Petrographers Perspective of Joint Associated Distress

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Overview

Although necessary in most pavements, joints can be viewed as the "weak link" in pavement design and performance. Distresses often encountered in aged pavements occur only at the joints or the distress mechanisms are more severely exhibited there. The ingress of moisture drives nearly all materials-related distresses. Non-sealed joints or compromised sealants (neoprene, silicon/backer rod, hot-pour) provide that access for moisture. Further, a lack of drainage from un-activated (un-cracked) joints, debris-plugged joints, and in-filled sub-base concentrates moisture and brines (from deicers) in the joints. It is highly likely in certain cases that the adjacent concrete at pavements joints becomes critically saturated – allowing freeze-thaw distress even in high quality concretes.

Photo 1: 6" diameter concrete pavement core through a neoprene compression – sealed joint.

Common Distress Mechanisms

Pavement distress occurs to the concrete paste, aggregates, or a combination of both. It may be a result of shortcomings in the concrete mix design, its execution, or its placement. Typical distresses a concrete pavement can exhibit are premature surface wear, surface spalling or scaling, joint raveling, and pattern cracking from bulk expansion, shrinkage, or structural overloading. Distresses can occur "symbiotically" and may be exacerbated by cyclic structural overloading. Again, joints act as a point of ingress of water.

ASR

Alkali-silica reaction (ASR) is a widely described expansive reaction that occurs between an unstable siliceous component in the coarse and/or fine aggregates and the highly alkaline pore solutions in the concrete. Rock types commonly implicated in ASR include: quartzite, quartz sandstone (arenite), chert, partly silicified carbonate rocks (by chert or chalcedony), gneisses/meta-granites, argillites, and glassy volcanic rock. These rock types are present in many regions of the USA and may or may not be susceptible to alkalis. All aggregates for concrete pavement should have been pre-qualified for susceptibility for ASR. Testing commonly performed on aggregates for ASR potential includes the accelerated mortar bar tests ASTM C1260 and C1567 (tested for mitigation with pozzolans), and petrography by C295. Petrography performed by an experienced concrete and concrete aggregate petrographer can tell you if potentially ASR susceptible silica is present in the aggregate but it cannot tell you if those materials will produce damaging ASR in the specific concrete mixture or under the ambient environmental conditions the concrete will be exposed to. ASTM C289 has fallen out of favor by most technologists due to reliability concerns and the length of time for results by ASTM C1293 (1-2 years) eliminates it from most specifications.

ASR generally produces concentrated cracking directly adjacent and parallel to the pavement joints and panel edges due to the exposure to persistent moisture in the joints (photo 2). Without the benefit of sampling and microscopy, this cracking has been confused with freeze-thaw distress. Cores taken from mid-panel locations in these cases can show little or no active ASR. Other pavements exhibiting ASR can be marked by more widespread map or “craze” cracking over their entire surfaces. This cracking can be confused in the field with a more common shrinkage-induced craze cracking. However, bulk expansion of the slab should be evident in the case of ASR. ASR is sometimes opportunistic or occurs “symbiotically” with freeze-thaw distress in older pavements and occurs only after the concrete “system” has been compromised.

The reaction between alkalis in the paste and the reactive silica in the aggregates produces an expansive silica gel product which induces cracking and bulk expansion in the concrete (photo 3). The gel product is hydroscopic; absorbing more water after formation to continue its growth. The reaction requires alkalis, reactive silica, and moisture. Eliminating or reducing any one of the components may prevent the reaction. Unfortunately, alkalis and moisture cannot be avoided in concrete pavement. The use of low alkali cements and pozzolans such as Class F flyash have been successful in mitigating ASR. Pozzolans can mitigate the ASR reaction by reacting with and eliminating the alkalis by incorporating them into the subsequent additional cementitious binder.

Photo 2: ASR cracking in a Mid-west pavement containing reactive quartzite coarse aggregate.

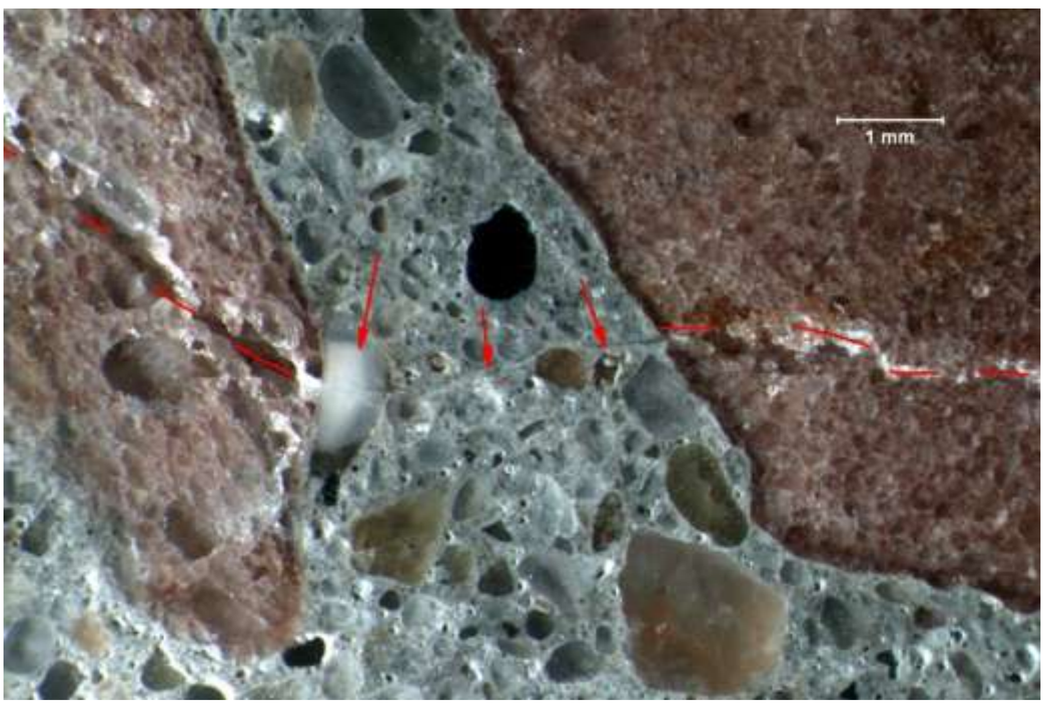

Photo 3: Clear to white colored ASR gel product fills a void and microcracking adjacent to reacted and cracked coarse quartzite aggregate particles.

Cyclic Freeze-Thaw

Saturated pavements are generally protected from distress from cyclic freeze-thaw action by entrained air-void systems meeting parameters recommended by ACI guidelines. Further, the use of hard, sound, and durable coarse aggregate sources prevents the “d-cracking” distress which was much more pervasive in concretes placed greater than 20 years ago. Most of these poorly performing aggregate sources were quarried crushed carbonates, commonly comprised of dolostone (also known as dolomite – the mineral). Some were naturally occurring pit-run gravels rich in dolostone. The offending carbonates commonly contained a pore system allowing critical saturation and freeze-thaw distress. Nearly all of these aggregate sources have been identified and locally or regionally precluded from use in exterior concrete though experience, thorough testing, or condition surveys. Carbonate-rich states, such as Iowa, have extensive pre-qualification procedures in place and have individual quarries surveyed by distinct ledges and geologic formations.

Air-void parameters recommended by ACI for concrete in freeze-thaw environments include volume, spacing factor and specific surface values. The great majority of all concrete pavement placements contain good quality, well distributed air-void systems. Rare, isolated cases of air void loss or segregation in “vibrator trails” have been described. Air void loss during placement has not been observed by this petrographer at slip formed surfaces or early-age sawcut control joints. However, a large apparent loss in air void effectiveness at joints has been observed due to complete in-filling of finer air voids from secondary ettringite. Reductions in air void volumes from 5 or 6% down to 3 or 4%, with a large increase in spacing factor were not uncommon in numerous Midwest pavements studied by this petrographer. Concrete contains all the necessary ingredients to produce secondary ettringite and it is a very common occurrence in voidspaces in concrete exposed to moisture movement. However, the sheer volume and degree of filling of concrete paste directly adjacent to joints and distress planes (vertical scaling) is alarming (photo 4).

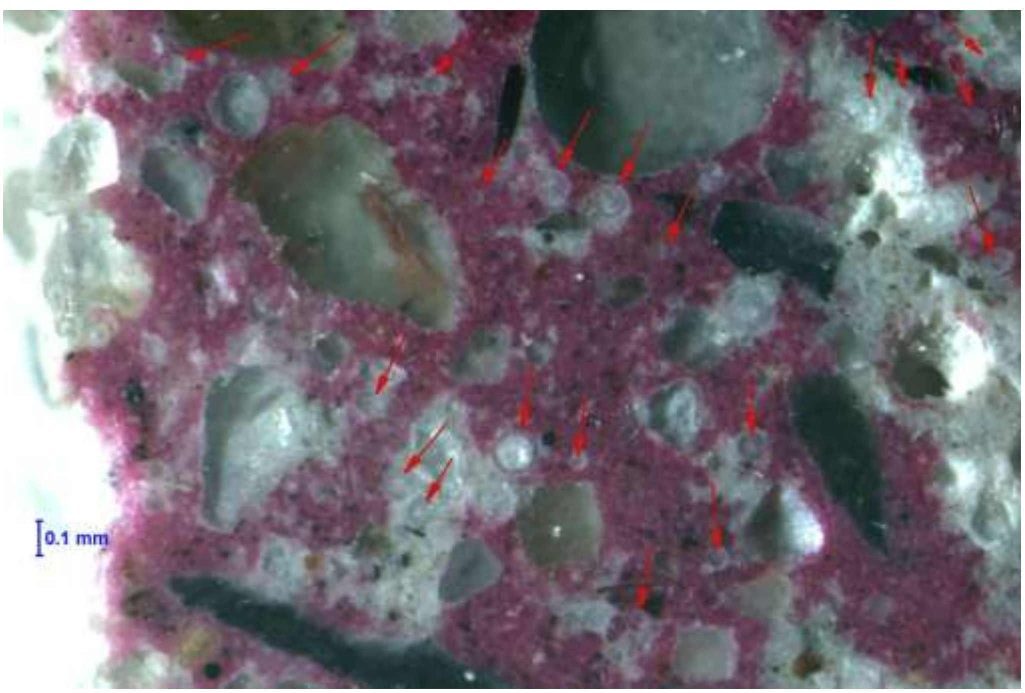

Photo 4: Translucent secondary ettringite fills most entrained air voids directly adjacent to a vertically spalled joint surface (L). Paste was stained magenta with phenolphthalein to aid in identifying filled voids.

The original distress mechanism postulated by this petrographer and others for the widespread “premature joint failure” encountered by numerous Midwest and Great Lakes state DOT’s at least 15 years ago was the severe loss of “entrained” air void volume and quality directly adjacent to the joints. We believed the distress was cyclic freeze-thaw action on the compromised paste – producing vertical “scaling” or spalling. The distress was progressive. As the paste was cracked, vertically or nearly vertically, commonly in a “conical” or “teepee” – like pattern (photo 5), the further ingress of deicers and identified exterior sulfates produced more ettringite.

Photo 5: Typical distress pattern in Midwest pavement core through joint. Note conical distress pattern at base of core (L).

The distress was commonly only noted on the surface by some “d-cracking”-like or ASR - like crack patterns adjacent to the joints and a “darkening” of the concrete surface in a frame-like pattern around the slab’s perimeter. Milling of the joints for rehabilitation commonly revealed a loss of several inches of concrete on each side of the vertical joint plane at the base of the pavement. Piles of concrete rubble would reside at the base of the hollow created by the joint distress. In general, the completely unaffected aggregates would be protruding from the distressed concrete paste.

There is a finite amount of sulfate available in the concrete “system”. But in the past, traditional sodium chloride mineral (rock salt) deicers generally contained some calcium sulfate as an impurity; due to its common geologic proximity in the stratigraphy of evaporate deposits mined for deicers. Gypsum was found in DOT rock salt analyzed petrographically. The rock salt can be a potential source for excess sulfate available for ettringite formation.

More recently, it has been postulated by researchers at Purdue that joints exposed to water and brines achieve “critical saturation” upon which damage is instantaneous when a freeze-thaw cyle occurs. The exposure to water and brines is exasberated by “un-activated” (un-cracked) sawcut jointing and the resulting ponding of water and brines in these zones. Hygroscopic salts precipitated in the concrete void space help hold moisture allowing for the critical saturation to be achieved. The distress starts as a "rounded" zone of compromised concrete paste at the base of the sawcut (in cross section). The term "tunneling" has also been recently used to describe this distress phenomenon. We have seen this initial appearance to the distress in "activated" joints which may have also been in-filled with debris (photo 6). The significant loss of air void volume from secondary ettringite fillings was also identified within the paste directly adjacent to the distress surface.

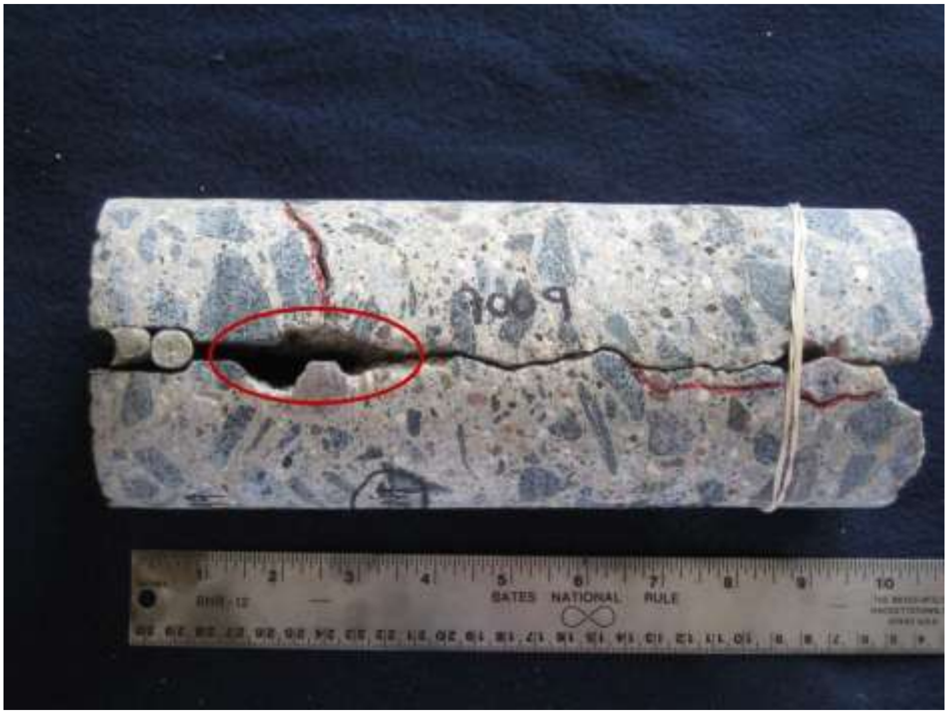

Photo 6: "Tunneling": A rounded zone of disintegrated concrete paste at the base of a sawcut and sealed joint (backer rod and silicon).

Deicers

As with concrete production technology, the evolution of deicers has progressed rapidly in the last several years. The use of materials other than traditional sodium chloride rock salt has increased greatly. Further, pre-wetted deicers, brines, and organics such as sugars and agricultural byproducts are becoming much more common. Their effectiveness is much greater than traditional rock salt; leaving pavements in northern tier states continuously wet vs. extended periods of dry or fairly continuously frozen pavements.

Magnesium chloride and calcium chloride brines have been found to be extremely destructive, even in the absence of freeze-thaw action, by researchers at Michigan Tech and the University of Toronto (Sutter 2006).

Construction Practices

Premature Saw-cutting

In rare cases, saw-cutting of control joints has produced distress in the form of raveling and/or tears in the pavement surface directly adjacent to the cutting (photo 7). The saw-cutting had commenced before the concrete had attained adequate strength to resist the movement of the generally much-harder-to-sawcut aggregates. Repairs undertaken in one such situation with our involvement included gravity-fed, low viscosity methacrylate which easily penetrated the “tearing”. We understand the concrete joints have performed well over the approx. 10 years into their life in a Midwest pavement.

Photo 7: Pavement joint compromised by premature saw-cutting. Note tears/deformation in the surface paste.

Deficient Concrete

Concrete placed with properties not sufficient for resisting cyclic freeze-thaw and cyclic structural loading is very rare but occasionally occurs. Batching errors, incomplete mixing (photo 8), and inconsistent or sub-standard concrete making materials can produce concrete not meeting the durability requirements of a long – lived pavement. Often, low quality entrained air-void systems are identified by petrography (ASTM C856) and the use of hardened air content testing by ASTM C457. If the concrete is deficient, the distress will often manifest itself at the joints first with little or no distress at mid-panel locations, much like some previously mentioned ASR occurrences.

Photo 8: Incomplete mixing in concrete pavement. Note raveled and saturated mass of concentrated flyash; core-sampled for analysis.

Curing

Curing is the act of keeping continuous moisture within the recently placed concrete surface paste to prevent excessive drying (desiccation). Surface paste which has been subjected to early-age desiccation can be less-resistant to surface abrasion and freeze-thaw action allowing premature mortar erosion and scaling, respectively. Relatively deep carbonation is a symptom of the compromised paste. Resulting drying shrinkage microcracking can allow further ingress of water and brines.

Generally, paving contractors follow the paving machinery closely with a “curing machine” which drops white-pigmented curing compound as a consistent, continuous membrane. The curing needs to be timely, even if evaporation conditions are thought to be favorable for paving. Also, as such with any exterior flatwork, the addition of water to the surface and over-manipulation of the surface with floats will generally lessen the surface durability by increasing the w/cm and porosity and decreasing the number of entrained air voids. Curing the top surface only will have little or no lasting effect on joint distress.

Joint Detailing

Today, considerable disagreement exists within the highway community regarding the value of sealed joints and as such sealing practice differs from agency to agency. Even State DOT’s that subscribe to the practice of not sealing joints on Interstate pavements, seal pavements on roadways with posted speed limits below 45 mph to keep out incompressibles.

Modern joint detailing consists of an initial contraction joint to relieve shrinking cracking and a reservoir cut to provide for a proper sealant shape factor. Initial contraction joints are typically sawed approximately 3/16” in width for a depth of T/3 or T/4. Reservoir cuts, if used, are typically 3/8” to ½” in width and constructed approximately 1 ¼ in depth.

Four joint designs are typically used: (1) a narrow single saw cut approximately 3/16” in width that extends T/3 or T/4 and is unsealed, (2) a single saw cut as described in (1) that is sealed with a hot pour and may or may not have a backer rod, (3) a 3/8” reservoir cut that is sealed either with a silicone or hot pour sealant and uses a backer rod, and (4) a 3/8” to ½” wide reservoir cut that uses a compression seal; commonly neoprene in composition.

Summary

It seems obvious that keeping water and brines out of the joints with a sealant will prolong the service life of even deficient pavements. Water is the root cause of all materials related distresses apart from structural deficiencies in design and construction. Unfortunately, joint detailing and maintenance may be an expensive addition to concrete pavement construction. Placing a successful sealant requires clean joint planes. Proper detailing of the joint to receive sealant may require more than pressurized air methods. Concrete “mud” (from wet cutting) can coat one or both sides of the joint and will prevent good adhesion of the sealant. Joint maintenance should be an integral part of the life span of the pavement.

Sutter, L.L., K.W. Peterson, and T.J. Van Dam, “Investigation of the Long Term Effects of Magnesium Chloride and Other Concentrated Salt Solutions on Pavement and Structural Portland Cement Concrete,” Final Report SD2002-01, South Dakota Department of Transportation, Pierre, South Dakota, June 2007