PETROGRAPHIC EXAMINATION OF CONCRETE CORES TAKEN FROM PAVEMENT SLABS ON THE ODOT DEL-23 TEST ROAD PROJECT AND THE ODOT HAN-75 14.41 PROJECT: Phase B: Examination of Abnormal Cracking Distress in an Ohio Department of Transportation Pavement Project in Hancock County, Ohio (State Job No. 134239)

Dr. David Lankard

for the
Ohio Department of Transportation
Office of Research and Development

State Job Number 134239

May, 2006
Concrete pavements were constructed using ODOT’s Class C concrete on Interstate 75 in Findley, Ohio in 1989-1990 (Han-75-14.41). In the late 1990’s distress was observed in the pavements in the form of (1) transverse joint deterioration, (2) corner cracking, (3) longitudinal joint cracking and spalling, and (4) mid-slab cracking and spalling. Beyond these distress features there was concern regarding the long term durability of these pavements. Petrographic examinations and strength tests were conducted on fourteen full depth cores taken from the pavements. The findings strongly support a conclusion that there are three design/construction factors involved in the cracking/spalling distress including (1) the use of recycled Portland cement concrete (RPCC) as the base material on the project, (2) a failure of the doweled transverse joints to function as intended, and (3) a transverse joint spacing of 27 feet. The role of the RPCC in the problem is examined and discussed in detail in the report. It is clearly established that the quality of the pavement concrete is not involved in the distress. Concrete compressive strength measurements averaged 8260 psi, with a range of 6880 psi to 10,500 psi. There is no concern regarding the overall durability of the HAN-75 pavement concrete from a material point of view. However, continuing maintenance associated with the type of cracking/spalling observed to date can be expected.
FINAL REPORT

PETROGRAPHIC EXAMINATION OF CONCRETE CORES TAKEN FROM PAVEMENT SLABS ON THE ODOT DEL-23 TEST ROAD PROJECT AND THE ODOT HAN-75 14.41 PROJECT: Phase B: Examination of Abnormal Cracking Distress in an Ohio Department of Transportation Pavement Project in Hancock County, Ohio (State Job No. 134239)

State Job No. 134239

By

Dr. David Lankard
Lankard Materials Laboratory
Columbus, Ohio

May 2006

Prepared in Cooperation with the Ohio Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or the policies of the Ohio Department of Transportation or the Federal Highway Administration
INTRODUCTION

Portland cement concrete (PCC) pavements were constructed on Interstate 75 in Findley Ohio (Hancock County) in 1989-1990 (ODOT Project HAN-75-14.41). In the late 1990’s distress was observed in the form of mid-slab cracking in the mainline and shoulder pavements. Repairs were first made to the pavement in 2002. Subsequently, other forms of distress became apparent including, (1) cracking and spalling at slab corners, (2) longitudinal joint cracking and spalling, and (3) cracking of transverse joints. Examples of the distress in the HAN-75 pavements are shown in Figure 1. Beyond these manifest distress issues there are concerns regarding the long-term durability of these pavements. Questions have arisen as to whether the problems are structural in nature (as relates to pavement design parameters and to the choice of base materials), or to material problems or deficiencies in the PCC material itself.

During May 2005 Lankard Materials Laboratory (LML) was requested by ODOT to perform a petrographic examination and other pertinent tests on core samples provided from the HAN-75...
pavements. The objective of the investigation is to identify the factors involved in the cracking and spalling distress and to assess the probable future serviceability of the pavements. The resolution of this matter will provide guidelines for avoiding these problems on future ODOT pavement projects.

**HAN-75 PAVEMENT DESIGN**

This pavement project was constructed using ODOT’s Class C concrete, which contains 600 lb/yd$^3$ of Portland cement, with a maximum water to cementitious material ratio of 0.50. The mainline pavement slabs are 11-in. thick. The shoulder slabs taper to a minimum thickness of 8-in. The mainline pavements contain a ¼-in. diameter steel mesh layer in the top third of the slabs. There is no mesh in the shoulder slabs. The slabs were placed with a paving machine.

The mainline and shoulder pavement slabs were placed on a 6-in. thickness of compacted base material. The base material is recycled Portland cement concrete (RPCC), which was graded to ODOT’s 304 specification. The RPCC base rests on 11-in. of lime-stabilized soil.

Transverse joints on the project are skewed (9 ½ º) and doweled. Joint spacing is 27-ft. The 1 ¼-in diameter dowels and the dowel basket are epoxy coated. Longitudinal joints are pinned with 3-ft. lengths of No. 5 deformed rebar (not epoxy coated).

**DESCRIPTION OF THE CORES FROM HAN-75**

Cores were taken by ODOT from the mainline and shoulder pavements in the fall of 2004. Information on the cores is summarized in Table 1. Full depth six inch diameter cores were taken at locations in close proximity to the distress features in the slabs. These cores were used for the petrographic examination. Full depth four inch diameter companion cores were taken in sound concrete within 2 ft. to 3 ft. of the petrographic cores. The companion cores were used for a measurement of compressive strength, although they too were subsequently examined.
petrographically. Three core pairs were taken from shoulder pavement slabs and four core pairs were taken from mainline pavement slabs. One core pair (17 and 5) was taken from a slab that showed no distress at the time of coring to provide a “good” standard for comparison. Figure 2 shows an example of coring in a shoulder slab on the project at Station 776+45 (Cores 15 and 1)

Most of the six-in. diameter cores contain a portion of one end of the epoxy coated steel dowel. Three of the four mainline cores were received intact. One of the mainline cores and all of the shoulder cores were received in pieces.

As part of the coring operation ODOT conducted dynamic cone penetrometer tests on the RPCC base. At some locations the base material was so hard that penetration was not possible. With this finding some cores were taken in the RPCC base material. These cores were retrieved intact and one of them is shown in Figure 2.

**EXAMINATION PROCEDURES**

The examination of the cores included (1) a petrographic examination, (2) a measurement of the parameters of the air void system, (3) a measurement of the compressive strength, and (4) a measurement of density.

**Petrographic Examination**

The seven cores provided specifically for the petrographic study were examined using the guidelines and procedures described in ASTM C 856, “Standard Practice for Petrographic Examination of Hardened Concrete”. This examination was conducted using reflected light microscopy (stereomicroscope at 7X to 100X) on (1) existing fracture surfaces, (2) as-received cored surfaces, (3) as-received bottom end surfaces, and (4) lapped surfaces. Lapped surfaces were prepared on saw-cut surfaces (diamond saw) on a steel wheel using successively finer silicon carbide grits as described in
ASTM C 856. Numerous sections were taken through the cores (saw-cut) both perpendicular to and parallel to the plane of the wearing surface. At the least these sections were taken perpendicular to the plane of the wearing surface through the full length of the cores.

The petrographic examination of lapped surfaces provides an opportunity to (1) identify the cementitious and aggregate constituents of the concrete, (2) identify the presence and distribution of air voids and other types of voids, (3) identify the location and orientation of cracks, (4) identify other types of distress such as cement-aggregate reactions, (5) identify the presence and extent of secondary deposits, and (6) identify the condition of steel embedments.

All of the six in. diameter cores showed some cracking distress. In many cases the cracks could be seen at high magnifications on the cored surfaces of the cores. Even more detail on the presence and location of cracking was seen at high magnification on lapped surfaces of the cores. In both cases the cracks were highlighted with a black marking pen to permit easy viewing of this feature.

Measurements of carbonation and pH of the concretes were made by applying indicating solutions to fresh saw-cut surfaces and the fresh fracture surfaces. The fresh fracture surfaces were created in portions of the cores containing steel embedments to measure the pH of the concrete in contact with the steel. The indication solutions included phenolphthalein and a commercial universal indicating solution (Rainbow Indicator manufactured by Germann Instruments).

Characterization of the Air Void System

The characterization was done using the modified point count method of ASTM C 457, “Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete”. Information was obtained on (1) the total air void content, (2) the specific surface area, and (3) the spacing factor of the air voids. These data were interpreted in light of published research.
findings that have identified the effect of these variables on freeze/thaw durability in concretes exposed to cyclic freezing and thawing.

The ASTM C 457 procedure was conducted on lapped surfaces of the cores. The lapped surface of the concrete is traversed using a stereomicroscope at a magnification of 100X. For every 0.05-inch of the traverse, the operator notes and records the microstructural feature that is present at that site, which can be (1) cement paste, (2) an entrained air void, (3) an entrapped air void, (4) a fine aggregate particle, or (5) a coarse aggregate particle. In the present examination a quantitative measure was made of the total air void content and the cement paste content of the concretes. The total number of stops in the traverse ranged from 1938 to 4236. The total traverse length ranged from 96.9 in. to 211.8 in. The total traverse area ranged from 29.2 in$^2$ to 108.8 in$^2$.

**Compressive Strength Measurement**

The compressive strength measurement was made on six of the four in. diameter companion cores as shown in Tables 1 and 2. The measurement was made following the guidelines of ASTM C 42, “Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete”. The portions of the cores used in the test were saw-cut from the full cores in such a way as to avoid, whenever possible, the steel mesh layer if it was present in the top portion of the core. The length to diameter ratio of the cores varied from 1.29 to 1.83. Details of the compressive strength testing are given in Appendix A.

**Density Measurements**

Density measurements were made on portions of the companion cores following a 48 hour water soaking period. This measurement was made using the water-immersion procedure of ASTM C 642, “Standard Test Method for Density, Absorption, and Voids in Hardened Concrete”. A density
measurement made on water-saturated concrete is expected to correlate with the original unit weight of the fresh concrete.

The results from these examinations and tests are discussed in the remainder of this report. In the Section entitled “Characterization of the HAN-75 Concrete” I provide a detailed description of the constituents and properties of the concrete represented by the cores examined here. The results of this portion of the study establish that, without exception, the concretes comprising both the mainline pavements and the shoulder pavements are of very good quality and do not show any material deficiencies that caused or contributed to the cracking and spalling distress observed on the HAN-75 pavement project. Following this in the report are Sections that discuss (1) the methodology for characterizing the cracking distress in the cores, and (2) discussions which provide compelling evidence that the cracking and spalling distress in the HAN-75 pavements is a structural issue relating to the probability that the transverse doweled joints were not working as-intended.

CHARACTERIZATION OF THE HAN-75 CONCRETE CORES

The concrete specified for this project in ODOT’s Class C concrete containing 600 lb of Portland cement per cubic yard with a maximum water to cementitious material ratio of 0.50. In all of the cores examined here the concrete is well consolidated, showing no abnormal amounts of gross porosity and no honeycomb.

Cementitious Phase

The cementitious phase in the concrete is comprised solely of well-hydrated Portland cement. The w/cm of the cementitious phase was estimated on the basis of the color, texture, water absorption properties, appearance of fresh fracture surfaces, and amount of unhydrated cement particles of the cement paste phase. In the cores examined here the cement paste is medium gray in color, and is hard and dense. It resists penetration with a steel probe, and shows a vitreous luster when probed. Both the
within-core variation and the between-core variation in w/cm is quite low. The w/cm of the concrete is estimated at 0.40. A generally accepted precision of an estimated w/cm value is ± 0.03.

**Cement Content**

As shown in Table 3 the cement paste content of the cores ranges from 25.6 % (volume percent) to 29.0 %, with an average value of 26.9 %. Using the measured average value for cement paste content and the estimated w/cm of the concrete (0.40), the cement content of the concrete is calculated at 630 lb/yd$^3$ (6.7 bags of cement per cubic yard).

**Carbonation**

The depth of carbonation of the cement paste in the wearing surface of the cores was measured by applying phenolphthalein to fresh surfaces that were saw-cut perpendicular to the plane of the wearing surface. Most of the cores show virtually no carbonation of the wearing surface. In others the depth of carbonation is very light, ranging from 0 to 2 mm. The shallow depth of carbonation is a consequence of the low w/cm of the cement paste phase. At this w/cm the cement paste has a very low permeability, and a low amount of capillary porosity.

**Aggregates**

The coarse aggregate in the concrete is a crushed dolomitic limestone with a maximum particle size of 1-in. This is a finely crystalline to very finely crystalline rock with a good hardness (relative to Ohio carbonate rocks) and a moderate rate of water absorption. Individual aggregate particles are platy to bladed in shape with colors typically on the light side ranging from yellowish gray to light brownish gray to medium dark gray. Occasional particles contain thin veins of argillaceous material and most show no macro-porosity. The coarse aggregate is well graded.
The fine aggregate is a natural sand composed of both siliceous and carbonate rock and mineral types. The sand is dominated by carbonate particles (limestone and dolomitic limestone) and quartz. Other siliceous rocks include igneous/metamorphic lithics, and shale. The sand is well graded.

**Cement Paste/Aggregate Bond**

A tight and uninterrupted bond persists between the coarse aggregate particles and the cement paste phase in the concretes. As will be shown in a later Section of the report, when structural cracking occurred in the concrete the cracks pass through the aggregate particles, not along the cement paste/aggregate interface surface. Cracking that occurred in the compressive strength testing also typically passed through, rather than around, coarse aggregate particles.

**Cement-Aggregate Reactions**

A close scrutiny was given in the petrographic examination for evidence of alkali-carbonate reactions (ACR) and alkali-silica reactions (ASR). No evidence of any cement-aggregate reactions was found in any of the cores.

**Air Void System**

The concrete represented by all of the cores is air entrained. The air void system of the cores was characterized using the procedure of ASTM C 457 with the results shown in Table 3. The specified air content for the ODOT Class C concrete is 6 % ± 2 %. In these cores the total air content ranges from 2.2 % to 8.9 %, with an average value of 5.2 %.

Five of the seven cores meet the ODOT standard for total air content. Core 16, a shoulder core, and Core 17, a mainline core, have a total air content below the minimum standard (2.2 % and 3.2 %). Core 17 was taken in a mainline pavement slab that currently shows no cracking/spalling distress. Despite the low air content, the size distribution of air voids in these cores confirm that these concretes
were intentionally air entrained. The entrapped air void content (air voids ≥ 1 mm) of all the cores ranges from 1.2 % to 2.6 %.

**Air Void Spacing Factor**

The historical industry-recommended maximum spacing factor to assure adequate freeze/thaw durability is 0.008-in. As shown in Table 3, the spacing factor for the HAN-75 cores ranges from 0.0218-in to 0.0055-in, with an average value of 0.0115-in. Four of the seven cores have a spacing factor at or below the desired maximum of 0.008-in.

**Specific Surface Area (SSA)**

The historical industry-recommended minimum specific surface area for the entrained air void system is 600 in$^2$/in$^3$. As shown in Table 3, the SSA of the HAN-75 cores ranges from 268 in$^2$/in$^3$ to 609 in$^2$/in$^3$, with an average value of 474 in$^2$/in$^3$. The core showing the lowest value is Core 17, the “good” concrete from the mainline pavement showing no distress.

**Secondary Deposits**

Secondary deposits are common in any concrete that has experienced long-term moisture cycling conditions in service. As the internal relative humidity in the concrete fluctuates, soluble chemical species in the pore water of the concrete come out of solution and are deposited on free surfaces such as air voids. The most common minerals in secondary deposits are calcium hydroxide, calcium carbonate, and ettringite, a hydrated calcium sulfoaluminate.

In all of the HAN-75 cores it is common to see coatings or deposits of solid material lining the surfaces of air voids. This condition is most common in the cores taken closest to the joints, and in the bottom portion of the cores in contact with the RPCC base. Moisture content and moisture cycling is expected to be highest at these locations. In the great majority of historical cases the presence of secondary
deposits is simply a reflection of the moisture cycling events. The secondary deposits are considered
to be innocuous and are not involved in the creation of distress in the concrete. Such is the case for the
HAN-75 cores.

**Concrete Density**

The density of the concrete represented by the cores was measured per ASTM C 642 following a 48
hour water soaking period. A density measurement made in this manner is expected to correlate with
the original unit weight of the fresh concrete. As shown in Table 2, the saturated density of the cores
ranges from 144.2 lb/ft$^3$ to 150.2 lb/ft$^3$, with an average value of 146.4 lb/ft$^3$. As expected, there is a
correlation between the total air content and density of the concretes.

**Concrete Strength**

The compressive strength results for the HAN-75 cores are reported in Table 2. When measured at an
age of approximately 16 years the compressive strength ranges from 6880 psi to 10,500 psi, with an
average value of 8270 psi. As expected, the cores showing the lowest air content also show the highest
compressive strength.

At a compressive strength of over 8000 psi, the concrete represented by the HAN-75 cores qualifies as
a high performance/high strength concrete. This is attributed to the low w/m ratio, good consolidation,
and good quality of the aggregates of the concretes.

**Summary of the Material Properties of the HAN-75 Concrete**

By any standard the concrete represented by the HAN-75 cores is characterized as being of very good
quality. As discussed in detail in the immediate past discussion this assessment takes in account (1)
the concrete mix proportions, (2) water to cementitious material ratio, (3) quality of the fine and coarse
aggregates, (4) consolidation of the concrete, (5) quality of the cement paste/aggregate bond, and (6)
air entrainment. It is concluded that there are no shortcomings or deficiencies in the concrete that can account for any of the cracking and spalling distress in the HAN-75 pavements.

As will be shown in the next Section of the report the cracking/spalling distress can be traced to the fact that the doweled transverse joints in the pavements have not functioned as intended over the life of the pavements. It will also be shown that the use of recycled Portland cement concrete (RPCC) as the base material on this project played a major role in this situation.

**METHOD FOR CHARACTERIZING CRACKING DISTRESS IN THE HAN-75 CORES**

In any concrete petrographic examination that is aimed at identifying the cause of cracking distress it is necessary to consider all of the factors that are known to either directly or indirectly lead to an abnormal amount of cracking in Portland cement concretes in service. These factors include,

- An elevated w/cm in the concrete.
- An elevated air content in the concrete.
- A compromised cement paste/aggregate bond in the concrete.
- A poor quality coarse aggregate in the concrete.
- Stresses associated with drying shrinkage strains and/or moisture saturation expansive strains.
- Stresses associated with plastic shrinkage strains.
- Stresses associated with thermal expansion and contraction strains.
- Stresses associated with cement-aggregate reactions.
- Stresses associated with freeze/thaw cycling (including D-Cracking).
- Stresses associated with the corrosion of steel embedments.
- Fatigue stresses.
• Live load and dead load stresses.

All of these factors were considered in the present petrographic examination. Pinning down the dominant factors involved in the cracking of the concrete requires that consideration be given to the following features of the cracks.

• When did the cracks first appear in service?

• In what portion of the construction did the cracks first appear?

• What is the width of the cracks?

• Is the crack width uniform or variable?

• What is the orientation of the cracks?

• What is the spatial relationship of the cracks to steel or other embedments?

• Do the cracks contain any secondary deposits or steel corrosion products?

• Does the construction contain the proper jointing design for the particular application?

• Have the joints functioned as intended in service?

• Do the service loads exceed those for which the construction was designed?

All of these factors were considered in the present petrographic examination and investigation. In the discussions that follow a distinction is made between cracking that is present in the cores that were examined here and cracking that is present in the pavement slabs in service. Information on the microstructural features, location, orientation, and extent of the cracking in the cores provides the basis for identifying the source of cracking distress for the pavement slabs in service.
CHARACTERIZATION OF CRACKING IN THE HAN-75 CORES

As summarized in Table 1, four of the seven cores were received in a number of pieces (Shoulder Cores 15, 16, and 18; and Mainline Core 6). Cracking in these cores is manifestly obvious.

Three of the mainline cores (17, 19, and 20) were received intact. A cursory visual examination of these cores in the as-received condition did not reveal any cracking. However, a subsequent stereomicroscopic examination of the cored surfaces revealed extensive cracking in Cores 19 and 20. Cores 19 and 20 were taken at locations near a doweled transverse joint in slabs that show cracking distress.

Core 17 was taken at a location removed from the transverse joints in a slab that currently shows no cracking distress. This is the “good” core. There is limited and minor cracking in Core 17 which will be discussed subsequently.

On Cores 19 and 20 the cracks were “mapped” on the as-cored surfaces by tracing over them with a black marking pen during the microscopic examination. An example of this exercise on Core 19 is shown in Figures 3 and 4. Core 19 was taken at a location where there is cracking and spalling at the pavement centerline joint (the point at which the transverse and longitudinal joints cross). However, at this Station the transverse joint itself has not yet shown any cracking or spalling. Core 19 was taken just off of the joint at a site where the pavement slab currently shows no manifest cracking or spalling distress. Core 19 contains a portion of the epoxy coated dowel bar with a cover depth (relative to the plane of the wearing surface) of 4 ¾-in., and a ¼-in. diameter steel mesh layer with 3 ¼-in. of cover. Portions of the dowel basket, which support the dowel bar, are present in the core.

The top photograph in Figure 3 shows Core 19 prior to the crack-mapping exercise. Cracks are difficult to detect with the unaided eye. The bottom photograph in Figure 3 and the photographs in
Figure 4 show Core 19 after the crack-mapping exercise. The location and orientation of these cracks fall into four distinct categories. For convenience of discussion the four categories of cracking in the cores are labeled Type I, Type II, Type III, and Type IV. They include,

- **Type I Cracks** are oriented roughly parallel to the plane of the wearing surface of the pavement slabs and are located in the bottom one inch of the core.

- **Type II Cracks** are oriented at a diagonal to the wearing surface in the core interval from the bottom one inch to the level of the dowel bar.

- **Type III Cracks** are oriented roughly parallel to the wearing surface right at the level of the dowel bar.

- **Type IV Cracks** emanate from the steel mesh layer in the top third of the core.

These four types of cracks are present in all of the cores examined here that were taken close to a transverse joint. These cores contain a portion of the dowel bar at these locations. Other examples of the four crack types discussed above are shown in Figure 5, which shows photographs of Core 20 following the crack mapping exercise. Core 20 was taken in a mainline pavement slab at Station 768+50. The dowel bar cover is 4 ⅝-in. and the mesh cover is 4-in. in Core 20.

A detailed characterization of the four crack types follows along with a discussion of their probable origin. As discussed earlier there is no shortcoming or deficiency in the HAN-75 pavement concrete from a material point of view that can account for the cracking. All of the cracking in these pavements has occurred in good quality, 8000 psi concrete that was originally sound. Stresses from several non-material related sources subsequently cracked the concrete after a number of years of service. The source of these stresses is discussed. Through a consideration of the nature of the cracking in the cores, it will be shown that the overall problem originates with a failure of the doweled transverse
joints to function as intended, which is related to an unusual bonding situation between the PCC pavement slabs and the RPCC base.

**Malfunctioning of the Transverse Joints in the HAN-75 Pavements**

The dowels used for the transverse joints in the HAN-75 project are epoxy coated and have a diameter of 1 ¼-in. The dowel bars are positioned by a dowel basket that is also epoxy coated. The depth of cover of the dowel bar from the wearing surface as measured on the cores is 4 ¼-in. to 4 ¾-in. All of the dowels are welded on one end to the dowel basket. Every other dowel bar is welded on the opposite side relative to the adjacent bars. During construction, after the dowel basket has been positioned on the base material the horizontal ties that held the basket together are cut so that the basket on either side of the joint can move independently of the other.

Figure 6 shows cross sections of the mainline pavement construction (not to scale). In the top drawing of Figure 6 the dowel basket is shown to be resting on the recycled Portland cement concrete (RPCC) base. When the dowel basket is free to move independently within the two joined PCC slabs, the doweled joint is able to function as intended. That is, the pavement slabs on both sides of the joint can move independent of each other, and stresses arising from movements of the slabs are relieved as the dowel bar slides. On the HAN-75 project the bottom transverse horizontal struts of the dowel basket became solidly cemented into the RPCC base material. Once in service the length of the RPCC base material did not change substantially. With the dowel basket cemented into the RPCC base material the effect was as if both sides of the dowel basket were still tied together. The PCC slabs experienced strains, but the dowels could not slide to accommodate the slab movement.

The crushing of old PCC material for use as base material creates numerous new fracture surfaces in the PCC, exposing a large amount of unhydrated Portland cement. Much of this unhydrated cement is in the form of a fine powder and is available for renewed hydration. Upon exposure to moisture in
service as base material the newly-exposed cement particles hydrate, which binds the intermediate and larger particles together to form what is in effect a low strength concrete.

On the HAN-75 project the RPCC base in many locations bonded monolithically to the PCC pavement slabs, and the dowel basket became cemented within the PCC/RPCC material. Evidence for these features is shown in Figure 7, which shows photographs of lapped surfaces of the bottom 3-in. to 4-in. thickness of Core 18 (Shoulder) and 20 (Mainline). The bottom end surface of these cores is a fracture surface within the RPCC material. A $\frac{1}{4}$-in. to 1 $\frac{1}{4}$-in. thickness of the RPCC is bonded monolithically to the PCC. The boundary between the PCC and RPCC is identified by the arrows on the photographs of Figure 7. In the petrographic examination the RPCC is distinguished from the PCC on the basis of w/cm and air content, and in some instances cement type (there is slag cement concrete in some of the RPCC).

All of the HAN-75 cores show this feature of bonding between the PCC and the RPCC material. In most cases there is no discontinuity or cold joint between the two materials. In the cores shown in Figure 7, one of the bottom transverse struts of the dowel basket is completely encapsulated with concrete. In Core 20 the strut is partially within the PCC and partially within the RPCC. In Core 18 the strut is primarily within the RPCC.

The solidification of the RPCC base in service (as shown in Figure 2) creates two conditions that prevent the intended functioning of the doweled transverse control joints including,

- The dowel bars can not slide in response to movement (strains) in the pavement slabs, and

- The bonding of the PCC slab to the RPCC base restrains in a random manner the strains that occur in the PCC slabs. The top portion of the PCC slab experiences strains in response to
drying shrinkage, moisture expansion, and thermal strains. The bonded bottom portion of the slab, at least at early ages; is not free to move.

With the PCC pavement slab initially bonded to the hardened RPCC base material, and the dowel basket bonded to the RPCC material the intended function of the dowels is effectively compromised.

**Stresses Acting on the HAN-75 Pavement Slabs in Service**

The bottom drawing in Figure 6 shows a cross-section of the HAN-75 mainline pavement which includes the full length of a pavement slab between the transverse joints. The PCC slabs, which are exposed to the elements, experience strains from a number of sources including (1) drying shrinkage strains accompanying moisture loss, (2) expansive strains experienced when the slab is re-saturated from precipitation, (3) thermal expansion and contraction strains in response to ambient temperature changes, and (4) strains accompanying live loads from traffic. All of these strains are cyclic.

The strains relating to temperature and moisture cycling are most extreme in the top of the slab (wearing surface). Strains due to these sources are much smaller in the bottom of the slab where the moisture content is continually high and temperature changes are low. This condition is expected to exaggerate curling strains in the slabs. Curling strains will be greatest along the edges of the slabs and will be the highest at slab corners. The cemented dowel basket within the joints restrains all of these movements within the slabs. Without proper functioning of the dowels, cracking within the concrete at the transverse joints is inevitable.

The longitudinal joints in the HAN-75 pavements are pinned with rebars. In service the two pinned twelve foot wide slabs that share transverse joints are expected to move in concert if the transverse joints are functioning as intended. In the HAN-75 pavements the two pinned slabs probably are not moving in concert due to the varying degrees of freedom of movement at the joints, and along the
contact surface between the PCC and the RPCC. This condition is expected to put stresses on the pinning rebars, which ultimately can be expected to lead to cracking and spalling at this location.

In some of the cores examined here there is evidence of corrosion in both the dowel bars and components of the dowel basket. In most of the cores, both the dowel bar and the dowel basket is epoxy coated. An exception is Core 18, where the dowel basket is bare steel. It will be shown that this corrosion activity was a result of the exposure of the steel due to the structural cracking discussed above. The corrosion activity did not cause the initial cracking, but once exposed, corrosion of the steel may have contributed to the severity and extent of cracking.

Characterization and Source of Type I Cracks in the Cores

Type I cracks are oriented roughly parallel to the plane of the wearing surface of the pavement slabs and are located in the bottom one inch or so of the cores. Cracks such as these are ubiquitous in the HAN-75 pavements but they have not contributed to any spalling or need for maintenance. Their presence does confirm that the PCC slabs and the underlying RPCC base slabs were initially bonded together.

Examples of this type of cracking in mainline Cores 19 and 20 in the as-received condition can be seen in Figures 3, 4, and 5. All of the petrographic cores and compressive strength cores examined and tested here show this type of cracking.

A more detailed characterization of this type of cracking was provided by the stereomicroscopic examination of lapped surfaces of the cores. The top photograph in Figure 8 shows section views of the bottom 4-inches of Core 19 perpendicular to the plane of the wearing surface. In this core the mainline pavement concrete (PCC) is monolithically bonded to the recycled Portland cement concrete base (RPCC). The fracture plane defining the bottom end surface of the core is entirely within the
RPCC. The yellow arrows point to the bond line between the two concretes. All of the concrete below the yellow arrows is RPCC (about ½-in. thick). Directly above the bond line is a horizontal crack that is totally within the PCC. The distinction between the two concretes is made on the basis of w/cm, air content, and cement type. In the RPCC the cracks typically pass around rather than through aggregate particles. In the PCC the cracks typically pass through aggregate particles.

The bottom photograph in Figure 8 shows Type I cracking in Core 17. Core 17 was taken in a “good” mainline slab that currently shows no distress. The same features described for Core 19 are present in Core 17. In Core 17 the thickness of the RPCC layer is ½-in. to 1-in.

The location and orientation of the Type I cracks are the result of stresses acting to pull the PCC and RPCC slabs apart from each other, with the stress oriented perpendicular to the plane of the wearing surface of the PCC slab. The origin of the stresses is the curling stresses in the top portion of the PCC slab. The PCC slab tried to “lift-off” the RPCC base slab. Fractures occurred normal to these stress creating the Type I cracks. The cracks occurred both within the PCC and the RPCC. The presence of the Type I cracks confirm that the PCC and RPCC slabs were initially joined together monolithically.

**Characterization and Source of Type II and Type III Cracks in the Cores**

What are referred to here as Type II and Type III cracks can be traced to movement (strains) in the PCC slabs at the transverse joint lines that are restricted by the fact that the dowel basket is locked into the RPCC base slab. The dowel basket components on the two sides of the joint can not move independent of one another.

**Type II Cracks**

Type II cracks are oriented at a diagonal to the wearing surface in the core interval from the bottom one inch to the level of the bottom of the dowel bar (5 ½-in to 6-in. below the plane of the wearing
surface). These cracks occur in close proximity to the vertical struts in the dowel basket, which are also oriented at a diagonal to the wearing surface. The Type II cracks follow the vertical struts of the dowel basket. All of the mainline and shoulder cores that contain a remnant of the dowel bar and the dowel basket exhibit this type of cracking.

Examples of Type II cracking in Core 19 in the as-received condition can be seen in Figures 3 and 4. Examples of Type II cracking in Core 20 in the as-received condition can be seen in Figure 5. Type II cracks can be seen on the lapped section views of Cores 19 in Figure 8 and Cores 18 and 20 in Figure 7. Virtually all of the Type II cracks pass through the coarse aggregate particles.

**Type III Cracks**

Type III cracks are oriented roughly parallel to the wearing surface right at the level of the dowel bar (4 ¼-in to 4 ¾-in. below the plane of the wearing surface). The cracks occur both above and below the dowel bar. This feature can be clearly seen in the top photograph of Figures 4 and 5, which shows the as-received condition of Core 19 and Core 20. These are tensile cracks that formed in response to curling strains in the PCC slab acting against the dowels, which cannot accommodate the movement due to embedment of the dowel basket in the RPCC base. It is expected that curling strains will be greatest along the edges of the slabs at the transverse joint lines. Type III cracks are uniquely associated with the dowel bar. Similar cracks are not present at this level in the cores in those portions of the cores where the dowel is not present.

Figure 9 shows examples of the consequences of the stresses that are responsible for the Type III cracking. The top photograph shows the core hole for the six inch diameter core at Station 774+56 (Shoulder Core 16). The severed dowel bar can be seen on the right. The cracking of the slab is most severe and extensive just above and below the level of the dowel bar. This feature is clearly seen in
the photograph taken of Shoulder Core 18 (Station 770+66) on site after it was removed from the core hole.

**Characterization and Source of Type IV Cracks in the Cores**

Type IV cracks are present as short “spokes” emanating from the steel mesh layer in the top third of the mainline pavement cores. All of the mainline cores that contain the mesh layer show this feature. The cracks do not appear to have contributed to any of the manifest distress in the pavements. Their presence however does indicate the restraining influence of the mesh to movements in the slabs.

Attention will now be given to the manifest cracking and spalling distress that has occurred in the HAN-75 pavement slabs in service. This distress is discussed in light of the findings and observations made on the cores examined in the present study.

**CRACKING/SPALLING DISTRESS IN THE HAN-75 PAVEMENTS IN SERVICE**

The distress that has occurred to date on the HAN-75 project includes.

- Mid-slab cracking and spalling.
- Corner cracking and spalling.
- Transverse joint cracking and spalling.
- Longitudinal joint cracking and spalling.

The distress problem that showed up first and the problem that is most widespread and of the greatest concern today is mid-slab cracking and spalling. Cracking and spalling at the intersection of transverse joints (and transverse cracks) and longitudinal joints (corner cracks) and along longitudinal joints came along after the mid-slab cracking problem and these types of distress are also now fairly common on the project. Despite the extensive cracking observed in the mainline cores taken within the transverse joint areas, manifest cracking and spalling of these joints in service is not yet common. Cracking and spalling is more common along the dowelled transverse joints in the thinner shoulder slabs.
As discussed previously in this report there are at least five sources of differential strains operative in the PCC pavement and shoulder slabs on the HAN-75 project. These strains include both contractive (shrinkage) and expansive strains, which are cyclic in nature. Some of the strains are lateral and some are vertical. In service, the restraint to these strains include (1) the bonding of the PCC slabs to the RPCC base material (with varying degrees of bond strength) and (2) malfunctioning of the doweled transverse joints.

In addition the longitudinal joints in the HAN-75 pavements are pinned with rebars. In service the two pinned twelve foot wide slabs that lie between common transverse joints are expected to move in concert if the transverse joints are functioning as intended. In the HAN-75 pavements the two pinned slabs probably have not moving in concert due to the varying degrees of freedom of movement of the PCC slabs due to the slab bonding and malfunctioning transverse joints.

Finally, the presence of the mesh layer in the mainline PCC slabs is expected to also have a restraining influence on the strains in these slabs.

The net result of all of these conditions is a high probability of widespread and widely varying stresses (varying in both magnitude and vector) responding to varying degrees of restraint within the mainline and shoulder pavement slabs on the HAN-75 project over its service life.

**Mid-Slab Cracking and Spalling.**

The first sign of cracking in the HAN-75 pavements was mid-slab cracking, which were first noticed following almost 10 years of service. It is reported that mid-slab cracking is the most common and widespread type of cracking on the HAN-75 project. It is most severe in the thinner shoulder pavements.
With movement restricted at the transverse doweled joints, it is expected that cracking would occur in the mid-portion of the slabs in response to restrained drying shrinkage and thermal contraction strains. A complication on the HAN-75 project is the large joint spacing of 27 ft. Based on current formulae for control joint spacing, the recommended spacing for an 11-in. thick slab is 20 ft. to 22 ft. Some of the historical guidelines recommend that a joint spacing never exceed 18 ft. regardless of slab thickness.

Many of the mid-slab cracks are a single crack that is oriented parallel to the joint and which span the full width of the pavement lane. In other slabs there are two or three similarly oriented, but non-contiguous cracks. In yet other of the shoulder slabs these cracks run at a diagonal to the transverse joint directions. The uncontrolled eccentricity of the restrained stresses in the slabs can account for differences in the length, location, and orientation of these cracks on the project.

The reason that it took the mid-slab cracks so long to develop (or at least to be noticed) could be due to (1) the large slab thickness in the mainline pavements, (2) the presence of the mesh layer in the top portion of the mainline slabs, and (3) the fact that the PCC pavement slabs were initially bonded to the RPCC base material. If the mesh played a key role here in controlling crack width, it is expected that mid-slab cracking would have occurred first in the thinner shoulder slabs, which did not contain the mesh layer.

**Corner Cracking and Cracking Along Transverse Joints**

Despite the extensive cracking observed in the mainline PCC concrete cores taken along the transverse joint lines, there is not much manifest distress that has occurred to date at these locations except at the slab corners where the transverse joints intersect longitudinal joints. Curling strains are expected to be the highest of all at these slab corners, which probably accounts for the corner cracking in the
pavements. Fatigue cracking from live loads on the pavements very likely has contributed to this type of distress.

Cracking and spalling distress associated with the corners and transverse joints is more advanced in the shoulder slabs due very likely to the fact that these slabs are thinner than the mainline slabs. Curling strains in the thinner slabs are expected to be higher. Although 1-in. diameter dowels are used in the shoulder slabs, the ratio of steel volume to concrete volume is higher in the shoulder slabs. The diagonal cracking (Type II Cracks) is expected to affect a larger portion of the shoulder slabs than the mainline slabs. Type II and Type III Cracks in the shoulder slabs are located closer to the wearing surface in the shoulder slabs

**Cracking Along Longitudinal Joints**

Cracking associated with the longitudinal joints is one of the last types of cracking to show up, and this type of cracking is becoming more common.

The longitudinal joints in the HAN-75 pavements are pinned with rebars. In service the two pinned twelve foot wide slabs that lie between common transverse joints are expected to move in concert if the transverse joints are functioning as intended. In the HAN-75 pavements the two pinned slabs probably have not moved in concert due to the varying degrees of freedom of movement at the transverse joints. The varying degree of bonding of the PCC slabs to the RPCC base also affects this situation. This condition is expected to put stresses on the pinning rebars, which ultimately can be expected to lead to cracking and spalling.

**Cracking Due to Corrosion of Steel Embedments**

In a number of the cores that contain steel embedments there has been some corrosion of the steel in service. Debonding of the epoxy coating from the dowel bar has occurred in Cores 6 and 18. Portions
of the bars that are bare are corroded. Core 6 was taken directly through a transverse joint on a mainline slab. Core 18 was taken adjacent to a transverse joint in a shoulder slab. It is likely that the debonding of the epoxy coating was hastened by the mechanical stresses on the bars in service. There is no evidence to suggest that corrosion of the bars played a role in creating the cracking distress in the concretes. For example in spalls that occur on the wearing surface of bridge decks, the cracks are frequently filled with steel corrosion products and virtually all of the steel in the spall planes is corroded. This is not the case for the corrosion activity on the HAN-75 project.

Corrosion activity in steel embedments in shoulder Core 18 can be seen in the bottom photograph of Figure 9. Corrosion of the dowel bar is occurring at a site where the epoxy coating has been lost. In the lab it was possible to easily remove all of the epoxy coating, which revealed that fifty percent or so of the bar showed various stages of corrosion.

The dowel basket in Core 18 (Figure 9) is not epoxy coated. A loop of the dowel basket can be seen exposed in an intact portion of the bottom end of the core. The exposed steel is fully corroded. When the intact concrete was intentionally fractured it revealed that the steel in this sound concrete showed no corrosion and the pH of the concrete is at a normal level of 13. This observation and the absence of corrosion product in the crack planes again confirm that the corrosion activity was a result rather than a cause of the cracking in the joint.

**SUMMARY AND CONCLUSIONS**

Cracking and spalling distress in mainline and shoulder pavements on the HAN-75-14.41 project in Findley Ohio was investigated through the conduct of petrographic examinations and other tests on thirteen concrete cores from the project. The distress that has occurred to date on the HAN-75 project includes.

- Mid-slab cracking and spalling.
• Corner cracking and spalling (corners formed by joints and joints and by joints and cracks).

• Transverse joint cracking and spalling.

• Longitudinal joint cracking and spalling.

The significant observations and conclusions derived from the present investigation are summarized below.

1. The concrete used in this pavement project is ODOT’s Class C concrete. In the cores examined here the concrete is of very good quality based on the criteria of (1) water to cementitious material ratio, (2) quality of the cementitious and aggregate constituents, (3) quality of the entrained air void system, (4) quality of the cement paste/aggregate bond, and (5) degree of consolidation.

2. From the material point of view there are no shortcomings or deficiencies in the pavement concrete that are involved in or are responsible for the cracking and spalling distress.

3. Three design and construction factors are involved in the cracking and spalling distress including, (1) the use of recycled Portland cement concrete (RPCC) as the base material on the project, (2) a failure of the doweled transverse joints to function as intended, and (3) a transverse joint spacing of 27 ft.

4. Following placement on the project, anhydrous Portland cement particles in the RPCC base material hydrated to form, in effect, a low strength concrete. The RPCC base material bonded monolithically to the Portland cement concrete (PCC) pavement slabs. This event restricted normal movement of the PCC slabs.

5. The solidification of the RPCC base also interfered with the intended independent movement of the dowel basket on either side of the transverse joint. In effect the joint was tied together by the dowel basket assembly, which prevented the joint from fulfilling its intended function. This function is to allow unrestricted movement in the pavement slabs in response to anticipated strains in service.
6. Mid-slab cracking was the first sign of distress on the HAN-75 project, which was first noticed after about 10 years of service. The mid-slab cracking occurred as a stress-relief mechanism in response to the malfunctioning of the transverse joints. The joint spacing of 27 ft. also contributed to this type of cracking distress. For these mainline pavement slabs a joint spacing of 20 to 22 ft. is recommended. The recommended joint spacing for the thinner shoulder slabs is even lower.

7. As discussed in detail in the present report all of the other types of cracking and spalling distress on this project can be traced to the restricted movement in the pavement slabs and joints as described above.

8. There is no concern regarding the overall durability of the HAN-75 pavement concrete from a material point of view. However, continuing maintenance in response to the type of cracking and spalling distress observed to date can be expected.

**Implementation of Findings**

To eliminate or minimize the possibility of cracking and spalling on future ODOT pavement projects the following should be considered.

1. Current American Concrete Institute recommendations should be consulted regarding the maximum control joint spacing to reduce the occurrence of mid-slab cracking.

2. ODOT pavement engineers should be made aware of the risks involved with the use of recycled Portland cement concrete (RPCC) as base material on pavement projects which include doweled transverse joints.

3. If it intended to use RPCC as base material on future projects, consideration should be given to establishing the means to prevent bonding between the RPCC and the PCC pavement slabs.
Table 1. Concrete Cores Taken on the ODOT HAN-75-14.41 Pavement Project.

<table>
<thead>
<tr>
<th>Petrographic Core Number</th>
<th>Core Location</th>
<th>Coring Site</th>
<th>Core Length, inches</th>
<th>Core Received Intact?</th>
<th>Companion Strength Core Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>SHOULDER</td>
<td>776+45</td>
<td>8</td>
<td>NO</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>SHOULDER</td>
<td>774+56</td>
<td>9</td>
<td>NO</td>
<td>2</td>
</tr>
<tr>
<td>18</td>
<td>SHOULDER</td>
<td>770+66</td>
<td>10</td>
<td>NO</td>
<td>3</td>
</tr>
<tr>
<td>6(a)</td>
<td>MAINLINE</td>
<td>769+60</td>
<td>11.5</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>17(b)</td>
<td>MAINLINE</td>
<td>771+90</td>
<td>12</td>
<td>YES</td>
<td>5</td>
</tr>
<tr>
<td>19</td>
<td>MAINLINE</td>
<td>769+60</td>
<td>11.5</td>
<td>YES</td>
<td>7</td>
</tr>
<tr>
<td>20</td>
<td>MAINLINE</td>
<td>768+50</td>
<td>12</td>
<td>YES</td>
<td>9</td>
</tr>
</tbody>
</table>

(a) Examine “secondary ettringite” issue.

(b) Taken as a “control” in a slab than has shown no distress of any type.
Table 2. Compressive Strength, Density, and Air Content of ODOT HAN-75-14.41 Pavement Project.

<table>
<thead>
<tr>
<th>Petrographic Core Number</th>
<th>Core Location</th>
<th>Companion Strength Core Number</th>
<th>Compressive Strength of Companion Core, psi</th>
<th>Density (a) of Companion Core, lb/ft³</th>
<th>Measured (b) Total Air Void Content, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>SHOULDER</td>
<td>1</td>
<td>6880</td>
<td>144.2</td>
<td>8.9</td>
</tr>
<tr>
<td>16</td>
<td>SHOULDER</td>
<td>2</td>
<td>10,500</td>
<td>150.2</td>
<td>2.2</td>
</tr>
<tr>
<td>18</td>
<td>SHOULDER</td>
<td>3</td>
<td>7520</td>
<td>147.2</td>
<td>4.4</td>
</tr>
<tr>
<td>6(c)</td>
<td>MAINLINE (Joint)</td>
<td>7</td>
<td>7850</td>
<td>144.8</td>
<td>5.9</td>
</tr>
<tr>
<td>17</td>
<td>MAINLINE (Good PCC)</td>
<td>5</td>
<td>9350</td>
<td>147.3</td>
<td>3.2</td>
</tr>
<tr>
<td>19</td>
<td>MAINLINE (C-Joint Spall)</td>
<td>7</td>
<td>7850</td>
<td>144.8</td>
<td>5.3</td>
</tr>
<tr>
<td>20</td>
<td>MAINLINE (Corner Break)</td>
<td>9</td>
<td>7530</td>
<td>144.8</td>
<td>6.7</td>
</tr>
</tbody>
</table>

(a) Density measured after a 48 hour water-soaking period. This value is expected to correlate with the original unit weight of the fresh concrete.

(b) ASTM C 457, measured on the petrographic cores.

(c) Core 6 is a 4-inch diameter core. All of the other petrographic cores have a 6-inch diameter.
Table 3. Parameters of the Air-Void System in the HAN-75 Pavement Cores.

<table>
<thead>
<tr>
<th>Core Identification Number</th>
<th>Coring Site</th>
<th>Cement Paste Content(^{(a)}), %</th>
<th>Air Void Parameters per ASTM C 457(^{(a)})</th>
<th>Spacing Factor, inch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total Air Content, %</td>
<td>Percent Air Voids ≥ 1 mm</td>
</tr>
<tr>
<td>HAN-15</td>
<td>Shoulder</td>
<td>25.7</td>
<td>8.92</td>
<td>2.61</td>
</tr>
<tr>
<td>HAN-16</td>
<td>Shoulder</td>
<td>29.0</td>
<td>2.15</td>
<td>1.18</td>
</tr>
<tr>
<td>HAN-18</td>
<td>Shoulder</td>
<td>27.9</td>
<td>4.36</td>
<td>1.79</td>
</tr>
<tr>
<td>HAN-6</td>
<td>Mainline</td>
<td>25.9</td>
<td>5.93</td>
<td>2.12</td>
</tr>
<tr>
<td>HAN-17(^{(b)})</td>
<td>Mainline</td>
<td>26.8</td>
<td>3.21</td>
<td>2.05</td>
</tr>
<tr>
<td>HAN-19</td>
<td>Mainline</td>
<td>27.4</td>
<td>5.33</td>
<td>1.63</td>
</tr>
<tr>
<td>HAN-20</td>
<td>Mainline</td>
<td>25.6</td>
<td>6.74</td>
<td>2.29</td>
</tr>
</tbody>
</table>

\(^{(a)}\) Minimum length of traverse of ≥ 95 inches; minimum number of stops of ≥ 1425; minimum traversed area of ≥12 in\(^2\).

\(^{(b)}\) Core 17 was taken from a mainline pavement slab showing no distress to serve as the reference for “good” concrete.
Figure 1. Examples of mid-slab cracking and spalling, corner cracking and spalling, and longitudinal cracking and spalling on the HAN-75 14.41 pavement project in Findley (Hancock County) Ohio. The photographs were taken in 2004.
Figure 2. The top photograph shows an example of the coring sites in a shoulder slab at Station 770+66 on the HAN-75 project (Cores 3 and 18). The bottom photograph shows an intact core taken through the recycled Portland cement concrete (RPCC) base on the HAN-75 pavement project. The photographs were taken in 2004.
Figure 3. Photographs of Core 19 taken in a mainline pavement slab at Station 769+60. The top photograph shows the core in the as-received condition. In the bottom photograph the cracks in the core are delineated with a black marking pen. The diagonal cracks follow the line of the dowel basket struts.
Figure 4. Photographs of Core 19 taken in a mainline pavement slab at Station 769+60. The top photograph shows horizontal cracks above and below the dowel bar. In the bottom photograph the diagonal cracks follow the line of the dowel basket struts. Cracks are oriented horizontally in the bottom inch or so of the core.
Figure 5. Photographs of Core 20 taken in a mainline pavement slab at Station 768+50. The top photograph shows horizontal cracks adjacent to the level of the dowel bar. In the bottom photograph the diagonal cracks follow the line of the dowel basket struts. Cracks are oriented horizontally in the bottom inch or so of the core.
Figure 6. Schematic illustrations (not to scale) of the design scheme for the HAN-75 mainline pavements. The top figure shows a section perpendicular to the plane of the wearing surface and perpendicular to the orientation of the doweled transverse joints. The bottom figure shows the same section that includes the full length of the pavement slabs between the transverse joints.
Figure 7. Lapped surfaces of the bottom 3 to 4 inches of Core 18 (Shoulder) and Core 20 (Mainline) perpendicular to the plane of the wearing surface. The arrows point to the bonding surface between the PCC pavement slab (above the arrows) and the RPCC base material (below the arrows). Sections through the dowel basket struts are marked with a red dot. The bottom strut is cemented within the PCC and RPCC.
Figure 8. Lapped surfaces of the bottom 3 to 4 inches of Core 19 (Mainline) and Core 17 (Shoulder). The arrows point to the bonding surface between the PCC pavement slab (above the arrows) and the RPCC base material (below the arrows). Horizontal cracks in the PCC just above the arrows (marked with a black marking pen) are a common feature in all of the HAN-75 cores. The bottom surface of the cores is a fracture in the RPCC.
Figure 9. The top photograph shows the core hole for Core 16, a shoulder core taken at Station 774+56. The most extensive cracking/spalling is at the level of the dowel bar. The bottom photograph is Core 18, a shoulder core at Station 770+66, immediately following its removal from the core hole. Here too the greatest amount of distress is at the level of the dowel bar.