TRANSVERSE JOINT DISTRESS AND MID-SLAB CRACKING DISTRESS IN PCC PAVEMENTS A PETROGRAPHER'S PERSPECTIVE

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Abstract
A forensic investigation was conducted on twenty jointed plain concrete and reinforced concrete pavements in the Ohio Department of Transportation system that have shown above average performance to date (Lankard, 2010). Included are three Interstate pavements, six US routes, and eleven State routes. The oldest pavement in the study was constructed in 1946 and the youngest in 1997. Petrographic examinations and concrete property measurements were made on cores that were taken (in 2009) through transverse control joints and through mid-slab cracks where they were present. The 10 cm (4 in) diameter, full-depth cores were taken at sites where no deterioration was manifest on the wearing surface at the time of coring. However, eighty percent of the joint cores showed some level of sub-surface cracking distress; as did seventy percent of the cores taken through a mid-slab crack. The origin, evolution, and consequences of this distress are discussed.

Introduction
The rationale for the conduct of this study was based on the premise that valuable information could be obtained through a thorough forensic examination of PCC highway pavements that had exhibited above average performance. An understanding of the factors influencing the performance of transverse control joints and of the factors influencing the formation and subsequent behavior of mid-slab cracking was (and is) of particular interest. Two cores were taken from each of the twenty study sites; one through a control joint and one through a mid-slab crack where they occurred (total of forty cores). In all cases the cores were taken at a location where no distress was present on the wearing surface of the pavement slabs at the time of coring.

Despite the appearance of sound concrete on the pavement wearing surfaces, most of the forty cores show some degree of sub-surface cracking. The petrographic evidence confirms that the cracking distress originated as a result of the effects of freeze/thaw cycling of the concrete while in a condition of critical moisture saturation. The sub-surface cracking takes three forms, which are illustrated in the drawing shown in Figure 1. They are identified as Types 1, 2, and 3 cracking.

In the Type 1 cracking pattern shown in Figure 1, the sub-surface cracks (singles and multiples) are roughly parallel to each other and to the plane of the original joint crack or to the plane of the mid-slab crack. These cracks are present in the cores just below the bottom of the joint saw-cut in the joint cores, and 2.5 to 7.5 cm (1 to 3 in.) below the wearing surface in the mid-slab crack cores. This cracking is referred to in future

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text as “Type 1 cracking.” Type 2 cracking occurs in the concrete at the bottom of the slab directly beneath the joint crack or the mid-slab crack.
When viewed in two dimensions as in Figure 1, the crack pattern has the shape of a bisected cone, with the apex of the cone lying under the original joint or mid-slab crack. Frequently, this results in a spall (red area).

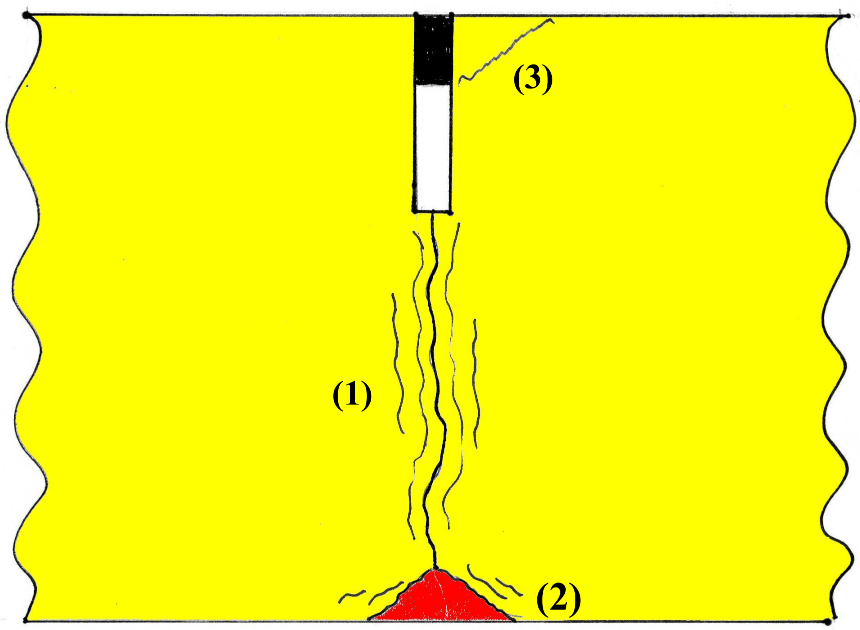

Figure 1. Schematic of the type of cracking exhibited by the joint and mid-slab crack cores examined in the present study (not to scale).

With time, the presence and progression of Types 1 and 2 cracking distress can lead to a complete break-up of the concrete within the confines of the cracks (becoming a spall). When this occurs, there is a loss of sub-surface support, and repeated traffic loadings place the concrete in the region of the joint and mid-slab crack in flexure, rather than compression (Site 3 in Figure 1). At this point the cracking and spalling will be manifested at the wearing surface along the joint or the mid-slab crack line. The Type 3 form of distress is made worse if upward curling has occurred in the pavement slabs.

There is common ground for comparing a transverse joint with a mid-slab crack. Both are separations (fractures) in the concrete, in which the fracture plane is oriented perpendicular to the plane of the pavement wearing surface. These fractures are access paths for moisture to enter from the wearing surface. The concrete adjacent to the separations can become saturated with water. Additionally, water can pond at the base of the slab beneath the fractures. Our findings indicate that this concrete is can experience freeze/thaw-related cracking, even when the concrete is satisfactorily air entrained, and when the concrete contains durable aggregates. In our study this scenario is the main factor involved in the initiation and progression of sub-surface cracking distress at both the joint and the mid-slab crack sites.

The twenty pavement concretes examined here are of good quality based upon the criteria of (1) freeze/thaw durability of the coarse aggregate phase, (2) air entrainment, and (3) water/cement ratio. In fact, the portions of the pavement concrete that lie *between* the control joints and any mid-slab cracks was in good condition at the time of coring and is currently (2012). The petrographic evidence confirms that the service environment in the vicinity of the joints and mid-slab cracks is much more severe than that experienced by the bulk of the concrete away from these sites. This phenomenon has much to do with the increased accessibility and retention of water in the joint and mid-slab crack regions of the pavement slabs.

Examples are given of pavement concretes in severe weather exposures that have survived 54 and 66 years of service and remain (as of 2012) in satisfactory condition. This finding confirms that PCC pavements can be designed to exceed a 50 year performance goal in severe weather exposure conditions. A service life goal of 75 or 100 years is within reach. To consistently realize this outcome it will be necessary to minimize the ingress and ponding of water at and near the control joints and the mid-slab and other transverse or longitudinal cracks.

The paper begins with a description of the twenty pavement concretes represented in the study and of the relevant pavement design parameters. This is followed by a discussion of the nature of deterioration in the joint concrete followed by a similar discussion of the deterioration of concrete along mid-slab and other transverse cracks. These discussions focus on (1) the unique environment for the concrete in the vicinity of the joints and transverse cracks, and on (2) the factors that are involved in the formation of mid-slab cracks and on the subsequent progressive of distress at these sites. The significance of the research is discussed in the last section of the paper.

Description of the Pavement Concretes

Pertinent features and properties of the twenty study concretes are summarized below.

The cement paste content and air void parameters were measured using the modified point count method of ASTM C 457, the Standard Test Method for Microscopical Determination of the Parameters of the Air Void System in Hardened Concrete.

Petrographic observations and estimates followed the relevant guidelines of ASTM C 856, the Standard Practice for Petrographic Examination of Hardened Concrete.

The strength and elastic properties were made on companion cores to the petrographic cores using relevant ASTM procedures.

- Nineteen of the concretes have a cement content of 326 to 356 kg/m^3 (550 to 600 lb/yd^3). The cement content of the 1946 concrete is 255 kg/m^3 (430 lb/yd^3).

- Eleven of the concretes are straight portland cement and nine have a binary blend of portland cement and fly ash.

- The coarse aggregate in the concretes includes (1) a siliceous/limestone gravel in six, (2) a crushed limestone or dolomitic limestone in eleven, and (3) a blast furnace slag in three.

- The nominal maximum size of the coarse aggregate is 10 mm ($^3/_8$ in.) in eleven of the concretes, 19 or 25 mm ($^3/_4$ or 1 in.) in eight, and 50 mm (2 in. in one.
- The fine aggregate in all the concretes is a natural sand containing both siliceous and limestone constituents. The dominant rock/mineral types include quartz, siltstones, and limestones.

Other properties of the concretes are listed below.

Property or feature	Average Value	Range of Values
Water to Cementitious Material Ratio (w/cm)	0.45	0.42 to 0.48
Cement paste content, %	27.5	20.3 to 31.0
Total Air Void Content, %	6.4	1.9 to 9.2
Air Void Specific Surface Area, mm^{-1}	31	22 to 56
Air Void Spacing Factor, mm	0.15	0.09 to 0.28
Water-Saturated Density, kg/m^3	2288	2220 to 2367
Compressive Strength, MPa	43	26 to 58
Splitting Tensile Strength, MPa	4.2	3.4 to 5.7
Static Modulus of Elasticity, 10^4 MPa	3.40	1.87 to 4.94

There is a Significant Variability in Concrete Properties Although all of the study concretes are judged to have shown above average performance to date, there is significant variability in their constituent make-up and in their physical and mechanical properties. Variability in compressive strength stands out in particular as the values range from 26 to 58 MPa (3770 to 8410 psi). The petrographic examination confirmed that the wide range in compressive strength is due to significant differences in the quality of the cement paste/aggregate bond, not to a high w/cm or to poor quality aggregates.

From a materials point of view, the good performance of these concretes to date is attributed in large part to,

- Acceptably low water to cementitious material ratios (0.42 to 0.48).

- All of the concretes are air entrained.

- A coarse aggregate that has shown intrinsically good freeze/thaw durability.

Pavement Design and Service Parameters

The pavements selected for study include heavily trafficked interstate highways, moderately trafficked US routes, and less heavily trafficked state roads. Pavement design parameters include,

- The selected pavements are in thirteen Ohio counties. As of 2012, pavement ages range from 66 to 15 years.

- Pavement thickness ranges from 20 to 30 cm (8 to 12 in).

- Spacing between transverse control joints is 4.6, 6.4, 8.2, 12.2, and 16.8 m (15, 21, 27, 40, and 55 ft).

- All of the joints are doweled and sealed. Eighteen of the joints have a pre-formed rubber joint sealant. A hot-poured joint sealant was used on two of the older pavements.

- Three of the pavements are plain concrete (all with 4.6 m [15 ft] joint spacing). The other seventeen pavements are reinforced.

- Three of the pavements have a drainable base.

The next section of the paper describes the condition of the cores that were taken through transverse control joints and identifies and discusses factors that have influenced the performance of the concretes at these sites.

Transverse Control Joint Deterioration Issues

The joint cores were taken at a location along transverse control joints where no joint deterioration was manifest on the wearing surface at the time of coring. An example is shown in Figure 2, which shows coring sites along a transverse control joint on State Route 682 in Athens County, Ohio in the southeastern part of the state. A saw-cut surface of the joint core is shown in Figure 3.

The State Route (SR) 682 pavement was placed in 1976 at a w/cm of 0.45. The concrete contains a 10 mm ($^3/_8$ in.) gravel coarse aggregate and is air entrained (7.6%), with an air void spacing factor of 0.16 mm (0.0064 in.). The original pavement thickness is 23 cm (9 in.), and the control joint spacing factor is 12.2 m (40 ft).

The SR 682 core shows cone-shaped cracking (in this case a spall) that was identified in Figure 1 as Type 2 cracking. This core also shows a near-surface crack identified in Figure 1 as Type 3 cracking. The coarse aggregate particles along the joint crack in Figure 3 have been highlighted in red to show that the joint crack passed around, rather than through the aggregate particles. There is no aggregate interlock.

Figure 2. Joint coring sites along a transverse control joint on PCC pavement on SR 682 in Athens County, Ohio (placed in 1976, photographed in 2009).

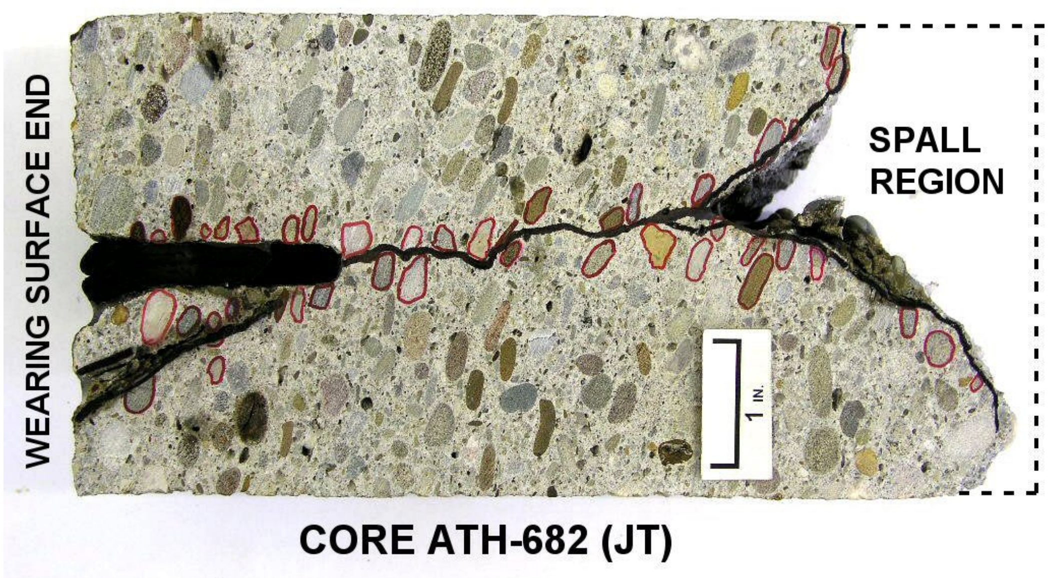

Figure 3. Saw-cut surface of the joint core taken from State Route 682 in Athens County, Ohio in 2009.

The bottom portion of the SR 682 core that has been lost as a result of the Type 2 cracking is the spall region in Figure 3. The petrographic evidence confirms that the cracking here is due to freeze/thaw distress within the cementitious phase of the concrete, despite the fact that the concrete is satisfactorily air entrained.

Sub-surface Cracking Distress in an Interstate Pavement Joint Core Figure 4 is a lapped surface of the joint core taken from Interstate 76 (East) in Summit County, Ohio, in the north-central part of the state. This is a 28 cm (11 in) pavement constructed in 1992. Joint spacing is 6.4 m (21 ft).

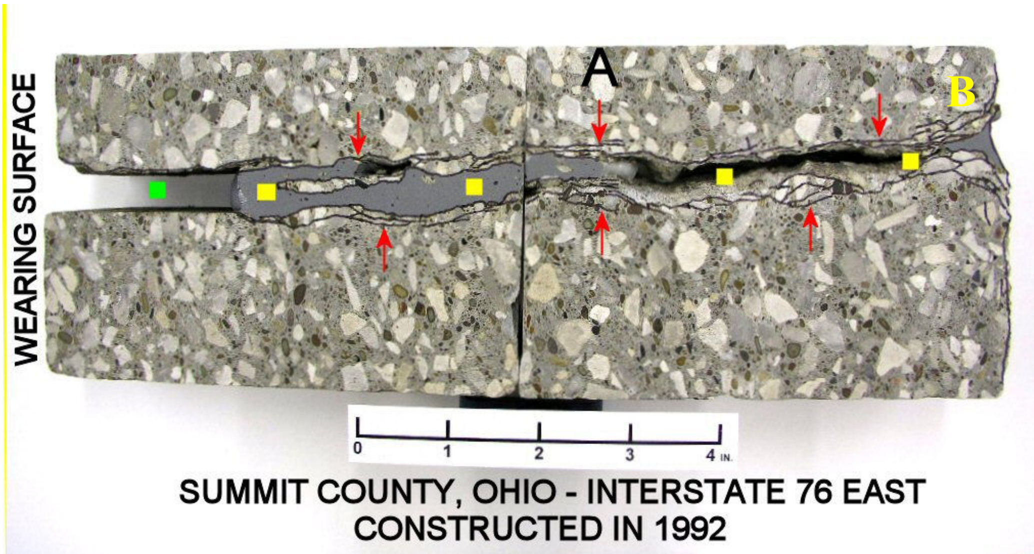

Figure 4. Lapped surface of the joint core taken from Interstate 76 East in Summit County, Ohio, showing sub-surface cracking and spalling distress.

The Summit County I-76 core concrete is air-entrained, with a total air void content of 6. 3 percent, and an air-void spacing factor of 0.12 mm (0.0050 in).

The red arrows in Figure 4 point to Type 1 cracks (highlighted in black) that are present throughout the length of the core (under the joint saw-cut). The yellow dots are placed on void spaces (now partially filled with gray epoxy) where cracked concrete spalled and was lost during the coring operation. At the bottom end surface of the core is the beginning of a cone-shaped Type 2 cracking and spall region.

The green dot in Figure 4 is placed within the joint saw-cut cavity. At this coring site, there is no adhesive bonding the pre-formed rubber sealant to the concrete and it easily dislodged during subsequent handling of the core.

The Type 1 cracks in the I-76 core are due to the effects of freezing and thawing at this coring site along the joint. Photographs taken at a 10X and 7X magnification at Sites A and B on the lapped surface of the I-76 core shown in Figure 4 are shown in Figures 5 and 6 (stereomicroscope views).

In Figure 5 (Site A in Figure 4) the blue arrows point to two of the Type 1 cracks in the concrete adjacent to the spalled area (which is filled with the gray epoxy in the photograph). The red arrows point to two of the numerous spherical entrained air voids that have been filled with white secondary deposits (innocuous ettringite).

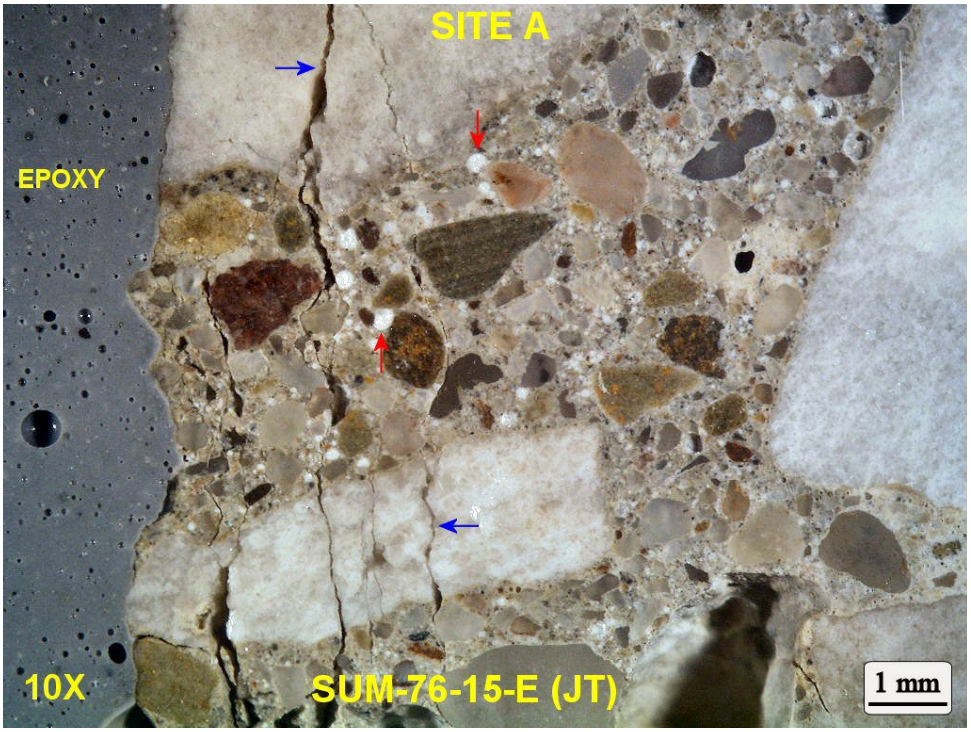

Figure 5. Enlarged view (10X) of the lapped surface of the I-76 core at Site A in Figure 4. The wearing surface is at the top in the photograph.

In Figure 6 (Site B in Figure 4) the blue arrows point to Type 2 cracks that have formed in concrete along the bottom end surface. The gray epoxy in this photograph fills the small cone-shaped spall volume. Here too, the entrained air voids are filled with innocuous secondary deposits.

The Cracking in the Joint Cores is Freeze/Thaw-Related The cracking shown in Figures 4, 5, and 6 for the Summit County, Ohio I-76 joint core is characteristic of cracks that were initiated within the cementitious matrix and not within the coarse aggregate particles (in this case a 10 mm [$^3/_8$ in] dolomitic limestone. When F/T cracking is initiated within the aggregate particles (as in D-Cracking), the cracks are randomly oriented within the particles, often intersect each other, and the crack planes frequently are parallel to the external surfaces of the particle, just below the surface.

The Type 1, 2, and 3 cracking shown for the SR 682 joint core and the I-76 joint core (shown in Figures 3 through 6) is present to some degree in sixteen of the twenty joint cores examined here. The freeze/thaw-related cracking can not be attributed to any shortcomings of the entrained air void systems in the concretes. For eighteen of the twenty core concretes the total air void content ranges from 4.2 percent to 9.2 percent, with air void spacing factors ranging from 0.09 mm (0.0036 in) to 0.20 mm (0.0080 in). In the US the industry guideline for air entrained pavement concrete is a total air content of 6 ± 1 ½ percent, with an air void spacing factor not exceeding 0.20 mm (0.0080 in).

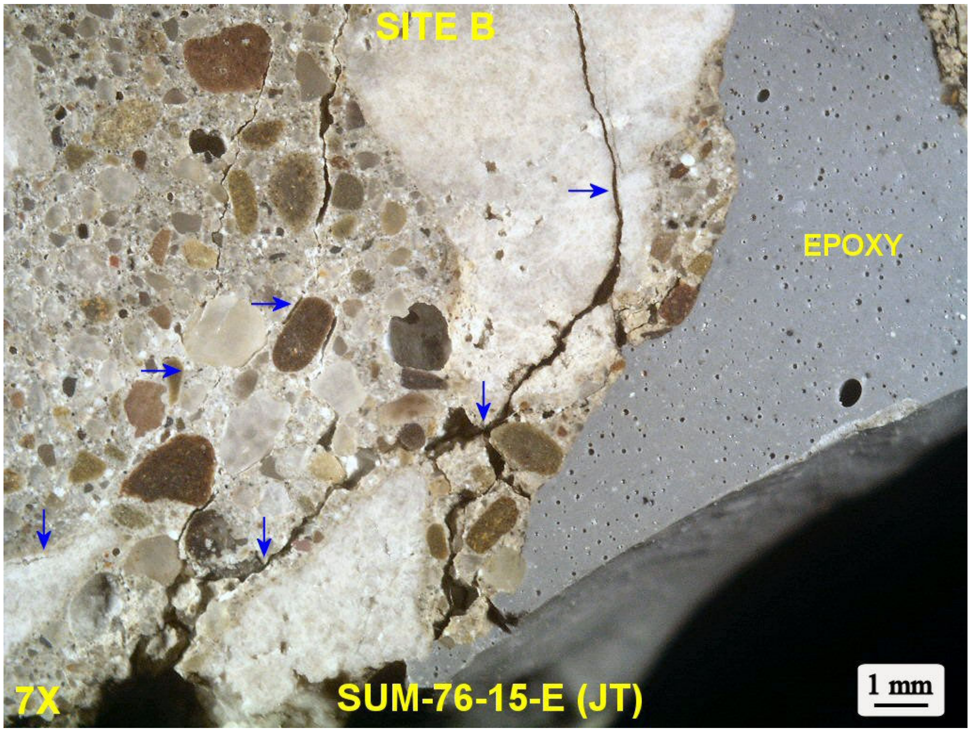

Figure 6. Enlarged view (7X) of the lapped surface of the I-76 core at Site B in Figure 4 (along the bottom end surface of the core).

There are at least three factors that are involved in the fact that these pavement concretes, which have an acceptably low w/cm (ca. 0.45), with a good quality entrained air void system are experiencing sub-surface freeze/thaw-related distress within the cementitious phase in the vicinity of the control joints.

- If not effectively sealed, the control joints provide an access route for moisture on the wearing surface to saturate the concrete along the joint crack and to pond on the base material at the bottom of the joint crack.

- Fueled by an inexhaustible supply of water from the surface, the on-going cycles of wetting and drying of the joint concrete result in the deposition of innocuous secondary deposits within entrained air voids. This condition compromises the intended function of the air voids, which is to provide an empty space within the cementitious microstructure during freezing events.

- For the concrete positioned within a few millimeters of a free surface (as shown in Figures 5 and 6) it is possible for the air to be expelled from the air void cavity, and subsequently to be filled with water. Again, this condition compromises the intended function of the entrained air voids.

For the concrete in the vicinity of the control joints, the science here is quite clear. Freeze/thaw damage will not occur in concretes (even non air-entrained concretes) that do not reach a condition of critical moisture saturation. And, in properly air entrained concretes, the potential for the entrained air voids to be rendered ineffective is diminished when the accessibility of water within the joint is eliminated or minimized. Despite the effort to seal the joints in these study concretes the seals have shown various levels of effectiveness. Adhesives for the preformed rubber sealants were not used at all of the pavement sites.

An example of an effective and durable joint sealant was encountered in one of the pavements in the present study.

Outstanding Joint Performance in a 66 Year Old PCC Pavement There is a lightly trafficked State Route in Gallia County, Ohio (south central), which was constructed in 1946 and which is in good condition at the present time (Figure 7). State Route 7 is a two lane, 20 cm (8 in) thick reinforced PCC pavement, with 12 m (40 ft) joint spacings. This 4 km (2.5 mile) stretch of the highway still retains many of its original control joints.

Figure 7. State Route 7 in Gallia County, Ohio. Photograph taken in 2009.

The control joints in the pavement were formed with a trapezoidal-shaped insert. The joint opening was covered until it was confirmed that the joint crack had formed. At that time a sanded, hot-melt bituminous material was poured in the joint cavity. A photograph of a lapped surface of the Gallia County SR 7 joint core is shown in Figure 8. This is the only pavement of the twenty that has a 5 cm (2 in) maximum size coarse aggregate (an Ohio River Gravel). Note the aggregate interlock.

The yellow arrows in Figure 8 define the top and bottom of the original formed joint cavity, which is around 6 cm (2 ¼ in) deep. In addition to filling the formed cavity, the hot-melt sealant has penetrated almost 2.5 cm (1 in) into the joint crack. The red arrow in Figure 8 identifies the depth of penetration of the sealant into the joint crack.

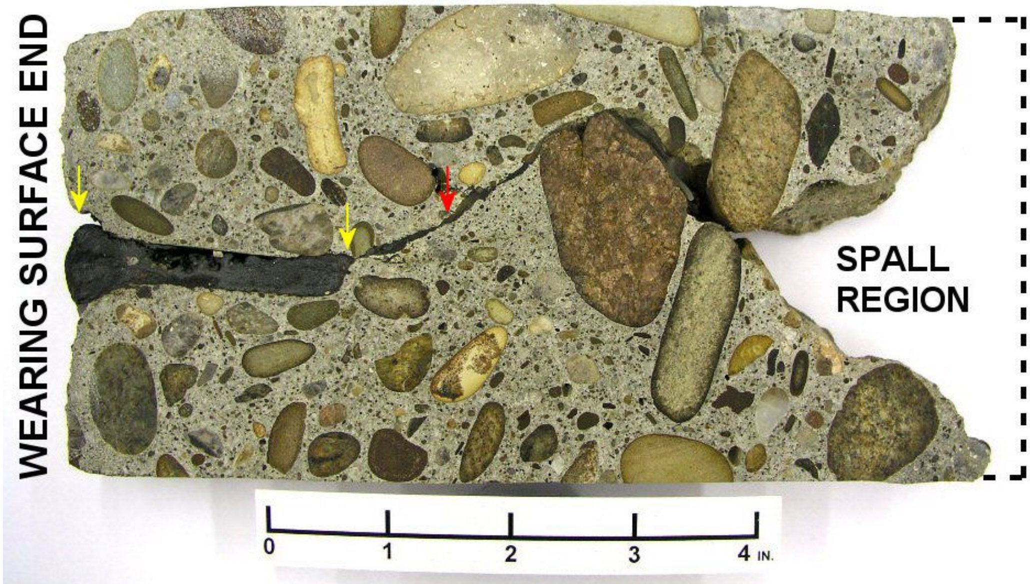

Figure 8. Lapped surface view perpendicular to the plane of the wearing surface in the Gallia County, Ohio SR 7 joint core. This is the original joint that was placed in 1946.

The joint sealant retains its elastomeric properties and was well bonded to the concrete when the core was taken. The only sub-surface distress in the core is the Type 2 cone spall at the bottom of the core. This freeze/thaw-related distress occurred as a result of the concrete in this portion of the slab experiencing water ponding along the bottom of the slab. Although the concrete is air-entrained, the total air void content is low (3.4 percent), and the spacing factor is moderately higher than desired at 0.24 mm (0.0097 in). The air voids in the vicinity of the spall are filled with secondary deposits. The petrographic evidence from the core suggests that the source of the water that ponded along the bottom of the slab over the years came from the base and not from the slab surface.

What Role did the Joint Sealant Play in the Performance of the SR7 pavement? The field notes recorded in 2009 when this 4 km stretch of SR7 in Gallia County was inspected and cored read "Pavement is in good condition with a few minor transverse cracks and spalling". A close look at the photograph of the pavement in Figure 7 provides verification of this assessment. Quite a few of the 12 m (40 ft) long panels show no surface distress of any kind. The hot-melt sealant in many of the transverse control joints is in good condition for the full width of the joint and is bonded to the concrete on both sides of the joint.

Although the Gallia County, SR7 pavement is lightly trafficked it has experienced (1) expansive and contractive strains due to thermal movements and moisture cycling, and (2) at least three months of freezing and thawing conditions each year for 66 years. Something is working! It is difficult to avoid a conclusion that the ability of the hot-melt sealant to limit the access of surface moisture into the pavement along the joints has made a substantial contribution to the outstanding performance of this pavement.

As will be shown in the discussions to follow, the factors involved in the formation of sub-surface cracking distress in the region of the transverse control joints are also in play in the concrete adjacent to a mid-slab crack.

In our study, we considered both the factors involved in the initial formation of mid-slab cracks and the factors that influenced the subsequent progression of cracking and spalling along the crack line once it had formed. These issues are addressed here.

The Formation of Mid-Slab Cracks

This issue of the causes of mid-slab cracking has received widespread attention from concrete researchers and engineers for many years, and there is a general consensus of opinion on the subject that was summed up in a 2002 study of jointed plain PCC pavements by researchers at Purdue University (Hung-Ming, 2002). These researchers reviewed the literature and conducted a thirty six state survey of state departments of transportation. Their findings are summarized below.

- "There is no one clear factor that can be identified as the major cause of mid-slab cracking in JPC pavements".

- "According to most researchers the combined mechanisms of curling and fatigue due to traffic loadings lead to the occurrence of the transverse cracking along with shrinkage cracking"

This opinion leads to a conclusion that factors that can limit the extent of curling (upward curling), and reduce the magnitude of strains due to thermal cycling and moisture cycling should reduce the probability of the formation of mid-slab cracks.

Beyond these issues it is also widely acknowledged that the use of steel reinforcement can not eliminate the formation of mid-slab cracks, but can limit the width of cracks once they do form.

Finally, there is the matter of the factors that restrain the movement of PCC slabs due to thermal and moisture cycling. In the industries concerned with the design and construction of interior PCC slabs on grade this situation is addressed by limiting the spacing between control joints, taking into account the slab thickness. Although many DOTs have reduced control joint spacings over the years, this has not eliminated the mid-slab cracking problem.

In the present study fourteen of the twenty PCC pavements showed mid-slab cracking, while six did not. The pertinent observations in both cases are discussed below.

Insights into the Cause of Mid-Slab Cracking Gained in the Present Study Six of the twenty study pavements showed virtually no mid-slab cracking. They include one Interstate pavement, one US route, and four State routes, constructed over the period 1992 through 1997. There were no "breakthrough" insights that set these six pavements apart from the fourteen that did show mid-slab cracking. However, the following observations are relevant.

- All six of the “no-crack” study pavements contain a limestone coarse aggregate. The coefficient of thermal expansion of these carbonate aggregates can be 25 to 50 percent lower than that for siliceous or slag aggregates. The use of limestone aggregates has the potential to reduce the expansive and contractive thermal strains relative to the other aggregate types. However, the other five study concretes that contain a limestone coarse aggregate did have a mid-slab cracking issue.

- It is expected that upward curling strains would be highest in those PCC pavements where the bottom portion of the slab is periodically saturated with water over long periods of time. Conversely, if the bottom of the slab is in a reasonably dry condition on a long term basis, the upward curling strains should be lower. Three of the six “no-crack” study pavements have a drainable or free-draining base. These are the only drainable bases for the twenty study pavements.

- Despite its 66 years of service, and despite having a control joint spacing of 12 m (40 ft), not all of the original control joints on the 4 km (2.5 mile) length of the Gallia County SR7 pavement project have been replaced or show any distress. This surprising performance may be related to the fact that the dowels used in this low traffic volume pavement have a diameter of only 19 mm ($^3/_4$ in), as compared to current practice where the dowels are 25 to 38 mm in diameter (1 to 1 ½ in). It has been conjectured that misalignments between dowels do occur in practice. It is reasonable to conclude that even slight misalignments of the dowels can result in a failure of the control joints to fully function as intended (without contributing to restraint). The smaller diameter, (and hence more flexible) dowels in the Gallia County pavement would be expected to be more capable of accommodating misalignments relative to the larger diameter, stiffer steel dowels in use today. It is also noted that the Gallia County SR7 pavement is the only one of the study concretes that had aggregate interlock at the control joint and the mid-slab crack.

- With further regard to restrained movement, it is noted that of the three study pavements having a joint spacing of only 4.6 m (15 ft), two have shown mid-slab cracking after 21 and 24 years of service. The one pavement that has not yet cracked has been in service for 18 years. Reducing the joint spacing below what would be considered safe for an interior slab on grade, has not had the same effect for these doweled pavement slabs.

Cracking and Spalling Along Mid Slab Cracks Once they have Formed
Once transverse cracks have formed in PCC pavement slabs they are vulnerable to the same type of freeze/thaw related cracking/spalling distress described previously for the transverse control joints. Fourteen of the twenty study pavements showed mid-slab cracking. Of these fourteen, ten showed some degree of the various types of cracking distress associated with the crack plane as illustrated in Figure 1. The most common cracking is of the Type 1 variety.

An example of a coring location along a mid-slab crack is shown in Figure 9, which is an overview of the SR 682 pavement in Athens County, Ohio (Constructed in 1976).

Figure 9. The coring site along a mid-slab crack on PCC pavement on State Route 682 in Athens County, Ohio. Photograph taken in 2009.

There is some of the Type 3 surface cracking and spalling in the portion of the crack closest to the shoulder, where moisture accessibility would be higher than in the center of the slab. The core at this site was taken at a location where there is no manifest distress in the wearing surface. This core is in good condition and shows only a minor amount of the Type 2 cracking along the bottom end surface.

Minor Type 1 Cracking Distress in a Mid-Slab Crack Core Figure 10 shows a lapped surface of the mid-slab crack core from the Summit County, Ohio, Interstate 76 East pavement. The concrete in the vicinity of the crack fracture plane shows the same distress features as described in Figure 5. The total air void content of the concrete is 6.3 percent with an air void spacing factor of 0.12 mm (0.0050 in).

Significant Amount of Type 1 Cracking in a Mid-Slab Crack Core The core taken through a mid-slab crack on State Route 7 in Jefferson County, Ohio shows the greatest amount of sub-surface distress of any of the mid-slab crack cores. Figure 11 is a lapped surface of the core, which has a blast furnace slag coarse aggregate. The total air void content of the concrete is 6.1 percent with an air void spacing factor of 0.18 mm (0.0071in).

The Type 1 cracking in the Jefferson County SR7 core has led to a significant amount of spalling along the crack fracture plane (Figure 11). I believe that the resultant loss of support in this region of the pavement contributed to the formation of Type 3 cracks (red arrows in Figure 11), which ultimately leads to spalling distress along the mid-slab crack in the wearing surface. Figure 12 shows an example of the Type 3 cracking distress feature on the Jefferson County, State Route 7 pavement.

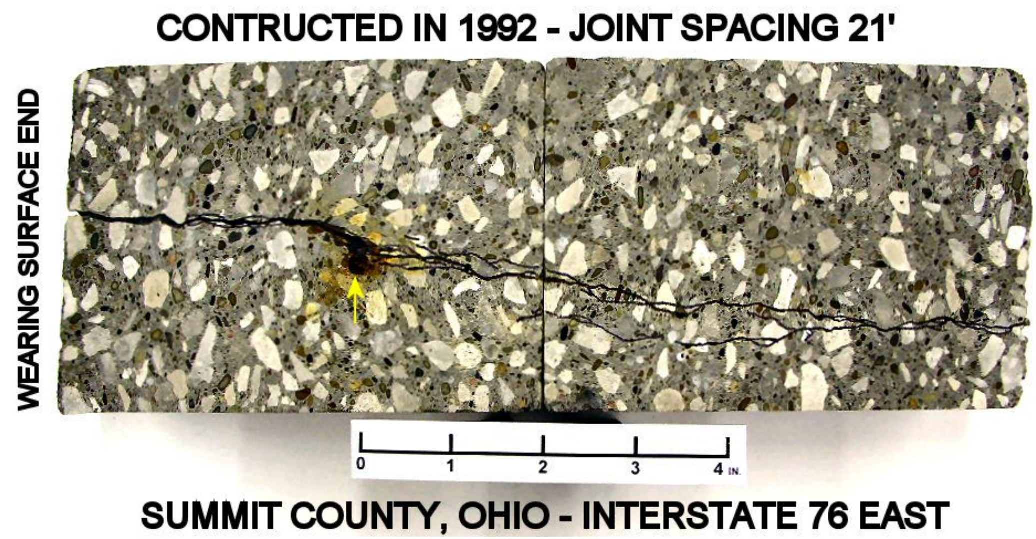

Figure 10. Lapped surface of the mid-slab crack core taken from Interstate 76 east in Summit County, Ohio. Type 1 cracks in the core are highlighted in black. The arrow points to a mesh strand, which shows a minor amount of rust.

Figure 11. Lapped surface of the mid-slab crack core taken from State Route 7 in Jefferson County, Ohio. This mid-slab crack core shows examples of Types 1, 2, and 3 cracking distress.

The Type 1 cracking in the Jefferson County SR7 core has led to a significant amount of spalling along the crack fracture plane (Figure 11). I believe that the resultant loss of support in this region of the pavement contributed to the formation of Type 3 cracks (red arrows in Figure 11), which ultimately leads to spalling distress along the mid-slab crack in the wearing surface. Figure 12 shows an example of this distress feature on the Jefferson County, State Route 7 pavement (not the joint from which the joint core in Figure 11 was taken). Note the sound concrete on each side of the crack.

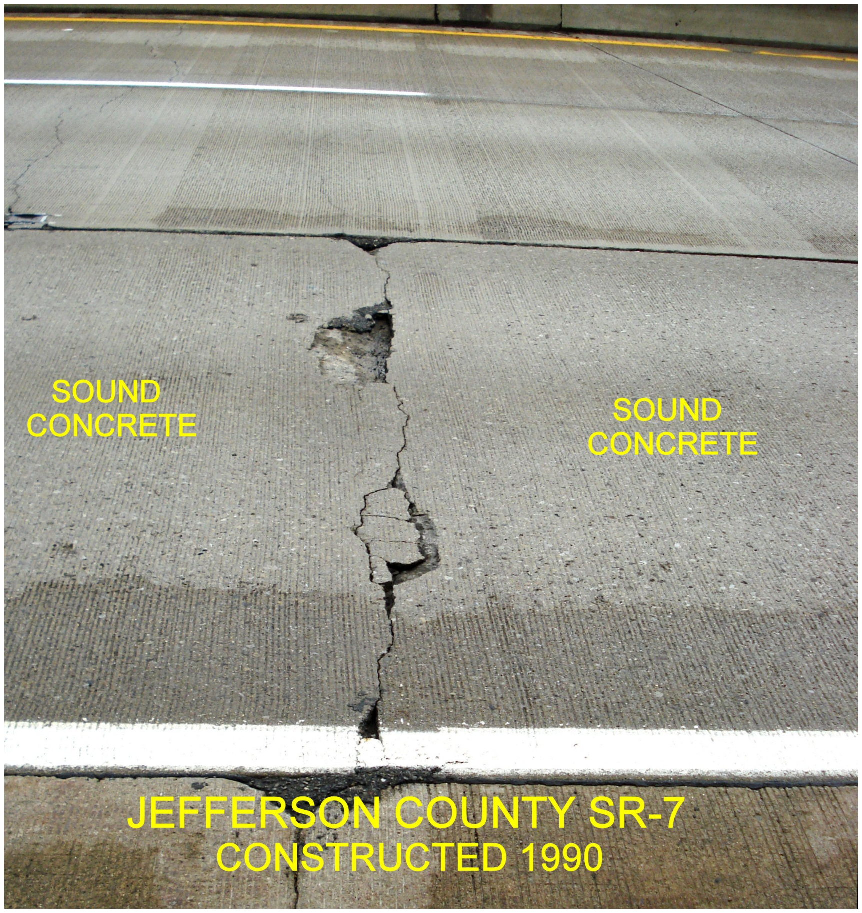

Figure 11. A mid-slab crack on the Jefferson County, Ohio State Route 7 pavement showing Type 3 cracking and spalling distress (Photographed in 2009).

Summary and Research Significance

The twenty PCC pavements examined in this forensic study were chosen on the basis of their good condition at the time of coring (2009). All of the study concretes are of good quality as judged by the criteria of (1) acceptable water to cementitious material ratio, (2) air entrainment, and (3) a durable coarse aggregate. The majority of the pavements have been in service for 15 to 20 years. One pavement has now (2012) been in service for 54 years; another for 66 years. The question considered at the conclusion of the study is "will the pavements currently in the 15 to 20 years of service category continue to perform satisfactorily for 54 or 66 years?" Based on the findings of the present study, it can be claimed with some confidence that the portion of the pavement concrete lying between the joints and the transverse cracks could indeed be expected to perform well up to and perhaps beyond 66 years (see Figures 2, 7, 9, and 11). However, it is clear that good quality pavement concretes are a necessary, but not sufficient criterion for overall PCC pavement longevity.

Not surprisingly, it is the vulnerability of the concrete in the vicinity of the joints and transverse cracks that is the greatest barrier to the realization of the consistent achievement of a service life of 50 to 100 years in PCC pavements. Relative to the pavement concrete positioned between the transverse control joint and any transverse cracks, the service environment of the concrete comprising the joints and transverse cracks is significantly more severe. In regions of North America where freezing occurs, this increased severity is a result of the joint and transverse crack concrete becoming critically saturated. As discussed in this paper, even a low water-cement ratio, a good quality entrained air void system, and a durable, freeze/thaw resistant coarse aggregate cannot prevent the occurrence of freeze/thaw related distress in these portions of a PCC pavement. Once this freezing-related cracking distress is initiated, the deterioration is aggravated by subsequent upward curling and traffic loadings on the control joints and transverse cracks.

The science here is quite clear. Freeze/thaw damage will not occur in concretes that do not experience critical water saturation levels. An increased service life for joint concretes and for the concrete adjacent to any transverse crack is dependent on (1) minimizing the water entering the concrete at these locations (one way is to provide durable and effective joint sealants), and (2) a base design which can eliminate or minimize the accumulation of water along the bottom of the pavement slabs (providing drainable bases). The present paper provides additional data for the ongoing discussions regarding the pros and cons of pavement joint sealing (Bagsarian 2011).

The findings of the our study can be strictly applied only to the twenty pavement concretes that were examined and tested. However, the weather conditions and traffic loading conditions in Ohio are similar to those of many of the states and provinces that experience freezing temperatures. Our findings should be applicable to pavement concretes from these other regions that show the same microstructural features as those described here.

References

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