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Specification Recommendation for Use of High Performance Repair Material

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SPECIFICATION RECOMMENDATION FOR USE OF HIGH PERFORMANCE REPAIR MATERIAL

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ABSTRACT

The State of Ohio and the Ohio Department of Transportation (ODOT) have sought out ways to extend the life of the repair materials used by their construction crews, specifically, using high performance repair materials for the purposes of patching worn down or cracked sections of highways and bridge decks. Ohio is known for its frequent changes in weather, with freeze-thaw cycles occurring multiple times throughout the year. These cycles affect the lifespan of the repair material and create more maintenance for the DOT. Products that combat this problem were chosen, installed and examined over a year period to determine which could be recommended for continued use.

The objective of this study was to thoroughly examine other state's specifications, as well as taking into consideration the results of the research and lab work done by fellow graduate students on high-performance repair material and to recommend a standard specification for the Ohio Department of Transportation. The research team documented the processes in which each of the repair materials was installed in order to compare ease of installation and to determine whether the material would be used in subsequent tests. After examination of previous recommendations and results, the materials that were chosen for the summer 2015 installation and testing were RepCon 928 and MG Krete. RepCon 928 was the only product that was used during the winter 2014/15 installations and was considered for further investigation.

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ACRONYMS

AASHTO	American Association of State and Highway Transportation Officials
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
ERDC	Engineer Research and Development Center
NTPEP	National Transportation Product Evaluation Program
ODOT	Ohio Department of Transportation
PCC	Portland Cement Concrete

CHAPTER I

INTRODUCTION AND RESEARCH OBJECTIVES

1.1 Introduction

This thesis, recommending a specification for the use of high performance repair material for use in patching of highway pavements and bridge decks, is part of Cleveland State University's research project for the Ohio Department of Transportation. The scope of this thesis is to explore high performance repairs of concrete through literature reviews. The recommendation is made based on current state specifications, as well as Larisa Susinskas' thesis covering field observation of installation and performance of repair materials (Susinskas, 2016), Kamran Amini's thesis providing analysis through laboratory testing of high performance repair material (Amini, 2015), Andrew Lesak's thesis discussing the field testing of high performance repair materials (Lesak, 2014), and Alice Sommerville's thesis which explains the selection of high performance repair materials (Sommerville, 2014).

1.2 ODOT Problem Statement

Patching of pavements and bridge decks is necessary for the Ohio Department of Transportation (ODOT) to ensure the safety of both its workers and the users of the

infrastructure. Spalling, cracking and unsound concrete not only create an aesthetic problem, but also are a safety concern. Repairing bridge decks and portland cement concrete pavement is not only costly in itself, but it also causes travel delays when having to shut down lanes and reroute traffic. The current products being used by ODOT include those that provide a temporary fix or cementitious materials that closely resemble the pavement or bridge deck materials, both of which have been used for decades. The specification provides current construction practices as well as mix design criteria for those types of materials and does not address the use of high performance repair material. Currently, several repairs have been made using high performance repair materials and research has been done in order to allow for a better understanding of the materials and their implementation into current or revised specifications.

1.3 Research Context

Issues that arise from the degradation of concrete and asphalt roadways, bridge decks and wearing surfaces continue to create problems for users and DOTs across the nation. Whether the materials were not mixed accurately, the mix was not placed properly, or for a variety of other reasons, repairs have to be made to the surfaces. High performance rapid hardening materials may be preferred over other conventional materials due to the need to limit disruption on bridge decks, roads and highways. The faster the lane can be reopened to traffic, the better. These types of materials are widely available in the market, but it is necessary to measure their actual performance.

Materials incorporated in the field installation, lab research and field observations included Delpatch, Pavesaver, Wabo Elastopatch, FlexSet, MG Krete, SR-2000, T 1060, FastSet DOT Mix, RepCon 928 and HD-50 (Sommerville, 2014). The state specifications will also be examined for their use of these materials.

Measuring material properties and performance in a lab can provide a lot of information about how that material will perform in the controlled environment of a laboratory. Measuring those materials out in the field, however, will provide much more insight into how that material will actually perform in the environment where it is needed. The ability to observe and record several of the materials' properties is key in recommending a new specification for widespread use.

Preparation of the area to be repaired and installation of the patching material play a vital role in the patch's performance and longevity. Ensuring the procedures for the removal of the existing unsound concrete, preparation, and installation are understood and followed are just as important as the mix itself. Proper curing of the concrete, although on a much smaller scale than that of a full slab, contributes to the patches' performance in the long run.

1.4 Study Objectives

The goal of the recommendation is to provide a specification that includes a more durable and longer lasting repair material that decreases the need of future maintenance and that ensures the safety of both the worker and the user. The objective of this thesis was to combine all pertinent material from previous investigations and reports into a recommended specification suitable for adoption by the Ohio Department of Transportation. The current specification that covers the use of portland cement concrete, as well as epoxy mortar and other types of repair materials will be the basis for the new recommendation. Changes to the recommendation will include preparation of the area to be repaired, preparation of the mixture, placement of the repair material and curing as it relates to using high performance repair material.

1.5 Research Plan

In order to provide a specification recommendation, the following objectives were to be accomplished.

1. Investigate and compare other states' specifications for bridge deck and highway repair.
2. Review recommendations made in other studies/theses.
3. Identify the high performance repair material(s) for use in the specification.
4. Identify a recommendation for a complete specification.

1.6 Benefits and Potential Application of Research Results

Current ODOT specifications for repair of bridge decks and highway surfaces by means of patching have been reviewed as well as those of other state DOTs. Improvements to current practices can result in a more durable and longer lasting high performance repairs. This will reduce the amount of maintenance required and improve the safety of roads for both the worker and the user.

1.7 Organization of this Thesis

This thesis consists of four chapters. The first chapter introduces why there is a need for a new recommendation, as well as an overview of the content of this thesis. The second chapter will review the current specification and construction practices that the Ohio Department of Transportation follows, while chapter three will review the specifications and construction techniques of the other states in the US. In chapter four, observations, conclusions and recommendations from the research and field visits that have an effect on the specification will be discussed. Supplemental material as well as the specification recommendation is included in the appendices following the thesis.

CHAPTER II

CURRENT OHIO DEPARTMENT OF TRANSPORTATION SPECIFICATION

In order to expand and revamp the current practices, it is necessary to look at the current specification and all special provisions that pertain to patching horizontal structures. This research will allow for the determination of its effectiveness and to identify those procedures that will continue to work. The current specification (ODOT, 2016) as well as ODOT's qualified product's list, does not provide for the use of high performance repair materials. The information gathered from this project will allow us to understand how to properly use materials such as polymer concrete, polymer modified concretes including magnesium phosphate and latex modifiers. Latex modifiers, when added to cement based patches, increase the bonding capabilities and resistance to harsh environmental conditions. The following sections cover patching using quick setting concrete and trowelable mortar as found in the current specification.

2.1 Construction and Material Specifications

Currently, the Ohio Department of Transportation's website contains a version of the construction and material specifications dated January 15, 2016. There are several sections that detail the practices required for patching of several types of surfaces, for the purposes of this

thesis, the specifications concentrating on Item 519 Patching Concrete Structures and Item 256 Bonded Patching of Portland Cement Concrete Pavement were examined (ODOT, 2016).

According to ODOT's current specification, patching is the work consisting of the placement of portland cement concrete in areas adjacent to cracks or joints or other areas of pavements as designated by the Engineer. Patching requires the removal of all unsound concrete and asphalt material; removal of sound concrete where necessary to create an approved area for placing the patch; preparing the area to be patched by use of approved equipment; furnishing and placing reinforcing steel if necessary; applying a bonding material where necessary according to recommendations of either the manufacturer or the Engineer; and mixing, placing, finishing, and curing the material used for patching according to the approved products list.

2.2 Removal of Unsound Concrete

All unsound concrete will be removed from the area to be repaired to an extent as to expose sound concrete. The area will be of a square or rectangular shape as long as it surrounds the deteriorating area. Pavement areas designated to be repaired will have a perimeter created with a saw cut to a depth of 1 inch (25 mm), concrete structures will contain saw cuts to a depth of 4 inches (100 mm) deep or 3 inches (75 mm) on top horizontal surfaces. Only use milling machines, concrete saws, jackhammers, or other approved machinery to include pneumatic or hand tools approved by the Engineer. Concrete will also be removed to include sound concrete to a depth of no less than ¼ inch (6 mm) and no more than 1 inch (25 mm) (ODOT, 2016).

In pavement repair, the minimum depth for a partial depth repair of concrete removal is 1 ½ inch (38 mm), except at the edges where the saw cuts may be 1 inch (25 mm). When working around reinforcing steel, carefully remove all unsound concrete without damaging or debonding the reinforcement that is completely surrounded by sound concrete or un-corroded. If necessary,

where reinforcement is exposed or concrete is unsound around the reinforcement, remove all concrete to ensure a 1 inch (25 mm) clearance around the reinforcement. Reduction of the clearance may be allowed to ½ inch (13 mm) when using No. 8 coarse aggregate. Remove all exposed reinforcement, needed to be replaced, with a cutting tool or torch.

2.3 Preparation of Patch Surface Area

To ensure a durable patch, unsound concrete must be removed with the use of hand tools in order to create a square or rectangular area. Once all of the unsound concrete is gone, sand blast the entire area in order to remove any loose materials, oils, dust, and other contaminants. Remove all residue with forced air, water or by means according to manufacturer requirements prior to applying bonding agents, patching material or bonding grout. If reinforcement is needed, install dowels or expansion bolts as necessary to hold reinforcement in place. When patching concrete structures, thoroughly wet the patch surface with clean water and allow to dry before placing material.

2.4 Placement of Concrete or Patching Material

When placing concrete for a repair on a concrete structure, use of Class QC 5 concrete must conform to mix design requirements. Patch material will consist of Type A, B, or C patch material and will conform to the requirements outlined in this section.

A. Type A. One part high early strength portland cement, one and a half parts fine aggregate, and one and a half parts coarse aggregate by volume. Air content will remain at a level of 8 ± 2 percent, air-entraining admixture will be used in order to maintain this level. Enough water will be added to the mixture in order to maintain a slump not to exceed 4 inches (100 mm). Material will be mixed on site. Do not use ready-mixed concrete.

Concrete will be placed while bonding agent or grout is still wet. Enough material will be added to area to allow for vibration and strike off.

B. Type B. Patching material will consist of quick setting concrete mortar that is found on the qualified products list, Type 1 or Type 2, that can be found in Appendix A of this thesis. Ensure mixing of quick setting concrete is done according to the recommendations of the manufacturer. Coarse aggregate may be added according to manufacturer's instruction where necessary to extend the amount of concrete. Place the concrete mixture into the patch area. If bonding grout is recommended by the manufacturer, place the concrete mixture while the bonding agent is still wet. Slightly overfill the patching area, vibrate mixture and strike off the concrete.

C. Type C. Patching material will consist of quick setting concrete mortar that is found on the qualified products list, Type 2, that can be found in Appendix A of this thesis and selected aggregates with an activator. Place concrete mixture according to manufacturer's recommendations. Coarse aggregate may be added according to manufacturer's instruction where necessary. Place the concrete mixture into the patch area. If bonding grout is recommended by the manufacturer, place the concrete mixture while the bonding agent is still wet. Slightly overfill the patching area, vibrate mixture and strike off the concrete.

Screed patches 12 feet (3.7 m) or less in length parallel to the centerline of the patch. Screed patches which are more than 12 feet (3.7 m) in length perpendicular to the centerline of the patch.

Test the surface of the patch for being flush with the adjacent slabs, before the patch hardens and is in a plastic state. Use a 10 foot (3 m) straight edge, with edges resting on the adjacent

slabs and run the straight edge across the patch parallel to the centerline. If there are any deviations, high or low areas exceeding an 1/8 inch in 10 feet (3 mm in 3 m), correct areas and then retest before the material hardens.

Texture patched area to resemble that of the surrounding areas.

Quick setting concrete mortar must be pre-packaged mortar material and must conform to the requirements in Table 1. These requirements for quick setting mortar will provide a basis for comparison when referring to the high performance repair material being used in the project.

Test	Type 1	Type 2
Compressive Strength ASTM C109, psi (MPa)		
@ 1 Hour	100 (0.7)	2000 (14)
@ 3 Hours	250 (1.7)	---
@ 24 Hours	2000 (14)	5000 (34)
@ 7 Days	---	7000 (48)
Compressive Strength ASTM C39, psi (MPa)		
@ 1 Hour	100 (0.7)	2000 (14)
@ 3 Hours	150 (1.0)	---
@ 24 Hours	1000 (10)	3500 (24)
@ 7 Days	---	6000 (41)
Initial Set Time ASTM C266, min	5	10
Bond Strength ASTM C882, psi (MPa)		
@ 24 Hours	1000 (7)	1000 (7)
@ 7 Days	1500 (11)	1500 (11)
Flexural Strength ASTM C78, psi (MPa)		
@ 4 Hours	---	200 (1.4)
@ 3 Days	650 (4.5)	500 (3.4)
Freeze & Thaw ASTM C666		
Procedure B (350 Cycles) Durability Factor	80%	80%
Procedure A (300 Cycles) Durability Factor	79%	79%

Table 1: ODOT Requirements for Quick Setting Concrete Mortar

2.5 Bonding Grout Installation

When bonding grout is required, for bonding Type A patches, use a mix that has equal parts, by volume, of portland cement and sand, mixed with enough water to create a stiff slurry. Use a wire/stiff brush or broom to paint the slurry onto all surfaces to be patched in a thin and even

coat. Apply grout just before placing patching material, do not allow grout to dry or gather in low spots. When using Type B or Type C patching material, use a grout that conforms to the manufacturer's recommendations.

2.6 Curing

Type A and Class QC 5 patches will be cured by spraying a uniform coating of sealing membrane to the surface of the patch as well as the saw cuts immediately after finishing and all free water has dissipated. Apply a minimum of 1 gallon (1 L) of curing compound for every 150 square feet (3.7 m^2) of patched surface. Type B and C patches will be cured according to manufacturer's recommendations. Allow the patch to cure long enough to attain a modulus of rupture of at least 400 psi (2.8 MPa) prior to opening the lane up to traffic.

CHAPTER III

DEPARTMENT OF TRANSPORTATION PRACTICES THROUGHOUT THE UNITED STATES

The practices and specifications followed by all the other states and/or territories were examined to compare to that of ODOTs. Identifying both similarities and differences to the specification that ODOT follows was necessary in order to decide on the proper course of action in the new specification recommendation. Focusing on states that use high performance repair materials similar to those discussed in section 1.3, as well as those states that have similar climates to Ohio, will provide information that can be used when recommending the specification.

3.1 Alabama Department of Transportation

Alabama Department of Transportation (ALDOT) uses a standards specification for highway construction with updates occurring every 2-4 years with the latest specification in 2012 (ALDOT, 2012). A special provision numbered 12-1538, dated in July 2015 was added to the specification and addressed the use of patches in concrete pavements and structures. ALDOT uses a patching material called Fibrecrete “G” manufactured by Fibrecrete Technologies, LLC. Fibrecrete is a hot applied, synthetic polymer modified resin compound that contains mineral fillers, chopped fibers, and graded aggregates. Along with fibrecrete, ALDOT includes SR2000

as a horizontal application patching material for portland cement concrete. The extent of repair and patching procedures are left to the contractor. The Contractor is required to submit plans to the Engineer for approval.

3.2 Alaska Department of Transportation

Alaska Department of Transportation (AKDOT) latest standard specification is dated 2004 with modifications made to the specification in 2007. AKDOT uses hot mix asphalt for pavements and portland cement concrete for bridges and airport runways and taxiways. The specification addresses only placement of both the asphalt and concrete, however has a special provision P-501 that addresses repair, removal and replacement of portland cement concrete slabs. No high performance repair materials were found on AKDOT's qualified product's list.

Review shows that AKDOT follows somewhat of a generalized specification adhering to ASTM and AASHTO for materials, mix design, and construction methods. Slabs shall be completely removed and replaced when cracks extend full depth, there will be no removal of partial slabs. In order to determine the depth of the crack, 4 inch (101.6 mm) diameter core samples shall be drilled if the Engineer is unable to determine the depth of the crack without them. When a crack is determined to be less than 4 inches (101.6 mm), the crack is cleaned with approved equipment and then pressure injected with an approved epoxy resin using recommended procedures for the material. Cracks found in the interior of the slab that exceed 4 inches (101.6 mm) require that the slab be removed and replaced. Cracks that are found within 6 inches (152.4 mm) on either side of a joint will be repaired dependent on the condition of the joint nearest the crack. If the joint is cracked as well, then the entire slab, full land width and length, will be replaced. If the joint nearest the crack is not cracked, then the crack shall be routed and sealed and the original joint will be filled with epoxy resin. The reservoir for joint

sealant in the crack shall be formed by routing to a depth of ¾ inch (19 mm), plus or minus 1/16 inch (2 mm), and to a width of 5/8 inch (16 mm), plus or minus 1/8 inch (3 mm).

Repairing spalling along joints is completed by saw cutting 1 inch (25.4 mm) outside of the spalled area to a depth of no more than 2 inches (50.8 mm). The unsound concrete within the formed rectangular area will be removed to within a ½ inch (13 mm) of sound concrete. The area to be repaired is cleaned with water jets supplemented with compressed air. Once the entire area is free of debris, a Type III, Grade 1 epoxy resin is brushed over the entire area, however is not put on joint faces. The resin will be applied with a coarse brush or broom and applied in a thin layer ensuring that pooling does not occur in low areas. The cavity shall be filled with low slump portland cement concrete or mortar or with epoxy resin concrete or mortar. Concrete will be used when the area of the cavity exceeds ½ cubic foot (0.014 m^3) and mortar will be used for those smaller. Epoxy resin will be used on cavities less than 0.1 cubic feet (0.003 m^3) and will not be placed in layers more than 2 inches (50.8 mm) thick (AKDOT, 2004).

3.3 Arizona Department of Transportation

The Standard Specification for Road and Bridge Construction dated 2008 is Arizona Department of Transportation's current specification (AZDOT, 2008). AZDOT details the use of four specific types of patching material for use in their repairs. Accelerated strength portland cement concrete patching material is a mixture of Type III Portland Cement and calcium chloride that attains a compressive strength of at least 2,000 psi (14 MPa) in six hours. This material can be mixed with approved coarse aggregates. Patch boundaries will be saw cut and broken out to at least 1.5 inches (38 mm). Bonding agent from approved material list, update monthly, is then applied with a stiff bristled brush to the patch area. Patch material is placed once bonding agent becomes sticky.

Rapid setting patch material, also found on approved product list, has boundaries which are saw cut and broken out to at least 1.5 inches (38 mm) or according to manufacture requirements, whichever is greater. If required or recommended by manufacturer, bonding agent will coat the patch area prior to placing the patch material.

Another type of patch material used, which also must be found on the approved product's list, is an epoxy resin grout which is a low modulus moisture insensitive epoxy mortar grout. Fine aggregate is added according to approved specification subsection 1006—2.03 (AZDOT, 2008), ensuring that the aggregate is free from excess moisture after washing. The ratio of binder to aggregate shall be between 1:7 and 1:10. Patch boundaries will be saw cut and broken out to at least 1.5 inches (38 mm). Proper mix of the epoxy resin will be obtained prior to adding aggregate.

A flexible epoxy patching material is a mixture of solventless, stress relieved flexible coating epoxy and 100% vulcanized granulated rubber. It is a two component, low viscosity mixture and is gray in appearance when mixed. The patching material has a seven-day curing period with a minimum of 2,000 psi (14 MPa) compressive strength. Patch boundaries will be saw cut and broken out to at least 2 inches (50 mm) in depth. For this mixture, it is recommended to mix only the amount that can be applied before expiration of the pot life of the material. Materials will be mixed in separate containers before being mixed together.

For all of the different types of patching materials, concrete will be removed within the area to be patched following minimum depths required by the material. The concrete will be removed until sound clean concrete is reached. If the patch's depth is more than half the width of the slab, then the entire area of affected pavement will be removed and replaced. The area to be patched will then be sandblasted and blown with compressed air to ensure a clean dry face.

3.4 Arkansas Highway and Transportation Department

Arkansas Highway and Transportation Department has a current standard specification edition from 2014 (AHTD, 2014). The specification contains mostly general construction practices with the use of Portland-Pozzolan Cement – AASHTO M 85, Type IP (20% maximum) and Slag-Modified Portland Cement – AASHTO M 240, Type IS (25% maximum) as the approved products for portland cement concrete pavement patching. All materials will conform to the Department's Qualified Products List, except that the slump will be a maximum of 4 inches (100 mm) and have a minimum 28-day compressive strength of 4000 psi (28.0 MPa).

Existing pavement will be saw cut to the complete depth of the slab as shown in the plans. If needed, one additional cut will be made it order to allow for an easy removal of the concrete. All loose material must be removed and the area cleaned before placing the patch. If the base material is granular, the base will be re-compacted as necessary. A mobile, continuous volumetric mixer may be used in lieu of a batch plant. The mixer will feed each component automatically according to mix requirements and will be calibrated prior to any placement of the mix. A trial batch of at least 2 cubic yards (1.5 m^3) will be produced, sampled, and tested by the engineer prior to any mix being placed.

3.5 California Department of Transportation

The current specification for the California Department of Transportation is dated 2015 (CALTRANS, 2015), however the state makes updates to their specifications every 2 to 3 years. CALTRANS uses three types of repair materials: magnesium phosphate concrete, modified high-alumina-based concrete, or portland-cement-based concrete. In order to be included in CALTRANS approved product's list, the concrete mixture must be either water activated or dual

component with a pre-packed liquid activator and must comply with the requirements found in the table below.

Quality Characteristic	Requirement
Compressive Strength, psi (MPa)	
@ 3 Hours	3000 (21)
@ 24 Hours	5000 (34)
Flexural Strength @ 24 hours, psi (MPa)	500 (3.4)
Bond Strength @ 24 hours, psi (MPa)	
Saturated surface dry concrete	300 (2.0)
Dry Concrete	400 (2.8)

Table 2:CALTRANS Bonding Material Requirements

Magnesium phosphate concrete will have an initial set time of 15 minutes and final set time of 25 minutes at 70 degrees F (21 degrees C). The mixtures will be prepared in containers with tools that do not contain zinc, cadmium, aluminum or copper metals. The concrete must contain 675 pounds of cementitious material per cubic yard (400 kg/m^3), have no more than 280 lb/cu yd (166 kg/m^3) of water, and contain between 50-55% fines within the aggregate. The remaining aggregate will be pea gravel with 100% passing the 1/2-inch (12.5 mm) sieve and <5% passing no.16 sieve (1.18 mm). The Engineer is the only one allowed to request the addition of admixtures.

Rapid setting concrete (RSC) may be extended using a rounded aggregate filler than is clean and uniform in shape. The aggregate may not contain more than 0.5% moisture with 100% passing the ½ in sieve and <5% passing no. 16 sieve. Dual-component magnesium phosphate mixes must be mixed according to manufacturers specification with no addition of any water. All RSC mixtures used for pavements must have a minimum of 4,000 psi (28 MPa) 28-day compressive strength, while mixtures used for bridge decks will have a minimum of 4,500 psi (31 MPa).

Areas to be patched must have all unsound concrete removed up to 4 inches deep. The temperature of the surrounding concrete must not fall below 40 degrees Fahrenheit (4.5 degrees Celsius). Unsound concrete makes a dull, dead or hollow sound when hit with a metal tool. The Engineer will determine whether or not the concrete is sound. The concrete will be tested 14 days after setting to ensure it emits a ringing sound similar to that of the concrete surrounding it.

3.6 Colorado Department of Transportation

The latest specification used by Colorado Department of Transportation (CDOT, 2011) is dated in 2011 with special provisions published in January, 2016. CDOT uses a variety of materials for different purposes and all mixtures will be prepared providing protection against sulfate attack. Unless used for specific purposes, all mixtures shall be Class 2.

Class DT concrete will be used for deck resurfacing and repairs, while Class P will be used for pavements. Class HT concrete may replace Class DT concrete when necessary. Class DT may be used with a water reducing admixture where necessary. The mix will have a minimum of 50% AASHTO M 43 size no. 7 or no. 8 coarse aggregate. Class P will contain a minimum of 55% AASHTO M43 size no. 357 or no. 43 coarse aggregate by weight. The mix will have a flexural strength of 650 psi (4 MPa) at 28 days. If flexural strength is the deciding factor of the mix, then the mix must contain no less than 520 lbs/yd^3 (308 kg/m^3) of cementitious material. The formula used for the concrete mix will be determined by trail to obtain a color match to the concrete in the surrounding area. Concrete mixtures used for patching will have a compressive strength > 4,500 psi (> 31 MPa).

Any mix design used in pavement repair will be submitted, reviewed and accepted by the engineer prior to placement. Lab tests will be conducted on the mix design within 2 years.

Sacked or bulk cement may be used and must be weighed prior to addition to the mix. The concrete may be mixed in a batch plant, a concrete mixing truck or by means of a self-contained mobile mixer. Self-contained mixers must be self-propelled and be capable of holding enough material to include all necessary aggregates, admixtures and water to produce 6 cubic yards (4.5 m^3) of concrete.

All Class DT concrete mixes will be placed in an area that has been prepared by shot blasting 1/8 to 3/16 inch (0.003 to 0.005 m) deep. The area will then be moistened 2-4 hours prior to placement and must be free of standing water before placement.

3.7 Connecticut Department of Transportation

Connecticut Department of Transportation (CONNDOT, 2004) follows a Standard Specification for Roads, Bridges and Incidental Construction dated 2004. Supplemental specifications are produced when necessary and review shows approximately two being published throughout a calendar year, with the most recent update occurring in 2015. A supplemental specification was found for partial depth patching using concrete with quick setting cement, fine and coarse aggregate and water (CONNDOT, 2012). The minimum required compressive strength for the concrete was 1,000 psi (7 MPa) within an hour after set and 3,000 psi (21 MPa) within three days. The ambient temperature must be above 35 degrees Fahrenheit (2 degrees C) and only enough concrete will be mixed that can be placed within 15 minutes.

3.8 Delaware Department of Transportation

Current standard specifications used by Delaware Department of Transportation (DELDOT, 2001) were produced in 2001 with supplemental specification additions added as necessary. There is no qualified or approved product's list maintained by DELDOT. Manufacturers may submit samples of their products for use on an approved project. DELDOT's specification has

patching categorized as the work consisting of cutting, removing of existing portland cement concrete pavement and replacing it with new portland cement concrete (PCC) pavement. There are two classes of PCC, Class A being used when it is necessary to open the repaired lane to traffic with a specified timeframe and Class B when an early opening to traffic is not specified. Class A concrete will have the minimum requirements of an internal temperature of 75 degrees F (24 degrees C) and a compressive strength of 2000 psi (15 MPa) achieved in six hours. Class B concrete will have the same minimum requirements set by Class A in terms of temperature, air content and slump, however a compressive strength of 2000 psi (15 MPa) may be reached in 72 hours.

Patches are classified as either a Type I patch which is 16 feet (4.8 m) or less in length of a Type II patch which is greater than 16 feet (4.8 m). The minimum length of conventional concrete pavement to be repaired may not be less than 6 feet (1.8 m).

3.9 District of Columbia Department of Transportation

District of Columbia Department of Transportation (DDOT, 2013) utilizes a standard specification produced in 2013. DDOT uses two types of grout for repair and patching of concrete surfaces. Fast-setting grout will achieve a compressive strength of 3,000 psi (21 MPa) at 3 hours and at 5,000 psi (34 MPa) at 24 hours. Aggregate filler will be used if necessary and must be clean, uniformly rounded and have a moisture content that does not exceed 0.5% by weight. Types of fast-setting grout include Magnesium Phosphate Grout, single-component water activated or dual component with a prepackaged liquid activator, Modified High Alumina Based Grout or Portland Cement Based Grout. Another type of grout used is a polyester grout that is a polyester resin binder mixed with dry aggregate. The aggregate will be either 3/8 inch

(9.5 mm) maximum grading or the no. 4 maximum grading. The binder will be 12% by weight of the dry aggregate.

Concrete will be cut using a diamond bladed saw. For fast setting grout, cut to a minimum depth of 2 inches (50.8 mm). With polyester grout, cut to a minimum depth of 1 ½ inches (38.1 mm) but no greater than 1/3 of the depth of the pavement. Remove all loose material from the area to be repaired. Clean the area with either sand or water blasting equipment that has a blast pressure of between 3,000 and 6,000 psi (21 to 41 MPa). Then use an air compressor with a rate of 120 cu ft/min (3 cu m/min) and 90 psi (0.62 MPa) of nozzle pressure to remove all remaining debris.

Fast-Setting Grout will be mixed in a small mobile drum or paddle mixer to manufacturer's instruction. The mixture must use the full amount of each component supplied by the manufacturer. Water will not be added to the mixture. A bonding agent may be used if recommended by the manufacturer. The Polyester Grout will be mixed by manufacturer's instruction.

3.10 Florida Department of Transportation

Specification standards for Florida Department of Transportation (FDOT, 2015) have been published every year since 2013. Current specifications require materials are used based on the requirements of the patch and will be found on the approved products list. The selection of materials will be made dependent upon the a) compatibility of the material to the original concrete, b) environmental considerations, including aesthetics, c) cost effectiveness, d) expected service life, e) availability, and f) familiarity of the contractors with the product.

The material chosen will be as close to the original concrete as possible to include the compressive strength, as well as the color and texture of the concrete's final appearance. Most

common materials used are latex modified concrete and mortar, epoxy patching compounds, polyester resin, acrylic concrete and mortar, polymer-modified cement based materials, pozzolanic modified concrete, high alumina cement compounds, magnesium phosphates, molten sulfur, calcium sulfate based materials, non-shrink quick setting mortar cement based polymer concrete, and pneumatically applied mortar.

All damaged or unbounded concrete material will be removed by means of water blasting, bush hammering or jack hammering. Saw cuts will be made if necessary to a depth of minimum 1 inch (25 mm). If repairing a deck, the depth required will be a minimum of 3/4 inch (19 mm) clearance below the reinforcing steel. The surfaces will be cleaned and given ample time to dry prior to placing the patching material.

3.11 Georgia Department of Transportation

A supplemental specification dated in 2005 on Rapid Setting Patching Materials for Portland Cement Concrete (PCC) details the requirements in using PCC by the Georgia Department of Transportation (GDOT, 2005). Use of rapid setting patching materials must conform to the following requirements; are nonmetallic, have a color similar to portland cement concrete, can be mixed and placed like concrete, have accelerated hardening characteristics, and must yield a permanent patch in concrete that can withstand traffic within 2 hours. Specific brands of rapid setting patching material can be found on the qualified product's list.

There are five types of concrete they may be used when patching existing surfaces. Minimum requirements for these types of concrete are shown in Table 3 when the tests are done following the requirements according to AASHTO and ASTM testing methods.

Requirement	Measurement
Compressive Strength, psi (MPa)	
@ 2 Hours	1200 (8.5)
@ 24 Hours	3000 (20)
@ 7 Days (moisture cure)	4000 (27.5)
Flexural Strength @ 24 Hours, psi (MPa)	500 (3.5)
Shear Bond @ 24 Hours, psi (MPa)	200 (1.5)
Freeze Thaw Durability Factor	75%

Table 3: GDOT Concrete Requirements

Type I concrete will be used for reinforced or non-reinforced horizontal portland cement concrete surfaces. Use Type II to patch only non-reinforced surfaces. Use Type III to patch reinforced vertical or overhead portland cement concrete surfaces. Use hot applied elastomeric patching material to patch non-reinforced horizontal cement concrete surfaces. Use two-component cross linked resins to patch non-reinforced horizontal portland cement concrete surfaces. All patching material approved for use must have a 2-hour compressive strength of 1,200 psi (8.5 MPA), 24-hour strength of 3,000 psi (20 MPa) and a 7-day moist cure compressive strength of 4,000 psi (27.5 MPa).

Patches will be saw cut with vertical faces no less than 2 inches (51 mm) or more than 3 inches (76 mm) in depth. Prior to placing the material, the existing transverse and longitudinal joints boarding the repair area will be sawed to 5 inches (127 mm) deep and ¼ inch (6 mm) wide with the full-depth of the saw cut. Extending at least one inch beyond the limits of the repair area. All material will be removed from the area to patched and the area will be cleaned by sand or air blasting.

The repair will only be made when the daily temperature is above 50 degrees F. The areas to be repaired will first be coated with a film of Type II Epoxy 10 to 20 mils thick. Concrete is then filled into the repair area while the epoxy is still tacky. The repaired area will be covered with wet burlap once complete and remain covered for 3 hours.

3.13 Idaho Transportation Department

Idaho Transportation Department's current specification, Standard Specifications for Highway Construction was published in 2012 and includes supplemental specifications (ITD, 2012). The specification addresses the removal of bridge deck concrete and categorizes them in two types, A and B. Class A removal consists of the removal of concrete up to the mean of concrete as shown on the plans. Class B removal is any removal needed after the completion of a Class A removal. The structural concrete section of the specification includes the use of portland cement concrete and does not address high performance or rapid set materials. The minimum requirements included in the section refer to ASTM and AASHTO standards. ITD has a qualified product's list that contains polymer-modified materials.

3.14 Illinois Department of Transportation

Illinois Department of Transportation currently uses a standard specification adopted in 2012 (IDOT, 2012). Supplemental specifications are published when necessary and a special provision on longitudinal joint and crack patching from April 2014 was also examined. IDOT uses a checklist in order to provide the construction inspector with guidelines and requirements. The work is categorized into four separate classes and the separated by type which are found in Tables 4 and 5.

Class A Patches:	Pavement Removal and Continuously Reinforced Portland Cement Concrete Replacement
Class B Patches:	Pavement Removal and Portland Cement Concrete Replacement Using Dowels or Tie Bars
Class C Patches:	Pavement Removal and Portland Cement Concrete Replacement
Class D Patches:	Pavement Removal and Hot-Mix Asphalt (HMA) Replacement
Pavement Patching:	Contractor's Option of Class C or Class D

Table 4: IDOT Classes of Patches

Type I	Less than 5 sq yd (5 sq m)
Type II	5 sq yd (5 sq m) or more, but less than 15 sq yd (15 sq m)
Type III	15 sq yd (15 sq m) or more, but less than 25 sq yd (20 sq m)
Type IV	25 sq yd (20 sq m) or more

Table 5: IDOT Patch Type

The specification breaks down requirements of ten classes of concrete and then divides those into use categories. The pavement will be scored or sawed no more than three days prior to the removal of the unsound concrete. Depending on the class and type of patch, the construction requirements are different. For this summary Class C patches are reviewed, which are those used for pavement removal and portland cement concrete replacement. Non-reinforced concrete will be scored to at least 6 inches (15 cm) from the face of the patch. The cut may not be squared if following an existing crack and shall not deviate from 1 ½ inch (4 cm) from vertical. The unsound concrete will be removed without creating more damage to the surrounding concrete.

3.15 Indiana Department of Transportation

Standard Specifications are published every two years by the Indiana Department of Transportation with the most current specification date January, 2016 (INDOT, 2016). According to their specification this work consists of the removal and replacement of portland cement concrete pavement. Patching material requires the following; fine aggregate, size no. 23, coarse aggregate for full depth patching, size no. 8, Class AP, coarse aggregate size for partial depth patching no. 11, Class A or higher, portland cement, water, calcium chloride, Type L, admixtures and chemical anchor systems. Concrete mixes are required to be submitted for approval and a trial batch is required for testing. Flexural strength tests are required for each mix design with a minimum of 300 psi (2 MPa) at 24 hours and minimum of 500 psi (3 MPa) at 3 days. All materials will be on the Department's list of approved materials. Minimum Portland

cement content is 658 pounds per cubic yard. The water cement ratio cannot exceed 0.45 and air content of 6.5% ± 1.5%.

Partial or full depth patches are conducted under different provisions. All unsound concrete around the patch must be removed, ensure depth is appropriate (full or partial), paying close attention to the location of the reinforcing steel. Partial depth removals contain saw cuts between 1 to 3 inches (25 to 75 mm). All unsound concrete will be removed from the area to be patched and must be cleaned. Full depth removals contain saw cuts to the full lane width and thickness of the pavement or if reinforcement steel is found during a partial depth patch. The concrete to be used will be mixed at a batch plant, shrink mixed, or transit mixed. The concrete must be poured within 30 minutes of adding water in non-agitating equipment or 90 minutes in agitating equipment. Concrete will be placed after 1300 hrs when the forecast will be 70 degrees Fahrenheit (21 degrees C) or higher the following day. On partial depth patches, a bonding agent will be applied to all exposed surfaces prior to placement. The patched area will be opened to traffic according to the temperature and dependent on the amount of traffic forecasted.

3.16 Iowa Department of Transportation

The Iowa Department of Transportation (IOWA DOT, 2015) utilizes a developmental specification for partial depth bridge deck patching. The guidelines used for deck patching are dependent upon when lane closures are utilized. Class O or HPC-O mixes are used whether there are lane closures, however if extended lane closures are not authorized, materials must be found on the approved materials list. It is advised to always follow manufacturer’s recommendations for materials. Do not use calcium chloride in any patching mixes. Coarse aggregate may be used only where necessary in the manufacturer’s recommendation.

The patched area is determined by the Engineer and includes 2 to 3 inches (50 to 75 mm) of sound concrete at its edges and will have a minimum depth of 1 inch (25 mm). If reinforcing material is present in the concrete, saw cuts will go no deeper than 1 inch (25 mm) of the top mat of steel. Sand blast the entire patch area and then remove all loose debris with compressed air.

Class O and HPC-O mixes will have a slump of 3 inches (75 mm) ± 1 inch (25 mm) and have an air content of 6.5%, plus 2% or minus 1%. All other mixes will be according to the manufacturer's recommendations. Add components of the mixture in the order required and place the mixture in the correct amount of time according to the manufacturer recommendations. Class O and HPC-O concrete require a cement-sand-water grout to be spread over the entire patch surface. The mix will be placed before the grout dries. Cure times for the mixture depend on the temperature and range from 3 hours for 61-74 degrees Fahrenheit (16-23 degrees C) and 2 hours for 75-90 degrees Fahrenheit (24-32 degrees C).

3.17 Kansas Department of Transportation

With a newly updated specification in 2015 (KDOT, 2015), Kansas Department of Transportation uses a list of prequalified rapid-set patching materials to repair spalling on bridge decks. These rapid-set patching materials will go through 300 freeze-thaw cycles and have an expansion of less than 0.10% and durability factor calculated of at least 90.0% before being added to the list. All material will be set forth by requirements in the plans. Aggregate, if necessary and allowed, can be combined to the setting material. Material is classified in three separate types, R1 Rapid Hardening, R2 Very Rapid Hardening or R3 Ultra Rapid Hardening. These types are based upon test of the original product and when extended with the maximum allowable amount of aggregate. All materials will comply with applicable requirements. Coarse

aggregate requirements will comply with the gradation percentage to allow for 90-100% retained on a #8 sieve.

All unsound concrete, material and rusted reinforcement will be removed from the area to be patched to a depth determined by the plans or the onsite engineer but no less than 4 inches (101.6 mm). Jack hammers must be no heavier than the 15-pound (6.8 kg) class when the depth of concrete to be removed is under 6 inches (152.4 mm). When there is sound concrete around part of exposed reinforcement, a ¾ inch (19 mm) minimum depth around the steel must be achieved before placing the patching material. The figures below show the required amount of concrete needed to be removed when coming into contact with reinforcement.

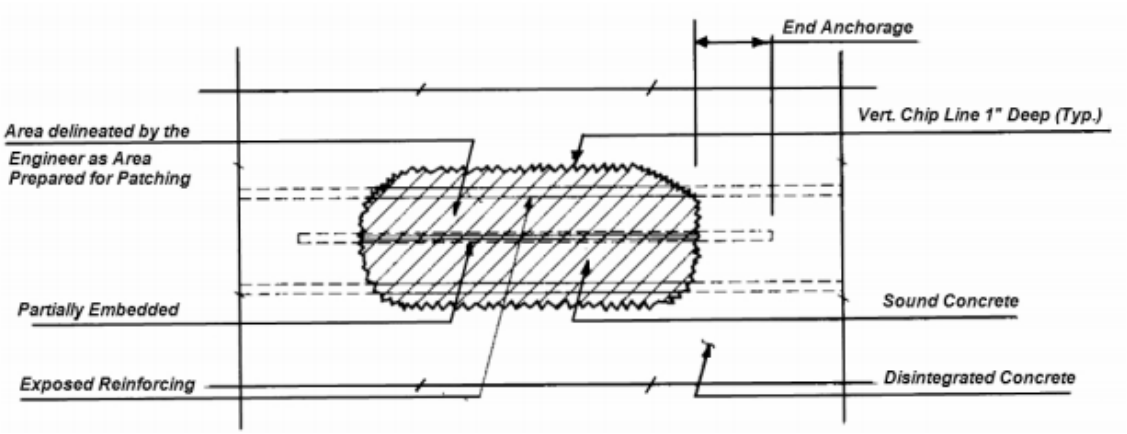

Figure 1: KDOT Reinforcement Exposure

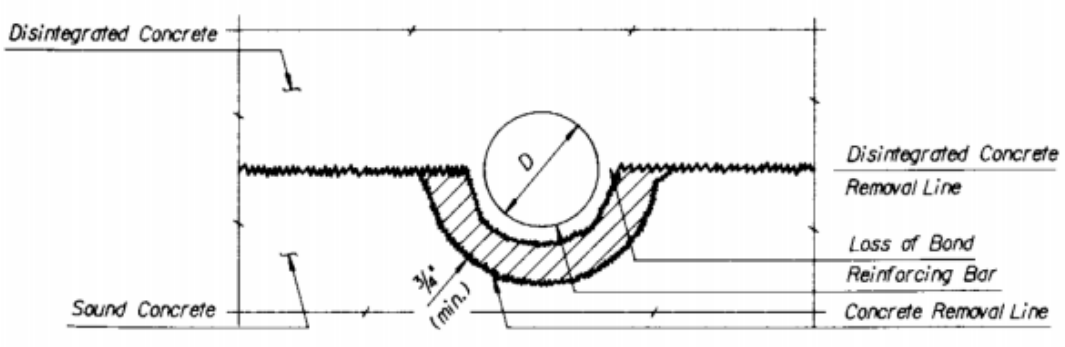

Figure 2: KDOT Plan for Removal of Concrete around Reinforcement with <½ Bar Exposed

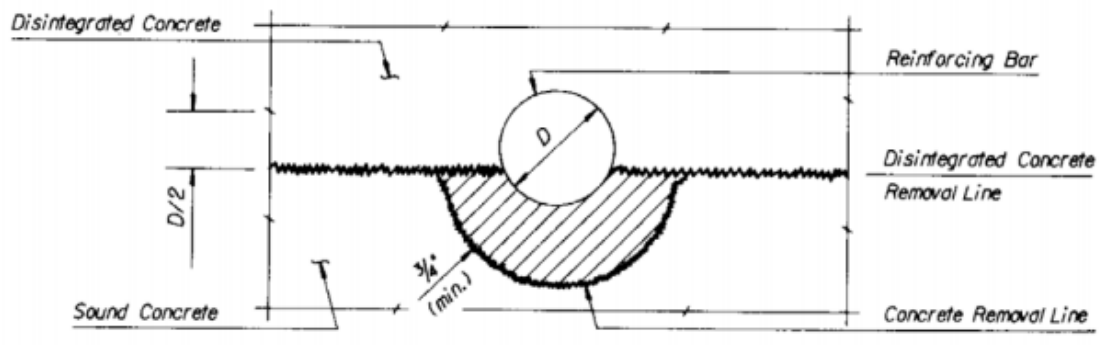

Figure 3: KDOT Plan for Removal of Concrete around Reinforcement with >½ Bar Exposed

Once all unsound material is removed, compressed air and a stiff rotary broom are used to clean the patch area. An epoxy resin base-bonding agent is applied to all vertical surfaces before placing material. Apply a grout of cement and water to all surfaces. Finish concrete surface with a burlap or broom drag.

At temperatures above 70 degrees Fahrenheit (21 degrees C), a monomolecular film will be used to prevent rapid evaporation of the water which rises to the surface. Concrete will not be placed when the temperature falls below 45 degrees Fahrenheit (7.2 degrees C). Concrete must have a flexural strength of 380 psi (2.6 MPa) or compressive strength greater than 1800 psi (12 MPa) before opening to traffic. A rebound hammer can be used to determine when the concrete is ready for traffic.

3.18 Kentucky Transportation Cabinet

Published in 2012, Kentucky Transportation Cabinet (KYTC, 2012) produces standard specifications every 4 years with supplemental specifications published when necessary. KYTC uses either class M1 or M2 concrete and an epoxy resin system when repairing, patching and overlaying bridge deck surfaces. For the removal and preparation of the patch area, KYTC uses standard practices with many similarities to ODOT. All materials and practices conform with

standards set forth by AASHTO and ASTM testing requirements. These include a minimum 28-day compressive strength of 4,000 psi (28 MPa).

There are three types of systems used dependent upon the nature of the repair. Type III is an epoxy-sand slurry which is used as a binder in epoxy mortars or epoxy concretes. Type IV is used when installing dowels into hardened cement concrete. Type V used when bonding plastic portland cement concrete to hardened portland cement concrete. When using the bonding agent on structural concrete, a minimum of 5,000 psi (34 MPa) 7-day compressive strength and a 2,000 psi (14 MPa) 0-hour contact time bond strength are required.

3.19 Louisiana Department of Transportation

A supplemental specification Section 830 Repair and Rehabilitation was examined for the practices followed by Louisiana Department of Transportation (LDOT, 2006). This was published in 2006 along with their Standard Specifications for Roads and Bridges Manual.

The Contractor will choose between portland cement concrete and epoxy mortar. Portland cement will be Type E with a Grade F aggregate where necessary. A set-accelerating admixture will be added at the site. Concrete will conform to the values found in Table 10 unless a rapid setting patching material is used from the Approved Materials List (AML).

Structural Concrete Patching Material Requirements		
Parameter	Test	Value
Minimum Compressive Strength	ASTM C39 or ASTM C109	2000 psi (min.) at 24 hrs 4000 psi (min.) at 7 days
Curing Shrinkage	ASTM C157	0.07% max. at 28 days
Curing Expansion	ASTM C157	0.03% max. at 1 day
Thermal Expansion	ASTM C531	5.0×10^{-6} in/in/°F (min.) at 28 days 9.0×10^{-6} in/in/°F (max.) at 28 days
Bond Strength by Slant Shear	ASTM C882	750 psi (min.) at 7 days

Table 6: LDOT Minimum Requirements of Structural Concrete

Partial depth patches will have saw cuts made between 1-½ inches (38 mm) and no more than 4 inches (100 mm). Pneumatic tools with a 30-pound (13.6 kg) maximum weight will be used to remove concrete. All loose material will be removed by means of sand blasting prior to placement of concrete patch. A bonding agent will be applied to the entire repair area before placement of the patching material. Concrete patches will remain closed to traffic until a compressive strength of 3200 psi (22.0 MPa) is met. Epoxy mortar patches will be primed with a blended epoxy prior to mortar placement. The patches will remain closed to traffic for at least 2 hours with temperatures over 60 degrees Fahrenheit (15.5 degrees C) and for 4 hours at temperatures lower than that.

3.20 Maine Department of Transportation

Maine has a current specification which was published in 2014 and supplemental specifications which were published most recently in December of 2015 (MaineDOT, 2014). According to the specification, contractors may choose to use a patching material found on the Prequalified Patching Material's list instead of using concrete as long as the requirements of the manufacturer of the material are met. If and when concrete is used, it must conform to minimum compressive strength dependent upon the specific concrete class. Concrete used for patching material falls into Class A and will have a minimum compressive strength of 4350 psi (30 MPa).

A bonding agent will be used to bond the concrete to the hardened concrete. The grout will have portland cement and fine aggregate proportioned to a 1 to 1 by volume. The fine aggregate will be that for which is used in the repair material and must not exceed 1/8 inch (3 mm). The fine aggregate will be placed in the mixture first, adding the sand second and finally the cement. Water will be added small amounts at a time until the mixture reaches a workable consistency and no more.

Removal of the unsound concrete and preparation of the area to be repaired will be done in the same manner as standard practice to a minimum of 5/8 inch (15 mm) and 1 inch (25 mm) behind reinforcing steel. The concrete will be placed when the ambient air temperature and the existing concrete temperature is above 45 degrees F (7 degrees C). When other patching material is used, the recommendations of the manufacturer will be followed.

3.21 Maryland Department of Transportation

Maryland's current standard specification was published in 2008 with necessary supplemental specifications published at the same time (MDOT, 2008). MDOT requires the patching of existing bridge deck surfaces as required for maintenance of traffic. A rapid hardening cementitious material for concrete pavement repairs which is found on the department's prequalified list of materials will be used. Any hole measuring over 1 inch (25 mm) in depth or having an area greater than 2 ft^2 (0.19 m^2) will be patched. The specification contains general guidance for removal, preparation and repair of the area to be patched. Included however is the use of steel plates when opening a lane to traffic prior to the patch achieving sufficient strength.

3.22 Massachusetts Department of Transportation

Massachusetts DOT has been working off a standard specification published in 1988, the Standard Specifications for Highways and Bridges and has chosen to continually publish supplemental specifications when required (MassDOT, 1988). A qualified product's list contains numerous rapid set concrete materials used in patching. The specification requires that all manufacturer recommendations be followed when using rapid setting materials and that all plans be approved by the Engineer. There are general guidelines for the removal and placement of concrete.

3.23 Michigan Department of Transportation

Michigan has a current specification published in 2012 (MIDOT, 2012). There are supplemental specifications published when necessary. The standard specification covers the use of mortar and concrete for patching, repair and resurfacing mixtures, however the qualified products list contains qualification procedures for prepackaged hydraulic fast-set materials for patching structural concrete. Requirements for these materials are provided in the specification. Compressive strength as measured by ASTM C39 must have a minimum of 2000 psi (14 MPa) at 2 hours, 2500 psi (17 MPa) at 4 hours and 4500 psi (31 MPa) at 28 days.

3.24 Minnesota Department of Transportation

Minnesota has printed editions to their standard specifications published four times in the last decade. Their current specification is dated 2016 and has change text added in the margins of the specification to show changes from the 2014 version (MnDOT, 2016). Supplemental specifications were only found regarding materials and not construction practices. MnDOT has a general specification for repair of structural concrete as well as a general supplemental specification with the requirements for concrete mixes. The concrete is either Type 1 or 3 and 8 concrete grades ranging from a compressive strength of 3,200 psi (22 MPa) to 6,300 psi (43 MPa).

3.25 Mississippi Department of Transportation

The Standard Specifications for Road and Bridge Construction for Mississippi Department of Transportation was published in 2004 (MSDOT, 2004). The specification addresses the use of polymer concrete for replacement of spalled areas on concrete pavement and structures. The materials used for these repairs can be found on MSDOT's qualified product's list. The recommendations in this section include using a jack hammer no larger than 20 pounds (9 kg)

which is different than most other specifications. Repairs include any spalled area that is greater than one inch (25 mm) in diameter and when saw cutting the area, it is to include an additional two inches (50 mm) around the circumference of the spalled area.

3.26 Missouri Department of Transportation

With supplemental specifications published at least twice a year, Missouri Department of Transportation publishes a complete standard specification for highway construction about once every eight years. Their current specification is dated in 2011 (MoDOT, 2011). MoDOT's specification is generalized and has a Qualified Product List that contains high-performance repair material that has been allowed for patching of horizontal surfaces. A 3-hour compressive strength requirement for all rapid setting concrete mixtures is 3,200 psi (22 MPa). The specification requires that all manufacturer recommendations be followed and that the repair material must not need a bonding agent.

3.27 Montana Department of Transportation

The current Standard Specification for Road and Bridge Construction was published by MDT in 2014 (MDT, 2014). This contains general provisions for concrete placement, mixture and repair. A supplemental guide was also published that contains a concrete pavement program to include guidelines for permanent patching of PCC pavements. This provision states that asphalt patching material does not qualify as a permanent solution and a high, early-strength PCC or rapid setting concrete product must be used for partial or full depth patches. Procedures are published for both rapid setting material and PCC pavement patching material.

3.28 Nebraska Department of Roads

Nebraska publishes standard specifications for highway construction every ten years. The most recent standard and supplemental specification was published in 2007 (NDOR, 2007). NDOR's approved products list is updated every year, the materials are found in the section for pavement and structural patching materials for horizontal placement. The specification includes construction methods for bridge deck repair using silica fume concrete and high density low slump concrete. The specifications are generalized with requirements being given according to the construction plans of the bridge and roadway. Special provisions are published for concrete pavement repair with emphasis on taking samples and cores to determine compressive strength of the concrete.

3.29 Nevada Department of Transportation

Standard specifications for road and bridge construction were published in 2014 (NevadaDOT, 2014). NevadaDOT produces a qualified products list yearly which includes rapid set repair materials for horizontal repairs. NevadaDOT also includes a structures manual that has a chapter on bridge rehabilitation for guidance on bridge deck repair. Within this manual, NevadaDOT discusses general practices as well as techniques used in bridge deck patching. Patching with fast-setting concrete is considered to be a temporary solution to the problem, however it is emphasized that a more permanent solution should be applied, which includes repairs such as a full slab replacement. NevadaDOT also addresses the use of ground penetrating radar to determine deck soundness.

3.30 New Hampshire Department of Transportation

New Hampshire's current standard specification for road and bridge construction was published in 2010 (NHDOT, 2010). The department also has supplemental specifications, special provisions, as well as special attentions published regarding important updates or additions to the

specification, which are published as necessary. Materials used in bridge deck repairs include a fast set, non-shrink patching mortar as well as a polymer-modified, 2-component, fast setting concrete patch. The minimum testing requirements for the materials will fall under the provisions found in provision 520. These include a 3-hour compressive strength of 500 psi (3.5 MPa), 1-day strength of 2000 psi (14 MPa), and a 28-day strength of 4000 psi (27.5 MPa).

3.31 New Jersey Department of Transportation

The department of transportation in New Jersey uses a standard specification with its latest being published in 2007 (NJDOT, 2007). NJDOT's specification is broken up into 15 divisions and additional sections that include test methods for different practices, determinations and samplings. Division 450 gives a generalized procedure for partial and full depth pavement repair with reference to quick-setting patch materials that are listed on a Qualified Product's List. The specification classifies the patch materials into 4 types. Type 1, 1A, and 1B are suitable for use above water. Differences between the types are allowable aggregate by size and weight with Type 1 being used neat or with less than 15 pounds of No. 8 aggregate. Type 1A is classified as such as there are manufacturer's provisions that do not allow it to be classified as Type 1. Type 1B, is a product that includes the aggregate, whether coarse, sand or both. They are prepackaged with the other components of the mixture and include specific instructions from the manufacturer. Requirements for the patch material are found in Table 7, which includes both bond and compressive strengths.

Test	Type 1, 1A, 1B	Type 2
Compressive Strength ASTM C109, psi (MPa)		
@ 3 Hour	2000 (14)	2000 (14)
@ 1 Day	3000 (21)	2000 (14)
@ 7 Days	4000 (28)	3000 (21)
@ 28 Days	4500 (31)	3000 (21)
Initial Set Time ASTM C266, min	15	15
Bond Strength ASTM C882, psi (MPa)		
@ 7 Days	1000 (7)	1000 (7)
@ 28 Days	2000 (14)	2000 (14)

Table 7 : NJDOT Requirements for Quick Setting Patch Material

3.32 New Mexico Department of Transportation

New Mexico Department of Transportation's current specification from 2014 is the Standard Specifications for Highway and Bridge Construction (NMDOT, 2014). Contained within the specification is a section on concrete structure repair. The recommendations include the use of a pre-packaged, pre-blended concrete material that is combined with water on site and is included on the state's approved products list. In order for the materials to be included on this list they must have the minimum requirements found in the table below.

PROPERTY	**ASTM TEST**	**REQUIREMENTS**
Compressive Strength, min	C-109	1 Day: 2500 psi (17 MPa) 7 Days: 3,000 psi (21 MPa) 28 Days: 4,000 psi (28 MPa)
Bond Strength, min	C-882	1 Day: 1000 psi (7 MPa) 7 Days: 2,000 psi (14 MPa) 28 Days: 3,000 psi (21 MPa)
Freeze/Thaw Resistance @ 300 cycles, min	C-666	85% durability

Table 8 : NMDOT Minimum Requirements for Concrete Repair

All boundaries will be saw cut to a minimum depth of ¾ inch (19 mm) and the concrete will be removed using pavement breakers and chipping tools at a 90-degree angle. The surface will be prepared and cleaned. In order to test the area, a 4 inch (100 mm) piece of duct tape will be placed every square yard (.84 m^2) and must not allow more than 25% of the tape surface to show dust coverage. When replacing corroded or damaged reinforcement bars, a bar of equal diameter with at least 2 feet (.61 m) more length will be used. The minimum splice length will be 1 foot (.3 m). The area around the bar will be chipped at least ¾ inch (19 mm) to allow for the new concrete to encircle the bar.

3.33 New York State Department of Transportation

Specifications for Construction and Materials as well as Standard Sheets are published every quarter for the New York State Department of Transportation (NYSDOT, 2016). A subsection of the the specification contains guidance for removal and replacement of structural concrete. The removal and replacement follow the same procedures that have been recognized by other state DOTs and suggest using Class A, Class D, or Class DP concrete for the patches. There is reference to using other materials for partial depth patching but the specification states to follow the manufacturer's recommendations and does not give any construction practices.

3.34 North Carolina Department of Transportation

North Carolina's specification was published in 2012 and covers both roads and structures (NCDOT, 2012). NCDOT also has a manual (NCDOT, 2015) that covers both partial and full depth repair of portland cement concrete pavement. The manual discusses in depth the common causes for distressed problems, as well as construction requirements for the repairs as well as the minimum requirements for the repair materials. Like most specifications, NCDOT requires that manufacturer recommendations be followed for prepackaged mixes. When submitting products

to be included on the state's qualified products list, NCDOT requires rapid setting concrete to have an opening time of 4-6 hours.

3.35 North Dakota Department of Transportation

North Dakota Department of Transportation's Standard Specifications for Road and Bridge Construction was published in 2014 (NDDOT, 2014). Supplemental specifications are also published when required and are included in all current specifications. NDDOT's specification suggests using a milling machine when cutting out the area to be repaired, however all the other construction requirements are similar to that of ODOT's. The use of PCCP for bridge deck repair is covered in the specification and the use of rapid setting concrete material for other uses is also covered. The guidelines and construction practices are generalized with no specifics provided in the specification.

3.36 Oklahoma Department of Transportation

Oklahoma Department of Transportation has a Standard Specifications Book, as well as special provisions and a construction manual (OKDOT, 2009). The specification includes a section on repair of concrete bridge decks, as well as a subsection on early strength concrete for bridge deck patching and overlays. The specification is very detailed and includes many recommendations which have not been found in other DOT's specifications. In order to begin a repair, a work plan must be submitted to the Engineer for review and must be approved prior to the beginning of the repair. The work plan must include the following:

- Material
- Equipment
- Procedures for placing and removing patches
- Forms
- Labor requirements

- Anticipated work schedule, including:
    - Traffic control
    - Project phasing
    - Patching cure times
    - Surface preparation
    - Estimated placement time

Patch preparation includes the use of a chain drag or other approved method to locate delaminations and a pachometer for location of reinforcing steel. Once the area is determined, the area to be repaired will be saw cut dependent upon the location of the reinforcing steel. Acceptable and unacceptable patch geometries can be found in the figure below.

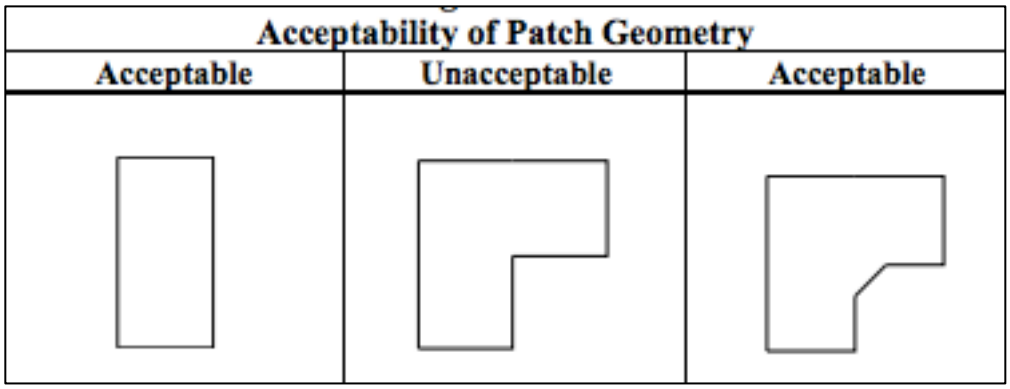

Figure 4 : ODOT Patch Geometry

Patches are classified depending on the location of the steel reinforcement. Class A includes repairs which remove unsound concrete to the top mat of reinforcing steel. Class B deck repairs remove all unsound concrete to at least 1 inch (25 mm) passed the bottom of the reinforcing steel. Lastly, Class C repairs are full depth repairs leaving the reinforcing steel intact. After removal, the specification details the installation of anodes along the perimeter of the patch to protect against corrosion.

Mixing, placing and curing the patch are also covered and include detailed practices to include following recommendations of both the Engineer and the manufacturer. Early strength concrete for bridge deck patching must have a minimum compressive strength of 3,000 psi (20.7

MPa) at road opening. Straightedge testing and surface tolerance will also be performed. The straightedge measurements will not vary more than 1/8 inch (3 mm) from its lower edge and any depressions more than 1/8 inch (3 mm) will be ground down and retested.

3.37 Oregon Department of Transportation

Published in 2015, Oregon Department of Transportation uses a standard specification that contains 13 subsections as well as separate provisions and unique specifications which are published when required (ORDOT, 2015). ORDOT uses high performance PCC for partial, shallow or full-depth concrete repairs. Primary requirement for the material is that it be pump-able with conventional grout/line pumps. The compressive strengths of the material will be a minimum of 3000 psi (20.6 MPa) at 24 hours and 4500 psi (31 MPa) at 28 days. The QPL for ORDOT includes PCC, polymer modified PCC and high performance PCC for use in structural concrete repair. The other sections of the specification discuss repair of PCC material, however, no specifics are given beyond the strengths discussed in the material requirements.

3.38 Pennsylvania Department of Transportation

PennDOT has a current specification which was published early 2016. Normal and accelerated concrete pavement patching is broken up into three types dependent upon the length of the patch when requiring patching at full depth, full length and at least half of the slab thickness. Type A being used with patches between 6 and 20 feet (1.8 to 6.1 meters), Type B for patches 20.1 to 65 feet (6.1 to 20 meters) and Type C for patches more than 65.1 feet (20 meters). When working with partial-depth repair, two types of concrete pavement are used, Type 1 for spot repairs with areas between 15 inches and 6 feet (0.4 and 1.4 meters) and Type 2 for extended length repairs greater than 6 feet (1.4 meters). When using rapid-set concrete patching material, it is required to have a minimum compressive strengths of 1,000 psi (7 MPa) at 3-

hours, 3,000 psi (21 MPa) at 1-day and 4,000 psi (28 MPa) at 7-days. Aggregate extenders are required when the depth of patches are greater than 2 inches (5 cm) and are to be added in accordance to manufacturer's recommendations. A minimum durability factor of 80% is required at 300 cycles, as well as expansion of no more than 0.40% and contraction of no more than 0.05% according to ASTM testing requirements.

Concrete removal to a minimum depth of 2 inches (50 mm) will be accomplished using a chipping hammer weighing no more than 35 pounds (16 kg) with a 30-60-degree angle. A compressive strength of 3,000 psi (21 MPa) is required of Class AA modified concrete prior to opening the area to traffic. Rapid-set patching material must attain a minimum 3-hour compressive strength of 1,000 psi (7 MPa) in order to be considered effective work.

3.39 Rhode Island Department of Transportation

Rhode Island's current specification for road and bridge construction (RIDOT, 2013) was amended in 2013. Supplemental documents are also published when necessary. Partial depth repairs are defined as repairs to concrete that extend less than 50% of the depth of the deck. All materials used in the repair are to meet the approval of the Enigneer. Depth of repair will be at a minimum of 1 inch (25 mm) and will not be opened to traffic until a minimum of 80% of its 28-day compressive design strength is reached.

3.40 South Carolina Department of Transportation

Currently South Carolina Department of Transportation has Standard Specifications for Highway Construction published in 2007 (SCDOT, 2007). SCDOT's specification has recommendations for both full and partial depth patching of PCC. The recommendations are general in nature and include materials, removal and construction procedures. There is reference to an epoxy cement with a latex admixture in the specification and rapid patch material is

included in the qualified product's list, however none of the products that are being researched are included.

3.41 South Dakota Department of Transportation

South Dakota's 2015 Standard Specifications for Roads and Bridges is the most current edition published with a few special provisions published when necessary (SDDOT, 2015). SDDOT's specification addresses the use of bonding mortar and concrete patch material for the repair of concrete. The patching material is broken up into three different types; Type I and II are packaged rapid-hardening materials with I being a mortar and II being a concrete mixture. Type III is a dry, bagged air entrained material with the following mix proportions. SDDOT suggest using coarse and fine aggregate in order to extend the mix for larger patch areas.

All other documented values refer to AASHTO and ASTM requirements. An epoxy resin mortar is identified within the specification as a viable option, however only refers to requirements based on AASHTO, Type III, Grade 2. Construction requirements are specified including patching material temperature ranging from 50 to 90 degrees F (10 to 32 degrees C) during placement and a maintained temperature of 45 degrees F (7 degrees C) until the patch reaches a strength of 3,000 psi (21 MPa).

3.42 Tennessee Department of Transportation

Published in 2015 Tennessee Department of Transportation's current Standard Specifications for Road and Bridge Construction contains nine supplemental specifications (TDOT, 2015). TDOT has also published a special provision on full and partial depth concrete pavement repair using high early strength materials. The requirements for the pavement repair are given with a partial depth repair being any repair where the depth does not exceed 4 inches (25 mm). The repair will not be opened to traffic until the cylinders reach a compressive strength of 2500 psi

(17 MPa). The materials used in the repairs must be found on the state's qualified product's list which is updated when necessary.

3.43 Texas Department of Transportation

The Department of Transportation in Texas has a current specification dated 2014 and published current versions every ten years. Standard Specifications for Construction and Maintenance of Highways, Streets and Bridges is accompanied by numerous special provisions and specifications along with supplemental specifications (TXDOT, 2014). TXDOT has an item within the specification that addresses pothole repair using numerous types of asphaltic materials as well as an item covering the repair of spalling in concrete pavement. The materials required are either a rapid-set concrete or a polymeric patching material must conform to ASTM requirements. Requirements of the rapid-set concrete include a flexural strength of 425 psi (3 MPa) in 5-hours, a minimum compressive strength of 5,100 psi (35 MPa) in 7-days and a 28-day strength of 6,300 psi (43 MPa).

3.44 Utah Department of Transportation

The 2012 Standard Specifications for Road and Bridge Construction is the most recent for Utah Department of Transportation (UDOT, 2012) with supplemental specifications written whenever changes occur that require immediate publication. UDOT's specification has a section on structural pothole patching that contains the procedures, materials and equipment used for patching bridge decks and approach slabs. The section discusses the use of portland cement concrete, rapid setting repair mortar as well as an epoxy resin adhesive, however no requirements are published other than to refer to ASTM and AASHTO. The removal, preparation and placement of the concrete patching material follows generalized procedures. The specification also states to follow all manufacturer's recommendations. UDOT's approved product's list

currently contains ten rapid setting materials for use in structural pothole patching and includes approved repair mortar.

3.45 Vermont Agency of Transportation

Vermont Agency of Transportation updates their specification book every five years with the current Standard Specification for Construction from 2011 (VTRANS, 2011). The specification is split up into seven divisions with Division 500 covering Structures. The section covering repair of structural concrete contains general practices for patching and suggests following manufacturer's recommendations when using prepackaged repair materials, as well as ASTM and AASHTO minimum requirements. VTRANS recommends that all these materials be contained on the agency's approved product list.

3.46 Virginia Department of Transportation

A final draft of Virginia Department of Transportation's Road and Bridge Specifications has recently been published in 2016 (VDOT, 2016). Patching is recommended using prepackaged rapid hardening materials. The specification has few recommendations besides following manufacturer's recommendations which include a 2500 psi (17 MPa) compressive strength within 2 hours and a saw cut perimeter at least 1 inch (25 mm) deep. VDOT believes that fewer larger rectangular patches save time and money compared to small many sided patches. VDOT's approved product list contains both rapid and very rapid setting patching materials.

3.47 Washington State Department of Transportation

Revisions to the Standard Specifications for Washington State Department of Transportation have been made every two years with the most recent being in 2016 (WSDOT, 2016). Amendments and special provisions are updated and published when necessary. WSDOT's

specification contains a section on concrete patching material, grout and mortar that covers recommendations aside from conforming to manufacturer's recommendations. Patching mortar will have a minimum compressive strength of 3,000 psi (21 MPa) at 3 hours, 5,000 psi (35 MPa) at 24 hours, as well as a bond strength of 1,000 psi (7 MPa) at 24 hours.

WSDOT provides general guidelines for patching of cement concrete and includes measurements for partial depth spall repair. A saw cut perimeter must be at least 2 inches (51 mm) in depth and if two repair areas are within 12 inches (300 mm) of each other, they will be combined. The qualified product's list for Washington contains several different types of materials classified into types by their capabilities.

3.48 West Virginia Division of Highways

In 2010, West Virginia Division of Highways published the Standard Specifications Roads and Bridges and has current supplemental specifications published in 2016 (WVDOH, 2010). The specification has a section covering concrete pavement repair, however the requirements are very general with all recommendations conforming to either AASHTO, ASTM or manufacturer recommendations. A construction manual reports the requirements for full and partial-depth patching of PCC pavements with partial depth being anything about one-third the slab depth and full-depth patching being anything greater. The patching material must conform to recommendations including a compressive strength of 2000 psi (14 MPa). The most recent approved product's list available was published in 2013 and contains numerous materials for repair of portland cement concrete.

3.49 Wisconsin Department of Transportation

Current specifications available through Wisconsin Department of Transportation were revised and published in 2016 (WISDOT, 2016). Part five of the specification discusses

structural concrete and overlay and repair. The requirements in this section are very general and do not go into specifics of the practices or materials. However, the section does refer to following AASHTO and ASTM standards. An approved product's list was published in 2016 and contains recommendations for rapid setting concrete patch material.

3.50 Wyoming Department of Transportation

Wyoming's current standard specification was published in 2010 (WYDOT, 2010). A supplemental specification was also published in 2010. The specification covers concrete patching material for horizontal applications and has minimum requirements of 5,000 psi (35 MPa) compressive strength at 24 hours and a bond strength of 2,000 psi (14 MPa) at 24 hours.

Requirements for all other types of patching material suggest following requirements in ASTM publications. Construction requirements include saw cuts to be a minimum of 2 inches (5 cm) in depth and an air temperature above 50 degrees F (10 degrees C). Repaired areas will not be opened to traffic until the patched area obtains a compressive strength of 4000 psi (28 MPa). WYDOT has an approved products list that contains qualified materials and products used for horizontal repairs.

3.51 Comparison of Specifications and Qualified Products lists

Ohio is part of the Midwest/Ohio Valley Region of the United States which consists of seven states and Ohio. Of the states within this region all seven of them use prepackaged high performance repair materials. When a specification contains instructions on the use of the prepackaged materials, following manufacturer recommendations on proper mix procedures and placement are included. If there are differences within the specification of the product's qualifications for use, they include minimum requirements for compressive strength, saw-cut depth prior for patch removal, or the different requests for qualification of products.

Illinois DOT requires all materials that are contained on the qualified products list to be retested by an independent lab every two years in order to remain on the approved list. The only requirement listed within the specification requires a water soluble chloride ion content of less than 0.40 lb/yd^3 (0.24 kg/m^3) (IDOT, 2012). All other qualifications refer to standard testing procedures. Compressive strength in the state's specifications range between 1,000 – 3,000 psi (7 – 21 MPa) at 3 hours.

All the available qualified/approved products lists were combined and the materials used in at least ten percent of the states were reported in Table 9 below. As shown, RepCon 928 developed by SpecChem LLC is found on 50% of the state's product lists. Of the other selected cementitious products used for research and testing, MasterEmaco T-1060 (48%, BASF), FastSet DOT Mix (44%, The Quickcrete Company), and HD-50 (46%, Dayton Superior) were also found to have been used by a majority of the State DOTs that had available qualified product's lists.

BRAND NAME	COMPANY NAME	TOTALS
RepCon 928	SpecChem LLC	25
MasterEmaco T1060	BASF	24
HD50	Dayton Superior	23
Sika Quick 2500	Sika Corp	23
Quikrete Commercial Grade Fast Set DOT Mix	The Quikrete Companies	22
Quikrete Rapid Road Repair With or Without Fibers	The Quikrete Companies	18
Rapid Set Concrete Mix	CTS Cement Mfg. Corp.	17
Five Star Highway Patch	Five Star Products, Inc.	16
Rapid Set DOT Repair Mix	CTS Cement Mfg. Corp.	15
Rapid Set Cement - All	CTS Cement Mfg. Corp.	12
Speed Crete 2028	Euclid Chemical Company	12
Pave Patch 3000	Dayton Superior	11
Eucospeed MP	Euclid Chemical Company	11
Five Star Structural Concrete	Five Star Products, Inc.	11
Futura 15	W.R. Meadows, Inc.	11
ChemSpeed 65	ChemMasters	10
Speed Crete Green Line	Euclid Chemical Company	10
Phoscrete Four-Seasons	Phoscrete Corporation	10
Duracal	U.S. Gypsum Co.	10
DOTLine	CeraTech, Inc.	9
Rapid Set Mortar Mix	CTS Cement Mfg. Corp.	9
Express Repair Mortar	Euclid Chemical Company	9
VeraSpeed	Euclid Chemical Company	9
Durapatch Hiway	L&M Construction Chemical	9
Planitop 18	Mapei Corp	9
DOT Patch HD	Symons Corporation	9
High Power DOT Grade Repair Concrete	US Concrete Products	9
US Spec Transpatch Concrete	US Mix Co.	9
MasterEmaco T1061	BASF	8
MasterEmaco T545	BASF	8
Pavemend SLQ	CeraTech, Inc.	8
Phoscrete VO-Plus	Phoscrete Corporation	8
Sikacrete 321 FS	Sika Corp	8
Sika Quick 1000	Sika Corp	8
PolyPatch FR	US Mix Co.	8
MasterEmaco T415	BASF	7
Pavemend TR	CeraTech, Inc.	7
Pavemend 15.0	CeraTech, Inc.	7
Pavemend SL	CeraTech, Inc.	7
Duracrete II	Kaufman Products	7
Eucospeed	Euclid Chemical Company	6
Fastset Concrete Mix	The Quikrete Companies	6
Fastset Repair Mortar	The Quikrete Companies	6
Prospec Rapid Patch VR	Bonsal American	5
Mainline	CeraTech, Inc.	5
Pave Patch 3000	Conspec Marketing & Mfg. Co., Inc.	5
Perma Patch	Dayton Superior	5
Re-Crete 20-Minute	Dayton Superior	5
Speed Crete Red Line	Euclid Chemical Company	5
Flexkrete 102	Flexkrete Technologies	5
Planitop X	Mapei Corp	5
RepCon V/O	SpecChem LLC	5
Transpo T-17	Transpo Industries, Inc.	5
Futura 45	W.R. Meadows, Inc.	5
FasTrac 246 Concrete	Western Material & Design, LLC.	5
FasTrac 220 FQ	Western Material & Design, LLC.	5

Table 9 : Top Materials from Qualified/Approved Product Lists

CHAPTER IV

FIELD, MATERIAL, AND PROCEDURAL OBSERVATIONS AND CONCLUSIONS

It is important to document some of the observations that came from the both the research done regarding the final installations and site visits, as well as taking into consideration the observations that were made from the first installations. These allowed for a more thorough specification recommendation for the use of high performance repair material which can be found in Appendix C of this thesis.

4.1 Field Inspections

At the final inspection in March 2016, it appeared that all of the patches have bonded well with the surrounding concrete with only two exceptions. The high performance repair material seems to not perform as expected when placed in worn asphalt pavement or due to unsoundness of the base material around it based on visual inspections. It has been concluded that none of the issues were due to construction practices or from the material itself. Although certain materials were recommended for use in asphalt repair by the manufacturer, the use of an asphaltic material in these repairs will be more consistent and cost-effective.

The set time of the patching material is very important to understand and to take in to account when placing the material. For the patch to have a proper bond with the concrete around it and

for proper curing and high strength, the amount of the material that is needed for a single patch should be able to be mixed and placed in as few layers as possible before the material begins to set. For larger patches, any patch area over four feet squared (1.5 m^2), a material that has the ability to be extended with aggregate should be used. Not only does this allow for a faster placement of the repair material, but it will also cut the cost associated with the repair. The workability of the materials as well as the ease of placement is also important. Materials that are hard to work with and place, add time to the installation.

4.2 Materials

When addressing the use of high performance repair materials in state's specifications, emphasis is placed on always following manufacturer's recommendations. These recommendations include proper mixing procedures, application, placement, size and type of aggregate to be used, as well as the appropriate way to handle and store all materials. It is important to consider the other key factors that go into choosing the material for certain types of repairs. These factors include but are not limited to the ambient temperature during placement and curing, the amount of time available for lane closure and traffic disruption, patch size, as well as durability and strength requirements. For these reasons, there are several materials that can be found on each state's qualified products lists.

The field results of each of the materials had no correlation to the price of the material, as the lowest cost repair product preformed just as well as the highest cost material. Understanding these results, the factors to consider when choosing the material should be those that match the actual job to be performed. When necessary or for extenuating circumstances, such that the other materials are not recommended for certain weather conditions, the higher cost material should than be used.

4.3 Procedures

After review of almost all of the state's current specifications and special provisions it has been determined that the practices followed for removal, preparation and placement of concrete repair material are fairly consistent. The methods used by ODOT throughout the project were consistent with those found to be useful in the other states. Similarities in the state recommendations include areas to be repaired are to be cut into squares or rectangles. The sides of the cuts are to be perpendicular to the surface to the existing material. Areas of the procedures that were found to have the most differences were the minimum requirements for compressive strength and the saw cut depth of the patch area ranging from 2 – 4 inches (50 – 100 mm). The requirements for compressive strength are based off of ASTM and AASHTO tests and those found in ODOT's specification as well as in the recommendation are found to be suitable for the use of high performance repair materials.

When determining the extent of the unsound concrete to be removed, the use of the Delam 2000 or a metal tool is recommended. When struck against unsound concrete, the metal tool will make a dull hollow sound. This procedure is also helpful after the patch cures. The sound the metal tool makes on the newly patched area should be fairly similar to that of the concrete surrounding it.

4.4 Specification Recommendations

The current specification contains practices for patching concrete structures using Class QC 2 concrete. Although most of the procedures are similar to those required for the high performance repair material, a new specification allows for the ability to include information for specific material types and prequalification. There are several sections within the specifications that have not changed, including Method of Measurement and Basis of Payment as these do not refer to

the actual use of the high performance repair material. The sections that include material properties, prequalification procedures, removal of concrete, and patching include the recommendations that came from the observations during laboratory work and field installations.

More specifically, Section 4 of the specification outlines the use of mobile drums and paddle mixers while on site. The mixer must be able to combine all materials, including the mix, cement, water and aggregates properly within the required time period. If a mobile mixer is to be used while repairing smaller areas, it should able to produce 6 cubic feet (0.17 cubic meters) of concrete. If larger areas are being repaired, the mixer must be able to produce a sufficient amount of the product to allow for undisturbed placement for prevention of cold joints in the patch.

When determining the extent of the unsound concrete, a metal tool or bar can be used. This can also be used when sounding the finished patch. If the patch contains unsound and cracked concrete, the material must be removed and the patch will be replaced. All unsound concrete shall be removed to include a ¼ inch (6 mm) depth of sound concrete. It was determined that the minimum depth of saw cuts for concrete removal will be 1 ½ inches (38 mm). Although varying from other department practices, this measurement when observed in the field provided enough surface area for a sound patch.

Placement, finishing, and curing of the high performance repair material requires strict adherence to manufacturer's recommendations that can be found on the product's technical data sheet. The specification also suggests that a representative from the manufacturer be present on the job site to ensure proper use of the product. Mixing the amount of concrete that can be placed within the setting period allows for a more durable and longer lasting patch. The use of aggregate as an extender is beneficial for patches over 16 cubic feet (1.5 cubic meters) and will increase the longevity of the patch and be more cost efficient. Due to the higher temperature of high

performance repair materials, concrete will be placed while ambient temperatures fall between 50 and 70 degrees F (10-20 degrees C) or temperature recommendations from the manufacturer. If the concrete must be placed when temperatures are outside of this range, it is recommended to add an accelerator or retarder to the mixture.

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APPENDICES

APPENDIX A

ODOT'S QUALIFIED PRODUCT LIST (As of April 2016)

Sample Id	PS CD	Mtl Cd	Mtl Name	Brand Name	P/S Name
QPLITEMS000426	06531-01	42802	QUICK SETTING CONCRETE MORTAR TYPE 1	MASTEREMCO T 415 (EMACO T415)	BASF BUILDING SYS/MN
QPLITEMS142A122144	06531-01	42803	QUICK SETTING CONCRETE MORTAR TYPE 2	MASTEREMACO T 1060 (T1060 RAPID MORTAR)	BASF BUILDING SYS/MN
QPLITEMS000848	09732-01	42803	QUICK SETTING CONCRETE MORTAR TYPE 2	MASTEREMACO T545HT (SET 45 HW)	BASF BUILDING SYS/OH
QPLITEMS142A123854	09732-01	42803	QUICK SETTING CONCRETE MORTAR TYPE 2	MASTEREMACO T 545 (SET 45)	BASF BUILDING SYS/OH
QPLITEMS000869	09810-01	42802	QUICK SETTING CONCRETE MORTAR TYPE 1	CHEMSPEED 55	CHEMMASTERS/MADISON
QPLITEMS12AQ141950	09810-01	42803	QUICK SETTING CONCRETE MORTAR TYPE 2	CHEMSPEED 65	CHEMMASTERS/MADISON
QPLITEMS107L111933	06789-01	42802	QUICK SETTING CONCRETE MORTAR TYPE 1	RAPID SET DOT REPAIR MIX	CTS CEM-RAPID SET/CA
QPLITEMS000326	06511-01	42803	QUICK SETTING CONCRETE MORTAR TYPE 2	EUCO-SPEED MP	EUCLID CHEMICAL CO
QPLITEMS000500	06554-01	42802	QUICK SETTING CONCRETE MORTAR TYPE 1	SPEEDCRETE RED	EUCLID CHEMICAL/IL
QPLITEMS000501	06554-01	42802	QUICK SETTING CONCRETE MORTAR TYPE 1	SPEEDCRETE GREEN	EUCLID CHEMICAL/IL
QPLITEMS000495	06554-01	42803	QUICK SETTING CONCRETE MORTAR TYPE 2	SPEEDCRETE 2028	EUCLID CHEMICAL/IL
QPLITEMS000446	06542-01	42802	QUICK SETTING CONCRETE MORTAR TYPE 1	RAPID HARDENING SAND	QUIKRETE/GA
QPLITEMS1062102022	06542-01	42802	QUICK SETTING CONCRETE MORTAR TYPE 1	FAST SET DOT MIX	QUIKRETE/GA
QPLITEMS000445	06542-01	42803	QUICK SETTING CONCRETE MORTAR TYPE 2	RAPID ROAD REPAIR	QUIKRETE/GA
QPLITEMS000444	06542-01	42803	QUICK SETTING CONCRETE MORTAR TYPE 2	RAPID ROAD-UNFIBERED	QUIKRETE/GA
QPLITEMS1062102340	06542-01	42803	QUICK SETTING CONCRETE MORTAR TYPE 2	FAST SET DOT MIX	QUIKRETE/GA
QPLITEMS000486	06548-01	42803	QUICK SETTING CONCRETE MORTAR TYPE 2	SIKAQUICK 2500	SIKA-LYNDHURST NJ
QPLITEMS142B122316	06531-01	42903	TROWELABLE MORTAR (SS-843)	MASTEREMACO S 488 CL (EMACO S 88 CL)	BASF BUILDING SYS/MN
QPLITEMS142B121622	06531-01	42903	TROWELABLE MORTAR (SS-843)	MASTEREMACO N 425 (GEL PATCH)	BASF BUILDING SYS/MN
QPLITEMS000866	09810-01	42903	TROWELABLE MORTAR (SS-843)	CHEMPATCH V01	CHEMMASTERS/MADISON
QPLITEMS000540	06789-01	42903	TROWELABLE MORTAR (SS-843)	RAPID SET CONC MIX	CTS CEM-RAPID SET/CA
QPLITEMS1116131023	06789-01	42903	TROWELABLE MORTAR (SS-843)	RAPID SET CEMENT ALL	CTS CEM-RAPID SET/CA
QPLITEMS000331	06511-01	42903	TROWELABLE MORTAR (SS-843)	SPEEDCRETE RED LINE	EUCLID CHEMICAL CO
QPLITEMS000332	06511-01	42903	TROWELABLE MORTAR (SS-843)	VERTICOAT	EUCLID CHEMICAL CO
QPLITEMS000497	06554-01	42903	TROWELABLE MORTAR (SS-843)	DURALTOP GEL	EUCLID CHEMICAL/IL
QPLITEMS000496	06554-01	42903	TROWELABLE MORTAR (SS-843)	DURALTOP FLOW MORTAR	EUCLID CHEMICAL/IL
QPLITEMS000379	06524-01	42903	TROWELABLE MORTAR (SS-843)	HI-CAP 15	KAUFMAN PRODUCTS/MD
QPLITEMS000439	06536-01	42903	TROWELABLE MORTAR (SS-843)	MARK 193.4	POLY-CARB, INC.
QPLITEMS000487	06548-01	42903	TROWELABLE MORTAR (SS-843)	SIKA REPAIR 224	SIKA-LYNDHURST NJ
QPLITEMS000488	06548-01	42903	TROWELABLE MORTAR (SS-843)	SIKATOP 111 PLUS	SIKA-LYNDHURST NJ
QPLITEMS000490	06548-01	42903	TROWELABLE MORTAR (SS-843)	SIKATOP 122 PLUS	SIKA-LYNDHURST NJ
QPLITEMS000489	06548-01	42903	TROWELABLE MORTAR (SS-843)	SIKATOP 123 PLUS	SIKA-LYNDHURST NJ

APPENDIX B

DOT CONTACT INFORMATION BY STATE

DOT Contact Information by State			
State	**Agency**	**Website address**	**Telephone**
Alabama	Alabama State Department of Transportation	www.dot.state.al.us	(334) 242-6358
Alaska	Alaska Department of Transportation and Public Facilities	www.dot.state.ak.us	(907) 465-3900
Arizona	Arizona Department of Transportation	www.azdot.gov	(602) 712-7011
Arkansas	Arkansas State Highway and Transportation Department	www.ahtd.state.ar.us	(501) 569-2000
California	California Department of Transportation	www.dot.ca.gov	(916) 654-5266
Colorado	Colorado Department of Transportation	www.dot.state.co.us	(303) 757-9201
Connecticut	Connecticut Department of Transportation	www.dot.state.ct.us	(860) 594-2000
Delaware	Delaware Department of Transportation	www.deldot.net	(302) 760-2080
District of Columbia	District of Columbia Department of Transportation	www.ddot.dc.gov	(202) 673-6813
Florida	Florida Department of Transportation	www.dot.state.fl.us	(850) 414-4100
Georgia	Georgia Department of Transportation	http://www.dot.ga.gov/	(404) 656-5267
Hawaii	Hawaii Department of Transportation	http://hidot.hawaii.gov/	(808) 587-2150
Idaho	Idaho Transportation Department	http://itd.idaho.gov/	(208) 334-8000
Illinois	Illinois Department of Transportation	http://www.idot.illinois.gov/index	(217)782-7820
Indiana	Indiana Department of Transportation	http://www.in.gov/core/	(217) 782-6953
Iowa	Iowa Department of Transportation	http://www.iowadot.gov/index.html#/services	(515) 239-1101
Kansas	Kansas Department of Transportation	http://www.ksdot.org/	(785) 296-3566
Kentucky	Kentucky Transportation Cabinet	http://transportation.ky.gov/Pages/default.aspx	(502) 564-4890
Louisiana	Louisiana Department of Transportation and Development	http://wwwsp.dotd.la.gov/Pages/default.aspx	(225) 379-1100
Maine	Maine Department of Transportation	www.maine.gov/mdot-stage	(207) 624-3000
Maryland	Maryland Department of Transportation	http://www.mdot.maryland.gov/	(410) 865-1000
Massachusetts	MA[T] Executive Department of Transportation and Construction	http://www.massdot.state.ma.us/	(617) 973-7000
Michigan	Michigan Department of Transportation	http://www.michigan.gov/mdot	(517) 373-2090
Minnesota	Minnesota Department of Transportation	http://www.dot.state.mn.us/	(651) 296-3000
Mississippi	Mississippi Department of Transportation	http://mdot.ms.gov/portal/home.aspx	(601) 359-7001
Missouri	Missouri Department of Transportation	www.modot.state.mo.us	(573) 751-2551
Montana	Montana Department of Transportation	http://www.mdt.mt.gov/	(406) 444-6200
Nebraska	Nebraska Department of Roads	http://roads.nebraska.gov/	(402) 471-4567
Nevada	Nevada Department of Transportation	https://www.nevadadot.com/	(775) 888-7000
New Hampshire	New Hampshire Department of Transportation	www.state.nh.us/dot	(603) 271-3734
New Jersey	New Jersey Department of Transportation	www.state.nj.us/transportation	(609) 530-3536
New Mexico	New Mexico Department of Transportation	www.nmshtd.state.nm.us	(505) 827-5100
New York	New York State Department of Transportation	www.dot.state.ny.us	(518) 457-6195
North Carolina	North Carolina Department of Transportation	http://www.ncdot.gov/	(919) 733-2520
North Dakota	North Dakota Department of Transportation	www.state.nd.us/dot	(701) 328-2500
Ohio	Ohio Department of Transportation	www.dot.state.oh.us	(614) 466-7170
Oklahoma	Oklahoma Department of Transportation	www.okladot.state.ok.us	(405) 522-6000
Oregon	Oregon Department of Transportation	http://www.oregon.gov/ODOT/Pages/index.aspx	(503) 986-4366
Pennsylvania	Pennsylvania Department of Transportation	www.dot.state.pa.us	(717) 787-2838
Rhode Island	Rhode Island Department of Transportation	www.dot.state.ri.us	(401) 222-2481
South Carolina	South Carolina Department of Transportation	www.dot.state.sc.us	(803) 737-2314
South Dakota	South Dakota Department of Transportation	www.sddot.com	(605) 773-3265
Tennessee	Tennessee Department of Transportation	www.tdot.state.tn.us	(615) 741-2848
Texas	Texas Department of Transportation	www.dot.state.tx.us	(512) 463-8585
Utah	Utah Department of Transportation	www.sr.ex.state.ut.us	(801) 695-4000
Vermont	Vermont Agency of Transportation	www.aot.state.vt.us	(802) 828-2657
Virginia	Virginia Department of Transportation	www.virginiadot.org	(804) 786-2801
Washington	Washington State Department of Transporation	www.wsdot.wa.gov	(360) 705-7000
West Virginia	West Virginia Department of Tranportation	www.wvdot.com	(304) 558-3456
Wisconsin	Wisconsin Department of Transportation	www.dot.state.wi.us	(608) 266-2211
Wyoming	Wyoming Department of Transportation	wydotweb.state.wy.us	(307) 777-4375
United States	United States Department of Transportation	www.dot.gov	(202) 366-4000

APPENDIX C

SPECIFICATION RECOMMENDATION

1. Description.

This work will consist of furnishing the necessary labor, materials and equipment to repair pavement and concrete bridge decks in accordance with current specifications and in close conformity with the grades, thickness, and cross sections shown on the plans or as directed by the Engineer. This work shall include the removal of all loose and unsound concrete; preparation of existing concrete surface; removal and concrete for partial-depth repairs; blast cleaning or high pressure water cleaning; furnishing, placing, finishing, texturing and curing of high performance, rapid setting repair material for partial-depth repair, as specified, and all operations necessary to complete this work according to these specifications and to the satisfaction of the Engineer.

2. High Performance Rapid Setting Repair Materials.

All materials shall be prepackaged, stored and incorporated in the work as recommended by the manufacturer. The Engineer or Owner may require a manufacturer's representative to be present at the beginning of the work to advise the contractor on the recommended practice for the material.

3. Test Requirements and Prequalification.

All materials shall be qualified in the proportions to be used on the job. If a material has options for different proportions, such as adding admixtures or aggregates, the material need only be qualified for the proportion used on the job, not for all options.

High performance repair material will meet the following test requirements:

Table 10: Recommended Test Methods and Requirements

Test	Minimum Requirements
Compressive Strength ASTM C109, psi (MPa)[1]	
@ 1 hour	2000 (14)
@ 24 hours	5000 (34)
@ 7 days	7000 (48)
Compressive Strength ASTM C39, psi (MPa)[1]	
@ 1 hour	2000 (14)
@ 24 hours	3500 (24)
@ 7 days	6000 (41)
Initial Set Time ASTM C266, min	10
Flexural Strength ASTM C78, psi (MPa)	
@ 4 hours	200 (1.4)
@ 3 days	500 (3.4)
Freeze and Thaw ASTM C666	
Procedure B (350 Cycles)	80%
Procedure A (300 Cycles)	79%
Modulus of Elasticity ASTM C469, ksi (GPa)	
@ 28 days	3500-4000 (24.2-27.6)

[1] Use C109 for cement or mortar type materials containing no aggregate or only fine aggregate (largest particle less than or equal to #4 sieve) and C39 for any material containing coarse aggregates.

Freeze-thaw testing shall be done using at least two repetitions of two specimens. Specimen 1 shall be the repair material. Specimen 2 shall be a composite specimen. A standard mold shall be filled half way with ODOT Class S concrete or a concrete specified by the Engineer. The surface shall be roughed to a broom finish. After curing for 28 days, the remainder of the mold shall be filled with the repair material after removing any loose material or laitance from the concrete surface. The test shall begin when the repair material has cured for 48 hours.

As an alternative, ODOT may, at its option, prequalify a material without testing if there is evidence from a controlled field study of at least 2 years in length of the satisfactory performance of that material.

High performance repair materials must be prequalified for use. In order to be contained on the Qualified Product's List,

1. Manufacturer's technical data sheet
2. Material safety data sheet
3. All components for testing or 50-lb (20 kg) sample
4. Mixing instructions

The Contractor shall furnish the Engineer with a copy of the manufacturer's comprehensive job specific preparation, mixing and application instructions. Any significant changes to these instructions which are recommended by the manufacturer for a specific job or an unanticipated situation shall be approved by the Engineer prior to the adoption of such changes.

4. Mixers.

Concrete shall be mixed according to manufacturer's recommendations.

Patching material may be mixed on site in small mobile drums or paddle mixers. Mixers at the site of construction shall be capable of combining all specified materials, aggregates, cement/product components and water into a thoroughly mixed and uniform mass within the specified mixing period. They shall have sufficient capacity to comply with minimum production requirements. Mixers will be kept clean, free of partially dried or hardened materials, and properly operating at all times.

5. Tools

Provide edgers, trowels, hand floats, brushes, and other small tools necessary to produce the results required. Milling machines, concrete saws, jackhammers, or other approved machinery to include pneumatic or hand tools must be approved by the Engineer.

6. Size of Patches

The Contractor shall follow all of the manufacturer's specifications concerning the maximum or minimum thickness of application and/or absolute size of a patch for the patching material. The contractor shall provide enough mixers with sufficient mixing to assure the material can be placed without the presence of cold joints. If the maximum allowable application thickness of a material is such that it would be necessary to place the material in two or more lifts with the formation of a cold joint, this shall be permitted only if the manufacturer's specifications allow this and with permission of the Engineer. If material is placed in multiple lifts, the manufacturer's specifications shall be followed.

7. Removal of Concrete.

The Engineer shall sound the structure and outline the areas to be removed. All loose, soft, honey-combed, disintegrated and unsound concrete, and ¼ inch (6mm) depth of sound concrete shall be removed. Where the bond between the concrete and a reinforcing bar has been destroyed, or where more than one-half of the periphery of such a bar has been exposed, the adjacent concrete shall be removed to a depth that will provide a minimum ½ inch (13mm) clearance around the bar except where other reinforcing bars make this impractical. After completion of the secondary removal operation, the Engineer will resound the areas to ensure that only sound concrete remains. All work shall be done in a manner that will not damage or shatter the concrete that is to remain, and will not cut, elongate or damage the reinforcing steel in any way.

Unless the manufacturer's specifications state otherwise, the area around the unsound concrete will be saw cut with straight lines to a minimum depth of 1 ½ inches (38 mm) in the shape of a square or rectangle.

8. Surface Preparation

Cleaning shall precede application of the patching material by not more than 24 hours. Surface preparation shall be according to the manufacturer's specifications. Exposed reinforcing and structural steel shall be cleaned to remove all loose and built-up rust, asphalt residue, and all other contaminants detrimental to achieving an adequate bond. It may be necessary to use hand tools to remove scale from the reinforcing steel or anchor bolts. The surface shall be free of spalls, laitance and all traces of foreign material. All un-chipped surfaces that will receive new material shall be mechanically roughened.

9. Patching.

The mixing, proportioning, placing and curing procedures, as well as, tools, equipment, labor and materials used shall be in accordance with the manufacturer's specifications and recommendations. Apply a thin coat of mortar or other recommended material to the concrete when necessary. Mix only the amount of concrete that can be placed within the setting period. Place concrete mixtures when the ambient temperature is between 50 and 70 degrees F (10-20 degrees C) or within the temperature limits set by the manufacturer. If necessary and allowed by manufacturer, add an accelerator or retarder to the mixture or prepare the area for temperatures outside of the range. For larger repair areas, over 2 feet by 2 feet by 3 inches (600 by 600 by 75 mm), adding 3/8 inch (10 mm) to ½ inch (13 mm) aggregate may be necessary to extend the mixture, but may be used only if allowed by the manufacturer's specifications. Trowel or screed

patching material into the prepared area ensuring contact with the outer surfaces of the patch. The finished surface of the repair area shall be flush with the surrounding area and conform to the original concrete surface.

10. Finishing/Curing.

Finish the patched area to match the texture of the surrounding concrete. Patches shall be cured in accordance with the manufacturer's recommendations.

11. Inspection and Sounding of Concrete Patches.

After curing and before final acceptance, all patches shall be sounded. All unsound or cracked patch areas shall be removed and re-patched according to this specification at the Contractor's expense. Aerosol paint for outlining shall be provided by the Contractor. All sounding and replacement of rejected areas will be the responsibility of the contractor and included in the unit bid price for this item. Sounding and re-patching shall continue until only sound, un-cracked patches remain.

12. Method of Measurement.

The quantity shall be the actual area of the exposed surface of all accepted patches, irrespective of depth or thickness of the patch. If the patch includes corners or edges of members, all of the exposed surfaces shall be included. The cost of all labor, equipment, incidentals and materials for sounding and patching shall be included in the unit price bid for this item.

13. Basis of Payment.

Payment will be made at the contract price for patching concrete structures with high performance rapid set repair material by square foot (square meter).