Survey and Literature Review of Fast-Track PCC Pavement Repair Processes and Materials

NDSU-2013-02
SPRR-034(010)

Final Report

Prepared for
North Dakota Department of Transportation

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U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL PROJECT REPORT

EXPERIMENTAL PROJECT

EXPERIMENTAL PROJECT NO. (1)
STATE: ND | Y EAR: 2013 | NUMBER: NDSU-2013-02 | SURF:

CONSTRUCTION PROJ NO (8): SPRR-034(010)

LOCATION (28):

EVALUATION FUNDING (48):
1 X HP&R
2 CONSTRUCTION
3 DEMONSTRATION
4 IMPLEMENTATION

NEEP NO. (49):

PROPRIETARY FEATURE? (51): Yes / X No

SHORT TITLE

TITLE (52): Literature Review of Fast-Track PCC Pavement Repair Processes and Materials

THIS FORM

DATE (140): MO. 10 -- YR. 2013

REPORTING: 1 INITIAL 2 ANNUAL 3 X FINAL

KEY WORDS

KEY WORD 1 (145): Fast-Track Concrete Repairs

KEY WORD 2 (167):

KEY WORD 3 (189):

KEY WORD 4 (211):

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PROPRIETARY FEATURE NAME (255):

CHRONOLOGY

Date Work Plan Approved	Date Feature Constructed:	Evaluation Scheduled Until:	Evaluation Extended Until:	Date Evaluation Terminated:
(277) 06-2013	(281)	(285)	(289)	(293) 10-2013

QUANTITY AND COST

QUANTITY OF UNITS (ROUNDED TO WHOLE NUMBERS): N/A (297)

UNITS: N/A (305)

1 LIN. FT
2 SY
3 SY-IN
4 CY
5 TON
6 LBS
7 EACH
8 X LUMP SUM

UNIT COST (*Dollars, Cents*): $20,000 (306)

AVAILABLE EVALUATION REPORTS

CONSTRUCTION	PERFORMANCE	FINAL
(315)		X

EVALUATION

CONSTRUCTION PROBLEMS (318):
1 X NONE
2 SLIGHT
3 MODERATE
4 SIGNIFICANT
5 SEVERE

PERFORMANCE (319):
1 EXCELLENT
2 GOOD
3 X SATISFACTORY
4 MARGINAL
5 UNSATISFACTORY

APPLICATION (320)

1 ADOPTED AS PRIMARY STD.
2 PERMITTED ALTERNATIVE
3 ADOPTED CONDITIONALLY
4 X PENDING
5 REJECTED
6 NOT CONSTRUCTED

(Explain in remarks if 3, 4, 5, or 6 is checked)

REMARKS (321)

The NDDOT has joined the Civil Engineering Department of NDSU to research fast-track concrete repair materials and methods. NDSU completed a literature review and survey along with recommended BMP's for fast-track concrete repairs. Restorative PCC repair methods used by the NDDOT have included installation of load transfer devices, partial depth repairs of localized spalled pavements, and full depth replacement of partial or complete panels as determined by the size of the affected area. These repairs require that a work zone be setup and most often require a lane closure for the duration of the repairs. The NDDOT desires to find successful methods and materials that have been used by other states and agencies that are durable and long-lasting so that repairs are not needed as often and so that repairs can be completed quickly and efficiently. (700)

Disclaimer

The contents of this report reflect the views of the author or authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not reflect the official views of the North Dakota Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Acknowledgements

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The authors acknowledge the guidance provided by the Project Advisory Committee of the North Dakota Department of Transportation and the involvement and input provided by the material engineers of the 27 northern states in United States and Canada.

Disclaimer

The contents of this report reflect the work of the authors, who are responsible for the facts and the accuracy of the information presented.

A list of abbreviations for state Department of Transportations

State	Abbreviation	State	Abbreviation	State	Abbreviation
Alabama	ALDOT	Michigan	MDOT	South Dakota	SDDOT
Arizona	AZDOT	Minnesota	MnDOT	Tennessee	TNDOT
Arkansas	ARDOT	Mississippi	MSDOT	Texas	TXDOT
California	CALTran	Missouri	MODOT	Utah	UDOT
Colorado	CDOT	Montana	MTDOT	Vermont	VTDOT
Connecticut	CTDOT	Nebraska	NDOR	Virginia	VADOT
Delaware	DEDOT	Nevada	NVDOT	Washington	WsDOT
Florida	FLDOT	New Hampshire	NHDOT	West Virginia	WVDOT
Georgia	GADOT	New Jersey	NJDOT	Wisconsin	WIDOT
Idaho	ITD	New Mexico	NMDOT	Wyoming	WYDOT
Illinois	ILDOT	New York	NYDOT		
Indiana	INDOT	North Carolina	NCDOT		
Iowa	IADOT	North Dakota	NDDOT		
Kansas	KsDOT	Ohio	ODOT		
Kentucky	KYDOT	Oklahoma	OKDOT		
Louisiana	LADOT	Oregon	ORDOT		
Maine	MEDOT	Pennsylvania	PENNDOT		
Maryland	MDDOT	Rhode Island	RIDOT		
Massachusetts	MADOT	South Carolina	SCDOT		

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Executive Summary

Project Background

NDDOT is interested in accelerated PCC pavement repairs and concerns about its durability. Even though there are vast documents in literature on accelerated PCC pavement repairs, different DOTs have distinct experiences, use different materials, and follow different guidelines. The objective of this research project was to survey all the states and literatures having accelerated PCC pavement repairs and found the BMPs for NDDOT, considering the effect of cold climate in northern plains region.

What the Researchers Did

Researchers surveyed more than 20 states with similar climate as North Dakota and reviewed the 20 states' specifications, research reports, and journal papers on accelerated PCC pavement repairs. The survey was conducted in two phases. The first phase was completed through an email survey and data was collected through surveymonkey.com. The second phase was conducted through the phone interview on successful and unsuccessful projects experienced by different DOTs. The literature review was conducted by summarizing state specifications, ACPA PCC pavement maintenance manual, State and Federal funded research reports, and Journal papers.

What They Found

Researchers contacted, surveyed and phone interviewed more than 20 state DOTs. The research team also reviewed most of the literatures on accelerated PCC pavement repairs. Combined with the above two results, the BMPs that are suitable for NDDOT are selected. Its specification source, its material mixture, and its implementation procedures are summarized and reported to NDDOT.

What This Means

Based upon findings from the study and guidance from the Project Advisory Committee, the following recommendations were submitted:

A. The best accelerated PCC pavement repair material is found to be Type III cement for partial and full depth patching, with conventional additives such as air entrants and water reducers, which could achieve the required early strength and durability.

b. The repair processes for the BMPs are found through the conducted survey and literature review. For partial depth and full depth patching, saw cut perimeter, remove material, sandblast, place patching material is the typical list of steps.

c. The sources of the specification implementing the BMPS are identified and provided to NDDOT.

Survey and Literature Review of Fast-Track PCC Pavement Repair Processes and Materials

1. Introduction and scope of the work

The conducted research summarized the literatures and surveyed twenty seven states that have similar climate as North Dakota on accelerated PCC pavement repair materials and processes. The research conducted identified the processes and materials that have been successfully and unsuccessfully used for restorative maintenance of PCC pavements on highway systems with climates similar to North Dakota. Research findings are used to compare the successful "Best Management Practices (BMP)" (processes and materials) of the surveyed agencies with current NDDOT PCC maintenance practices. Field evaluation of these successful BMPs is suggested to NDDOT and will be conducted depending on NDDOT's request.

The report will summarize the literature review results first and follow with the survey results.

2. Literature review on Fast-Track PCC pavement repair processes and materials

In general, types of concrete pavements are categorized as plain concrete pavement (PCP), continuously reinforced concrete pavement (CRCP), joint reinforced concrete pavement (JRCP), and steel fiber reinforced concrete pavement (SFCP). All the four types PCC pavements are considered in this review and the major distress types involved in these PCC pavements include cracks, joint deterioration, and spall. To repair the above mentioned distresses the main repair methods that have been considered are:

- Full depth repair
- Partial depth repair
- Full panel replacement
- Joint repair
- Spall repair
- Dowel bar retrofit

ACPA accelerated pavement repair guidelines, state manuals including Canadians' specifications, journal papers, and research report publications are considered to summarize the materials and processes used for fast-track PCC pavement repairs. Mainly, the specifications on the accelerated PCC pavement repairs that differentiate from each another are highlighted in this study.

The literature review is organized following the sequence of the repair materials used for each repair type, the corresponding repair methods and processes for the repair type, and the comparison of specifications adopted for the repair materials and processes. Finally a summary is provided for all the repair types used in accelerated PCC pavement repairs.

Concrete Joint Repair

Repair Materials

The typical repair materials used in joint repair includes Hot-Applied Thermoplastic Sealant Materials and Cold-Applied Thermosetting Sealant Materials, which are used as a repair or backfill material to encase the load transfer device in the existing pavement. Desirable properties of the repair material include little or no shrinkage, thermal compatibility with the surrounding

concrete, good bond strength with the existing (wet or dry) concrete, and the ability to rapidly develop sufficient strength to carry the required load. Generally, cementitious materials that work well for partial-depth repairs also work well as a backfill material for load transfer.

Many different types of devices have been used to restore load transfer across joints and cracks, but smooth, round, epoxy-coated dowel bars have exhibited the best long-term performance. These devices provide shear load transfer while also permitting horizontal opening and closing of the joint or crack in response to daily and seasonal temperature and moisture fluctuations.

Some researchers explored to use geoploymer concrete for joint repairs. However curing condition is critical in these initial researches.

Selection of repair materials for joint repairs depends on climate conditions (at time of installation and during the life of the sealant), traffic level and percentage of trucks in traffic, crack characteristics and density, material availability and cost, contractor experience, and safety concerns.

Methods and Processes for Repair

Typical processes for joint repair includes old sealant removal, joint re-facing, joint reservoir cleaning, backer rod installation, and new sealant installation in sequence.

All the agencies have similar procedures with small adjustments.

Specifications for Repair Material

For joint repairs, the difference of conventional and accelerated joint repairs lies in joint sawing and sealing. The typical time sequence used for joint sawing and sealing in conventional concrete pavement joint repair is not compatible with rapid strength gain and early opening to traffic of accelerated repairs. Rapid strength gain reduces the time for sawing. To meet public traffic opening requirements, it also may be necessary to seal the reservoir sooner and require special consideration of sealant materials. Sawing using light saws-cleaning-sealing are the typical procedures for jointing and sealing in fast-track pavement constructions. The sawing time recommended by ACPA is shown in Table 1. ACPA also summarized available joint sealant materials which are listed in Table 2.

Table 1. Strength required for joint sawing recommended by ACPA (ACPA, 2006)

Coarse Aggregate Shape	Coarse Aggregate Hardness	Cement Content Kg/m^3 (lb/yd^3)	Acceptable Cut (Some raveling)[1] MPa (psi)	Excellent Cut (Almost no raveling)[2] MPa (psi)
Crushed	Soft	300 (500) 385 (650) 475[3] (800)	2.5 (370) 2.2 (320) 1.9 (270)	3.9 (560) 3.7 (530) 3.4 (500)
Crushed	Hard	300 (500) 385 (650) 475[3] (800)	4.9 (715) 4.8 (700) 4.7 (685)	7.0 (1010) 6.8 (980) 6.6 (950)
Rounded	Soft	300 (500) 385 (650) 475[3] (800)	1.4 (210) 1.0 (150) 1.0 (150)	2.5 (360) 2.1 (310) 1.8 (260)
Rounded	Hard	300 (500) 385 (650) 475[3] (800)	3.3 (480) 3.1 (450) 2.9 (420)	4.9 (710) 4.8 (690) 4.6 (670)

1. *Some raveling present on cut [540 mm^2 (0.84 in^2) per 7.3 m (24ft) of cut], acceptable if another saw cut will be made for sealant reservoir.*
2. *Almost no raveling present on cut [80 mm^2 (0.12 in^2) per 7.3 m (24ft) of cut].*
3. *Compressive strength criteria extrapolated from data at 300 and 385 kg/m^3 (500 and 650 lb/yd^3).*

Table 2. Common sealant types and related specifications for sealants used on concrete pavements (ACPA 2006)

Sealant Type	Specification(s)	Description
Liquid, Hot- Applied		Thermoplastic
Rubberized Asphalt	ASTM D 6690, Type II	Self-leveling
Polymeric	ASTM D 6690, Type II	Self-leveling
Elastomeric	ASTM D 3406	Self-leveling
Elastic	ASTM D 1854	Jet fuel resistant
Elastomeric PVC Coal Tar	ASTM D 3569, 3582	Jet fuel resistant (though PVC is rarely used)
Liquid, Cold/Ambient-Applied		Thermosetting
Single Component		
Silicone	ASTM D 5893	Non-sag, toolable, low modulus
Silicone	ASTM D 5893	Self-leveling, no tooling, low modulus
Silicone	ASTM D 5893	Self-leveling, no tooling, ultra low modulus
Polysulfide	Fed Spec SS-S-200E	Self-leveling, no tooling, low modulus
Polyurethane	Fed Spec SS-S-200E	Self-leveling, no tooling, low modulus
Two Component		
Elastomeric Polymer	Fed Spec SS-S-200E	Jet fuel resistant
Preformed Compression Seals		
Polychloroprene Elastomeric	ASTM D 2628	Jet fuel resistant
Lubricant	ASTM D 2835	(Used in installation)
Expansion Joint Filler		
Preformed Filler Material	ASTM D 1751 (AASHTO M 213)	Bituminous, nonextruding, resilient
Preformed Filler Material	ASTM D 1752 (AASHTO M 153)	Sponge rubber, cork, and recycled PVC
Preformed Filler Material	ASTM D 994 (AASHTO M 33)	Bituminous
Backer Rod	ASTM D 5249	For hot- or cold-applied sealants

The detailed states' specification on joint repair materials and processes are included as Appendix I. In general, almost all of the DOTs share the same repair process for the joint repair. The only differences are in the details such as saw-cut depth, extension of boundaries beyond the delaminated area, type of bonding agent, etc. Nevertheless, all the states share the same procedure including saw-cutting, concrete removal, cleaning, and placement of fill-back materials.

Concrete Crack Sealing

Repair Materials

A range of materials are available for crack sealing in concrete pavements, the two most common being hot-poured, rubberized asphalt sealants (generally conforming to American Society for Testing and Materials [ASTM 2005a] D6690) and silicone sealants (generally conforming to ASTM [2005b] D5893). The hot-poured, rubberized asphalt sealants are less expensive than silicone materials but generally have shorter life expectancies (typically, 4 to 8 years for hot-poured sealants and 5 to 10 years for silicone sealants). Preformed compression seals, while used in new concrete pavement construction, are not commonly used in crack resealing activities. The selection of an appropriate crack sealant material should take into account of past performance, local experience, availability of materials, initial and life-cycle costs, expected joint movements, and climatic exposure conditions.

Methods and Processes for Repair

With the exception of a sealant removal step, the sealing of cracks in concrete pavements essentially follows the same basic steps as the sealing of joints: refacing, cleaning, backer rod installation, and sealant installation (ACPA 1995). Please note, cleaning process is as important as the sealant materials.

Specifications for Repair Material

Most of the states have the specifications for crack sealing materials, including epoxy resin, grout, or hot-poured fillers. Epoxy resin is the most common material among the studied DOT specifications, however, with different brands. Majority of the states use hot poured sealant such as Indiana, Minnesota, South Dakota, Wisconsin, Washington, Idaho, Iowa, and Missouri. In addition to that, some states have a list of additional alternatives such as silicone by South Dakota and Idaho. Montana only mentioned silicone as joint or crack sealant. NYDOT has recommended hydrophobic urethane resin and appropriate additives. Idaho has listed hot poured elastomeric type concrete joint sealer, neoprene compression seal, and silicone sealant but it prefers silicone and compression seals.

ODOT requires using sealing materials with similar color to the existing PCC pavement. It requires sealing materials to be used as blotter and sand as the backer material for large cracks. It allows using low or high modulus concrete or crack sealer. Low modulus flows under gravity until refusal. ODOT has the following requirements for sealants (Table 3). The qualified low or high modulus crack sealants are listed in Table 4.

Table 3. Requirements for sealants used in ODOT

Test	Test Method	Requirements
Viscosity (Mixed)	ASTM D2393	<120 Centipoises
Tensile Elongation	ASTM D638	≥30%
Tensile Strength	ASTM D638	≥ 500 psi
Slant Sheer Bond Strength	ASTM C882	>1500psi for 14 days (moist Cure)
Flash Point	ASTM D3278	>175^{o}F
Epoxy VOC Content	MSDS	0% maximum
HMWM VOC Content	MSDS	45% Maximum
Pot Life	Not Identified	15-60 Minutes
Ambient Temperature Range	Not Identified	Recommended by Manufacturer

Table 4. Qualified sealants for ODOT

Sealant type	Product Name	Provider	Remarks
Crack sealer high modulus epoxy	CCS coating epoxy healer sealer	CHEMCO SYSTEMS	100% Solids, for cracks between 0.002 and 0.33 in Not good with dampness
	DURAL 335	TAMMS INDUSTRIES, DAVE DILLON, MASONS SUPPLY	For cracks up to 0.25 in, OK with dampness
Crack sealer high modulus HMWM	KBP 103	KWIK BOND POLYMERS, AL KLAIL	For .004 -.118 in cracks, ok with damp surface
	KBP 204	KWIK BOND POLYMERS, AL KLAIL	
	SIKA PRONTO 19TF	SIKA CORP , MASONS SUPPLY, ATLAS SUPPLY, THAD BROWN	For .002 -.25 in cracks and O.K. with dampness
Crack sealer low modulus epoxy	DURAL 50 LM	TAMMS INDUSTRIES, DAVE DILLON	Cracks up to 0.25 in, OK with damp surface
	POLYCARB MARK 135	POLY-CARB, DAN PATACCA	Cracks up to 0.25 in, OK with damp surface
	PRO-POXY 40 LV LM	Unitex by Dayton Superior, WILLIAMS FORM ENG, KNIFE RIVER	Cracks within 0.010 - 0.25 in, OK with dampness
	TRANSPO SEALATE T70MX-30	TRANSPO INDUSTRIES	Cracks up to 0.25 in, no dampness

Unlike ODOT, PENNDOT does not specify or provide QPL for crack sealers but under a general category for structures it specifies epoxy resins as penetrating crack sealers that have to meet the strength requirements of ASTM-C881, Type 1, Grade 1 for epoxy injection and from a manufacturer listed in Bulletin 15. Some of these products are SIL-ACT ATS 100LV, Aquron CPT-2000, Enviroseal 40, and Densicrete. Similarly, UDOT does not provide specific information about repair of PCC pavement crack but it has requirements for structural concrete crack repair. It requires repairing cracks from 1/64 inch to ¼ inch wide by epoxy injection and sealing cracks greater than ¼ inch wide as delamination repair.

MDOT mandates using injection epoxy resin for cracks of at least 0.005 in wide. It also allows using fast setting grout or fast setting temporary seal recommended by manufacturers. Cracks can also be sealed with hot poured sealants. For deeper crackers backer rod is used.

NDOR is different from the other states discussed above, and it requires using hot-poured fillers for repair of longitudinal and transverse cracks. Material properties shall conform to ASTM D 3405. Examples of sealing materials are CSL 315 SL, Dow Corning-890-SL, and Pecora 300 as self-leveling silicone joint sealers, Bostik Chem-calk 950, Eucolastic 1, and Pecora NR-201 as type 1 (flow, self-leveling) sealing compound, and Daraseal AR, Vulkem 116, and Rubber Calk 5000 as type 2 (non-sag).

KsDOT like the majority of other states recommends using injection epoxy resin for crack repair. For surface cracks one of these two materials are recommended:

- Silicone Rubber Building Sealant (clear or gray) that complies with SECTION 1724.
- Type IV, Grade 3, epoxy material that complies with SECTION 1705.

Joints or spalls which extend wider than ¼ in are repaired by hot type joint sealing compound. The ones wider than 1/2 in are repaired with the epoxy patching material.

Specifications for Methods and Processes

ACPA summarized the specifications for crack sealing. The first step is to reface the crack to the desired width. However, the random orientation of most concrete pavement cracks makes it difficult to create a uniform sealant reservoir directly over the crack. The formation of a reservoir should be accomplished with a small diameter diamond-bladed saw (ACPA 2006). Note that while crack routers have been used in the past to form sealant reservoirs, their use is not recommended due to the chipping and micro-cracking damage this equipment causes to the concrete (ACPA 2004). The cutting blades for the crack saws are typically 175 to 200 mm (7 to 8 in) in diameter and 6 to 13 mm (0.25 to 0.5 in) wide. The width of the saw cut generally provides an appropriate shape factor to accommodate the expected crack movement. Smaller blade diameters, in addition to lightweight two- or three-wheel unit designs, allow crack saws to pivot and follow irregular crack profiles.

Once the reservoir is created, the crack should be cleaned following those steps prescribed for joint resealing. Sandblasting is particularly recommended to remove laitance from the sawing operation. After cleaning, the crack is blown with compressed air and the backer rod (if specified) and sealant material are installed. The same precautions that apply to the installation of sealant materials into joints also apply here (ACPA 1995).

In terms of the states' specifications on crack sealing, most of them follow the ACPA guidelines described above with small adjustments.

Most of the states have the specifications for crack sealing processes, including routing, saw-cutting and creating reservoir for the filler or creating ports at designated locations. They require using backer rods in case the opening size is large. There are a few states that recommend crack sealing when the crack width is wider or narrower than a certain size. MnDOT and SDDOT do not recommend crack sealing for the cracks wider than respectively 1 ¼ in and ¾ in. Idaho recommends sealing the cracks wider than ¼ in. But, MTDOT considers 1/8 in as the lower limit for crack sealing. Many of states do not allow crack sealing below a certain temperature ranging between 30 and 45°F, such as 40°F for Indiana, 35°F for MnDOT, and 45°F for Washington. All the states require placing the sealant up to about 1/8 or ¼ in below the pavement surface to avoid generating noise due to passing vehicles. In large cracks, backer rod with a size of about 25% larger than crack size is recommended to be placed at the bottom of joint or crack prior to sealing.

ODOT requires removing the foreign objects from the crack by a probe or a rotary device and cleaning it with compressed air. Sealing materials are then placed in the crack.

In contrast, although PENNDOT is not as specific as ODOT in the sealing materials, it gives more detailed information about the repair process. for cracks having opening of 1/16 inch and wider the cracks are required to be sawed and ground to a width of ¾ in wide by 1 in deep, followed by flushing with water. If the crack is between ¾ and 1 inch, it has to be ground to a width of 1 in and depth of 1¼ in. PENNDOT requires allowing another day after the crack is flushed with water. Then it is cleaned with compressed air and the sealant is placed up to 1/8 to ¼ below the pavement level. It does not allow placing the sealant when the temperature is below 40°F.

Similar to all other DOTs, MDOT requires sawing and sealing of cracks.

NCDOT recommends repairing cracks through one of the partial depth or full depth repair methods.

NDOR's process for crack sealing is similar to PENNDOT's except for the dimension limits. For cracks between ¼ and ½ in, a crack reservoir of ½ in wide and 5/8 in deep will be provided. The reservoirs can be saw cut. The crack will be first cleaned and sand blasted and then the hot-pour sealant is placed. For cracks over ½ in wide, a backer rod might be used.

KsDOT requires the cracks repaired by providing injection ports drilled into concrete and the epoxy injected through the ports moving from one to another. Back pressure is maintained at 30 psi for cracks of 1/8 in and over and between 80 and 100 psi on other cracks.

INDOT requires saw cutting cracks to width of ¾ in and depth of ¾ in after cleaning. It also recommends using V shaped wand to facilitate flowing the sealant into crack and sealing the top portion of crack with asphalt.

According to NYDOT, injection holes are drilled first. Resin shall be continuously injected in any hole until it appears at adjacent holes or in the surrounding joint or crack. In dry areas, water shall first be injected into the holes prior to grouting. Open joints or cracks may be temporarily sealed during the injection process with commercially available expanding foam insulation, epoxy or urethane based products. When injection is completed, holes are sealed with mortar.

ITD (Idaho Transportation of Department) requires removing the old materials and objects from cracks or joints by a power-driven rotary machine. This helps to roughen the sides simultaneously which enhances the bond between the sealant and side walls. ITD also requires the sealant be poured up to 1/8 in below the surface.

MODOT suggests plowing to remove old objects from a joint. Plowing involves pulling a thin blade through a joint to remove old sealant and backer rod from the joint and to clean sealant from the sides of the joint. It requires saw cutting the crack to width of ½ in and depth of ¾ in. Herbicide mixed, a commercially available product, can be used if there is vegetation inside the crack. The sealant must be placed 1/8 in below the surface.

Partial Depth Patching

Repair Materials

Many materials have been used for partial-depth repair of concrete pavements. Choosing the proper material depends on the available curing time (opening to traffic), the climate condition, the material cost, urgency, the desired performance based on the future rehabilitation scheduled, and the size and depth of the repairs. Often, the selection of the repair material is based on the required opening times for a specific project. Partial-depth repair materials are divided into three categories: cementitious materials, polymer-based concrete, and bituminous materials:

- Cementitious materials include conventional Portland cement concrete, gypsum-based materials, and magnesium phosphate concretes. Conventional Portland cement concrete is the most commonly used partial-depth repair material, and can be formulated to provide opening times of 4 hours or less.
- Polymer-based concrete materials are a combination of a polymer resin, aggregate, and an initiator. The most common polymer-based concrete materials are epoxy, methyl methacrylate, polyester-styrene, and polyurethane. These materials typically gain strength rapidly but are also very expensive.

- Bituminous materials are a combination of bituminous binder (either an asphalt emulsion or asphalt cement) and aggregate. These materials are inexpensive and widely used as a partial-depth spall repair material, but are often considered temporary patches.

Selection of the proper material should include an evaluation of the material properties per ACPA repair guidelines. Currently the most widely reported property used for selection is the strength of the material at a given time (i.e., when the patch can be opened to traffic). However, other factors also play a role in the short and long-term performance of the patch, such as the shrinkage characteristics and coefficient of thermal expansion of the material. Another important property of the repair material is freeze-thaw durability. Material with rapid gain characteristics may be particularly susceptible to durability problem due to the accelerated nature of the material and the reduced curing time.

Methods and Processes for Repair

Selection of partial depth patching depends on allowable lane closure time / strength of repair mixture required for opening; shrinkage characteristics of the repair materials; coefficient of thermal expansion of the repair materials; ambient temperature of the construction field; cost; size of repair; and estimated performance and service duration. The repair process begins with determining repair boundaries; following by removing concrete; preparing repair area; preparing joint; applying bonding agent (do not allow to dry); placing patch material; applying curing compound; optional diamond grinding; and sealing joints.

To identify materials used in a project, the installation conditions, time open for traffic, and aggregate and pavement moisture will impact the selection of repair materials. Some of the installation conditions and time open to traffic for the materials listed in Table 2 are summarized in Table 5.

Table 5. Applicable conditions for different repair materials (Wilson, et al, 2001)

Criteria	Materials[a]										
	III	Dur	Set45	5HP	Pyr	SP11	Pen	MC64	PFL	UPM	Spray
Installation temperature[b]											
-9.4˚F < T < 32˚F							●		●	●	●
32˚F < T < 39.2˚F[b]	●	●	●	●	●		●		●	●	●
39.2˚F < T < 89.6˚F	●	●	●	●	●	●	●	●	●	●	●
T > 89.6˚F[b]	●	●					●		●	●	●
Time-to-traffic at 70˚F											
5 min										●	●
30 min							●		●	●	●
2 hr		●	●	●	●	●	●	●	●	●	●
4 hr	●	●	●	●	●	●	●	●	●	●	●
Aggregate moisture											
1-3% moisture allowed	●	●	●	●						●	●
Oven-dried[c]	●	●	●	●	●	●	●	●	●	●	●
Pavement surface moisture											
Saturated, surface-dry	●	●		●	●	●[d]				●	●
Dry[e]	●	●	●	●	●	●	●	●	●	●	●

[a] III = Type III PCC, Dur = Duracal, St45 = Set-45, 5HP = Five Star HP, Pyr = Pyrament 505, SP11 = SikaPronto 11, Pen = Penatron R/M-3003, MC64 = MC-64, PFL = Percol FL, UPM = UPM High-Performance Cold Mix, Spray = Spray-Injection Mix.

[b] Patching is generally not recommended when the temperature is below 4°C or above 32°C. At cold or hot temperatures, special precautions may be needed, such as the use of warmed or iced water during mixing, or insulating blankets during curing.

[c] Water content should be adjusted as needed.

[d] The manufacturer states that a saturated, surface-dry pavement surface is acceptable; however, lab tests indicate that bonding needs a dry surface.

[e] Wet surface before material placement if required by manufacturer.

Specifications for Repair Material

The FHWA/SHRP Manual of Practice, Materials and Procedures for Rapid Repair of Partial-Depth Spalls in Concrete Pavements, details the policy on material selections and implementation procedures (Wilson, Smith, and Romine 1999b), which could be referred to select materials and processes for accelerated partial depth patch repairs.

Many highway agencies maintain a qualified products list that can be also consulted to help identify appropriate partial-depth repair materials. Most of the states have the specifications for partial depth patching, including Minnesota, Colorado, Nebraska, etc, which can be located through the survey results in Appendix IV.

Most of the states have the specifications for partial depth patching, including modified concrete with accelerators/cement type III or commercially available patching materials and epoxy resin or grout as bonding agent between the patching material and old concrete. Only two states allow using asphalt for partial depth repair including Montana and Indiana.

ORDOT requires using "PCC Patching - Rapid Set" or "PCC Patching- very Rapid Set" and it does not allow using the patches which contain magnesium sulfate.

PennDOT have different classes of concrete for spall repair including Type 1 to Type 5, each of which uses different types of repair ingredients. Type 3 is a rapid set concrete patching material such as Chemspeed 65, Euco-Speed, Duracal, and SikaQuick 2500.

CDOT uses Class E concrete for rapid concrete repairs which is standard concrete pavement with an accelerating admixture. It requires a 28-day compressive strength of 4200 psi with 4-8% air content, and 0.44 water to cement ratio. Type III cement is used for high early strength along with at least 10% of pozzolans.

UDOT allows using both fast setting concrete which incorporates accelerators and other available patching materials. Unlike other states, UDOT does not need using epoxy as bonding agent when fast setting concrete is used due to environmental impacts

MDOT requires using modified concrete with accelerators and provides a list of approved accelerators for fast setting concrete.

NDOR recommends high early strength concrete using type III cement and accelerators.

NCDOT requires using elastomeric concrete for transverse joint repair due to concerns about wheel load.

ODOT has three classes of patching materials: Type A, B, and C. Type A consists of one part high early strength Portland cement, one and half part fine aggregates, and one and half part No. 8 coarse aggregates. Sufficient air entraining agent must be added to maintain air content at a level of 8%$\pm$2%. Type B consists of quick setting concrete mortar after adding sufficient amount of coarse aggregates. Type C consists of quick setting mortar type 2 and selected aggregates with an activator.

KsDOT suggests rapid available setting patching materials ranging from rapid hardening to ultra-rapid hardening materials.

MnDOT recommends concrete grade 3U18 for partial depth repair with grout (1 part cement, 2 parts sand) as bonding agent. In 3U18 grade, '3' designates air entrained concrete, 'U' designates specific strength, '1' designates upper limit for slump, and '8' designates the gradation range. Grade "U" concrete must have 28-day compressive strength of 6300 and 5600 psi for type 1 and type 3 concretes respectively. Type 1 has no air entrained but type 3 concrete has entrained air. MnDOT offers three options for high early strength concrete:

1. Adding 30% more cement (% weight to the normal cement content (the fine aggregate is reduced)) while the water and air contents remain unchanged.
2. Adding chemical admixtures to the standard mix.
3. A combination of 1 and 2.

In case of early opening to traffic, type A admixture with maximum dosage for 24 hours and type E admixture with 40% of maximum dosage for 12 hour opening to traffic are used. Type A admixture is with mid-range water reducer and type E is with water reducer and accelerator.

SDDOT offers bonding mortar (cement + water + sand), concrete patch (type III cement shall be used), and epoxy resin as partial depth repair materials.

NYDOT, in addition to concrete materials for patching, offers "Rapid Hardening Polymer Concrete". Portland cement mortar bonding grout is used as the bonding agent.

ITD suggests three options to produce high early strength concrete: reducing water to cement ratio, using type III or IIIA of Portland cement, or using water reducing additives. The patching concrete can be handmade or ready to mix.

IADOT classifies patching materials into three groups: Class A patching concrete contains modified cement to provide rapid setting and high early strength. Class B is also high early strength and rapid set within 5 hrs. It may contain calcium chloride but not fly ash. Class C contains early set additives so that the pavement opens to traffic within 24 hrs to 36 hrs. When patching extends to an adjacent lane which is open to traffic or when there is patching on two lane pavements or other locations where overnight closures are not permitted, Class A or Class B patching material shall be used. On pavements with three or more lanes and where overnight closure is permitted, Class C patching material shall be used. MODOT has two classes of partial depth repair: class A and B. Class A is the regular method but class B uses bituminous mixtures. It is used when resurfacing is needed.

MTDOT classifies patching as temporary or permanent patching depending on requirements of the repair. Plant mixed asphalt cement bituminous is used for temporary patching and high, early-strength PCC or a rapid setting proprietary concrete product would be used for permanent patching.

It seems that in terms of fast-setting material there are large variations in the type of materials used for repair. Most of the states allow using type III Portland cement along with accelerating admixtures. BASF Corporation, Euclid Chemical Co, and Sika Corporation are of the companies recommended by most DOTs. All the states have clarified the criteria for the time open to traffic, either use flexural strength, compressive strength, or adopt rupture modulus to determine maturity of concrete.

Specifications for Methods and Processes

Essentially when the damage area is close to the transverse joints the repair type is counted as joint repair but in other areas it is repaired as partial depth replacement. In all states, partial depth

repair consists of saw cutting, concrete removal, cleaning (sand blasting, water blasting, blowing with compressed air), coating with bonding agent, and patching. The only differences are in the details such as saw-cut depth, extension of boundaries beyond the delaminated area, type of bonding agent, etc. For example PENNDOT requires marking at least 80 mm beyond the damaged area and saw cut to depth of at least 50 mm while UDOT needs only 2 in beyond it and saw cut to depth of 2 in. NDOR also requires saw cutting to depth of 2 in. INDOT needs full lane be patched for partial depth repair and saw cut has to be a minimum of 3 in deep and 6 in beyond the damaged area.

Common types of tools for concrete removal are milling machine, jackhammer, or chipping hammer. Preference varies from state to state. For example SDDOT recommends chipping hammer or jackhammer. NYDOT suggests chipping hammer or milling machine or a combination of both. However, MnDOT does not allow using jackhammer. MODOT suggests milling method for concrete removal.

Since INDOT recommends HMA as patching material, the patching material after placement has to be compacted by vibrating roller with a minimum of 4 passes.

SDDOT does not allow patching after OCT 15th or at temperatures below 40°F. SDDOT has two types of spall repairs. Type A and B. Type A is for repair area of over 0.2 ft. wide and type B between 0.06 and 0. 2 ft. The spalls smaller than 0.06 ft are filled with silicone sealant. SDDOT and IADOT require removal of rebars if they were encountered in the chipping process. IADOT requires cutting the rebar and flushing with the edge. In SD, Bonding mortar is used for type A repair and epoxy resin without aggregate for type B.

Similar to SDDOT, NYDOT recommends a faster way to repair small and isolated spalls but with epoxy resin rather silicone sealant. According to NYDOT, spalls with an area greater than 5,000 mm^2 and the shortest side at least 50 mm long shall be repaired with the standard patching method. Partial-depth removal using the coring method is highly preferable. The pavement will be opened to traffic after 5 days; otherwise it has to reach at 3000 psi.

Washington DOT requires sealing of perimeter of the patch at the end of repair. Slab/patch interfaces that will not be subjected to surface grinding shall be sealed with a 1:1 cement-water grout along the patch perimeter. The pavement will open to traffic when the concrete reaches at 2500 psi strength. It requires patching material achieving 3000 psi at 3 hrs and 5000 psi at 24 hrs and reaching a minimum of 1000 psi bond strength in 24 hours.

Some states have patch length minimum especially at expansion joints. ITD has a 6ft minimum when one side of patch is at expansion joint and 12 ft when both edges are at expansion joint. Although all the states recommend rectangular or square patch shapes, ITD recommends triangular or diamond shape at corners for better performance.

According to MODOT, if roadway opens to traffic within four hours the repair concrete must gain 1600 psi in 4 hours and 4000 psi in 24 hrs and contain 4% entrained air and has a slump of 1 in or lower. If it opens in 24 hours instead, 1600 psi and 4000 psi will be the required strengths at 1 and 7 days.

Full Depth Patching

Repair Materials

The most appropriate material for full-depth repairs is conventional Portland cement concrete and it has been widely used as a repair material for full-depth patching. Practically any opening time can be met (from 1 hour to 24 hours or more), depending on the needs of the project.

Typically, high early strengths in concrete mixtures are achieved by reducing the water-to-cement ratio, using a well-graded aggregate, increasing the cement content, and adding a chemical accelerator. However, faster setting mixes generally have higher costs and special handling requirements. Therefore, a good rule of thumb in selecting the material for a concrete pavement full-depth repair project is to use the least exotic (most conventional) material that will meet the opening requirements.

Two NCHRP projects have been conducted on this topic. NCHRP report 540-Guidelines for Early-Opening-to-Traffic (EOT) Portland Cement Concrete for Pavement Rehabilitation is the most recent one. In the report, the main difference between EOT concrete and normal paving concrete is listed and stated as the strength gain occurs much more rapidly in EOT concrete, thus more cement, less water, admixtures, and aids to retain heat are commonly used. Typical mixtures used in fast-track full depth patch concrete pavement repairs are listed: (1) Type I or III cements are commonly used in EOT concrete. Additional water may be required to enhance workability with Type III cements. The use of a water reducer can reduce this need for additional water (ACPA 1995); (2) Common cement contents for mixtures that are to be opened to traffic within 24 hours range from 385 to 530 kg/m^3 (650 to 890 lb/yd^3), with more cement being added for earlier opening times. For 24-hour accelerated strength concrete, a draft specification stipulates a minimum cement content of 446 kg/m^3 (750 lb/yd^3) (FHWA 2003); (3) The w/c ratio in EOT concrete is typically between 0.40 and 0.48. A draft specification for 24-hour accelerated strength concrete stipulates a maximum w/c ratio of 0.45 (FHWA 2003); (4) An accelerator is commonly employed and is almost a necessity for mixtures that are to be opened in 6 to 8 hours. The most common accelerator is calcium chloride, which is commonly added at 1 percent by weight of cement when the air temperature exceeds 27°C (80°F) and up to 2 percent by weight of cement when the air temperature is lower. Several suggested mixtures are listed in Appendix II.

Another NCHRP project, with project No. 20-07, Task 184: Pavement Preservation: Practices, Research Plans, and Initiatives also studied the similar topic. The report summarizes the current researches on pavement preservation into the following aspects: Treatment selection procedures/guidelines; Treatment timing; Innovative materials and construction techniques; Materials selection and mix design; Treatment performance; and Specifications. All of them are quite subjective. Related to the current project, a cost effectiveness methodology tied with a pavement MIS system will be an objective guideline. Assisted with local conditions and constrains, small empirical adjustment on the developed guideline could lead to an effective management methodology for pavement repairs.

Methods and Processes for Repair

The construction of an accelerated full depth patching repair includes: concrete sawing, concrete removal, repair area preparation, restoration of load transfer in JCP or reinforcing steel in CRCP, concrete placement and finishing, curing, diamond grinding (optional), and joint sealing on JCP. No special equipment or curing is needed for the full depth patching repairs.

Specifications for Repair Material

ACPA specifies several guidelines on material selection, dowel size requirements, and strength for opening to traffic for the full depth patching pavement repairs, which are shown in Table 6-8.

Table 6. Examples of high early-strength mix designs for full depth patching (ACPA 1994; Jones 1988; Whiting et al. 1994).

Mix Component	Type I (GADOT)	Type III (Fast Track I)	Type III (Fast track III)	RSPC	RSC
Cement,(kg/m^3)	447	381	441	363	386
Fly ash, (kg/m^3)	-	43	48	-	-
Coarse Aggregate	1067	828	776	1011	1070
Fine Aggregate, (kg/m^3)	612	808	774	832	595
w/c Ratio	0.40	0.40 to 0.48	0.40 to 0.48	0.41	0.45
Water Reducer	-	Yes	Yes	-	-
Air Entraining Agent	As needed to obtain air content of 6 ± 2 percent				
$CaCl_2$ % wt. cement	1.0	-	-	-	-
Opening time	4 hr	24 – 72 hr	12 – 24 hr	4 hr	4-6 hr

Note: 1 kg/m^3 = 1.69 lb/yd^3; RSPC stands for Regulated-set Portland Cement from Ideal Cement Company; RSC stands for Rapid Set Concrete used in Whiting et al, 1994.

Table 7. Dowel size requirements for full-depth repairs in JCP (Concrete pavement preservation reference manual, 2008)

Pavement Thickness, mm (in)	Dowel Diameter, mm (in)	Drilled Hole Diameter, mm (in)		Min, length, mm (in)	Spacing, mm (in)
		Grout	Epoxy		
≤150 (≤6)	19 (0.75)	24 (0.95)	21 (0.83)	350 (14)	300 (12)
<200 (6.5 to 8)	25(1.0)	20 (1.2)	27 (1.08)		
200 to 240 (8 to 9.5)	32(1.25)	37 (1.45)	34 (1.33)		
250+ (10+)	38(1.5)	43 (1.7)	40 (1.58)		

Table 8. Minimum opening strengths for full-depth repairs (ACPA 2006)

Slab Thickness, mm (in)	Strength for Opening to Traffic, Mpa (lbf/in^2)			
	Repair Length < 3 m (10 ft)		Slab Replacements	
	Compressive	3rd – Point Flexural	Compressive	3rd – Point Flexural
150 (6.0)	20.7 (3000)	3.4 (490)	24.8 (3600)	3.7 (540)
175 (7.0)	16.5 (2400)	2.6 (370)	18.6 (2700)	2.8 (410)
200 (8.0)	14.8 (2150)	2.3 (340)	14.8 (2150)	2.3 (340)
225 (9.0)	13.8 (2000)	1.9 (275)	13.8 (2000)	2.1 (300)
250+ (10.0+)	13.8 (2000)	1.7 (250)	13.8 (2000)	2.1 (300)

State manuals follow the similar procedures with adjustments on specific requirements, such as strength to open for traffic, candidate materials, etc.

For full depth repairs, similar to partial depth repairs, patching materials or modified concrete with accelerators are used. None of the studied DOT specifications make distinctions between partial and full depth repair materials in terms of used materials. However MnDOT clarifies the distinctions and suggests Grade 3A32 or 3A41 for full depth repairs. '3' is the type of concrete as described above and grade A designates the grade of concrete which requires 3600 psi for 28-day's strength. The first digit following the letter denotes the upper limit for slump and the last digit indicates the aggregate gradation range. IADOT suggest the following requirements based on time to open to traffic (Table 9).

Table 9. Material list adopted by IADOT for accelerated PCC pavement repairs

Patch Type	Cement Type	Maximum Allowable Substitution	Minimum Mix Temperature
5 Hour	Type I, Type II	0% Fly Ash	75°F (24°C)
	Type IS	0% Fly Ash	80°F (27°C)*
10 Hour	Type I, Type II	10% Fly Ash	65°F (18°C)
	Type IS	0% Fly Ash	70°F (21°C)*
* When a Type A Mid Range Water reducing admixture is used, limit the minimum mix temperature to that required when Type I/II cement is used.			

IADOT also requires composite full depth repairs when resurfacing is required. In this case patching materials and HMA are used together.

Specifications for Repair Processes

Process of full-depth repair is quite similar between the states. It includes saw cutting of full depth of the damaged area and cleaning and replacing with new concrete. The new concrete or patching material needs to be tied to the existing concrete. To do this, holes are drilled to the concrete and they are filled with epoxy resin. However, NYDOT states that, dowels are used when transverse and longitudinal joints define the repair boundaries. NDOR suggests an

alternative way of stabilizing the patching concrete which is making its edge beveled so it can be supported by the existing concrete. ITD offers two options for the load transfer between old concrete and the new patch:

1- Option 1: #3 x 17 inch rebar dowels is installed at the mid-depth of the adjacent concrete slabs 24 inches on center around the entire patch. Dowels should be drilled and set to a depth of 8.5 inches into the existing slabs. No dowel is set in the area where expansion joint is an edge of the patch.
2- Alternatively an area with a depth of 8.5 in and width of 12 in is excavated in the adjacent slabs and the new concrete will flow under the existing slabs.

IA has three types of processes for full depth repair. First, without dowel, which is similar to Option 2 of ITD, i.e. load transfer is done through forming a tapered edge at the transverse edge of the old concrete slab. Second is using the existing rebar in pavements, which is then cut but left 20 in of it protruded outward of the slab. This will be embedded in patching material. Third method is composite, which uses patching material and HMA at the surface.

All DOTs recommend caution when removing damaged concrete so that the subbase is not disturbed. Lift-out method is recommended by most of them. Criteria for time to open to traffic are based on compressive strength or modulus of rupture. INDOT require 300 psi for rupture modulus and ITD requires 3000 psi for compressive strength.

Full Pavement Panel Replacement

Repair Materials

The most common material used in the full pavement panel replacement is precast concrete. The precast concrete can use early strength concrete or conventional concrete, and is manufactured remotely from the field site.

Methods and Processes for Repair

The typical processes for full panel replacements are fabricating the precast concrete panels at a nearby plant, transporting precast concrete panels to the site, rapid removal of old pavement, rapid reparation of the base/subbase; installing precast concrete panel on finished base/foundation, matching adjacent pavement surface grade as closely as possible, interconnecting precast concrete panels and existing pavement using a mechanical load transfer system, typically a version of the dowel bar retrofit technique; grouting the dowel/tie-bar slots, as applicable, and injecting bedding grout to firmly seat panels, as applicable.

Specifications for Repair Material

In June 2008, AASHTO Technical Implementation Group developed several documents on full panel replacements, including (1) Generic Specification for Precast Concrete Pavement System Approval; (2) Guidance and Considerations for the Design of Precast Concrete Pavement Systems; (3) Generic Specification for Fabricating and Constructing Precast Concrete Pavement. In these guidelines, the panel geometry and thickness are recommended to be standardized. The width of the full panel replacement is 1.8 m (6.0 ft) and shorter of 0.5 m of the repaired area and the thickness is typically 0.25 to 0.5 in thinner than the existing concrete. Load transfer needs to be provided. Fast-setting cementitious or polymer based flowable material needs to be put into and injected into the bedding before or after the installation of the precast panel.

Washington DOT is the only one which clearly presents requirements for this type of repair. Ready mix concrete is used for new panels and it has to reach at 650 psi in 14 days and 2500 psi before opened to traffic.

Specifications for Methods and Processes

According to Washington DOT, all saw cuts must be full depth. In order to prevent damage to adjacent slabs that are to remain, a second full depth relief cut is required 12 to 18 in inside the panel in both the transverse and longitudinal directions. After removal, subgrade must be compacted, if it is not compactable, geotextile or crushed surfacing base course will be placed. If new concrete pavement is to be placed against existing concrete pavement, epoxy coated dowel bars and tie bars shall be drilled and grouted into the existing concrete pavement.

Slab Stabilization

Repair Materials

Desirable characteristics for materials used for slab stabilization include fluidity (ability to flow into very small voids) and durability (ability to resist traffic and environmental loadings). Over the years, a wide range of materials has been used for slab stabilization, the most common being cement-fly ash grouts, asphalt, and polyurethane. Traditionally, the most commonly used material has been cement-fly ash grout mixture, with some recent increase in the use of polyurethane. Other materials used less frequently include asphalt cement, limestone dust-cement grouts, and silicone rubber foam (Taha et al. 1994).

The following is a typical mix design for a pozzolanic-cement grout for use in slab stabilization (ACPA 2003; ACCA 2003): One part by volume Portland cement type I or type II (type III may be specified if there is a need for early strength); Three parts by volume pozzolan (Class F fly ash; it may be possible to reduce the cement component if Class C fly ash is used); Pozzolans shall conform to the requirements of ASTM C 618, if used, and limestone dust shall comply with AASHTO M 17 for mineral fillers; Water (usually about 1.5 to 3.0 parts) is used to achieve required fluidity; If ambient temperature is below 10^{o} C (50^{o} F), an accelerator may be used (if approved); A minimum compressive strength (typically 4.1 MPa [600 lbf/in^2] at 7 days) is normally required to ensure the durability of the grout. The ultimate strength of the grout will typically be much higher (on the order of 10 to 28 MPa [1,500 to 4,000 lbf/in^2]); with some additives, superplasticizers, water reducers, and fluidifiers as needed.

Methods and Processes for Repair

The typical processes for slab stabilization include drilling of injection holes; material preparation; and material injection. The whole process is well controlled with the maximum allowable pressure of 0.69 MPa (100 lbf/in^2), the slab lift does not exceed 3 mm, and no outflow of the grouts from other injection holes.

Specifications for Repair Material

ACPA(2006) has developed the recommendations on materials selection and implementation procedures, which decides the repair materials and repair implementations. State manuals share the similar guidelines as ACPA (2006) with small adjustments of each individual state.

The most important properties of grouting material are flowability, durability, and strength. Thus, different states use different materials as shown in Fig. 1, however, pozzolan cement and high density polyurethane (HDP) are the most common one. Pozzolans improve flowability of cement.

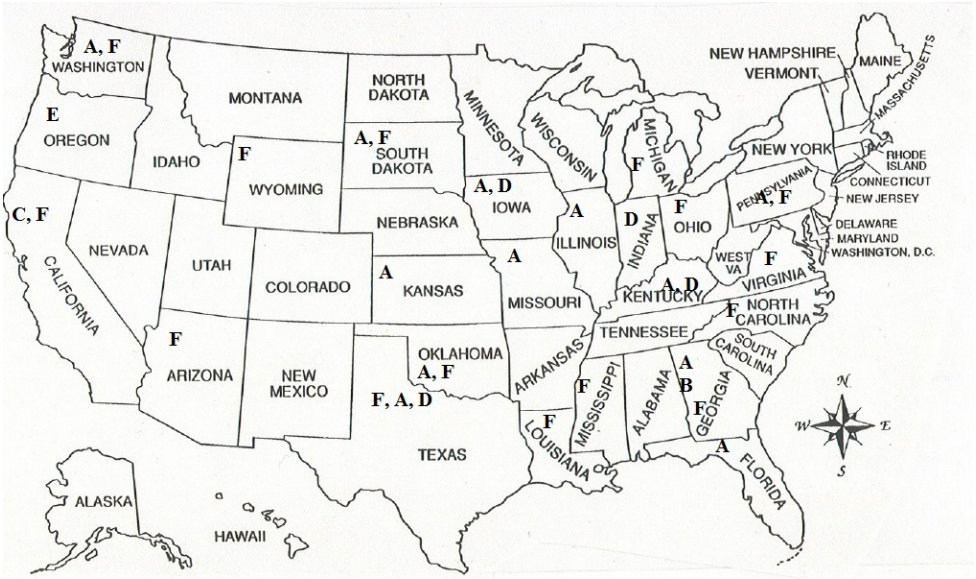

Fig. 1. Slab stabilization materials used throughout U.S. ((A: pozzolan cement, D: limestone dust cement, C: cement only, A:Asphalt cement only, E: sand cement, F: high density polyurethane, adopted from ACPA)

MDOT requires water insensitive HDP so that it is not compromised with soil moisture after injection. HDP is required to achieve 90% of its ultimate strength in first 15 minutes. KsDOT suggests using grout for undersealing including mixture of cement (type I or II) and fly ash and fine aggregates. 3-day compressive strength has to reach at 100 psi and 600 psi at 7-day. Similarly, ODOT uses mixture of Portland cement and fly ash modified with high range water reducing admixture (type F). PENNDOT, in addition to Portland cement and pozzolans, calls for using expansive agents, accelerators (if required), and rapid set patching materials. Patching materials are used to seal the drilled holes. A 7-day compressive strength of 700 psi is required. NDOR recommends using grout or bituminous material for slab stabilization. UDOT also suggests grouting for undersealing and slab jacking, however, it divides grouts into two groups based on the size of void. For voids less than 3 in grout consists of one part cement type I or II and three parts pozzolan. For voids greater than 3 in, it consists of one part cement, one part pozzolan, and 2 parts clean sand. ODOT considers grout as the undersealing materials.

Indiana uses utility asphalt, UA-II or UA-III for undersealing. Utility asphalt is classified in Table 10.

Table 10. Utility asphalt adopted by Indiana DOT for slab stabilization

Characteristics/Grades	UA-I	UA-II	UA-IIII
Softening Point (Ring & Ball), °C (°F)	46-63 (114-145)	63-85 (145-185)	79.5-96 (175-205)
Penetration of Original Samples[1] (0.1 mm (0.004 in)) at 4°C (39°F), 200 g (0.44 lb), 60 s, min. at 25°C (77°F), 100 g (0.22 lb), 5 s at 46°C (115°F), 50 g (0.11 lb), 5s	 10 (0.4 in) 50-100 (2-4 in) 100 min. (4 in)	 10 (0.4 in) 25-45 (1-2 in) 130 max. (5.1 in)	 10 (0.4 in) 15-35 (0.6-1.4 in) 90 max. (3.5 in)
Ductility@25°C (77°F), 50 mm/min (2 in/min), 10 mm (0.4 in), min.[1]	30	10	2.5
Solubility in Organic Solvents, % min.[1]	99.0	99.0	99.0
Flash Point (Cleveland Open Cup), °C (°F), min.[1]	225 (437)	225 (437)	225 (437)
Penetration of Residue from Thin Film Oven Test, 25°C (77°F), 100 g (0.22 lb), 5 s, (0.1mm (0.004 in)) min.[1]	30 (1.2 in)	15 (0.6 in)	10 (0.4 in)
[1] Test will be performed when complete physical characteristics are needed or desired.			

MnDOT suggests cement/fly ash grouts or expansive polyurethane foam for slab stabilizations. Polyurethane materials are more costly but are considered more durable, and must be applied using properly trained personnel. Pozzolan and fly ash based grouts generally consist of three to seven parts fine aggregates or a mixture of aggregate and pozzolan or fly ash to one part portland cement with enough water to produce the desired consistency. SDDOT uses grout, which consists of 1 part cement (type 1 or 2), 3 parts fly ash and sufficient water to achieve fluidity with time of efflux between 9 and 15 seconds in a flow cone test according to ASTM C939. 7-day strength shall be 600 psi. NYDOT suggests high-density polyurethane foam material. It has to be hydro-insensitive to avoid the reaction to moist. ITD requires grout or expanding foam. Expanding foam is an ethafoam-type material that when pumped under the concrete slab attempts to expand up to fifteen times its original volume. It is more suitable for fast-track repairs because after expansion, it take approximately 20 minute to harden and the pavement can open to traffic afterwards. IA requires grout, which contains 1 part cement type I and 3 parts class C fly ash. MO requires High density polyurethane or asphalt cement only for slab stabilizations. However, for slab jacking, high density polyurethane or cementitious grout shall be used.

Specifications for Methods and Processes

Process of slab stabilization is quite similar in all DOT specifications which include drilling holes, filler injection, and sealing the holes. Most of the DOTs leave it to the designer to come up with a plot for hole pattern. However, they have to be close to the damaged area due to punch-out action. For majority of states the hole size vary between 1 and 2 in. 1.5 in by INDOT, 1.5-2 in by SDDOT, 1.25 to 1.5 in by IADOT are the minimum hole diameters required by the respective DOTs. ODOT and NYDOT do not allow slab stabilization when temperature is below 35 °F due to frozen water in soil. INDOT sets 40 °F as the minimum allowable temperature. KsDOT states that if pressure does not stay more than 7 seconds at 150 psi, the injection must be terminated. ODOT termination criteria are when grout is observed in close cracks or it moves

3/16 in. PENNDOT does not allow upward movement of slab more than 0.05 in. The termination criterion is when the maximum pressure of 200 psi is reached or grout flows from other holes. UDOT requires that the final grade after jacking must be within ±1/8 inch of the finished grade profile. The same maximum pressure is stated in MnDOT specifications. IADOT limits the upward movement to 0.1 in and the maximum pressure to 20 psi at the start and 7 psi afterwards. To ensure uniform uplift the holes must be spaced as closely as possible. NYDOT requires 5 ft spacing between holes. MnDOT requires the holes to be between 12 and 18 in from transverse joints. IADOT requires that two holes be placed in the leave panel, 3 feet (1 m) from the joint or crack, and 3 feet (1 m) from the panel edges. Holes may be washed to create a small cavity at subgrade to facilitate initial grout flow.

Summary

ACPA summarized all the repair materials and repair processes, and published a guideline on fast-track concrete pavement in 2006, which details the materials, processes, and equipment used. In the guideline, the comparison of fast-track PCC pavement construction with conventional PCC pavement construction has also been made. The guideline summarizes the construction and repair of PCC pavements in the following aspects:

(1). Project applications and possible change of fast-track PCC concrete with conventional PCC pavement construction.

Fast-track PCC pavement mostly is used in Highways and Tollways, urban streets, intersections, and airports. The great advantage of fast-track PCC pavement construction is its short time to open for traffic and the most disadvantages is its durability. In order to successfully implement a fast-track PCC pavement project, no matter it is a new construction or a repair, possible changes compared to conventional PCC pavement are from planning, to material selection, jointing and sealing, curing, and traffic opening criteria. Typically multiple materials will be considered for a project and blanket curing and temperature monitoring need to be conducted.

(2). Special Equipment.

Several improvements in paving equipment enhanced the versatility of fast-track concrete. Minimum-clearance slipform paving machines with dowel bar inserters and dowel bar supporting baskets allow the close placement of concrete pavement adjacent to traffic lanes and quick installation of dowel bars.

Large diameter coring and large size cutting machines can reduce the demolishing time of need-repair pavements.

(3). Concrete materials

Typical materials are cement type I, II, and III with different accelerators, water reducers, and air-entraining admixture to enhance its durability.

Aggregates that comply with standard ASTM C33 specifications are acceptable for use in fast-track concrete. Typical procedures consider the proportions of coarse and fine aggregates without significant concern to the combined or total grading. To improve grading uniformity, additional intermediate size materials sometimes are also included.

Shape and texture of aggregates also impact concrete properties. Shape and rough particles reduces workability, however improves bond strength. It is advisable to allow no more than 15% flat or elongated aggregate by weight of total aggregate.

Water-cement ratio is well controlled in fast-track concretes, typically around 0.37-0.43. In order to have higher early strength, mix temperature elevation through hot water sometimes used in cool weather construction. Blanket curing is typically used in fast-track concrete construction as well.

A list of actual mixture used in fast-track projects is shown in Table 11.

Table 11. Actual mixture used in past fast-track PCC pavement projects

	Location & Description	Year	Cement Type	Cement Content Kg/m^3 (lb/yd^3)	Water Cement Ratio	Fly Ash kg/m^3 (lb/yd^3)	Coarse Aggregate Kg/m^3 (lb/yd^3)	Fine Aggregate Kg/m^3 (lb/yd^3)	Admixtures Type & Quantity Ml/m^3 (oz/yd^3)	Method to Place	Curing/Insulation	Air Temp. Range First 24 hour	Maximum Concrete Temp.	Sawing/ Sealing	Opening Strength Specified MPa (psi)	Time to Meet Specified Strength Hours
1	US-71 Bonded Overlay Storm Lake, IA	1986	III	380(640)	0.45	42 (70) Type C	1006 (1696)	670 (1130)	Air-223(10) WR-Type-A-1018(45)	Slipform	Wax-Based Compound/ R=0.5 Blankets	31-33ºC (87-92ºF)	47ºC (116ºF)	Dry-Abrasive/ Hot-Pour	Flexural[5] 2.4 (350)	7.5
2	Runway Keel Reconstruction Barksdale, AFB (LA)	1992	Special Blended	418 (705)	0.27	None	1020 (1720)	819 (1380)	None	Form-rider	Wax-Based Compound/ None	0ºC (32ºFmin.)	14ºC (58ºF)	Wet Diamond/ Hot-Pour	4 Hr. Flex. 3.1 (450)	4
3	Highway 100 Intersection replacement Cedar Rapids, IA	1988	III	440 (742)	0.380	47 (80) Type C	774 (1305)	772 (1302)	AIR-249(11) WR-Type A-565 (25)	Form-der & Hand	Wax-Based Compound/ R=0.5 Blankets	16-29ºC (61-85ºF)	34ºC (93ºF)	Dry-Abrasive/ Hot-Pour & Compression	12Hr. Flex.[5] 2.8 (400)	7.5
4	SR-81 Arterial Reconstruction Manhattan, KS	1990	III	427 (719)	0.44	None	869.4[2] (1465)	422.5[2] (712)	AIR-296(13) WR-Type A-848 (38)	Slipform	Wax-Based Compound/ R=0.5 Blankets	19-22ºC (66-72ºF)	52ºC (126ºF)	Wet Diamond/ Hot-Pour	Flexural 3.1 (450)	24
5	Lane Additon to I-496 Lansing, MI	1989	III	418 (705)	0.45	None	1127 (1900)	736 (1240)	AIR-475 (21) WR-Type A-791 (35)	Slipform	Wax-Based Compound/ R=0.5 Blankets	9-15ºC (48-59ºF)	41ºC (105ºF)	Tooled & Wet-Diamond/ Silicone	24 Hr. Flex. 3.8 (550)	19
6	I-25 to I-70 Interchange Ramp Reconstruction Denver, CO	1992	I	446 (752)	0.32	None	534 (900)[3]	593 (1000)	AIR-430 (19) WR-Type A-2035 (90) 2% $CaCl_2$ / cement wgt.	Handform	Wax-Based Compound & Plastic Sheets/ None	±16ºC (±60ºF)	54ºC (129ºF)	Wet Diamond/ Hot-Pour	12 Hr. Comp. 17.2 (2500)	8[6]
7	Single-Route Access Road Reconstruction Dallas County, IA	1987	III	380 (640)	0.425	42 (70) Type C	838 (1413)	838 (1413)	AIR-226 (10) WR-Type A-633(28)	Slipform	Wax-Based Compound/ None	N.A.	N.A.	Dry Abrasive/ Hot-Pour	Flexural[5] 2.4 (350)	9
8	Interstate 80 Widening	1992	III	390 (658)	0.47	None	1054 (1777)	658 (1109)	AIR-226 (10)	Slipform	Wax-Based Compound/	16-32ºC (60-90ºF)	29ºC (85ºF)	Wet Diamond/	24 Hr. Comp. 20.7	20[6]

	Rawlins, WY								WR-Type A-678 (30)		None			Compressio n	(3000)	
9	SR 832 & I-90 Interchange Reconstruction Erie County, PA	1991	I	446 (751)	0.37	None	1023 (1725)	583 (983)	AIR-1018 (45) SRA-Type D-136 (6) WR-Type F-2374 (105)	Handfor m	Wax-Based Compound & Plastic Sheets/ R=2.5 Blankets	21-32ºC (70-90ºF)	23ºC (73ºF)	Wet Diamond/ Compressio n	24 Hr. Comp. 20.7 (3000)	13
10	I-70 Bonded Overlay Cooper County, MO	1991	III	421 (710)	0.40	None	961 (1620)	777 (1310)	AIR-317 (14) WR-Type A-497 (22)	Slipform	Polyethylene Sheets/ None	±32ºC (±90ºF)	N.A.	Wet Diamond/ Hot-Pour	18 Hr. Comp. 24.1 (3500)	10
11	Runway 18/36 Extension Reconstruction Dane County, WI	1992	III	392 (660)	0.455	None	524 (884)[4]	700 (1180)[4]	AIR-565 (25) WR-Type A-3934 (174)	Slipform	Wax-Based Compound/ None	23-33ºC (73-91ºF)	N.A.	Wet Diamond/ Silicone	12 Hr. Comp. 24.1 (3500)	11[5]
12	SR 13 Bonded Overlay North Hampton, VA	1990	II	445 (750)	0.420	None	1114 (1877)	620 (1045)	AIR-452 (20) WR-Type D-565 (25)	Slipform	Wax-Based Compound/ R=0.5 Blankets	18-33ºC (65-91ºF)	38ºC (100ºF)	Wet Diamond/ Hot-Pour & Silicone	24 Hr. Comp. 20.7 (3000)	18
13	US-81 Reconstruction Menominee, NE	1992	II	363 (611)	0.423	None	534 (900)	1241 (2092)	AIR-271 (12) WR-Type F-950 (42)	Slipform	Wax-Based Compound/ None	13-17ºC (55-62ºF)	N.A.	Dry-Abrasive/ Compressio n	24 Hr. Comp. 24.1 (3500)	36
14	US-70A Inlay of Aphalt Intersection Approaches Smithfield, NC	1990	I	424 (715)	0.35	None	1127 (1900)	644 (1085)	AIR-136 (6) SRA-Type D-317 (14) WR-Type F-927 (41)	Handfor m	None/ R=0.5 Blankets	±18ºC (±65ºF)	26ºC (78ºF)	Wet Diamond/ Hot-Pour	48 Hr. Flex. 3.1 (450)	18

1) Contractor had two fast track mix choices on the project depending on desired set speed – details are for faster set mix and intersection work.
2) Third aggregate size also in mix [383.9 Kg/m^3 (846 lb/yd^3)] AASHTO No.57 stone.
3) AASHTO No.4 stone graduation. Third aggregate size also in mix [489.9 Kg/m^3 (1100 lb/yd^3)] AASHTO No. 57 stone.
4) Third aggregate size also mix [401.4 Kg/m^3 (885 lb/yd^3)] 19mm (0.75 in) maximum size.
5) Centerpoint flexural strength (flexural strength for all other projects in table are 3rd point)
6) Interpreted from available data.

(4). Time to open for traffic

The ultimate factor in fast-track construction is determining when traffic can begin to use the new pavement. The basis for this decision is recommended on the concrete strength, not on the time from the placement. The required strength for opening recommended by ACPA is shown in Table 12.

Table 12. Recommended strength of concrete for opening to traffic (ACPA, 2006)

REQUIRED STRENGTH FOR OPENING, MPa (psi)				
Slab Thickness mm (in)	Repair length < 3m (10 ft.)		Slab replacements	
	Compressive	3-point flexural	Compressive	3-point flexural
150 (6.0)	20.7 (3000)	3.4 (490)	24.8 (3600)	3.7 (540)
175 (7.0)	16.5 (2400)	2.6 (370)	18.6 (2700)	2.8 (410)
200 (8.0)	14.8 (2150)	2.3 (340)	14.8 (2150)	2.3 (340)
225 (9.0)	13.8 (2000)	1.9 (275)	13.8 (2000)	2.1 (300)
250+ (10.0+)	13.8 (2000)	1.7 (250)	13.8 (2000)	2.1 (300)

In some states, they preferred to use the compressive strength instead of flexural strength. The required compressive strength for opening to traffic ranges from 2.5 ksi to 3.5 ksi.

Durability is important in PCC pavement repairs. In wet and freezing climates, such as North Dakota, the continued presence of water on and in the pavement and the use of deicing salts often make the damage even worse. Many preventive maintenance approaches have been used, such as Slab stabilization, Partial-depth repair, Full-depth repair, Use of precast panels in full-depth repairs, Retrofitted edge drains, Load transfer restoration, Diamond grinding and grooving, and joint resealing and crack sealing in literatures. Not all projects will include all treatments. The most common treatments are partial- and full-depth repairs, and load transfer restoration.

In order to enhance durability in accelerated PCC pavement repairs, 4-6% air entrants are recommended to be included, which will form microscopic air cells and reduce internal pore water pressures when it freezes.

The above reports covered both domestic and international researches on the Fast-Track PCC pavement repair and maintenance. Summarization of the literature review, we see (a) critical factors determining Fast-Track PCC pavement repair materials and processes are bonding strength and curing conditions; (b) The best Fast-Track PCC pavement repair practices are found with rapid setting concrete.

3. Email survey and phone interview

3.1 Survey instruments

A survey was conducted in States with climates similar to North Dakota. The survey instrument is shown in Appendix III and has been approved by RAC of the research project. The survey has been sent to the states in Table 13 with their material engineers provided by NDDOT or their state DOT website.

Table 13. Surveyed states and their material engineer contact info

Name	Contact Information	State
Jing Xu	jing.xu@gov.ab.ca	Alberta
Bill Schiebel	bill.schiebel@state.co.us	Colorado
Mike Santi	mike.santi@itd.idaho.gov	Idaho
David Lippert	david.lippert@illinois.gov	Illinois
Ronald Walker	rwalker@indot.in.gov	Indiana
Greg L Mulder	greg.mulder@dot.iowa.gov	Iowa
Richard Kreider	richard.kreider@ksdot.org	Kansas
Richard Bradbury	Richard.Bradbury@maine.gov	Maine
Liske, Tara (MIT)	Tara.Liske@gov.mb.ca	Manitoba
Patricia Schafer	SchaferP@michigan.gov	Michigan
Curt Turgeon	curt.turgeon@state.mn.us	Minnesota
David Ahlvers	david.ahlvers@modot.mo.gov	Missouri
Matt Strizich	mstrizich@mt.gov	Montana
Mick Syslo	Mick.Syslo@nebraska.gov	Nebraska
Reid Kaiser	rkaiser@dot.state.nv.us	Nevada
Alan Rawson	arawson@dot.state.nh.us	New Hampshire
Robert A. Burnett	bburnett@dot.state.ny.us	New York
Lisa Zigmund	Lisa.Zigmund@dot.state.oh.us	Ohio
Cole Mullis	cole.f.mullis@odot.state.or.us	Oregon
Timothy Ramirez	tramirez@pa.gov	Pennsylvania
Manoj Jogi A	Manoj.Jogi@gov.sk.ca	Saskatchewan
Joe Feller	joe.feller@state.sd.us	South Dakota
Scott Andrus	scottandrus@utah.gov	Utah
William Ahearn	bill.ahearn@state.vt.us	Vermont
Tom Baker	bakert@wsdot.wa.gov	Washington
Steven Krebs	steven.krebs@dot.wi.gov	Wisconsin
Greg Milburn	Greg.milburn@wyo.gov	Wyoming

3.2 Survey analysis

Based on the survey conducted, a summary of the survey is provided here with the detailed survey responses attached as appendix IV.

The survey investigated 15 questions to respondents. The first question asked is “What types of concrete pavement are commonly used in your state?”. From all 20 responses, 11 responders indicated they adopted plain concrete pavements; 11 indicated they adopted joint reinforced concrete pavements; only 2 use continuously reinforced concrete pavements. From question (1), most of distresses and repairs are with plain and joint reinforced concrete pavements.

The second question asks whether they use accelerated repairs for these PCC pavements. 14 indicated they did, 5 indicated no, and 1 skipped.

In the question “whether the state has the specification for the accelerated repairs”, 14 indicated they have the specifications for the accelerated repairs, and 1 states no. All the ‘yes’ responses provided the links and documents for their specifications.

For the method in developing their specifications, all responses indicated that they developed their specification following their own experiences with referring to other states' guidelines. Research outcomes and industrial recommendations helped to enrich their specifications.

For the most common repair types faced at the states with similar climates as North Dakota, there are partial depth repair, full panel replacement, full depth repair, dowel bar retrofitting, joint repair, and crack sealing.

For the materials used in these accelerated repairs, there are rubberized Joint Sealing Material, ASTM D6690-Type II and Type I, Hot pour sealant, and Hot Pour or Silicone for jointing and cracking repairs. For partial and full depth repairs, there are PR Concrete, Epoxy and grout, Normal Concrete, Rapid Set Concrete, Latex Modified Concrete, and high early strength CDOT Class E concrete. For dowel bar retrofits, epoxy coated dowel bars with rapid set concrete is typically used.

For the unsuccessful cases with accelerated repairs, 83% of responses indicated they have experienced unsuccessful repairs. The unsuccessful repairs are related to all repair types, including dowel bar retrofit, partial depth repair, full panel replacement, full depth repair, and joint repair. The causes for these unsuccessful experiences are bonding and cracking issues, likely improper cleaning and use of patching material, poor subgrade/base, insufficient control over mix design and air content, workmanship, and/or potentially inherent material properties, long term durability of patch material, and early cupping and early wear.

For question "Which are the factors your agency uses to select a repair material for a given PCC pavement?", 47% of responses indicated it is the time to open for traffic; 20% of responses indicated it is the repair type to determine the repair material; Durability and curing time are sharing the same importance in determining the repair materials.

For question "Is special curing and placement method need?", it is needed for most repair types from the survey responses, although some aligns with the curing and placement of conventional concrete repairs. For joint repairs, the curing and placement is performed through spraying white cure on the finished concrete surface and then covered with plastic and insulation board. The concrete remains covered until reaching the required strength. For placement, most states (80%) require that not place PCC during periods of rain, not place PCC on frozen bases, and not placement when air temperature falls below 35 °F.

In the question asking the special accelerated pavement repair equipment, no special equipment is needed for accelerated PCC pavement repairs, except light saws.

For the question on factors determining pavement repair types, most responses responded with distress type (100%), then distress locations, and the time to open for traffic.

For the question on time to open for traffic, all the responses used compressive strength for open to traffic, while some uses maturity. The strength value used for time to open for traffic varies from 2.5 ksi to 4.0 ksi.

In the question on the expected service life of these accelerated repairs, 72% responses indicated more than 10 years' service life for joint repair, 75% responses indicated more than 3 years' service life for crack sealing, and 75% responses indicated more than 10 years for partial, full depth repair and full panel replacement, respectively.

KsDOT uses Type III cement for accelerated PCC pavement repairs and did not experience durability issues. Since the Blaine fineness of Type III is higher than these of Type I/II cement, it needs more water to hydrate. A combination of Type A water reducer and air entrants (4-6%)

will enhance the durability of Type III cement materials used as the accelerated PCC pavement repair materials.

The responses from each state are also organized into Tables 14-21 for easy reading.

Table 14. Surveyed states and their respective repair materials

State	Repair Type	Repair materials utilized
Colorado	Full panel replacement	Using high early strength CDOT Class E concrete
Indiana	Full depth patching	Experimenting with different concrete materials
Kansas	Concrete Joint repair	Rapid set patching material
	Partial depth patching	Type III cement adding calcium chlorite for durability
	Dowel bar retrofit	Rapid set patching material/super raid set patching materials.
Minnesota	Concrete crack sealing	Proprietary
	Partial depth patching	Proprietary
	Dowel bar retrofit	Proprietary
	Full panel replacement	Ready mix
Nebraska	Concrete Joint repair	PR Concrete
	Partial depth patching	PR Concrete
	Full depth patching	PR Concrete
	Full panel replacement	PR Concrete
	Intersection repair	PR Concrete
Ohio	Concrete Joint repair	RRCM or FS in Item 255
	Full depth patching	RRCM or FS in Item 255
Oregon	Partial depth patching	Epoxy and grout. Specific product types are on our QPL.
	Full depth patching	Type I/II cement and "Rapid Set" product
	Full panel replacement	Type I/II cement and "Rapid Set" product
	Others	Type I/II cement and "Rapid Set" product
Pennsylvania	Concrete Joint repair	Rubberized Joint Sealing Material ASTM D6690-Type II and Type I
	Concrete crack sealing	Rubberized Joint Sealing Material ASTM D6690-Type II and Type I
	Partial depth patching	Normal Concrete, Rapid Set Concrete, Latex Modified Concrete
	Full depth patching	Normal and Accelerated Strength Concrete Mixes
	Dowel bar retrofit	Rapid Set Concrete Patching Materials
	Full panel replacement	Normal Strength Concrete Mixes

Table 14. Surveyed states and their respective repair materials (continued)

South Dakota	Concrete crack sealing	Hot Pour or Silicone
	Partial depth patching	Bagged rapid strength concrete mix
	Full depth patching	High early strength PCC mix
	Dowel bar retrofit	DBR rapid strength patch material
	Full panel replacement	Normal PCC to High early strength PCC.
Utah	Concrete Joint repair	Hot pour sealant
	Partial depth patching	Patching mixes such as 5 star
	Full depth patching	High cement content mixes and patching mixes such as 5 star
	Dowel bar retrofit	Patching mortar
	Full panel replacement	Precast panels and high cement content mixes
Washington	Partial depth patching	Rapid setting concrete patching material
	Dowel bar retrofit	epoxy coated dowel bars, rapid setting concrete patching material
	Full panel replacement	Portland cement concrete or rapid setting concrete
Wisconsin	Concrete Joint repair	High early concrete
	Partial depth patching	High early concrete
	Full depth patching	High early concrete
	Dowel bar retrofit	Approved grout
	Full panel replacement	High early concrete

Table 15. Unsuccessful experiences with accelerated repair materials of different states

State	Repair Type	Reason for unsuccessful
Colorado	Dowel bar retrofit	Improper grout application on retrofit dowels.
	Full panel replacement	When partial panels removed. have since gone to full panel remove/replace
Indiana	Full depth patching	mid-panel cracks and shrinkage on long patches
Kansas	Concrete Joint repair	Product cured faster than anticipated. Contractor may choose repair material type
	Partial depth patching	1/2-1 in. deterioration around the joint
	Dowel bar retrofit	Durability problem. Deterioration on the top using rapid set patching materials

Table 15. Unsuccessful experiences with accelerated repair materials of different states (continued)

Minnesota	Concrete Joint repair	Bonding and cracking issues
	Partial depth patching	Bonding and cracking issues
	Dowel bar retrofit	Durability issue
Nebraska	Nebraska has not ever had unsuccessful experience with accelerated PCC pavement repair materials	
Ohio	Concrete Joint repair	Class FS concrete has 900 lbs of cement - shrinkage cracking above dowels
	Full depth patching	Class FS concrete has 900 lbs of cement - shrinkage cracking above dowels cracking above dow els
	Full panel replacement	For FS shrinkage cracking from too much cement
Oregon	Full depth patching	"Rapid Set" product. Our unsuccessful experiences are due primarily to poor subgrade/base, insufficient control over mix design and air content, workmanship, and/or potentially inherent material properties. We have made improvements to the product control and have added macro-fibers. It is too soon to determine if we have an improved success rate.
	Others	Same as full depth patching
Pennsylvania	Partial depth patching	In spall repair applications, certain materials perform better than others.
	Others	In bridge deck applications, certain rapid set material does not work well for large areas
South Dakota	Partial depth patching	Material not staying bonded and cracking of patch material
	Full depth patching	Long term durability of patch material
	Dowel bar retrofit	freeze thaw durability

Table 15. Unsuccessful experiences with accelerated repair materials of different states (continued)

Utah	Partial depth patching	Likely improper cleaning and use of patching material
	Full depth patching	Likely improper cleaning and use of patching material
	Dowel bar retrofit	Likely improper cleaning and use of patching material
Washington	Dowel bar retrofit	Improper patching material resulting in depressions at slots
	Full panel replacement	Isolated incidences of cracking and/or scaling of rapid setting concrete patching material
Wisconsin	Wisconsin has not ever had unsuccessful experience with accelerated PCC pavement repair materials	

Table 16. Strength criteria used by different states in determining the time to open for traffic

state	Compressive strength	Flexural strength	Maturity	Other strength	Time (hours/days)	Other
Colorado	3000 psi					
Illinois	Skipped					
Indiana		Experimenting				
Kansas	3.5 ksi					
Michigan	Skipped					
Minnesota	3,000 psi	500 psi				
Missouri	3,000 psi					
Nebraska	3,500 psi					
Nevada	Skipped					
Ohio		400 psi 3 pt flexural	400 psi 3 pt flexural			
Oregon	2,500 psi if "rapid set" or similar product is used. 3,000 psi for Type I/II/III cement					
Pennsylvania	3,000 psi for all repairs except partial depth = 2,000 psi					

Table 16. Strength criteria used by different states in determining the time to open for traffic (continued)

South Dakota	Varies depending on time to open to traffic. From 3,600 to 4,000.			Rebound hammer to evaluate compressive strength at early ages	48 hour spec at a minimum temp.	
Utah	4,000 psi					
Washington	2,500 psi		Maturity is used to determine if the concrete has reached the required 2,500 psi compressive strength			
Wisconsin	3,000 psi					

Table 17. Priority used by different states in selecting a repair material

State	Repair Type	Curing Time	Time to open for traffic	Durability	Cost	Other, please specify
Colorado	5	2	1	3	4	
Illinois	Skipped					
Indiana	2	4	1	3	5	
Kansas	5	4	3	1	2	6
Michigan	Skipped					
Minnesota	1	1	1	1	3	
Missouri	Skipped					
Nebraska	4	1	1	2	5	
Nevada	Skipped					
Ohio	6	2	1	3	3	
Oregon	1	3	2	4	5	

Table 17. Priority used by different states in selecting a repair material (continued)

Pennsylvania	1	5	2	3	4	
South Dakota	2	3	1	4	5	
Utah	3	5	5	4	3	
Washington						1
Wisconsin	2	2	1	3	4	

Table 18. Special placement and curing methods for accelerated repair materials

State	Repair Type	Repair materials utilized
Colorado	Partial depth patching	It would depend on the material used. If it was pre-packaged rapid set repair materials, mixing, placing and curing would follow the manufacturer's recommendations. For accelerated concrete, it would be cured with curing compounds and insulating blankets. External heat may also be used in cold environments.
	Full depth patching	Same as partial depth repair
	Full panel replacement	Same as partial depth repair
	Intersection repair	Same as partial depth repair
Illinois	Skipped	
Indiana	Concrete Joint repair	Experimenting
	Full depth patching	Experimenting
Kansas	Kansas does not have requirements for replacement and curing	
Michigan	Skipped	
Minnesota	Minnesota does not have requirements for replacement and curing	
Missouri	Skipped	
Nebraska	Concrete Joint repair	The finished concrete is sprayed with white cure and then covered with plastic and insulation board. The concrete remains covered until we have strength using the Maturity Method.
	Partial depth patching	Same as concrete joint repair
	Full depth patching	Same as concrete joint repair
	Full panel replacement	Same as concrete joint repair
	Intersection repair	Same as concrete joint repair
Nevada	Skipped	
Ohio	Concrete Joint repair	See our spec book for all the following
	Full panel replacement	See our spec book for all the following

Table 18. Special placement and curing methods for accelerated repair materials (continued)

Oregon	Concrete Joint repair	Do not place PCC during periods of rain. Do not place PCC on frozen bases. Stop placement when descending air temperature falls below 35 °F. Do not begin placement until the air temperature is 35 °F in the shade and rising and is forecast to remain above 35 °F.
	Partial depth patching	Dry
	Full depth patching	Same as concrete joint repair
	Full panel replacement	Same as concrete joint repair
	Others	Same as concrete joint repair
Pennsylvania	Partial depth patching	Cured the same as normal pav't or mfr. rec. for product used
	Full depth patching	Same as Partial depth patching
	Dowel bar retrofit	Same as Partial depth patching
	Full panel replacement	Same as Partial depth patching
South Dakota	Skipped	
Utah	Partial depth patching	Gain a specified strength prior to opening for traffic, penalty for not meeting
	Full depth patching	Same as Partial depth patching
	Dowel bar retrofit	Same as Partial depth patching
	Full panel replacement	Same as Partial depth patching
Washington	Partial depth patching	Cure patching material according to manufacturer's recommendations, must attain 2,500 psi compressive strength prior to opening to traffic.
	Dowel bar retrofit	Cure patching material according to manufacturer's recommendations.
	Full panel replacement	Conventional practices for placing and curing cement concrete pavement are used. Concrete must achieve
Wisconsin	Skipped	

Table 19. Special equipment needed for the accelerated repair materials used by different states

State	Repair Type	Special equipment or method used
Colorado	Concrete Joint repair	Sawcut the area needing replacement, jack hammer out the damaged concrete. Recondition base material if needed. Drill and epoxy new joint steel if needed. Place concrete.
	Concrete crack sealing	Cracks are usually not sealed, but they are, standard joint sealing materials and equipment is used. Sometimes, our maintenance crews seal concrete joints with hot poured HMA crack sealant.
	Partial depth patching	We follow the guidelines from FHWA http://www.fhwa.dot.gov/pavement/concrete/repair04.cfm
	Full depth patching	Same as concrete joint repair
	Dowel bar retrofit	We follow the FHWA procedures http://www.fhwa.dot.gov/pavement/preservation/ppcl08.cfm
	Full panel replacement	Same as concrete joint repair
	Intersection repair	Same as concrete joint repair
Illinois	Skipped	
Indiana	Full depth patching	Experimenting with admixtures and possibly internal curing with light weight aggregates
Kansas	Dowel bar retrofit	quick light saw in specification
Michigan	Skipped	
Minnesota	Minnesota does not require the use of special equipment or methods	
Missouri	Skipped	
Nebraska	Nebraska does not require the use of special equipment or methods	
Nevada	Skipped	
Ohio	Concrete Joint repair	Blankets see spec book
	Full depth patching	Blankets see spec book
Oregon	Oregon does not require the use of special equipment or methods	
Pennsylvania	Pennsylvania does not require the use of special equipment or methods	
South Dakota	South Dakota does not require the use of special equipment or methods	
Utah	Utah does not require the use of special equipment or methods	
Washington	Washington does not require the use of special equipment or methods	
Wisconsin	Wisconsin does not require the use of special equipment or methods	

Table 20. Factors determining selection of a repair process

State	Distress location	Time to open for traffic	Cost	Others	Other, please specify
Colorado	1	2	3		
Illinois	Skipped				
Indiana		1			
Kansas	1	3	2	4	
Michigan	Skipped				
Minnesota	1	1	1		
Missouri	Skipped				
Nebraska	1	1	3		
Nevada	Skipped				
Ohio	1	3	2		
Oregon	3	2	4	1	Type of failure and whether or not it justifies partial depth (spall) repair or full depth-type repairs.
Pennsylvania	1	2	3		
South Dakota	3	2	4	1	Distress Type
Utah	2	1	2		
Washington				1	The repair process is determined by the type of distress.
Wisconsin	2	1	2		

Table 21. The expected service time of each repair type

State	Concrete Joint repair	Concrete crack sealing	Partial depth patching	Full depth patching	Dowel bar retrofit	Full panel replacement	Intersection repair	Others
Colorado	Skipped							
Illinois	Skipped							
Indiana	Skipped							
Kansas	5 to 10		10 to 15		10 to 15			
Michigan	Skipped							
Minnesota	5 to 10	0-3	5 to 10		5 to 10	10 to 15		
Missouri	Skipped							
Nebraska	10 to 15	10 to 15	10 to 15	10 to 15		10 to 15	10 to 15	
Nevada	Skipped							
Ohio	10 to 15			10 to 15		>15		
Oregon	10 to 15		10 to 15	5 to 10		>15		5 to 10
Pennsylvania	>15	>15	10 to 15	>15	>15	>15		
South Dakota		10 to 15	5 to 10	>15	>15	>15		
Utah	>15		10 to 15	10 to 15	10 to 15	10 to 15		
Washington			10 to 15		>15	>15		
Wisconsin	Skipped							

3.3 Phone interview results

The phone interview was conducted for technical experts on this topic following the email survey results. The phone interview further investigated the best repair materials and processes the targeted agency has used for different types of repairs and what are their successful and failed stories on these repairs.

Table 22-23 summarized the successful and unsuccessful stories through the phone interview results on four states. From the Table results, we may see successful accelerated repairs are pervasive. The result of non-Portland cement is better with fiber inclusions.

For KsDOT point of view, the materials were not the issue. Prequalification is performed through NTPEP. The following is a link to their prequalified list: http://www.ksdot.org/burmatrres/pql/pql-05-03.PDF. And the link to the implementation specification is: http://www.ksdot.org/burConsMain/specprov/2007/1716.pdf. KsDOT also has a special provision to the spec: http://www.ksdot.org/burConsMain/specprov/2007/pdf/07-17001.pdf. The issue with the unsuccessful experiences at KsDOT was adequate consolidation of the RSCP material. The contractor was leaving voids in the corner of the milled patch area. This permitted accumulation of water that could freeze and force pop outs. It's important to verify that the contractor is filling the entire patch. The best way to check this is to take periodic cores. I would recommend that the contractor proves their ability to perform the work with the material they have chosen prior to permitting them disrupt traffic, perhaps at a parking lot or DOT

maintenance area. The successful outcome KsDOT reaches is the patched material staying in place: no cracks, no delamination, and no issues.

For SDDOT, dowel bar retrofit and partial depth patching are successful when they work as designed and last as long as planned (in terms of good performance and longevity). However it is much harder to quantify the materials or methods that make dowel bar retrofit and partial depth patching unsuccessful. When the same specifications, materials, and contractor are used, one location is successful and another is not. Thus it becomes hard to quantify why. Some of the reasons dowel bar retrofit or partial depth patching have failed prematurely are due to contractor care/uniformity, material freeze thaw damage, cracking of new material, debonding and eventual loss of patch, and even incorrect use/location where a different fix was needed.

Table 22. Successful cases for the states phone interviewed

State	**Successful cases**
Kansas	We had several projects in the immediate Topeka area, on both I-70 and I-470 (southwestern portion). Of these projects, we personally consider most of them successes.
Ohio	They have a new QC FS specification which is not having the cracking problems. The more successful specification is located at: http://www.dot.state.oh.us/Divisions/ConstructionMgt/Specification%20Files/2013%20CMS%2011142012%20FINAL.PDF
Oregon	We have noticed that when we have used non Portland cement products they appear to have very mixed success. Several have had scaling issues, which may be due to historic poor control of air content. Also, we have noticed that some of our CRCP repairs with non Portland cement products have experienced detrimental shrinkage. We currently use poly macro fibers and control the air content better than in the past. Initial observations are that this has improved our success rate to some extent.
South Dakota	For things like Dowel Bar or tie bar slot retrofits and some partial depth patching. Almost all DBR projects have went very well, partial depth patching projects vary where some may be successful on a project and others are not.

Table 23 summarized the unsuccessful stories through the phone interview results on four states.

Table 23. Unsuccessful cases for the states phone interviewed

State	**Unsuccessful cases**
Kansas	The one specific project that was not a success can be associated with the western portion of I-70 inside of Topeka.
Ohio	Unsuccessful experience was with our old FS repair concrete mix. It had 900 lbs. of cement per cy and essentially cured too fast and cracked above every dowel bar before the 4 hour set time it required. A link to view this unsuccessful spec is at: http://www.dot.state.oh.us/Divisions/ConstructionMgt/Specification%20Files/2010%20CMS%20Final%2012222009.pdf.
Oregon	We have noticed that when we have used non Portland cement products they appear to have very mixed success. Several have had scaling issues, which may be due to historic poor control of air content. Also, we have noticed that some of our CRCP repairs with non Portland cement products have experienced detrimental shrinkage.
South Dakota	Some materials and or patch locations/sizes have not worked will with fast setting repair mortars. Things like surface cracking, excessive shrinkage cracking, premature deterioration, debonding from substrate all are cause for failures.

3.4 Compare the surveyed and phone interviewed Fast-Track PCC pavement repair processes and materials with the City of Fargo pavement repair practice, considering the repair type, time to cure, time to open for traffic, and the service period of each repair.

City of Fargo uses Fast-Track concrete with Type I/II cement for PCC pavements and their repairs. These materials can reach a compressive strength of 2.5 ksi in 24 hours. Typically, these fast-track concrete mixes will include at least 20% direct replacement of cement with fly ash. Most of the fast-track PCC mixes can provide the strength required for opening to traffic in 12-14 hours (City of Fargo Specifications, Section 2100, Concrete Paving and Curbs & Gutters, 2012).

4. Cost-benefit analysis of the best management practices identified in the survey

The cost-benefit (C/B) analysis is a method to estimate costs required to achieve a given road condition. The method consists of:

- Determining the costs: initial capital cost of equipment, the operating and maintenance costs per mile, the net salvage value if any, and the material and labor cost per mile for different repair types.
- Selecting units of benefits to be used in the analysis, and estimating the annual benefit for the project in the selected units. Examples: total number of maintenance reduced at the same level of service, number of traffic disrupt reduced, etc.
- Calculating the difference of benefits and costs.

The benefits of roads are judged through the shortened traffic closure time, which can be related to the cost saving through reduced traffic closure frequency and number of traffic disruptions. Costs, on the other hand, are straightforward to assess and quantify, and related to labor, equipment and material used. The results for the selected 2-3 materials for partial depth repairs in Task 2 will be then ranked in terms of their C/B.

Example 1 considers the placement of 100 patches. Material, labor, and equipment costs can be directly entered on the cost-effectiveness worksheet. However, the average daily productivity, the estimated number of days for the patching operation, and the partial-depth patch survival rate require a few advance calculations.

In calculating the average daily productivity and the estimated number of days for patching, the examples assume that the last patch will be placed at the latest possible time and that preparation will stop when there is not enough time to place the next patch. Therefore the patch preparation rate will control the number of patches that can be placed per day. The example also assumes that a crew of seven places seven patches per hour, and the average patch volume is 0.006 m3.

Patches prepared per hour = 7
Work hours per day = 8
Material cure time = 4 hr
Number of hours available for preparation and placement (work hours - cure hours) = 4 hr
Average preparation rate (7 patches/hr) × (0.006 m^3/patch) = 0.042 m^3/hr
Average daily productivity 4 hr × 0.042 m^3/hr × (1 patch/0.006 m^3) = 28 patches
Estimated number of days for patching (rounded up) 100 / 28 = 4 days
The material prices and their sources are listed in Table 24.

Table 24. The material and labor prices and their sources used in the cost-benefit analysis

Material	Price	Source of Price
Type I Cement	173 \$/m^3	Aggregate Industries (www.aggregate-us.com), (218)236-9880.
Bonding Agent	11 \$/Bag	www.alibaba.com
Joint Bond Breaker	1 \$/m	http://www.amazon.com/
Concrete Curing Compound	250 \$/m^3	www.alibaba.com
Average Daily Wage per Person	120 \$/Day	Wilson, Thomas P., K. L. Smith, and A. Russell Romine. *Materials and Procedures for Rapid Repair of Partial-depth Spalls in Concrete Pavements--manual of Practice*. No. FHWA-RD-99-152, 2001.

Table 24. The material and labor prices and their sources used in the cost-benefit analysis (continued)

Supervisor Daily Wage	200 $/Day	Wilson, Thomas P., K. L. Smith, and A. Russell Romine. *Materials and Procedures for Rapid Repair of Partial-depth Spalls in Concrete Pavements--manual of Practice*. No. FHWA-RD-99-152, 2001.
Material Truck	20 $/Day	Same as Supervisor Daily Wage
Traffic Control Truck and Signs	150 $/Day	Same as Supervisor Daily Wage
Patch Preparation Equipment	285 $/Day	Same as Supervisor Daily Wage
Cleaning Equipment	350 $/Day	Same as Supervisor Daily Wage
Mixing Equipment	35 $/Day	Same as Supervisor Daily Wage
Consolidation/Compaction Equipment	20 $/Day	Same as Supervisor Daily Wage
User Daily Costs	1000 $/Day	Same as Supervisor Daily Wage

Based on the email survey results, the mean patch survival life is estimated at 120 months for a situation where rehabilitation will be implemented in approximately 150 months. The following worksheet shows the completed cost-effectiveness example.

Estimate of project size or seasonal partial-depth patching needs

	amount	units	
Expected numbers of patches	100		(A)
Average finished patch length	380 (15)	mm(in)	(B_1)
Average finished patch width	330 (13)	mm(in)	(B_2)
Average finished patch depth	49 (2)	mm(in)	(B_3)
Expected total volume of finished patches [($B_1 \times B_2 \times B_3 \times A) \div 10^9$]	0.62 (22.2)	m^3 (ft^3)	(C)

MATERIAL COSTS (e.g., cold mix, cement, aggregate, sand, bonding agent, joint bond breaker, curing agent, etc.)

Material 1 = Portland Cement concrete			
Material 1 Purchase Cost	173	$/ m^3	(D_1)
Expected Material 1 needs	0.75	m^3	(E_1)
Material 1 Shipping cost	0	$	(F_1)
Total Material 1 Cost [($D_1 \times E_1$) + F_1]	129.75	$	(G_1)

Material 2 = Bonding Agent			
Material 2 Purchase Cost	11	\$/Bag	(D_2)
Expected Material 2 needs	2	Bag	(E_2)
Material 1 Shipping cost	0	\$	(F_2)
Total Material 2 Cost [($D_2 \times E_2$) + F_2]	22	\$	(G_2)
Material 3 = Joint Bond Breaker			
Material 3 Purchase Cost	1	\$/m	(D_3)
Expected Material 3 needs	100	m	(E_3)
Material 3 Shipping cost	0	\$	(F_3)
Total Material 3 Cost [($D_3 \times E_3$) + F_3]	100	\$	(G_3)
Material 4 = Concrete Curing Compound			
Material 4 Purchase Cost	250	\$/m^3	(D_4)
Expected Material 4 needs	0.5	M^3	(E_4)
Material 4 Shipping cost	0	\$	(F_4)
Total Material 4 Cost [($D_4 \times E_4$) + F_4]	125	\$	(G_4)

LABOR COSTS

	amount	units	
Number in Repair Crew	9		(H)
Average Daily Wage per Person	120	\$/day	(I)
Number in Traffic Control Crew	2		(J)
Average Daily Wage per Person	120	\$/day	(K)
Supervisor Daily Wage	200	\$/day	(L)

EQUIPMENT COSTS

Material Truck	20	\$/day	(M)
Traffic Control Truck and Signs	150	\$/day	(N)
Patch Preparation Equipment (e.g., concrete saw, jackhammer, milling machine, water blaster)	225	\$/day	(O_1)
	60	\$/day	(O_2)

Cleaning Equipment (e.g., sandblaster, air blaster)	350	$/day	(P_1)
	0	$/day	(P_2)
Mixing Equipment (e.g., mortar mixer, Jiffy mixer)	35	$/day	(Q_1)
	0	$/day	(Q_2)
Consolidation/Compaction Equipment (e.g., pencil vibrator, vibrating screed, vibratory roller)	20	$/day	(R)
Extra Equipment Truck	0	$/day	(S)
Miscellaneous Equipment (e.g., spray-injection machine, joint sealing equipment, etc.)	0	$/day	(T_1)
	0	$/day	(T_2)

SUMMARY COSTS

	amount	units	
Total Material Cost (G1 + G2 + G3 + G4)	376.75	$	(U)
Total Daily Labor Cost [(H × I) + (J × K) + L)]	1520	$/day	(V)
Total Equipment Cost [M + N + (O1 + O2 + …) + (P1 + P2 + …) + (Q1 + Q2 + …) + R + S + (T1 + T2 + ….)]	860	$/day	(W)
User Daily Costs	1000	$/day	(X)
Average Daily Productivity	28	patches/ day	(Y)
Estimated Number of Days for Patching Operation (A/Y)	4	days	(Z)
Total Patching Operation Cost [U + {Z × (V+ W + X)}]	13,896.75	$	(AA)

Expected Mean Life for Partial-Depth Patches[1] (Duration may vary)	120	months	(BB)
Time to Pavement Rehabilitation	150	months	(CC)
Effective Patching Cost over time [AA × (CC/BB)]	17,370.90	$	(DD)

[1] Until expected mean life values have been determined, agency experience should be applied.

Example 2 considers the placement of 100 patches. The same conditions of Example 1 are used except the Type III cement concrete with shortened cure time is adopted for the accelerated pavement repair.

Patches prepared per hour = 7
Work hours per day = 8
Material cure time = 2 hr
Number of hours available for preparation and placement (work hours - cure hours) = 6 hr
Average preparation rate (7 patches/hr) × (0.006 m^3/patch) = 0.042 m^3/hr
Average daily productivity 6 hr × 0.042 m3/hr × (1 patch/0.006 m3) = 42 patches
Estimated number of days for patching (rounded up) 100 / 42 = 3 days

The mean patch survival life is estimated at 120 months for a situation where rehabilitation will be placed in approximately 150 months. The following worksheet shows the completed cost-effectiveness example.

Estimate of project size or seasonal partial-depth patching needs

	amount	units	
Expected numbers of patches	100		(A)
Average finished patch length	380(15)	mm(in)	(B_1)
Average finished patch width	330(13)	mm(in)	(B_2)
Average finished patch depth	49(2)	mm(in)	(B_3)
Expected total volume of finished patches [($B_1 \times B_2 \times B_3 \times A) \div 10^9$]	0.62(22.2)	m^3(ft^3)	(C)

MATERIAL COSTS (e.g., cold mix, cement, aggregate, sand, bonding agent, joint bond breaker, curing agent, etc.)

Material 1 = Type III Cement concrete			
Material 1 Purchase Cost	288	$/ m^3	(D_1)
Expected Material 1 needs	0.75	m^3	(E_1)
Material 1 Shipping cost	0	$	(F_1)
Total Material 1 Cost [($D_1 \times E_1$) + F_1]	216	$	(G_1)

Material 2 = Bonding Agent			
Material 2 Purchase Cost	11	\$/Bag	(D_2)
Expected Material 2 needs	2	Bag	(E_2)
Material 1 Shipping cost	0	\$	(F_2)
Total Material 2 Cost [($D_2 \times E_2$) + F_2]	22	\$	(G_2)
Material 3 = Joint Bond Breaker			
Material 3 Purchase Cost	1	\$/m	(D_3)
Expected Material 3 needs	100	m	(E_3)
Material 3 Shipping cost	0	\$	(F_3)
Total Material 3 Cost [($D_3 \times E_3$) + F_3]	100	\$	(G_3)
Material 4 = Concrete Curing Compound			
Material 4 Purchase Cost	250	\$/m^3	(D_4)
Expected Material 4 needs	0.5	M^3	(E_4)
Material 4 Shipping cost	0	\$	(F_4)
Total Material 4 Cost [($D_4 \times E_4$) + F_4]	125	\$	(G_4)

LABOR COSTS

	amount	units	
Number in Repair Crew	9		(H)
Average Daily Wage per Person	120	\$/day	(I)
Number in Traffic Control Crew	2		(J)
Average Daily Wage per Person	120	\$/day	(K)
Supervisor Daily Wage	200	\$/day	(L)

EQUIPMENT COSTS

Material Truck	20	\$/day	(M)
Traffic Control Truck and Signs	150	\$/day	(N)
Patch Preparation Equipment (e.g., concrete saw, jackhammer, milling machine, water blaster)	225	\$/day	(O_1)
	60	\$/day	(O_2)

Cleaning Equipment (e.g., sandblaster, air blaster)	350	$/day	(P_1)
	0	$/day	(P_2)
Mixing Equipment (e.g., mortar mixer, Jiffy mixer)	35	$/day	(Q_1)
	0	$/day	(Q_2)
Consolidation/Compaction Equipment (e.g., pencil vibrator, vibrating screed, vibratory roller)	20	$/day	(R)
Extra Equipment Truck	0	$/day	(S)
Miscellaneous Equipment (e.g., spray-injection machine, joint sealing equipment, etc.)	0	$/day	(T_1)
	0	$/day	(T_2)

SUMMARY COSTS

	amount	units	
Total Material Cost (G1 + G2 + G3 + G4)	463	$	(U)
Total Daily Labor Cost [(H × I) + (J × K) + L)]	1520	$/day	(V)
Total Equipment Cost [M + N + (O1 + O2 + …) + (P1 + P2 + …) + (Q1 + Q2 + …) + R + S + (T1 + T2 + ….)]	860	$/day	(W)
User Daily Costs	1000	$/day	(X)
Average Daily Productivity	42	patches/ day	(Y)
Estimated Number of Days for Patching Operation (A/Y)	3	days	(Z)
Total Patching Operation Cost [U + {Z × (V+ W + X)}]	10,603	$	(AA)

Expected Mean Life for Partial-Depth Patches[1] (Duration may vary)	120	months	(BB)
Time to Pavement Rehabilitation	150	months	(CC)
Effective Patching Cost over time [AA × (CC/BB)]	13,253.75	$	(DD)

[1] Until expected mean life values have been determined, agency experience should be applied.

From the two examples, we may see the benefits of adopting accelerated pavement repairs using Type III cement concrete compared to Portland cement concrete. For a similar patching project, the cost of adopting Type III cement concrete is only $13,253.75 compared to $17,370.90, with referring to the benefits due to the shortened time open for traffic.

Summarizing all the cost analysis results, the best materials and processes used in literatures and identified through the survey can be shown in Table 25.

Table 25. Best repair materials and best repair processes identified through literature review and survey for accelerated PCC pavement repairs

Repair Type	Best repair material	Best repair processes	Cost ratio compared to the benchmark cost
Joint repair	Rubberized sealant	Saw, clean, place bond breaker, place backing matl, place sealant.	1 (compared to hot pour sealant)
Crack sealing	Rubberized sealant	Saw, clean, place bond breaker, place backing matl, place sealant.	1 (compared to hot pour sealant)
Partial depth patching	Type III cement	Saw cut perimeter 2" minimum depth, remove material, sandblast, place patching material according to manufacturer's recommendation.	0.76 (compared to type I cement)
Full depth patching	Type III cement	Saw, remove material, clean patch, recompact base, place dowels, place concrete.	0.76 (compared to type I cement)
Dowel bar retrofit	Rapid Set Concrete Patching Materials	Saw slots, remove material, prepare and place dowels, bonding agent and concrete, Patch material	0.55 (compared to conventional dowel bar retrofit)
Full panel replacement	Portland cement concrete	Saw, remove material, clean patch, recompact base, place dowels, place concrete.	1

5. Report the source of the identified BMPs

The team selected the best management practices, reported their sources, and developed a booklet to help NDDOT in their implementations (Table 26).

Table 26. Identified best repair materials and best repair processes and their sources

Repair type	Best repair practice(materials and processes)	Link to the implementation
Joint repair	Rubberized sealant, and the process is Saw, clean, place bond breaker, place backing matl, place sealant.	1. www.dot.state.pa.us 2.http://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:3694, See Specs 02751 and 02753
Crack sealing	Rubberized sealant, and the process is Saw, clean, place bond breaker, place backing matl, place sealant.	www.dot.state.pa.us
Partial depth patching	Type III cement, and the process is Saw cut perimeter 2" minimum depth, remove material, sandblast, place patching material according to manufacturer's recommendation.	1.http://www.oregon.gov/ODOT/HWY/SPECS/Pages/2008_special_provisions.aspx#Part_00700 2.http://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:3694, See Specs 02751 and 02753 3. www.dot.state.pa.us
Full depth patching	Type III cement, and the process is Saw , remove material, clean patch, recompact base, place dowels, place concrete.	www.dot.state.pa.us
Dowel bar retrofit	Rapid Set Concrete Patching Materials, and the process is Saw slots, remove material, prepare and place dowels, bonding agent and concrete, Patch material	www.dot.state.pa.us
Full panel replacement	Portland cement concrete, and the process is Saw, remove material, clean patch, recompact base, place dowels, place concrete.	1.http://www.dot.state.oh.us/Divisions/ConstructionMgt/Specification%20Files/2013%20CMS%2011142012%20FINAL.PDF 2.http://www.oregon.gov/ODOT/HWY/SPECS/Pages/2008_special_provisions.aspx#Part_00700 3.www.dot.state.pa.us

6. Report documentations and final project presentation

A draft final report was submitted to NDDOT on Oct 1st, 2013 and a project presentation meeting with NDDOT is arranged to be conducted on Oct 15th and the review comments from the Research Advisory Committee (RAC) will be solicited. The review comments will be implemented in the final report which will be submitted to NDDOT after the project presentation.

7. Reference:

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5. David A. Lange, and Daniel I. Castaneda. "Repair Materials & Methods at O'Hare Airport." *CEAT Brownbag Seminar Series Friday, September 21, 2012.*
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9. Markey, SM, Lee, SI, Mukhopadhyay, AK, Zollinger, DG, Whitney, DP, and Fowler, DW, *Investigation of Spall Repair Materials for Concrete Pavement*, FHWA /TX-06/0-5110-1
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18. FHWA Office of Pavement Technology, *Concrete Pavement Preservation Workshop Reference Manual*, 2008
19. City of Fargo, *Concrete Paving and Curbs & Gutters*, Section 2100, City of Fargo Specifications, 2012

Appendix I

DOT MANUALS AND POLICIES ABOUT FAST-TRACK REPAIR MATERIALS AND PROCESSES

1. Alberta Transportation, Technical Standard Branch, Specification for Concrete Patching Materials

Alberta Transportation categorizes patching types according to their implementation conditions, such as normal horizontal (NH), overhead and vertical (OH-V), low temperature horizontal (LTH), high early horizontal (HEH), form and pour or form and pump (FP).

Table 1. Patching category

Class	Application	Time of application	Remarks
NH	Bridge deck potholes or curb top spalls	During summer	Open to traffic in 3 days
OH-V	Girders, underside decks, inside curbs, abutment seat, and backwall	During summer	Applied by troweling
LTH	Similar to NH	Fall and Spring (0 to 5° C)	
HEH	Similar to NH	Summer	Fast setting
FP	Similar to OH-V and vertical surfaces	NA	Self-compacting and high viscosity

Alberta Department of Transportation, according to our correspondence, has very limited experience with PCC pavements and no repair approach has so far taken by this agency since most of the constructed PCC pavements are fairly new in Alberta.

2. Oregon Department of Transportation, SP758

ODOT specification section SP758 for full replacement including saw cutting of concrete and replacing with continuously reinforce concrete lists the following material, it recommends using high early strength concrete for fast track PCC pavement repairs.

- Reinforcing bar
- Furnish Class 4000 - 3/4 or Class 4000 - 1 paving concrete, Portland cement type I, II, and III or blended hydraulic cement shall be used. Blended Portland cement can be Type IP Portland-Pozzolan cement (Pozzolan can be fly ash or granulated blast furnace slag) or Type I (SM) slag-modified Portland cement conforming to AASHTO M 240
- Curing material
- Epoxy and Non-epoxy Bonding Agents
- Epoxy and Non-epoxy grouts
- Galvanizing
- Poured Joint Fillers
- Preformed Expansion Joint Filler
- Structural Steel

For spall repair it requires using "PCC Patching - Rapid Set" or "PCC Patching- very Rapid Set" and it does not allow using the patches which contain magnesium sulfate. According to ODOT Qualified Product List (QPL), the commercial PCC Patching – Rapid and Very Rapid Set are listed in the following table:

Table 2. List of fast setting patching material approved by ODOT.

PCC Patching – Rapid Set	CHEMPATCH VO1
	SPEED CRETE GREEN LINE
	PPC EASY PATCH STANDARD
PCC Patching – very Rapid Set	US SPEC TRANSPATCH
	US SPEC POLYPATCH FR
	FIVE STAR HWY PATCH
	US SPEC TRANSPATCH
	MBT SET 45
	MBT THOROC 10-60 RAPID MORTAR
	SPEED CRETE 2028

ODOT pavement design guide discusses different types of repair process, i.e. partial and full depth repair, joint sealing, undersealing, diamond grinding, and dowel bar retrofits.

Partial depth repair which is intended for local deficiencies consists of saw cutting the upper portion of slab (limited to upper one third) and replacing it with a certified low slump patch material. It is important that the repair does not come into contact with reinforcements or dowels, otherwise, full-depth repair is used. Besides, full depth repair is used for corner breaks, punch-outs, and longitudinal cracks.

For jointed concrete pavements, full-depth repair involves saw-cutting and replacing the defected area with new concrete. The patched area will be tied to the existing concrete. In jointed reinforced concrete pavements, new longitudinal rebars have to be lap-spliced to the existing rebars to ensure integrity of the patch to the old concrete. To do this, usually bar lap area is created beyond the ends of the patch area with a depth of 2 in. For chipping out the existing concrete jackhammer or hand chipping tools are used. To avoid longitudinal crack development in patch area, transverse rebar at 1 ft spacing is also used. As shown in Fig. 1, when the repair

area is close to transvers joints, the patch is extended to transvers joint. For continuously reinforced concrete pavements, ODOT recommends that the patch be extended at least 3 ft beyond the tip of a longitudinal crack.

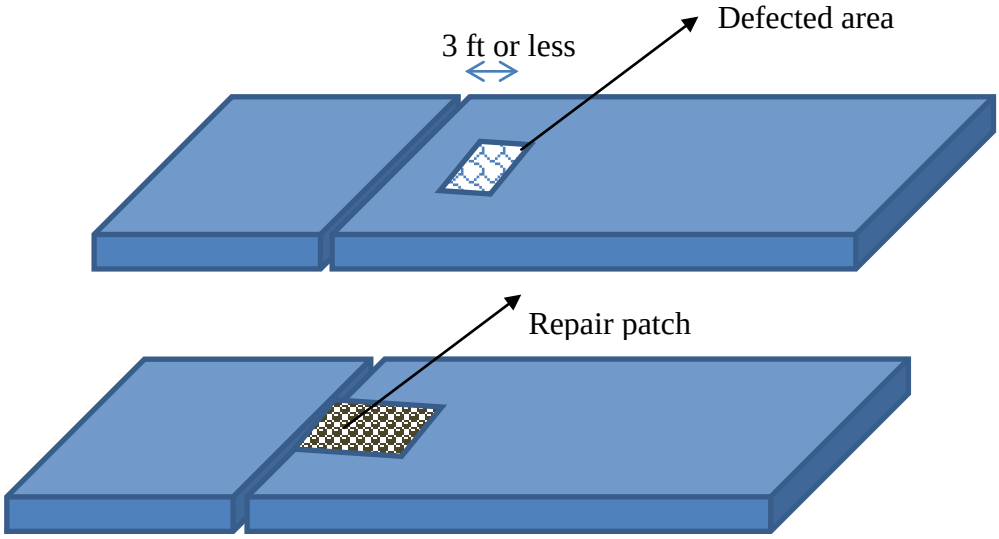


Fig. 1. ODOT recommendation for jointed concrete pavement repairs when defect area is close to joints.

3. Pennsylvania Department of Transportation

PENNDOT categorizes the concrete material as following:

Table 3. Classification of Portland cement concrete used in PENNDOT

CLASS OF CONCRETE	USE	CEMENT FACTOR[3,7] (Bags/ C.Y.)		MAXIMUM WATER CEMENT RATIO[8] (lbs/lbs)	SLUMP RANGE[2] (IN.)	MINIMUM MIX[2] DESIGN COMPRESSIVE STRENGTH (PSI)			PROPORTIONS COARSE[1] AGGREGATE SOLID VOLUME (Cu.Ft/Cu.Yd)	28-DAY STRUCTURAL DESIGN COMPRESSIVE STRENGTH (PSI)
						DAYS				
		Min.	Max.			3	7	28		
AAA	BRIDGE DECK	6.75	8.00	0.43	1-35	_	3600	4500	_	4000
AA	Paving	6.25	8.00	0.477	1-36	_	3000	3750	9.93 – 13.10	3500
AA	Structures and Misc.	6.25	8.00	0.477	1-3		3000	3750	9.93 – 13.10	3500
A		6.00	8.00	0.507	1-3	_	2750	3300	10.18 – 13.43	3000
C		4.20	7.00	0.667	2-6	_	1500	2000	11.45 – 15.10	2000
H.E.S.		8.00	9.00	0.407	1-3	3000	_	3750	9.10 – 12.00	3500

Spalls can be joints or surface spalls. Joint spalls are along longitudinal or transverse joints with a width of greater than 50 mm (2 in.) and length of less than 100 mm (4 in.) and surface spalls are also less than 100 mm (4 in.) in depth. Spall repairs are classified into five types:

(a) Concrete Pavement Spall Repair, Type 1. Using Class AA Cement Concrete, Modified.
(b) Concrete Pavement Spall Repair, Type 2. Using Class AA Cement Concrete, Special.
(c) Concrete Pavement Spall Repair, Type 3. Using Rapid Set Concrete Patching Materials.
(d) Concrete Pavement Spall Repair, Type 4. Using Latex Modified Concrete.
(e) Concrete Pavement Spall Repair, Type 5. Using thin Bonded Portland Cement Concrete Inlay.

PENNDOT in Bulletin 15 lists a variety of products from licensed manufacturers as rapid setting patching materials (Table 4).

Table 4. List of rapid setting patching material approved by PENNDOT.

Product Name	Manufacturer
10-60 Rapid mortar	BASF Corporation
Emaco GP	
EMaco T415 repair mortar	
FE 663.01	BASF Polyurethane foam enterprises LLC
Rigid pour foam	
486 Star	Baysystems NA LLC
ProSpec F-77 Const. Grout	Bonsal American
Tyberpatch HS	Cempro
Pavemend 15.0	Ceratech
CGM Highway Patch	CGM Inc.
Chemspeed 65	Chem Masters
HD-50	Dayton Superior
Pave Patch 3000	
Euco-Speed	Euclid Chem Co.
Speed Crete 2028	
Speed Crete Green Line	
Express Repair	
Versaspeed	
5 Starr Highway Patch	Five Star Products, Inc.
5 Start Structural Concrete	
5 Start Structural Concrete V/O	
Gill 33B & P Superbond	Gill Industries, Inc.
Ducracrete II	Kaufman Products
Durapatch Hiway Crystex	L&M Construction Chemicals Inc
Rapid Road Repair	The Quikrete Companies
FastSet Non-Shrink Grout	
FastSet Dot Mix	
CG Fastset Concrete Mix	
Sikatop III	Sika Corporation
Sika Set Road Patch	
SikaQuick 2500	
SikaQuick 1000	
Duracal	US Gypsum Co,
Duracal-S	

For repairs of continuously reinforced concrete pavements, they are classified into three types:

- Type A: patches between 6 and 20 ft long when using tied splices and between 4 and 20 ft long when using welded splices
- Type B: patches between 20.1 and 65 ft long
- Type C: patches between 65.1 and 500 ft long

Concrete class AA or HES shall be used and curing material can be only white polyethylene sheeting, white polyethylene sheeting, burlapbacked, or burlap.

For joint sealing, cork, sponge rubber, or fiber joint fillers can be used.

For spall repairs, the repair area is first examined and marked at least 80 mm (3.15 in.) beyond the delaminated area. The repair areas have to be at least 600 mm (23.60 in.) apart from each another, otherwise, they are combined into one repair area. The repair area has to be chipped out by a chipping hammer lighter than 14 Kg. For type 1, 2, and 3, this is done to a depth of at least 38 mm (1.5 in.) but for type 4 to the depth of delamination and for type 5 spall repair, it has to be a minimum depth of 50 mm (2 in.). Reinforcement in jointed reinforced concrete pavement that is exposed after the removal of delaminated concrete has to be removed but this is not allowed in continuously reinforced concrete pavements. The area has to be square and it has to be cleaned from loose aggregates than sandblasted or waterblasted within 24 hours before concrete placement. For final cleaning, it is air blasted half an hour before concrete placement. After cleaning, epoxy or grout is applied in the thin layer first and before it dries, concrete or other applicable patching materials are placed. If the spall is close to the joints, preformed cellular polystyrene in the joint to a depth equal that of repair area is installed. Traffic will be permitted on patch areas that have been saw cut for a maximum of 48 hours.

For PCC patching, if only one lane is patched, a full-depth saw cut in the existing longitudinal joint for the full length of the patch is made. Concrete can be removed with air hammer or hand tools. The concrete in patch area can be entirely lifted or in pieces, however, the sub-base should not be disturbed, otherwise it has to be re-compacted.

For crack repair having an opening of 1/16 in or wider, it is first sawed and ground to open it to ¾ in wide and 1 in deep. Then it is flushed with water. Sealing will be done in a different day. Prior to sealing the opening is cleaned with compressed air and sealant is then placed.

4. Colorado Department of Transportation

CDOT uses Class E concrete for rapid concrete repairs which is standard concrete pavement with an accelerating admixture. Concrete class E requires a 28-day compressive strength of 4200 psi with 4-8% air content, and 0.44 water to cement ratio. This type of concrete is used for fast track repairing. Type III cement is used for high early strength along with at least 10% of pozzolans. Laboratory trial shall exhibit a 28-day flexural strength of 650 psi. CDOT doesn't offer specific type of accelerating material and requires it to conform to the requirements of AASHTO M 194.

5. Utah Department of Transportation

For partial depth repairs, UDOT allows to use Portland cement concrete according to Section 03055 of UDOT specifications (which refers to AASHTO) or use patching products after the project engineer's approval. Usage of accelerators along with concrete is referred to AASHTO M

194. UDOT classifies Portland cement concrete and its requirements as in Table 5. For concrete pavements, according to Section 02752, type AA shall be used.

For full depth repair, it is allowed to use water reducers such as plasticizer or accelerators.

UDOT in Technical Bulletin MT-04.05 discusses how to use fast repair materials. With a certain class of concrete there would not need using epoxy or other bonding agents and more than 3300 psi can be reached in 1-4 hours. The advantages are the environmental friendliness of the material and the minimized closure time. The fast setting patching material for partial and full depth repair are different. They are not entirely Portland Concrete Cement but consist of cement, aggregate, polymer, and resins. They come under different commercial names such as PaveMend, TechCrete, Degussa's "4 X 4 Concrete", and Caltrans' "SSP 40-020".

Table 5. Classification of PCC by UDOT

Class	Max. Water/ Cementitious Ratio	Min. Cementitious Content (lb/yd^3)	Max. Slump (Inch)	Air Content Percent (%)*	Mix Design Compressive Strength f'_{cr} (Psi)	28 Day Minimum Compressive Strength f'_c (Psi) **
AA(AE)	0.44	564	3.5	4.0 - 7.0	5,200	4,000
	0.44	564	3.5	4.5 - 7.5	5,200	4,000
	0.44	611	3.5	5.0 - 7.5	5,200	4,000
	0.44	611	3.5	5.0 - 7.5	5,200	4,000
A(AE)	0.53	470	3.5	4.5 - 7.5	3,900	3,000
	0.53	470	3.5	4.5 - 7.5	3,900	3,000
	0.48	517	3.5	4.5 - 7.5	3,900	3,000
B or B(AE)	0.62	376	5	-- 3.0 - 6.0	3,250	2,500

In partial repairs, the spall area is saw-cut in square or circular shape at least 2 in beyond the spall or 6 in beyond the failed area and at a minimum depth of 2 in. Using a jackhammer the concrete is removed and the area is cleaned by sand-blasting or water-blasting. For bonding purposes, grout or epoxy is first applied. Then the patching material is placed and finished to 1/8 in of the existing pavement.

In full depth repair, the area is first saw cut and the removed pieces are removed by the lift-out method. Disturbance of base material has to be minimized. Then the dowels and bars are placed. For bar installation, the slab is horizontally drilled and the bar is cleaned and greased. Then epoxy resin is injected into the back of the hole and eventually concrete is placed. The pavement is not open to traffic until it reaches 4000 psi verified by:

- Maturity Method – (AASHTO T 325).
- Cast cylinders

According to Technical Bulletin MT-04.05, when rapid setting materials are used for partial depth repair, a minimum of 8 in depth must be used. Similar to above mentioned procedures, the failed area is removed by saw cutting and it is air-blown or water-blasted. If water blasted it must be allowed to dry for about 15 minutes. The patching material must be applied at 40°F or above.

6. Michigan Department of Transportation

MDOT requires using concrete type P1, P1M or P-MS, P-NC according to its classification. Different grads of MDOT qualified concretes are shown in Table 6. The concrete minimum required flexural strength would be 300 psi for grade P-NC if it opens in less than 72 hours to traffic and 550 psi for grade P1 and P1M if it opens in more than 3 days to traffic. For rapid setting, non-chloride set accelerating admixture, Type C or Type E, from the Qualified Products List, with the required cement content to achieve the flexural strength of 300 psi by the required opening-to-traffic time may be used. Some of the approved trade names listed in QPL are presented in Table 7.

Table 6. Grades of concrete required by MDOT.

Concrete Grade (b, c, g)	Section Number Reference (i)	Cement Content (d,h)		Minimum Class Design Strength (a)							
				Flexural Strength (psi)				Compressive Strength (psi)			
		lb/cyd	Sacks	3 days	7 days	14days	28days	3days	7days	14 days	28days
P-NC	603. 801	658	7.0	550	600	-	650	2,600	3,000	-	3,500
P1M (f)	602. 603	470-564	5.0 – 6.0	-	550	600	650	-	2,600	3,000	3,500
P1	602. 603 801. 802. 803. 810.	564	6.0	-	550	600	650	-	2,600	3,000	3,500
		526 (e)	5.6								
P2	602. 803. 804. 806. 808. 810. 813.814. 819	517	5.5	-	500	550	600	-	2,200	2,600	3,000
		489 (e)	5.2								
M	Commercial grade concrete containing 517 lb/cyd (5½ sacks/cyd) of cement. If substituting 1.0 lb. of fly ash for each pound of cement removed, the Contractor may reduce portland cement up to 20%, by weight.										
X	Unless otherwise specified, Grade X concrete contains at least 282 lb/cyd (3.0 sacks/cyd) of cement. If substituting 1.0 lb. of fly ash for each pound of cement removed, the Contractor may reduce protland cement up to 20% by weight.										

Table 7. List of accelerators listed by MDOT QPL

Trade Name	Minimum Dosage (ml/100k)	Manufacturer
Catexol 2000 RHE	1300	AXIM CONCRETE TECHNOLOGIES, INC
Catexol CN-Cl (water reducer as well)	4890 - 9780	AXIM CONCRETE TECHNOLOGIES, INC
Pozzolith NC-534	650	BASF CONST. CHEM.
Pozzutec 20+	650	BASF CONST. CHEM.
Accelguard 80	1,175-2,085	EUCLID CHEMICAL CO.

Table 7. List of accelerators listed by MDOT QPL (continued)

Polychem Super Set	1045 - 2090	GENERAL RESOURCE TECHNOLOGY (GRT)
NitroCast K	650 – 5870	PREMIERE CONCRETE ADMIXTURES
RCI	520	RUSSTECH
SikaSet NC	650	SIKA CORP.

For patching joints and spalls, MDOT, similar to other DOTs, requires saw cutting and removing the failed area and cleaning it first (Section 602). For patching transverse joints, it classifies the spalls into minor, intermediate, and major spalls. In minor spalls, it is patched with a Department-approved epoxy mortar before installing the joint seal. After removing the failed area, it has to be sand blasted or power wire brushed. Then it is cleaned with compressed air. For concrete surfaces below 32 °F, it has to be heated to defrost the concrete. Type I epoxy binder for temperatures from 60 °F to 104 °F and Type II epoxy binder for temperatures from 36 °F to 60 °F are used. Before placing the epoxy mortar, first a thin layer of fresh epoxy binder is applied on the surface.

Intermediate spalls are larger than 36 in^2 and do not exceed either of the following:

- Extend below the reinforcement in reinforced pavement; or
- Greater than 4 inches deep in non-reinforced pavement.

To repair intermediate spalls, the area is first saw cut parallel to joints at least 1 in deep then the concrete is chipped out and the area is sand-blasted and blown with compressed air. After that, the area is flushed with water and the water is removed by compressed air. Then a rigid polyethylene sheet, or other rigid material, covered with polyethylene film, is inserted into the joint groove to hold tightly against the joint face being patched. Bottom and face of the repair area are primed with Type R-1 grout with a creamy consistency. A type R-2 mortar with a stiff consistency is tamped into the primed repair area. A liquid air-entraining admixture to maintain an air content from 8 percent to 11 percent is added.

Section 602 of MDOT Specification does not give any specific procedure for major spalls rather it calls for following the project engineer's instructions.

To install dowels and ties in transverse joints, the holes are drilled then cleaned by compressed air and grouted by the grout listed in QPL. Then the bar is slowly inserted into the hole.

For joint sealing after repairing process, they are re-sawed to produce freshly sawed finish surface and cleaned by water flush, and to create a cut of 1:1 width to depth ratio for hot poured sealant. Backer rod is then inserted.

Cracks are also sealed with hot poured sealants. Cracks from 1/2 inch to 5/8 inch deep and from 3/8 inch to 1/2 inch wide are saw cut. For deeper crackers backer rod is used. After sawing, hand tools or a lightweight chipping hammer are sued to remove slivers of concrete, less than 1 inch wide, along the crack. Immediately before sealing, both faces of the sawed crack are blasted with dry abrasive to remove contamination and texture the faces. After dry abrasive blasting, the crack is cleaned with compressed air. Then the cracked is sealed with hot poured sealant.

7. North Carolina Department of Transportation

NCDOT requires the material used for partial depth repair meets the following requirements:

Table 8. Material requirements of partial depth repairs at NCDOT

% water by weight			7.9-8.0
Flow @ 5 *drops*			100
Setting time (ASTM C 266 @ 72ºF Initial: Final:			 14 to 75 minutes 20 to 90 minutes
Compressive Strength, psi (ASTM C 109)			
			70 ºF
2 hours			1500
24 hours			4500
7 days			8000
28 days			9000
	1 day psi	7 days psi	28 days psi
Flexural Strength (ASTM C 348)	580-850	880-1000	1100-1150
Splitting Tensile (ASTM C 496)	550-850	1100-1200	1250-1300
Slant Shear Bond (ASTM C 882)	1800-2500	2900-3000	3100-3360
Direct Shear Bond (Michigan DOT)	150-200	350-390	375-450
Direct Tensile Bond (ChemRex, Inc. Method	100-150	170-190	290-300
Modulus of Elasticity (psi X 10^6)	3.8		4.7-5.1
Abrasion resistance, inches of wear (ASTM C 779A, 28 day, air cured sample) 30 minutes 60 minutes			 0.0110 inches 0.0260 inches
Freeze/thaw Resistance (ASTM C 666A)		Retain 98.3-98.5% of original dynamic modulus	

Table 8. Material requirements of partial depth repairs at NCDOT (continued)

Rapid Chloride Permeability[2] (AASHTO-T277/ ASTM C 1202)		960-990 coulombs (very low)
Scaling resistance (ASTM C 672)		
	Weight Loss lb./ft^2	
25 cycles	$CaCl_2$ 0.003	NaCl 0.067
50 cycles	$CaCl_2$ 0.005	NaCl 0.084

It also requires using elastomeric concrete for transverse joint repair due to concerns about wheel load. Its 14 day properties should meet the following requirements.

Table 9. Material requirements for joint repairs at NCDOT

Concrete Properties	Test Method	Minimum Requirement
Bond Strength to Concrete, psi	ASTM D 638 Ball Drop	450 7
Brittleness by impact, ft-lb.	ASTM D 695	2800
Compressive Strength, psi		
Binder Properties (with aggregate)	**Test Method**	**Minimum Requirement**
Tensile Strength, psi	ASTM D 638	800
Ultimate Elongation	ASTM D 638	150%
Tear Resistance, lb/in	ASTM D 624	90

For partial repair the following procedure is followed:

a. Survey the failed area, the boundaries of repair must be extended 4 in beyond the detected limits.
b. Remove the joint or crack sealant adjacent to the repair area.
c. The area is saw-cut to a minimum depth of 4 in. The repair area has to be rectangular.
d. Concrete is removed without damaging the underlying concrete or exposing the dowels.
e. Sound-test the newly exposed concrete to ensure that there is no delaminated concrete.
f. The area is sand blasted and blown by compressed air for cleaning from debris.
g. If the repair area is next to a joint, material flowing to the adjacent panel must be prevented by placing a compressible insert such as styrofoam, asphalt-impregnated fiberboard, or plastic joint inserts into the joint.
h. Apply bonding agent.
i. Place the patching material.

Panels with full depth cracking extending full length or width of the panel must be replaced with a new panel. Also, full-depth corner cracks must be repaired by replacement of the panel. The following procedure shall be followed for full-depth repair:

a. Define the boundaries. Repair boundaries must be full lane width and at least 6 ft long.

b. Saw cut the area. It should not take more than 2 days due to elimination of load transfer at the cuts.
c. The failed concrete is removed without damaging adjacent panels preferably by lift-out method.
d. After cleaning the area, the sub-base must be repaired if damaged.
e. Tie bars and dowels are installed as shown in Fig. 2.
f. Sandblast and clean the area.
g. Place the concrete and cure it by insulation.
h. Saw the joints within 7- 12 hours and reseal them.

Fig. 2. Installation of tie bars and dowels for load transfer

8. Nebraska Department of Transportation

Nebraska Department of Transportation classifies PCC pavement repairs into three groups: type A with an area of less than 5 yd^2, type B 5-15 yd^2, and type C with an area larger than 15 yd^2.

Repairs shall be made with Class PR1-2,900 or Class PR3-2,900 concrete when the repair work is done under traffic maintained conditions and Class 47B-2,900 when traffic is detoured. Classification of concrete is shown in Table 10. High early concrete (HE) will achieve a compressive strength of 3,625 psi at 48 hours after initial set. Type III Portland cement shall be used in Class PR 3 and 47B-PHE concrete. Type I and II Portland cement shall be used in all other classes of concrete. For curing of HE type concrete, ambient temperature has to be 70°F or higher otherwise it should be insulated by polyethylene film. Minimum time before opening to traffic based on ambient temperature and concrete class is shown in Table 11. A non-calcium chloride accelerator shall be used when the ambient temperature is 70°F or less. A list of approved accelerators (Type C admixture) is shown in Table 12.

Table 10. Classification of concrete by Nebraska Department of Transportation (the last four digits indicate strength in psi, HE: high early strength concrete).

	Cementitious Material (pounds per cubic yard)			
Class of Concrete (1), (6), (7)	Total Min.	Portland Cement Min.	Fly Ash Max.	Silica Fume Min.
47B-3,625	565	480	98	
47B-SG-2,900	565	480	98	
47BD-4,350	657	560	113	
47B-Special-3,625	612	519	106	
AX-3,625	657	560	113	
PR1-3,625	752	752	Exclude	
PR3-3,625	799	799	Exclude	
Overlay Concrete SF- 3,625	615	565	Exclude	51
Overlay Concrete HD- 3,625	823	823	Exclude	
47B-HE-3,625	565	565	Exclude	
47B-P-3,625 & 47B-PHE-3,625	657 to 705	560 to 598	113 to 121	

Table 11. Minimum time before opening to traffic based on concrete grade and ambient temperature.

Time Until Traffic Allowed (Class PR1-3,625, PR3-3,625)	
Minimum Ambient Air Temperature (Degrees Fahrenheit)	Minimum Time Before Opening (Hours)
Below 41	12
41-60	8
Above 60	4
Time Until Traffic Allowed (Class 47B-3,625)	
Minimum Ambient Air Temperature (Degrees Fahrenheit)	Minimum Time Before Opening (Hours)
Below 41	120
41-60	72
Above 60	48

Table 12. List of accelerators suggested by Nebraska Department of Transportation.

		Mfg. Recommended Dosage		
PRODUCT	TYPE	Per 100 lbs Cement	MANUFACTURER	
Catexol 2000 RHE	C	10-20 fl oz.	Axim	
Accelguard NCA	C	12-75 fl oz.	Euclid Chemical Co.	
Accelguard 80	C	16-32 fl oz.		
Accelguard 90	C	10-90 fl oz.		
NCA	C	1-3 bags per Cubic yard	Fritz-Pak	
Polychem Super Set	C	8-32 fl oz.	General Resource Technology	
Pozzolith NC 534	C	10-45 fl oz.	BASF Admixtures, Inc.	
Pozzutec 20+	C	5-60 oz.		
Plastocrete 161 FL	C	5-64 fl oz.	Sika Corp.	
Sika Rapid- 1	C	8-48 fl oz.		
SikaSet NC	C	10-45 fl oz.		
SikaSet R.H.E.	C	10-20 fl oz.		
Daraset 400	C	10-60 fl oz.	W.R. Grace	
PolarSet	C	8-60 fl oz.		

In general, if the length of the repair is 4’ to 9’, it is considered “Joint Repair”. If the repair is over 9’, then it is called “Pavement (Panel) Repair”. If the repair area extends across more than one panel, it will be counted as a separate repair. For full width panel repair, the repair area width has to be at least 6.5 ft and for partial-depth repair, it has to be at least 3 in deep.

In cold weather following insulators are used:

- 3 layers of Burlene.
- 1 layer of Fast Track Blankets.
- 1 layer of 12 mm (1/2 inch) extruded polystyrene.
- 2 layers of 6 mm (1/4 inch) air celled polyethylene.
- 1 layer of 12 mm (1/2 inch) air celled polyethylene

In full depth repair, to prevent settlement of the repaired part, the transverse edges are beveled to wedge the patch or are connected to the panel by dowels. However, the longitudinal edge will be vertical and may have tie bars. Like other states’ specifications, after full-depth repair, the joints must be saw-cut. However, Nebraska DOT requires this to be done as soon as possible, especially when high early strength concrete is used because it develops shrinkage cracks toward the joints and this would be minimized by saw-cutting.

For partial depth repair, the area is cut into a minimum depth of 2 inches, and then the concrete is removed by pneumatic tools. For full depth repairs, drop hammer can be used. For partial depth repair, after removing and cleaning, the area is coated with grout for bonding.

9. Ohio Department of Transportation

ODOT similar to other DOTs requires the following materials for PCC pavement repair:

- Portland cement

- Aggregates
- Curing materials
- Grout
- Air entraining admixtures
- Quick setting concrete mortar

ODOT classifies concrete materials as shown in Table 13. For full depth repair Class QC 1, QC MS, QC FS shall be used. However, these classes are not used for rapid setting repair materials in full depth repair. In such case, concrete mix is designed following the 4X4 concrete material, rapid 1, or other manufactured materials acceptable to the Director. For rapid setting concrete design, the contractor tests 6 in by 6 in beam specimens and they have to reach at 400 psi flexural strength between 4 and 6 hours.

Table 13. Classification of concrete materials by ODOT.

Quantities per Cubic Yard Provide Concrete with 6 +/- 2% Air Content				
Class	Design Strength psi (Mpa)	Permeability [1] Maximum (Coulombs)	Cementitious Content Minimum. lbs (kg)	Aggregate Requirements
QC 1	4,000 (28.0) at 28 days	2,000	520 (236)	Well- Graded
QC 2	4,500 (31.0) at 28 days	1,500	520 (236)	Well- Graded
QC 3 Special	As per plan	1,500 or as per plan	520 (236) or as per plan	Well- Graded
QC 4 Mass Concrete	As per plan [3]	2,000 or as per plan	470 (213) [4] [5] or as per plan	Well- Graded
QC MS [7]	See Supplement 1126	N/A	800 [7] (475)	1 inch nominal maximum size
QC FS [7]	See Supplement 1126	N/A	900 [7] (534)	1 inch nominal maximum size
QC Misc [6]	4,000 (28.0) at 28 days	N/A	550 [8] (233)	1 inch nominal maximum size

Patching material are divided into three groups: Type A, B, and C. Type A consists of one part high early strength Portland cement, one and half part fine aggregates, and one and half part No. 8 coarse aggregates. Sufficient air entraining agent must be added to maintain air content at 8% $\pm 2\%$. Type B consists of quick setting concrete mortar after adding sufficient amount of coarse aggregates. Type C consists of quick setting mortar type 2 and selected aggregates with an

activator. ODOT requires curing type A patch until reaching 400 psi before opening to traffic. For type B and C it requires to follow manufacturer's recommendations. Quick setting mortar has to meet the requirements shown in Table 14.

Table 14. Requirements for quick setting mortar (after Ohio Department of Transportation).

Test		**Type 1**	**Type 2**
Compressive Strength ASTM C 109 [2]			
psi (MPa)	@ 1 Hour	100 (0.7)	2000 (14)
	@ 3 Hour	250 (1.7)	---
	@ 24 Hours	2000 (14)	5000 (34)
	@ 7 Days	---	7000 (48)
Compressive Strength ASTM C 39 [1] [2]			
psi (MPa)	@ 1 Hour	100 (0.7)	2000 (14)
	@ 3 Hour	150 (1.0)	---
	@ 24 Hours	1000 (10)	3500 (24)
	@ 7 Days	---	6000 (41)
Initial Set Time (min) ASTM C 266 [2]		5 Minutes	10 Minutes
Bond Strength, ASTM C 882 [1]			
psi (MPa)	@ 24 Hours	1000 (7)	1000 (7)
	@ 7 Days	1500 (11)	1500 (11)
Flexural Strength, ASTM C 78 [1]			
psi (MPa)	@ 4 Hour	---	200 (1.4)
	@ 3 Day	650 (4.5)	500 (3.4)
Freeze and Thaw ASTM C 666 (use either Procedure B or A) [1]			
Procedure B (350 Cycles)			
Durability Factor		80%	80%
Procedure A (300 Cycles)			
Durability Factor		79%	79%

A list of the quick setting admixtures listed in ODOT QPL is presented in the following table.

Table 15. List of quick setting admixtures recommended by ODOT

Product Name	TYPE	Company
EMACO T415	1	BASF BUILDING SYS/MN
10-60 RAPID MORTAR	2	BASF BUILDING SYS/MN
SET 45 HW	2	BASF BUILDING SYS/OH
SET 45	2	BASF BUILDING SYS/OH
PAVEMEND SL	1	CERATECH INC/MD
CHEMSPEED 55	1	CHEMMASTERS/MADISON
CHEMSPEED 65	2	CHEMMASTERS/MADISON

Table 15. List of quick setting admixtures recommended by ODOT (continued)

RAPID SET DOT REPAIR MIX	1	CTS CEM-RAPID SET/CA
EUCO-SPEED MP	2	EUCLID CHEMICAL CO
SPEEDCRETE RED	1	EUCLID CHEMICAL/IL
SPEEDCRETE GREEN	1	EUCLID CHEMICAL/IL
SPEEDCRETE 2028	2	EUCLID CHEMICAL/IL
FAST SET DOT MIX	1	QUIKRETE/GA
RAPID HARDENING SAND	1	
RAPID ROADUNFIBERED	2	
FAST SET DOT MIX	2	
RAPID ROAD REPAIR	2	
SIKAQUICK 2500	2	SIKA-LYNDHURST NJ

For full depth repair, ODOT procedure is similar to other DOT specifications. Similarly it required lift-out method to remove the saw-cut concrete. For dowel and tie bar installation, it needs to use a grout retention disc to retain the grout inside the hole. Concrete has to be placed after the grout dries. The dowel bars must be coated with bonding materials. When rapid setting concrete is placed, maturity sensors must be installed (according to supplement 1098) to measure the maturity of each day's placement. For rapid setting concrete, it will be open to traffic after it attains 400 psi modulus of rupture based on maturity testing.

In patch or partial depth repair, ODOT allows using jackhammer or milling machine (Fig. 3) to remove the delaminated concrete. The patch area has to be saw cut to a minimum depth of 1 inch. After concrete removal, the patch area has to be prepared by abrasive blasting. All the pieces are then removed by compressed air. For type "A" patch, grout must consist of equal parts, by volume, of Portland cement and sand and mixed with sufficient water to form stiff slurry. For type B and C manufacturer's recommendations must be followed. For type A, concrete mixture is placed while the bonding grout is still wet. It is slightly overfilled, vibrated, and strokes off the concrete. For type B and C the same procedure is followed for concrete placement unless the manufacturer specifies otherwise. Criterion for opening to traffic is the same as that for full-depth repairs.

Fig. 3. Concrete removal for patching using jackhammer (left) and milling machine (right).

ODOT specifications describe two more repair processes including grinding and dowel bar retrofitting. Grinding is to texture concrete surface longitudinally to eliminate joint and crack

faulting and to restore proper riding quality of the pavement surface (ITEM 257). Dowel bar retrofit consists of sawing slots across transverse cracks, cleaning, injecting caulking filler, placing a dowel in the slot, and filling the slot with a patching material. For patching, ASTM C928, R3 concrete material with final setting time of 25 minutes shall be used for dowel bar retrofit. The retrofitting procedure is as following:

a. Locate the cracks and cut a 2.5 in slot to the mid-depth parallel to the pavement centerline.
b. Clean the edge of the slots by approved blast methods to produce a rough surface.
c. Seal the cracks in the slot with silicone sealant.
d. Place a 0.5 in thick performed filler board.
e. Place 1.5 in diameter 18 in long dowel coated with bonding material. Place an expansion cap on each end of the dowels prior to installation. Use two chairs to firmly hold the dowel in slot.
f. Mix, place, and cure the patching material. It should be vibrated after placement.

10. Kansas Department of Transportation

KsDOT requires that fast setting cementitious materials comply with ASTM C198 and at the end of 300 freeze-thaw cycles, acceptable products must exhibit expansion of less than 0.10% and a calculated durability factor of 90.0% minimum. The fast setting materials are classified as Rapid Hardening (R1), Very Rapid Hardening (R2), or Ultra Rapid Hardening (R3). Additionally, for rapid hardening, Type III Portland cement is allowed to be used. Type I, IP, I(PM) IS, I(SM), or II are used for all other constructions. Type I, IP, II, or I/II cement may be used as high early strength concrete if strength and time requirements are met. KsDOT's prequalified rapid setting patching materials are listed in the following table.

Table 16. List of rapid setting patching material prequalified by KsDOT.

Product Name	Hardening Class	Company
BMT – EMACO T415	Very rapid	BASF Construction Chemicals, LLC
PavePatch Concentrate DBM	Ultra rapid	Conspec, a Dayton Superior Company
Rapid Set DOT Repair Mix	Ultra rapid	CTS Manufacturing Corporation
Highway DB Retrofit Mortar	Ultra rapid	Dayton Superior Corporation
PavePatch 3000	Ultra rapid	
Day-Chem Perma Patch	Very rapid	
HD-50	Ultra rapid	
Speed Crete 2028	Ultra rapid	Euclid Chemical Co
Commercial Grade	Ultra rapid	The Quikrete Companies
FastSet DOT Mix	Ultra rapid	
With Fibers	Ultra rapid	
RepCon 928	Ultra rapid	SpecChem
Transpo T-17	Very rapid	Transpo Industries, Inc.

Joints spalls which extend winder than ¼ in are repaired by hot type joint sealing compound. The ones wider than 1/2 in are repaired with epoxy patching material. If the spalls extend wider than 1 inch, the area has to be saw cut at least 1 in beyond the failed area and 2 in into depth. Concrete is chipped out by a chipping hammer lighter than 15 lb and then the area is cleaned and

the bonding epoxy is then applied. Portland cement concrete, epoxy resin concrete or mortar is placed immediately following application of the epoxy.

Any panel which is cracked from an edge to another must be fully replaced.

11. Indiana Department of Transportation

Repair material used in Indiana Department of Transportation includes Asphalt Binder for Crack Sealing PG 64-22, Asphalt Emulsion AE-90, AE-90S, AE-150, Dowel Bars, Fine Aggregates Size No. 23 or 24, Joint Sealing Materials, Rapid Setting Patch Materials.

Examples of rapid setting patching material: BASF CONSTRUCTION CHEMICALS, 10-61 Rapid mortar, BASF CONSTRUCTION CHEMICALS, SET 45 HW, U.S. GYPSUM CO DURACAL AG,

11.1 Joint Repair

Sealing and filling operations shall not be conducted on a wet surface, when the ambient temperature is below 40°F, or when other unsuitable conditions exist.

Joint is saw cut, cleaned and sealed. Transverse joints shall be sealed with silicone sealant or preformed elastomeric joint sealant. Longitudinal joints shall be sealed with hot poured joint sealant or silicone sealants. Joint is filled within ¼ in of surface using V shape wand tip.

11.2 Crack Sealing

Sealing and filling operations shall not be conducted on a wet surface, when the ambient temperature is below 40°F, or when other unsuitable conditions exist.

Cracks are routed and cleaned with a routing machine capable of cutting uniform shape of maximum ¾ wide and ¾ in deep. Then it is cleaned with compressed air. Water-blasting is not allowed. Cracks shall be sealed with hot poured joint sealant in accordance with the manufacturer's recommendations within 1/4 in. of the surface. a "V" shaped wand tip is used to allow penetration of sealant. After sealing cracks are filled with asphalt.

11.3 Partial Depth Repair

Saw cut to 1 to 3 in depth with hand chipping tools or hand held mechanical tools. Full lane is removed and the area is 6 in beyond the damaged area. If reinforcement is encountered, full depth is performed. If there is unsound concrete below 3 in, full depth is performed. The partial depth cavities shall be thoroughly sandblasted and, prior to placing new concrete, cleaned of all dust, chips, and water. The bonding agent and concrete shall be placed in accordance with the bonding agent manufacturer's recommendations.

The milled area shall be filled with HMA partial depth patching. After patching it will be compacted with a vibratory roller of at least 4 passes.

11.4 Full Depth Repair

The saw cut shall be full lane width and thickness of the PCCP. After the full depth saw cut is completed, vehicles mounted with a removal 190 equipment may be used to remove the concrete provided this equipment does not damage the adjacent sound concrete. Removal areas in the same lane which are closer than 10 ft shall require the PCCP between these areas to be removed and replaced. If a transverse joint is located within the removal area, the limits of

removal shall be increased to a minimum of 1 ft beyond the joint. Patches shall be anchored to the existing panel with dowel bars.

Table 17. Curing temperature and time to open for traffic adopted in Indiana DOT

T	H	HT	T	H	HT
40 - 42°F	30	26	61 - 63°F	14	9
43 - 45°F	27	23	64 - 66°F	14	9
46 - 48°F	24	21	67 - 69°F	14	8
49 - 51°F	21	19	70 - 72°F	14	7
52 - 54°F	19	16	73 - 75°F	14	6
55 - 57°F	16	14	above 75°F	14	5
58 - 60°F	16	11			
T = Lowest ambient temperature during placement, or the temperature of concrete at time of deliver, whichever is lower H = Time in ours to open to traffic HT = Time in hours to open to traffic when the average daily traffic is less than 10,000					

Concrete with calcium chloride can be opened to traffic sooner than the indicted time above if it reaches a modulus of ruptures over 300 psi.

11.5 Slab Stabilization

Indiana DOT uses utility asphalt, UA-II or UA-III for undersealing.

Where there is transverse joints, hole diameter should not exceed 1.5 in. and it shall be drilled in the centerline. They shall be located longitudinally between transverse joints or cracks at approximately 30 to 36 in. from the joints or cracks. Asphalt shall be pumped by a metallic hose and the hole is plugged with wood plug after completion. No material shall be applied on a frozen subgrade when the atmospheric temperature is 40°F or lower and falling.

Utility asphalt is classified in Table 18.

Table 18. Utility asphalt adopted in Indiana DOT for slab stabilization

Characteristics/Grades	UA-I	UA-II	UA-IIII
Softening Point (Ring & Ball), °C (°F)	46-63 (114-145)	63-85 (145-185)	79.5-96 (175-205)
Penetration of Original Samples[1] (0.1 mm (0.004 in)) at 4°C (39°F), 200 g (0.44 lb), 60 s, min. at 25°C (77°F), 100 g (0.22 lb), 5 s at 46°C (115°F), 50 g (0.11 lb), 5s	 10 (0.4 in) 50-100 (2-4 in) 100 min. (4 in)	 10 (0.4 in) 25-45 (1-2 in) 130 max. (5.1 in)	 10 (0.4 in) 15-35 (0.6-1.4 in) 90 max. (3.5 in)
Ductility@25°C (77°F), 50 mm/min (2 in/min), 10 mm (0.4 in), min.[1]	30	10	2.5
Solubility in Organic Solvents, % min.[1]	99.0	99.0	99.0
Flash Point (Cleveland Open Cup), °C (°F), min.[1]	225 (437)	225 (437)	225 (437)
Penetration of Residue from Thin Film Oven Test, 25°C (77°F), 100 g (0.22 lb), 5 s, (0.1mm (0.004 in)) min.[1]	30 (1.2 in)	15 (0.6 in)	10 (0.4 in)
[2] Test will be performed when complete physical characteristics are needed or desired.			

12. Minnesota Department of Transportation

Repair Types:

1- Type A repairs consist of joint or crack resealing. These repairs include sawing or routing to prepare the concrete joint or crack faces for adhesion of the sealer and to provide the proper shape factor. Joints wider than 1 inch may increase noise by tires slapping the joints, depending on traffic speed.

2- Type B repairs generally consist of partial depth milling or chipping to remove deteriorated or delaminated concrete and preparation and placement of the repair. Type SA-BE repairs include removal to the bottom of the pavement if necessary.

3- Type SA-C repairs consist of full depth removal of the concrete at joints or cracks and preparation and placement of the repair. The Type SA-CX repair is used in conjunction with either a Type SA-CA or a Type SA-CD repair if removal is required beyond the required 3'-6'' length along centerline.

Generally eight grades of concrete are provided by MNDOT. The basis of this classification is the relative strength and general quality, as governed by the cement-voids (C/V) ratio law. All concrete is classified by type, grade, mix designation, and coarse aggregate designation. For example in Grade 3A32, '3' is the type of concrete, 'A' is the grade of concrete, the second '3' is the upper slump limit, and '2' designates the gradation curve range.

12.1 Joint Repair

For joint repair hot-poured sealant is used. Sealing of joints wider than 1-1/4 inch is not recommended. Saw the existing joint 1/8 inch wider than the existing joint.

There are three designated joint repairs:

- SA-A1: This work shall consist of cleaning and sawing transverse contraction joints or longitudinal joints to the specified width. In preparation for resealing with hot pour sealant, remove the in-place seal, saw both faces and flush with water then clean and dry the joint by sandblasting and air blasting. Place the backer and fill with hot poured sealant. Do not use backer for longitudinal joints (Figure 4).

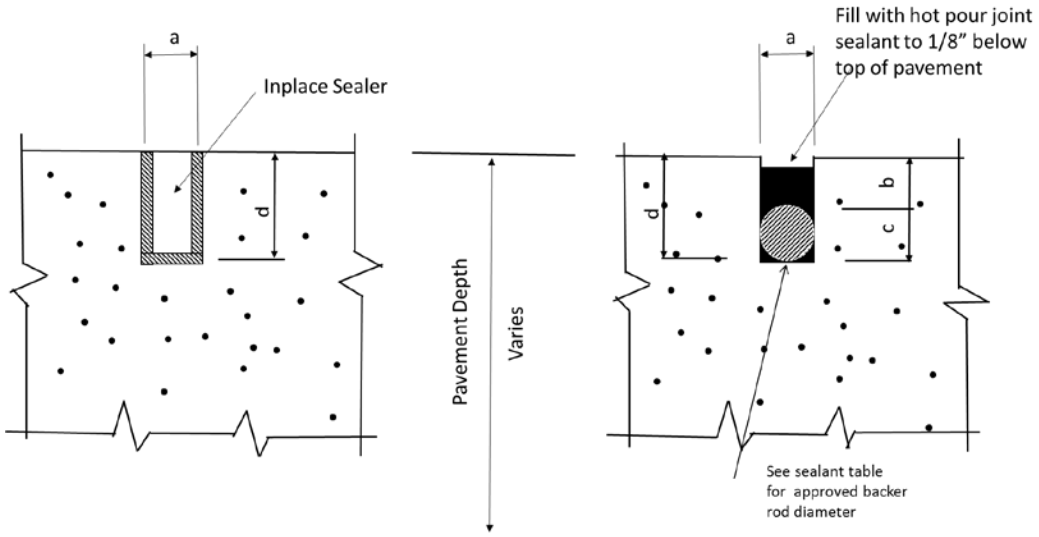


Figure 4. SA-A1 joint repairs

- SA-A2: This repair is used for the cleaning and filling of transverse contraction joints or longitudinal joints without sawing the joint face. Removal of the existing joint seal material from the joints can be accomplished with ripping teeth, wire brush, sawing or other reasonable equipment to the satisfaction of the engineer. However, the contractor shall not use equipment that will cause spall of the pavement surface beyond the limits of the existing joint width. Process of repair for this repair type is the same as SA-A1 (Figure 5).

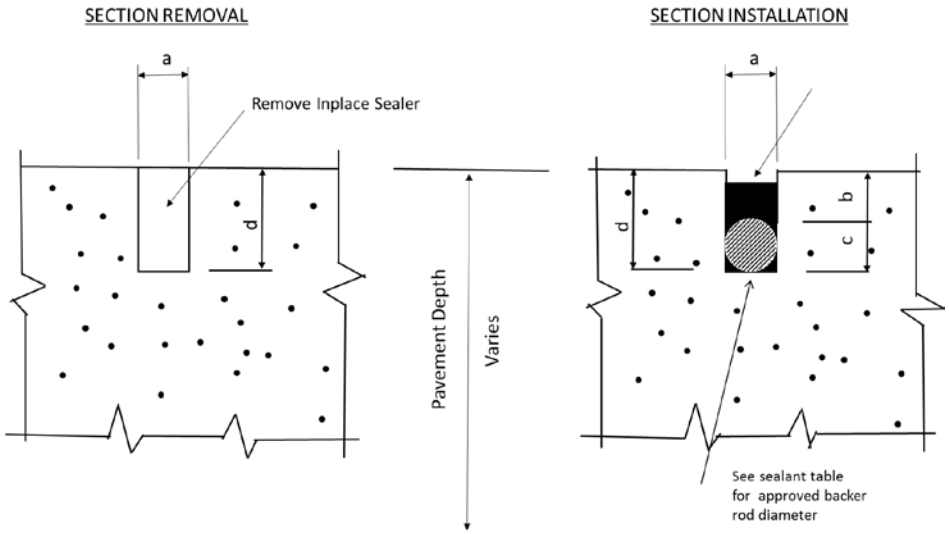


Figure 5. SA-A2 joint repairs

12.2 Crack Sealing

For crack repair hot-poured sealant is used. The intent of this repair is to saw and seal cracks, or those portions of cracks, between ¼ inch and 1 inch wide with hot pour sealant. For cracks

wider than 1 inch it is recommended that a Partial Depth Repair Type SA-BA be performed to make a narrower crack width. Backer is used when crack width is greater than ¼ in (Figure 6).

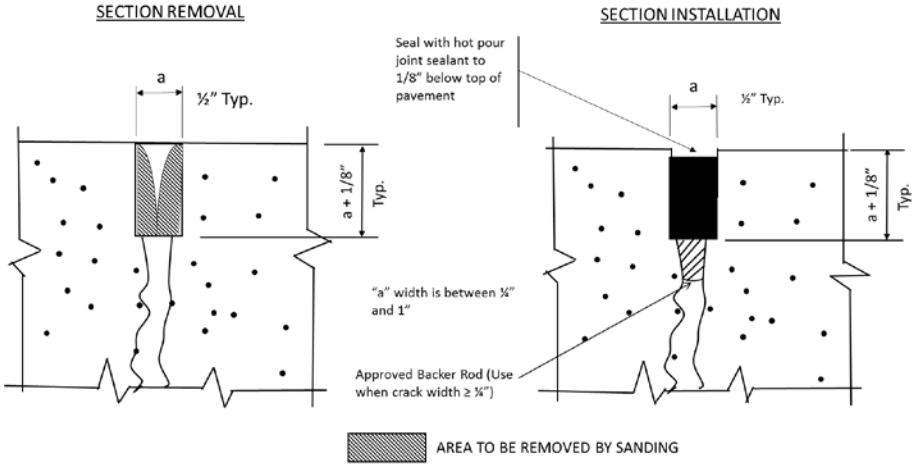


Figure 6. SA-BA crack sealing

12.3 Partial Depth Repair

When no early opening time is required, use standard concrete mixes of Grade 3U18 for Type SA-B partial depth repairs. Bonding grout is used before placing the designated grade of concrete, which consists of 2 part cement and 1 part sand mixed with sufficient amount of water. Table 19 is used for early opening.

Table 19. List of materials used in partial depth patching at MnDOT

Repair Type	Concrete Mix Grade	Minimum Time to Opening (hours)[1]	Admixture Dosage 2 & Type/Curing Requirement
Type SA-B	3U18	24	Maximum Type A
Type SA-B	3U18	12	40% of Maximum Type E
Type SA-C	3A32HE	24	Maximum Type A
Type SA-C	3U27, 3U28	12	40% of Maximum Type E[3]
Type SA-C	3A32HE	12	40% of Maximum Type E[3]/Use curing blankets and insulatoin[4]
Type SA-CX (Less than 50’ long)	3U27, 3U28	24	25% of Maximum Type E[3]
Type SA-CX (Less than 50’ long)	3A32HE	72	Maximum Type A[5]
Type SA-CX (From 50’ to 200’ long)	3A32HE	72	Maximum Type A[5]
Type SA-CX (From 50’ to 200’ long)	3A32HE	6	[5, 6]

Table 19. List of materials used in partial depth patching at MnDOT (continued)

Type SA-CX (More than 200’ long)	3A32	6	[5, 6]
Type SA-CX (More than 200’ long)	3A41	6	[5, 6]
Type SA-CX (More than 200’ long)	3A32HE	6	[5, 6]

List of rapid setting materials used in MnDOT is shown in Table 20.

Table 20. List of rapid setting materials used in MnDOT

Rapid Patch concrete Surface Repair	Akona Manufacturing LLC
Ardex TRM	Ardex Engineered Cements
10-60 Rapid Mortar	BASF Construction Chemical
10-61 Rapid Mortar	BASF Construction Chemical
Set 45 HW	BASF Construction Chemical
Rapid Patch – VR	Bonsal
Fast Set Cement Mix	Bonsal
Fast Patch 928	Burke
Pavement SL	CERATECH Incorporated
DOTLine	CERATECH Incorporated
MainLine	CERATECH Incorporated
Tectonite	CFB
Pave Patch 3000	Dayton Superior
Rapid Set Cement All	CTS Cement Manufacturing
Rapid Set Mortar Mix	CTS Cement Manufacturing
Rapid Set Concrete Mix	CTS Cement Manufacturing
Rapid Set DOT Repair Mix	CTS Cement Manufacturing
Re-Crete 20 Minute Set	Dayton Superior
Five Star Highway Patch	Five Star Products
SikaQuick 1000	Sika Corporation
SikaQuick 2500	Sika Corporation
Sikacrete 321FS	Sika Corporation
Rep Con 928	SpecChem
Highway Patch 928	Specco Industries Inc.
Speccopatch RS	Specco Industries Inc.
Speed Crete 2028	Tamms Industries
Speed Crete Greenline	Tamms Industries
Speed Crete Express Repair	Tamms Industries
Uni Road Repair DOT	Universal Form Clamp
Polypatch	US Mix Products
Transpatch	US Mix Products
Transpatch Concrete	US Mix Products
Polypatch FR	US Mix Products
Futura	W.R. Meadows

The repair is a shallow 2-inch through 4-inch deep spot surface repair. The repair may be along a joint or crack, or at any location within a panel. This work shall consist of removing deteriorated concrete at designated Type SA-BA repair areas, furnishing, placing, and curing grade 3U18 concrete to the original slope and grade and reestablishing joints or cracks.
Jackhammer is not allowed to be used in this type of repairs.

Compression relief material shall be installed at the time of placement of concrete to re-establish joints and cracks at their original locations

12.4 Full Depth Repair

When no early opening time is required, standard concrete mixes of Grade 3A32 or 3A41 for full depth repairs are used. Table 21 lists all the materials used for early opening.

Table 21. List of rapid setting materials used for full depth repairs at MnDOT

Repair Type	Concrete Mix Grade	Minimum Time to Opening (hours)[1]	Admixture Dosage 2 & Type/Curing Requirement
Type SA-B	3U18	24	Maximum Type A
Type SA-B	3U18	12	40% of Maximum Type E
Type SA-C	3A32HE	24	Maximum Type A
Type SA-C	3U27, 3U28	12	40% of Maximum Type E[3]
Type SA-C	3A32HE	12	40% of Maximum Type E[3]/Use curing blankets and insulatoin[4]
Type SA-CX (Less than 50’ long)	3U27, 3U28	24	25% of Maximum Type E[3]
Type SA-CX (Less than 50’ long)	3A32HE	72	Maximum Type A[5]
Type SA-CX (From 50’ to 200’ long)	3A32HE	72	Maximum Type A[5]
Type SA-CX (From 50’ to 200’ long)	3A32HE	6	[5, 6]
Type SA-CX (More than 200’ long)	3A32	6	[5, 6]
Type SA-CX (More than 200’ long)	3A41	6	[5, 6]
Type SA-CX (More than 200’ long)	3A32HE	6	[5, 6]

12.5 Slab Stabilization

A variety of materials have been successfully used for slab jacking. These materials range from cement/fly ash grouts to expansive polyurethane foam. Polyurethane materials are more costly but are considered more durable, and must be applied using properly trained personnel. Pozzolan and fly ash based grouts generally consist of three to seven parts fine aggregates or a

mixture of aggregate and pozzolans or fly ash to one part Portland cement with enough water to produce the desired consistency.

As a general rule, holes should not be placed less than 12 in. or more than 18 in. from a transverse joint or slab edge**.** Holes that are 1.25 to 2.0 in. in diameter are drilled by pneumatic drills, core drills, or other devices which are capable of drilling grout injection holes through the concrete pavement and the base material. The pressure should not exceed 200 psi.

13. South Dakota Department of Transportation

13.1 Joint Repair

Silicone or hot poured sealant and backer are used as joint repair materials. SDDOT suggests taking samples from silicone after curing for acceptance. SDDOT does not allow seal removal after OCT. 15th or at temperature below 40^{o}F.

Prior to placing the patch, the joint shall be formed to a width less than the final opening. The area shall be chipped to a uniform depth, to facilitate forming to the depth of removal or depth of dowel bars, whichever is less. Joints that are open at time of pouring due to thermal contraction shall be formed to the full repair depth. Forming material shall be one unit for the length of the spall repair area.

For joint sealing, the joint is first sandblasted and then sealant is poured. Backer road must be 25% larger than the joint opening.

13.2 Crack Sealing

Hot-poured sealant materials or silicone depending on the field conditions are used for repair. Cracks wider than ¾ in cannot be repaired by this way. Initially the crack is sawed for routing.

13.3 Partial Depth Repair

For spall repair the applicable materials are: bonding mortar (cement +water+sand), concrete patch (type III cement shall be used), and epoxy resin. SDDOT does not allow spall repair after OCT. 15th or at temperature below 40^{o}F.

There are two types of spall: Type A and B. Type A is used for spall length over 0.2 ft and type B is used for spall length less 0.2 ft and over 0.06 ft. Silicone sealant is used for spalls of less than 0.06 ft.

Spall area will be chipped down to a minimum of 1.5 in with jackhammer or chipping hammer. The bottom of chipped areas shall be left rough to obtain a good bond between the patch and the old concrete. The area shall then be sandblasted, and cleaned using compressed air. If concrete below the dowel bar is removed, the dowel bar has to be removed too. A layer of bonding mortar shall be broom into and over the surfaces to be patched. Temperature of patching material has to be maintained above 40°F. The patch will be sprayed with curing material. Joint forming material will be removed after 72 hrs and will be saw cut.

In spall type B, saw cut and concrete removal will be conducted the same as that of type A. However, Epoxy resin without aggregates will be applied to the surface prior to patching. Form removal, joint sawing, and traffic over the patch area will not be permitted for eight hours after placement.

Grout is used for undersealing which consists of 1 part cement (type 1 or 2), 3 parts fly ash and enough water. 7-day strength shall reach 600 psi.

1.5 to 2 in holes shall be drilled. Subgrade penetration shall not exceed 3 inches. Holes may be washed to create a small cavity, allowing initial spread of grout. Upward movement of slab shall not exceed 0.125 in during grouting. Grouting continues until 60 psi pressure is built up. At the end, the holes shall be sealed with fast setting sand/cement mixture or other patch material

14. Wisconsin Department of Transportation

14.1 Joint Repair

For joint sealing, hot poured sealant is used which conforms to AASHTO Designation M 324.

Exposed joint faces shall be cleaned by sandblasting, or by water blasting with sufficient pressure to thoroughly and completely clean the joint. The hot sealant has to be ¼ in below the top of the joint after shrinkage.

15. New York Department of Transportation

15.1 Joint Repair

Crack and joint sealing consists of drilling holes and injecting hydrophobic urethane resin and appropriate additives. The resin shall be hydrophobic and it must react with water to cure and form either a flexible gel or elastomeric foam. Grout is used to seal the injection holes.

Similar to other states, injection holes are drilled first. Resin shall be continuously injected in any hole until it appears at adjacent holes or in the surrounding joints or cracks. In dry areas, water shall first be injected into the holes prior to grouting. Open joints or cracks may be temporarily sealed during the injection process with commercially available expanding foam insulation, epoxy or urethane based products. At the end, holes are sealed with mortar.

15.2 Crack Sealing

Crack sealing material is just like what discussed for joint repairs. For NYDOT, crack and joint sealing processes are similar.

15.3 Partial Depth Repair

Partial-depth repairs may be conducted with Class D concrete, High-Early-Strength Class D concrete, Concrete Repair Material, Rapid Hardening Concrete Repair Material (§701-09), Epoxy Resin Systems (§721-01), or Rapid Hardening Polymer Concrete (§721-20). Repair material selection is based on the time frame how long the work area is closed, repair sizes, and quantities of material required.

High Early Strength Concrete (HES) must reach at least 28-day strength of 4350 psi and 3000psi at the time open to traffic. To achieve rapid hardening only non-chloride accelerators are allowed. Rapid Hardening Polymer Concrete and Rapid Hardening Concrete must be one of the products presented in the approved list (Table 22).

Table 22. Approved list of patching materials in the State of New York

BRAND NAME	SHELF LIFE (MONTHS)	SUPPLIER AND PLANT LOCATION(s)
AHT Highway DB Retrofit Mortar[1]	12	American Highway Technology Kankakee, IL

Table 22. Approved list of patching materials in the State of New York (continued)

Alcrete Pipe Patch[1]	12	Allied Construction Supplies Corporation Dallas, TX
Cempatch[1]	12	Chesco Creative Products Downingtown, PA
Conpatch V/O[1]	6	Conspec Kansas City, KS
CONSET GROUT-NY[1]	12	ChemMasters Madison, OH
DOT PATCH HD	12	Symons Corporation Bethlehem, PA
EMACO T-415	12	BASF Corporation/Building Systems Streetsboro, OH
Euco Patch[1]	12	The Euclid Chemical Company Cleveland, OH
Euco Speed[1]	12	
Fastrak	12	L&M Construction Chemicals, Inc. Bayville, NJ
FX 929NY [1]	6	Fox Industries Baltimore, MD
FX 250	12	
HD 50	12	Dayton Superior Specialty Chemical Corporation Kansas City, KS
HiCap[1]	12	Kaufman Products, Inc. Baltimore, MD
Hy-Speed 500[1]	12	Garon Products Inc. Wall, NJ
MONO-PATCH	12	Bindan Corporation Oak Brook, IL
Permacrete[1]	12	National Permacrete Company Devon, PA
Pyrament® 505 Rapid Concrete Repair Material[1]	12	Pyrament Industries Division of Lonestar Houston, TX
Quickcem Top 202[1]	12	Mapei Laval, QC, Canada
Quick-Setting Cement #1240[1]	12	Quikrete Latrobe, PA

Table 22. Approved list of patching materials in the State of New York (continued)

Rapid Road Repair	9	Quikrete Stormville, NY
Rapid Set® Cement All™ Non-Shrink Multi-Purpose Grout Extra High Strength Mix[1]	12	CTS Cement Manufacturing Company Canaan, CT
Right Crete Speed Repair[1]	12	Right Pointe Company DeKalb, IL
Sika Set Roadway Patch[1]	12	Sika Chemical Corporation Lyndhurst, NJ
Speed Crete Green Line[1]	12	The Euclid Chemical Company Kirkland, IL
Speed Crete Red Line[1]	12	The Euclid Chemical Company Cleveland, OH Kirkland, IL
Tiger-Crete[1]	12	Garon Products Inc. Wall, NJ
Tyberpatch[1]	12	Tyber, Inc. Rocky River, OH
Unisorb Concrete Repair Compound[1]	9	Unisorb Machinery Installation Systems Jackson, MI

Partial depth patching is used for damages having an area greater than 5,000 mm^2 (7.75 in^2) with the shortest side at least 50 mm (2 in^2) long. Isolated smaller repairs may be repaired with epoxy resin materials. Partial-depth removal using the coring method is highly preferable. Saw cut is performed to at least 4 in deep using chipping hammer or combination for chipping hammer and milling machine. Portland Cement Mortar Bonding Grout is used as bonding agent if the repair material is Class D concrete or HES concrete. Class D concrete or HES will be immediately coated after placement with double coat of curing materials. If there is no opening time limitation in the contract, the pavement will be opened to traffic after 5 days. Otherwise, as mentioned earlier, it has to reach at 3000 psi in terms of compressive strength.

15.4 Full Depth Repair

HES concrete can be used as full depth patching material. Like other states, saw cut, clean, and removal of the damaged concrete are the procedures of full depth repairs. Similarly, lift-out method is preferred for removal. Dowels are anchored into the transverse faces that define the repair boundary and, if the repair is 2 or more slabs long, longitudinal joints ties are drilled and anchored into the longitudinal faces that define the repair boundary. In some cases, to enhance sub-base condition, the sub-base might be removed and replaced with suitable materials. In full depth repairs, dowels are used when transversal and longitudinal joints define the repair boundaries. The minimum repair length is the maximum slab width at any location divided by 1.5.

15.5 Slab Stabilization

Undersealing is performed by water blown high-density polyurethane foam material. It has to be hydro-insensitive to avoid the reaction to moist.

Undersealing must be performed when temperature is 35^{o}F and warmer. Up to 1 in diameter holes at 5 ft interval shall be drilled in the area to be raised. After injection is done, the hole shall be sealed with cement grout. The slab shall return to the indicated level in contract with a tolerance of ¼ in.

16. Washington Department of Transportation

16.1 Joint Repair

Joints and cracks are not allowed to be poured below 45^{o}F. Joints are sealed with approved sealing materials including hot poured joint sealant, poured rubber joint sealant, and joint mortar. Joint mortar consists of one part Portland cement and three part fine sand and enough amount of water.

Transverse and longitudinal joints repair process consists of removing all old sealant material with a diamond blade saw, cleaning the joint and sealing with an approved joint sealant material.

16.2 Crack Repair

Similar to joints, for crack repair poured joint sealant or poured rubber joint sealant shall be used.

Cracks must be routed out before pouring. They should be cleaned and dried with compressed air prior to pouring. Foam backer rod can be used in larger cracks to keep the sealant in the top 1 inch of the crack. The sealant materials must be placed ¼ in below the top of crack to avoid the noise due to traffic passing over the crack.

16.3 Partial Depth Repair

Patching material shall achieve 3000 psi at 3 hrs and 5000 psi at 24 hrs and a minimum of 1000 psi bond strength in 24 hours.

The damaged area has to be saw cut at least 2 in deep to reach at sound concrete. Jackhammer or chipping hammer shall be used and all power-driven hammers must be operated at 45 degree angle. The patch area shall extend 3 in beyond the damage area. Patches are square or rectangular. If patches are less than 12 in close, they have to be combined. After removing the damaged concrete the area must be sandblasted. Spall repair shall not be conducted in areas where dowel bars are encountered. If the repair area is adjacent to a joint, polyethylene film, roofing paper, or other bond breaking material will be used. Slab/patch interfaces that will not subject to surface grinding shall be sealed with a 1:1 cement-water grout along the patch perimeter. The pavement will open to traffic when the concrete reaches at 2500 psi strength.

16.4 Full Panel Replacement

Ready mix concrete is used for new panels and it has to reach at 650 psi in 14 days and 2500 psi before open to traffic. Patching material can also be used for panel replacement.

All saw cuts must be full depth. In order to prevent damage to adjacent slabs that are intact, a second full depth relief cut is required 12 to 18 in inside the panel in both the transverse and longitudinal directions. After removal, subgrade must be compacted, if it is not compactable,

geotextile or crushed surfacing base course will be placed. If new concrete pavement is to be placed against existing concrete pavement, epoxy coated dowel bars and tie bars shall be drilled and grouted into the existing concrete pavement.

17. Idaho Department of Transportation

17.1 Joint Repair

Joint sealer for asphalt and concrete pavements (ASTM D6690 Type II), hot poured elastomeric type concrete joint sealer (ASTM D3406), neoprene compression seal, and silicone sealant are the listed sealing materials in ITD (Idaho Department of Transportation). However, silicone and compression seals are preferred methods of sealing all concrete joints. Silicone joint filler is also needed. The joint is cleaned with routing or sandblasting. Power-driven rotary cutters remove old sealing material and foreign matter and simultaneously roughen the sidewalls of the joint to ensure a good bond with the new seal. The cleaning process must remove all the materials down to 3 in deep. After cleaning the joint must be allowed to dry and then cleaned by compressed air. Stiff fiber or steel brooms and bars shaped to fit the joint space must be placed into the joint. Sealant is poured up to a depth of 1/8 in.

17.2 Crack Repair

Only cracks wider than ¼ in are sealed because for narrower cracks sealant are not effective and they may be removed by passing vehicles. Crack is cleaned and sandblasted first. It is then blown by compressed air if there is any available. Power-driven rotary brushes can also be used to remove all dirt and other inert materials.

17.3 Partial Depth Repair

High early strength patching material is used to open early to traffic. ITD suggests three methods to produce high early strength patch: using low water to cement ratio, using high early-strength Portland cement (Types III or IIIA), or using plasticizer or water reducer chemical additive. Ready mix concrete can also be used for patching.

ITD classifies patches in the following figure (Figure 7). When a patch is at an expansion joint, the patch length is at least 6 ft but it is 12 ft if both sides of the joint need to be patched. Patches are rectangular in shape but diamond or triangular shape has shown good performance at slab corners which are not on the exterior edge of the pavement. ITD also recommends the following thickness depending on the slab (Table 23).

Table 23. Patch thickness recommended at Idaho DOT

Slab	Depth of patch
Thickened-edge slab	1.3 times center thickness of original slab on all patches involving unprotected corners 1.2 times center thickness of original slab on all patches not involving unprotected corners
Uniform-thickness slab with dowels or other load transfer devices at expansion joints	1.1 times original slab thickness for all patches involving unprotected corners
Uniform-thickness slab without load transfer devices at expansion joints	same depth as existing slab for all patches not involving unprotected corners

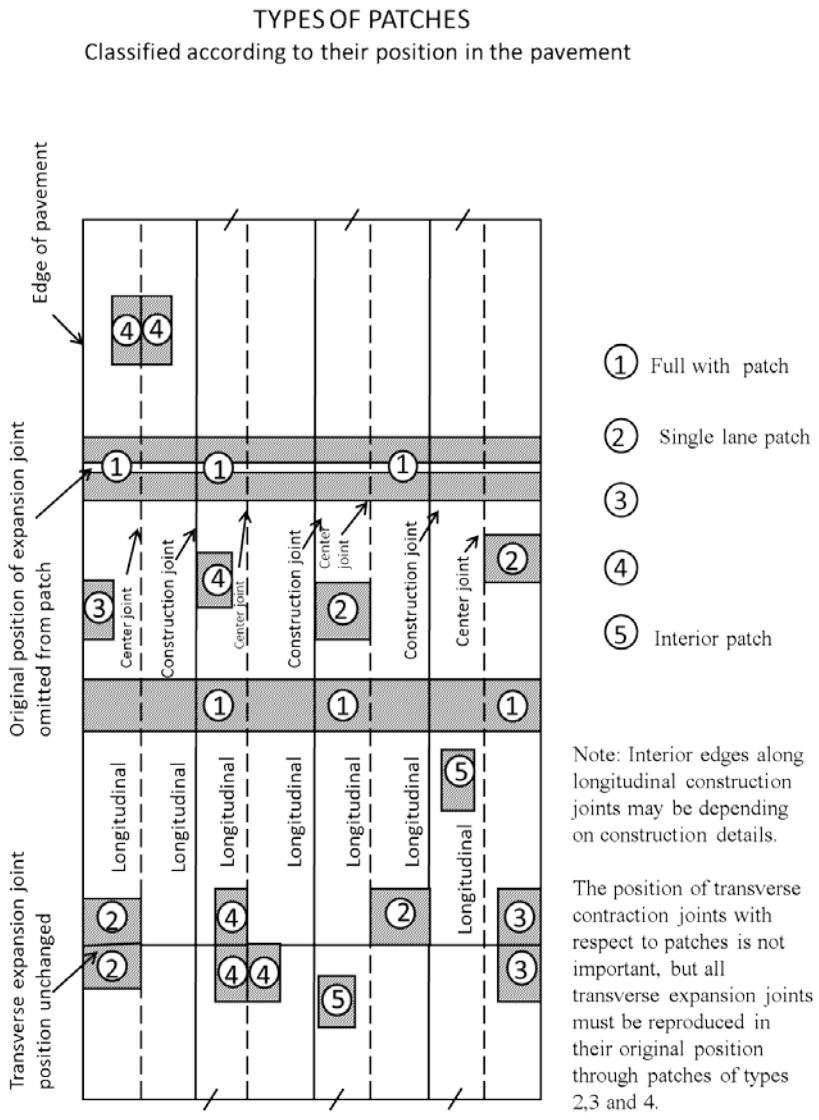


Figure 7. Type of patches used in Idaho Department of Transportation

The repair process consists of saw cutting to the depth of 1.5 to 2 in and removing the concrete. Usually, the edges of the patch below the saw cut are broken by using pneumatic chisels or drills. After that, the repair area is cleaned and patched. Before placing patch, the old concrete edges are dampened. The patch surface is sealed with thin concrete latex bonder. When concrete is first placed, it is struck-off and vibrated or tamped at an elevation slightly higher than the intended finished surface of the patch.

17.4 Full Depth Repair

Type III cement must be used with appropriate additives to provide 6% air content to produce the needed concrete. Accelerators can also be used to reduce curing time.

In full depth repair there are two options for load transfer. Option 1: #3 with 17 inch long rebar dowels is installed at the mid-depth of the adjacent concrete slabs 24 inches on center

around the entire patch. Dowels should be drilled and set to a depth of 8.5 inches into the existing slabs. No dowel is set in the area where expansion joint is an edge of the patch. Alternatively option 2: an area with depth of 8.5 in and width of 12 in is excavated in the adjacent slabs and the new concrete will flow under the existing slabs.

All surfaces must be moistened prior to placement of patch. After placement of patching the wet concrete has to be vibrated or tamped if concrete contains heavy amounts of additives, it will appear sticky and be difficult to trowel. In these instances you may use a pre-packaged finishing aide to assist in the troweling operation. Sika, Degussa and Eucolid Concrete Products have such finishing aid products. After finishing, curing material must be sprayed over patch or covered by wet burlap. 3000 psi is the minimum required compressive strength before open to traffic.

17.5 Slab Stabilization

A sand-cement grout with about 20 percent cement and fine sand is recommended by ITD. Expanding foam can be also used as a replacement for grout. It is an ethafoam-type material that when pumped under the concrete slab attempts to expand up to fifteen times its original volume. It is more suitable for fast-track repair because it takes approximately 20 minute to harden after expansion and the pavement can open to traffic afterwards.

Similar to other states, slab jacking is performed by drilling holes and injecting grout into the cavities. After completion of injection, the holes must be filled with concrete mortar having a 1:3 mix. For uniform lifting of the slab, the holes must be drilled close enough. Rate of injection is important due to slab cracking at high speed. A heavy grout should not be pumped at more than 1 cu. ft./minute while an average grout flows freely under the slab at about 3 cu. ft./minute

18. Iowa Department of Transportation

18.1 Joint and Crack Sealing/Repair

Hot poured joint sealer and backer rod are used for sealing joints and cracks. The cracks are routed with power driven routing or saw equipment. The cracks or joints are routed to a width of 3/8 in to provide a sealant reservoir of 3/8 in wide and ½ in deep.

Water blast shall be used to remove existing joint sealer, debris, and loose material from the crack or joint. The cracks or joints are sand blasted prior to placement of backer rod if they are contaminated. Two passes of sandblast are used for each crack. After sandblasting, compressed air is used to further clean the joints and cracks.

18.2 Partial Depth Repair

When patching encroaches on an adjacent lane which is open to traffic or when there is patching on two lane pavements or other locations where overnight closures are not permitted, Class A or Class B patching material shall be used. On pavements with three or more lanes and where overnight closure is permitted, Class C patching material shall be used.

Class A patching concrete contains modified cement to provide rapid setting and high early strength. Class B is also high early strength and rapid set within 5 hrs. It may contain calcium chloride but not fly ash. Class C contains early set additives so that the pavement opens to traffic within 24 hrs to 36 hrs.

The edge of patch has to be 6 in beyond the damaged area. The repair area is milled to a minimum of 3 in and a maximum of 75% of the slab thickness (but not greater than 9 in). If the

sound concrete is below rebars, they can be cut and flushed with patch edge. After removal, the repair area is sandblasted and then cleaned with compressed air. Grout shall be used as bonding agent prior to patching.

18.3 Full Depth Repair

IADOT intends to achieve high early strength for early opening to traffic. Table 24 shows the applicable cement types.

Table 24. High early strength cement used in IADOT for accelerated PCC pavement repairs

Patch Type	Cement Type	Maximum Allowable Substitution	Minimum Mix Temperature
5 Hour	Type I, Type II Type IS	0% Fly Ash 0% Fly Ash	75°F (24°C) 80°F (27°C)*
10 Hour	Type I, Type II Type IS	10% Fly Ash 0% Fly Ash	65°F (18°C) 70°F (21°C)*
* When a Type A Mid Range Water reducing admixture is used, limit the minimum mix temperature to that required when Type I/II cement is used.			

All patches will be full-lane width and at least 6 ft long in interstates and 4 ft in other pavements except for continuously reinforced pavements. Minimum length is 8ft for continuously reinforced pavements. IADOT describes patching processes for different types of patches including patch without dowel and with dowel and composite patches. Without dowel, the damaged area is saw cut to full depth. However, if the area is repaired without dowel installation, the transverse boundaries are first saw cut to a depth of 1.5 in. Then 1.5 in inside the boundary is fully cut and removed by a drop hammer, hydro hammer, or other heavy equipment. The formed ledge at the transverse edge is then cut to bottom at a uniform taper. This is to provide load transfer between the patch and existing slab.

For continuously reinforced concrete pavements, the process is similar to that of without dowel which was described above. However, after saw cutting transversely to 1.5 in and along the centerline, a severance cut through the depth is made and the concrete between the 1.5 in edge saw cut and the severance is then removed by jackhammer. 20 in of the rebars from slab must protrude toward the patch. Therefore they should not be cut during saw cutting the transverse edge.

Full depth composite patch process is used when the surface of PCC pavement needs to be resurfaced with hot mixed asphalt (HMA) of 4.5 in thickness or less. First the area is patched and then resurfaced with HMA. Before resurfacing, the PCC has to be allowed to cure for 5 hours. In full depth repair, the patch is cured by covering with an insulating blanket-type cover.

18.4 Slab Stabilization

Grout shall be used for slab jacking which contains 1 part cement type I and 3 parts class C fly ash. 1.25 to 1.5 in holes are drilled at designated locations. One hole is to be drilled in the approach panel, 1.5 feet (0.5 m) from the joint or crack, and 4 feet to 8 feet (1.2 m to 2.4 m) from the center line. Two holes are to be placed in the leave panel, 3 feet (1 m) from the joint or crack, and 3 feet (1 m) from the panel edges. Holes may be washed to create a small cavity at subgrade to facilitate initial grout flow. The grouting will continue until movement of slab is detectable. However, its movement should be limited to 0.1 in. Initial pumping pressure is limited to 20 psi

and it must be limited to 7 psi after start. At the end, the drilled holes are plugged with dry concrete, which contains 1 part cement and 2 part sand.

19. Missouri Department of Transportation

19.1 Joint and Crack Sealing

Sealer material shall be in accordance with ASTM 6690, Type II. A minimum of 95% of old sealant must be removed. Plowing is an acceptable method of removing old sealant from concrete joints especially when sawing is required to keep the saw blades from gumming up. Plowing involves pulling a thin blade through a joint to remove old sealant and backer rod from the joint and to clean sealant from the sides of the joint. Joints narrower than ½ in shall be widened and cut to a depth of 1.25 in. After plowing, the crack or joint is sand blasted and then water blasted. After it dries, the final cleaning is performed by compressed air. After cleaning, backer rod with a size of 1.25 times the joint width is placed.

Cracks shall be routed, grooved, or saw cut to a width of ½ in and depth of ¾ in. Herbicide mixed, a commercially available product, can be used if there is vegetation inside the crack. In both cracks and joints, the sealant will be poured to the 1/8 in from top.

19.2 Joint Repair

When placing a partial depth pavement repair directly against a transverse joint or crack, a compressible insert shall be placed against the joint or crack to form a bond breaker between the patch material and joint or crack. The compressible insert shall be placed into the existing joint to a minimum depth of one inch below the bottom of the repair and shall extend a minimum of 3 inches beyond each end of the prepared repair boundaries. A thin polyethylene strip no less than 1/8 inch thick or asphalt impregnated roofing felt shall be used for longitudinal joint.

19.3 Partial Depth Repair

Partial depth repair according to MODOT can be class A or B. Class A is the regular method which is described below but in class B, bituminous mixture is used. This is applicable to the projects that resurfacing is required.

If roadway opens to traffic within four hours the repair concrete must gain 1600 psi in 4 hrs and 4000 psi in 24 hrs and contains 4% entrained air and has a slum of 1 in or lower. If it opens in 24 hrs instead, 1600 psi and 4000 psi will be the required strengths at 1 and 7 days. Type II epoxy shall be used as the bonding agent. Type 2, Class B liquid membrane-forming compounds, in accordance with AASHTO M 148, shall be used for curing the concrete patch material.

Partial depth repair will be performed on pavements that have not been resurfaced yet or resurfacing is less than 3 in. Patch area shall be extended 3 to 4 in beyond the damaged area. If repair areas are less than 2 ft apart, they will be merged to one. The damaged concrete shall be removed by milling process.

19.4 Full Depth Repair

When the pavement opens to traffic after 24 hrs, the patching concrete must meet the following strength requirement based on thickness of the slab (Table 25).

Table 25. Strength requirement for time to open for traffic at MODOT

Property	Existing Slab Design Thickness	Requirement
Compressive Strength in 24 hours	8 in. or less 9 in. 10 in. or more	3,000 psi, min. 2,700 psi, min. 2,000 psi, min.
Compressive Strength in 28 days	--	4,000 psi, min.

If the pavement has to open to traffic in less than 24 hrs, the above strength requirements must be met within 4 hrs. The concrete may contain Type III cement, calcium chloride, and an accelerator.

All full depth pavement repairs exceeding 30 feet in length shall be constructed with tie bars along the longitudinal centerline joint. Dowel bars should be epoxy coated. Drilled holes for dowel bars are first filled with bonding agent. Insulating curing mat will be used if ambient temperature is below 50^{o}F.

19.5 Slab Stabilization

High density polyurethane or asphalt cement (ASTM D3141) is used for slab stabilizations. For slab jacking, high density polyurethane or cementitious grout shall be used. Grout is a mixture of Portland cement, fly ash.

For undersealing 1 ½ in injection holes are drilled first. The holes must be drilled 7 days prior to injection.

For slab jacking, movement should not exceed 0.125 in.

20. Montana Department of Transportation

20.1 Crack/Joint Sealing

According to MTDOT, cracks of 1/8 in wide or wider are subjected to corrective measurements.

Joint between the concrete pavement and asphalt should be filled with rubberized asphalt crack filler. Silicone is the preferred sealant for concrete-to-concrete joints or cracks.

The sealing process is similar to other states' processes described above. Old sealant is first removed and the joint is re-sawed to specified dimensions. It is then cleaned and sandblasted and the backer rod is placed. If self-leveling type of silicone is not used, it should be placed about ¼ in below the pavement surface.

20.2 Partial Depth Repair

MTDOT calls for two types of spall repair: temporary and permanent patching. Temporary patching which is associated with asphalt patch. It preferably adopts mixed asphalt cement bituminous surfacing when the spall is minor and weather and time does not allow permanent patching. In contrast, permanent patching is used when there is severe spall or temporary patching fails. High, early-strength PCC or a rapid setting proprietary concrete product shall be used for permanent patching.

For temporary patching the concrete is removed just as stated by other DOTs. The surface is then coated by emulsified asphalt and the asphalt concrete is placed and compacted. Patching

process for permanent type is also similar to the ones described above. Damaged concrete is removed first and cleaned, the area is then coated with epoxy adhesive and patching material is placed, tamped or vibrated.

Summary

In general, almost all of the DOTs share the same repair process for the four main repair types: partial-depth repair, full-depth repair, spall repair, and joint repair. The only differences are in the details such as saw-cut depth, extension of boundaries beyond the delaminated area, type of bonding agent, etc. Nevertheless, they all share the same procedure including saw-cutting, concrete removal, cleaning, and placement of patching materials. It seems that in terms of fast-setting material there are large variations in the type of materials used for repair. Most of the states allow using type III Portland cement along with accelerating admixtures. BASF Corporation, Euclid Chemical Co, and Sika Corporation are of the companies that more than one DOT recommends. Most states that have clarified the criteria for the time open to traffic use flexural strength, compressive strength, or rupture modulus to determine maturity of concrete.

Appendix II

Suggested accelerated PCC pavement repair material mixes

There are many ways to achieve high early strength while maintaining durability for accelerated PCC pavement repairs. Mixtures 1, 2, and 3 are good examples listed in NCHRP 450 with air entraining agent, providing good performance for 6- to 8-hour early opening for traffic.

• Mixture 1
– Cement Type: Type III
– Cement Content: 525 kg/m^3 (885 lb/yd^3)
– *w/c* ratio: 0.40
– Accelerator Type: non-chloride
– Water Reducer: Type A
– Coarse Aggregate: 1,030 kg/m^3 (1,736 lb/yd^3) crushed limestone
– Fine Aggregate: 427 kg/m^3 (720 lb/yd^3) natural sand
– Average Slump: 90 mm (3.5 in.)
– Average Air Content: 5.0 percent
– 8-hour Compressive Strength: 26.4 MPa (3,823 psi)
– 28-day Compressive Strength: 44.0 MPa (6,400 psi)
– 8-hour Flexural Strength: 2.4 MPa (350 psi)
• Mixture 2
– Cement Type: Type III
– Cement Content: 525 kg/m^3 (885 lb/yd^3)
– *w/c* ratio: 0.36
– Accelerator Type: non-chloride
– Water Reducer: Type A
– Coarse Aggregate: 1,030 kg/m^3 (1,736 lb/yd^3) crushed limestone
– Fine Aggregate: 482 kg/m^3 (812 lb/yd^3) natural sand
– Average Slump: 70 mm (2.75 in.)
– Average Air Content: 5.0 percent
– 8-hour Compressive Strength: 30.4 MPa (4,400 psi)
– 28-day Compressive Strength: 56.3 MPa (8,150 psi)
– 8-hour Flexural Strength: 3.0 MPa (435 psi)
• Mixture 3
– Cement Type: Type I/II
– Cement Content: 425 kg/m^3 (716 lb/yd^3)
– *w/c* ratio: 0.40
– Accelerator Type: calcium chloride
– Water Reducer: Type A
– Coarse Aggregate: 1,030 kg/m^3 (1,736 lb/yd^3) crushed limestone
– Fine Aggregate: 425 kg/m^3 (716 lb/yd^3) natural sand
– Average Slump: 65 mm (2.5 in.)
– Average Air Content: 5.6 percent
– 8-hour Compressive Strength: 17.0 MPa (2,465 psi)

– 28-day Compressive Strength: 53.8 MPa (7,800 psi)
– 8-hour Flexural Strength: 2.4 MPa (350 psi)

Mixtures 4, 5, and 6, all of which were made using a vinsol resin air-entraining agent, provided good performance for 20- to 24-hour early opening for traffic

• Mixture 4
– Cement Type: Type I
– Cement Content: 400 kg/m^3
– *w/c* ratio: 0.43
– Accelerator Type: calcium chloride
– Water Reducer: none
– Coarse Aggregate: 1,030 kg/m^3 (1,736 lb/yd^3) crushed limestone
– Fine Aggregate: 628 kg/m^3 (1,060 lb/yd^3) natural sand
– Average Slump: 85 mm (3.35 in.)
– Average Air Content: 6.6 percent
– 20-hour Compressive Strength: 24.5 MPa (3,550 psi)
– 28-day Compressive Strength: 46.0 MPa (6,670 psi)
– 20-hour Flexural Strength: 3.4 MPa (490 psi)

• Mixture 5
– Cement Type: Type I
– Cement Content: 400 kg/m^3
– *w/c* ratio: 0.40
– Accelerator Type: non-chloride
– Water Reducer: none
– Coarse Aggregate: 1,030 kg/m^3 (1,736 lb/yd^3) crushed limestone
– Fine Aggregate: 659 kg/m^3 (1,110 lb/yd^3) natural sand
– Average Slump: 50 mm (2 in.)
– Average Air Content: 5.7 percent
– 20-hour Compressive Strength: 19.9 MPa (2,890 psi)
– 28-day Compressive Strength: 40.6 MPa (5,890 psi)
– 20-hour Flexural Strength: 3.8 MPa (550 psi)

• Mixture 6
– Cement Type: Type I
– Cement Content: 475 kg/m^3
– *w/c* ratio: 0.43
– Accelerator Type: none
– Water Reducer: none
– Coarse Aggregate: 1,030 kg/m^3 (1,736 lb/yd^3) crushed limestone
– Fine Aggregate: 659 kg/m^3 (1,110 lb/yd^3) natural sand
– Average Slump: 150 mm (6 in.)
– Average Air Content: 5.9 percent
– 20-hour Compressive Strength: 17.8 MPa (2,580 psi)
– 28-day Compressive Strength: 39.3 MPa (5,700 psi)
– 20-hour Flexural Strength: 3.6 MPa (520 psi)

Appendix III

Survey Instrument

Accelerated PCC Pavement Repair Processes and Materials Survey

North Dakota Department of Transportation
North Dakota State University
July 2013

Introduction:

We thank you for agreeing to take this survey, which is part of a research project entitled "Accelerated PCC Pavement Repair: Survey and Literature Review of Processes and Materials". Research is funded by North Dakota Department of Transportation and is being conducted by the Civil Engineering Department at North Dakota State University. The research is aimed at collecting information on the successful and unsuccessful experiences of accelerated repair materials and processes that other states, particularly the states with similar climates to North Dakota, have been using to repair damaged concrete pavements. NDDOT's goal is to identify materials and methods that can be used to reduce construction time, shorten lane closure time, and minimize public impact. Please kindly submit your completed survey by August 12th, 2013. The invaluable information you provide will help us improve our management and maintenance of concrete pavements in North Dakota and thus every answer is important to us. If there is any ambiguity with the questions, please do not hesitate to contact us via:

Telephone: (701) 231-5647
Fax: (701) 231-6185
Email: Mijia.yang@ndsu.edu
Contact Person: Dr. Mijia Yang
Assistant Professor
Civil Engineering Department
North Dakota State University
Fargo, ND58108-6050

Please provide us your information for the survey.

Name	
Position	
Email	
Phone NO.	
State	

Legal Notice:

Please be informed that by participating in this survey you are giving permission to the research group to use your questionnaire results in their analysis and publish the results. The information

obtained from this survey is considered as NDDOT property and can be published or re-produced in any format or media.

(1) What types of concrete pavement are commonly used in your state?

- ☐ Plain Concrete Pavement
- ☐ Continuously Reinforced Concrete Pavement
- ☐ Joint Reinforced Concrete Pavement

(2) Does your state/agency use accelerated repair processes for PCC pavements?

- ☐ Yes
- ☐ No

If the answer is "No", you do not need to proceed to the other questions.

(3) Does your state/agency have specifications for accelerated PCC repairs?

- ☐ Yes
- ☐ No

If yes, please provide a link to that information.

(4) How did your agency develop its specification? Has your agency followed successful experiences, research outcomes, recommendations etc. from,

- ☐ Agency's own experience
- ☐ Research outcomes
- ☐ Industry recommendations
- ☐ Other DOTs
- ☐ Other sources, please identify

(5) Which repair types are used in your agency for PCC pavements?

- ☐ Concrete joint repair;
- ☐ Concrete crack sealing;

☐ Partial depth patching;

☐ Full depth patching;

☐ Dowel bar retrofit;

☐ Full panel replacement;

☐ Intersection repair;

☐ Other(s)

If other(s), please specify:

(6) What is the most successful accelerated PCC pavement repair material used in your agency for each repair type listed below?

Repair Type	Repair Materials
☐ Concrete joint repair;	
☐ Concrete crack sealing;	
☐ Partial depth patching;	
☐ Full depth patching;	
☐ Dowel bar retrofit;	

☐ Full panel replacement;	
☐ Intersection repair;	
☐ Other(s)	

(7) Please list the steps in the accelerated PCC repair processes used in your agency for each type of repair you mentioned in (6).

Repair Type	Repair Processes
☐ Concrete joint repair;	
☐ Concrete crack sealing;	
☐ Partial depth patching;	
☐ Full depth patching;	
☐ Dowel bar retrofit;	
☐ Full panel replacement;	
☐ Intersection repair;	
☐ Other(s)	

(8) Have you ever had unsuccessful experience with accelerated PCC pavement repair materials?

☐ Yes
☐ No

If yes, please specify the types of materials you used and the reason they were unsuccessful.

Accelerated repair type	Materials used and the reason(s) for failure
☐ Concrete joint repair;	
☐ Concrete crack sealing;	
☐ Partial depth patching;	
☐ Full depth patching;	
☐ Dowel bar retrofit;	
☐ Full panel replacement;	
☐ Intersection repair;	
☐ Other(s)	

(9) Which are the factors your agency uses to select a repair material for a given PCC pavement? Please use numbers 1-6 in the boxes to indicate the priority of the factors (1 = highest priority)

☐ Repair type
☐ Curing time
☐ Time to open for traffic (criteria for time to open for traffic, such as strength gain)
☐ Durability
☐ Cost
☐ Other, please specify

(10) Does your agency have requirements for placement and curing for the following accelerated PCC repairs?

Accelerated repair type	Require special placement and curing?	If yes, please describe
Concrete joint repair	☐ Yes ☐ No	
Concrete crack sealing	☐ Yes ☐ No	
Partial depth patching	☐ Yes ☐ No	
Full depth patching	☐ Yes ☐ No	
Dowel bar retrofit	☐ Yes ☐ No	
Full panel replacement	☐ Yes ☐ No	
Intersection repair	☐ Yes ☐ No	
Other(s)	☐ Yes ☐ No	

(11) Does your agency require the use of special equipment or methods for the following accelerated PCC pavement repairs?

Accelerated repair type	Require special equipment or methods?	If yes, please describe
Concrete joint repair	☐ Yes ☐ No	
Concrete crack sealing	☐ Yes ☐ No	
Partial depth patching	☐ Yes ☐ No	
Full depth patching	☐ Yes ☐ No	
Dowel bar retrofit	☐ Yes ☐ No	
Full panel replacement	☐ Yes ☐ No	
Intersection repair	☐ Yes ☐ No	
Other(s)	☐ Yes ☐ No	

(12) Which factors determine your selection of a type of repair process? Please use numbers 1-4 in the boxes to indicate the priority of the factors (1 = highest priority).

☐ Distress location

☐ Time to open for traffic

☐ Cost

☐ Others, please specify

(13) What criteria does your agency use to determine the time to open for traffic? For example, if strength is used as the criterion, what is the minimum required strength?

☐ Strength
- ☐ Compressive, please specify
- ☐ Flexural, please specify _____
- ☐ Maturity, please specify _____
- ☐ Other, please specify _____

☐ Time (hours/days), please specify _____

☐ Other, please specify _____

(14) What is the expected service life of the accelerated PCC pavement repairs listed below?

Repair Type	How many years of its expected service life?
Concrete joint repair;	☐ 0-3 years; ☐ 3-5 years; ☐ 5-10 years; ☐ 10-15 years; ☐ >15 years
Concrete crack sealing;	☐ 0-3 years; ☐ 3-5 years; ☐ 5-10 years; ☐ 10-15 years; ☐ >15 years
Partial depth patching;	☐ 0-3 years; ☐ 3-5 years; ☐ 5-10 years; ☐ 10-15 years; ☐ >15 years
Full depth patching;	☐ 0-3 years; ☐ 3-5 years; ☐ 5-10 years; ☐ 10-15 years; ☐ >15 years
Dowel bar retrofit;	☐ 0-3 years; ☐ 3-5 years; ☐ 5-10 years; ☐ 10-15 years; ☐ >15 years
Full panel replacement;	☐ 0-3 years; ☐ 3-5 years; ☐ 5-10 years; ☐ 10-15 years; ☐ >15 years
Intersection repair;	☐ 0-3 years; ☐ 3-5 years; ☐ 5-10 years; ☐ 10-15 years; ☐ >15 years
Other(s)	☐ 0-3 years; ☐ 3-5 years; ☐ 5-10 years; ☐ 10-15 years; ☐ >15 years

(15) We will follow up a phone interview with this email survey if NDDOT is interested in the repair materials, the repair methods, and the repair processes used in your agency. Please provide the information for the person we should contact.

Name	
Position	
Email	
Phone NO.	
State	

Appendix IV

ACCELERATED PCC PAVEMENT REPAIR PROCESSES AND MATERIALS SURVEY

Conducted by

Department of Civil Engineering

North Dakota State University

September 09, 2013

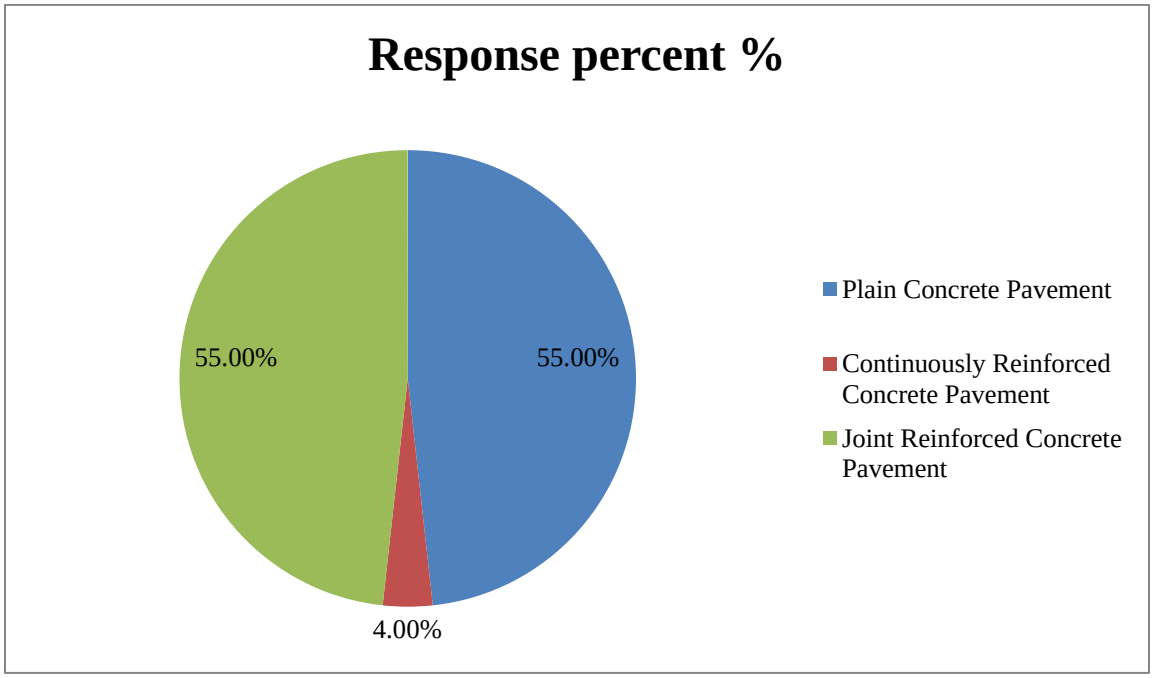
1. What types of concrete pavement are commonly used in your state?

State	Plain Concrete Pavement	Continuously Reinforced Concrete Pavement	Joint Reinforced Concrete Pavement
Alberta	Plain Concrete Pavement	NA	NA
Colorado	NA	NA	Joint Reinforced Concrete Pavement
Idaho	Plain Concrete Pavement		
Illinois	NA	Continuously Reinforced Concrete Pavement	Joint Reinforced Concrete Pavement
Indiana	NA	NA	Joint Reinforced Concrete Pavement
Kansas	Plain Concrete Pavement	NA	Joint Reinforced Concrete Pavement
Maine	Maine DOT does not use PCC pavement		
Manitoba	NA	NA	Joint Reinforced Concrete Pavement
Michigan	Plain Concrete Pavement	NA	NA
Minnesota	Plain Concrete Pavement	NA	NA
Missouri	Plain Concrete Pavement	NA	NA
Montana	Plain Concrete Pavement	NA	Joint Reinforced Concrete Pavement
Nebraska	Plain Concrete Pavement	NA	NA
Nevada		NA	Joint Reinforced Concrete Pavement
Ohio	Plain Concrete Pavement	NA	NA
Oregon	Plain Concrete Pavement	NA	NA
Pennsylvania	NA	NA	Joint Reinforced Concrete Pavement
Saskatchewan	Saskatchewan DOT does not use PCC pavement		
South Dakota	NA	Continuously Reinforced Concrete Pavement	Joint Reinforced Concrete Pavement
Utah	NA	NA	Joint Reinforced Concrete Pavement
Washington	Plain Concrete Pavement	NA	NA
Wisconsin	NA	NA	Joint Reinforced Concrete Pavement

* Some states use two types of concrete pavement

1. What types of concrete pavement are commonly used in your state?

Answer option	Response percent	Response count
Plain Concrete Pavement	55.00%	11
Continuously Reinforced Concrete Pavement	4.00%	2
Joint Reinforced Concrete Pavement	55.00%	11
Answered questions		20
Skipped questions		2



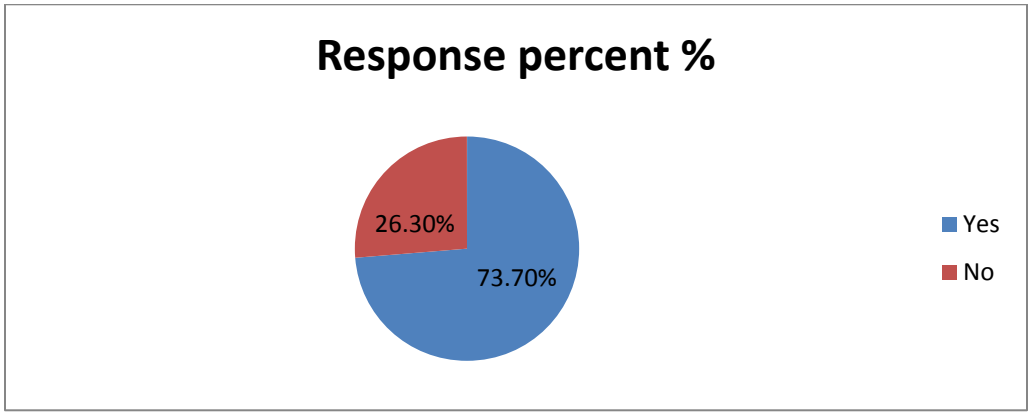
2. Does your state/agency use accelerated repair processes for PCC pavements?

State	Yes	No
Alberta		No
Colorado	Yes	
Idaho		No
Illinois	Skipped	
Indiana	Yes	
Kansas	Yes	
Manitoba		No
Michigan	Yes	
Minnesota	Yes	
Missouri		No
Montana		No
Nebraska	Yes	
Nevada	Yes	
Ohio	Yes	
Oregon	Yes	
Pennsylvania	Yes	
South Dakota	Yes	
Utah	Yes	
Washington	Yes	
Wisconsin	Yes	

* Maine and Saskatchewan don't use PPC, so they are dropped

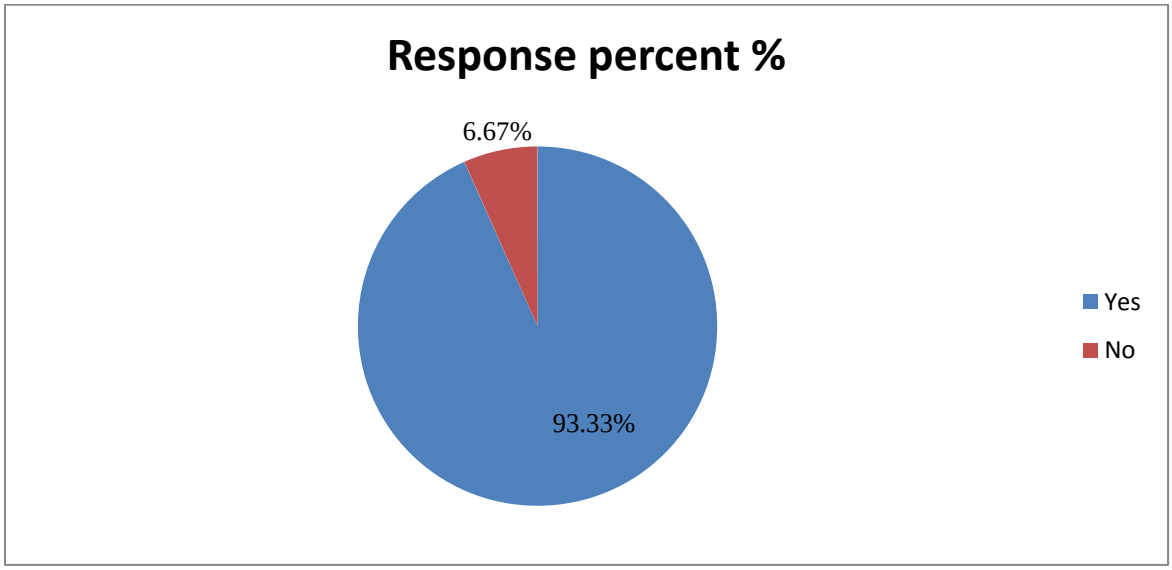
2. Does your state/agency use accelerated repair processes for PCC pavements?

Answer option	Response percent	Response count
Yes	73.70%	14
No	26.30%	5
	Answered questions	19
	Skipped questions	1



3. Does your state/agency have specifications for accelerated PCC repairs?

Answer option	Response percent	Response count
Yes	93.33%	14
No	6.67%	1
	Answered questions	15



State	**If yes, please provide a link to that information.**
Colorado	Please contact Mr. Eric Prieve for spec information at 303-398-6542 or Eric.Prieve@state.co.us
Illinois	Generally, Illinois uses a concrete with Calcium Aluminate Cement to speed up patching.
Indiana	We are currently studying the process for placing long patches and will be refining the specification in 2013.
Kansas	http://www.ksdot.org/burConsMain/specprov/2007/pdf/07-08011-r05.pdf; http://www.ksdot.org/burConsMain/specprov/2007/833.pdf
Michigan	In the initial development stage.
Minnesota	We don't publish the Ultra High Early (UHE) specifications as we do our other standard specs. The main reason we (MnDOT Concrete Office) don't publish the UHE specification for concrete rehab is, the spec gets over used. Be careful…When the word get out that you are opening to traffic in 3-4 hour after pouring the concrete, no one wants to close a road any more.
Nebraska	Skipped
Nevada	We let the contractor come up with the concrete mix design (other than specifying the type of cement) and they have to comply with our time restrictions.

Ohio	http://www.dot.state.oh.us/Divisions/ConstructionMgt/Specification%20Files/2013%20CMS%2011142012%20FINAL.PDF
Oregon	Note that we are currently working with industry to update this specification. Section 00758: http://www.oregon.gov/ODOT/HWY/SPECS/Pages/2008_special_provisions.aspx#Part_00700
Pennsylvania	www.dot.state.pa.us
South Dakota	Plan note details are used. I can provide plan notes upon request.
Utah	http://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:3694, See Specs 02751 and 02753
Washington	Skipped
Wisconsin	The specification resides as a Special Provision which is not posted on the Web.

4. How did your agency develop its specification? Has your agency followed successful experiences, research outcomes, recommendations etc. from,

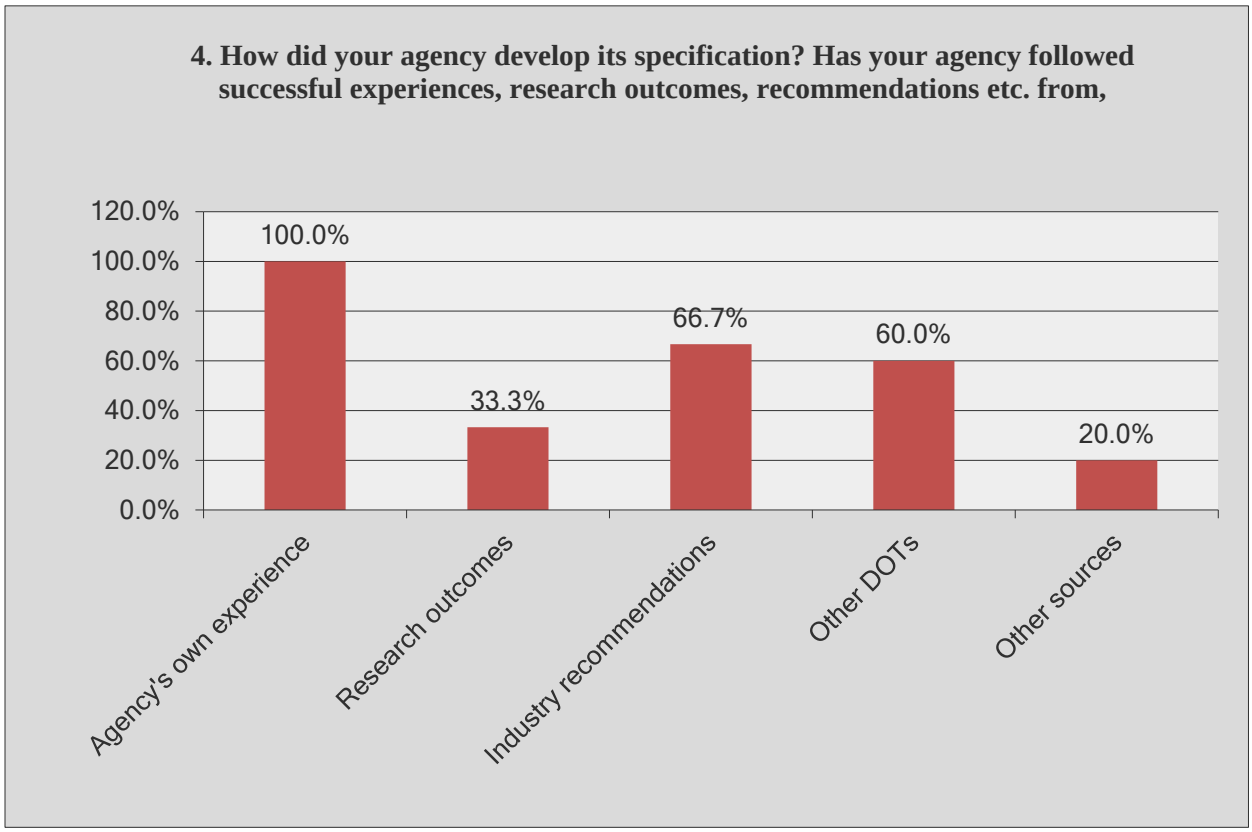
State	How did your agency develop its specification?
Colorado	Agency's own experience, Research outcomes, Industry recommendations, Other DOTs.
Illinois	Agency's own experience, Research outcomes, Industry recommendations, Other DOTs.
Indiana	Agency's own experience.
Kansas	Agency's own experience, Research outcomes, Industry recommendations, Other DOTs.
Michigan	Agency's own experience, Industry recommendations, Other DOTs.
Minnesota	Agency's own experience
Nebraska	Agency's own experience
Nevada	Agency's own experience, and other sources.
Ohio	Agency's own experience, Industry recommendations, Other DOTs.
Oregon	Agency's own experience, Industry recommendations, Other DOTs, and Other sources. Section 00758: http://www.oregon.gov/ODOT/HWY/SPECS/Pages/2008_special_provisions.aspx#Part_00700
Pennsylvania	Agency's own experience, Industry recommendations, Other DOTs. See Specs 02751 and 02753
South Dakota	Agency's own experience, Other DOTs, and Other sources.
Utah	Agency's own experience, Research outcomes, Industry recommendations, Other DOTs. See Specs 02751 and 02753
Washington	Agency's own experience, and Industry recommendations.
Wisconsin	Agency's own experience, Research outcomes, Industry recommendations.

If other source, please identify

Response State	If other source, please identify
Nevada	We try to stay away from high/early concrete since our experience has been that we cannot control the cracking.
Oregon	Participation in the CRCP ETG sponsored by CRSI and FHWA.
South Dakota	Skipped.

4. How did your agency develop its specification? Has your agency followed successful experiences, research outcomes, recommendations etc. from,

Answer Options	Response Percent	Response Count
Agency's own experience	100.0%	15
Research outcomes	33.3%	5
Industry recommendations	66.7%	10
Other DOTs	60.0%	9
Other sources	20.0%	3
answered question		**15**



5. Which repair types are used in your agency for PCC pavements?

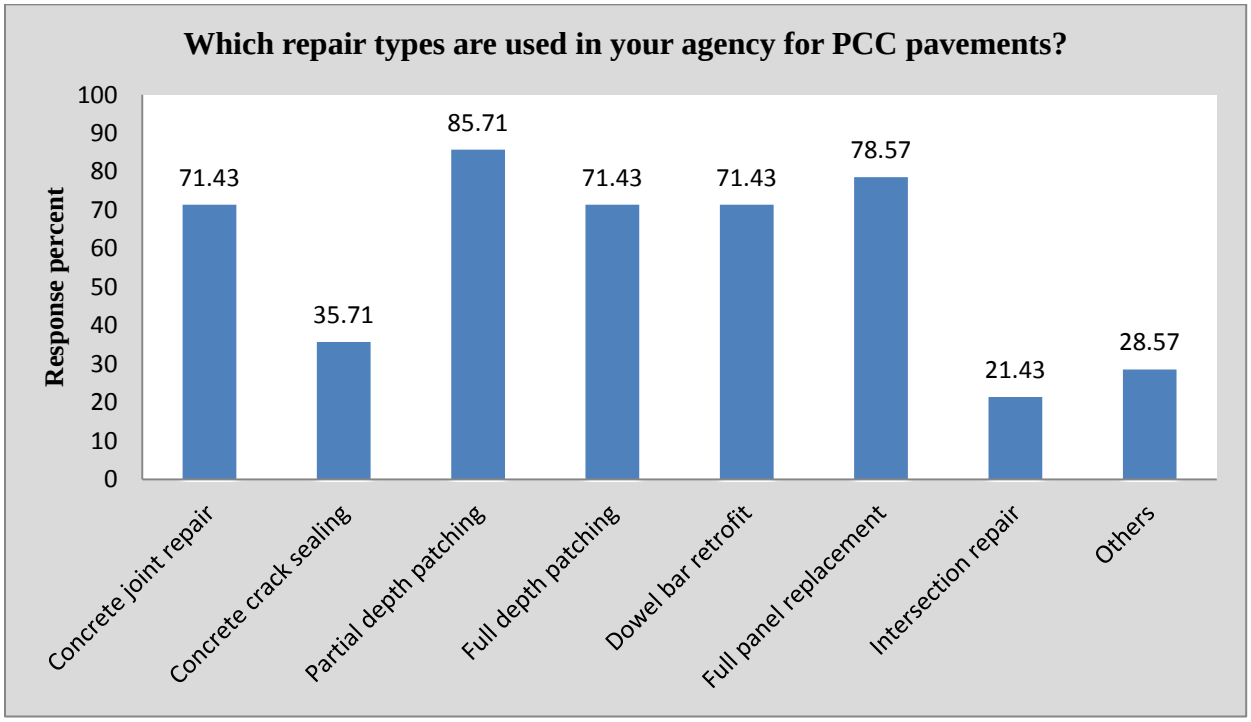
State	Concrete Joint repair	Concrete crack sealing	Partial depth patching	Full depth patching	Dowel bar retrofit	Full panel replacement	Intersection repair	Others
Colorado	x	x	x	x	x	x	x	
Illinois	NA	NA	NA	NA	NA	NA	NA	A myriad of techniques are used
Indiana	x	NA	NA	x	NA	NA	NA	NA
Kansas	x	NA	x	NA	x	NA	NA	NA
Michigan	Skipped							
Minnesota	x	x	x	NA	x	x	NA	NA
Missouri	x	NA	x	x	x	x	NA	NA
Nebraska	x	x	x	x	NA	x	x	NA
Nevada	Skipped							
Ohio	x	NA	x	x	x	x	NA	Tie bar retrofit
Oregon	NA	NA	x	x	NA	x	NA	CRCP full-depth repair
Pennsylvania	x	x	x	x	x	x	NA	NA
South Dakota	NA	x	x	x	x	x	NA	NA
Utah	x	NA	x	x	x	x	NA	NA
Washington	NA	NA	x	NA	x	x	NA	Grinding to remove ruts and restore profile
Wisconsin	x	NA	x	x	x	x	x	NA

If other, please specify

Response State	If other, please specify
Illinois	A myriad of techniques are used.
Ohio	Tie bar retrofit.
Oregon	CRCP full-depth repair.
Washington	Grinding to remove ruts and restore profile

5. Which repair types are used in your agency for PCC pavements?

Answer option	Response percent	Response count
Concrete joint repair	71.43	10
Concrete crack sealing	35.71	5
Partial depth patching	85.71	12
Full depth patching	71.43	10
Dowel bar retrofit	71.43	10
Full panel replacement	78.57	11
Intersection repair	21.43	3
Others	28.57	4
Answered questions		14
Skipped questions		2

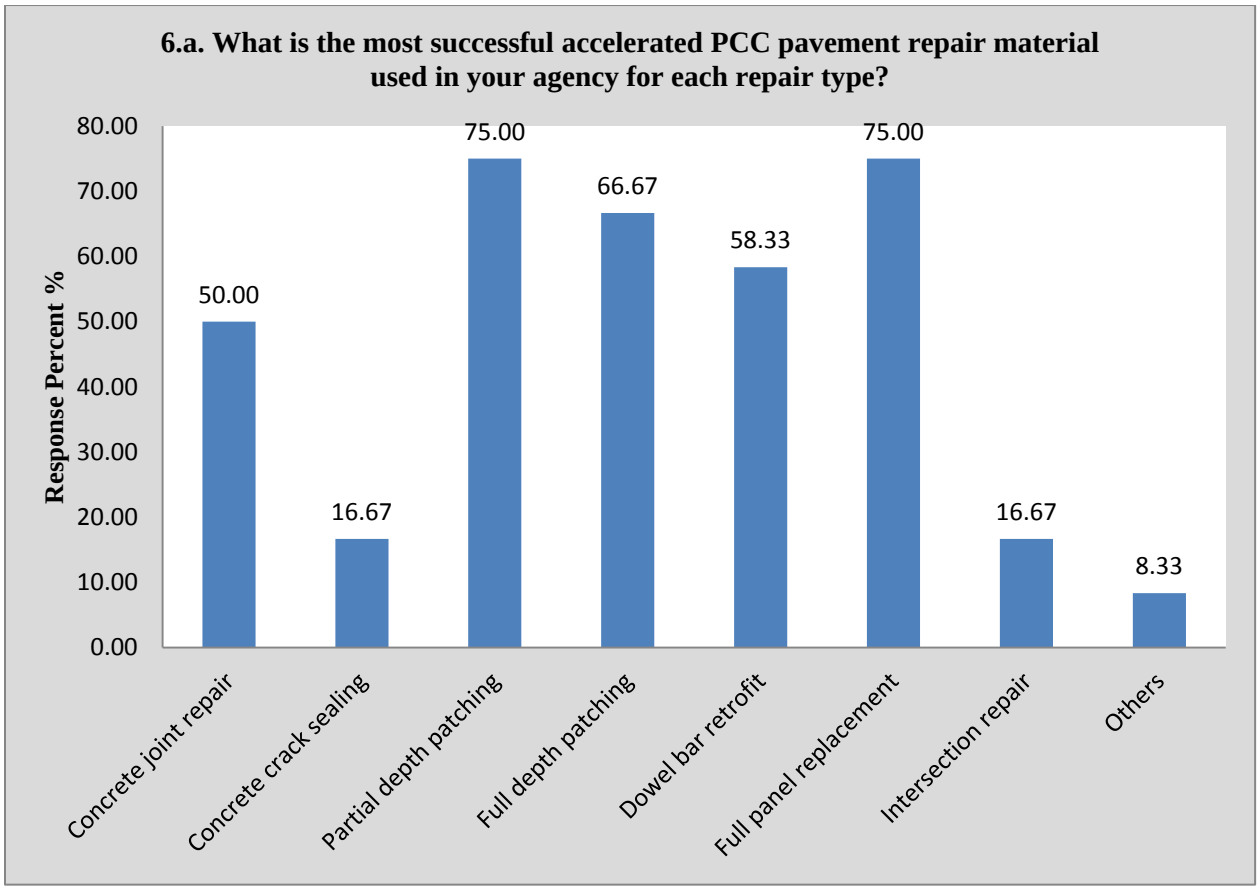


6.a. What is the most successful accelerated PCC pavement repair material used in your agency for each repair type listed below?

State	Concrete Joint repair	Concrete crack sealing	Partial depth patching	Full depth patching	Dowel bar retrofit	Full panel replacement	Intersection repair	Others
Colorado	NA	NA	NA	NA	NA	x	NA	NA
Illinois	Skipped							
Indiana	NA	NA	NA	x	NA	NA	NA	NA
Kansas	x	NA	x	NA	x	NA	NA	NA
Michigan	Skipped							
Minnesota	NA	NA	x	NA	x	x	NA	NA
Missouri	Skipped							
Nebraska	x	NA	x	x	NA	x	x	NA
Nevada	Skipped							
Ohio	x	NA	NA	x	NA	NA	NA	NA
Oregon	NA	NA	x	x	NA	x	NA	x
Pennsylvania	x	x	x	x	x	x	NA	NA
South Dakota	NA	x	x	x	x	x	NA	NA
Utah	x	NA	x	x	x	x	NA	NA
Washington	NA	NA	x	NA	x	x	NA	NA
Wisconsin	x	NA	x	x	x	x	x	NA

6.a. What is the most successful accelerated PCC pavement repair material used in your agency for each repair type listed below?

Answer option	Response percent	Response count
Concrete joint repair	50.00	6
Concrete crack sealing	16.67	2
Partial depth patching	75.00	9
Full depth patching	66.67	8
Dowel bar retrofit	58.33	7
Full panel replacement	75.00	9
Intersection repair	16.67	2
Others	8.33	1
Answered questions		12
Skipped questions		4



6.b. For the chosen repair types in question (6.a), what are the repair materials utilized?

State	Repair Type	Repair materials utilized
Colorado	Full panel replacement	Using high early strength CDOT Class E concrete
Indiana	Full depth patching	Experimenting with different concrete materials
Kansas	Concrete Joint repair	Rapid set patching material
	Partial depth patching	Type III cement adding calcium chlorite for durability
	Dowel bar retrofit	Rapid set patching material/super raid set patching materials.
Minnesota	Concrete crack sealing	Proprietary
	Partial depth patching	Proprietary
	Dowel bar retrofit	Proprietary
	Full panel replacement	Ready mix
Nebraska	Concrete Joint repair	PR Concrete
	Partial depth patching	PR Concrete
	Full depth patching	PR Concrete
	Full panel replacement	PR Concrete
	Intersection repair	PR Concrete
Ohio	Concrete Joint repair	RRCM or FS in Item 255
	Full depth patching	RRCM or FS in Item 255
Oregon	Partial depth patching	Epoxy and grout. Specific product types are on our QPL.
	Full depth patching	Type I/II cement and "Rapid Set" product
	Full panel replacement	Type I/II cement and "Rapid Set" product
	Others	Type I/II cement and "Rapid Set" product
Pennsylvania	Concrete Joint repair	Rubberized Joint Sealing Material ASTM D6690-Type II and Type I
	Concrete crack sealing	Rubberized Joint Sealing Material ASTM D6690-Type II and Type I
	Partial depth patching	Normal Concrete, Rapid Set Concrete, Latex Modified Concrete
	Full depth patching	Normal and Accelerated Strength Concrete Mixes
	Dowel bar retrofit	Rapid Set Concrete Patching Materials
	Full panel replacement	Normal Strength Concrete Mixes
South Dakota	Concrete crack sealing	Hot Pour or Silicone
	Partial depth patching	Bagged rapid strength concrete mix
	Full depth patching	High early strength PCC mix
	Dowel bar retrofit	DBR rapid strength patch material
	Full panel replacement	Normal PCC to High early strength PCC.

Utah	Concrete Joint repair	Hot pour sealant
	Partial depth patching	Patching mixes such as 5 star
	Full depth patching	High cement content mixes and patching mixes such as 5 star
	Dowel bar retrofit	Patching mortar
	Full panel replacement	Precast panels and high cement content mixes
Washington	Partial depth patching	Rapid setting concrete patching material
	Dowel bar retrofit	epoxy coated dowel bars, rapid setting concrete patching material
	Full panel replacement	Portland cement concrete or rapid setting concrete
Wisconsin	Concrete Joint repair	High early concrete
	Partial depth patching	High early concrete
	Full depth patching	High early concrete
	Dowel bar retrofit	Approved grout
	Full panel replacement	High early concrete

7. Please list the steps in the accelerated PCC repair processes used in your agency for each type of repair you mentioned in question (6).

State	Repair Type	Repair materials utilized
Colorado	Full panel replacement	Saw cut, removal, subgrade rehab if needed, dowel/tie drilling and replacement, cast in place, finish grinning
Illinois	Skipped	
Indiana	Skipped	
Kansas	No special procedures taken	
Michigan	Skipped	
Minnesota	Skipped	
Missouri	Skipped	
Nebraska	Concrete Joint repair	Close lane, remove concrete, place PR Concrete, depending whether using PR1 or PR3 open same day or in 24 hours.
	Partial depth patching	Same as concrete joint repair
	Full depth patching	Same as concrete joint repair
	Full panel replacement	Same as concrete joint repair
	Intersection repair	Same as concrete joint repair
Nevada	Skipped	
Ohio	Concrete Joint repair	See item 255 in link above
	Full depth patching	See item 255 in link above
Oregon	Partial depth patching	Partial depth sawing and squaring repair area, jack hammering, cleaning, placement.
	Full depth patching	Full depth sawing, preparing base, roughening edges using a bush hammer, drilling and tying in rebar and/or dowel bars depending on location, preparing base, placing rebar, pouring and finishing.
	Others	Same as Full depth patching
Pennsylvania	Concrete Joint repair	Saw, clean, place bond breaker, place backing matl, place sealant.
	Concrete crack sealing	Saw, clean, place bond breaker, place backing matl, place sealant.
	Partial depth patching	Saw, remove mat'l, clean patch, place bonding agent, place conc.
	Full depth patching	Saw , remove mat'l, clean patch, recompact base, place dowels, place conc.
	Dowel bar retrofit	Saw slots, remove mat'l, prep and place dowels, bonding agent and conc. Patch material
	Full panel replacement	Saw , remove mat'l, recompact base, place dowels, place conc.

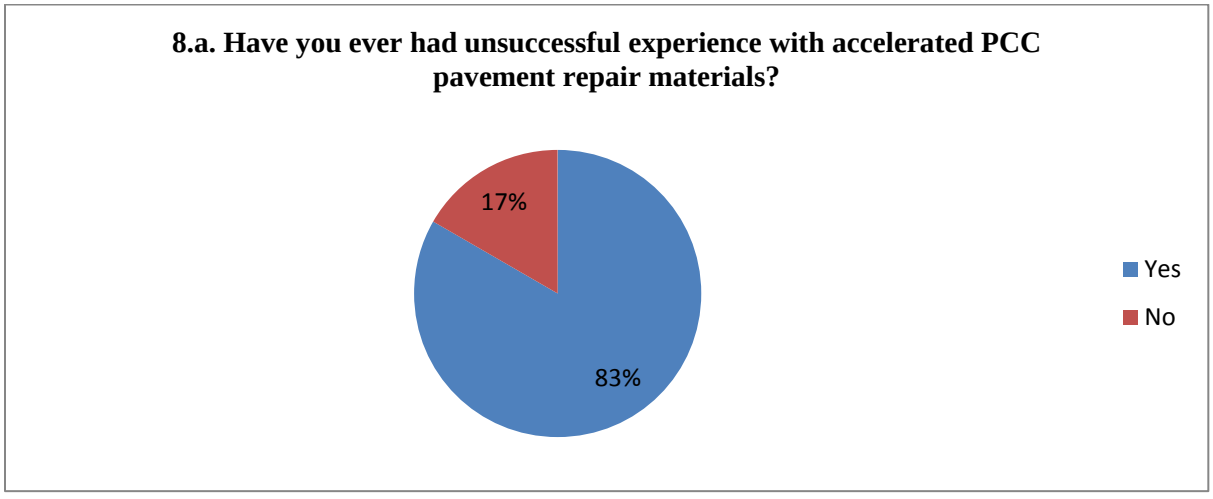
South Dakota	Skipped	
Utah	Concrete Joint repair	Clean out joints with pressurized water jets and air place new sealant
	Partial depth patching	Remove failing materials and replace with patching material, for corner breaks core with 1 ft core filled in with patching material
	Full depth patching	Remove failing material insert tie bars and dowel bars where needed and fill patching material or high early strength concrete
	Dowel bar retrofit	Cut slots on transverse joint place dowel bars fill with patching materials
	Full panel replacement	Use precast panels of high early strength concrete mixes
Washington	Partial depth patching	Saw cut perimeter 2" minimum depth, remove material, sandblast, place patching material according to manufacturer's recommendation.
	Dowel bar retrofit	Cut slots with gang saw, remove material between slots with jackhammer, sand blast slot, place dowel bar assebly, place patching material, saw cut to reestablish joint
	Full panel replacement	Saw cut panel perimeter and relief saw cuts, remove panel, regarded repair base as needed, place dowel bars, place bond breaker material, place and finish concrete
Wisconsin	Skipped	

8.a Have you ever had unsuccessful experience with accelerated PCC pavement repair materials?

State	Yes	No
Colorado	Yes	
Illinois	Skipped	
Indiana	Yes	
Kansas	Yes	
Michigan	Skipped	
Minnesota	Yes	
Missouri	Skipped	
Nebraska		No
Nevada	Skipped	
Ohio	Yes	
Oregon	Yes	
Pennsylvania	Yes	
South Dakota	Yes	
Utah	Yes	
Washington	Yes	
Wisconsin		No

8.a. Have you ever had unsuccessful experience with accelerated PCC pavement repair materials?

Answer option	Response percent	Response count
Yes	83.33	10
No	16.67	2
	Answered questions	12
	Skipped questions	4



8.b. If yes, please specify the material used and the reason they were unsuccessful.

State	Repair Type	Reason for unsuccessful
Colorado	Dowel bar retrofit	Improper grout application on retrofit dowels.
	Full panel replacement	When partial panels removed. have since gone to full panel remove/replace
Indiana	Full depth patching	mid-panel cracks and shrinkage on long patches
Kansas	Concrete Joint repair	Product cured faster than anticipated. Contractor may choose repair material type
	Partial depth patching	1/2-1 in. deterioration around the joint
	Dowel bar retrofit	Durability problem. Deterioration on the top using rapid set patching materials
Minnesota	Concrete Joint repair	Bonding and cracking issues
	Partial depth patching	Bonding and cracking issues
	Dowel bar retrofit	Durability issue
Nebraska	Nebraska has not ever had unsuccessful experience with accelerated PCC pavement repair materials	
Ohio	Concrete Joint repair	Class FS concrete has 900 lbs of cement - shrinkage cracking above dowels
	Full depth patching	Class FS concrete has 900 lbs of cement - shrinkage cracking above dowels cracking above dow els
	Full panel replacement	For FS shrinkage cracking from too much cement
Oregon	Full depth patching	"Rapid Set" product. Our unsuccessful experiences are due primarily to poor subgrade/base, insufficient control over mix design and air content, workmanship, and/or potentially inherent material properties. We have made improvements to the product control and have added macro-fibers. It is too soon to determine if we have an improved success rate.
	Others	Same as full depth patching

Pennsylvania	Partial depth patching	In spall repair applications, certain materials perform better than others.
	Others	In bridge deck applications, certain rapid set material does not work well for large areas
South Dakota	Partial depth patching	Material not staying bonded and cracking of patch material
	Full depth patching	Long term durability of patch material
	Dowel bar retrofit	freeze thaw durability
Utah	Partial depth patching	Likely improper cleaning and use of patching material
	Full depth patching	Likely improper cleaning and use of patching material
	Dowel bar retrofit	Likely improper cleaning and use of patching material
Washington	Dowel bar retrofit	Improper patching material resulting in depressions at slots
	Full panel replacement	Isolated incidences of cracking and/or scaling of rapid setting concrete patching material
Wisconsin	Wisconsin has not ever had unsuccessful experience with accelerated PCC pavement repair materials	

8.b. If yes, please specify the material used and the reason they were unsuccessful.

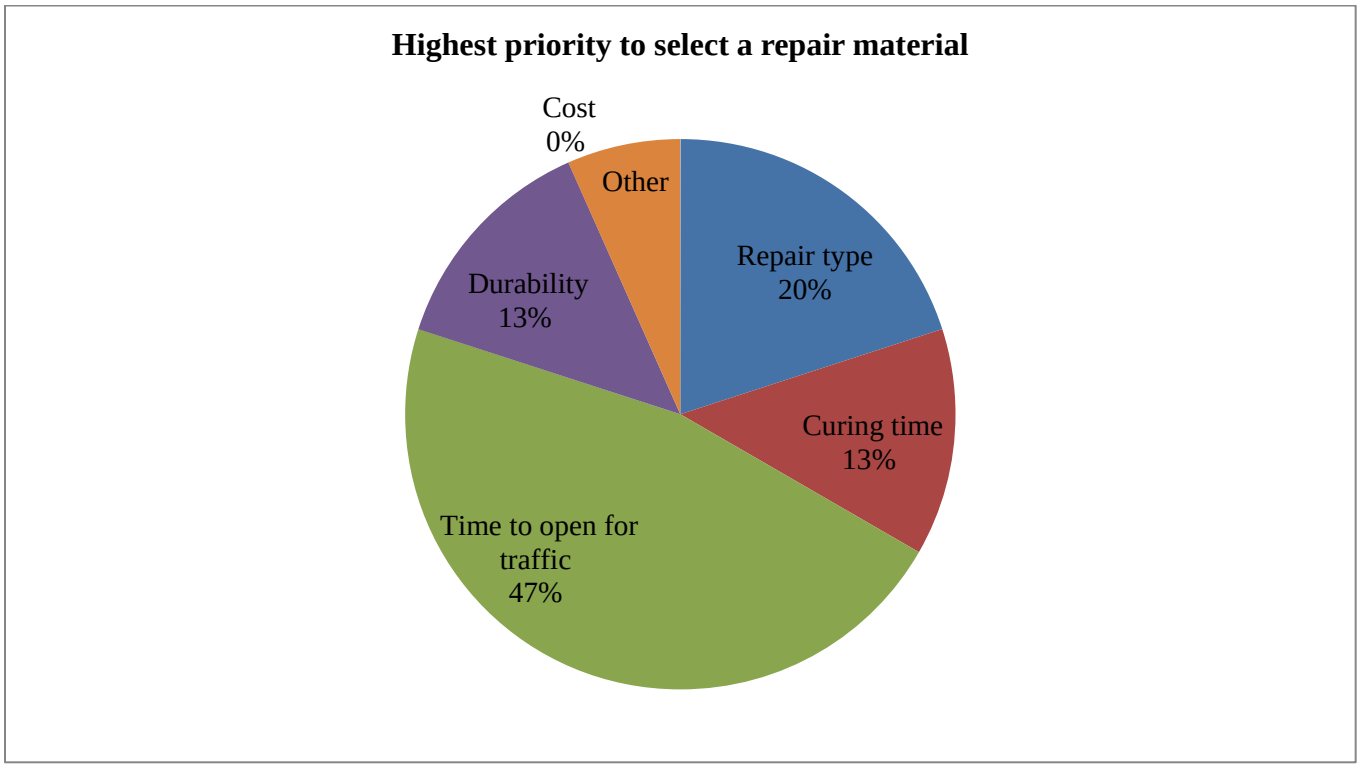
Answer Options	Response Percent	Response Count
Concrete joint repair	30.0%	3
Concrete crack sealing	0.0%	0
Partial depth patching	50.0%	5
Full depth patching	50.0%	5
Dowel bar retrofit	60.0%	6
Full panel replacement	30.0%	3
Intersection repair	0.0%	0
Other(s)	20.0%	2
	answered question	10

9. Which are the factors your agency uses to select a repair material for a given PCC pavement? Please use numbers 1-6 in the boxes to indicate the priority of the factors (1 = highest priority)

State	Repair Type	Curing Time	Time to open for traffic	Durability	Cost	Other, please specify
Colorado	5	2	1	3	4	
Illinois	Skipped					
Indiana	2	4	1	3	5	
Kansas	5	4	3	1	2	6
Michigan	Skipped					
Minnesota	1	1	1	1	3	
Missouri	Skipped					
Nebraska	4	1	1	2	5	
Nevada	Skipped					
Ohio	6	2	1	3	3	
Oregon	1	3	2	4	5	
Pennsylvania	1	5	2	3	4	
South Dakota	2	3	1	4	5	
Utah	3	5	5	4	3	
Washington						1
Wisconsin	2	2	1	3	4	

9. Number of states for each answered option selected (1 = highest priority)

Answer Options	1	2	3	4	5	6	Response Count
Repair type	3	3	1	1	2	1	11
Curing time	2	3	2	2	2	0	11
Time to open for traffic (criteria for time to open for traffic, such as strength gain)	7	2	1	0	1	0	11
Durability	2	1	5	3	0	0	11
Cost	0	1	3	3	4	0	11
Others	1	0	0	0	0	1	2
answered question							**12**
skipped question							**4**



10.a. Does your agency have requirements for placement and curing for the following accelerated PCC repairs?

Require special placement and curing?

Answer Options	Yes	No	Response Count
Concrete joint repair	5	5	10
Concrete crack sealing	0	4	4
Partial depth patching	8	2	10
Full depth patching	7	0	7
Dowel bar retrofit	5	4	9
Full panel replacement	8	1	9
Intersection repair	2	1	3
Other(s)	0	0	0
		answered question	**10**
		skipped question	**6**

10.a. Does your agency have requirements for placement and curing for the following accelerated PCC repairs?

State	Concrete Joint repair	Concrete crack sealing	Partial depth patching	Full depth patching	Dowel bar retrofit	Full panel replacement	Intersection repair	Others
Colorado	No	No	Yes	Yes	No	Yes	Yes	NA
Illinois	Skipped							
Indiana	Yes	NA	NA	Yes	NA	NA	NA	NA
Kansas	No	NA	No	NA	No	NA	NA	NA
Michigan	Skipped							
Minnesota	No	No	No	NA	No	No	NA	NA
Missouri	Skipped							
Nebraska	Yes	NA	Yes	Yes	NA	Yes	Yes	NA
Nevada	Skipped							
Ohio	Yes	NA	NA	NA	NA	Yes	NA	NA
Oregon	Yes	No	Yes	Yes	No	Yes	No	NA
Pennsylvania	No	No	Yes	Yes	Yes	Yes	NA	NA
South Dakota	NA	NA	Yes	Yes	Yes	NA	NA	NA
Utah	No	NA	Yes	Yes	Yes	Yes	NA	NA
Washington	NA	NA	Yes	NA	Yes	Yes	NA	NA
Wisconsin	Yes	NA	Yes	NA	Yes	Yes	NA	NA

10.b. If you answered with yes in question (10.a), please describe the placement and curing condition used

State	Repair Type	Repair materials utilized
Colorado	Partial depth patching	It would depend on the material used. If it was pre-packaged rapid set repair materials, mixing, placing and curing would follow the manufacturer's recommendations. For accelerated concrete, it would be cured with curing compounds and insulating blankets. External heat may also be used in cold environments.
	Full depth patching	Same as partial depth repair
	Full panel replacement	Same as partial depth repair
	Intersection repair	Same as partial depth repair
Illinois	Skipped	
Indiana	Concrete Joint repair	Experimenting
	Full depth patching	Experimenting
Kansas	Kansas does not have requirements for replacement and curing	
Michigan	Skipped	
Minnesota	Minnesota does not have requirements for replacement and curing	
Missouri	Skipped	
Nebraska	Concrete Joint repair	The finished concrete is sprayed with white cure and then covered with plastic and insulation board. The concrete remains covered until we have strength using the Maturity Method.
	Partial depth patching	Same as concrete joint repair
	Full depth patching	Same as concrete joint repair
	Full panel replacement	Same as concrete joint repair
	Intersection repair	Same as concrete joint repair
Nevada	Skipped	
Ohio	Concrete Joint repair	See our spec book for all the following
	Full panel replacement	See our spec book for all the following

Oregon	Concrete Joint repair	Do not place PCC during periods of rain. Do not place PCC on frozen bases. Stop placement when descending air temperature falls below 35 °F. Do not begin placement until the air temperature is 35 °F in the shade and rising and is forecast to remain above 35 °F.
	Partial depth patching	Dry
	Full depth patching	Same as concrete joint repair
	Full panel replacement	Same as concrete joint repair
	Others	Same as concrete joint repair
Pennsylvania	Partial depth patching	Cured the same as normal pav't or mfr. rec. for product used
	Full depth patching	Same as Partial depth patching
	Dowel bar retrofit	Same as Partial depth patching
	Full panel replacement	Same as Partial depth patching
South Dakota	Skipped	
Utah	Partial depth patching	Gain a specified strength prior to opening for traffic, penalty for not meeting
	Full depth patching	Same as Partial depth patching
	Dowel bar retrofit	Same as Partial depth patching
	Full panel replacement	Same as Partial depth patching
Washington	Partial depth patching	Cure patching material according to manufacturer's recommendations, must attain 2,500 psi compressive strength prior to opening to traffic.
	Dowel bar retrofit	Cure patching material according to manufacturer's recommendations.
	Full panel replacement	Conventional practices for placing and curing cement concrete pavement are used. Concrete must achieve
Wisconsin	Skipped	

11.a. Does your agency require the use of special equipment or methods for the following accelerated PCC pavement repairs?

State	Concrete Joint repair	Concrete crack sealing	Partial depth patching	Full depth patching	Dowel bar retrofit	Full panel replacement	Intersection repair	Others
Colorado	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA
Illinois	Skipped							
Indiana	NA	NA	NA	Yes	NA	NA	NA	NA
Kansas	NA	NA	NA	NA	Yes	NA	NA	NA
Michigan	Skipped							
Minnesota	No	No	No	NA	No	No	NA	NA
Missouri	Skipped							
Nebraska	No	No	No	No	No	No	No	NA
Nevada	Skipped							
Ohio	Yes	NA	NA	Yes	NA	NA	NA	NA
Oregon	No	No	No	No	No	No	No	NA
Pennsylvania	No	No	No	No	No	No	NA	NA
South Dakota	NA	No	No	No	No	No	NA	NA
Utah	No	NA	No	No	No	No	NA	NA
Washington	NA	NA	No	NA	No	No	NA	NA
Wisconsin	No	No	No	No	No	No	NA	NA

11.b. If you answered with yes in question (11.a), please describe the special equipment or method used

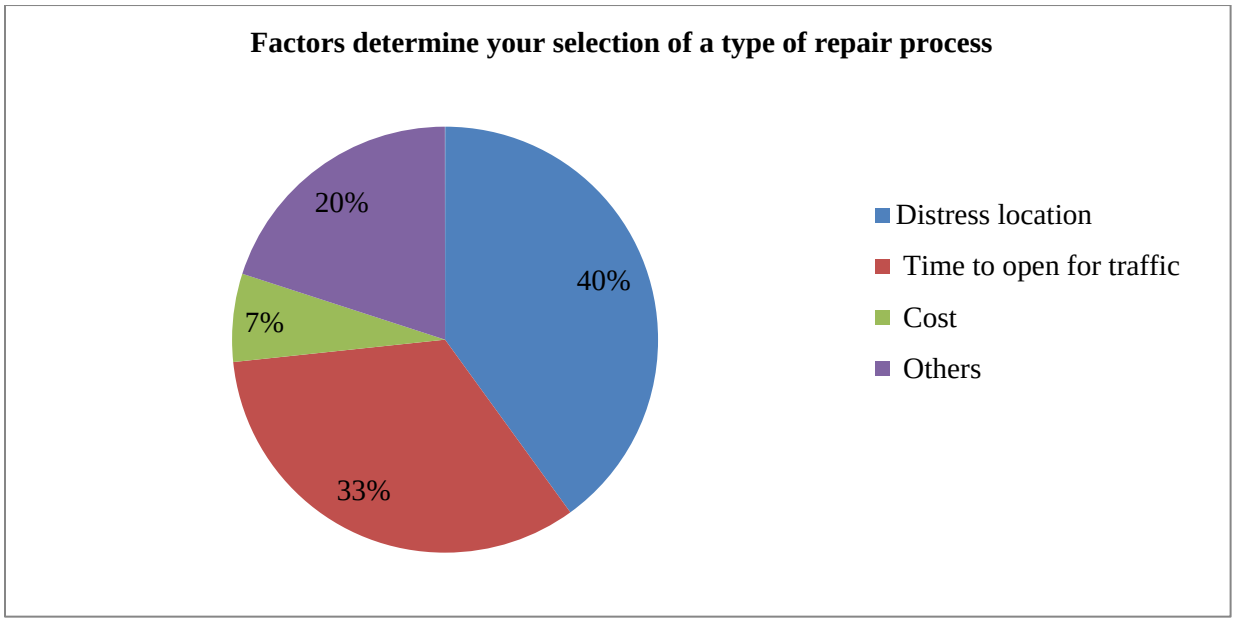
State	Repair Type	Special equipment or method used
Colorado	Concrete Joint repair	Sawcut the area needing replacement, jack hammer out the damaged concrete. Recondition base material if needed. Drill and epoxy new joint steel if needed. Place concrete.
	Concrete crack sealing	Cracks are usually not sealed, but they are, standard joint sealing materials and equipment is used. Sometimes, our maintenance crews seal concrete joints with hot poured HMA crack sealant.
	Partial depth patching	We follow the guidelines from FHWA http://www.fhwa.dot.gov/pavement/concrete/repair04.cfm
	Full depth patching	Same as concrete joint repair
	Dowel bar retrofit	We follow the FHWA procedures http://www.fhwa.dot.gov/pavement/preservation/ppcl08.cfm
	Full panel replacement	Same as concrete joint repair
	Intersection repair	Same as concrete joint repair
Illinois	Skipped	
Indiana	Full depth patching	Experimenting with admixtures and possibly internal curing with light weight aggregates
Kansas	Dowel bar retrofit	quick light saw in specification
Michigan	Skipped	
Minnesota	Minnesota does not require the use of special equipment or methods	
Missouri	Skipped	
Nebraska	Nebraska does not require the use of special equipment or methods	
Nevada	Skipped	
Ohio	Concrete Joint repair	Blankets see spec book
	Full depth patching	Blankets see spec book
Oregon	Oregon does not require the use of special equipment or methods	
Pennsylvania	Pennsylvania does not require the use of special equipment or methods	
South Dakota	South Dakota does not require the use of special equipment or methods	
Utah	Utah does not require the use of special equipment or methods	
Washington	Washington does not require the use of special equipment or methods	
Wisconsin	Wisconsin does not require the use of special equipment or methods	

12. Which factors determine your selection of a type of repair process? Please use numbers 1-4 in the boxes to indicate the priority of the factors (1 = highest priority).

State	Distress location	Time to open for traffic	Cost	Others	Other, please specify
Colorado	1	2	3		
Illinois	Skipped				
Indiana		1			
Kansas	1	3	2	4	
Michigan	Skipped				
Minnesota	1	1	1		
Missouri	Skipped				
Nebraska	1	1	3		
Nevada	Skipped				
Ohio	1	3	2		
Oregon	3	2	4	1	Type of failure and whether or not it justifies partial depth (spall) repair or full depth-type repairs.
Pennsylvania	1	2	3		
South Dakota	3	2	4	1	Distress Type
Utah	2	1	2		
Washington				1	The repair process is determined by the type of distress.
Wisconsin	2	1	2		

12. Number of states for each answered option selected (1 = highest priority).

Answer Options	1	2	3	4	Response Count
Distress location	6	2	2	0	10
Time to open for traffic	5	4	2	0	11
Cost	1	4	3	2	10
Others	3	0	0	1	4
				answered question	**12**
				skipped question	**4**

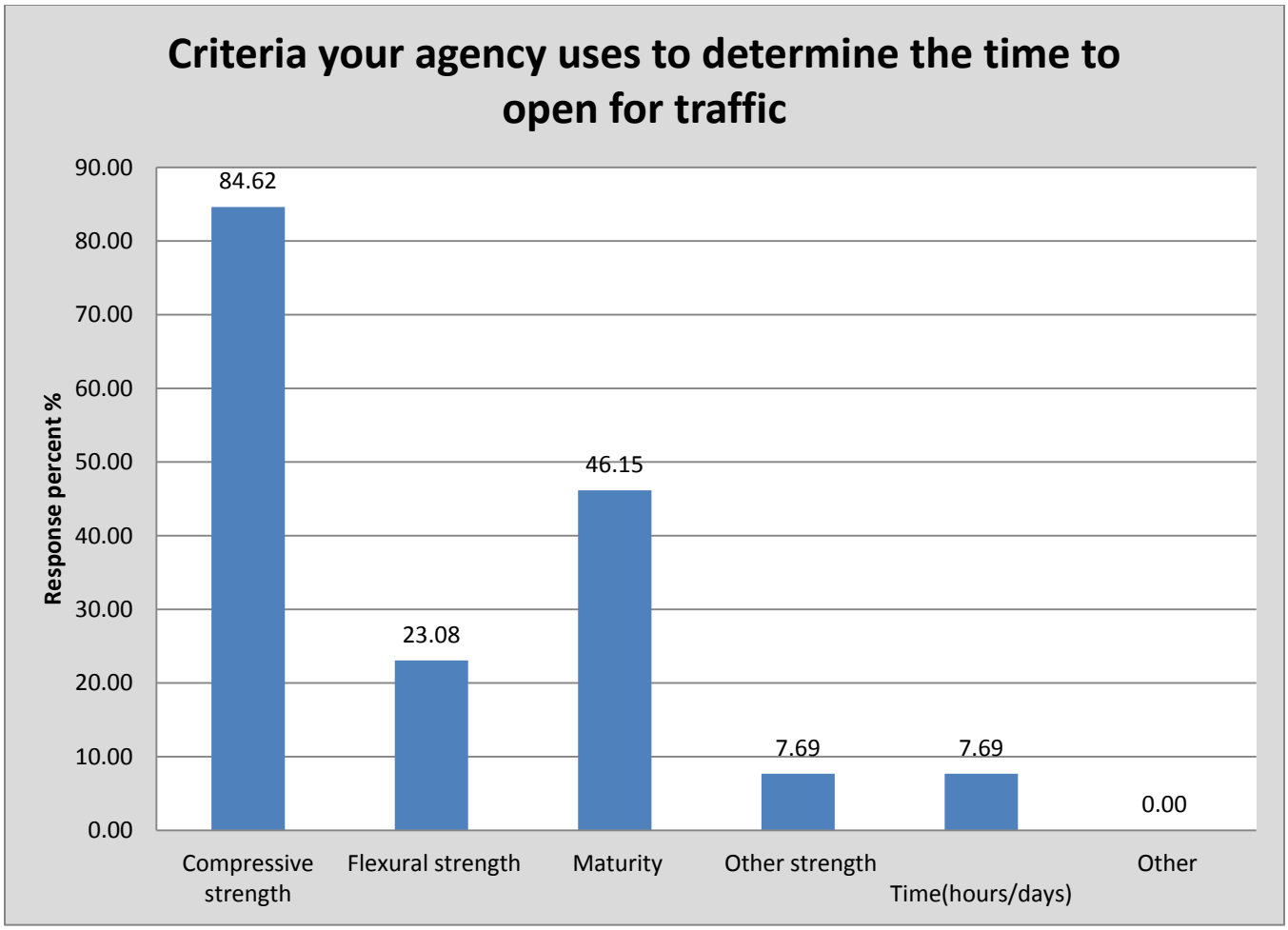


13.a. What criteria does your agency use to determine the time to open for traffic?

state	Compressive strength	Flexural strength	Maturity	Other strength	Time (hours/days)	Other
Colorado	x	NA	x	NA	x	NA
Illinois	Skipped					
Indiana	NA	x	x	NA	NA	NA
Kansas	x	NA	NA	NA	NA	NA
Michigan	Skipped					
Minnesota	x	x	NA	NA	NA	NA
Missouri	x	NA	NA	NA	NA	NA
Nebraska	x	NA	x	NA	NA	NA
Nevada	Skipped					
Ohio	NA	x	x	NA	NA	NA
Oregon	x	NA	NA	NA	NA	NA
Pennsylvania	x	NA	NA	NA	NA	NA
South Dakota	x	NA	x	x	NA	NA
Utah	x	NA	NA	NA	NA	NA
Washington	x	NA	x	NA	NA	NA
Wisconsin	x	NA	NA	NA	NA	NA

13.a. What criteria does your agency use to determine the time to open for traffic?

Answer Options	**Response Percent %**	**Response Count**
Compressive Strength	84.62	11
Flexural Strength	23.08	3
Maturity	46.15	6
Other Strength	7.69	1
Time (hours/days)	7.69	1
Other	0.00	0
answered question		**13**
skipped question		**3**


Criteria your agency uses to determine the time to open for traffic
Response percent %
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
84.62
23.08
46.15
7.69
7.69
0.00
Compressive strength
Flexural strength
Maturity
Other strength
Other
Time(hours/days)

13.b. Please elaborate on the chosen criterion in question (13.a), for example, if strength is used as the criterion, what is the minimum required strength?

state	Compressive strength	Flexural strength	Maturity	Other strength	Time (hours/days)	Other
Colorado	3000 psi					
Illinois	Skipped					
Indiana		Experimenting				
Kansas	3.5 ksi					
Michigan	Skipped					
Minnesota	3,000 psi	500 psi				
Missouri	3,000 psi					
Nebraska	3,500 psi					
Nevada	Skipped					
Ohio		400 psi 3 pt flexural	400 psi 3 pt flexural			
Oregon	2,500 psi if "rapid set" or similar product is used. 3,000 psi for Type I/II/III cement					
Pennsylvania	3,000 psi for all repairs except partial depth = 2,000 psi					
South Dakota	Varies depending on time to open to traffic. From 3,600 to 4,000.			Rebound hammer to evaluate compressive strength at early ages	48 hour spec at a minimum temp.	
Utah	4,000 psi					
Washington	2,500 psi		Maturity is used to determine if the concrete has reached the required 2,500 psi compressive strength			
Wisconsin	3,000 psi					

14. What is the expected service life of the accelerated PCC pavement repairs listed below?
How many years of its expected service life?

Answer Options	0-3 years	3-5 years	5-10 years	10-15 years	>15 years	Response Count
Concrete joint repair	0	0	2	3	2	7
Concrete crack sealing	1	0	0	2	1	4
Partial depth patching	0	0	2	6	0	8
Full depth patching	0	0	1	3	2	6
Dowel bar retrofit	0	0	1	2	3	6
Full panel replacement	0	0	0	3	5	8
Intersection repair	0	0	0	1	0	1
Other(s)	0	0	1	0	0	1
					answered question	**9**
					skipped question	**7**

14. The expected service time of each repair type

State	Concrete Joint repair	Concrete crack sealing	Partial depth patching	Full depth patching	Dowel bar retrofit	Full panel replacement	Intersection repair	Others
Colorado	Skipped							
Illinois	Skipped							
Indiana	Skipped							
Kansas	5 to 10		10 to 15		10 to 15			
Michigan	Skipped							
Minnesota	5 to 10	0-3	5 to 10		5 to 10	10 to 15		
Missouri	Skipped							
Nebraska	10 to 15	10 to 15	10 to 15	10 to 15		10 to 15	10 to 15	
Nevada	Skipped							
Ohio	10 to 15			10 to 15		>15		
Oregon	10 to 15		10 to 15	5 to 10		>15		5 to 10
Pennsylvania	>15	>15	10 to 15	>15	>15	>15		
South Dakota		10 to 15	5 to 10	>15	>15	>15		
Utah	>15		10 to 15	10 to 15	10 to 15	10 to 15		
Washington			10 to 15		>15	>15		
Wisconsin	Skipped							