Specification Synthesis and Recommendations for Repairing Uncontrolled Cracks that Occur During Concrete Pavement Construction

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By
Gerald F. Voigt, P.E.
Vice President - Technical Operations
American Concrete Pavement Association
5420 Old Orchard Road, Suite A100
Skokie, IL 60077-1059
Phone: 847-966-2272; Fax: 847-966-9970
Email: gvoigt@pavement.com

INTRODUCTION

Contraction joints usually control the formation of cracks in newly placed concrete pavement. However, in some circumstances, various design and construction factors influence the ability of contraction joints to control cracking. Substantial changes in the weather during and after construction also can induce uncontrolled cracking despite normally adequate design, construction and jointing techniques. As a result of the complexity of anticipating and accounting for the interrelating factors, uncontrolled cracks do occur in some newly constructed concrete pavements.

When early uncontrolled cracking occurs, agencies and contractors must determine how to address the cracks. There appears to be little consistency in this regard. This paper reviews factors that can cause or contribute to uncontrolled cracking, and examines jointing and remediation procedures outlined in current state highway agency specifications. This paper also recommends remedial repairs for cracking based on current practices and available techniques.

FACTORS THAT CAUSE EARLY CRACKING

For most projects, transverse and longitudinal contraction joints are made by sawing the concrete with single-blade, walk-behind saws. For wider paving, contractors may elect to use span-saws that are able to saw the full-width in one pass. Each transverse and longitudinal saw cut induces a point of weakness where a crack will initiate, and then propagate to the bottom of the slab.

New concrete slabs crack when tensile stresses within the concrete overcome the concrete's tensile strength. The tensile stresses develop from restraint of the concrete's volume change at early ages, and restraint of bending from temperature and moisture gradients through the concrete *(1,2)*. Early volume changes are associated with the concrete's drying shrinkage and temperature contraction.

In most cases, cracks first appear at large intervals, 10-45 m (30-150 ft), and then form at closer intervals over time. From this experience one may infer that restraint to volume change is the initial factor controlling cracking. Studies of plain pavements, 4-6 m (15-20 ft) transverse joint spacing support this inference *(1,3).* These studies show that intermediate sawed joints — normally required to control cracking from differentials — sometimes do not crack for several weeks to months after opening the pavement to traffic. However, this may not be true on every pavement, and it may be very difficult to determine whether restraint to volume change or restraint to gradients cause the first cracks.

Unfortunately, some concrete pavements do not crack at the saw cuts and instead crack at unplanned locations. The common terms for these early cracks are “random cracks” or “uncontrolled cracks.” *(2,4)* There are many reasons that uncontrolled cracks occur, and it is usually a challenging task to isolate the cause(s). However, experience in examining projects has led to identification of some consistent characteristics and causes.

Saw Timing

There is an optimum time to saw contraction joints in new concrete pavements, which is defined as the sawing window (Figure 1) *(2,5).* The window is a short period after placement when the concrete can be cut successfully before it cracks. The window begins when concrete strength is acceptable for joint sawing without excessive raveling along the cut. The window ends when significant concrete shrinkage occurs and induces uncontrolled cracking.

Under most normal weather conditions and for typical pavement designs the window will be long enough to complete sawing with excellent results. However, certain design features and weather conditions can considerably shorten the window (Table 1).

Orientation & Time of Crack Occurrence

The orientation of uncontrolled cracks can indicate the possibility that sawing was too late. If a crack reverses direction, or develops in an unusual orientation, it may have initiated at the bottom of the slab and may have been influenced by high friction or bonding to the subbase *(2)*. When an uncontrolled crack extends across the entire width of a paving slab, or begins and ends at a functioning joint, the possibility of late sawing remains. In most cases uncontrolled longitudinal cracks from late sawing will be in predictable locations as depicted in Figure 2A-C. Transverse cracks from late sawing are less predictable, but generally extend across the entire slab or traverse diagonally (Figure 2D).

Sometimes cracks continue to form well after paving and sawing are complete. In some cases these may be cracks that formed early and are simply becoming visible. In other cases, this is a clue that something is restraining or moving the concrete, which is creating tensile stresses that lead to further cracking.

Aggregate Condition Along the Crack Face

Examining the faces from a core taken through an uncontrolled crack provides a clue to the time the crack occurred. Cracks that form below saw cuts usually develop after some reasonable strength development and will break through some coarse particles. If the crack travels around the coarse aggregate particles, it is most likely that the crack formed at a very early age, before the cement paste was able to bond sufficiently to the aggregates. For example, this may occur when the subbase contracts from a reduction in temperature and induces reflective cracks in the concrete at an early age. The bond strength between the cement paste and dirty, dusty or extremely hard coarse aggregate also may be low at an early age, which could also contribute to cracking around coarse particles.

Sawing Pop-Off Cracks

At or near the end of the sawing window, cracks may form while the saw operator is making a cut. These cracks often occur as the saw progresses to within about 1 m (3 ft) of the free edge of the slab (Figure 2D). Pop-off cracks are an indication that sawing is too late for the prevailing conditions. There is a higher tendency for pop-off cracks if a high wind is blowing against the edge of the slab, accelerating evaporation and shrinkage. Experienced saw operators will orient the direction of sawing with the wind whenever possible.

Saw Cut Depth

The influence of the saw cut depth on the occurrence of early transverse cracking primarily depends on the time of the sawing *(3)*. According to Zollinger, early-age sawing methods with sawing depths less than 0.25d (d=slab depth), should provide better crack control than conventional methods with depths of 0.25d or 0.33d. He cites that sawing sooner with early-age saws can take advantage of larger changes in the concrete's surface moisture content or surface temperature, which has been shown to induce cracking *(2)*. Zollinger verified the effectiveness of early-age sawing methods with field experience on 330 mm (13 in.) plain concrete pavement, made with a variety of coarse aggregates, on granular soils. Further verification is necessary for crack control in plain concrete on stabilized subbases that induce more restraint.

Deeper saw cuts are necessary for conventional sawing equipment because the concrete is generally under more restraint than when sawed at earlier ages with early-age sawing equipment. Practical experience shows that transverse cuts from one-fourth to one-third the slab thickness (0.25d to 0.33d) will provide crack control under most circumstances for conventional sawing operations. However, there is little information to quantify the increased probability of uncontrolled cracking should the cut depths not meet a specified (0.25d or 0.33d) minimum depth. Okamoto attempted to determine the necessary transverse cut depth for conventional sawing equipment and operations *(2)*. He concluded that there are too many confounding factors to develop a verified recommendation for transverse joints.

For longitudinal contraction joints, McCollough found that uniformity in concrete strength, slab thickness and cut depth should improve the probability of longitudinal crack control *(6)*. According to his model, a saw depth of 0.25d controls longitudinal cracking with 98% reliability in mixtures containing crushed limestone aggregate, and with 86% reliability in mixtures containing river gravel. However, other experiences show that more factors also may be involved in longitudinal cracking. On one test pavement in Minnesota, sections on granular subbase had very little longitudinal cracking, while sections on asphalt or cement stabilized materials — that induce higher frictional restraint — had extensive longitudinal cracking *(2)*. On all sections the contractor formed the longitudinal joint with a plastic-tape insert at a similar time and orientation during paving.

While it is not precisely proven that saw cut depth alone directly relates to occurrence of transverse or longitudinal cracking, it is a commonly specified factor. Currently 96% of state agencies require a cut depth of 0.25d for transverse contraction joints *(7)*. The American Concrete Pavement Association recommends a depth of 0.33d for longitudinal contraction joints, and transverse contraction joints in highway pavements, and all pavements placed on stabilized subbase materials *(1)*.

On projects where contractors use conventional diamond-bladed sawing equipment, shallow (less than 0.25d or 0.33d) saw cuts are often a symptom of late sawing rather than a direct cause of cracking through poor equipment set-up. When cracking is imminent near the end of the sawing window, saw operators may tend to push a saw too fast, causing the saw blade to ride up out of its full cut.

Another possible cause of shallow saw cuts are worn abrasive saw blades. During use, the diameter of an abrasive blade becomes progressively smaller as the abrasive cutting material wears away. Saw operators must closely monitor abrasive blade wear and replace worn blades to consistently meet depth requirements.

Weather & Ambient Conditions

The weather almost always has some role in the occurrence of uncontrolled cracking. Air temperature, wind, relative humidity and sunlight, influence concrete hydration and shrinkage. These factors may heat or cool concrete or draw moisture from exposed concrete surfaces. The subbase can be a heat sink that draws energy from the concrete in cold weather, or a heat source that adds heat to the bottom of the slab during hot, sunny weather.

Under warm sunny summer conditions, the maximum concrete temperature will vary depending on the time of day when the concrete is paved. Concrete paved in early morning will often reach higher maximum temperatures than concrete paved during the late morning or afternoon because it receives more radiant heat (Figure 3). As a result, concrete paved during the morning will generally have a shorter sawing window, and often will exhibit more instances of uncontrolled cracking.

After the concrete sets, uncontrolled cracking might occur when ambient conditions induce differential thermal contraction *(2,8)*. Differential contraction is a result of temperature differences throughout the pavement depth. Research indicates that a sudden drop in surface temperature more than 9.5°C (15°F) can result in cracking from excessive surface contraction *(2)*. This degree of temperature change is common year-round in arid climates, and possible in most other climates during the spring and fall when air temperatures drop significantly from day to night. Differential contraction also may occur when a rain shower cools the slab surface, or when the surface cools after removing insulating blankets from fast-track concrete.

Subbase

Stabilized subbases may induce uncontrolled cracking because of the high friction and, in some cases bonding, between the subbase and concrete slab. The friction or bond restrains the concrete's volume change (shrinkage or contraction), inducing higher stresses than might occur in concrete pavement on granular subbases. According to Okamoto, as the subbase friction increases, cracks occur from smaller drops in surface temperature than are necessary on low-friction subbases *(2)*. This corresponds to field experiences on projects with cement-treated subbases, and asphalt-treated or cement-treated permeable subbases that were known to have bonded to the concrete pavement *(9-11)*.

Cracks from bonding to the subbase are likely to initiate from the bottom of the slab and travel toward the slab surface, sometimes reflecting from shrinkage cracks in the stabilized subbase. Cracks from high friction can be erratic in orientation, sometimes reverse direction and seem to follow zones of restraint between the concrete and subbase (Figure 2G).

In addition to adding restraint, bonding or high friction between the pavement and subbase also will reduce the effective saw cut depth. For example, a typical 250-mm (10-in.) slab requires a 63 mm (2.5-in) saw cut to meet typical 0.25d requirements. If the slab bonds to a 100 mm (4-in.) stabilized subbase, the effective depth of the saw cut is only about 0.18d, which may not be adequate to control cracking with normal sawing equipment and timing.

To prevent bonding between the concrete and subbase requires the application of a bond-breaking medium. For lean concrete or econocrete subbases, current recommendations are for two spray applications of wax-based curing compound on the subbase surface *(2,12)*. There are no standard or common bond-breaker recommendations for cement-treated subbases or asphalt-stabilized subbase materials. However, many cement-treated subbase specifications recommend a cutback asphalt for curing, that is sometimes believed to also serve as a bond-breaker. However, in some cases the treated subbase surface is disturbed by trimming prior to paving. After trimming the surface may be rough in certain locations creating an excellent surface for bonding. The ACPA recommends the application of two coats of wax-based curing compound before paving on cement-treated subbases.

Slag or very dry granular subbases also may contribute to uncontrolled cracking. Some contractors postulate that the slags draw moisture from the concrete pavement, which dries the lower portion of the slab before the middle or the top. This induces differential shrinkage in the reverse of surface drying from high winds. Most specifications for granular materials appropriately require moistening a granular subbase surface before placing any concrete. It is debatable whether typical subbase moistening efforts are practical or effective for slag subbase materials due to the high absorptive capacity of the aggregates.

Concrete Mixture

The internal temperature and moisture of concrete will influence the time available for joint sawing. The temperature relates to the concrete's strength gain and controls the ability to start sawing without raveling, and to finish sawing before the onset of cracking. Okamoto found that an easy way to determine the end of the sawing window is by monitoring the concrete surface temperature *(2)*. He suggests that it is preferable to begin sawing when practicable, when the concrete sets enough to accept sawing, and to complete sawing before the surface temperature begins to fall since thermal contraction begins as the concrete temperature falls.

Higher concrete strength should enable the concrete to withstand more tensile stress when it first cools and undergoes temperature differentials. However, concrete mixtures that gain strength rapidly may have a shorter window for sawing than normal mixtures if the heat from hydration is high. These mixtures will experience a larger temperature differential than mixtures that gain strength more slowly and do not become as warm. It is not uncommon for concrete pavement temperatures to exceed 45 °C (113 °F) in summertime, particularly for fast-track concrete paving *(5,8)*.

Mixtures containing certain fly ashes or lower quantities of portland cement can delay early age strength development in cooler weather. Depending on the air and concrete temperature, this could delay concrete setting and the ability to saw without excessive raveling. After setting, the time available for sawing before the onset of cracking may be much shorter than normal.

Concrete with granite and limestone coarse aggregate is less sensitive to temperature than concrete made from siliceous gravel, chert or slag aggregate. Granite and limestone have lower coefficients of thermal expansion than the other aggregates. Therefore, concrete made with granite or limestone is less temperature sensitive and generally allows a longer spacing between contraction joints without any additional chance of cracking. The influence of coarse aggregate was recognized many years ago, as seen in Table 2 showing spacing recommendations from 1955 *(14)*. Interesting recent field tests show that cracks form at the saw cut sooner and more frequently with concrete made from river gravel than concrete made with crushed limestone *(8)*.

Saw Blade Selection

Raveling usually occurs when sawing too soon, but it can also be caused by the saw equipment or saw blade. *(14)* A saw blade must be compatible with the power output of the saw, the concrete mixture, and the application. An improper saw blade will dull rapidly and can dislodge aggregate while trying to cut. In some cases switching to a different saw blade will correct the problem.

Plugging or clogging of the cooling water tubes on a diamond-bladed saw also may cause a raveled cut. Therefore it is important for saw operators to monitor the sawing equipment to determine if it is creating a raveled cut in concrete that is otherwise ready for sawing. Experienced saw operators rely on their judgment and the scratch test to make this determination, and then adjust their equipment so that it can operate correctly. The scratch test is the most common and one of the simplest tests that contractors use to determine when to begin sawing *(14)*. The test requires scratching the concrete surface with a nail or knife blade, and then examining how deep the surface scratches. As the surface hardness increases the scratch depth decreases. In general, if the scratch removes the surface texture it is probably too early to saw without raveling problems.

Joint Spacing

Pavement with long transverse joint spacing may crack due to tensile stresses from temperature curling. Theoretical and practical studies of concrete pavement have determined that the optimal spacing between joints depends on the slab thickness, subbase stiffness, and concrete strength. Most state agencies specify transverse contraction joints in plain pavement at an interval between 4.5 and 6.1 m (15 and 20 ft.) *(7)*. For granular subbase materials American Concrete Pavement Association recommends a maximum spacing of 24d, and for stabilized materials a maximum spacing of 21d *(1)*. Still others recommend an even closer joint spacing based on maintaining the ratio of the slab length to the radius of relative stiffness below 5 *(15,16)*. It is also important to check the transverse and longitudinal contraction joint spacing to see if it is within the limits recommended for different coarse aggregates.

Misaligned Dowels

The influence of dowel alignment on the development of early cracking is not well understood. If saw timing and saw cut depth are adequate, the misalignment of dowels can induce a crack away from a transverse joint if the dowels physically lock two slabs together and restrain their contraction (Figure 4). For this possibility, a crack must exist that extends below the saw cut. If there is no crack meeting the saw cut, then late sawing or subbase restraint is likely the cause of the uncontrolled crack. In some cases a crack may wander in and out of a saw cut above a doweled joint (Figure 2D). This also indicates that sawing was too late for the prevailing conditions.

An unanswered question is whether misalignment of dowels can ever induce a crack to form away from a saw cut if there is no crack extending from the cut. This would require that the dowels reinforce the concrete and mask the presence of the weakened plane. Since tied longitudinal contraction joints create significant restraint, without alarm for unusual cracking, it seems reasonable the same would hold true for misaligned dowels.

Rapid Surface Moisture Evaporation

It is important not to confuse cracks from restraint of the concrete at early ages, to plastic shrinkage cracks. Plastic shrinkage cracks are generally tight, about 0.3-0.6 m (1-2 ft) long, extend down about 25-100 mm (1-4 in.) from the surface, and form in parallel groups perpendicular to the direction of the wind at the time of paving. Plastic shrinkage cracking is a result of rapid drying at the concrete pavement surface, and therefore adequate curing measures are necessary to prevent their occurrence *(5)*. Experience has shown that these cracks rarely influence the overall performance of a pavement.

SYNTHESIS OF SPECIFICATIONS

Each U.S. state highway agency standard specification for highway construction was reviewed for the requirements on sawing and repairing uncontrolled cracking. A computerized version of the current specifications on CD-ROM was used for this purpose *(17)*. Two other specifications, the federal government (FP-96), and the AASHTO Guide Specification for Highway Construction, were also examined *(18).* The uniqueness of each state agency specification necessitated some interpretation of the intent of certain passages, in order to generalize and compare the specifications. In all, 47 specifications were compared. Five states do not have a standard specification for concrete pavement (Alaska, Maine, New Hampshire, Rhode Island, and Vermont) and are not included in the statistics.

The premise before analyzing the specifications was that there are two basic approaches to specifying contraction joint sawing and dealing with the potential for uncontrolled cracking. The first approach is to provide specific and detailed requirements for the timing of sawing operations. It was thought that this approach would be rooted in the traditional method specification style of the state agencies. Specifications noting specific sawing requirements would likely not have many directions for repairing cracks, since this would be direct conflict with the language specifying against their occurrence. A second approach would rely on the contractor to determine specifically when to saw the concrete pavement, but would then provide specific directions on how to repair uncontrolled cracks should they occur. In essence, both of these approaches would address the basic fundamental that there is a window of opportunity for sawing.

After reviewing the specifications it is apparent that there is no consistent and logical approach in use by many agencies. Many specifications include conflicting requirements. For example, several specifications require the contractor to start sawing at a specific time after paving, and also require the saw cut to have no raveling. Obviously in many instances a contractor will be unable to meet either and surely not both potentially conflicting requirements.

Sixteen states (Alabama, California, Connecticut, Delaware, Georgia, Hawaii, Massachusetts, Michigan, North Carolina, North Dakota, Nebraska, New Mexico, New York, South Carolina, Texas, and Wisconsin) use a method specification approach to jointing with no uncontrolled crack repair specification. Arizona, Colorado, Kansas, Montana, Utah and Washington follow the second approach, leaving decisions on sawing to the contractor, but outlining remedial measures in detail. The other specifications either are difficult to interpret, follow no specific approach, or provide limited guidance for sawing or repair.

Requirements for Time of Sawing

Three specific clauses were sought from each specification that would indicate specific requirements for the time of joint sawing: 1) start sawing at “x” hours after paving, 2) finish sawing at “x” hours after paving, and 3) allow “x” raveling along the saw cut. Seventy percent of the specifications do not specifically mention a time when sawing must begin, but many do suggest that it must begin as soon as possible. In contrast, 43% of the specifications do not mention any requirement for finishing sawing, and an additional 26% are not specific and only require sawing to continue, day or night, regardless of the weather. Therefore, a total of 69% of the specifications are not specifically requiring a time for completion.

The clauses that limit raveling are interesting to interpret since they indirectly control the time sawing can begin. Forty percent of the specifications allow some raveling if it is not excessive, 30% require a cut with no raveling and 28% do not mention raveling at all. One state, South Carolina, encourages the contractor to saw a raveled cut. Their specific clause reads, *“Some raveling of the green concrete must be expected in order for the sawing process to prevent uncontrolled shrinkage cracking. If sharp edged joints are being obtained the sawing process shall be speeded up to the point where some raveling is observed.”* This unique clause is clear and specific and provides excellent guidance to the contractor and the inspector.

Obviously, specifying a specific time for starting or completing contraction joint sawing is subject to some field application and enforcement problems. Delayed set due to cold weather conditions is just one possibility that could prevent sawing at the specified time after paving. Perhaps this is why only about 30% of the agencies take this approach.

Requirements for What to do if Cracks Occur

Four clauses were sought for specific requirements or generalized guidance to the contractor on what to do if uncontrolled cracks occur during or before sawing. Table 4 summarizes the following clauses: 1) if slab cracks before sawing, 2) if slab cracks while sawing, and 3) allow skipping joints. The fourth clause relates to any general requirements on what to do if sawing does not prevent cracking.

Over half of the specifications do not provide any guidance to the contractor or inspector on what is expected and appropriate action when cracking occurs either before or during sawing. However, a fairly significant 40% of agencies require the contractor to omit the joint if a crack forms at or near the planned location for the joint before sawing starts. Of these agencies, only 26% also provide recommendations for handling the crack once it occurs.

Thirty-eight percent of the specifications require the contractor to stop sawing the joint upon noticing a pop-off crack. The preferable practice would be to stop the saw cut , so as not to create a potential spall between the saw cut and the crack. A majority of the specifications (60%) provide no guidance.

Five specifications (11%), require the contractor to skip 3 or 4 joints when first sawing transverse contraction joints. The skip sawing procedure intends to provide control joints where the initial cracking will occur. An additional 11 specifications (23%) allow the contractor to skip joints in the event of uncontrolled cracking and 2 (4%) at the engineer’s discretion. Thirty-six percent of the specifications do not mention joint skipping. It would seem that skipping joints is a reasonable approach to prevent uncontrolled cracking in the event of unexpected weather change, like a storm or cold front. The one negative aspect of skip sawing is that the initial control joints will open much wider then the 2 or 3 intermediate joints. This could decrease the performance of sealants in the control joints, especially preformed sealants that are made for a specific joint reservoir opening. However, this is a relatively minor problem to accept in order to provide an additional method to avoid uncontrolled cracking.

If sawing does not control cracking, 7 specifications (15%) require the contractor to change to tooling or forming contraction joints on any remaining work. Twelve specifications (26%) require the contractor to revise their sawing procedure, sawing sequence, or add more saws. However, the majority of specifications (56%) have no clause directing any adjustment of procedures or switch in methodology.

Tennessee is the only state that suggests switching to early-age sawing equipment in the event that *"extreme conditions exist which make it impractical to prevent erratic cracking."*

Requirements for Repairing Cracks and Spalls

The requirements for repairing uncontrolled cracking or other defects were sought from each specification. Nineteen specifications (40%) did not address repairing any defects (cracks or spalls). The remaining 60% had some requirements, ranging from a single sentence to specific and detailed requirements in a separate section of the standard specification. Only thirteen specifications (28%) provide details for handling the repairs. The disparity was not limited to the detail of the requirements, but also to the coverage as well. Arizona, Illinois, West Virginia and Wyoming only provide specific details for repairing cracks, while Arkansas, California, and Michigan only provide specific details for repairing spalls. Six states (Colorado, Indiana, Kansas, Montana, Utah, and Washington) and the AASHTO guide specification clearly stand out as providing the most detailed guidance for both uncontrolled cracking and spalling.

The AASHTO guide specification provides an excellent model specification for repairing uncontrolled cracking and spalling along saw cuts. Section *501.03 Q. Repair of Defective Pavement Slabs* provides specific and detailed recommendations that are summarized as follows:

- Doing nothing to tight, uncontrolled cracks that only partially penetrate the full slab depth. The depth of the crack penetration will be determined by inspection of a core drilled at the Contractor's expense.
- Saw and seal any single, transverse uncontrolled crack that penetrates the full slab depth.
- When a transverse uncontrolled crack terminates in or crosses a transverse contraction joint, the uncracked part of the joint shall be filled with epoxy-resin mortar or grout, and the crack shall be routed and sealed.
- Where a transverse uncontrolled crack parallels the planned contraction joint and is within a distance of 5 feet from the nearest contraction joint in the pavement, the joint and the crack shall be sealed.
- Remove the entire slab if it has more than one crack and is divided into three or more parts.
- Remove the portion of a slab that contains a diagonally oriented crack. (The removal must be at least 3 m long and the full-width of the slab, and cannot leave a segment of the in-place slab less than 3 m.)
- Repair spalls using standard partial-depth repair procedures.

It is interesting that only 4 state agency specifications (Colorado, Montana, Utah and Washington) follow the AASHTO model for repairing defective concrete pavement. A majority of state specifications are considerably less detailed and presumably prone to much debate whenever an uncontrolled cracking problem arises on a project. The clauses for repairing defective concrete pavement in the standard specifications from Indiana and Kansas are also detailed, but deviate some from the repair recommendations in AASHTO guide specification.

POSSIBLE REPAIR METHODS

Table 5 outlines recommended repairs for uncontrolled cracking and spalling along saw cuts. It is based on the AASHTO model specification, but also considers two available techniques, cross-stitching and load transfer restoration.

CONCLUSIONS & RECOMMENDATIONS

1. The ability to adequately saw concrete pavement without excessive raveling and before uncontrolled cracking, depends on design features, jointing techniques and environmental circumstances.
2. An examination of all state highway agency standard specifications revealed little consistency regarding jointing and repairing defective slabs.
3. For clarity, agencies should develop new jointing specifications that are built around the sawing window concept, recognizing the possibility of raveling and uncontrolled cracking.
4. It is important that jointing specifications provide reasonable guidance to the contractor and inspector for handling uncontrolled cracking that may occur before or while sawing, including skipping joints and using early-age saws.
5. Many agencies should consider adding a damage repair clause to their specification, or modifying the existing clause to conform with the thorough methodology outlined in the 1993 AASHTO Guide Specifications for Highway Construction, or Table 5 in this report.

REFERENCES

1. *Design and Construction of Joints for Concrete Highways.* TB010P. American Concrete Pavement Association, Arlington Heights, IL, 1991.
2. Okamoto, P., and others. *Guidelines for Timing Contraction Joint Sawing and Earliest Loading for Concrete Pavements, Volume 1: Final Report*. FHWA-RD-91-079. FHWA, U.S. Department of Transportation, February 1994.

3. Zollinger, D., and others. Sawcut Depth Considerations for Jointed Concrete Pavement Based on Fracture Mechanics Analysis. In *Transportation Research Record 1449*, TRB, National Research Council, Washington, D.C., 1994, pp. 91-100.

4. *Joint and Crack Sealing and Repair for Concrete Pavements.* TB012P. American Concrete Pavement Association, Arlington Heights, IL, 1993.

5. *Fast-Track Concrete Pavements*. TB004.02P. American Concrete Pavement Association, Skokie, IL, 1994.

6. Saraf, C.L., and B.F. McCollough. Controlling Longitudinal Cracking in Concrete Pavements. In *Transportation Research Record 1043*, TRB, National Research Council, Washington, D.C., 1985, pp. 8-13.

7. McGhee, K., Design, Construction, and Maintenance of PCC Pavement Joints. *NCHRP Synthesis 211*. TRB, National Research Council, Washington, D.C., 1995.

8. Accelerated Rigid Paving Techniques: State-of-the-Art Report (Special Project 201). FHWA-SA-94-080. FHWA, U.S. Department of Transportation, December 1994.

9. Halm, H.J., W.A. Yrjanson and E.C. Lokken. *Investigation of Pavement Cracking Utah I-70, Phase I Final Report*. ID-70-1(31)7. American Concrete Pavement Association, Arlington Heights, IL, 1985.

10. Voigt, G.F., *Cracking on Highway 115 Petersborough, Ontario*. American Concrete Pavement Association, Arlington Heights, IL, 1992.

11. Voigt, G.F., *Investigation of Pavement Cracking on General Aviation Airport, Fremont Nebraska.* American Concrete Pavement Association, Arlington Heights, IL, 1994.

12. *Subbases and Subgrades for Concrete Pavements*. TB011P. American Concrete Pavement Association, Skokie, IL, 1991.

13. *Concrete Pavement Manual, Suggested Practices for Office and Field*. Fifth Edition. Portland Cement Association, Chicago, IL, 1955.

14. *Construction of Portland Cement Concrete Pavements, Participant's Manual*. FHWA-HI-96-027, National Highway Institute, FHWA, U.S. Department of Transportation, March 1996.

15. Rasmussen, R.O., and D.G. Zollinger, *The Development of a Mechanistic-Empirical Design Model for Uncontrolled Cracking in Jointed Plain Concrete Pavements using the LTPP GPS-3 Data*, Paper

Prepared for Presentation, 76th Annual Meeting, Transportation Research Board, Washington, D.C., 1997.

16. Ioannides, A.M., Salsilli-Murua, R., Temperature Curling in Rigid Pavements: An Application of Dimensional Analysis. In *Transportation Research Record 1227*, TRB, National Research Council, Washington, D.C., 1990, pp. 1-11.

17. *Road Trip - Specifications Software*. Version 3.0. Profile Development Corporation, West Chicago, IL, 1996.

18. *Guide Specifications for Highway Construction 1993*. American Association of State Highway and Transportation Officials, Washington, D.C., 1993, pp. 139-163.

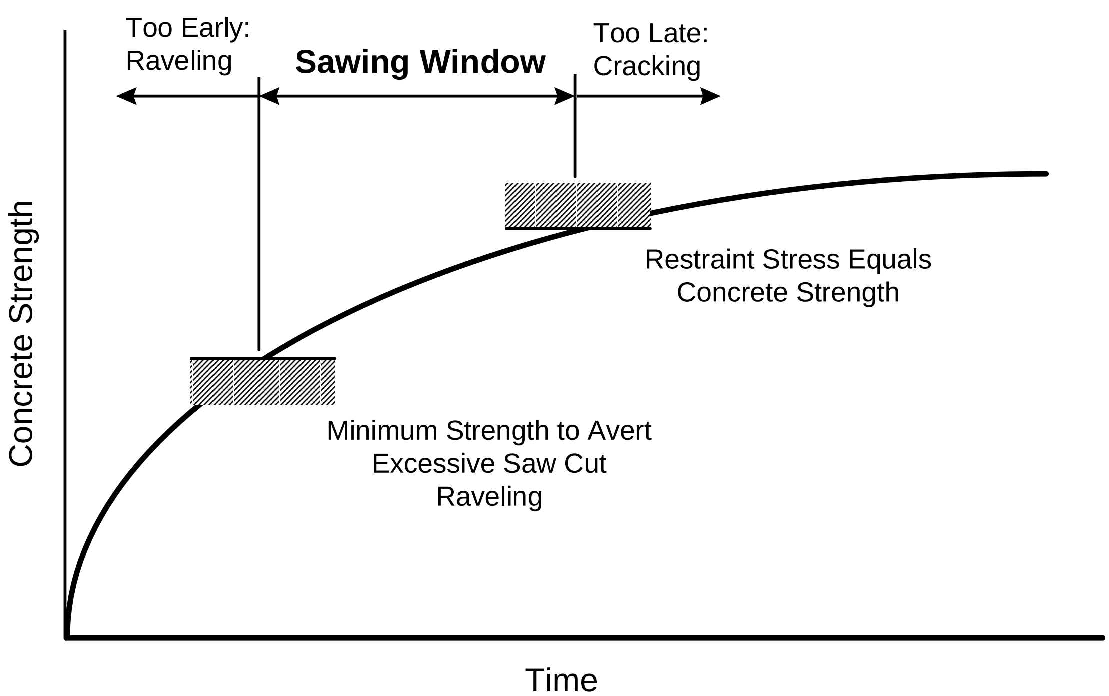

Figure 1. The sawing window.*(2)*

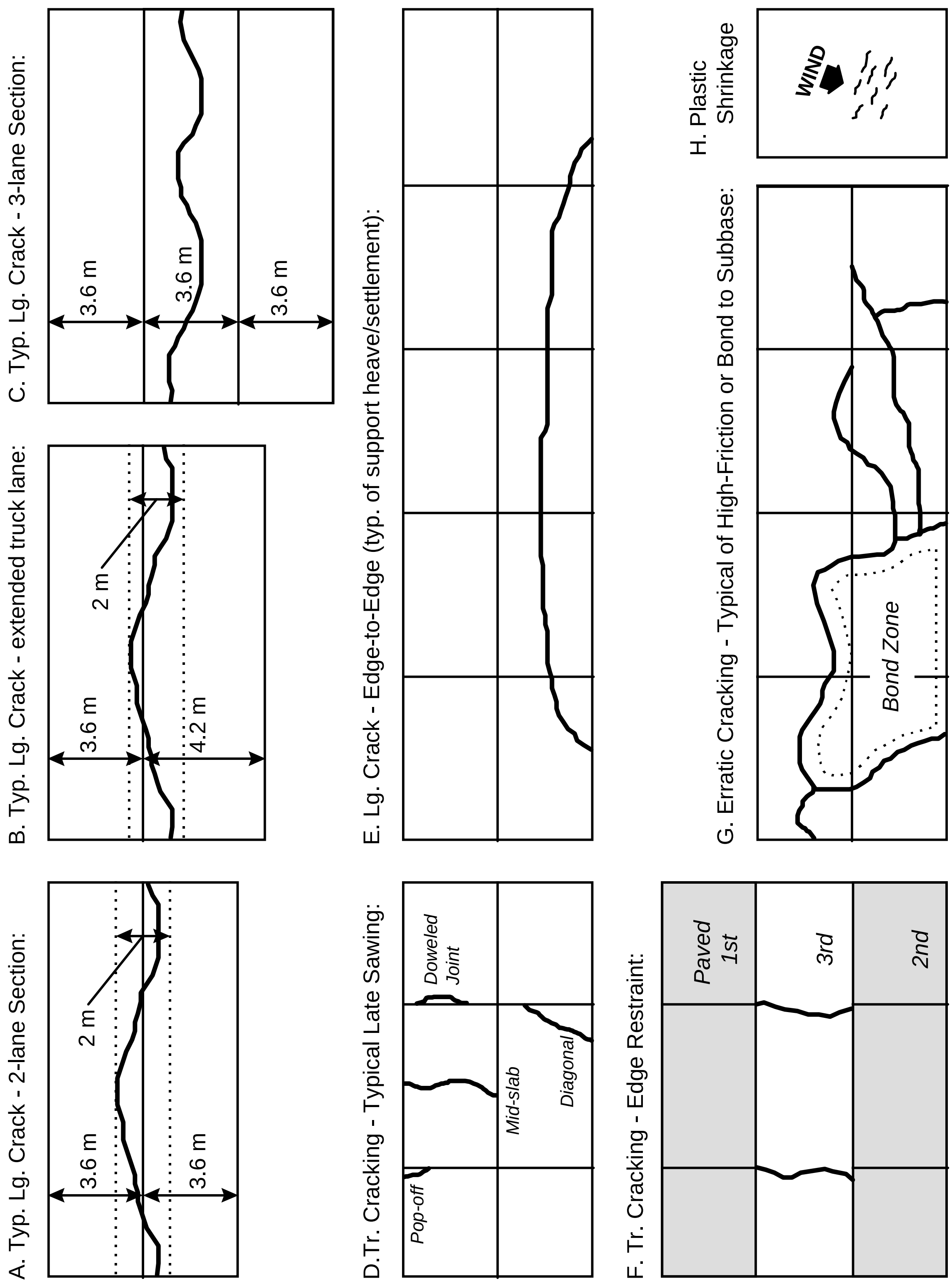

Figure 2. Typical early cracks on newly constructed concrete pavements (1 m = 3.28 ft).

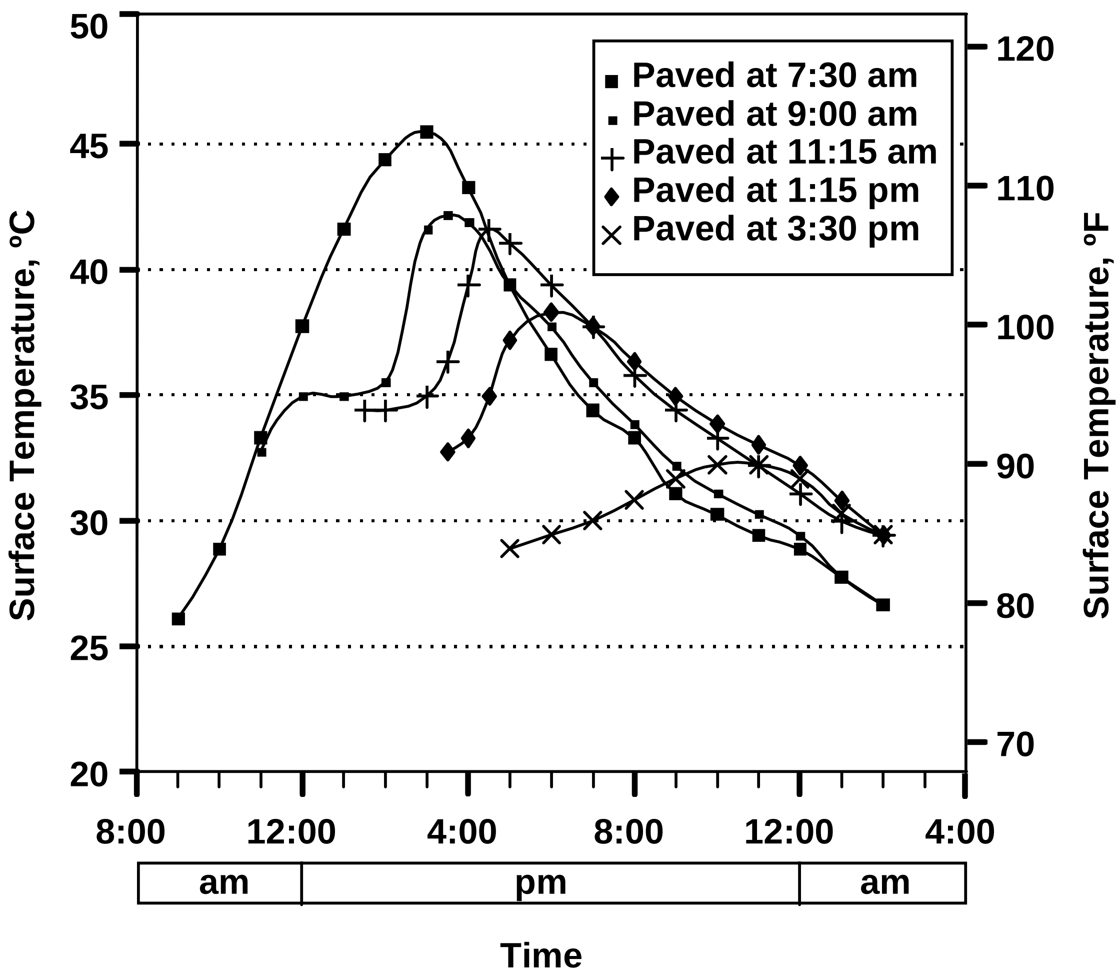

Figure 3. Surface temperatures of pavement slabs paved at different times of the day. (5)

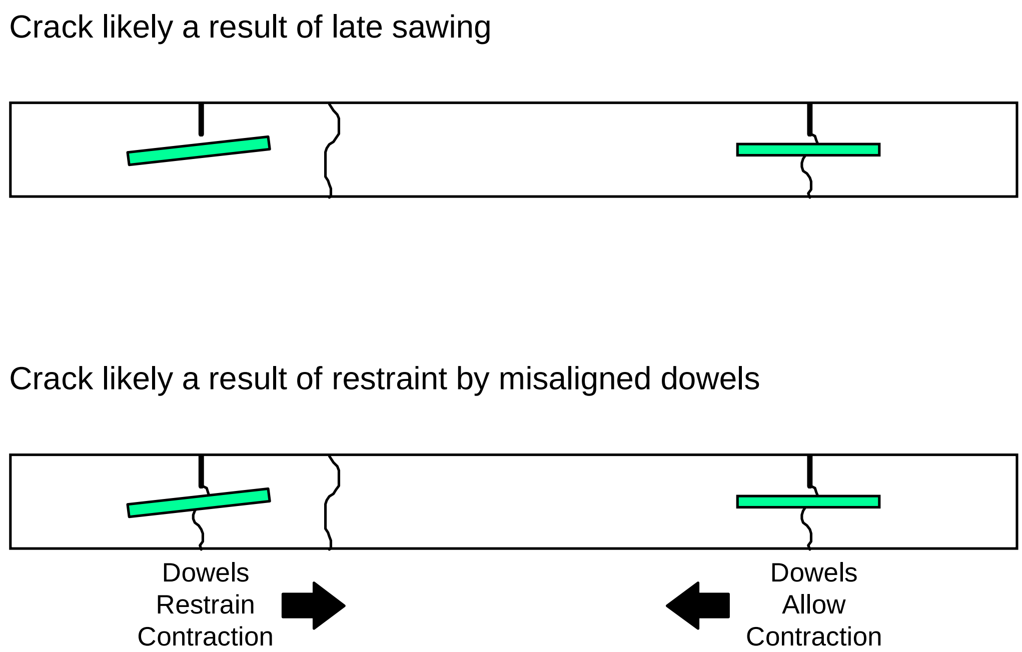

Figure 4. Mechanism necessary for cracking caused by misaligned dowel bars.

Table 1. Factors that shorten the sawing window.

Factor	Affects
Weather:	
Sudden temperature drop or rainshower	End of Window
Sudden temperature rise	End of Window
High winds and low humidity	Start of Window
Cool temperatures & cloudy	End of Window
Hot temperatures & sunny	End of Window
Subbase:	
High friction between the underlying subbase and concrete slab	End of Window
Bond between the underlying subbase and concrete slab	End of Window
Dry surface	Start of Window
Porous aggregate subbase materials	Start of Window
Concrete Mixture:	
Rapid early strength	End of Window
Slow early strength	Start of Window
Retarded set	Start of Window
Coarse aggregate	Start and End of Window
Miscellaneous:	
Paving against or between existing lanes	End of Window
Saw blade selection	Start of Window (False)
Delay in curing protection	Start of Window

Table 2. Transverse Joint Spacing Recommendations From 1955 [a]. *(12)*

Kind of Coarse Aggregate[b]	Joint Spacing[c] (converted to SI units)
Granite	7.6-9.1m
Limestone	6.1-9.1m
Flinty Limestone	6.1-7.6 m
Calcareous Gravel	6.1-7.6 m
Siliceous Gravel	4.6-6.1 m
Gravel (< 19 mm maximum size)	4.6 m
Slag	4.6 m

[a] Original note from the table: *This range of spacing provides for various subgrades, climatic conditions and characteristics of each coarse aggregate. The shorter spacing for each aggregate should be used unless specific experience has shown the longer spacing to be satisfactory.*
[b] 25 mm = 1 in.
[c] 1 m = 3.28 ft.

Table 3. Summary data on specification requirements relating to saw timing.

Number of Specifications					
Time to Begin		Time to Finish		Allow Raveling	
No Mention	33	No mention	20	No mention	13
24 Hours max.	8	Continue until done	12	If not excessive	19
12 Hours max.	2	24 Hour max.	9	None	14
6 Hours max.	3	12 Hour max.	3	Encouraged	1
As Directed	1	10 Hour max.	1		
		By Midnight	1		

Table 4. Summary data on clauses relating to handling cracks that occur during or before sawing.

Number of Specifications					
If Slab Cracks Before Sawing[a]		If Slab Cracks While Sawing		Allow Skipping Joints?	
No Mention	27	No mention	28	No mention	17
Omit the joint	14	Stop saw cut	18	Yes	11
Omit if w/in 1.5 m	3	Does not apply	1	Yes, if directed	2
Relocate if w/in 1.5 m	1			No	11
Omit if w/in 3 m	1			Required	5
Does not apply[b]	1			Does not apply	1

[a] 1 m = 3.28 ft.
[b] New Jersey uses an expansion type joint at 23.8 m (78.17 ft) intervals with no transverse contraction joints.

Table 5. Recommended Repair of Defects in New Pavement.

Defect Type	Orientation	Location[a]	Description	Recommended Repair	Alternate Procedures
Plastic Shrinkage	Any	Anywhere	Only partially penetrates depth	Do nothing	Fill with HMWM[b]
Unc. Crack	Transverse	Mid-slab	Full-depth	Saw & seal crack	LTR[c]
Unc. Crack	Transverse	Crosses or ends at transverse joint	Full-depth	Saw & seal the crack; Epoxy uncracked joint	
Unc. Crack	Transverse	Relatively parallel & w/in 1.5 m of joint	Full-depth	Saw & seal the crack; Seal joint	FDR[d] to replace crack and joint
Saw cut or Unc. Crack	Transverse	Anywhere	Spalled	Repair spall by PDR[e] if crack not removed	
Unc. Crack	Longitudinal	Relatively parallel & w/in 0.3 m of joint; May cross or end at longitudinal joint	Full-depth	Saw & seal the crack; Epoxy uncracked joint	Cross-stitch[f] or Slot-stitch crack
Unc. Crack	Longitudinal	Relatively parallel & in wheel path (0.3-1.35 m from joint)	Full-depth, hairline or spalled	Remove & replace slab	Cross-stitch[f] or Slot-stitch crack
Unc. Crack	Longitudinal	Relatively parallel & further than 1.35 m from a long. joint or edge	Full-depth	Cross-stitch[f] or Slot-stitch crack; Seal long. joint	
Saw cut or Unc. Crack	Longitudinal	Anywhere	Spalled	Repair spall by PDR[e] if crack not removed	
Unc. Crack	Diagonal	Anywhere	Full-depth	FDR[d]	
Unc. Crack	Multiple per slab	Anywhere	Two cracks dividing slab into 3 or more pieces	Remove & replace slab	

[a] 1 m = 3.28 ft

[b] HMWM = High molecular weight methacrylate poured over surface and sprinkled with sand for skid resistance.

[c] LTR = load-transfer restoration; 3 dowel bars per wheel path grouted into slots sawed across the crack; Slots must be parallel to each other and the longitudinal joint. Backfill with non-shrink, cement-based mortar (see reference 4).

[d] FDR = full-depth repair; 3 m (10 ft) long by one lane wide. Extend to nearest transverse contraction joint if 3-m (10-ft) repair would leave a segment of pavement less than 3 m (10 ft) long.

[e] PDR = partial-depth repair; Saw around spall leaving 50 mm (2 in.) between spall and 50-mm (2-in.) deep perimeter saw cuts. Chip concrete free, then clean and apply bondbreaker to patch area. Place a separating medium along any abutting joint or crack. Fill area with patching mixture.

[f] Cross-stitching; for longitudinal cracks only, drill holes at 35° angle, alternating from each side of joint on 750-1000 mm (30-36 in.) spacing. Epoxy deformed steel tiebars into holes. (see reference 4).

[g] Slot-stitching; for longitudinal cracks only,. Deformed bars grouted into slots sawed across the crack; Backfill with non-shrink, cement-based mortar.