9th. International Conference on Concrete Block Paving. Buenos Aires, Argentina, 2009/10/18-21
Argentinean Concrete Block Association (AABH) - Argentinean Portland Cement Institute (ICPA)
Small Element Paving Technologists (SEPT)

DEVELOPMENT OF A PAVEMENT CONDITION INDEX PROCEDURE FOR INTERLOCKING CONCRETE PAVEMENTS

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Note: The following is the notation used in this paper: (.) for decimals and ( ) for thousands.

Summary

Most North American cities use a pavement management system (PMS) to budget maintenance and rehabilitation costs. PMS is a programming tool that collects and monitors information on pavement conditions and forecasts future performance. Many municipal PMS programs incorporate condition evaluation guidelines that follow U.S. Army Corps of Engineers MicroPAVER distress guide (published by ASTM) to evaluate flexible and rigid pavements. The procedure includes a methodology to evaluate surface distresses in terms of type, extent and severity and combines this information to develop a standard pavement condition index. While there has been some research completed to develop methods of evaluating the condition of interlocking concrete pavements (ICPs), there is no common methodology used in North America.

This paper outlines the procedures used to develop a pavement distress guide for ICPs following the MicroPAVER protocol. The paper provides an overview of the development of distress guidelines for ICPs, summarizes the results of the analysis and provides an example of the use of the procedures to determine the pavement condition index for a roadway constructed using ICPs. A detailed survey of pavements was completed and a list of typical interlocking concrete pavement distress types and photographs were compiled. The influence of each of the distresses on the performance of the pavement was determined through consultation with industry and other design professionals. Influence functions were then developed for each distress type and severity to permit the calculation of "deduct" values. The deduct values are combined to determine the overall pavement condition index (PCI) for the pavement section.

The deduct curves were then validated through field inspections of municipal roadway type pavements constructed using interlocking concrete pavers. Members of the Interlocking Concrete Pavement Institute (ICPI) were canvassed to identify field evaluation sections for investigation. A total of 83 pavement sections were inspected at locations throughout North America to validate the deduct curves. The comparison of the predicted PCI values versus field estimated PCI values indicated a good correlation.

1. BACKGROUD

Interlocking Concrete Pavements (ICPs) known internationally as “block pavements”, provide high resistance to freeze-thaw and deicing salts, high abrasion and skid resistance, high resistance to temperature related deformation, and high resistance to damage from fuel spills and other petroleum products. They can also be designed with excellent drainage characteristics and are often used to help mitigate storm water runoff. In a typical municipal application, joint sand between the individual concrete pavers facilitates vehicle wheel load transfer through shear transfer, and the joints also provide controlled crack locations in order to minimize stress cracking and surface degradation. Concrete pavers are set in coarse bedding sand, which is typically placed over an untreated aggregate base. They can also be placed over bituminous or cement treated base, asphalt concrete, or Portland cement concrete.

Over the past 30 years or so, there has been extensive work advancing the theory and practice of the structural design of interlocking concrete block pavements particularly in countries such as Australia, Canada, England, the Netherlands, South Africa and the United States. This has resulted in the increasing use of these types of pavements for municipal applications.

Currently, there are approximately 80 million square metres of concrete pavers sold annually in North America and approximately 300 million square metres in Europe [ICPI, 2008]. An increasing amount of concrete pavers are being used for municipal applications. With the increasing use of interlocking concrete pavements, there is a need to expand the focus from design and construction to maintenance and management of the system.

Many municipal PMS programs incorporate condition evaluation guidelines that follow the U.S. Army Corps of Engineers MicroPAVER distress guide for determining a PCI value. PCI for asphalt concrete and concrete pavement evaluation were published by the U. S. Army Construction Engineering Research Laboratory (CERL) in the 1970s for the United States Air Force [Shahin, 1994]. Procedures were soon adopted by the others including the American Public Works Association (APWA) and the Federal Aviation Administration (FAA). Procedures for collecting data and calculating PCI remained unchanged until 1993, when the American Society for Testing and Materials (ASTM) published D5340, “Standard Test Method for Airport Pavement Condition Index Surveys” and D6433, “Standard Test Method for Roads and Parking Lots Pavement Condition Index Surveys”.

2. HISTORICAL ICP CONDITON RATING PROCEDURES

Pavement management tools have been developed in Australia [Shackel, 1998], Israel [Geller, 1996], the United States [Rada, 1993] and the Netherlands [Netherlands, 1993], however, much of this work focuses on specific pavement distress types rather than on a composite condition index for pavement management purposes. All of the research recognized that additional work is necessary to come up with an overall pavement condition index. Otherwise without a composite condition index predicting the future pavement condition for use in an overall pavement management system is quite difficult for practitioners.

The Dutch methodology used by the VIAVIEW pavement management system [Netherlands, 1993] provides for a sound PMS methodology calibrated to conditions specific to the Netherlands. This system, however, is somewhat limited as it considers only rutting and local unevenness as distresses in calculating the composite condition index. Other distress types not considered in the VIAVIEW methodology can also have a significant impact on pavement condition and performance.

Shackel, outlined the development of a pavement management system for interlocking concrete pavements in Australia [Shackel, 1998]. This PMS is based on five primary distress types including rutting, horizontal creep, spalling, cracking and lippage and suggests that while other distresses such as joint width, staining etc. can affect the performance of the pavement, they are insufficiently defined to warrant their inclusion in the pavement management system. In the Australian methodology, the individual distresses are categorized and quantified, multiplied by their individual weight and extent and then summed to determine an overall "deduct" value. This deduct value is then subtracted from 100 to determine an overall pavement condition index (PCI).

In work completed in 1992 by PCS/LAW Engineering [Stephanos, 1992], a distress measuring system for interlocking concrete block pavers was created based on the U.S. Army Corps of Engineers MicroPAVER pavement management system. This system was adapted and used by the ICPI for airport pavements as published in the ICPI publication, "Airfield Pavement Design with Concrete Pavers" [ICPI, 2000]. The airfield procedure identifies the following interlocking concrete block pavement distresses:

1. Loss of sand in joints,
2. Inconsistent joint widths,
3. Corner or edge spalling,
4. Cracked blocks,
5. Joint seal damage,
6. Disintegration,
7. Depressions/distortions, and
8. Settlement or faulting.

Each distress is identified by type with severity rating ranging from low to high. The ICPI airfield rating system provides sound guidance on remedial maintenance treatments for the various distress types, but stops short of developing deduct values or calculating an overall pavement condition index value for the section.

In work completed in Ontario, the procedure outlined above was further adapted to develop an overall pavement condition index for interlocking concrete pavements [ICPI, 2000]. The method included the above airfield distresses and also included rutting, pumping and polished aggregates. For each distress, three levels of severity were assigned deduct values based on the type of distress and its expected impact on the overall pavement condition. The density level of distress was not based on individual measurements but rather five levels of distress density as follows:

1. Few – up to 5 percent of the surface,
2. Intermittent – up to 15 percent of the surface,
3. Frequent – up to 35 percent of the surface,
4. Extensive - up to 65 percent of the surface, and
5. Throughout – 100 percent of the surface.

Similar to the MicroPAVER/ASTM methodology adopted for asphalt concrete and portland cement concrete pavements, the higher the deduct value, the greater the impact that the particular distress, severity and extent has on the overall condition of the pavement.

The pavement management work by the Australians, Canadians, Dutch and Americans, described above, is the most relevant to assist in developing engineering tools to evaluate the life-cycle management of interlocking concrete pavements. Literature review shows the Canadian work to most closely duplicate the MicroPAVER methodology for use in determining a PCI value for ICPs. However, the Canadian methodology does not use the direct measurement of distress quantities

which may introduce a level of subjectivity which is avoided in the more objectively based MicroPAVER methodology. Furthermore, no studies were found on the rigorous validation testing that would be required before a standardized PCI method for rating ICPs can be formally adopted by standards bodies such as ASTM.

3. DIRECTION FORWARD

The development of a rational system to determine the condition and provide maintenance and rehabilitation guidelines for ICPs in North America is considered to be very important in supporting the industry's drive to expand the municipal market for interlocking concrete pavements for the following reasons:

- Similar pavement evaluation and management tools are already in place for the competing products including gravel, flexible and exposed concrete pavements.
- The pavement maintenance and management tools for gravel, flexible and exposed concrete pavements allow direct "one-on-one" comparisons of pavement condition through the use of pavement condition parameters such as the PCI.
- The regular update and tracking of pavement condition using the PCI permits the development of pavement performance curves (pavement condition versus time) which will assist in the development of appropriate life-cycle cost models for ICPs.
- The regular update of the condition of ICPs through the use of PCI and pavement performance curves will provide municipal engineers and planners with scientific data showing the benefits of these pavements.

Based on the results of the literature review, there are obvious benefits to developing PCI procedures for ICPs that follow the MicroPAVER methodology already adopted for other pavement types. While distress types and deduct values presented herein are specific to ICPs, the methodology used for selecting sample units, conducting the survey, and using a corrected deduct value for multiple distress types is based on the same principals as the MicroPAVER / ASTM procedure. The logical sequence to develop the pavement maintenance and management tools for ICPs is as follows:

- Develop an interlocking concrete pavement distress guide.
- Identify the distresses that affect the performance of ICPs.
- Describe how to identify the individual distresses.
- Describe how to determine the severity of the distresses.
- Determine the procedures for measuring the quantity of the distresses.
- Establish a deduct curve for each distress type and severity to determine the influence of the distress on the overall condition of the pavement.
- Establish procedures to determine a corrected deduct value when multiple distress types and severities are present.
- Develop pavement maintenance and rehabilitation trigger values for municipal interlocking concrete pavements.

Select representative pavement locations and collect PCI data to validate the methodology.

4. ICP DISTRESS GUIDE

The MicroPAVER procedure requires the identification of the type of pavement distress, its extent and severity. These values are then used to calculate an overall PCI for the pavement section

(Figure 1). The pavement distress, extent and severity are combined using "deduct" curves to establish the impact of the individual distress on the condition of the pavement.

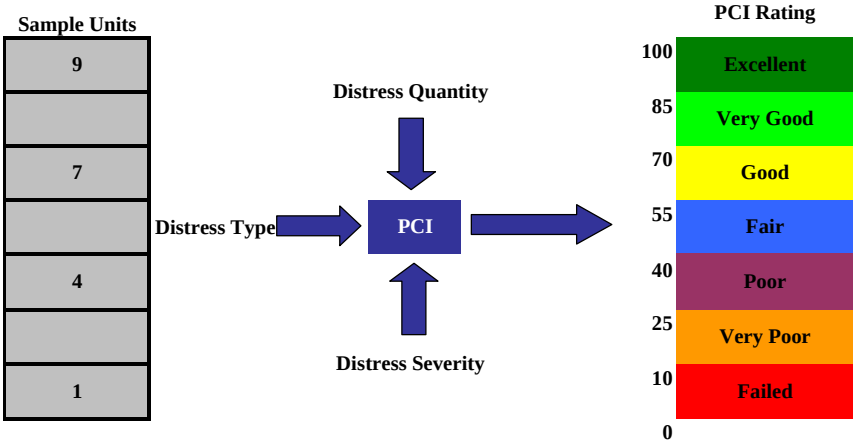

Figure 1. Flowchart for Determination of PCI.

Based on literature review, consultation with industry experts, and analysis of multiple ICP sites throughout North America, 11 common distress types for ICPs were identified:

101 Damaged Pavers
102 Depressions
103 Edge Restraint
104 Excessive Joint Width
105 Faulting
106 Heave
107 Horizontal Creep
108 Joint Sand Loss/Pumping
109 Missing Pavers
110 Patching
111 Rutting

This is the most comprehensive listing of ICP distress types to date and adds several additional distress types to those used in previous studies. A detailed description of each distress along with guidelines for the measurement of their extent and severity has been published and is available through ICPI [ICPI, 2008]. To assist field surveyors to identify and assess ICP distresses, the distress guide includes photographs of distresses and severity levels. Examples of the distress guide photos for rutting (111) are shown in Figures 2 to 4. The distress guide contains similar photographs for each of the distresses listed above (101 through 111). Each distress is described in terms of low, medium, and high severity level.

5. DISTRESS DEDUCT VALUES

The deduct value for an individual distress is determined by entering the distress extent in terms of a distress density. Distress density is calculated by taking the measured distress area and dividing by the total area of the pavement sample unit area being inspected. By matching the distress density with the distress severity, the deduct value is determined from a curve similar to that shown in Figure 5.



Figure 2. Low Severity Rutting (5-15 mm).



Figure 3. Medium Severity Rutting (15-30 mm).



Figure 4. High Severity Rutting (>30 mm).

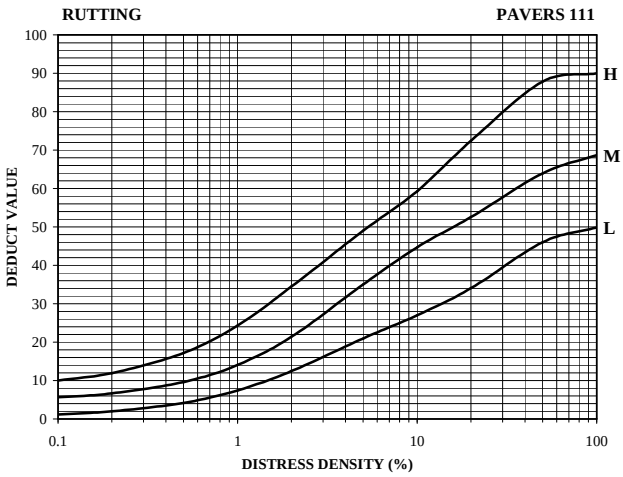

Figure 5. Deduct Curve for Rutting.

Similar deduct curves were developed for each distress type and severity based on engineering experience and input from the industry. Deduct curves for all 11 distress types are provided in the distress manual. When multiple distress types are present it is theoretically possible to obtain a PCI value that is less than zero. To adjust for the interaction between multiple distress types, the procedure uses an iterative process to determine a corrected deduct value (CDV). The CDV procedure used for ICP is based on the same principals established by MicroPAVER /ASTM and is detailed in the distress guide.

6. VALIDATION

Using the distress manual and deduct curves, a software model was developed to calculate a pavement condition index (PCI) from the distress type, extent and severity levels. The deduct curves were then validated through field inspections of municipal roadway type pavements constructed using ICP. A total of 83 pavement sections were inspected at the following locations throughout North America:

- Baltimore, Maryland,
- Boston, Massachusetts,
- Hamilton and North Bay, Ontario,
- Portland, Oregon,

- San Antonio, Texas,
- San Francisco, California,
- Syracuse, New York,
- Tampa, Florida
- Vancouver, British Columbia, and
- Winnipeg, Manitoba.

At each of the site locations, the methodology described in the distress guide was used to assess and measure each of the distresses and to calculate the overall PCI of the pavement. Numerous photographs of representative pavement features were taken. Prior to calculating the PCI, a surveyor experienced in using the PCI methodology for other pavement systems estimated the overall condition rating of the pavement on a scale of 0 (Poor) to 100 (Excellent). The survey crew members then reviewed the calculated and estimated PCI values along with the photographs of the sites. The comparison of the estimated versus calculated PCI values are shown in Figure 6. While the correlation coefficient (R^2) of the data is considered to be fair (at 0.57) it must be recognized that the field crew estimates of PCI are based on a limited number of test sites. Based on the results of the field review and the correlation, several of the distress curves were revised. These included missing pavers (109) and loss of joint sand (108). It was felt that the original deduct curves were treating these distresses too harshly and that the observed performance in the field was much better than predicted by the original distress curves.

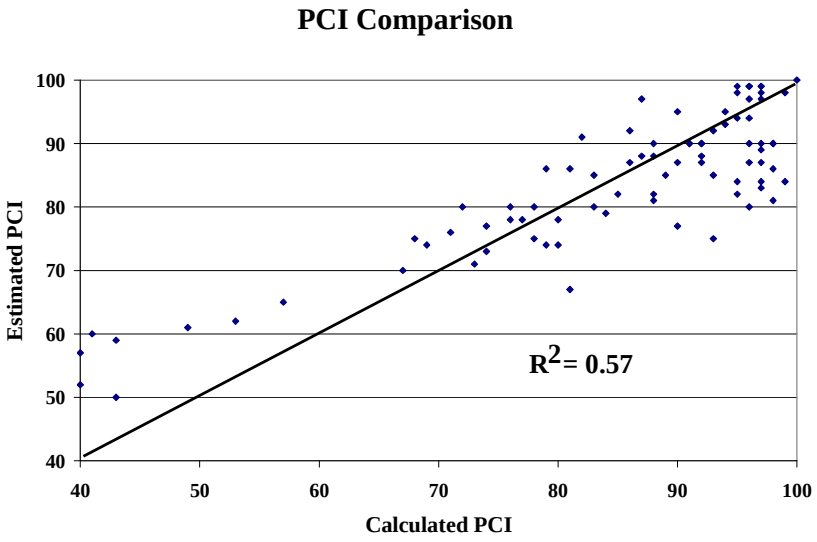

Figure 6. Initial Predicted versus Calculated PCI.

Figures 7 through 14 provide overview photos from three validation sites with PCI values ranging from 43 (poor) to 92 (excellent). Table 1 documents the distress types, severity, extent, density, deduct values, and overall calculated PCI value for each of the three sections. Not all of the distresses used to calculate the PCI are visible in the example photographs.

Figures 7 and 8 provide an overview of validation site number 21. This site was in excellent condition with an overall calculated PCI of 92. The estimated PCI for this section prior to detailed inspection was 90. The distress type with the largest deduct value is excessive joint width categorized as low severity (104L).

Table 1. Details from Selected Validation Sites

VALIDATION SITE #21			VALIDATION SITE #43			VALIDATION SITE #44		
Distress/ Severity	**Density (%)**	**Deduct Value**	**Distress/ Severity**	**Density (%)**	**Deduct Value**	**Distress/ Severity**	**Density (%)**	**Deduct Value**
101 L	0.63	0.35	104 M	2.73	15.37	101 L	4.74	1.48
102 L	0.41	3.37	108 M	2.73	1.77	102 M	2.03	14.00
104 L	3.81	5.49	102 L	0.40	3.35	104 L	10.16	12.34
105 L	0.41	0.00	102 M	0.93	10.97	110 L	2.37	13.70
108 M	0.14	0.37	102 H	0.93	22.27	111 L	0.41	0.27
			110 M	2.00	0.63	111 M	3.39	17.25
			110 H	6.67	0.74	111 H	3.39	28.89
			110 L	1.27	0.61		0.68	19.88
TDV		**9.6**			**55.7**			**107.8**
CDV		**8.2**			**33.3**			**56.7**
PCI		**92**			**67**			**43**



Figure 7. Validation Site # 21 (Overview).



Figure 8. Validation Site # 21 (Distress 104L low severity excessive joint width).

Figures 9 through 11 provide an overview of validation site number 43. This site was in good condition with an overall calculated PCI of 67. The estimate PCI for this section prior to detailed inspection was 70. The distress types having the largest deduct values are depressions (102) and excessive joint width (104).



Figure 9. Validation Site # 43 (Overview).



Figure 10. Validation Site # 43 (Distress 102 depressions with 110 patching in background).

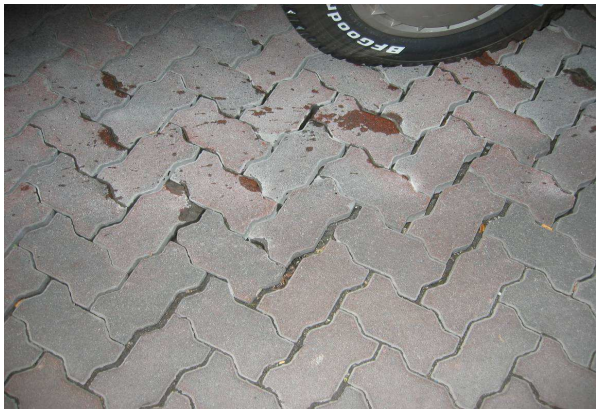

Figure 11. Validation Site # 43 (Distress 104M medium severity excessive joint width).



Figure 12. Validation Site # 44 (Overview).

Figures 12 through 14 provide an overview of validation site number 44. This site was in fair condition with an overall calculated PCI of 43. The estimate PCI for this section prior to detailed inspection was 50. The distress types having the largest deduct values are rutting (111), depressions (102) and excessive joint width (104).



Figure 13. Validation Site # 44 (Distress 101 damaged pavers, 102 depression, & 104 excessive joint width).



Figure 14. Validation Site # 44 (Distress 111 rutting).

As an additional check, the PCI of the inspected validation sections were plotted against their age as shown in Figure 15. It is expected that the initial service life of a properly designed and maintained municipal pavement would be in the order of 20 years. The service life is usually defined as the time in years taken for the pavement to deteriorate from a condition rating of 100 (new) to rehabilitation (60). As seen in Figure 15, the service life predicted for the inspected pavements would be approximately 20 years. Reviewing the data from Figure 15, it appears that there are 8 or 9 sections with relatively low PCI values. This may be due to inaccurate age information for the original pavement construction as in some cases where age information was not available, the age was estimated. It is also possible that these values are lower due to original improper structural design of the pavements. If these values were excluded from the analysis, the expected design life of the pavements would be closer to 32 years which is consistent with properly constructed interlocking concrete pavements that were constructed when the system was introduced to North America in the mid to late 1970's.

The distress criteria and deduct curves will continue to be "adjusted" as additional data becomes available and the distress manual rating procedure is used by the industry.

7. TRIGGER VALUES

The trigger values for various preventive maintenance, rehabilitation and reconstruction are shown in Figure 16 and are consistent with those being used for other pavement types such as asphalt concrete and Portland cement concrete. Maintenance and rehabilitation actions should always be based on the actual distress present; however, for network level planning purposes it is helpful to categorize actions based on a range of PCI values. For PCI values of

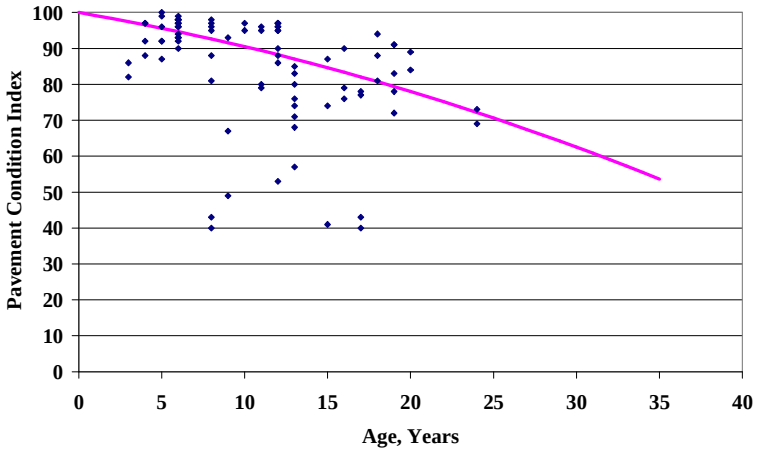

Figure 15. Pavement Condition Index versus Age..

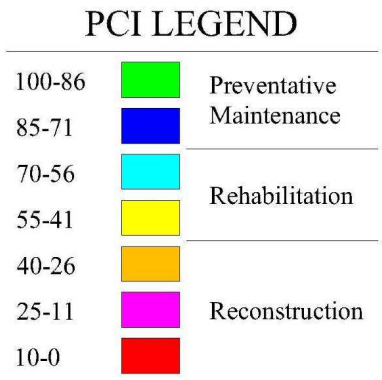

Figure 16. Trigger Values.

71 and above, actions are typically confined to routine maintenance. For values between 41 and 70, some form of rehabilitation is typically the most appropriate action. In this range, the difference between maintenance and rehabilitation can be somewhat gray. To further subdivide this category, pavement with a PCI between 60 and 70 is typically a candidate for a "major" maintenance treatment. Pavement with a PCI in the range of 40 to 59 typically requires action that falls squarely in the rehabilitation category. For pavement with a PCI value below 40, reconstruction is typically the most cost effective action.

8. CONCLUSIONS

The information outlined in this paper and in the distress guide available through ICPI provides a methodology for the pavement practitioner to objectively evaluate the condition of ICP's. The intent was to establish an overall pavement condition for pavement management and pavement maintenance management purposes. Field evaluations were completed to validate the deduct severity for the various combinations of distress type, extent, and severity. The field validation of the PCI procedure and deduct curves indicated that the deduct values for missing pavers and joint sand loss were harsher than the observed field conditions. As a result, the deduct curves were adjusted to better reflect the observed field conditions.

It is believed that the procedures outlined herein are equally valid for ICPs as the MicroPAVER/ASTM methodologies that are currently being used for other pavement types. Use of this procedure is expected provide a PCI value that can be equally compared to the PCI value determined for asphalt concrete or Portland cement concrete pavements. It is expected that the distress criteria and deduct curves will continue to be adjusted as additional data becomes available and the distress manual rating procedure is used by the industry.

On a final note, ICPI has introduced the distress manual to the ASTM Subcommittee E17.41 on Pavement Testing, Evaluation, and Management Methods for balloting. It is written in an ASTM format similar to *D6433 Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys.*

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