Application of a Materials-Related Distress Rating System for Portland Cement Concrete Airfield Pavements

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Introduction

The Pavement Condition Index (PCI) procedure is a well-documented standard used by the aviation industry to visually assess pavement condition. During a PCI survey, visible signs of deterioration are observed and recorded by distress type, severity, and quantity. The results, aggregated into a score from 0 to 100, are widely acknowledged to be a consistent, objective, and repeatable tool that can be used to represent and communicate the overall condition of a pavement. When regularly applied to all of the pavements in a defined network, the PCI becomes an important tool in the management of that network.

However, a significant shortcoming of the PCI procedure is that it does not adequately address materials-related distress (MRD). Without going into great detail on the development and progression of different types of MRD, there are several aspects of MRDs that affect the evaluation and management of affected pavements.

- For a properly designed and constructed pavement, the development of load and environmental distresses follows expected patterns whereby maintenance, rehabilitation, and even replacement times can be predicted. In contrast, MRDs can develop at varying and unexpected times in the life of such a pavement. For example, while signs of alkali-silica reactivity (ASR) may take one or more decades to develop at one airport, at another (perhaps with a harsher environment, compromised air-void system in the portland cement concrete (PCC), and/or greater exposure to saturation) it may become apparent several years after construction.

- Pavement engineers are generally familiar with typical rates of pavement deterioration for different periods of a pavement's life. Early in its life a pavement may lose 1 to 2 PCI points a year, while later that may increase to 2 to 4 points. However, once signs of MRD become apparent, the pavement often will deteriorate at a much accelerated rate.

- The maintenance and rehabilitation (M&R) options for MRD-affected pavements can be different than for sound PCC pavement. Furthermore, the period during which M&R may be appropriate is shorter, and is commonly followed by the need for reconstruction.

As such, while generally the PCI is a very useful tool for managing networks of airfield pavements, it becomes much less useful when that network includes pavements affected by MRD. The greatest concern is that the PCI may indicate that conditions are acceptable when they actually are not, or that the pavement needs maintenance when it is actually a candidate for rehabilitation or reconstruction.

This paper describes how the MRD rating (MRDR) procedure developed under IPRF Project 06-06 is used to provide critical information on the presence and progression of MRD in airport PCC pavements. It describes the practical application of the evaluation procedure, both as part of a conventional pavement condition survey and, for the pavement with documented MRD issues, as part of a stand-alone monitoring procedure. It also describes how the MRDR results can be used to more effectively manage pavements with an MRD problem. Actual MRDR data are used to illustrate this point.

MRDR Field Application

The MRDR inspection procedure is a stand-alone pavement evaluation procedure that produces a numerical MRD rating. The procedure can be conducted at both the project and the network level, and it can either be used independently to specifically evaluate an MRD problem or as a supplement to the conventional PCI pavement evaluation procedure described in ASTM D5340 (ASTM 2009). When performed as a supplement to the PCI survey, the MRDR procedure typically adds about 10 minutes to the evaluation time for each sample unit.

The MRDR procedure calls for the identification and close examination of a sample unit (or a series of sample units) that is considered representative of the overall pavement being inspected. Once the MRDR procedure is triggered, an additional MRDR form is used along with the detailed evaluation process to identify and record the type, severity, and location of MRD-associated distress and indicators.

The following steps are taken to complete the MRDR inspection to supplement a conventional PCI evaluation:

1. Conduct a PCI survey, either as part of a network-level inspection or as a stand-alone (project-level) survey.

2. Determine if an MRDR inspection is warranted based upon the observed distress.

3. If an MRDR inspection is warranted, determine the number of sample units that need to be surveyed.

4. Conduct the MRDR inspection.

The first step in the MRDR inspection procedure is to conduct a PCI survey of the sample unit in accordance with ASTM D5340. Conducting the PCI survey allows the progression of PCI distress to be calculated from information collected during previous PCI surveys. It also allows the inspector to scan the slabs within the sample unit for signs of MRD.

The second step is to determine if an MRDR inspection is warranted. In the course of conducting the PCI survey, the inspector should note whether potential MRD indicators, such as the following (described in detail later), are evident:

- Staining near joints and/or cracks.
- Pattern cracking.

- Perpendicular cracking.
- Parallel cracking.
- Exudate and/or discoloration of cracks.
- Signs of expansion.

A short checklist for noting the presence of these potential MRD indicators may be added to the bottom of a standard PCI form. If one or more of the indicators are observed during the PCI survey of the sample unit, it is recommended that the MRDR inspection be conducted using the MRDR inspection form. The PCI form and the MRDR form can be printed two-sided on a single piece of paper, greatly simplifying the management of the forms in the field and ensuring that the sample unit PCI data on one side corresponds to the same sample unit MRDR data on the reverse side. An example of a modified PCI form and the MRDR inspection form are provided in figures 1 and 2.

The third step in the process is to calculate the number of sample units within a section (feature) to be inspected using the MRDR procedure. If the MRDR inspection is being conducted as part of a network-level PCI survey, it is recommended that the same sampling rate used for the PCI network-level survey be used for the MRDR procedure. Recommended sampling rates, shown in table 1 (where N is total number of sample units within the section and n is the number of sample units to survey), are based on the ASTM D5340 network-level survey procedure. It is also recommended that the same network definition be used and sample units inspected as for the PCI survey. The benefits of this are two-fold: it avoids confusion and expedites conducting the survey procedure and it also provides a convenient way to track the progression of MRD over time and identify how this progression impacts the PCI on a sample unit basis, which will prove useful in the development of improved MRD prediction models.

Although the MRDR has been developed specifically for network-level analysis, there might be benefit in applying this tool to support a project-level analysis, particularly if details regarding the type, severity, and extent of MRD are being used to formulate a repair or rehabilitation plan. In such cases, the sampling rate must be increased significantly from what is used at the network level, and it is recommended that all (100 percent) of the sample units be inspected; however, the actual sampling rate for this application will be set by the project manager. All other aspects of the inspection will remain the same.

The fourth and final step of the process is to conduct the MRDR inspection on slabs within the selected sample units. A typical concrete sample unit consists of 20 slabs, but sample units containing between 12 and 28 slabs are allowed. Analysis of data obtained in the development of this procedure indicates that a reasonable estimate of MRDR for network-level analysis can be obtained by inspecting roughly 40 percent of the slabs within each sample unit. Thus, for a sample unit containing 20 slabs, 8 slabs will need to be inspected. Due to potential variations in materials and construction used in individual paving lanes, at least two slabs should be inspected in each identified paving lane in an alternating staggered pattern, with a minimum of 40 percent of the slabs being inspected. It is emphasized that this is not random sampling, and in fact, randomized sampling is inappropriate. An example of a recommended inspection pattern for a typical 20-slab sample unit (4 slab by 5 slab) is shown in figure 3.

PAVEMENT CONDITION INDEX (PCI) INSPECTION FORM
CONCRETE SURFACED PAVEMENTS **PCI**

PROJECT ____________ INSPECTION DATE ____________
AIRPORT ____________ INSPECTION CREW ____________

BRANCH ____________ **SAMPLE UNIT** ____________ SLAB SIZE, TYP ____________
SECTION ____________ SAMPLE UNIT SIZE ____________ (R)ANDOM/(A)DDITIONAL ____________

61 BLOWUP (L,M,H)
62 CORNER BREAK (L,M,H)
63 CRACK., LONG., TRANS., AND DIAG. (L,M,H)
64 DURABILITY ("D") CRACKING (L,M,H)
65 JOINT SEAL DAMAGE (L,M,H)
66 PATCHING, SM. (L,M,H)
67 PATCHING, LG. AND UTIL. CUTS (L,M,H)
68 POPOUTS (N/A)
69 PUMPING (N/A)
70 SCALING, MAP CRACK., CRAZING (L,M,H)
71 SETTLEMENT OR FAULTING (L,M,H)
72 SHATTERED SLAB (L,M,H)
73 SHRINKAGE CRACKS (N/A)
74 SPALLING, LONG. AND TRANS. JOINT (L,M,H)
75 SPALLING, CORNER (L,M,H)

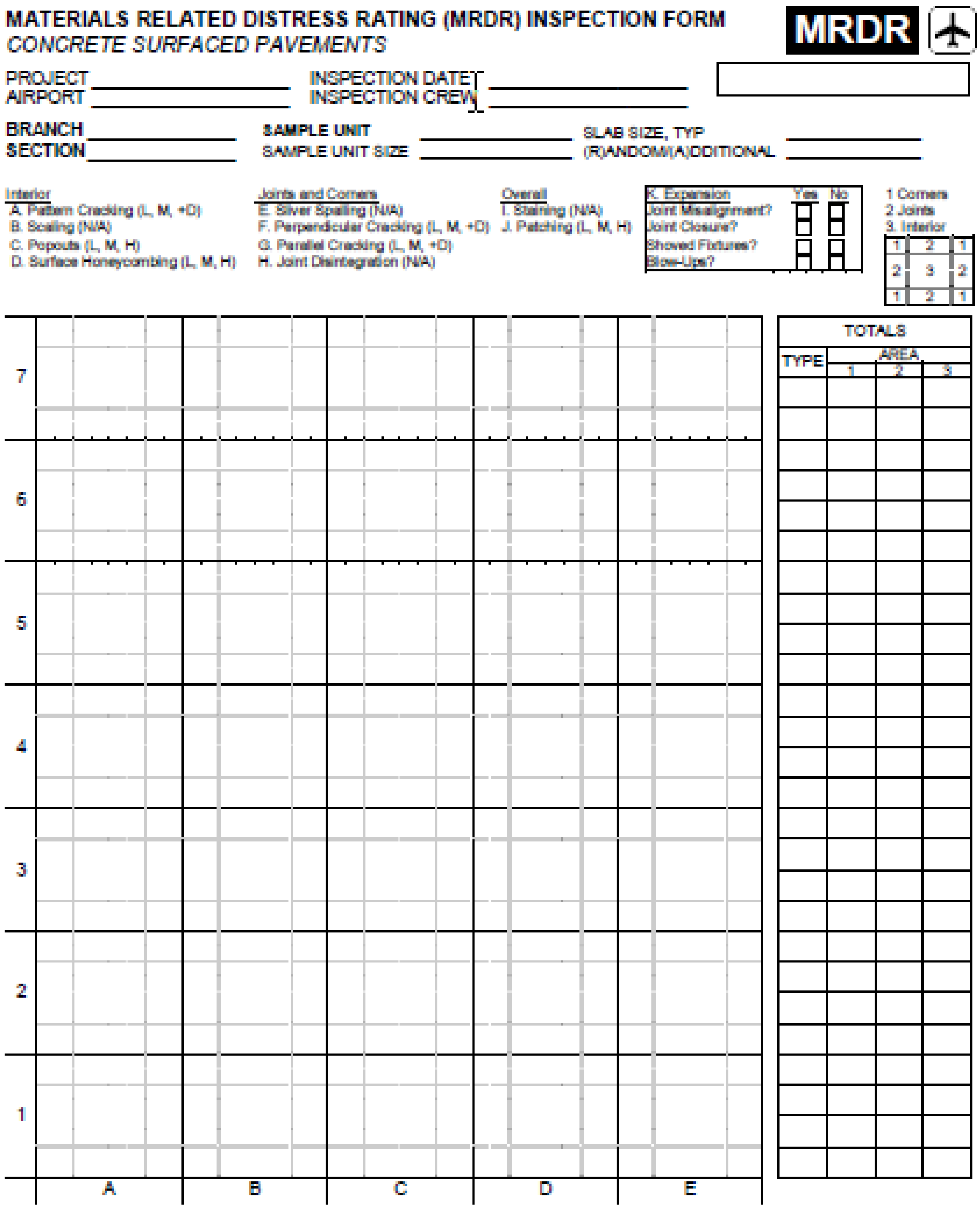
7						
6						
5						
4						
3						
2						
1						
	1	2	3	4	5	6

TOTALS		
TYPE	SEV.	QTY.
65		ALL

Signs of MRD Present?	Yes	No	Descriptors
Staining along joints?	☐	☐	Discoloration that does not appear natural
Staining near cracks?	☐	☐	Discoloration of cracks that does not appear to be moisture
Pattern Cracking?	☐	☐	Defined pattern cracking over majority of slab
Perpendicular Cracking near joints?	☐	☐	Small cracks perpendicular to a joint
Parallel Cracking along joints?	☐	☐	Cracking running parallel to joints not associated with spalling
Exudate from cracks?	☐	☐	Clearly visible deposit on pavement surface at cracks
Expansion at joints or fixed structures?	☐	☐	

If yes is checked for any, conduct MRD survey on other side.

Figure 1. PCI field form modified to trigger the supplemental MRDR inspection.



MATERIALS RELATED DISTRESS RATING (MRDR) INSPECTION FORM
CONCRETE SURFACED PAVEMENTS
MRDR

PROJECT ____________ INSPECTION DATE ____________
AIRPORT ____________ INSPECTION CREW ____________

BRANCH ____________ SAMPLE UNIT ____________ SLAB SIZE, TYP ____________
SECTION ____________ SAMPLE UNIT SIZE ____________ (R)ANDOM/(A)DDITIONAL ____________

Interior
A. Pattern Cracking (L, M, +D)
B. Scaling (N/A)
C. Popouts (L, M, H)
D. Surface Honeycombing (L, M, H)

Joints and Corners
E. Silver Spalling (N/A)
F. Perpendicular Cracking (L, M, +D)
G. Parallel Cracking (L, M, +D)
H. Joint Disintegration (N/A)

Overall
I. Staining (N/A)
J. Patching (L, M, H)

K. Expansion	Yes	No
Joint Misalignment?	☐	☐
Joint Closure?	☐	☐
Shoved Fixtures?	☐	☐
Blow-Ups?	☐	☐

1 Corners
2 Joints
3. Interior

1	2	1
2	3	2
1	2	1

	A	B	C	D	E
7					
6					
5					
4					
3					
2					
1					

TOTALS

TYPE	AREA 1	AREA 2	AREA 3

Figure 2. Sample MRDR inspection form.

Table 1. Recommended MRDR network-level sampling rates.

N	n
1 – 3	all
4	3
5 – 7	4
8 - 10	5
11 - 16	6
17 - 28	7
29 - 64	8
65 - 90	9
> 90	10%, but < 32

The discussion below focuses on the inspection of an individual slab, a process that is repeated for all slabs inspected in the sample unit and in all subsequent sample units.

MRDR Inspection Procedure for a Given Slab

The MRDR inspection form is similar to the PCI survey form, having a project identification area and a list of distress manifestations near the top, a 7 by 5 grid representing up to 35 slabs within the sample unit covering most of the page, and a summary table along the right side to "tally" the inspection results. However, there are two important differences between the MRDR and the PCI rating forms. The first is the MRD distress manifestations listed are consistent with the development of materials-related distress, being labeled alphabetically "A" through "K" to avoid confusion with the numerically labeled PCI distresses. The second difference is that each of the cells representing individual slabs within the 7 by 5 grid is subdivided into the following nine sub-areas corresponding to specific locations where signs of MRD may appear:

- Corners (four positions): Location 1.
- Joints (four positions): Location 2.
- Interior (one position): Location 3.

The corner location is defined as a 2-ft square at each corner, while the joint location lies 2 ft inward from the joint and along its length. The remaining slab area is defined as the interior location. Figure 4 illustrates how a typical slab is subdivided into the three locations, as previously shown in the example MRDR inspection form (figure 2).

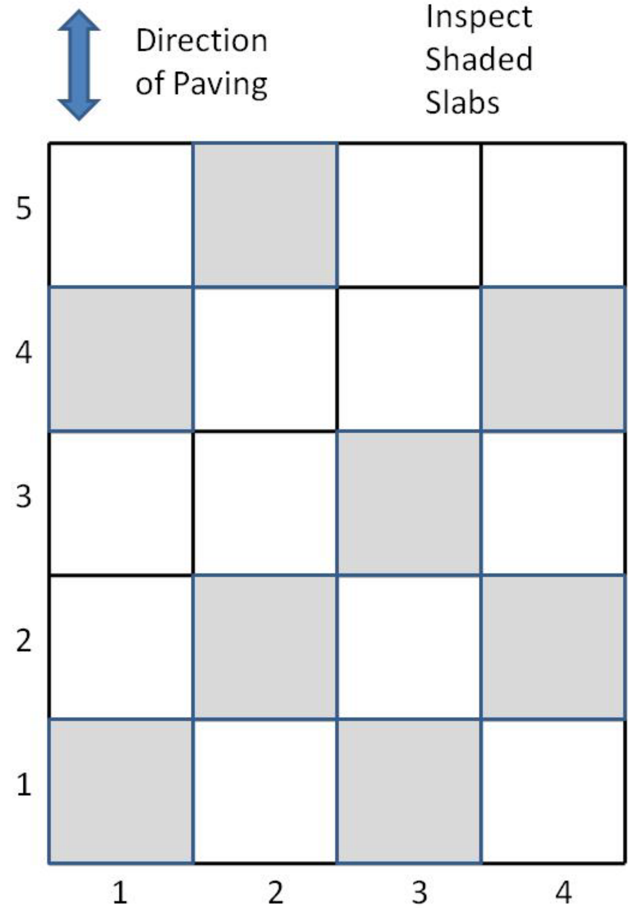


Figure 3. Recommended slab locations for a network-level inspection in a typical 20-slab sample unit.

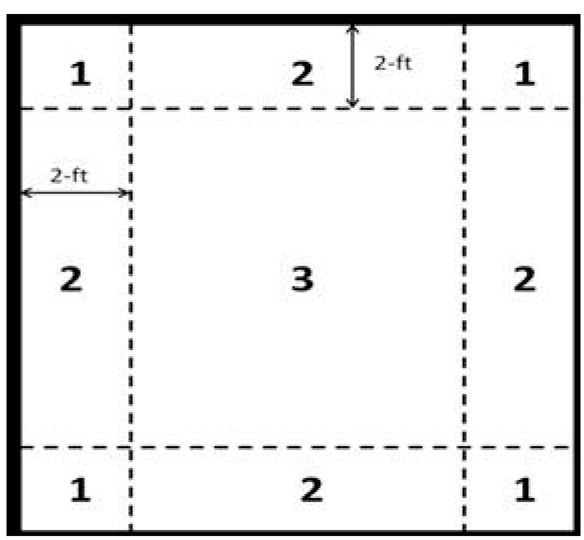


Figure 4. Typical slab layout showing the three locations (1: corner, 2: joint, and 3: interior).

As previously mentioned, each type of MRD indicator has a letter designation and many are further defined by their observed severity level. When conducting the survey, the type and severity of each MRD indicator is recorded within the nine slab locations, or may be indicated as "not present" using a dash. Cracking with discoloration (exudate and/or discoloration directly associated with the crack) is further identified with a "(*D*)" designation. Descriptions of each type of MRD indicator and severity level, along with photographs, are included in the field guide (Van Dam et al. 2009). This information will assist the inspector in conducting an MRDR inspection.

In their early stages, some of the distresses may be difficult to see. The MRDR inspection may involve pre-wetting the pavement (with water or ethanol) and/or approaching the affected pavement from different directions to find the best way to enhance the visibility of the distresses. Poor or artificial lighting conditions may compromise the ability of the inspector to see the subtle initial indicators of MRD, and thus should be avoided if possible.

The MRDR procedure should be repeated for the remaining slabs in the sample unit that are to be inspected and then repeated as needed for the remainder of the sample units within the section being surveyed in accordance with the sampling rate previously discussed.

Interpreting the MRDR

The MRDR provides a numerical indicator of the presence and severity of materials-related distress on an existing concrete pavement. The current MRDR can be used to indicate when normal maintenance or repair may be needed, or when more substantial rehabilitation (or perhaps even reconstruction) may be required. Moreover, the tracking of MRDR results over time can help identify rates of deterioration so that projected future pavement conditions may be used to aid in the planning and programming of capital improvement expenditures. This section briefly describes the use of the MRDR as a management tool and provides an overview of some of the treatments that may be used to address materials-related distresses.

As described previously, the MRDR is computed for individual sample units and then the average MRDR for the section is computed. The MRDR scale starts at 0 (representing a pavement free of any signs of materials-related distress) and increases with increasing quantities and severities of MRD. Although there is no upper limit for the MRDR, a practical upper limit may be taken as 3000. Nevertheless, a narrow range of values occurring at the lower end of the scale are indicative of MRD problems and, consequently, will be useful in managing these pavements. Generally speaking, MRDR values less than 25 are not of critical concern (but should be closely monitored), MRDR values between 25 and 100 suggest that maintenance is needed soon, and MRDR values greater than 100 indicate the need for major repair or rehabilitation. Thus, MRDR values of 200, 500, 1000, or even 2000 indicate pavements with increasing levels of distress, yet each is probably in need of major repair or rehabilitation. Figure 5 illustrates the interpretation of MRDR values. Figure 6 shows a relationship between the PCI and the MRDR with associated trigger values.

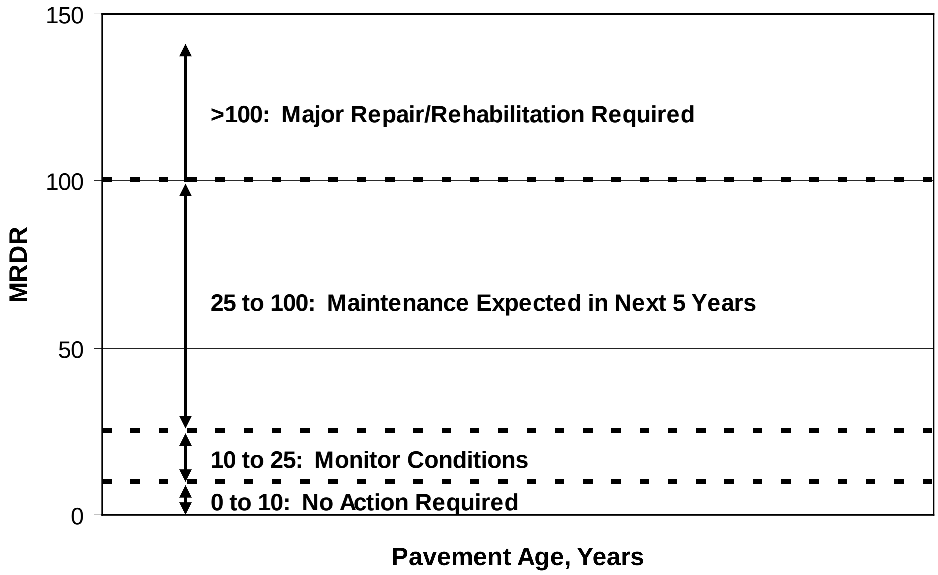


Figure 5. Interpretation of MRDR values.

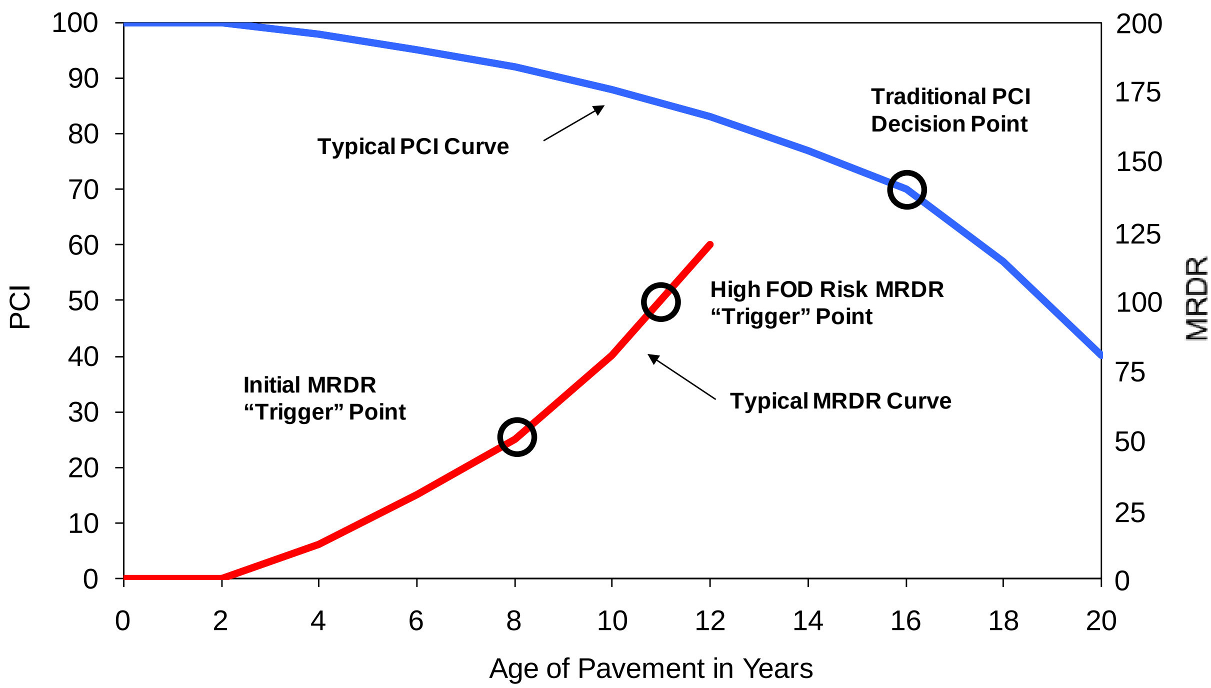


Figure 6. Illustration of trigger points for PCI and MRDR.

Taken a step further, table 2 summarizes possible treatments associated with the range of MRDR values shown in figure 5. For each primary MRDR range category, possible or typical signs of MRDR are noted, the interpretation of the MRDR is provided, and some of the possible treatments are listed. These treatments range in magnitude and intrusiveness from preventive measures (such as joint sealing or surface sealers) to reactive repair techniques (full- and partial-

Table 2. Summary of possible treatments for MRDR categories.

MRDR	Possible Signs of MRDR	Interpretation	Possible Treatment(s)
0 to 10	• None • Slight staining of corners • Low-severity perpendicular cracking	No Action Required	• None
10 to 25	• Staining of joints/corners • Low-severity pattern cracking • Low- to medium-severity popouts • Low-severity perpendicular cracking • Low-severity parallel cracking	Monitor Condition	• None • Joint sealing • Surface sealers
25 to 100	• Medium-severity pattern cracking • High-severity popouts • Medium-severity perpendicular cracking • Medium-severity parallel cracking • Medium-severity patching	Maintenance Expected in Next 5 Years	• Joint sealing • Surface sealers • Partial-depth repairs • Full-depth repairs
> 100	• Scaling • Joint disintegration • High-severity patching • Expansion	Major Repair/Rehabilitation or Reconstruction	• Partial-depth repairs • Full-depth repairs • Structural HMA overlay • Unbonded PCC overlay • Reconstruction

depth) to structural overlays and reconstruction. The preventive measures seek to eliminate or reduce the rate of deterioration on pavements that are not exhibiting severe levels of deterioration. Reactive repair techniques are intended to address specific areas of deterioration (cracking/spalling) that compromise the integrity of the pavement or present a major FOD issue. Overlays and reconstruction options may be most appropriate where widespread deterioration is present and virtually no other approach is available to address the performance problems.

The type and severity of MRD will in large part drive the type of treatment that will be required, but other factors—such as the type of facility and the potential FOD hazard—must also be considered. The MRDR value itself does not identify the specific type of MRD or the actual distress manifestations, so a separate project-level survey is required to identify specific repair activities, repair areas, and quantities, and a petrographic analysis would be required to identify the specific type of MRD (Van Dam et al. 2002, Walker et al. 2006).

MRDR Implementation Study

In 2009 the MRDR procedure was applied as part of a project-level evaluation of a PCC pavement feature at a commercial airport in the western US in order to develop a comprehensive long-term maintenance and rehabilitation plan. Other investigations included a PCI survey (in which 100 percent of the PCI distresses were also mapped), non-destructive testing using a falling weight deflectometer, coring and boring, and petrographic analyses. Based on differences in the pavement cross section, date of construction, and usage, the feature was divided into four sections. The results of the PCI survey, along with percent deduct values for the sections included in this evaluation are summarized in table 3. Based on the PCI results, the pavement is performing satisfactorily, with a range in values from 72 to 80 and an overall area-weighted PCI of 80.

Using the available PCI data for the facility a PCI deterioration curve is estimated. The curve is developed from both the collected project-level data as well as available historical airport pavement management system (APMS) data. The model determined for the facility is as follows and summarized in figure 7:

$$PCI = 100 - 1.3642 * age \quad \text{Eq. (1)}$$

where:

PCI = Predicted Pavement Condition Index
Age = Age of the pavement, years

Based on this model, a critical PCI of 65 is reached around 2018, which suggests major rehabilitation would not be needed for approximately 8 more years.

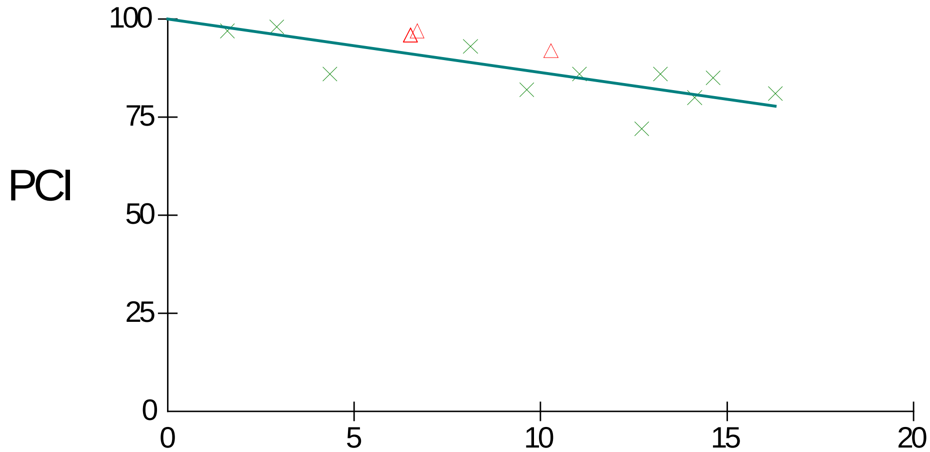


Figure 7. PCI deterioration curve for pavement.

Table 3. Summary of 2009 project-level PCI inspection.

Section	PCI	% Due To Load	% Due To Climate	% Due To Other	Observed Distresses and Severities
10	72	4	61	35	Corner Break (M) Durability Cracking (L, M, H) Joint Seal Damage (M) Small Patch (L, M) Large Patch (L, M) Popouts Shrinkage Cracking Joint Spall (L, H) Corner Spall (L, M, H)
20	81	7	49	44	Corner Break (L) Linear Cracking (L, M) Durability Cracking (L, M, H) Joint Seal Damage (M) Small Patch (L, M, H) Large Patch (L, M) Map Cracking (M) Pumping Shrinkage Cracking Joint Spall (L, M, H) Corner Spall (L, M, H)
30	80	6	35	59	Linear Cracking (L, M) Durability Cracking (L, M) Joint Seal Damage (M) Small Patch (L, M, H) Large Patch (L) Popouts Pumping Shrinkage Cracking Joint Spall (L, M, H) Corner Spall (L, M, H)
40	80	59	29	12	Linear Cracking (L) Durability Cracking (L) Joint Seal Damage (M) Large Patch (L) Shrinkage Cracking Corner Spall (L)

The MRDR procedure was also applied as part of the investigation. For this study, it was determined to use the network-level sampling rate to facilitate future inspections (the same sample units used in the APMS were used for the MRDR) and to balance project time/budget concerns. The determined MRDR are summarized in table 4; figures 8, 9, and 10 illustrate the MRDR for each sample unit in the feature sections inspected as part of the MRD survey. The fourth section is not full-strength pavement and was not included in the MRDR procedure.

Table 4. Summary of 2009 MRDR.

Pavement Section	MRDR
10	88
20	103
30	54

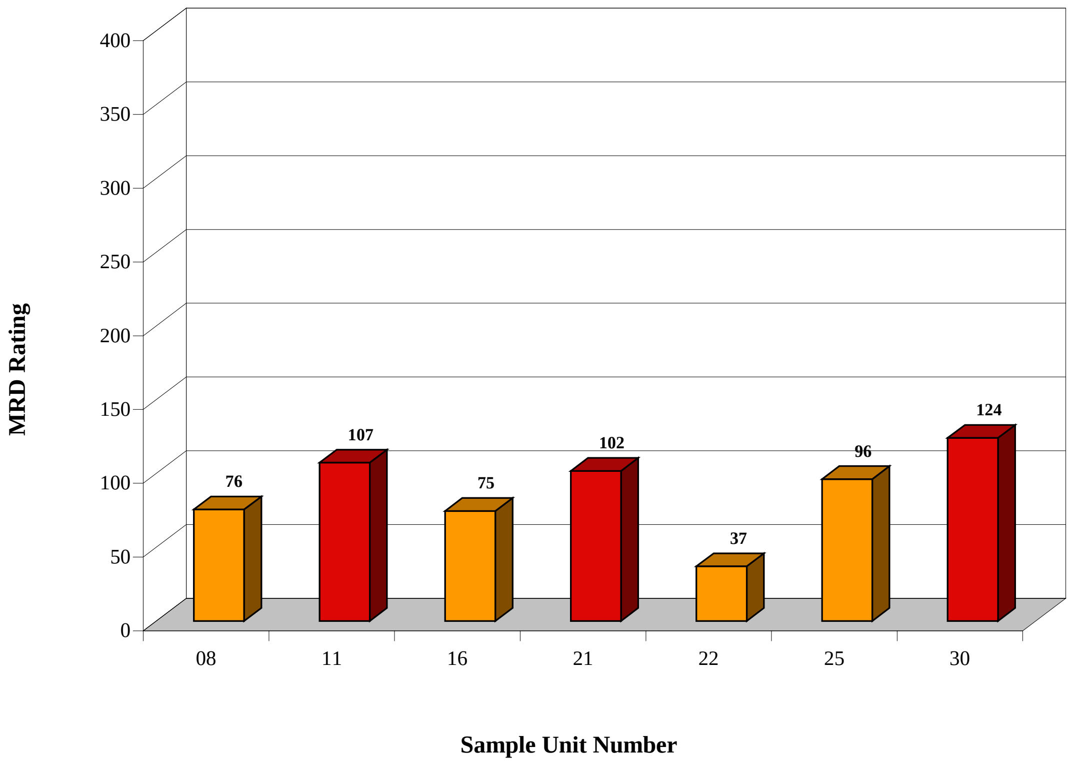


Figure 8. Summary of sample unit MRDR for section 10.

The primary MRD indicators on the feature are parallel and perpendicular cracking, illustrated in figures 11, 12, and 13. Both cracking types were observed with and without discoloration. The deterioration has also progressed to joint disintegration (figure 14) in numerous locations. Other observed widespread MRD indicators are honeycombing, popouts, patching (primarily repairs of previous joint/corner disintegration), and staining.

To help to identify the probable cause of deterioration, microscopic analyses were conducted on six cores: two cores were tested in accordance with ASTM C 457, *Standard Test Method for Microscopial Determination of Parameters of the Air-Void System in Hardened Concrete* and four cores were tested in accordance with ASTM C 856, *Standard Practice for Petrographic Examination of Hardened Concrete*.

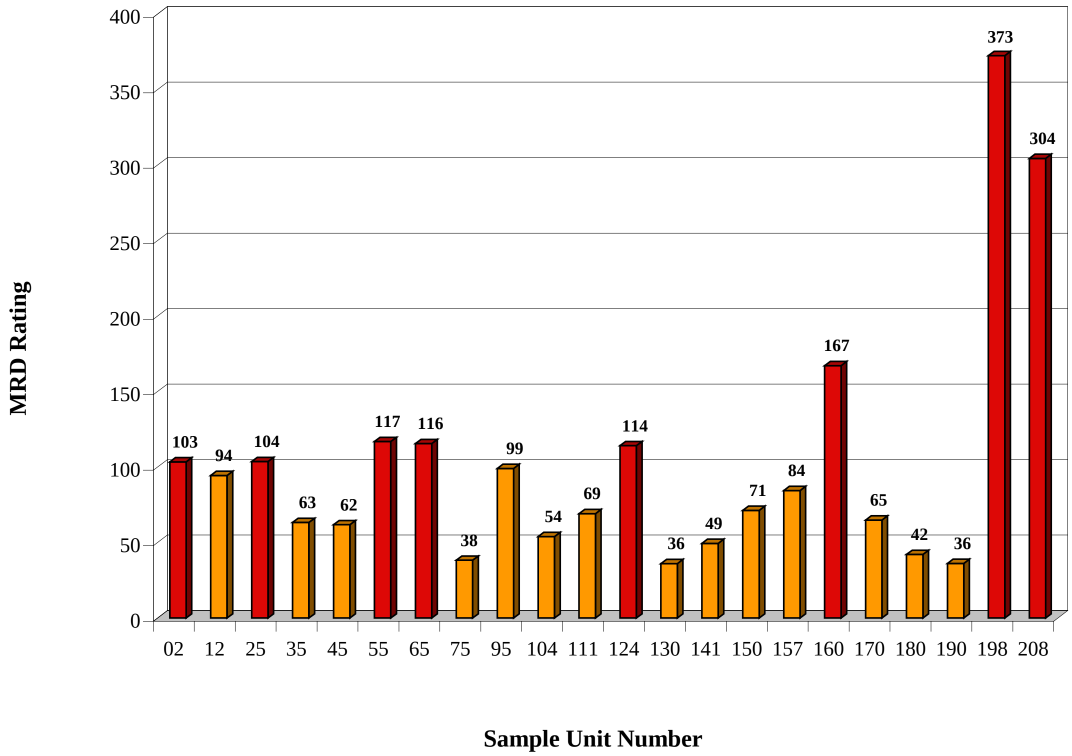


Figure 9. Summary of sample unit MRDR for section 20.

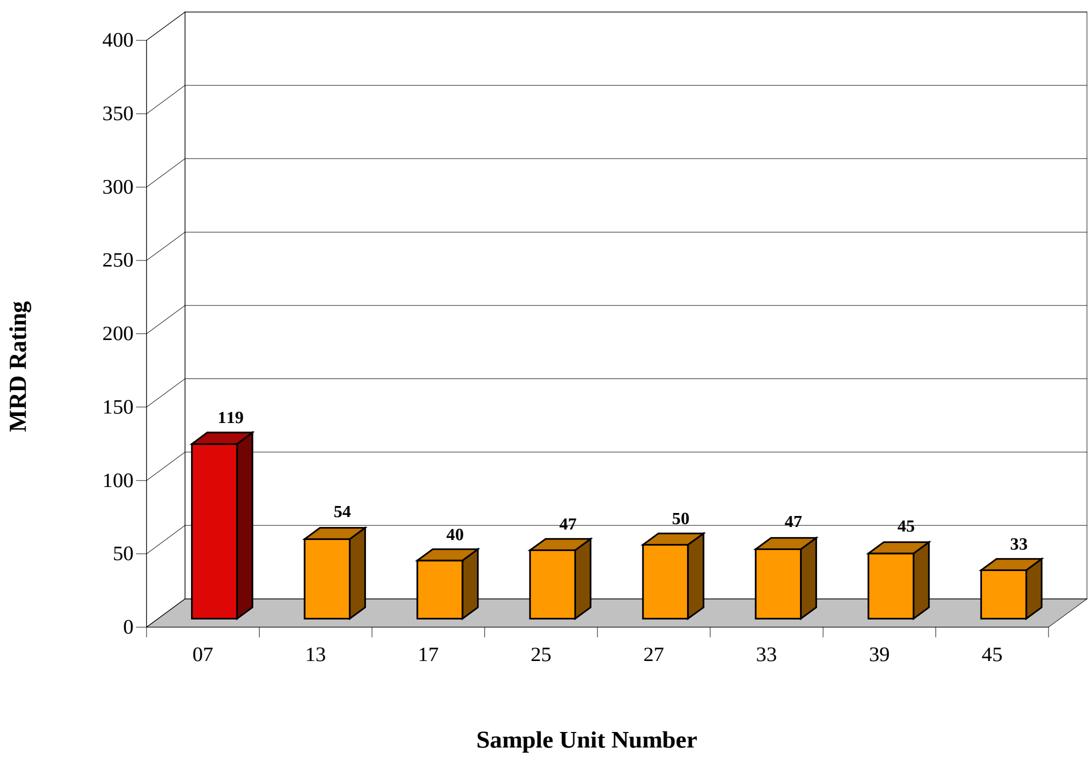


Figure 10. Summary of sample unit MRDR for section 30.

Figure 11. Low-severity parallel cracking with discoloration and staining.

Figure 12. Low-severity perpendicular and parallel cracking with discoloration and staining.

Figure 13. Medium-severity perpendicular and parallel cracking with discoloration and staining. (Note: corners at top of photograph have progressed to disintegration)

Figure 14. Joint disintegration.

Point count analysis indicates varying conditions in the cores. One core was retrieved from an area showing only surface staining (i.e., no cracking) and appears to have satisfactory air content and other air-void system parameters. However, a core taken adjacent to apparent durability cracking has low air content as well as a specific surface and spacing factor that are outside of the generally accepted range for durable concrete. The core did not appear to have air entrainment either.

Petrographic examination of four cores indicates the coarse aggregate consists of limestone and dolomitic limestone, and the fine aggregate is siliceous material, consisting primarily of quartz and feldspar. The cores all include a Class C fly ash. ASR was identified in all core specimens, but the associated micro-cracking and gel product are relatively localized and do not appear to be resulting in wide-spread deterioration. Only in a few instances does the micro-cracking extend into the surrounding paste, as shown in figure 15. Secondary ettringite deposits are also observed within air voids, but are not considered to be responsible for the observed deterioration.

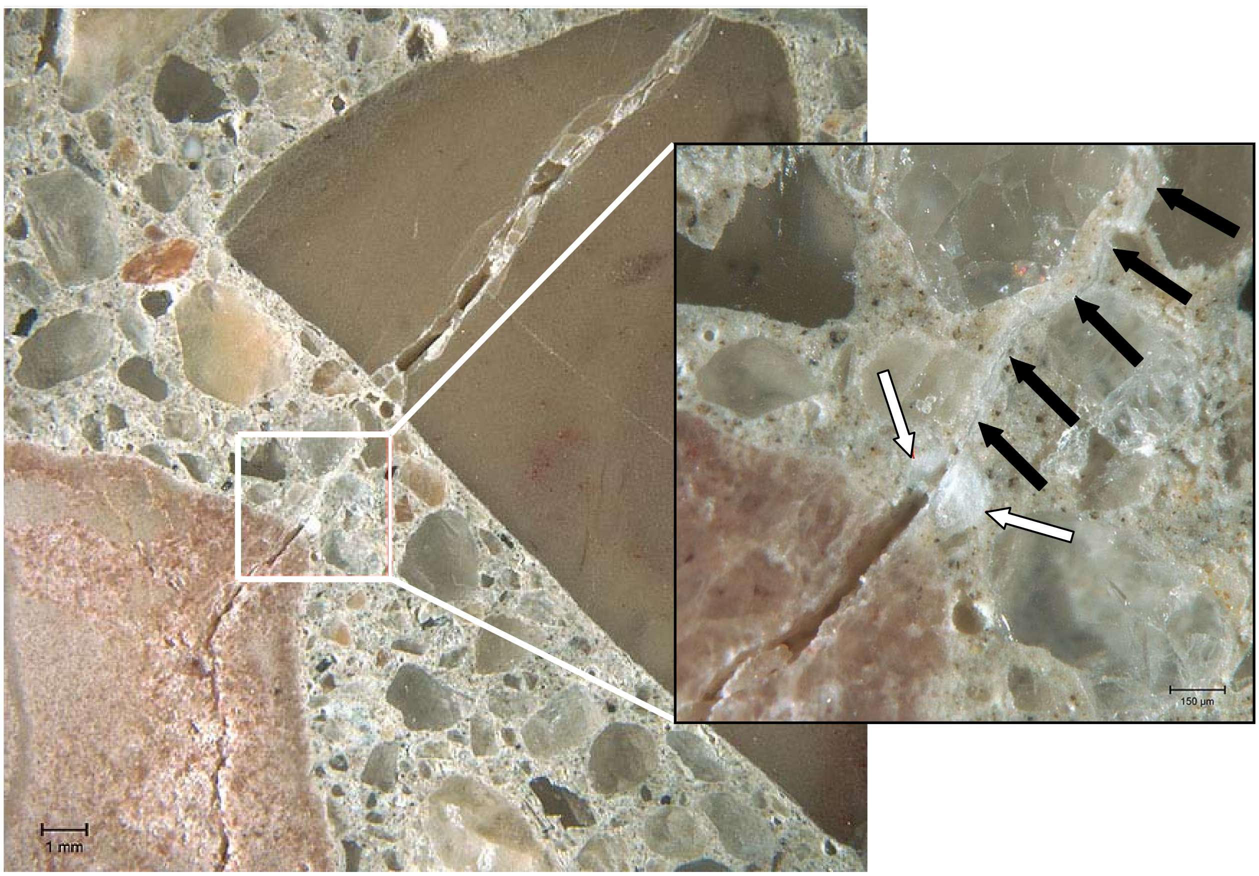


Figure 15. Illustration of micro-cracking and ASR gel formation within core C-6.
(Note: white and black arrows indicate void and crack, respectively, filled with ASR gel.)

The observed map cracking appears to be relatively confined to the surface (i.e., it does not extend significantly into the pavement), as shown in figure 16, generally indicating that it is likely the result of early-age volume change.

Deflection testing was conducted to assess the structural condition of the pavement. Testing was conducted in multiple lanes over the feature at mid-slab locations. Backcalculation of material properties from the collected deflection data indicates the PCC is generally in good condition at the center-slab testing locations. Backcalculated PCC elastic moduli are all above 4,000,000 psi, suggesting that the significant deterioration observed along the joints is relatively isolated to those locations.

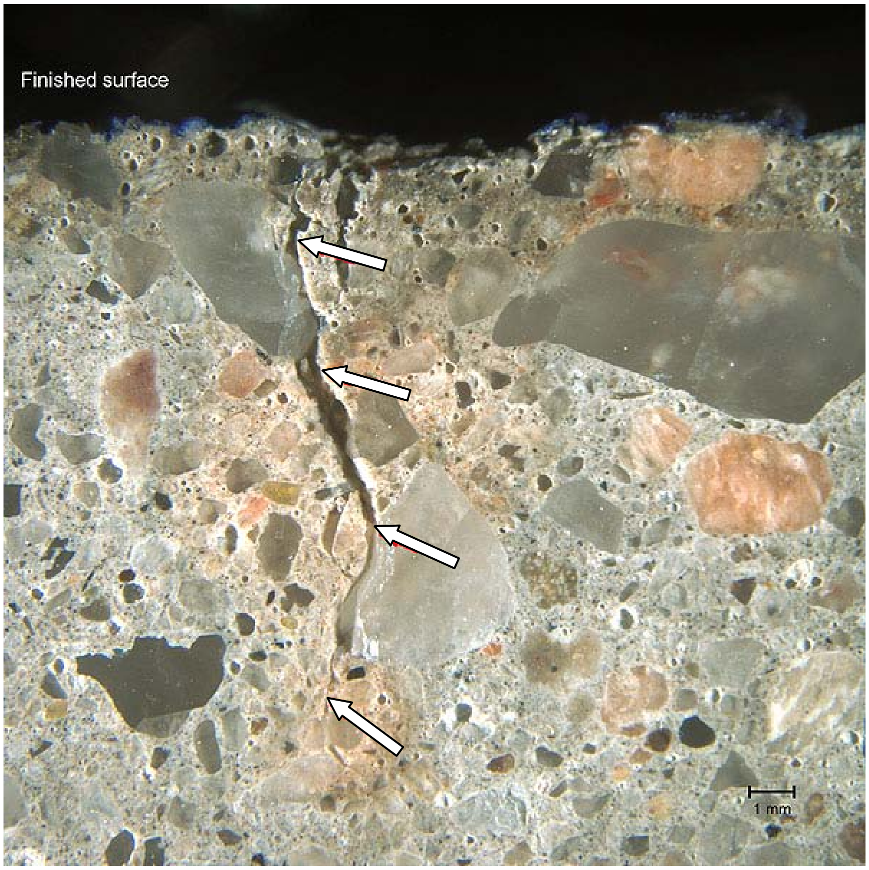


Figure 16. Sub-surface micro-crack.
(Note: white arrows indicate subsurface micro-crack.)

The airport has on-going maintenance to address FOD, primarily partial-depth repairs. The repairs are typically short-lived because of the continued deterioration of the original pavement adjacent to the repair as well as below the repair. The areas of FOD-producing distresses have become so widespread that they are an operational concern for the airport. In this case, the MRDR better reflects the pavement performance and immediate needs.

SUMMARY

This project represents the first known application of the MRDR procedure for an airport pavement project and the results clearly show the advantages of the MRDR in planning future maintenance and rehabilitation activities for pavements with a developing MRD problem. On the one hand, the PCI indicates the pavement is in satisfactory condition, and the deterioration model developed suggests the pavement will continue to perform for about 8 years before major rehabilitation is needed. However, the MRDR determined from the collected data indicate one section is already at a level requiring major rehabilitation, and the remaining two sections will reach a level requiring major rehabilitation within several years. It is clear that in this limited example, the MRD procedure is better suited than the PCI procedure to asses FOD risk and monitor continued materials-related deterioration so that planned M&R activities address actual and expected conditions.

The MRDR protocol is expected to be a useful tool for monitoring the performance of airfield PCC pavements exhibiting materials-related distress. A process is described in which the evaluation of a pavement with MRD is triggered as part of a routine PCI survey. The results are particularly helpful in the early stages of MRD, when the distresses are not severe enough to affect the PCI or require any maintenance actions.

Over time, it is expected that guidelines related to the frequency of application of the procedure will be developed. For example, if the rate of increase in the MRDR is very slow then perhaps the time between surveys can be increased. Refinements in the interpretation of the MRDR will also be developed as the progression of severity levels is studied under a broader range of conditions.

REFERENCE

Van Dam, T.J., Nelson, F., K. Smith, and D. Peshkin (2009). “Field Guide for Identification of Materials-Related Distress and Projected Pavement Life – Concrete Airfield Pavement,” Report IPRF 01-G-002-06-6(G). Innovative Pavement Research Foundation. Washington, D.C.