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Best Practices for Patching Composite Pavements

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16. Abstract

Concrete and composite (asphalt over concrete) pavement distress frequently occurs in the vicinity of joints or cracks in the concrete slabs. Water can enter into the pavement structure at these locations, leading to concrete deterioration and loss of subgrade support. Permanently patching these weakened areas can extend the pavement life considerably before major rehabilitation or reconstruction becomes necessary. Identifying where these or other distresses are occurring in composite pavements is problematic, however, because the asphalt overlay masks the defects in the underlying concrete. Reflective cracking in the overlay can indicate the presence of the joints or working cracks in the concrete, but the visual appearance of the surface is not a reliable indication of the soundness of the concrete. So, accurately identifying where to patch and how long patches should be is extremely difficult.

The preferred method for repairing these pavements in Indiana and many other states is through the use of full-depth doweled concrete patches with asphalt overlay. In many cases, matching the existing pavement in terms of foundation and pavement materials and layer thicknesses is called for. This can create logistical and construction problems because of the need to perform different types of work with different materials and equipment, often with restricted times for lane closures. This research was undertaken in an attempt to identify best practices used by other states and documented in the literature to improve the identification, construction and performance of patches in composite pavements through a literature review and survey.

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EXECUTIVE SUMMARY

Introduction

Concrete and composite (asphalt over concrete) pavement distress frequently occurs in the vicinity of joints or cracks in the concrete slabs. Water can enter into the pavement structure at these locations, leading to concrete deterioration and loss of subgrade support. Permanently patching these weakened areas can extend the pavement life considerably before major rehabilitation or reconstruction becomes necessary. However, identifying where these or other distresses are occurring in composite pavements is problematic because the asphalt overlay masks the defects in the underlying concrete. Reflective cracking in the overlay can indicate the presence of the joints or working cracks in the concrete, but the visual appearance of the surface is not a reliable indication of the soundness of the concrete. Therefore, accurately identifying where to patch and how long patches should be is extremely difficult.

The preferred method for repairing these pavements in Indiana and many other states is through the use of full-depth doweled concrete patches with asphalt overlay. In many cases, matching the existing pavement in terms of foundation and pavement materials and layer thicknesses is called for. This can create logistical and construction problems because of the need to perform different types of work with different materials and equipment, often with restricted times for lane closures. This research was undertaken in an attempt to identify best practices used by other states and documented in literature to improve the identification, construction, and performance of patches in composite pavements through a literature review and survey.

Findings

A survey was distributed to members of the AASHTO Subcommittee on Maintenance and other contacts. A total of 29 responses from 26 states were received. In general, the responding states share INDOT's concerns and issues. Unfortunately, none reported innovative techniques to definitively define patching locations or significantly improve constructability and performance.

The literature review did document a number of approaches that have been tried and, in some cases, implemented. Most commonly, patch locations and quantities are estimated by a visual survey of the asphalt surface, though this is acknowledged to be inaccurate. Several states supplement the visual survey with deflection testing in an attempt to estimate load transfer at the joints and the stiffness of the concrete. The success of this approach is mixed at best; it can give somewhat more information than a visual survey alone but is not definitive. Other states use ground penetrating radar (GPR) in addition to deflection testing. GPR can indicate thickness of the asphalt layer and may give some additional information on the condition of the asphalt or, to a lesser extent, the concrete, but again is not definitive.

The literature review was more successful at finding alternative materials and types of patches that could be considered for use in various situations in Indiana. These alternatives, as well as possible ways to improve the constructability of these types of patches, are enumerated for INDOT's further consideration and as a starting point for discussions with district personnel. The options include such things as the following:

- Continuing to use doweled concrete patches and matching the existing pavement type (concrete/composite) when feasible but having other options available.
- Placing the concrete full depth (up to the existing surface) to save time, which is needed to place and compact multiple lifts of asphalt in the patched area when patching prior to removal of the overlay.
- Exploring alternate rapid setting concretes that can increase early strength without compromising ultimate strength or durability.
- Allowing the use of full-depth asphalt patches in some cases and milling off the bump formed when the asphalt is "squeezed" by expansion of the adjacent concrete during hot weather.
- Using coarse aggregate or concrete rubble to stabilize the base and backfill the lower part of the patch.
- Using visual survey plus deflection testing and perhaps GPR to identify the location of needed patching. While this approach has not been totally reliable, it can give some indication of the presence of sound concrete. The cost, time, and resources required to do extensive FWD testing and analysis must be weighed against the benefits of potentially improved patch location and quantity determinations.
- Coring near reflective cracks or other areas of surface distress is destructive but gives the clearest, least risky picture of the soundness of the concrete.
- Milling the asphalt overlay before doing a visual inspection or FWD testing of the concrete allows inspection of the actual concrete pavement. This would likely require revising the current policy on how long a milled surface can be trafficked and could impact the estimation of patching quantities.
- Over-cutting the pavement beyond what is needed to repair any subgrade issues will allow for better compaction or place patches deeper than the existing pavement to eliminate working in and compacting the subbase.
- Stabilizing the foundation before removing the pavement by deep polymer injection to improve the support conditions, reduce or eliminate the need to compact the base/subgrade, reduce the construction time, and ultimately improve the patch performance. The initial and life cycle costs, however, need to be considered.
- Placing steel plates over the concrete to protect it from traffic during curing, at least on lower volume, lower speed roadways.
- Allowing longer lane closures would give contractors more time to do the job properly and could result in better performance. There is, of course, more chance for increased congestion, delays, and accidents. Improved patch performance, however, might mean a longer service life before additional rehabilitation has to occur.

Implementation

No specific specification or policy changes are recommended at this time; rather a wide range of options have been identified for further consideration. Two changes discussed with the study advisory committee have already been implemented. This includes the use of vertical saws instead of circular saws to avoid cutting into and damaging the sound pavement adjacent to the patch. The other change is allowing the saw cuts to be made the night before pavement removal so that the road can be opened to traffic and the patching process can progress more efficiently the next night.

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1. INTRODUCTION

Concrete and composite (asphalt over concrete) pavement distress frequently occurs in the vicinity of joints or cracks in the concrete slabs. Water can enter into the pavement structure at these locations, leading to concrete deterioration and loss of subgrade support. Permanently patching these weakened areas can extend the pavement life considerably before major rehabilitation or reconstruction becomes necessary.

The preferred method for repairing these pavements in Indiana and many other states is through the use of full-depth doweled concrete patches. Inverted T patches have also been used in many places. In this technique, the base or subbase is removed below the patch and for some distance (usually 6 inches) under the edges of the adjacent pavement then replaced with concrete. Inverted Ts, however, have largely fallen into disfavor because of poor performance. This is usually attributed to poor compaction of the material under the patched area, especially under the adjacent pavement, or poor consolidation of the concrete in the Ts. Constructability is also an issue with inverted Ts, particularly in excavating the areas under the adjacent pavement. Full-depth asphalt patches are sometimes used, but often lead to "mini-speed bumps" when expansion of the surrounding concrete pavements in hot weather causes the asphalt to bulge upwards.

While full-depth doweled patches reportedly perform better than inverted Ts, they are not without construction difficulties and performance issues. Dowels or tie bars are needed to prevent the patch from moving relative to the adjacent pavement, which would cause faulting and poor ride quality. For this type of patch to perform adequately, it is essential that the dowels be inserted into sound concrete in the existing pavement; otherwise the concrete around the dowels can continue to deteriorate and the dowels will not be able to stabilize the patch. How far back to cut into the existing pavement is difficult or impossible to determine reliably through visual inspection of the pavement surface, however, especially with a composite pavement. While the patches are required to be at least 6 feet long (according to Indiana's design manual), they can be longer in order to repair the distress and get into sound concrete. (If the concrete is not sound enough to hold dowel bars at some point, another rehabilitation strategy is probably needed.) Dowels cannot be used if slab fracturing (rubblizing or cracking and seating) has been previously performed on the concrete pavement; in these cases, inverted Ts or full-depth asphalt patches may be the only viable options.

Once saw cuts are made at the ends of the patch area, the deteriorated concrete has to be removed, either by lifting the slab or breaking it up and removing it in pieces. The latter, in particular, can disrupt the underlying base or subbase material. This area needs to be well-compacted and smooth for the patch to perform well. Compacting in this tight area and determining that adequate compaction has been achieved (quality acceptance) can be difficult. If the subbase is in such a condition that it needs to be removed, it is generally directed that it be replaced with material of the same type. Drainage must also be maintained. Existing edge drains should be undisturbed or reinstated. If the adjacent base, subbase or subgrade does not drain well, there can be concerns about "building a bathtub" if the replacement material is not well compacted.

The Indiana DOT *2013 Design Manual* (INDOT, 2013) states that patches in composite pavements "should always match the existing pavement composition and depths where practical." That is, a composite patch is installed. If the performance problem is confined to the overlying asphalt layers, say because of stripping in the asphalt, it is possible to mill out and replace the asphalt only. If the asphalt is removed and the concrete underneath is deteriorated, at least 6 feet of the concrete must be cut out. If the remaining concrete pavement is not sound, additional pavement must be removed until sound concrete is found. Then the underlying material must be compacted, and dowel bars inserted and grouted. Different sizes of dowel bars may be needed depending on the thickness of the existing concrete. Concrete is poured up to the top of the existing concrete. (If the entire project is to be overlaid after patching, in some cases concrete can be poured up to the top of the pavement to allow traffic to continue to travel until the milling and resurfacing can be completed. The top of the concrete patch is then milled off along with the adjacent asphalt.) After some time for curing, each layer of asphalt is placed and compacted. Each area to be patched must be evaluated individually to determine how much material has to be removed. This multiple-step process creates logistical challenges. Contractors are required to have a variety of materials (concrete and asphalt mixes, dowel bars) and equipment (for removing pavement, compacting base/subbase, and inserting dowel bars) on hand though not all of these materials will necessarily be used. Preparing for all possible contingencies can lead to increased costs for the patching operations because of the uncertainty.

The process can also be time consuming since multiple steps are involved, and time is needed for the concrete to cure and asphalt to cool after compaction. This can cause issues with maintenance of traffic. On interstates, traffic must be maintained in accordance with the Interstate Highways Congestion Policy 2017, (formerly known as the Lane Closure Policy), which may require that all work be completed between 9:00 p.m. and 6:00 a.m. so that the road can be reopened to traffic. Maintenance of traffic can be especially problematic on two-lane roads.

In addition to constructability and logistical issues, performance problems have been reported with both full-depth and inverted T patches. These problems include settlement of the patches, cracking and deterioration within the patch and continued deterioration in the existing pavement adjacent to the patch. These problems have been variously attributed to construction defects (e.g., poor consolidation), failure to remove enough of the existing pavement (i.e., identification of sound concrete), materials issues (shrinkage of fast-setting concrete) and other problems.

1.1 Problem Statement

Patching composite and, to a lesser extent, concrete pavements poses numerous constructability and performance issues. A synthesis of research and experience was needed to identify ways to facilitate proper construction and improve the ultimate performance of these patches. This research explored possible ways to improve the constructability and performance of pavement patching. The main focus is on composite pavements, but findings may also apply to patching concrete pavements.

1.2 Objectives

The objective of this project was to synthesize existing information relative to the materials, design, and placement of patches in composite and concrete pavements, with the ultimate goal of improving the performance of patches in composite and other pavements. That information was gathered through a thorough literature review and a survey of other states' practices, procedures and policies. The search for information attempted to determine the following:

- What techniques can be used to determine the patch length (i.e., to identify sound concrete)?
- What materials do other states use for patching composite pavements?
- What can be done or used to allow opening the patched area to traffic quickly?
- Are there any materials that can be used to stabilize the subbase or seal the adjacent concrete to reduce the risk of settlement or further deterioration around the joint?
- Are there any other techniques to improve the constructability of patching composite pavements?
- How is the subbase or base compacted and how can the adequacy of compaction be assessed?
- How well do patches placed using the alternatives above perform?
- Any other related questions suggested by the Study Advisory Committee.

1.3 Work Plan

Achieving the objectives of this research project was initially planned to involve completion of the following tasks:

1. *Literature review*
2. *Survey of states*
3. *Review of selected INDOT patching contracts*
4. *Analysis of collected information*
5. *Reporting*

The intent of Task 3 was to try to identify one successful and one less successful contract to compare and contrast within a single district. During the course of this project, however, the business owner was tasked with doing a more detailed evaluation covering more projects. It was felt that the resulting analysis and documentation would be more comprehensive and valuable than the limited comparison planned in this study. In addition, working with district personnel from multiple districts affords the opportunity to get their feedback on potential options identified through this JTRP project so that INDOT can consider implementing some of these options through specification or policy changes. Therefore, the focus of this project shifted to more thoroughly enumerating options for INDOT's consideration. (The PI remains committed to participate in these discussions after completion of this project in order to facilitate implementation.)

2. LITERATURE REVIEW

There is little in the way of research literature regarding patching composite pavements, though there is quite a bit about patching concrete and asphalt pavements. The literature search, however, did identify some agency design and maintenance manuals and similar documents related to composite pavements.

2.1 Types of Patches and Their Performance

There are basically three types of patches used in composite pavements.

1. Full-depth doweled concrete patches with or without an overlay (usually asphalt)
2. Inverted T patches with or without an overlay
3. Full-depth asphalt patches

Undoweled concrete patches are not recommended because of their tendency to settle. Hall and Darter (1994) found that full-depth undoweled patches in Illinois deteriorated more quickly than doweled patches. Nonetheless, some states do continue to use them, as shown later in the survey results. Inverted Ts are intended to support the adjacent concrete to limit faulting at the ends of the patch. As mentioned in the Introduction, however, these pose construction difficulties and can also settle if not constructed properly. Asphalt patches often cause ride problems when expansion of the adjacent concrete causes a "hump" in warm weather or a dip when traffic consolidates the asphalt.

Li and Wen (2014) studied the effects of existing pavement conditions and repairs on the subsequent performance of asphalt overlays. They compared the performance of 111 overlays of composite pavements in Wisconsin placed over non-patched pavements, full-depth asphalt patches, undoweled concrete patches and doweled concrete patches. They concluded that the thickness of the overlay had a significant impact on transverse and longitudinal cracking, as well as edge and surface raveling. Not surprisingly, the traffic level affected transverse cracking and rutting in the overlay. Full-depth asphalt patches were found to perform best in terms of reducing longitudinal cracking, while doweled concrete patches resulted in the least amount of surface raveling. No significant differences in transverse cracking were observed between the different repair techniques.

2.1.1 INDOT Patching Practices

According to INDOT's *2013 Design Manual*, the preferred patching method is to match the existing pavement in terms of depth and materials "where practical" (INDOT, 2013). Inverted T patches are included in the *2013 Design Manual* but are not intended to be included in the next revision; in fact, they are being removed from existing pavements during rehabilitation (JTRP, 2017). In addition, the *General Instructions to Field Employees* (INDOT, 2020) reports that keyed patches (aka inverted Ts) are no longer used.

The sequence of activities, then, begins by removing any asphalt and unsound concrete. The use of vertical saws is now required to prevent over-cutting into the adjacent pavement by more than 6 in. A specification change is to cut the pavement the night before removing it to improve productivity was accepted by the Specification Committee in March 2019; this will now be allowed on a case-by-case basis through a special provision. The subbase is to be left in place if possible; if the subbase must be replaced or removed to treat the subgrade, the subbase is to be replaced with the same material (INDOT, 2005). The subbase should be compacted in place if clean and relatively dry. If the subbase is clean but saturated, the area engineer and project engineer or supervisor should determine if drainage or new aggregates should be installed. Existing underdrains should be maintained or reinstated. Dowel bars are inserted into the adjacent concrete at each end of the patch and may be required within long patches. Reportedly, these procedures are not being uniformly practiced across the state (JTRP, 2017).

2.2 Identifying Patch Locations and Extent

Identifying the location and extent of underlying concrete that needs to be replaced is one of the most challenging aspects of patching composite pavements since the presence of the asphalt overlays obscures the condition of the underlying concrete. In fact, a JTRP study in Vincennes using neural networks found no correlation between asphalt and concrete distress (Kang et al., 2015).

Pavement condition assessment on composite pavements typically consists of a visual inspection of the surface, deflection testing (usually Falling Weight Deflectometer, FWD) and limited coring (Construction Technology Laboratories, Inc., 2003). Hall and Darter (1994) produced guidelines for using the FWD to evaluate composite pavements for the Illinois DOT. They developed a back calculation procedure to identify sound concrete and estimate the moduli of the concrete and foundation that correlated well with the condition of cores. Sound concrete would be expected to have a modulus of 3 to 8 million psi (28 million psi for sound CRCP) while concrete with significant D cracking would have a modulus in the range of 500,000 to 3 million psi (Hall & Darter, 1994). However, many references note that visual inspection and FWD analysis are not reliable methods (Kang et al., 2015; Construction Technology Laboratories, Inc., 2003).

Ohio recommends coring ahead of patching to identify sound concrete using a minimum 4-inch diameter core. Cores are extracted a minimum of 3 ft from existing joints or cracks, presumably to allow for a minimum 6-ft patch. If the core detects sound concrete, a concrete patch is placed using one of four classes of concrete depending on the time available for curing. If sound concrete cannot be found, an asphalt patch is allowed. The manual states that visual inspection and FWD analysis will not identify the areas needing patching (ODOT, 2020). The *Ohio Asphalt* magazine published by Flexible Pavements of Ohio maintains that coring is "one of the easiest and most cost effective ways to minimize risk and improve plan quantity" (Flexible Pavements of Ohio, 2018).

The Ontario Ministry of Transportation conducted an extensive pavement investigation (46 km) on Highway 401 near the border crossing at Windsor/Detroit (Hein, 2002). This pavement was originally constructed in the 1950s and overlaid in the late 1960s because of faulting. Various overlays and patching had been performed as well. After about 35 years of service as a composite pavement, in 2000, a special provision was added to a shoulder paving contract to provide a detailed assessment of the pavement condition for future rehabilitation contracts in the corridor. It was determined that milling off the asphalt throughout the corridor would be expensive and would cause too much user delay, so an innovative evaluation plan was developed. Detailed evaluations were conducted at 16 investigation areas, each about 50-m long, in the driving lane. At each site, the asphalt overlay was removed, and the underlying concrete conditions were determined. In addition, cores were taken; test pits were cut through the shoulder at a joint; FWD testing was performed at joints and cracks to assess load transfer and slab support conditions; and samples were taken for lab testing and classification of the base, subbase and subgrade. The authors concluded that there was no correlation between the visual condition of the asphalt overlay and the underlying concrete condition. They also concluded that FWD testing on the asphalt overlay would not accurately reflect the support and load transfer in the concrete though this type of testing could help develop an initial estimate of patching quantities needed. In practice, the visual survey is used to estimate plan quantities of patching, then they are revised based on another condition survey and deflection testing after removal of the overlay. Lastly, the authors concluded that an extensive condition assessment such as this could be cost effective on a corridor to estimate the pavement conditions for several different rehabilitation contracts at one time (Hein, 2002).

Maryland uses the typical combination of visual distress surveys, deflection testing and coring, plus a drainage survey, to evaluate composite pavements (Construction Technology Laboratories, Inc., 2003). A study conducted for Maryland by Construction Testing Laboratories, Inc., concluded that this combination is reasonable but suggested some refinements. For example, the FWD testing should be conducted at those locations identified as problematic by the condition survey, specifically those locations with load transfer efficiencies (LTE) <70%. Because reflection cracking is the predominate distress observed on Maryland's composite pavements, the extent of reflective cracking should be quantified separately from other distresses. Areas with reflective cracking and LTEs <70% should be cored to determine the concrete condition and are likely candidates for repair. That information should be used to estimate patch quantities. The report also considered implementation of additional non-destructive testing to better refine the patching quantities. Ground penetrating radar (GPR), impact echo and impulse response were explored but it was concluded that routine use was not practical given the then-current state of the technology. (Construction Technology Laboratories, Inc., 2003)

Since the time of the Maryland study, additional work has been done with nondestructive testing, especially the use of GPR. In fact, INDOT explored the use of network-level FWD and GPR testing to evaluate structural condition as part of the pavement management system (Noureldin et al., 2003). In a study looking at the condition of interstates, US routes and state highways, the utility of this type of network-level evaluation was demonstrated. Three FWD tests per mile were recommended in the driving lane to assess the structural capacity of the pavements at that level. The GPR testing was intended to develop a pavement thickness inventory. (Noureldin et al., 2003) This level of data collection would not be sufficient to estimate patching quantities on a particular contract where more detailed information tied to specific joints or cracks would be needed.

Maser explored the use of GPR data to evaluate composite pavement thickness and underlying concrete condition on interstates in Illinois, Connecticut and New York. The data was analyzed to determine the thickness of the asphalt overlay as well as the dielectric constant of the concrete at the asphalt/concrete interface. A high or low dielectric constant could indicate a high moisture content or low density. The GPR data was compared to cores. The thickness estimated from the GPR data correlated well with the core thickness. While it was concluded that GPR data could identify areas where the dielectric constant was either high or low, and therefore might indicate high moisture infiltration or unsound concrete, "ground truth" data was not available to verify the accuracy (Maser, 2002).

The Connecticut DOT also explored the use of GPR and FWD testing in conjunction with a visual survey and boring to improve the accuracy of planned repair quantities on composite pavements (Khan et al., 2017). The visual survey was conducted using downward facing images to rate the condition of underlying joints. The GPR data was used to estimate layer thicknesses and assess joint conditions. Then FWD testing was performed at selected joints to determine the load transfer efficiency and at mid-slab to assess modulus. The researchers concluded that the combination of GPR, FWD and visual survey correlated well and could be used to better estimate which joints need repair. This conclusion had not yet been verified by assessing the concrete condition during construction when the asphalt will be milled off (Khan et al., 2017).

Zhou and Scullion looked into use of GPR plus FWD and rolling dynamic deflectometer (RDD) to evaluate pavement condition (2007). Texas routinely uses the RDD, so it was included in this study with the other two NDT methods, to identify areas needing repair and to design the needed overlay thickness. The RDD provides continuous deflection profiles as opposed to the spot tests of the FWD. The authors conclude that in addition to providing asphalt layer thickness, the GPR data could help to identify major defects in the overlay or voids beneath the concrete (Zhou & Scullion, 2007).

Some states, including New Jersey and Missouri, sometimes mill off the overlay then do a visual inspection to determine patching locations (Blight, 2009; MoDOT, 2018). This does make the concrete condition much clearer and might help to identify areas where only partial depth patching of the concrete, which is faster and less expensive, could be performed (JTRP, 2017). One difficulty in implementing this in Indiana is a restriction on how long traffic is allowed to travel on milled surfaces (JTRP, 2017). A presentation from New Jersey pointed out one risk of allowing traffic on the concrete after milling the overlay; if the concrete is in poor condition, the ride quality could be very bad and could be hazardous (Blight, 2009).

2.3 Patching Alternatives, Construction, and Considerations

In a report by Grove, Cable, and Taylor (2009), they suggested using thicker patches to avoid working with the subbase and its compaction; this can be done at little to no additional cost since the cost of concrete is low compared to labor costs. In practice, PennDOT does allow patches thicker than the pavement if more than 1 inch of the subbase is disturbed (2016). Grove et al. (2009) attribute the need for concrete patching to two primary causes: lack of subbase support and extensive cracking caused by heavy loads or construction and materials defects. They also point out that a patch need not be designed to last as long as a new pavement; rather, it should last as long as the remaining service life of the surrounding pavement, which should be more economical (Grove et al., 2009).

Grove et al. (2009) also said most specifications for opening to traffic are the same as opening a new pavement to traffic. They maintained that the patches do not need that much strength to meet the remaining service life of the pavement. They also point out that the critical patch is the last one placed—the others have had additional curing time.

Grove et al. advocated using a maturity meter or minimum closure time to decide when to allow traffic (2009). This should be used with caution since some types of rapid-set concrete gain early strength at the sacrifice of later (28-day) strength (JTRP, 2017). The Pennsylvania DOT does not recommend the use of high early strength concrete because of the potential for excessive shrinkage; accelerated concrete is allowed in some cases (PennDOT, 2015). Cramer et al. (2017) evaluated the performance of rapid-setting concrete for patching in Wisconsin. Most of the rapid repair materials used there were 9-bag (846 lb/yd^3) mixes with 2% calcium chloride. They found little evidence of durability problems in 11 field projects and severe scaling on one project. In the laboratory, calcium chloride was found to reduce scaling and drying shrinkage while increasing early strength. A non-chloride accelerator used in the lab resulted in improved scaling resistance but slightly higher shrinkage and somewhat slower strength gain than with calcium chloride (Cramer, 2017).

Maryland removes some of the asphalt at each end of the patch (2 ft), places the concrete patch then protects it with a steel plate flush with the surface while the concrete cures (MDOT State Highway Administration, 2016). This allows traffic back on the repaired area sooner (this might be an option on lower volume, lower speed roads, but might be problematic on higher speed roadways (JTRP, 2017)).

Missouri requires the concrete to be brought to the surface elevation of the asphalt even if the asphalt is to be milled off later; the exception is if the asphalt is milled first (MoDOT, 2018). Any damage to surrounding concrete during the sawing and removal of the unsound material must be repaired at the contractor's expense; nothing is stated about any damage caused by milling the new concrete after patching. Missouri's specifications also require that any overcuts into the adjacent pavement, caused by the use of circular concrete saw blades, must be "filled with an expansive mortar, epoxy, polyester or joint material" if not overlaid after patching (MoDOT, 2018).

Penn DOT allows full-depth asphalt patches for concrete pavements that have been cracked and seated but discourages their use for intact concrete pavements. Coarse aggregate is used to repair rubblized concrete prior to overlay (PennDOT, 2015).

In a study examining ways to reduce settlement of utility cuts, which are similar in many ways to pavement patches, Schaefer et al. (2005) recommended cutting the pavement back 2 to 3 ft further than the trench excavation so that the existing base material could be compacted as well as the replaced base in the trench itself. They pointed out that when the trench is cut, the materials at the sides of the trench lose their lateral support and can slough into the trench, losing density. (While this does allow more room for compaction, it also requires a greater amount of pavement to be replaced.) They also point out the importance of the moisture content of the backfill material to avoid bulking.

One possible way to deal with the issue of poor compaction of the subgrade or base under the patches is to stabilize that material before removing the patch. New Jersey uses the FWD to estimate the quantity of slab stabilization needed in some cases. Joints with high deflections (>15 mils) are located with the FWD then grouted with HDP by Uretek. Areas needing full depth repairs are then patched with asphalt (Blight, 2009). Uretek is one material that has been promoted as a means of stabilizing areas where full-depth repairs are needed by injecting polymer under the pavement. This reportedly avoids the need to cut out or replace the poor foundation materials and related issues with compacting the replaced materials (Uretek USA, n.d.a). The operation is similar to Indiana's pavement undersealing process but the stabilizing material can be injected deeper and forms a polymer network to improve the density and support conditions. The injection is conducted in a grid pattern in the area of joints or working cracks. The product can purportedly be used even with wet subgrades because the polymer is not sensitive to water (Uretek USA, n.d.b).

3. SURVEY OF STATES

A survey was prepared and sent to the AASHTO Subcommittee on Maintenance and to people who had responded to an earlier survey on patching asphalt and concrete pavements conducted by the research team. The 17-question survey addressed issues related to this project as well as another JTRP study on slab stabilization/undersealing. The questions relevant to this patching study were the following:

- Do you use specific types of patches with or without subgrade stabilization or undersealing? (Options: doweled concrete, plain concrete, inverted T, asphalt, or other.)
- What materials are used for patching a composite (asphalt over concrete) pavement? (Options: match existing pavement, use full-depth concrete patches, use full-depth asphalt patches, or other.)
- Do you use any special materials or techniques to speed the repair of composite pavements? (Options: yes, if so please describe; no.)
- Do you have a technique to identify the limits of sound concrete to determine the length of patch needed for composite pavements? (Options: yes, if so please describe; no.)
- Do you use any type of mechanical equipment/machinery for soil stabilization/slab undersealing or for compaction when performing "small area" PCC or composite pavement restoration and repair operations? (Options: yes, if so please describe; yes, but only for repairing by contract; no.)
- Has your organization undertaken or sponsored any past (or ongoing) research in the area of soil stabilization/slab undersealing for PCC pavement restoration and repair or

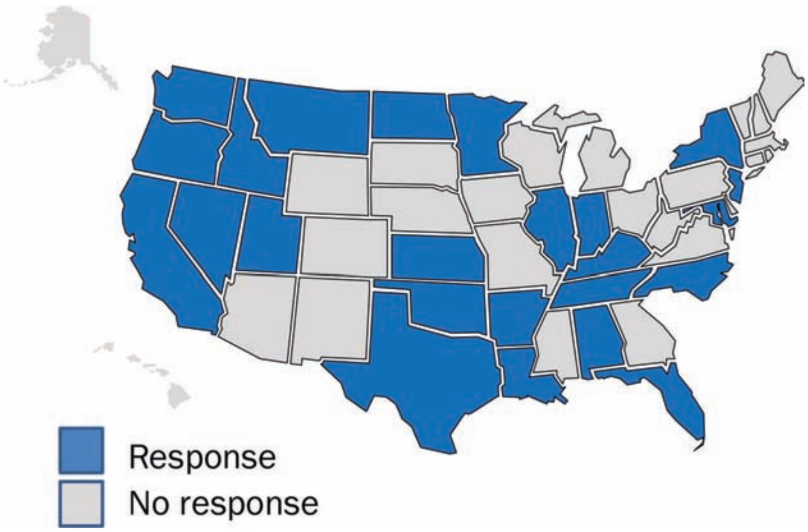

Figure 3.1 States responding to survey.

patching of composite pavement? (Options: soil stabilization, slab undersealing, both, patching composite pavements, none, planning to initiate research.)

A total of 29 responses were received from 26 states, shown in Figure 3.1. Duplicate responses from Indiana were combined. Some states did not answer all the questions, so the total number of responses is not always 26.

Most states use more than one type of patch, depending on the project specifics. Some use three or four different types. Doweled concrete patches are the most commonly used (22 responses) and are the standard in the seven states indicating only one type of patch is used. Ten states use plain concrete patches and ten use full-depth asphalt. Three states use inverted T patches.

Patches for composite pavements match the existing pavement in 12 of the responding states. Only one state reported using full-depth concrete patches, while seven reported using only full-depth asphalt. One state reported using all three options, and one said they use either full-depth concrete or asphalt depending on the project scope.

Four states reported using special materials or techniques to speed patching of composite pavements; in three cases this was the use of rapid or high early strength concrete, and one was the use of a maturity meter to determine when the concrete had gained adequate strength. One of the states using rapid strength concrete had also used precast panels on one project (Oregon) and, in response to a different question, New Jersey also indicated they had used precast panels.

Five states reported having techniques to identify the limits of sound concrete, but only four detailed what those techniques were. Three use visual surveys and one (Texas) uses the rolling dynamic deflectometer. Hand operated vibratory compactors seem to be the norm.

It was hoped that this survey would identify some new, innovative techniques for composite pavement patching, especially for determining the limits of sound concrete, but none were found. The rolling dynamic deflectometer may be able to detect weak areas, but weak areas do not always correlate with unsound concrete (Zhou & Scullion, 2007). In addition, the literature review showed that falling weight deflectometers, which are stationery, could not reliably detect sound concrete under an asphalt overlay. No innovative uses of special equipment were identified through the survey.

4. POSSIBLE PATCHING OPTIONS AND CONSIDERATIONS

Based on the literature review, survey and conversations with the SAC, the following list summarize the options that seem most feasible to implement to improve the identification of locations needing repair in composite pavements, their constructability and their performance. This list is offered for consideration by INDOT engineers and as a starting point for discussions with the districts. The overall intent is to bring about more consistency in how patching of composite pavements is approached and managed across the state, provide a variety of patching options for different situations (more tools in the proverbial toolbox), improve the constructability of patches in composite pavements, and eventually lead to better performance of these types of patches.

4.1 Types of Patches

There are options for the types of patches to place and the materials to use in those patches.

- The continued use of doweled concrete patches and matching the existing pavement may still be the best approach, but alternate methods and materials should be considered if they can perform reliably.
- If the patches must be placed prior to milling off the existing overlay, place the concrete full depth (up to the

existing surface) to save the time needed to place and compact multiple lifts of asphalt in the patched area. When it is time to mill off the overlay, mill off the excess concrete and place the new overlay continuously over the prepared pavement. While this can save time and thereby reduce congestion and user costs, it will result in placing (and paying for) concrete that is soon removed. There is also some risk of damaging the newly placed concrete during the milling. The savings in time and user costs must be weighed against the additional material cost. This may be a more attractive option in cases where the existing asphalt is relatively thin.

- Drying shrinkage is reportedly an issue in Indiana. Rapid setting concretes have been used in some states without excessive drying shrinkage or durability issues. Optional concrete materials or internal curing options could be explored to reduce shrinkage and durability issues. While some of these materials may show early strength gains at the cost of ultimate strength, as Grove et al. pointed out, patches do not necessarily need to have the same strength as new concrete—they just need enough strength to serve the remaining service life of the existing, somewhat deteriorated concrete (2009).
- Full-depth asphalt patches can perform and are easier and faster to construct, also reducing congestion and user costs. The drawback is that the asphalt can be "squeezed" by expansion of the adjacent concrete during hot weather. There may be cases where some loss of ride quality is acceptable, such as low volume or low speed roadways. Also, the asphalt humps could be milled off when they occur, improving the ride quality; this would require fairly thick asphalt patches so that the structural integrity of the patch would be adequate after some reduction in thickness.
- If there is adequate drainage (to avoid creating a bathtub under the patch), stabilizing the base and backfilling part of the lower reaches of the patch with large sized coarse aggregate or even concrete rubble (from the removed pavement, perhaps) could perform well and be constructed quickly.

4.2 Identifying Patch Locations and Determining Patch Quantities

Uncertainty in determining where to patch composite pavements can lead to delays during construction, logistical problems, higher bid prices, and contract cost overruns. Some of the options to deal with these issues include the following:

- It is generally recognized that a visual survey of a composite pavement is not adequate to accurately determine patching locations or quantities. Previous research in Indiana showed no correlation between the condition of the asphalt overlay and the concrete (Kang et al., 2015).
- Some states have had some success combining a visual survey to identify the location of joints and cracks in the concrete (reflective cracks) with FWD testing to assess load transfer at the joints/cracks and mid-slab testing to determine the pavement modulus. The modulus value can give some indication of the presence of sound concrete (Hall & Darter, 1994) while the load transfer can indicate the joint condition. Sound concrete would be expected to have a modulus of greater than 3 million psi. A good joint should have a load transfer efficiency of at least 70%. The cost, time, and resources required to do extensive FWD testing and analysis must be weighed against the benefits of potentially improved patch location and quantity determinations.
- Other states have combined visual surveys with FWD and GPR testing. The GPR can give reasonably good thickness information and may give some suggestions of defects in the asphalt (such as stripping) or concrete (e.g., high moisture content from cracks). This is not, however, an absolutely definitive way to define problems. Again, the benefits of this additional information needs to be compared to the costs of collecting the data.
- Coring near reflective cracks or other areas of surface distress is destructive but does allow inspection of the concrete condition and possibly some assessment of the foundation conditions (presence of moisture, dynamic cone penetrometer testing, etc.). While coring is generally frowned upon and does impede traffic, it gives the clearest, least risky picture of the soundness of the concrete.
- Milling the asphalt overlay before doing a visual inspection or FWD testing of the concrete allows inspection of the actual concrete pavement. This would likely require revising the current policy on how long a milled surface can be trafficked and could impact the estimation of patching quantities. In the long run, however, this could be cost effective by making the removal and replacement operations more efficient and perhaps allowing for more partial depth patching instead of full-depth patching.

4.3 Improving Constructability/Logistics

Some of the biggest complaints about patching composite pavements involve the constructability (e.g., compaction) and time (lane closure limits, productivity). Some of the options to alleviate some of these issues include the following, in addition to some of the options mentioned above (e.g., rapid setting concrete):

- Over-cutting the pavement beyond that needed to repair any subgrade issues could allow larger compaction equipment and better compaction of the foundation. This increases the amount of patching material needed as well as the time to construct the patch.
- Reducing the types of equipment and materials needed by reducing the number of different mix sizes and layers required (i.e., not matching the existing pavement exactly).
- Placing patches deeper than the existing pavement to eliminate working in and compacting the subbase. This would require adherence to the minimum 6-ft patch length to avoid cracking caused by beam action. And it would increase material quantities and costs somewhat.
- Stabilizing the foundation before removing the pavement would be expected to improve the support conditions, reduce or eliminate the need to compact the base/subgrade, reduce the construction time, and ultimately improve the patch performance. This technique has been used successfully in several states and by other agencies. The initial and life cycle costs, however, need to be considered.
- Placing steel plates over the concrete to protect it from traffic during curing, at least on lower volume, lower speed roadways.

- Allowing longer lane closures would give contractors more time to do the job properly and could result in better performance. There is, of course, greater chance for increased congestion, delays, and accidents. Improved patch performance, however, might mean a longer service life before additional rehabilitation has to occur.

These are some of the alternatives and considerations for potential ways to improve the identification, construction and performance of patches in composite pavements. INDOT has already taken some steps to improve this process. The use of vertical saws to avoid overcutting into the adjacent lane is a positive step. Cutting the pavement the night before removal and patching should improve productivity during the patching operation itself. There is no single approach that will work in every case, so having a variety of options available for use is advisable.

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On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

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