Concrete Pavement Patching—Simpler Can Be Better

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INTRODUCTION

Repair of concrete pavements includes both partial- and full-depth patching of distressed areas of the slab. Full-depth patching is a small subset of concrete paving and has a number of unique features. This is the focus of this paper. Unfortunately, many agencies approach patch design and construction from the mindset of conventional concrete paving, resulting in a number of unique properties of a patch repair being overlooked. Too often, patches do not perform well, and often the cause of failure can be traced back to procedures that are not appropriate for the patching operation.

In this paper, several of those paving paradigms are discussed with reasons why they may be working against the long-term durability of the patch. Also, those aspects that are unique to patching are discussed and despite the best of intentions, may be the reason why patches are not performing as intended.

This is a practical, application paper based on over 50 years of combined experience by the authors in the area of concrete pavement construction. Research is cited to support the ideas presented. The goals of the recommendations are to provide a highway agency with a method for patching concrete pavement that reduces the time required, allows lower opening strength, reduces cost, and results in a patch with a long life.

WHY DO WE PATCH?

There are many reasons that pavement damage can occur. A pavement is designed and built with all the components—subgrade, subbase, base, and pavement—being optimized to perform together to provide adequate serviceability throughout the design life. Unfortunately we do not live in a perfect world. Most concrete pavements continue to provide service to the driving public long after they have reached the end of their design life. However, sometimes there are small sections that do not perform as well as the rest. When a pavement section starts to crack, pump, or become unstable, it is time to repair this area with a concrete patch.

Most patching repair falls into two general categories of causes. One is loss of base support, and the other is significant cracking of the pavement due to heavy loads or materials and construction issues. (Spalling can necessitate partial-depth repair but the focus of this paper is full-depth repair.)

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Loss of Subbase Support

Loss of subgrade support can occur from a loss of base, subbase, or subgrade material under the pavement, and the pavement eventually cracks under traffic loading. Such of support is normally related to moisture that has weakened the underlying material, which is then lost through pumping. Water can collect under a pavement by a number of means: it can go down through joints, commonly when joint sealant fails, or it can come up under the pavement when the ground is saturated. This happens when a “bathtub” design has been used, and water has been trapped by the shoulder material.

Heavy Loads

Cracking of the pavement can occur due to loading. In rural areas, heavy agricultural loads are carried on pavements in farm wagons with few axles. A single occurrence can crack the pavement. Heavy or repeated loadings can also cause failure if base support is insufficient or if loading occurs near the edges of slabs where it cannot be transferred to a neighboring element.

Construction Issues

Damage to concrete pavements may be due to non-uniformity of the paving material at the time of construction. If a single truckload of concrete was batched incorrectly, or water was inappropriately added to a load, then that relatively small area of the pavement affected may fail early, while the remainder of the pavement is satisfactory.

Another common problem is cracking due to non-uniformity of base material. This can occur when localized base material is not properly consolidated, when a trench across the roadway is incorrectly backfilled before paving, or when there is a localized area of saturated base material.

Poor management of concrete volume changes due to temperature variations can also cause cracking: high temperature gradients due to combination of ambient temperature and heat due to cement hydration, cold front, late sawing, or built-in curl.

Also failures may be due to non-uniform curing. The curing compound may have been applied to a given area poorly, very late, or not at all.

HOW LONG MUST THE PATCH LAST?

State highway departments are constantly looking for ways to reduce the traffic delay caused by patching operations, reduce construction costs, and improve the performance of patches. One of the first questions the designers should ask themselves is, “What is the purpose of this patch and how long must it provide satisfactory performance?” Too often that question is never asked, and the designers assume the patch must “outlast” the existing pavement. They think in terms of 20, 30, or more years as they would for a new pavement.

Patches are placed in a pavement to replace a small area that is not performing to the level of the pavement surrounding it. We place the patch rather than replace the entire pavement because we believe there is remaining life in the surrounding pavement. In other words, the patch needs to provide the same service life as the remaining service life of the original pavement, however the agency defines pavement life. The AASHTO pavement design guides (AASHTO 2008) provide multiple ways to determine the remaining life in the surrounding pavement from knowledge of the original pavement design parameters, actual traffic loadings, and nondestructive testing etc. The patch should only be designed in terms of materials and construction methods to extend the life of this spot in the pavement to equal that of the pavement surrounding it. Designing for longer patch life is a waste of public funds.

Alternatively, the patch can be designed for a short period of time (1–5 years) to allow the highway agency to complete the design of a major reconstruction or rehabilitation of the entire pavement. This is the art of extending the life of the pavement until the entire pavement can be replaced.

WHAT MAKES A LONG-LIFE PATCH?

A number of factors contribute to the success of a full-depth patch. The opening strength of the concrete should be sufficient to carry the immediate loading when traffic is applied. Over time, strength should increase to resist cyclic loading. This is discussed further in the following section. In general, a lower opening strength limit can generally be used for full-depth concrete patches and still achieve long-life performance.

Another material property of the mixture is the modulus of elasticity. It is critical that this be similar to, or less than, that of the existing pavement, otherwise when loads are applied, the new patch may act as a stress concentration point, leading to further damage in the existing pavement near the patch. Likewise, the coefficient of thermal expansion of the patch mixture should be similar to, or less than, that of the existing concrete to prevent stress being set up because of differential movements in the patch with respect to the remaining pavement.

The thickness of a patch should be sufficient to carry the loads applied at the time of opening, and as discussed below, there is benefit to be gained from using a thicker patch than the original pavement thickness.

WHAT OPENING STRENGTH IS NEEDED?

Most States have minimum opening strength limits for concrete pavements. These empirically established limits have served the public well, but they may be more conservative than necessary for concrete pavement maintenance and repair applications like full-depth patches.

First of all, many minimum opening strength limits were established during a time when the only way to measure pavement strength was to cast and test a sample specimen. But specimen strength is only an estimate of pavement strength: The specimen does not have the mass of the pavement, so even when it is placed on top of the patch, under blankets, it does not gain strength in the same way as the patch concrete. The time required to remove specimens from under the blanket, strip the forms, deliver specimens to the laboratory, and test them also contributes to the difference between the tested strength of the specimen and the actual strength of the pavement concrete. To account for the various factors that contribute to differences between specimen strength and in-place concrete strength, a large factor of safety was built in to meet minimum opening strength limits. Now, however, in-place testing methods, like maturity testing, can more closely estimate concrete’s in-place strength. A large factor of safety is no longer necessary.

Second, a pavement's minimum opening strength is generally based on the ultimate strength needed to carry expected traffic and loadings over the pavement's lifetime. By the time a full-depth patch is being considered, a portion of the traffic volumes and loads used in the original pavement design has passed over the road. Therefore, as described earlier, less strength is required of the patch to provide a service life corresponding to the remaining life of the pavement.

Finally, a full-depth patch need not be the same thickness as the original pavement. If a thicker patch is constructed, it will require less strength at opening.

Research by Okamoto et al. (1994) and Davis and Darter (1989) determined that the necessary strength needed for opening concrete pavement to traffic is significantly lower than the value commonly used by most State agencies. Field research by Cable et al. (2004) confirmed that good performance can be realized even when traffic is allowed on a patch before it has achieved commonly accepted opening strength values. ACPA Technical Bulletin TB002-02P also offers opening-to-traffic minimum strengths for patches much lower than conventional paving. More detailed discussion of these publications is provided below.

Each State must choose a strength value that balances the need for early opening with the need for a durable patch. Okamoto's research indicates that the limit may not need to be much above final set. Intuitively that seems low, but that is because our point of reference is traditional specifications based on new construction. These low values are such that under certain conditions, they may not always be achieved and tire marks in the patch are observed. When this happens, the sky is not falling! Many examples in Iowa, Georgia, and other States can be found where sections of pavement with tire marks in the concrete have performed as well as the surrounding pavement. An example is a section of a city street that runs in front of one of the authors' home. It is over 25 years old, and tracks from a car driving on the fresh concrete are visible today. There is no sign of damage caused by this early loading.

Construction sequence is another factor that should be considered when determining the necessary opening strength for a full-depth concrete patch. Normally the length of roadway section that will be closed for a patching operation is based on the time needed to complete the work within a day's working period. Often the operation proceeds from one end to the other. On larger patching projects, there may be a significant number of patches that can be completed in that one closure.

The critical patch is the last one to be placed. All others have more time to cure and therefore more time to gain strength than the last one. In most cases it would be impractical to have different opening criteria for various patches within the day's work zone; therefore all the patches except the last will automatically have an additional factor of safety.

In addition, the moment that opening strength has been achieved, there is a time lag before the first vehicle passes over it. Curing protection and then traffic control have to be removed. All this takes time, and a number of hours can easily pass before live traffic starts passing over this section of the roadway. Curing continues during that lag time and the concrete will be stronger than it was when the opening strength determination was made.

The time of the year, that is, the weather conditions, the concrete mixture, and curing methods, will determine the time needed to reach opening strength. If a 6-to-8-hour window is needed for curing and time to remove traffic control, then patching on a two-lane roadway, where the road must be open before dark, will dictate that the last patch must be placed by shortly after midday. Admittedly this could shorten the work day somewhat, but if the proposed procedure is quicker than the traditional approach, the number of patches placed per day may not be reduced.

HIGH EARLY STRENGTH—ARE WE SHOOTING OURSELVES IN THE FOOT?

Sometimes agencies focus on accelerating the development of sufficient concrete strength for opening by using calcium chloride, heated water, and/or Type III cement in the mixture. One characteristic of concrete, however, is that the faster it gains strength, the sooner strength gain will slow or stop. In other words, accelerating early strength gain can sacrifice long-term strength.

Calcium chloride is an inexpensive admixture used to accelerate early strength gain of concrete. Its effect is to accelerate early hydration, leading to elevated strengths in the first few hours and days. The side effect is to reduce later age hydration, meaning that there is little to no strength development after the first few weeks. This has the effect of reducing the safety margin in that no additional strength is developed over time to help carry long-term cyclic loads. Therefore using a mixture that will not gain much additional strength poses more risk than a mixture that will, over time, achieve strengths in excess of the opening strength. In the few hours when the strength is lower, very few loadings occur compared to those of the life of the patch, and therefore long-term strength is important for long-term performance.

Mixtures containing calcium chloride will normally generate significant amounts of heat, leading to the concrete mixture’s setting at relatively high temperatures. High stresses may be incurred when the mixture cools. When the blankets are removed when low ambient temperatures are present (such as in the fall), thermal shock can initiate cracking.

Calcium chloride will also significantly increase the risk of corrosion of any embedded steel, whether dowels or tie bars. Another side effect is that the risk of efflorescence and discoloration is increased.

Another technique often used to increase early strength gain is to add extra cement. Experience shows that adding extra cement may not provide extra strength, but it will increase drying shrinkage, heat, cracking risk (Buch et al. 2008), and the cost of the mixture.

Since we have determined that lower values for opening strength can provide adequate concrete patch strength at the time of opening, we can design for increased long-term patch strength rather than accelerated strength. There will always be exceptions: When patching must be performed during weather conditions that are cool or cold (in general below 60 ^{o}F [16 ^{o}C]), for example, methods to accelerate hydration may be necessary. The use of heated water or other means to raise the concrete temperature may need to be employed, although if at all possible, calcium chloride should still be avoided. It may be necessary to extend the curing period under these conditions. A time-to-opening specification may need to be modified when cold temperatures are encountered.

EXTRA THICKNESS—LONGER LIFE PATCH AT NO EXTRA COST?

Extra concrete thickness provides several advantages. First, it results in lower stresses in the pavement. Thicker pavements are built on the Interstate system than on residential streets because they need to withstand heavier loads. Second, thicker full-depth concrete patches need less strength before opening to traffic.

Third, when considering the whole patching process, extra concrete thickness may be added for almost no extra cost. The real cost of patch repair is in the labor cost of the hand work required and the traffic control needed for the operation. The material cost is minimal in comparison. Most patching specifications require excavation of unsuitable material and replacement with compacted granular material. That granular material is delivered in a dump truck, but an individual patch only needs far less. Therefore the cost of the granular material is high because of the small amount that is used. The cost of the hand work to place the material and the cost to hand compact it is considerable, and hand work adds time to the whole operation. The alternative is to simply fill the hole with concrete. The ready-mix truck is already on site. The only added cost for extra concrete thickness is the concrete itself. When the cost of the conventional approach is weighed against simply using more concrete, the thicker patch offers the advantages listed above and may not incur any additional cost.

Fourth, the number of patches that can be placed in a day may be increased, since the backfill, placement, and compaction operations are eliminated.

One concern about replacing a pavement section with a thicker patch is the deeper pavement blocking the drainage. The climate conditions in each region of the country must be considered with this issue. When longitudinal subdrains are in place and working properly, they should be able to provide needed drainage, since the transverse slope away from the high point of the crown will still direct water to the edge of the pavement.

In some regions there may be a drainage issue when no subdrains are present. That is often the issue that initiated the failed pavement; therefore the problem has to be addressed whatever the method of repair used.

Some agencies may have a concern about possible heave from the use of a thicker patch. This is a phenomenon related to moisture. A small change in pavement thickness will not change those conditions. As discussed above, steps should be taken to address excess moisture if that is the cause of the original failure or if it is a concern because of the climatic and soil conditions. Additionally, the dowels that resist the downward movement from traffic loadings will also resist upward movement from any heaving forces.

WHAT DO THE RESEARCH AND TECHNICAL BULLETINS SAY?

A number of research studies support the recommendations of this paper, including an ACPA technical publication that gives guidance on full depth patching.

- A Federal Highway Administration study by Okamoto et al. (1994) investigated how much pavement life is consumed by early loading. Edge loading was the critical location, but most traffic will not drive on the edge. Also, cones or other traffic devices can be used to keep traffic away from the edge until higher strengths are achieved. This research found that for a 10-in. (254-mm) pavement, compressive strength of 1,041 lbf/in^2 (7.18 MPa) (note: this would be less than 200 lbf/in^2 [1.38 MPa] flexural strength, depending on the conversion utilized), under interior loading, the pavement would experience no fatigue damage over 10,000 cycles). The report states that "Interior loading produced virtually no fatigue damage for 10- and 12-in. slabs, even if loaded when the compressive strength was 260 psi."

Okamoto goes on to state that the bearing stresses produced by the dowels are often the controlling factor. He concludes that "Larger diameter bars were very effective in reducing the magnitude of the dowel-bearing stress." This is another design element that is normally not reconsidered for patching, with new-pavement dowel sizes normally being used. The cost to use larger dowels would be negligible with respect to the cost of the patch, but could significantly improve the early performance.

- In research conducted by Davis and Darter (1989), it was determined that the thicker the patch, the lower the opening strength needed to be. Table 1 lists the results from that research:

Table 1
Opening Strength Required for Varying Pavement Thickness

Slab Thickness, in.	**Minimum Slab Flexural Strength,** lbf/in^2
7	370
8	335
9	275
10	200

- Cable et al. (2004) conducted research to meet the following objectives:
  - Investigate the relationship between pavement patch thickness and allowable opening time for concrete pavements.
  - Investigate the relationship between patch thickness and early traffic load capacity of concrete pavements.
  - Investigate the use of the maturity method being suitable for determining concrete strength and pavement early opening to traffic timing.

The experiment consisted of various combinations of concrete mix design, pavement patch thicknesses, and times of opening to traffic. The concrete mixes utilized in the experiment included a conventional paving mix and a patching mix. The existing roadway on this project consisted of a two-lane pavement, 24 ft (7.3 m) wide and 9 in. (229 mm) thick, with doweled transverse joints. The 9-in. (229-mm) depth served as the default thickness. Additional patch depths of 11, 13, and 15 in. (279, 330, and 381 mm) were tested to determine the effect of patch thickness on performance. The thickness also represents the impact of removal of unstable base and replacing it with concrete rather than special backfill and extra compaction effort.

Traffic opening criteria consisted of allowing traffic to begin to drive over the patches at 3, 5, and 7 hours. An additional set of patches was designed for opening at 350 lbf/in^2 (2.41 MPa) flexural strength based on maturity measurements. The overall layout of the test patches resulted in 16 separate patches utilizing the patching mix and an additional 16 patches employing the paving mix.

The study produced the following results:

- Increased patch depth enhanced the concrete strength gain associated with the heat of hydration determined by maturity testing.
- Performance measures indicated no differences due to concrete mix (standard mixes or those with calcium chloride), opening times for traffic, or concrete patch depths.
- Maturity testing proved to be an accurate and consistent method of estimating concrete strength gain with regard to determining traffic opening strengths.
- Time of patching was equal to or less than conventional methods, with the substitution of over-depth concrete patch material placement versus subgrade preparation and pavement replacement.

- Buch et al (2008) investigated high early strength mixtures for patching, particularly from a durability standpoint. They reported that high-range water reducers negatively affect the air-entraining system. They found that the use of both Type III cement and high-range water reducer together often negatively influenced the air-void system and to a greater degree when calcium chloride was used.

- Narotam and Vu (1993), Iowa Department of Transportation, conducted a study in 1993. They reported that water reducers resulted in lower early strengths. They also recommended a 6-hour cure time minimum.

- ACPA Concrete Paving Technology—Guidelines for Full-Depth Repair recognizes opening-to-traffic criteria can be either minimum strength or minimum time. Although they recommend a strength criteria for opening, in early opening applications (24 hours or less), they also provide a minimum strength requirement of 250 lbf/in^2 (1.72 MPa) for patches 10 in. (254 mm) thick or more. This strength value is repeated in a later ACPA publication (ACPA 2006) and referenced in the FHWA publication "Concrete Pavement Preservation Workshop" (FHWA 2008).

WHAT ARE STATES DOING?

When constructing full-depth patches, one way to remove the focus from early strength gain to long-term performance is to remove the requirement for strength to be met before the pavement can be opened. At least two States have done that. Georgia and Iowa do not have a minimum strength specification for opening to traffic. Both simply use a minimum time—or age—requirement. This can be sufficient if the mixture design demonstrates that adequate strength can be achieved, weather conditions and concrete temperatures are conducive to achieving those strengths, and proper curing and protection are applied.

In the current environment of limited inspection staff by most agencies, the need to measure strength is a work item that is often not realistic for inspection personnel. A time specification is much easier to enforce, and if equal or better performance is achieved, then this is a reasonable approach.

For a two-lane roadway patching project, where the road is to be opened by dark, the contractor is not required to have night lighting or reflective clothing for workers. What is going to happen at dusk is that the road will be opened, despite the strength of the concrete. With a strength specification, the contractor and the inspection personnel are placed in a no-win position of having to violate at least one specification, the open-by-dark or the strength specification. In most cases, the patch does not fail, but the wrangling over the specification has just begun. Neither is desirable, and neither changes the performance of the patch.

CONCLUSIONS AND RECOMMENDATIONS

As discussed in this paper, some concrete pavement full-depth patch repair practices that have been commonly a part of most State specifications may actually lead to reducing the life of the patch. The practices discussed in this paper have the potential to shorten time to open, decrease cost, and improve the performance of full-depth patches.

Numerous variables influence how a patching operation will be conducted. A two-lane or four-lane facility, length of time allowed for closure, and weather conditions all must be considered and will affect the specifications and limitations. Although the practices recommended below may not be applicable to every project, in general they can be applied to both two-lane and four-lane roadways, where a minimum of 6 to 8 hours of curing is acceptable and when conditions are warm enough to not impede rapid strength gain, at least 65 ºF to 70 ºF (18 ºC to 21 ºC) air temperature. One variation to these proposed practices can be to utilize them for most of a day's work and then for the last patches placed, accelerated techniques may be used.

In circumstances where strength measurement is required for opening, the maturity method should be utilized. Bear in mind that using a test specimen to estimate the strength of the pavement is no less an estimate. Breaking a core or beam merely determines the sample strength, not the pavement strength.

Below are recommendations to increase performance and reduce the time needed to complete a patch repair with little change in cost.

- *Use a conventional concrete mixture with no calcium chloride.*

- *Make the patches thicker and eliminate granular backfill.*
  Remove any unsuitable material and excavate to a depth of at least 12 in. (305 mm). Then, fill the hole with only concrete.

- *Use larger dowel bars.*

- *Use age as the only criteria for opening, along with certain curing and temperature requirements.*
  Conduct laboratory testing to establish opening-to-traffic criteria based on time only. Test the strength of the mixture, using a reduced strength requirement, at temperatures

similar to anticipated field conditions. Of the three research and technical bulletins cited, for a patch 10-in. (254 mm) thick, ACPA recommends 250 lbf/in^2 (1.72 MPa) flexural strength; Davis and Darter recommend 200 lbf/in^2 (1.38 MPa); and Okamoto's recommendation is less than 200 lbf/in^2 (1.38 MPa). The authors believe that if a 12-in. (305-mm) minimum thickness patch is specified, 200 lbf/in^2 (1.38 MPa) could be used as a minimum strength for determining the opening time requirement.

REFERENCES

American Association of State and Highway Transportation Officials (AASHTO), 2008, "Mechanistic-Empirical Pavement Design Guide, Interim Edition: A Manual of Practice," Washington DC.

American Concrete Paving Association (ACPA), 1995. Concrete Paving Technology-Guidelines for Full-Depth Repair, TB002.02P, Skokie, IL. 1995.

American Concrete Paving Association (ACPA), 2006. Concrete Pavement Field Reference-Preservation and Repair, TB239P, Skokie, IL.

Buch, Neeraj, Thomas J. Van Dam, Karl Peterson, and Larry Sutter, *Construction and Building Materials*, Vol. 22, No. 3, March 2008, pp. 162–174.

Cable, J. K., K. Wang, S. J. Somsky, and J. Williams, "Portland Cement Concrete Patching Techniques vs. Performance and Traffic Delays," Center for Portland Cement Concrete Pavement Technology (National Concrete Pavement Technology Center), January 2004.

Davis, D. D., and M. I. Darter, "Early Opening of Concrete Pavements to Traffic," ASCE Structural Congress 1989, *Proceedings of Session on Structural Materials*, ed. by J. F. Orofino, San Francisco, CA, 1989.

Federal Highway Administration (FHWA). 2008. Concrete Pavement Preservation Workshop. Federal Highway Administration, Washington, DC.

Narotam, C. L., and J. H. Vu, "Evaluation of Concrete Patching Mixes and Opening Time Using the Maturity Concept," Iowa Department of Transportation, Iowa Highway Research Board, Ames, Iowa, MLR-93-01, 1993.

Okamoto, P. A., P. J. Nussbaum, K. D. Smith, M. I. Darter, T. P. Wilson, C. L. Wu, and S. D. Tayabji, "Guidelines for Timing Contraction Joint Sawing and Earliest Loading for Concrete Pavements, Vol. 1, Final Report," Federal Highway Administration, FHWA-RD-91-079, February 1994.