280	435	162	275	437	146	242	388	123	300	423
6:30	158	256	414	178	272	450	141	274	415	202	263	465	137	329	466
6:45	143	252	395	240	305	545	235	306	541	220	289	509	176	293	469
7:00	196	225	421	246	294	540	270	287	557	235	293	528	238	317	555
7:15	260	250	510	256	310	566	260	308	568	290	320	610	241	344	585
7:30	230	228	458	302	302	604	314	317	631	301	322	623	259	348	607
7:45	268	246	514	320	312	632	304	330	634	312	312	624	255	338	593
8:00	209	234	443	307	303	610	296	333	629	317	313	630	232	384	616
8:15	247	244	491	273	353	626	283	340	623	286	329	615	239	388	627
8:30	225	277	502	248	355	603	255	324	579	263	297	560	214	364	578
8:45	208	256	464	238	323	561	240	338	578	257	342	599	209	335	544
9:00	191	269	460	203	300	503	203	332	535	228	334	562	174	325	499
9:15	210	235	445	198	303	501	193	325	518	203	300	503	204	304	508
9:30	202	291	493	181	278	459	198	287	485	223	299	522	173	290	463
9:45	224	256	480	199	285	484	217	272	489	180	273	453	169	274	443

10:00	204	227	431	204	222	426	203	210	413	188	248	436	180	234	414
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Time of Day	NB	SB	NB&SB	NB	SB	NB&SB	NB	SB	NB&SB	NB	SB	NB&SB	NB	SB	NB&SB
10:15	252	196	448	207	226	433	208	225	433	225	251	476	206	221	427
10:30	244	226	470	210	206	416	215	247	462	196	217	413	165	209	374
10:45	238	231	473	206	214	420	244	201	445	239	218	457	172	198	370
11:00	239	196	435	190	179	369	222	222	444	184	200	384	196	187	383
11:15	214	207	421	195	178	373	199	189	388	208	189	397	170	200	370
11:30	240	216	456	199	190	389	200	179	379	221	204	425	183	189	372
11:45	212	217	429	190	179	369	188	186	374	171	206	377	206	189	395
12:00	256	200	456	209	182	391	178	186	364	209	198	407	193	200	393
12:15	249	221	470	215	202	417	229	205	434	216	196	412	214	196	410
12:30	262	226	488	228	194	422	208	186	394	229	211	440	207	195	402
12:45	257	197	454	212	185	397	212	172	384	213	214	427	189	201	390
13:00	278	219	497	245	207	452	224	171	395	249	167	416	192	207	399
13:15	269	236	505	231	210	441	216	209	425	247	215	462	211	211	422
13:30	280	217	497	236	204	440	223	170	393	244	198	442	226	213	439
13:45	248	237	485	262	208	470	224	193	417	264	203	467	230	209	439
14:00	307	256	563	270	196	466	261	202	463	328	177	505	217	223	440
14:15	281	228	509	283	222	505	279	204	483	317	198	515	284	221	505
14:30	349	217	566	306	224	530	302	186	488	311	192	503	267	234	501
14:45	308	194	502	294	213	507	325	200	525	320	208	528	265	222	487
15:00	309	220	529	332	210	542	281	231	512	318	205	523	293	199	492
15:15	317	245	562	317	208	525	284	221	505	352	211	563	280	213	493
15:30	317	269	586	351	207	558	321	204	525	359	236	595	283	233	516

15:45	383	243	626	362	225	587	350	182	532	356	227	583	303	235	538
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16:00	327	229	556	389	224	613	323	213	536	359	222	581	310	249	559
16:15	362	246	608	368	198	566	361	224	585	358	221	579	300	226	526
16:30	307	249	556	406	225	631	351	213	564	400	224	624	307	243	550
16:45	326	242	568	371	199	570	344	233	577	371	238	609	292	227	519
17:00	329	213	542	371	210	581	352	203	555	390	209	599	330	250	580
17:15	336	218	554	378	243	621	403	215	618	399	204	603	331	236	567
17:30	331	238	569	383	214	597	386	219	605	422	212	634	319	221	540
17:45	344	252	596	382	195	577	364	204	568	340	230	570	337	211	548
18:00	354	215	569	382	194	576	336	183	519	317	186	503	312	217	529
18:15	336	232	568	388	190	578	348	196	544	316	215	531	321	221	542
18:30	252	233	485	366	200	566	360	170	530	318	213	531	275	212	487
18:45	242	203	445	297	211	508	337	205	542	321	231	552	268	227	495
19:00	270	216	486	283	192	475	250	221	471	215	212	427	230	209	439
19:15	246	213	459	290	200	490	293	175	468	285	199	484	240	200	440
19:30	241	181	422	236	168	404	255	167	422	287	197	484	210	191	401
19:45	199	181	380	198	170	368	190	142	332	221	171	392	190	177	367
20:00	175	159	334	235	157	392	190	129	319	197	172	369	162	153	315
20:15	178	179	357	214	114	328	191	137	328	205	140	345	166	126	292
20:30	206	125	331	195	117	312	185	139	324	201	141	342	172	117	289
20:45	173	121	294	196	112	308	182	131	313	185	122	307	145	110	255
21:00	184	143	327	189	112	301	180	123	303	184	121	305	139	132	271
21:15	195	141	336	188	123	311	182	146	328	180	90	270	162	137	299

21:30	195	128	323	198	142	340	171	132	303	199	103	302	137	128	265
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Time of Day	NB	SB	NB&SB	NB	SB	NB & SB	NB	SB	NB & SB	NB	SB	NB&SB	NB	SB	NB&SB
21:45	160	134	294	152	115	267	172	91	263	162	90	252	150	117	267
22:00	161	127	288	175	120	295	183	100	283	164	100	264	141	124	265
22:15	182	126	308	147	114	261	155	110	265	184	89	273	154	126	280
22:30	169	112	281	149	95	244	151	101	252	167	116	283	132	96	228
22:45	133	125	258	164	88	252	131	106	237	181	94	275	129	85	221
23:00	150	75	225	151	78	229	130	69	199	164	89	253	131	77	208
23:15	163	69	232	158	78	236	142	72	214	193	73	266	120	74	194
23:30	143	87	230	126	66	192	129	63	192	174	71	245	109	59	168
23:45	102	79	181	98	60	158	101	68	169	124	59	183	82	71	153