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Comprehensive Field Evaluation of Asphalt Patching Methods and Development of Simple Decision Trees and a Best Practices Manual

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16. Abstract (Limit: 250 words)

The long-term performance of pothole patches largely depends on the selection of the patching method. A number of pothole patching methods are in practice in Minnesota and other nearby states. However, pavement maintenance crews often encounter problems in selecting the most appropriate patching method because proper guidelines are not available. The objective of this project was to investigate the effectiveness of different pavement patching methods and to develop simple decision trees and a best practices manual. The performance of 20 different pothole patches, which were patched with four different types of patching methods and located at five different construction sites, were monitored for approximately two years. Based on the observed performance of the pothole patches considered in this study, two forms of decision trees and a best practices manual have been developed for selecting the most appropriate patching method for a given pothole condition. The developed decision trees can be used to select the patching method based on the location of the pothole (e.g., along longitudinal joints, localized potholes, etc.), construction season, condition of the pothole, and pothole area and depth. The best practices manual provides guidelines on the selection of patching method, pothole preparation, placement of patching materials, and compaction.

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Comprehensive Field Evaluation of Asphalt Patching Methods and Development of Simple Decision Trees and a Best Practices Manual

FINAL REPORT

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EXECUTIVE SUMMARY

The long-term performance of pothole patches on asphalt pavement largely depends on the selection of the patching method. A number of pothole patching methods are in practice in Minnesota and other nearby states. Cold asphalt mixes are generally used during the winter season. The objective of winter patching is to quickly patch distressed areas and maintain ride quality until more permanent patching operations can be performed. Hot asphalt mixes are mostly used in non-winter seasons and they are semi-permanent in nature. In recent years, research has been conducted investigating ways to provide hot-mix asphalt in the winter months, when asphalt production plants are not in service. Several types of on-site machineries are available for preparing hot asphalt mixes on the job site, such as Stepp SRM10-120 Asphalt Recycler/Mixer and Heatwurx® HWX-30 infrared heater. Slurry mix and mastic material are also used for patching potholes. Almost all of the above-mentioned patching methods are used in Minnesota. However, maintenance crews encounter the problem in deciding the most appropriate patching method for their job.

The objectives of this project were: (i) to explore different patching tools, materials, and methods used in Minnesota and identify the most appropriate materials and methods based on the pothole condition (e.g., depth, area, etc.), location (e.g., potholes along the longitudinal crack, localized potholes, etc.), and season (winter season and non-winter seasons); (ii) to study the effectiveness of the different pothole patching methods in terms of durability, customer satisfaction, road safety, riding quality, etc.; (iii) to develop decision trees to help maintenance crews select the most appropriate pothole patching method for their job; and (iv) to develop a best practices manual outling different steps for performing patching operations.

In order to achieve the abovementioned objectives, a comprehensive literature survey was conducted to be familiar with the current practices of pothole patching in Minnesota and other states. Several construction sites were then selected for monitoring and evaluating the performance of the different patches. All sites were located in Minnesota Department of Transportation (MnDOT) District 1. A total of five sites were selected in which 20 different potholes were repaired with four different types of patching methods: cold mix, recycled asphalt mix, mastic material, and mill and fill with virgin hot-mix asphalt (HMA). The performance of the patched potholes were monitored for approximately two years. The following are some major findings and recommendations based on the performance and evaluation of the above-mentioned 20 pothole patches:

Cold mix: Cold-mix patches should only be placed in potholes with a depth of less than two inches. If the depth is greater than two inches, patching must be performed in two lifts. One of the main issues with cold-mix patching is the dishing (settlement) that occurs when placed in potholes that are deeper than two inches.

Hot recycled mix: The recycled milling is not a suitable patch material because of the presence of aged binder in it. Binder present in the mixer slows down the heating process and creates a patch that rapidly ages. The fine material in the recycled milling can prevent the bond required between binder and aggregate. The additional oil (asphalt binder) added to the mix differs from the asphalt binder that exists

in the mill tailings. The oil does not appear to rejuvenate the old asphalt but simply adds a negligible amount of new binder.

Mastic material: The current mastic practice appeared to be working well. The use of mastic material to fill larger potholes that exist along a longitudinal crack is not recommended. Mastic material does not have enough structure to support loads. Filling potholes with this material may lead to an area with a dished patch. The material creates a smooth service; however, it is recommended that this operation only be used on centerline joints or longitudinal joints along the shoulder. The use of this material in a wheel path could cause a hazardous driving surface.

Mill and fill with virgin HMA: Sufficient tack should be applied during the operation. Trucks driving in the milled trench after the placement of tack should be avoided. Attentiveness to what areas are milled is importance to ensure that the correct areas of the roadway are treated. Attentiveness to the proper amounts of HMA being placed is important to ensure proper compaction and to help eliminate distresses such as dishing or raveling at the patch and old pavement interface. The main concern with the mill and fill operation is the longevity of the patch. Significant deterioration was found to occur along the patch and old pavement interface after being in the service for a little longer than 100 days. This low service life can cause more damage to the roadway than the original distress.

Based on the above-mentioned findings, two forms of decisions trees have been developed. The decision trees have been developed in two formats: one in the form of flow chart that can be used in the maintenance guide and the other in the form of flash cards that can be kept by the maintenance crew for quick reference. Finally, a best practices manual was developed to provide a brief discussion on the patching method selection, placement, and compaction of the patching materials and moisture abatement.

CHAPTER 1: INTRODUCTION

The long-term performance of pothole patching on asphalt pavement largely depends on the selection of the patching method. A number of pothole patching methods are in practice in Minnesota and other nearby states. However, pavement maintenance crews often encounter problems in selecting the most appropriate patching method for their job. They do not have a proper guideline to decide on the most appropriate patching method based on the severity and extent of the pothole, season, location, and the distresses responsible for causing the pothole. The objective of this project was to conduct research on different pavement patching methods in order to obtain: (i) longer-lasting patches, (ii) higher customer satisfaction, (iii) safer roads, (iv) improved rides, and (v) enhanced tools for the determination of repair methods. These objectives were achieved through the observation and documentation of several pavement patching test locations in MnDOT District 1.

The project had several different tasks involving activities such as reviewing relevant literature, monitoring performance of different types of patches at selected locations, analyzing performance of the selected patches, and developing decision trees and a best practices manual to provide guidelines for selecting the most appropriate patching method. Based on the findings from the literature review and performance analysis of the patches considered in this study, decision trees have been developed for selecting the most appropriate patching method. Decision trees were developed in two formats: (i) in the form of flow charts that can be included in the pavement maintenance guide, and (ii) in the form of flash cards that can be used by pavement maintenance crew staff, who often get very limited time to go through a large maintenance guide. In addition to the decision trees, a best practices manual has also been provided, which discusses the selection of the patching method, pothole preparation procedure, placement and compaction procedure, and moisture abatement issues.

CHAPTER 2: BACKGROUND

Patching potholes of the asphalt pavement is one of the most important maintenance operations that keep roadways serviceable. Potholes are mostly the end results of pavement distresses irrespective of the distress mechanism. Potholes vary in sizes and severities based on the distress mechanism, pavement material qualities, and construction procedures. According to the European Road Administrations (ERA-Net road), pothole refers to the following:

- Potholes typically have a depth of at least 1 inch and an area equivalent to a diameter between 4 inches and 3 feet.
- Potholes can grow once they have emerged, but generally stop growing after a certain time. However, other potholes can appear close to an existing one.
- Potholes can occur due to several mechanisms (such as fracture, attrition and seasonal).
- Among several reasons, three main causes of potholes include freeze-thaw action, traffic, and poor base support.
- Potholes require repair action rapidly to maintain the safety of road users.
- Potholes require repair to maintain the functional requirements and comfort.

Not only are potholes detrimental to the integrity of the roadway and user safety; they are also a huge economic burden for transportation agencies. Pothole repair can cost millions of dollars every year, especially in regions with cold and wet climates. There are two main repair operations that happen during a year; winter season repair and spring season repair. During the winter, as the temperature is low, hot mix asphalt is generally unavailable. Hot mix asphalt is available during the spring, however base conditions are wet and soft. The following section provides a discussion on the different types of patching methods and materials used in pothole patching operation.

2.1 PATCHING WITH COLD MIX

The main objective of winter patching is to quickly patch distressed areas and maintain ride quality until a more permanent patch can be applied. Despite a short life expectancy, it is still important to create a high quality patch. Winter patching has a shorter life expectancy due to more stress being acted on the patching materials as they go through cold and warm cycles. Installing a low quality patch is however likely to fail sooner and may result in waste of time, money, and resources. It is understood that around 60-80% of the total patching cost is due to labor and equipment. This percentage can even increase to 95% when emergency repairs are performed (Unique Paving Materials Corporation, 2014).

A winter time cold mix patch made with high-quality material, good workmanship, and compaction using a work truck can provide a semi-permanent repair (Unique Paving Materials Corporation, 2014). The procedure for cold mix patching is quite simple. Maintenance crews use brooms or air compressors to sweep and clean the debris out of potholes. The use of compressed air also helps to dry out the potholes if a minimal amount of water is present. Once the pothole is cleaned, crews place the cold mix. Mix temperatures vary but are usually in the range of 50°F-100°F. Material is over filled in the pothole and crews provide various levels of compaction. Different methods of compaction include tamping with a shovel, rolling a truck's wheel over the patch, using a small compactor, or no compaction at all. The degree to which a patch is compacted can make a large difference in the durability of a patch.

2.2 PATCHING WITH HOT MIX

Patching with hot mix asphalt (HMA) is generally performed in non- winter seasons. However, in recent years, research has been conducted investigating ways to provide hot mix asphalt in the winter months as well when asphalt production plants are not in service. Several types of on-site machinery are available for this purpose. Two pieces of equipment that were looked at in this study include:

- Stepp SRM10-120 Asphalt Recycler/Mixer
- Heatwurx® HWX-30 infrared heater

The use of conventional asphalt in patch work such as mill and fill operations and application of mastic were also included in this study.

2.2.1 Stepp SRM 10-120

The Stepp SRM10-120 is a single unit asphalt recycler that is able to reheat small batches of asphalt millings on site to provide hot patching material during the off season of asphalt production. The SRM 10-120 uses an indirect heating method inside its ten cubic foot hopper. This heating method does not have the flame come in direct contact with the mix. An indirect method reduces the amount of oil that is burned off in the process and can allow up to 90% of the oil in a mix to be retained. A picture of the SRM 10-120 unit is shown below in Figure 2.1.

Figure 2.1 Stepp SRM 10-120 Asphalt Recycler.

The mixing process with a Stepp SRM 10-120 is fairly simple. First asphalt millings are loaded into the hopper by shoveling the millings onto the hydraulic loading conveyor. Millings are taken by the conveyor and dumped into the pre-heating hopper where they are heated by the exhaust of the machine's diesel engines. Next, material is put into the mixing chamber. The chamber heats the millings while additional oil is added. The mix is heated to a desired temperature (usually 300°F) and then discharged out of the chamber (Stepp Mfg., 2014). The manual for this machine claims that it can produce up to 3 tons of mix per hour however MnDOT has been unable to produce recycled asphalt mixes at such a rate.

Benefits

- Minimal new material required
- Functions at air temperatures as low as 20°F
- Single lane closure

Concerns

- In field, mix rates do not match to the claimed capabilities
- Additional oil required is dependent on recycled milling used
- Recycled millings contain imperfections that can lead to inconsistent strength properties

Use of Stepp SRM 10-120 can be helpful in using reclaimed asphalt pavements (RAP) in patching mixes. The driving force for the use of RAP material is creating an economical mix. RAP material is acquired through the milling of old asphalt roadways during construction of rehabilitation projects. The use of RAP in projects reduces the amount of virgin material required. This recycling reduces the asphalt costs of projects as well as providing environmental benefits by reducing the amount of virgin material being manufactured (Zofka et al., 2010). Although there are both economic and environmental benefits, the inconsistency of the asphalt binder in RAP material can make mix designs and batching difficult. Another setback of RAP material arises during the batching process. The Stepp machine heats up milling material to a temperature of around 300°F. During the heating process the machine is unable to run at full heating capacity because it ignites the binder material in the RAP. To address this issue the current method has the machine heating up the material in intervals. The heat is on for one minute and then off for two. This significantly slows down the production process requiring about an hour to create a 500 pound batch.

2.2.2 Heatwurx®HWX-30

Heatwurx® HWX-30 is a self-contained unit that includes a generator and an infrared heater. This unit is designed to heat up in-place asphalt concrete to a temperature of 350°-375°F in order to perform patching on distressed areas. The unit has a footprint of 3.5 by 8 feet in which it can heat up the pavement. The unit was designed to easily attach to a skid steer for moving and placing of the unit on site. Figure 2.2 shows a picture of a Heatwurx® HWX-30.

The patching process can be performed in a single lane closed to traffic; however for the positioning of the heating unit, two lanes may sometimes be required for maneuvering. The Heatwurx unit is placed over the distressed area and begins to heat the asphalt to the set temperature. According to the HWX-30 spec sheet, the unit can heat pavement up to 350°-375°F in a time of 20-40 minutes (Heatwurx, 2014a). The unit can be lifted by a skid steer in order to check the pavement temperature with the use of an infrared thermometer. Once the pavement reaches the desired temperature the unit is removed. A skid steer with an HWX-AP40 asphalt processor attachment scarifies and mills the surface to be treated. The HWX-AP40 has a 5/16 inch processing blade that can mill at a width of 40 inches (Heatwurx, 2014b). The pavement is broken down within several passes. At this point, rejuvenator and additional patching material is added in order to rejuvenate the old asphalt being recycled and to reach the required patch volume to create a flush profile. The amount of rejuvenator added is based on the experience of the maintenance crew. The materials are mixed using the HWX-AP40 and then compacted using a small vibratory hand roller. Once the patch has cooled the lane is opened to traffic. Some of the benefits and concerns of using Heatwurx machinery are listed below.

Figure 2.2 Heatwurx® HWX-30 (Source: Freeman and Epps, 2012).

Benefits

- Minimal new material required
- Only requires a single lane closure
- Can patch a 3.5 by 8 foot area at once

Concerns

- Depths over two inches are insufficiently heated to allow milling
- Considerable judgment is required during process including
  - The time required for heating Asphalt
  - The amount of rejuvenator and additional material to be added
  - When proper compaction is obtained

It may be stated that during the discussion of site locations and pothole patching methods to consider in the present study with the MnDOT maintenance staff, it was decided not to include Heatwurx in the study because MnDOT district-1 did not have access to the Heatwurx unit and was not sure of using it as pothole patching equipment.

2.2.3 Conventional Hot Mix Asphalt (HMA)

The use of conventional HMA for patching material is common for patching operations. Different placement methods can be used for HMA, such as temporary applications like throw and go to more permanent patching like mill and fill. Since HMA is only available during the warmer season when bituminous plants are in operation, it is often used for more permanent patching practices. The mill and fill practice uses a milling machine to remove a section of roadway and fill the area with new HMA materials. The width of a mill patch varies based on the width of the milling machine used and the number of passes a machine makes. The depth at which a road is milled is also variable by setting the milling blades to the required depth. In practice, a depth of two inches is common. Once the area is milled and cleaned, new HMA material is placed and compacted. Compaction can be accomplished through hand held machines or steel drum rollers for larger projects.

2.2.4 Slurry Mix

A slurry seal is a mixture of fine aggregate, asphalt emulsion, cement, and water (CalTran, 2013). Curing is generally controlled by ambient temperatures and other climatic factors (Wood et al., 2009). This treatment is placed by a slurry box that uses a screed to control the thickness applied. Often a slurry seal is placed to prevent water penetration, oxidation, and solar radiation (Wood et al., 2009). It should be noted that different aggregate gradations are recommended based on the functional classification of the roadway being repaired. The slurry machine used by MnDOT is shown below in Figure 2.3. This machine was built specifically for MnDOT by Stepp. The machine uses a weight monitored hopper to measure the aggregate placed in the hopper to create a slurry batch. Cement, asphalt emulsion, and water are then added based on a percentage of the aggregate weight. These percentages are inputs typed into the machine's computer and can be adjusted to create different batches of patch material. The material is mixed and dispensed out the back of the machine. A batch ranging from 200-1000 pounds can be mixed and dispensed in approximately 15 minutes.

The following is the procedure for a slurry seal as described by the International Slurry Surfacing Association in "Recommended Performance Guidelines for Emulsified Asphalt Slurry Seal" (International Slurry Surfacing Association, 2014). Surface preparation should occur immediately before the slurry seal application. The surface should be cleaned of loose material, oil, etc. Cracks need time to thoroughly dry before application of the seal if water is used during the cleaning process. Utility covers, manholes, and inlets need to be protected from the seal. A tack coat is normally not required unless the surface has raveling or is excessively dry. Cracks are to be pre-treated with a crack sealer prior to the slurry seal application.

Figure 2.3 Stepp Slury Machine.

Slurry seals are mixed on site using a self-contained mixing machine. The machine has the capability to provide an accurate proportion of materials to create the project's slurry seal mix design. The mix is placed using a spreader box that is attached to the mixing machinery. This box has the capability to agitate and spread material evenly throughout the entire box to a desired level. Attached behind the box is a screed which drags across the slurry seal to provide a uniform and textured mat. After the seal is placed, proper curing time is required before opening the road to traffic. In general, the time required is between 4-8 hours. Roads with sharp turns or stopping actions may require a longer curing time. Slurry seals are not to be applied if the air temperature is below 50°F, if rain is imminent, or there is a potential to freeze within 24 hours (International Slurry Surfacing Association, 2014). It may be stated that the present project has conducted a study on the slurry mix design refinement through a laboratory program at the University of Minnesota Duluth. The mix design related work is reported in Appendix A. However, the field performance of the slurry mix as pothole patching method could not be included in this project because of not having access to a test site during the field performance study under this project.

2.3 POTHOLE PREPARATION

There are several methods that prepare a pothole for patching. Each method prepares the roadway to a different degree. In general, the easier and quicker procedures do not clean the pothole as much as longer methods.

- Sweeping: A crew member uses a steel brush to sweep out a pothole removing dirt, debris, and any standing water. This method removes large particles from the hole but does not necessarily remove fine material.
- Compressed air: A crew member uses a hose attached to an air compressor to remove dirt, debris, and any standing water. This method removes both fine and large particles as well as helps to dry the surface of the pothole.
- Milling: Two different types of machinery are used for the milling process. The first process is used for smaller milling operations such as milling out single potholes or shorter length cracking and distresses. A mill head attached to a skid steer is used to mill out the pavement in the area immediately adjacent to the pothole. A crew member shovels the large debris and millings away from the hole and then uses an air compressor to remove any remaining dirt and fine material. The second method uses a milling machine. This machine is used for larger milling projects such as the replacement of longitudinal joints. The machine removes the old pavement and places it into a truck for removal. A sweeper vehicle follows behind the operation to clean up any debris left behind. This method removes both fine and large particles as well as creates a square hole with flat edges and a relatively uniform depth. This shape improves the ease of compaction and facilitates a stronger bond between the patch and the existing roadway.

CHAPTER 3: PERFORMANCE EVALUATION OF POTHOLE PATCHES

Under the scope of this study, performance of pothole patches were monitored at selected locations. The following section describes each site location and details about the patch work completed including patch preparations, construction method, a pothole's existing conditions and size, and completed patchwork and performance over a period of two years. Also, this section analyzes the retention of pothole materials for three locations one year after the construction. A pictorial step by step process for each maintenance operation is also provided in Appendix B.

3.1 PROJECT SITES SELECTION

Project sites were selected through discussions between the MnDOT District 1 maintenance department and the research team. All the selected project sites were located within the MnDOT District 1. Table 3.1 provides the locations of preliminary selected sites. This table also presents the suggested method of patching in each preliminary selected location and the corresponding schedule of construction. It should be noted that the Heat Wurx was also initially included in this list as it was part of the work plan; however, because this method was not in practice in District 1 during the project duration, and also due to a short maintenance season, maintenance members were initially unsure if they would have time to test this particular method of pothole patching operation.

Due to various factors such as time, traffic control, weather and other constraints, not all sites and methods listed in Table 3.1 were used for this study. Table 3.2 provides a list of the locations where the performance of the pothole patches could actually be investigated. A total of five sites (A through E) were finally selected. The corresponding pothole patching methods and construction schedule are also included in Table 3.2. Out of five project locations mastic and patching with recycled asphalt mix were each studied in one site. The cold mix method and mill & fill method each were applied at two sites. The patching work was performed between April, 2014 to August, 2014. The following subsections present discussion on each project site separately.

Table 3.1 List of Preliminary Selected Pothole Locations and Possible Patching Method

Method	Location	Highway	Time
Cold Mix	Lester Hill	61	April, 2014
Recycle	Lester Hill	61	April, 2014
Rapid Patch	Expressway (Homestead NB)	61	May, 2014
Mastic	Conc. - T. Hill	35	June, 2014
Slurry	53	53	September, 2014
Cold Mix	Grand Ave	23	April, 2014
Recycle	Grand Ave	23	April, 2014
Mill & Fill	1" Grand Ave	23	August, 2014
Mill & Fill	2" Proctor	2	September, 2014
Mastic	Bit - Cloquet	33	April, 2014
Hot Mix	33 @ Gordy's	33	July, 2014
Heat Wurx	33 @ Gordy's	33	July, 2014

Table 3.2 Final Pothole Patching Site Locations and Patching Methods

Site Number	Method	Location	Number of potholes	Hwy	Time
A	Cold Mix	Lester Hill	5	61	April
B	Cold Mix; and Recycled Asphalt Mix	Grand Ave	6	23	April
C	Mastic	I-35 (Bituminous)	1	I-35	May
D	Mill & Fill	Trinity Ave	3	53	July
E	Mill & Fill	Highway 53	5	53	August
Total number of potholes considered in the study			**20**		

3.2 CONSTRUCTION AND PERFORMANCE STUDY

Multiple potholes were considered in each of the locations mentioned in Table 3.2. The exact locations of these potholes in terms of longitude and latitude can be found in the Appendix B. Description of potholes in selected sites and the corresponding patching methods and construction details are provided in this subsection.

3.2.1 Site A: Northbound Trunk Highway 61

This site is located on Trunk Highway 61 just north of where the road turns into an expressway. This site was selected to study the performance of cold mix patching materials. Five different potholes were chosen to monitor the performance of the patch material and method. In order to properly reference these potholes in this report, five pothole locations were numbered as A-1 through A-5. In general, the potholes exist in the top 2-inch overlay with a flat bottom in each hole at the interface of the underlying asphalt layer. Three out of five potholes were badly damaged and located along the right hand shoulder joint (Potholes A-1, A-3 and A-5). The other two potholes, with some minor damages, were located in non-wheel path areas of the driving lane (Potholes A-2, and A-4). All five potholes were patched on April 8, 2014. The temperature was 30°F with overcast sky. Three maintenance crew members performed the patching work, one member was involved in cleaning and the other two members performed the patching operation. The following points provide brief description of all five potholes considered in Site A, Highway 61.

Pothole A-1: This pothole was located along the shoulder joint of the roadway. The pothole lies in between two reflective transverse cracks and has a longitudinal crack running along the bottom of the pothole as shown in Figure 3.1. The pothole was prepped by sweeping the area. The size of the pothole was 40 inches x 14 inches x 2 inches.

Pothole A-2: This pothole was located in the non-wheel path of the driving lane. The pothole lies along a large transverse crack with the north face of the pothole being a previously placed patch material as shown in Figure 3.2. The pothole was prepped by sweeping. The size of the pothole was 13 inches x 9 inches x 2 inches.

Pothole A-3: This pothole was located along the shoulder joint. The pothole lies along an existing longitudinal crack in the overlay with a reflective transverse crack crossing through the pothole as shown in Figure 3.3. The pothole was prepped using compressed air. The size of the pothole was 37 inches x 13 inches x 2 inches.

Pothole A-4: This pothole was located in the non-wheel path of the driving lane. The pothole exists at the intersection of a reflective longitudinal and transverse crack as shown in Figure 3.4. The pothole was prepped using compressed air. The size of the pothole was 10 inches x 10.5 inches x 1.5 inches.

Pothole A-5: This pothole was located along the shoulder joint. The pothole lies along an existing longitudinal crack in the overlay with a reflective transverse crack crossing through the pothole as shown in Figure 3.5. The pothole was prepped using compressed air. The size of the pothole was 17.5 inches x 13 inches x 1.5 inches.

Figure 3.1 through Figure 3.5 show the potholes prior to patching and Figure 3.4 illustrates the difference in conditions before and after cleaning a pothole using A-4 as an example.

Figure 3.1 Pothole A-1 prior to Patching (After Cleaning).

Figure 3.2 Pothole A-2 prior to Patching (After Cleaning).

Figure 3.3 Pothole A-3 prior to Patching (After Cleaning).

Figure 3.4 Pothole A-4 prior to Patching (Before and After Cleaning).

Figure 3.5 Pothole A-5 prior to Patching (After Cleaning).

All five potholes were patched using cold mix at a temperature of 100°F and tamped using a shovel. The depths of all the potholes were around 1.5 to 2 inches. Each of the potholes were patched and tamped within a few minutes of placement. The potholes after the completion of patching are shown in Figure 3.6 through Figure 3.10.

Figure 3.6 Pothole A-1 after Patching.

Figure 3.7 Pothole A-2 after Patching.

Figure 3.8 Pothole A-3 after Patching.

Figure 3.9 Pothole A-4 after Patching.

Figure 3.10 Pothole A-5 after Patching.

3.2.1.1 Performance Analysis

Performance of the patching materials on all five pothole locations mentioned above was monitored for approximately a year. Table 3.3 presents dates of the site visits conducted for monitoring the performance through first 240 days since the day of installation of patching. The performance was monitored a total of eight times from April 8, 2014 through December 4, 2014. Performance of the patches could not be monitored in the following years because of the rehabilitation work performed on the Site A location.

Table 3.3 Schedule of Visits for Site A

Date Visited	Days Since Installation
4/8/2014	0
4/11/2014	3
4/15/2014	7
4/18/2014	10
4/29/2014	21
7/9/2014	92
9/4/2014	149
12/4/14	240

Figure 3.11 through Figure 3.20 provide some photographs of the patches taken at different times to demonstrate how cold mix patches aged over time. It appears that the largest change had occurred within the first three days after patching installation while the cold mix material was still compressing under self-weight and traffic loads. Loose material around the patch edges was also removed during this time. Minimal material was removed after the initial three days.

Figure 3.11 Pothole A-2 (3 Days after Patching).

Figure 3.12 Pothole A-2 (149 Days after Patching).

Figure 3.13 Pothole A-3 (149 Days after Patching).

Figure 3.14 Pothole A-4 after Patching.

Figure 3.15 Pothole A-4 (3 Days after Patching).

Figure 3.16 Pothole A-4 (149 Days after Patching).

Figure 3.17 Pothole A-5 (3 Days after Patching).

Figure 3.18 Pothole A-5 (92 Days after Patching).

Although the cold mix patches had a hard compacted layer on the top of the patch, underneath that layer was pliable material that still had an oily shine consistent with the day the pothole was patched. Based on the last visit conducted on December 4, 2014, the conditions of the patches were found to be somewhat similar to the previous visits. The only noticeable difference was some abrasion on the patch material from snow plow blades. This abrasion was most noticeable in patch A-4 (Figure 3.19). Also on

December 4, 2014, it was observed that the pothole A-5 experienced a significant depression in the material since the last visit, as well as some material loss near the bottom of the patch (Figure 3.20).

Figure 3.19 Pothole A-4 (240 days after installation) with Snow Plow Abrasion.

Figure 3.20 Pothole A-5 (240 Days after Installation).

3.2.1.2 Retention Analysis

Using AutoCAD, the surface area of different patches was modeled in order to find the retention of patch material over time. This modeling was performed for Pothole A-4 and A-5 from Site-A.

Pothole A-4: Two different site visit dates were used to calculate the retention of material. The dates of comparison are April 29, 2014 (Figure 3.21) and July 9, 2014 (Figure 3.22). During that 71 day time span, the patch lost was approximately 13% of its surface area. The material lost was mostly extra patch material overlaying the existing road. The entire pothole was still patched and protected from moisture.

Figure 3.21 Image used for A-4 Retention Calculation (4/29/14).

Figure 3.22 Image Used for A-4 Retention Calculation (7/9/14).

Pothole A-5: Three different site visit dates were used to calculate the retention of material. The dates of comparison are April 29, 2014 (Figure 3.23), July 9, 2014, and December 4, 2014 (Figure 3.24). Over time this patch lost a bit of material at the bottom. The total amount of material lost from April 29 to December 4 (219 days) was 17%.

Figure 3.23 Image Used for A-4 Retention Calculation (7/9/14).

Figure 3.24 Image Used for A-5 Retention Calculation (12/4/14).

3.2.2 Site B: Eastbound Grand Avenue

This roadway was heavily damaged and had existing-patchwork all along the road. The most severe damage was along the right wheel path in the driving lane. This project site was selected to study the performance of patches prepared with cold mix and hot recycled asphalt millings. A total of six potholes (designated as B-1 through B-6) were selected in this location. All six potholes selected at this site were along the right wheel path in the driving lane that was previously repaired. Unlike the site A, this site had a great quantity of patching works and six crew members were involved in the operation. One crew member was for milling, one for prepping the potholes, two for shoveling mix, one for compacting the mix, and one for running the SRM 10-120. Four of the potholes (B-1 through B-4) were filled with cold mix material. Potholes B-5 and B-6 were filled with hot recycled asphalt millings heated with the SRM 10-120 recycler machine. The patching was performed on April 11, 2014. The weather was clear and the ambient temperature was 38°F. Figure 3.25 through Figure 3.31 shows pictures of the different potholes at different phases of the patching work. The following points provide brief description of all the six potholes.

Pothole B-1: This pothole was located in the wheel path of the driving lane. The pothole lied along a large longitudinal crack with alligator cracking. The pothole was prepped with compressed air. The size of the pothole patch was 57 inches x 16 inches x 2.5 inches.

Pothole B-2: This pothole was located in the wheel path of the driving lane. The pothole lied along a large longitudinal crack with alligator cracking. Two transverse cracks ran through the pothole location. The pothole was prepped with compressed air. The size of the pothole patch was 45 inches x 30 inches x 3 inches.

Pothole B-3: This pothole was located in the wheel path of the driving lane. The pothole lied along a large longitudinal crack with alligator cracking. A transverse crack ran through the pothole location. The pothole was prepped with compressed air. The size of the pothole patch was 47 inches x 34 inches x 3 inches.

Pothole B-4: This pothole was located in the wheel path of the driving lane. The pothole lied along a large longitudinal crack with alligator cracking. A transverse crack ran through the pothole location. The pothole was prepped with compressed air. The size of the pothole patch was 61 inches x 32 inches x 2.75 inches.

Pothole B-5: This pothole was located in the wheel path of the driving lane. The pothole lied along a large longitudinal and transverse crack with alligator cracking. The pothole was prepped with compressed air. The size of the pothole patch was 52 inches x 103 inches x 2 inches.

Pothole B-6: This pothole was located in the wheel path of the driving lane. The pothole lied along a large longitudinal crack with alligator cracking. The pothole was prepped with compressed air. Hot recycled asphalt millings were used to patch the pothole. The size of the pothole patch was 36 inches x 16 inches x 2 inches.

Figure 3.25 Pothole B-1 before and after Milling.

Figure 3.26 Pothole B-2 after Milling.

Figure 3.27 Pothole B-3 while Filling with Cold Mix Material.

Figure 3.28 Pothole B-4 with Milling Debris Still in Place.

Figure 3.29 Pothole B-5 before Milling.

Figure 3.30 Pothole B-5 after Milling.

Figure 3.31 Pothole B-6 after Milling.

It may be stated that unlike the site A, all potholes were milled using a skid steer and cleaned using compressed air. Potholes B-1 through B-4 were patched using cold mix with a mix temperature of 50°F. Potholes B-5 and B-6 were patched using hot recycled asphalt. The material was 100% recycled millings from a previous project. The millings were heated to 295°F using the Stepp SRM 10-120 machine. While heating an additional 1.5 gallons of asphalt binder was added to the pug mill per 1,000 pounds of millings. Once the patches were placed they were tamped using a single plate compactor. After compaction, the potholes were flush with the roadway. Figure 3.31 to Figure 3.35 show some photographs of patched potholes. It may be stated that within the first hour, several of the potholes had settled below the roadway surface. Pothole B-2 (Figure 3.33) was about ½ inch below the roadway surface within an hour. It takes fifteen to twenty minutes to complete a pothole from milling to compaction. The patch material placed in pothole B-6 (Figure 3.35) was the first mix to come out of the SRM 10-120 hopper. It cooled more rapidly than the mix placed in B-5 (Figure 3.34) and appeared to be drier.

Figure 3.32 Pothole B-1 after Patching.

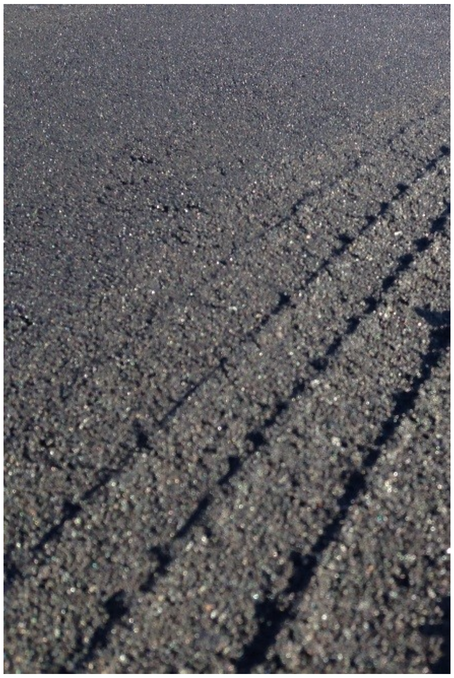

Figure 3.33 Settlement (Dishing) of Pothole B-2 an Hour after Compaction.

Figure 3.34 Pothole B-5 after Patching.

Figure 3.35 Pothole B-6 after Patching.

3.2.2.1 Performance Analysis

Cold Mix Patches: Performance of the patching materials and methods on all the six pothole locations mentioned above were monitored for approximately a year. Table 3.4 presents dates of the site visits conducted for monitoring the performance through the first 237 days since the day of installation of patching. The performance was monitored a total of seven times from April 11, 2014 through December 4, 2014. Performance of the patches could not be monitored in the following years because of the rehabilitation work performed on the Site B location. Figure 3.36 through Figure 3.41provide some photographs of the patches taken at different times to demonstrate how patches performed with cold mix and hot recycled asphalt millings aged over time.

Table 3.4 Schedule of Visits for Site B

Date Visited	Days Since Installation
4/11/2014	0
4/14/2014	3
4/18/2014	7
4/29/2014	18
7/9/2014	89
9/4/2014	146
12/4/2014	237

The cold mix patches at Site-B performed similar to Site-A. One difference at this site was the existence of significant dishing. After compaction, the potholes were flush with the roadway, however within the first hour several of the potholes had settled below the roadway surface. The depressed material is along the right edge of the crack. Pothole B-2 which suffered the most dishing was about ½ inch below the roadway surface within an hour (Figure 3.38).

Figure 3.36 Pothole B-1 after Patching.

Figure 3.37 Pothole B-1 (3 Days after Patching).

The reason for this depression was due to the depth of the patch filled. Cold mix has a small aggregate size paired with a slow curing asphalt binder. These two factors prevent the patch material from forming a stiff structure. When the pothole depth is too large, like Pothole B-2, the patch material cannot support itself. This did not occur at Site-A, because all potholes had a depth less than two inches. Dishing is common in these patches along the edges due to the inability for hand compactor machinery to properly compact along the interface. The compactor rests on the existing roadway during the compaction process preventing a complete compaction along the patch interface. Over time this area compresses under self-weight and creates the dished area shown in Figure 3.38 through Figure 3.41. After three days the patches appeared to reach their steady state compaction level. Minimal material was lost after those three days.

Figure 3.38 Settlement (Dishing) of Pothole B-2 an Hour after Compaction.

Figure 3.39 Pothole B-2 (3 Days after Patching).

Figure 3.40 Pothole B-5 (146 Days after Patching).

One of the main concerns regarding dishing distresses is the accumulation of water. Pooled water on a roadway provides areas that facilitate hydroplaning during wet conditions as well as icy surfaces in cold conditions (Figure 3.41). Dished areas along patch edges may provide areas for water to infiltrate increasing the deterioration rate of both the roadway and patch material. Dished areas also provide a lower ride quality and potential hazard areas for snow plows.

Figure 3.41 Water Accumulation in Dished Areas of Patch B-3 (18 Days after Patching).

Hot Recycled Patches: The millings used in the hot recycler did not perform as well as the cold mix patches did at this site. The main issue with this patch work was the material used. Two problems with the recycled millings existed: (i) the percent of fines present, and (ii) the amount of additional virgin oil added to the mix. The millings used were from an old road and contained a significant amount of fine material due to the milling process. A gradation was run on two samples of patching material after it was removed from the recycler machine. The gradation results showed an average of 12% fine material (Passing #200 sieve).

An insignificant amount of additional oil was mixed into the millings to help rejuvenate the mix. For this mix 1.5 gallons of asphalt oil was added to approximately 1000 pounds of mill tailings. The result was a patch material that aged and oxidized at a rapid rate. This aging is visually apparent over time as shown in the Figure 3.42 to Figure 3.48. Raveling was a common distress due to the aged binder and significant material was lost along the edge and surface of the patches over time.

The placement of patch material actually facilitated further damage to the roadway. The damage occurring appears similar to pumping action that is common with concrete panels. As traffic loads travel across the patch area there is not an efficient load transfer causing vertical movement of the patch material. This movement ejects water and fine material from underneath the patch and abrades the adjacent roadway. Comparing Figure 3.43 and Figure 3.44 illustrates that damage to the roadway in Patch B-5. Figure 3.47 provides a close view of this deterioration in Patch B-6.

Figure 3.42 Pothole B-5 after Patching.

Figure 3.43 Pothole B-5 (3 Days after Patching).

Figure 3.44 Pothole B-5 (146 Days after Patching).

Figure 3.45 Pothole B-6 immediately after Patching.

Figure 3.46 Pothole B-6 (3 Days after Patching).

Figure 3.47 Pothole B-6 (146 Days after Patching).

The importance of compaction is shown below in Figure 3.48. Extra hot recycled material was placed in smaller potholes in the wheel path. The potholes were not prepped before patching material was placed, and the material was only compacted under live traffic. As shown in Figure 3.48, the material was removed from the pothole after seven days. This serves as evidence that proper pothole preparation and patching material compaction can be the difference between a successful patch and a waste of resources. The last site visit conducted on December 4, 2014 (237 days after installation) showed that patches were affected by the first few uses of snow plows in the winter months.

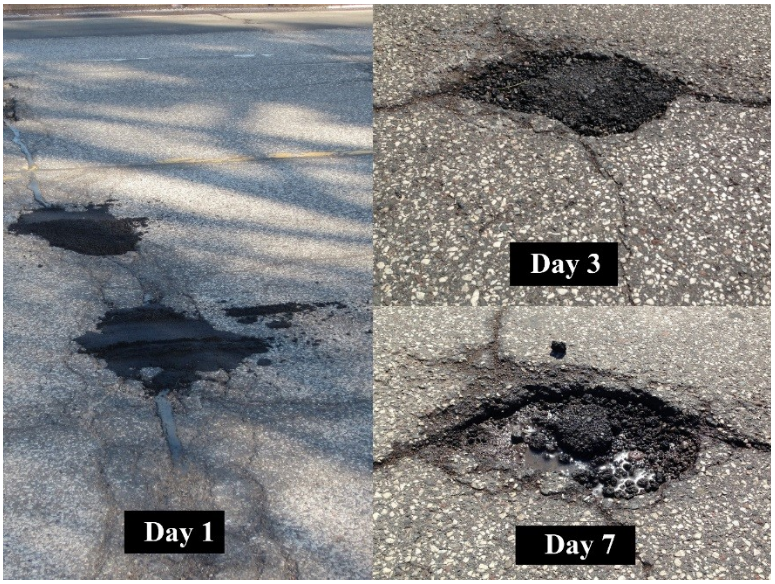

Figure 3.48 Uncompacted Hot Recycled Material in Wheel Path.

3.2.2.2 Retention Analysis

Two different site visit dates were used to calculate the retention of hot recycler material. The dates of comparison are April 14, 2014 (Figure 3.49) and July 9, 2014 (Figure 3.50). Unlike the two cold mix patches from Site-A, this patch lost a significant amount of material over time. The dry material previously discussed broke down over time and was removed from the pothole area. During this time (86 days) 19% of the patch material was lost. This percent only accounts for the material lost around the edge of the patch. The figures show that some material was also lost due to surface raveling.

Figure 3.49 Image Used for B-6 Retention Calculation (4/14/14).

Figure 3.50 Image Used for B-6 Retention Calculation (7/9/14).

3.2.3 Site C: Northbound Interstate 35

This location was used to monitor the patching method using mastic material. The mastic material was placed in a continuous longitudinal crack along the centerline joint. The longitudinal crack varies between a minimal width (hairline crack that is visible but not separated) to a width of three inches. Several locations including larger potholes that may be up to six inches wide were found in this site. The potholes were two inches deep and stop at the underlying asphalt layer. This longitudinal crack appears to be a reflective crack as there was a crack along the underlying asphalt layer as well. The longitudinal crack was prepared and cleaned using compressed air. Once the crack was cleaned (Figure 3.51), maintenance workers filled the damaged area with mastic material (Figure 3.52). A box screed was used to evenly apply the mastic material along the crack (Figure 3.53). The mastic material had a rapid cure time minimizing the required traffic control. The patched longitudinal crack can be seen in Figure 3.54. This patching method required four maintenance crew members, one member to prepare the potholes, one to drive the mastic truck, and two members to place the mastic. The patching work was performed on May 28, 2014. The weather was clear and the temperature was 70°F.

Figure 3.51 Longitudinal Crack before Placing Mastic (Cleaned with Compressed Air).

Figure 3.52 Filling Longitudinal Crack with Mastic.

Figure 3.53 Using a Box Screed to Evenly Spread Mastic along Crack.

Figure 3.54 Finished Mastic Patch.

3.2.3.1 Performance Analysis

Due to the high traffic levels on Interstate 35, site visits were not conducted after the placement of the mastic material. Instead several drive-by observations were made until two years since the day of installation. During the first several months after installation the mastic material was holding well along the longitudinal crack. Minimal material was removed and the mastic material provided protection from further joint raveling and water infiltration. One issue with the current practice is the use of mastic material to fill larger potholes along the longitudinal crack. Mastic material does not have enough structure to support significant loads. Filling potholes deeper than two inches with this material may lead to an area with a dished patch.

3.2.4 Site D: Southbound Highway 53 (Trinity Rd)

This roadway was distressed along the longitudinal joint (near centerline). The joint was a continuous crack with an average width of three inches. The crack was filled with sealer and raveling was present along the crack edges. Three locations (designated as D-1 through D-3) along the longitudinal crack were chosen to monitor the performance of hot mix asphalt patching materials.

Pothole D-1: This pothole was located in the non-wheel path of the passing lane. The pothole lies along a large longitudinal crack. The pothole was prepped with a milling machine. The size of the milled pothole was 114 inches x 20 inches x 2 inches. While patching, excess material was placed in the pothole. Once rolled, extra fill material was compacted onto the roadway surface extending six inches beyond the milled trench.

Pothole D-2: This pothole was located in the non-wheel path of the passing lane. The pothole lies along a large longitudinal crack. The pothole was prepped with a milling machine. The size of the milled pothole was 114 inches x 20 inches x 2 inches. The fill was placed and compacted very well providing a driving surface that was both clean and level to the surrounding roadway.

Pothole D-3: This pothole was located in the non-wheel path of the passing lane. The pothole lies along a large longitudinal crack with a transverse crack running through the middle of the pothole area. The pothole was prepped with a milling machine. The size of the milled pothole was 108 inches x 20 inches x 2 inches. The fill was placed and compacted well. The location before milling can be seen in Figure 3.55 and Figure 3.56.

Figure 3.55 Longitudinal Crack along Trinity Road.

Figure 3.56 Section of Longitudinal Crack with Sealer Missing.

The potholes at this site were patched with the mill and fill method on July 31, 2014. The weather was clear with a temperature of 68°F. The milling machine removed a strip of asphalt 20-inch wide and 2-inch deep. This milling machine had the ability to clean the trench as it milled the pavement. Figure 3.57 and Figure 3.58 show photos of the milled trench.

Figure 3.57 Milled Trench.

Figure 3.58 Milled Trench with Transverse Crack (Pothole D-3 Location).

Hot mix asphalt was poured into the milled trench by a truck. When placed, the material was between 260°F and 270°F. A skid steer with an attached spreader was used to fill the trench to a proper level. Material was piled to about an inch above the road surface. Two workers used shovels to help facilitate the proper leveling of new material. A roller followed behind compacting and leveling the hot mix until the patch was flush with the existing roadway surface. In general the roller ran two or three passes over each section of roadway. Finally a sweeper machine cleaned up any excess material left behind from the operation. The speed of the process depends on how spread out the different machines are as well as how long it takes for a new load of hot asphalt to be delivered. An estimate for this operation is about 30 to 45 minutes from the time a section of roadway is milled until that section has new asphalt placed and compacted.

This patching operation requires eight to ten crew members. Three members operate the milling operation; one operator each for the dump truck (to carry milled material), one to operate the milling machine, and one to operate a sweeper. For the filling process an operator supplied a truck of HMA, one drove a skid steer to place HMA, two workers shoveled HMA to proper levels, one operated a steel drum roller, and one operated a sweeper. Multiple sweepers and truck drivers to remove milled material and place HMA material helped to increase the operation rate but also increased the number of maintenance crews used for this maintenance operation.

At this site all three patch samples were provided with the same milling and preparation, however, the quality of asphalt placement varied between the samples. Excess material was placed along some areas of the patch. During compaction the excess material was pushed outside of the pothole area. The difference between excess material placement (Figure 3.59) and proper placement (Figure 3.60) is illustrated below. Placing the proper amount of material leaves a much cleaner looking product as well as reduces the amount of waste material. Figure 3.61 Shows finished patching work at Pothole D-3.

Figure 3.59 Pothole D-1 after Compaction (Excess Fill Material on Roadway).

Figure 3.60 Pothole D-2 with Clean Compaction.

Figure 3.61 Pothole D-3 with Clean Compaction.

One issue with a mill and fill operation is the compaction along the edge of a patch. A closer look along the edge (Figure 3.62) shows that steel drum rollers, used to compact the fill material, are unable to completely compact the fill material. Since rollers are wider than the patch, the steel drum sits on the existing roadway preventing the compaction of material near the edge. This area of lesser compacted material may lead to a higher rate of water infiltration or patch material raveling.

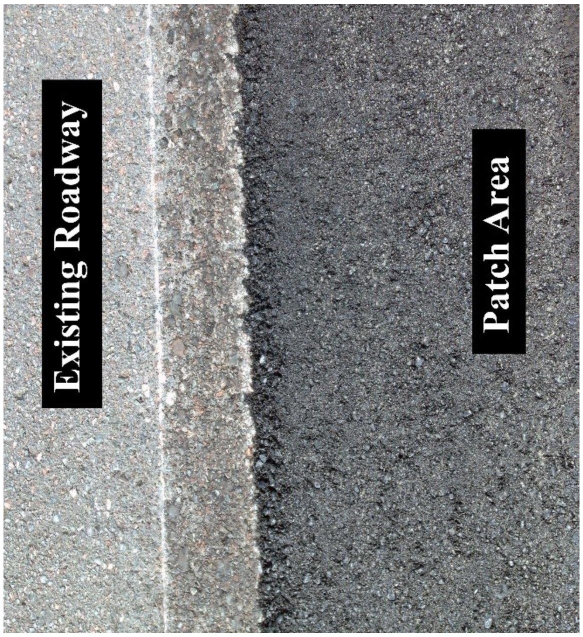

Figure 3.62 Interface between Patch Area and the Existing Roadway.

3.2.4.1 Performance Analysis

Performance of the patching materials and method on all the three pothole locations mentioned above were monitored for approximately one and half years. Table 3.5 presents dates of the site visits conducted for monitoring the performance through the first 446 days since the day of installation of patching. The performance was monitored a total of six times from July 31, 2014 through October 20, 2015.

As shown in Figure 3.57 and Figure 3.58, one issue with the mill and fill operation in Site D was the tacking process used: (i) insufficient amounts of tack was applied to the milled trench and (ii) trucks placing HMA needed to place the truck's wheels into the trench in order to line up where the HMA was discharged. This led to the dirt and debris from truck wheels into the trench which covered some of the tack. Also tack stuck to the truck wheels at many locations further reduced the amount of effective tack. Without a sufficient tack coating, a strong bond at the interface of the patch will not occur, leading to possible delamination or freeze-thaw damage due to water infiltration. Figure 3.63 through Figure 3.65 provide three photographs of the patched locations taken 35 days after the installation of the patching. The patch interface at that time is shown below in Figure 3.66. Improper compaction may also lead to dished areas where hydroplaning and icy surfaces can occur.

Table 3.5 Schedule of Visits for Site D

Date Visited	Days Since Installation
7/31/2014	0
8/7/2014	7
9/4/2014	35
12/4/14	126
7/29/15	363
10/20/15	446

The site visit on December 4, 2014 indicated that Both D-1 and D-2 had significant raveling of material along the interface of the patch and existing roadway (Figure 3.67). It is also shown in Figure 3.67 that some distresses have occurred along parts of the patch surface. The crack running underneath Patch D-3 has propagated through the patch and has a width varying between ¼ and ½ inch.

Figure 3.63 Pothole D-1 (35 Days after Patching).

Figure 3.64 Pothole D-2 (35 Days after Patching).

Figure 3.65 Pothole D-3 (35 Days after Patching).

Figure 3.66 Patch Interface (35 Days after Patching).

Figure 3.67 Pothole D-1 (126 Days after Installation) with Deterioration along the Patch Interface.

Figure 3.68 Pothole D-3 (126 Days after Installation) with Crack Running Through Patch.

Site visits conducted on July 29, 2015 and October 20, 2015 revealed that severity of the raveling did not increase in second year of service. See Figure 3.69 and Figure 3.70. It was also discovered that the cracks that had propagated through and along the edges of the patches had been sealed sometime during the summer of 2015 (Figure 3.70 and Figure 3.71). This probably helped in arresting the raveling in the year two.

Figure 3.69 Pothole D-1 (446 Days after Installation).

Figure 3.70 Pothole D-2 (426 Days after Patching).

Figure 3.71 Pothole D-3 (446 Days after Installation) with Crack Running Through Patch.

3.2.5 Site E: Northbound Highway 53

This roadway was distressed along the longitudinal joint between the passing and driving lane and along the wheel path (also a joint) of a turning lane. The joints had continuous cracks with an average width of three inches. The same mill and fill process conducted at Site D was used at this site. The performance of the patches was monitored at five locations (designated as E-1 through E-2) along the different longitudinal cracks. The patching operation was performed on August 7, 2014. The weather was clear with 61°F temperature. Photographs of the five pothole areas can be seen in Figure 3.72 through Figure 3.76.

Pothole E-1: This pothole was located in the wheel path of the turning lane. The pothole lies along a large longitudinal crack. The pothole was prepped with a milling machine. The size of the milled pothole was 108 inches x 20 inches x 2 inches. A longitudinal crack was present on the left side of the patch as shown in Figure 3.72.

Pothole E-2: This pothole was located in the non-wheel path of the passing lane. The pothole lied along a large longitudinal crack. This crack was along the joint between the driving and passing lane. The pothole was prepped with a milling machine. The size of the milled pothole was 121 inches x 20 inches x 2 inches. Several smaller transverse cracks existed and ran into the milled trench.

Pothole E-3: This pothole was located in the non-wheel path of the passing lane. The pothole lies along a large longitudinal crack. This crack is along the joint between the driving and passing lane. The pothole was prepped with a milling machine. The size of the milled pothole was 108 inches x 20 inches x 2 inches. Several smaller transverse cracks and one larger sealed transverse crack existed and ran into the milled trench.

Pothole E-4: This pothole was located in the non-wheel path of the passing lane. The pothole was located along a large longitudinal crack. This crack was along the joint between the driving and passing lane as well as in the intersection of TH53 and Highway 194. The pothole was prepped with a milling machine. The size of the milled pothole was 114 inches x 20 inches x 2 inches. Several smaller transverse cracks and one large transverse crack existed and ran into the milled trench.

Pothole E-5: This pothole was located in the non-wheel path of the passing lane. The pothole was located along a large longitudinal crack. This crack was along the joint between the driving lane and passing lane. The pothole was prepped with a milling machine. The size of the milled pothole was 121 inches x 20 inches x 2 inches. Several medium sized transverse cracks existed and ran into the milled trench.

Figure 3.72 Pothole E-1 with Parallel Longitudinal Cracking.

Figure 3.73 Pothole E-2 after Compaction.

Figure 3.74 Pothole E-3 after Compaction.

Figure 3.75 Pothole E-4 with Transverse Crack.

Figure 3.76 Pothole E-5 after Compaction.

The lack of compaction issue near the interface of the pothole and roadway discussed above in Site D section also existed at this site. The issue however was more prevalent and also included some raveled material right after compaction (Figure 3.77).

Figure 3.77 Lack of Compaction and Material near Interface of Patch Material and Roadway.

3.2.5.1 Performance Analysis

Performance of the patching materials on all the five pothole locations mentioned above was monitored. Table 3.6 presents date of the site visits conducted for monitoring the performance through the first 119 days since the day of installation of patching. The performance was monitored a total of three times from August 7, 2014 through December 14, 2014. Performance of the patches could not be monitored in the following years because of the rehabilitation performed on this site.

Table 3.6 Schedule of Visits for Site E

Date Visited	Days Since Installation
8/7/2014	0
9/4/2014	28
12/4/14	119

Figure 3.78 through Figure 3.85 provide a visual of how HMA mill and fill patches aged over time at Site E. This site illustrated the importance of proper patching method identification as well as the need for quality workmanship during the patching process. At this site, it was common to see longitudinal cracks parallel to the patch (Figure 3.81 and Figure 3.83). For patch work to be successful, it is imperative that maintenance is performed with quality workmanship. An example of poor workmanship is shown in Figure 3.80 where proper compaction was not applied near the edge of the patch. A final site visit for

the year was made on December 4, 2014. Figure 3.82 to Figure 3.85 show that a significant amount of damage had occurred to the patch material including cracks and raveling along the patch interface.

Figure 3.78 Pothole E-2 (28 Days after Patching).

Figure 3.79 Pothole E-4 (28 Days after Patching).

Figure 3.80 Poorly Compacted Interface (28 Days after Patching).

Figure 3.81 Patch E-1 Parallel to Existing Distresses (28 Days after Patching).

Figure 3.82 Cracking of Pothole E-3 (119 Days after Installation).

Figure 3.83 Pothole E-4 (119 Days after Installation).

Figure 3.84 Pothole E-5 (119 Days after Installation).

Figure 3.85 Close View of Distresses on Pothole E-5 (119 Days after Installation).

CHAPTER 4: DECISION TREES AND BEST PRACTICES MANUAL FOR POTHOLE PATCHING OPERATION

4.1 DECISION TREES

A decision tree is helpful to decide on the most appropriate type of maintenance work for a given condition of a distressed pavement. Based on the findings from the literature review and performance analysis of the pothole patches considered in this study, a couple of decision trees have been developed for providing guideline to the maintenance crew to decide on the most appropriate pothole patching method for their job. In this study, two different forms of decision trees were developed: (i) in the form of flow charts which can be included in the pavement maintenance guide, and (ii) in the form of flash cards which can be used as a quick reference by the pavement maintenance crew who often gets very limited time to go through a large maintenance guide.

The Task 2 through Task 4 of this project dealt with monitoring and analyzing performance of the patches at 20 different selected patch locations at five different sites. Performances of the patches were periodically monitored for more than a year. However, because of reconstruction of the pavement at multiple site locations in the year 2, several of the patches were eliminated from the year 2 performance study. It may also be noted that almost all the potholes selected in this study were either localized potholes or existed along the longitudinal joints. Because of this particular limitation, decision trees have been developed only for the (i) potholes at the longitudinal joints and (ii) localized potholes. Figure 4.1 presents the two decision trees developed for the above-mentioned two types of locations. These two decision trees can be incorporated in the pavement maintenance guide. Figure 4.2 presents the other format, in which decision trees are provided in a flash card format which will be very easy to use by the pavement maintenance crew. By referring these decision trees for a short time, a pavement maintenance crew would be able to make decisions on a patching method based on the location of the potholes, severity, extent of the distresses and the construction season. Patching methods such as mill and fill with virgin HMA, fill with mastic, fill with hot recycled mix, fill with advanced proprietary materials and fill with cold mixes were considered. It may be noted that the use of hot recycled mix for the purposes of patching potholes should be avoided until the development of better processes. The current recommendation for hot recycled mix based patching is based on the observation of only two patches; however both of those failed almost immediately.

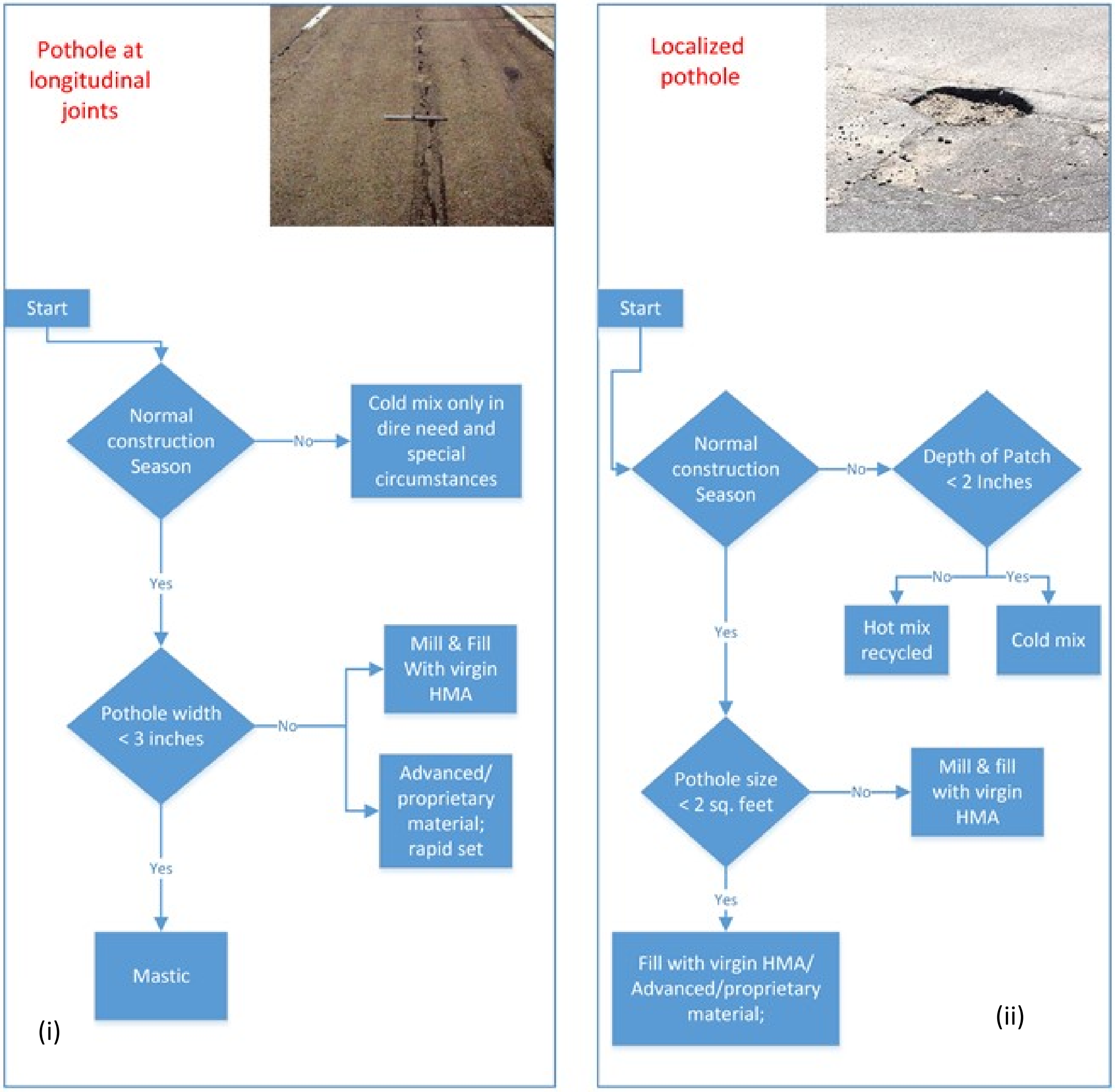

Figure 4.1 Decision Trees for Patching (i) Potholes Located at the Longitudinal Joints and (ii) Localized Potholes; these can be used in the Pavement Maintenance Guide.

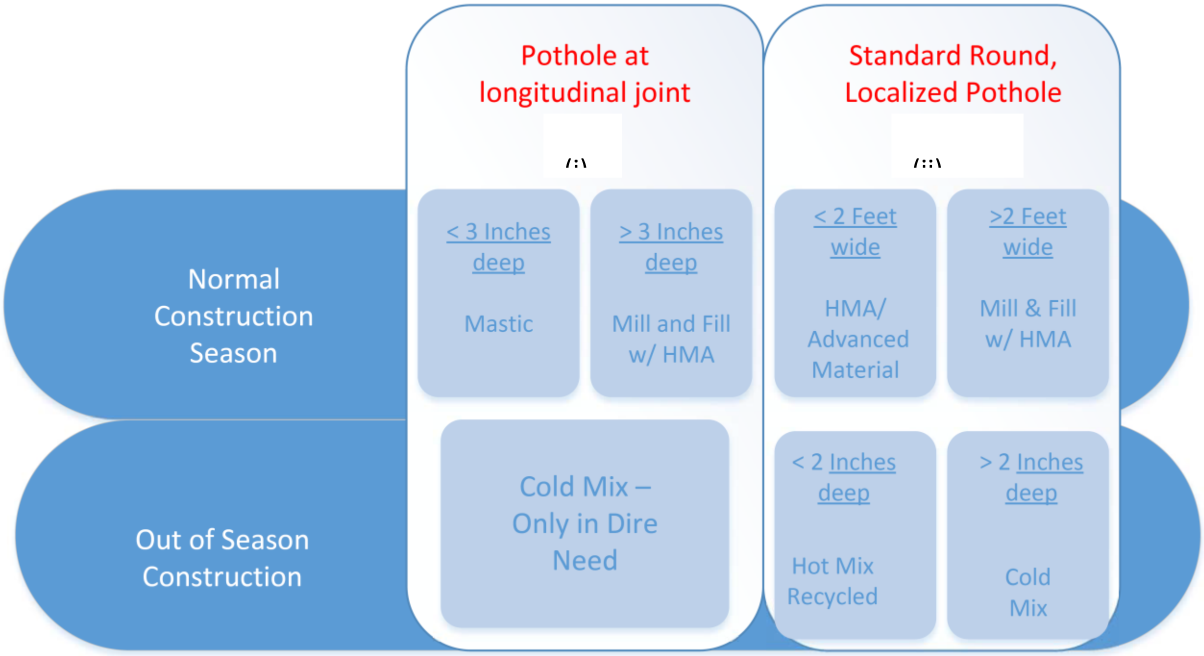

Figure 4.2 Decision Trees for Patching (i) Potholes Located at the Longitudinal Joints and (ii) Localized Potholes; these can be used as Flash Cards.

4.2 BEST PRACTICES MANUAL

4.2.1 Selection of Patch Method

4.2.1.1 Cold Mix Asphalt Patch

Cold mix asphalt patch should only be used for temporary fixes in small to medium potholes. The pothole depth to be repaired should not exceed 2 inches. The material is not designed to be structurally sound for depths beyond 2 inches. If this cannot be avoided, the patch should be placed in 2 lifts and compacted separately.

4.2.1.2 Mill & Fill with Virgin HMA

Hot mix asphalt during the regular season is the most acceptable option for filling milled areas. This option can be used in any situation, mill and fill or established potholes. HMA works for any depth repair, however, when the patch depth exceeds four inches, multiple lifts should be considered with compaction taking place after each lift.

4.2.1.3 Advanced Material/ Propriety Materials

There are several advanced rapid set materials available. This study did not research any of these options. These materials would be employed at sites that require short reopening times. Compaction of these materials may not be necessary as they are cementitious in nature.

4.2.1.4 Mastic

Mastic, although expensive, is the best option for repairing small holes as well as longitudinal joints. As long as the patch area is dry to begin with, the mastic seems to not be affected by future moisture infiltration. As with any maintenance operation, quality control of the work being performed is paramount. The proper amount of matching material leads to better compaction and longer lasting patches.

4.2.2 Pothole Preparation

4.2.2.1 Minimum required cleaning method

Sweeping: A crew member uses a steel brush to sweep out a pothole removing dirt, debris, and any standing water. This method removes large particles from the hole but does not necessarily remove fine material.

4.2.2.2 Recommended cleaning method

Compressed air: A hose attached to an air compressor is used to remove dirt, debris, and any standing water. This method removes both fine and large particles as well as helps to dry the surface of the pothole.

4.2.2.3 Milling operations

The standard methods for milling both longitudinal joint distress and localized potholes are acceptable. There must be adherence to the guidelines for cleaning the patch area prior to placement of the patching material.

4.2.3 Placement and Compaction

4.2.3.1 HMA

- Complete coverage of the patch area with an approved tack material is recommended.
- When the HMA delivery vehicle drives directly in the milled area, debris from the tires covers the tack material rendering it non-functional. This should be avoided if at all possible.
- Compaction should be as thorough as possible to ensure patch longevity. Vibratory steel rollers should be employed to achieve this.

4.2.3.2 Mastic

- Standard mastic operations are sufficient.
- The material is moderately self-leveling and requires no compaction.

4.2.3.3 Cold mix patching material

- Manual placement with shovels is the preferred method.
- Deeper patches require the use of multiple lifts with compaction occurring after each lift
- Compaction with vibratory devices is insufficient, great effort must be taken to ensure that the material reaches a maximum density.
- Manual compaction with tampers and driving over the patch may be required.

4.2.4 Moisture Abatement

Moisture is of major concern when dealing with patching operations. If water is present in the patch area, every effort should be made for removal.

HMA patches

- Once the area is dry, a liberal amount of sealant or tack should be applied to keep infiltrating moisture out of the patch contact point.

Mastic

- Mastic itself has a sealing quality that is moisture resistant.

Cold mix patching material

- This method is generally used during the off season which normally means less moisture. Since this is a temporary solution the abatement of moisture is of less concern.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

This study investigated the performance of different types of patching methods. The different tasks under the scope of this study involved a literature study and performance monitoring and analysis for 20 different patches at five different locations. The performance was monitored for approximately two years. Four patching methods involved in this study were patching potholes with (i) cold mix, (ii) hot recycled asphalt millings, (iii) mastic material, and (iv) mill and fill using virgin HMA. The following are some major findings and recommendations based on the field observations and evaluations conducted on four different types of the patching methods.

Cold Mix

- All patches should be cleaned using compressed air.
- Cold-mix patches should only be placed in potholes with a depth of less than two inches.
- Patches with a depth of greater than two inches should have patch material placed in two lifts.
- Cold-mix material with a larger aggregate may allow for an increased allowable pothole depth.

The cold-mix material is quick to place and retains the majority of its material over time. One of the main issues with this product is the dishing that occurs when placed in potholes that are deeper than two inches.

Hot Recycled Material

- The use of recycled millings should not be used as a patch material because of the aged binder present.
- Binder present in the mixer slows down the heating process and creates a patch that rapidly ages.
- The use of a handheld compactor is required to create a quality patch.
- Equipment such as Stepp SRM 10-120 should be used to create virgin hot patch material using sand/small aggregates and asphalt oil.

It is not recommended that mill tailings are used as an aggregate with the hot recycle machine. The heating process is slow, the material comes out oxidized and ages quickly in the field, and there is a large presence of fine material in the mix, which can prevent the bond required between binder and aggregate. The additional oil added to the mix differs from the asphalt that exists in the mill tailings. The oil does not appear to rejuvenate the old asphalt but simply adds a negligible amount of new binder. This machine is best served as a mixer for creating a pothole patching material made of virgin sand and oil.

Mastic Material

- The current mastic practice appears to be working well.
- The use of mastic material to fill larger potholes that exist along a longitudinal crack is not recommended. Mastic material does not have enough structure to support loads. Filling potholes with this material may lead to an area with a dished patch.

Mastic material stays in place when used to fill longitudinal joints. The material creates a smooth service, however, it is recommended that this operation is only used on centerline joints or longitudinal joints along the shoulder. The use of this material in a wheel path could cause a hazardous driving surface.

Mill and Fill with Virgin HMA

- Higher amounts of tack should be used during this operation.
- Trucks driving in the milled trench after the placement of tack should be avoided.
- Attentiveness to what areas are milled is important to ensure that the correct areas of the roadway are treated.
- Attentiveness to the proper amounts of HMA being placed is important to ensure proper compaction and help eliminate distresses such as dishing or raveling at the patch interface.

The main concern with the mill and fill operation is the longevity of the patch. Significant deterioration was found to occur along the patch interface after being in the field for a little longer than 100 days. This low service life can cause more damage to the roadway than the original distress. A mill and fill operation fixes a longitudinal crack. However, with such a service life, this single crack is fixed for 100 days and then becomes two cracks in the roadway. The patch material is not always level with the existing roadway, which can deteriorate the rideability of a roadway. Thus, a mill and fill operation can leave a road in worse condition a few months after the maintenance than if no maintenance operation was conducted. Although a minimal amount of total patch material was lost at each site, damage to the patches such as cracking or raveling at the interface provides areas where water infiltration is possible. This infiltration will facilitate the continued deterioration of the patch material. Damage due to water infiltration will occur the most during winter and spring months as a result of freeze-thaw cycles. Based on the abovementioned findings, decisions trees have been developed. The decision trees have been developed in two formats: one in the form of flow chart that can be used in the maintenance guide and the other one in the form of flash cards that can be used by the maintenance crew for quick reference. Finally, a best practices manual is provided, offering a brief discussion on the patching method selection, placement and compaction of the patching materials, and moisture abatement.

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APPENDIX A:

SLURRY MIX REFINEMENT

The purpose of laboratory testing to refine the slurry mix was twofold: (i) to test different proportion combinations of material in smaller batches. This was done to help reduce the cost of wasted material during the testing process and (ii) to test and compare the strength parameters of different proportion combinations in order to optimize the strength and cost of the patch material. Indirect tensile strength (ITS) testing was used to determine the strength of this slurry mix samples. The testing procedure is based on ASTM D6931-12 Standard Test Method. In this method, cylindrical specimens were prepared with slurry mix and tested with a monotonically increasing load.

In order to prepare the slurry mix for ITS test specimens, first a small batch of slurry mix was prepared using different proportions of aggregate, cement, emulsion, and water for each sample. The sample sizes varied between six and eight pounds.

Slurry Mixing Procedure: Aggregate and cement were placed in a small mixing drum. The designated amount of water was added while the mix drum was turning. Once the aggregate was moist, emulsion was added and the drum continued to mix for several minutes. The samples were mixed at an ambient room temperature (about 70°F). The mix was then placed in a bowl (Figure A1) and then placed in the laboratory oven for two hours at 158°F. The purpose of placing the trial mix into the oven was to simulate the curing process of the mix. Figure A2 shows a photograph of the slurry mix after curing in the oven for two hours.

Figure A1: Slurry Trial Mix Immediately after Mixing.

Figure A2: Slurry Trial Mix after Placement in Oven for Two Hours (Curing Simulation).

After two hours the trial mix was removed from the oven and compacted using a gyratory compactor. The compaction was completed using 30 gyrations. An example of a compacted sample is shown below in Figure A3. The samples are then left to cure at ambient temperatures in the lab for at least seven days.

Figure A3: Slurry Trial Mix after Compaction in Gyratory Compactor.

After seven days of curing, samples were tested for their indirect tensile strength. The test apparatus is shown below in Figure A4. Samples were placed in compression at a test rate of 25 mm/min. Data including the load, time, extension, stress, and strain on the sample are recorded for later analysis. Cracking of the samples occurs during testing and usually indicates the peak load has been reached (Figure A5).

Figure A4: Compacted Sample Placed in Indirect Tensile Strength Test Apparatus.

Figure A5: Cracking of Sample due to Testing of Indirect Tensile Strength.

Field Trials: A total of eight different trials were mixed and tested in between the first and second field mixing trials. The proportions in Table A1 are based on the total volume of the trial batch mixed. These percentages were converted into the percentages based on the weight of aggregate which was how the slurry machine was calibrated. The converted percentages are shown below in Table A2.

Table A1: Slurry Trial Proportions Based on Total Volume.

Trial	Percentage of Total Volume (%)			
	Aggregate	Cement	Emulsion	Water
1	78	2	15	5
2	80	2	13	5
3	82	2	11	5
4	83	2	13	2
5	82	2	16	0
6	82	2	13	3
7	82	2	16	0
8	84	0	16	0

Table A2: Slurry Trial Proportions (after First Field Mixing) Converted to Percentage Based on Aggregate Weight.

Trial	Percentage Based on Weight of Aggregate (%)		
	Cement	Emulsion	Water
1	2.6	19.2	6.3
2	2.5	16.3	6.2
3	2.4	13.4	6.0
4	2.4	15.7	2.4
5	2.4	19.5	0
6	2.4	15.9	3.6
7	2.4	19.5	0
8	0	19.0	0

Three trials batches were mixed after the second field mixing trial based on the observations made at the field testing. The trial proportions based on aggregate weight are found below in Table A3.

Table A3: Slurry Trial Proportions (after Second Field Mixing) Converted to Percentage Based on Aggregate Weight

Trial	Percentage Based on Weight of Aggregate (%)		
	Cement	Emulsion	Water
9	3.0	16	3.5
10	3.0	16	5
11	3.0	16	4.5

During the testing of the first eight trials the mix appears to be too wet, however, after curing in the oven the material was able to be compacted using the gyratory compactor. Through the first eight trials the liquid material (emulsion and water) was slowly reduced to find a suitable proportion. This issue was a result of the misinterpretation of percentages. The later trials (Trial 5-Trial 8) had around 19% liquid material in its mix. This percentage of liquid matched the successful trials completed at the second field mixing. After the second field mixing, Trials 9 through 11 were created to find the strength of values of mixes that closely resembled the successful field mixes. Below in Table A4 are the results for all eleven indirect tensile strength trials conducted. It should be noted that the mixes created after the second field mixing was conducted.

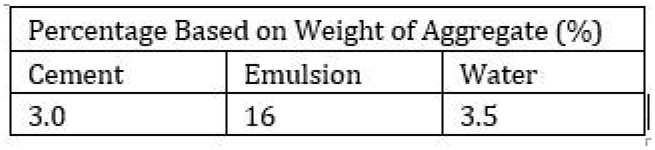
Table A4: Indirect Tensile Strength Results

Trial	Load (N)	Time (sec)	Extension (mm)	Strength		Strain (mm/mm)
				(Mpa)	(psi)	
1	3,164.64	15.71	13.04	0.19	27.14	0.26
2	4,180.90	13.23	10.98	0.24	34.27	0.22
3	5,149.72	9.53	7.88	0.27	39.62	0.16
4	5,013.19	6.09	5.03	0.26	38.03	0.10
5	1,894.49	101.32	16.88	0.08	12.07	0.33
6	2,898.43	19.48	8.10	0.21	29.99	0.16
7	4,076.70	30.58	12.72	0.21	30.28	0.25
8	2,381.54	27.18	11.30	0.12	17.59	0.22
9	9,798.77	6.47	2.68	0.54	77.75	0.05
10	5,218.20	6.69	2.77	0.29	42.02	0.05
11	7,400.79	5.73	2.37	0.41	59.31	0.05

Based on the field mixing and discussions with MnDOT maintenance workers, the mix that most closely matched a slurry mix design based on visual inspection had the proportions of Trial 9. This trial was also the best performing mix design in the laboratory testing with the highest strength (77.75 psi) and the lowest strain (0.05 mm/mm).

Recommended Proportions for Slurry Mix Design: Based on field testing, visual observations, and laboratory testing, the recommended proportions for a slurry mix design based on the weight of aggregate is as prescribed below in Table A5. It should be noted that these proportions are based on a dry aggregate, and a reduction in the required water may occur if aggregate stockpiles are damp.

Table A6: Recommended Proportions for a Slurry Mix Design



Percentage Based on Weight of Aggregate (%)		
Cement	Emulsion	Water
3.0	16	3.5

APPENDIX B:

PATCH LOCATIONS AND PICTURES AT DIFFERENT STAGES OF PATCHING OPERATIONS

Table B1: Location Summary for Patching Performance Study Sites.

Site ID	Location	Distress Type	Construction Details				
			Patch Material	Preparation	Number of Workers	Estimated Time Requirement (minutes)	Patching Finish
A	TH 61	Pothole	Cold Mix	Broom Sweep, Compressed Air	3	10	Shovel Tamping
B (Cold)	Grand Ave	Milled Pothole	Cold Mix	Milling, Compressed Air	5	20	Handheld Compression
B (Hot)	Grand Ave	Milled Pothole	Hot Recycled Asphalt	Milling, Compressed Air	5	20	Handheld Compression
C	I-35	Longitudinal Crack	Mastic	Compressed Air	3	10	Leveling Box
D	Hwy 53	Longitudinal Crack	HMA	Milling, Sweeper Machine	9	40	Steel Drum Rolled
E	Hwy 53	Longitudinal Crack	HMA	Milling, Sweeper Machine	9	40	Steel Drum Rolled

Table B2: Equipment Used in Patching Potholes in this Study.

Site ID	Equipment Requirements
A	Shovels, Brooms, Air Compressor, Cold Mix Trailer
B (Cold)	Shovels, Air Compressor, Skidsteer with Milling Head, Handheld Compactor, Cold Mix Trailer
B (Hot)	Shovels, Air Compressor, Skidsteer with Milling Head, Handheld Compactor, Hot Recycler Machine, Millings Trailer
C	Mastic Machine, Shovels, Air Compressor, Leveling Box
D	Milling Machine, Shovels, Skidsteer with Fill Attachment, 2 Dump Trucks, Steel Drum Roller, Sweeper
E	Milling Machine, Shovels, Skidsteer with Fill Attachment, 2 Dump Trucks, Steel Drum Roller, Sweeper

PICTORIAL OVERVIEWS

The following are step by step pictorial overviews of the different maintenance operations.

Cold Mix (Site A and B)

Step 1: Milling. If required potholes are milled using a milling head placed on a skid steer.

Figure B1: Cold Mix Step 1.

Step 2: Pothole preparation. Potholes are prepared for cold mix patching by removing the milled debris and then either sweeping the area or clearing debris with compressed air.

Figure B2: Cold Mix Step 2.

Step 3: Patching material is placed in the pothole.

Figure B3: Cold Mix Step 3.

Step 4: Material is compacted using either shovels (Site A) or handheld compactors (Site B).

Figure B4: Cold Mix Step 4.

Figure B5: Cold Mix Placement and Compaction Using Only a Shovel.

Hot Recycled Material (Site B)

Step 1: Milling. Procedure is the same as Step 1 of Cold Mix (above).

Step 2: Pothole preparation. Procedure is the same as Step 2 of Cold Mix (above).

Step 3: Heating recycled material for placement. Recycled material is placed into the Stepp SRM 10-120 Asphalt Recycler and heated to 300°F.

Figure B6: Hot Recycler Step 3.

Step 4: Heat material is placed into the pothole.

Figure B7: Hot Recycler Step 4.

Step 5: Material is compacted using hand held compactor.

Figure B8: Hot Recycler Step 5.

HMA Mill and Fill (Site D and E)

Step 1: Milling machine mills out Trench along distressed area.

Figure B9: Mill and Fill Step 1.

Figure B10: Milled Material is placed in a Truck to be Hauled Away.

Step 2: Trench is swept clean of remaining debris.

Figure B11: Mill and Fill Step 2.

Step 3: Windrows of fill material are placed in the milled trench and leveled out by a skidsteer.

Figure B12: Mill and Fill Step 3.

Step 4: A steel drum roller compacts the fill material to complete the patch.

Figure B13: Mill and Fill Step 4.

SITE DATA

The following tables provide complete data for the potholes identified and observed at each location.

Table B3: Site-A Data

Location		Site ID	A1	A2	A3	A4	A5
		Roadway	TH 61	TH 62	TH 63	TH 64	TH 65
		GPS (N)	N46° 50" 41.648' W91° 59" 45.974'	N46° 50" 41.486' W91° 59" 45.576'	N46° 50" 41.541' W91° 59" 45.568'	N46° 50" 43.229' W91° 59" 45.345'	N46° 50" 43.641' W91° 59" 45.327'
Time		Date	4/8/2014	4/8/2014	4/8/2014	4/8/2014	4/8/2014
		Time	8:30 AM	8:30 AM	8:30 AM	8:30 AM	8:30 AM
Characteristics	Pothole	Part of Roadway	Shoulder Joint	Non-Wheel Path	Shoulder Joint	Non-Wheel Path	Shoulder Joint
		Direction	North	North	North	North	North
		Length (in)	40	13	37	10	17.5
		Width (in)	14	9	13	10.5	13
		Depth (in)	2	2	2	1.5	1.5
		Crack Type	Both	Both	Both	Both	Both
		Water Present	No	No	No	No	No
	Patching	Material Used	Cold Mix	Cold Mix	Cold Mix	Cold Mix	Cold Mix
		Preparation	Swept	Swept	Air Blown	Air Blown	Air Blown
		# of Workers	3	3	3	3	3
Temp (°F)		Air	30	30	30	30	30
		Pavement	30	30	30	30	30
		Material	100	100	100	100	100

Table B4: Site-B Data

Location		Site ID	B1	B2	B3	B4	B5	B6
		Roadway	Grand Ave	Grand Ave	Grand Ave	Grand Ave	Grand Ave	Grand Ave
		GPS (N)	N46° 43" 34.798' W92° 11" 15.943'	N46° 43" 31.798' W92° 11" 12.973'	N46° 43" 35.947' W92° 11" 12.041'	N46° 43" 37.592' W92° 11" 08.883'	N46° 43" 37.664' W92° 11" 09.096'	N46° 43" 337.65' W92° 11" 109.09'
Time		Date	4/11/2014	4/11/2014	4/11/2014	4/11/2014	4/11/2014	4/11/2014
		Time	9:30 AM	9:30 AM	9:30 AM	9:30 AM	9:30 AM	9:30 AM
Characteristics	Pothole	Part of Roadway	Wheel Path	Wheel Path	Wheel Path	Wheel Path	Wheel Path	Wheel Path
		Direction	East	East	East	East	East	East
		Length (in)	57	45	47	61	52	36
		Width (in)	16	30	34	32	103	16
		Depth (in)	2.5	3	3	2.75	2	2
		Crack Type	Transverse	Both	Both	Both	Both	Both
		Water Present	No	No	No	No	No	No
	Patching	Material Used	Cold Mix	Cold Mix	Cold Mix	Cold Mix	Recycled Mix	Recycled Mix
		Preparation	Milled	Milled	Milled	Milled	Milled	Milled
		# of Workers	5	5	5	5	5	5
Temp (°F)		Air	37	37	37	39	39	39
		Pavement	38	38	38	42	42	44
		Material	50	50	50	53	295	295

Table B5: Site-C Data

Location		Site ID	C1
		Roadway	I35
		GPS (N)	N45° 50" 34.634' W92° 58" 34.428'
Time		Date	5/28/2014
		Time	10:00 AM
Characteristics	Pothole	Part of Roadway	Centerline Joint
		Direction	North
		Length (in)	N/A
		Width (in)	N/A
		Depth (in)	N/A
		Crack Type	Longitudinal
		Water Present	No
	Patching	Material Used	Mastic
		Preparation	Air Blown
		# of Workers	3
Temp (°F)		Air	70
		Pavement	85
		Material	350

Table B6: Site-D Data

Location		Site ID	D1	D2	D3
		Roadway	Hwy 53	Hwy 53	Hwy 53
		GPS (N)	N46° 47" 16.256' W92° 08" 53.881'	N46° 47" 17.062' W92° 08" 53.455'	N46° 47" 16.997' W92° 08" 51.761'
Time		Date	7/31/2014	7/31/2014	7/31/2014
		Time	9:00 AM	9:00 AM	9:00 AM
Characteristics	Pothole	Part of Roadway	Centerline Joint	Centerline Joint	Centerline Joint
		Direction	East	East	East
		Length (in)	114	114	108
		Width (in)	20	20	20
		Depth (in)	2	2	2
		Crack Type	Both	Longitudinal	Longitudinal
		Water Present	No	No	No
	Patching	Material Used	Hot Mix Asphalt	Hot Mix Asphalt	Hot Mix Asphalt
		Preparation	Milled	Milled	Milled
		# of Workers	9	9	9
Temp (°F)		Air	68	68	68
		Pavement	75	75	75
		Material	270	270	270

Table B7: Site-E Data

		Site ID	E1	E2	E3	E4	E5
Location		Roadway	Hwy 53	Hwy 53	Hwy 53	Hwy 53	Hwy 53
		GPS (N)	N46° 50" 33.127' W92° 15" 16.523'	N46° 50" 36.427' W92° 15" 24.491'	N46° 50" 38.004' W92° 15" 28.108'	N46° 50" 40.111' W92° 15" 33.264'	N46° 50" 40.466' W92° 15" 34.271'
Time		Date	8/7/2014	8/7/2014	8/7/2014	8/7/2014	8/7/2014
		Time	9:00 AM	9:00 AM	9:00 AM	9:00 AM	9:00 AM
Characteristics	Pothole	Part of Roadway	Wheel Path	Centerline Joint	Centerline Joint	Centerline Joint	Centerline Joint
		Direction	North	North	North	North	North
		Length (in)	108	121	108	114	121
		Width (in)	20	20	20	20	20
		Depth (in)	2	2	2	2	2
		Crack Type	Longitudinal	Longitudinal	Longitudinal	Longitudinal	Longitudinal
		Water Present	No	No	No	No	No
	Patching	Material Used	Hot Mix Asphalt	Hot Mix Asphalt	Hot Mix Asphalt	Hot Mix Asphalt	Hot Mix Asphalt
		Preparation	Milled	Milled	Milled	Milled	Milled
		# of Workers	9	9	9	9	9
Temp (°F)		Air	61	61	61	61	61
		Pavement	80	80	80	80	80
		Material	260	260	260	260	260