Operational Life of Hot Mix Asphalt (HMA) Airfield Pavements

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ABSTRACT: The objective of this study was to evaluate whether the Federal Aviation Administration (FAA) thickness design standards for flexible pavements are consistent with the FAA's standard for a 20-year pavement design life requirement contained in Advisory Circular (AC) 150/5320-6D. The FAA pavement thickness design procedures refer to the determination of the thickness of a pavement structure and its components (surface, base, and subbase layers) not to the design of the materials in a pavement (e.g., hot mix asphalt or Portland cement concrete mixes). The intent is to protect the lower layers, particularly the subgrade, from shear failure. In this study, Pavement Condition Index (PCI) data from the field condition surveys were converted into Structural Condition Index (SCI) data to evaluate airport pavement structural life. For rigid pavements, there is a clear definition and procedure for calculating SCI. But, currently, there is no definition or established procedure to calculate the SCI of flexible pavements. This study introduces a procedure to calculate SCI for flexible pavements using two distresses—alligator cracking and rutting. The PCI data from the airport pavement field surveys were used to calculate SCI for flexible pavements at the end of 20 years of use. Analysis of the survey data showed, on average, that the SCI for flexible pavements, and for all types of pavement features (runways, taxiways, and aprons), is higher than 80 after 20 years.

KEY WORDS: Flexible pavements, Pavement Condition Index, Structural Condition Index.

1 INTRODUCTION

The Federal Aviation Administration (FAA) requirement for a 20-year pavement design life is contained in Advisory Circular (AC) 150/5320-6D (FAA, 1995). A 20-year pavement life represents the total anticipated load applications the pavement will be subjected to over a 20-year period. For the purpose of thickness design, the total number of load applications is the defining parameter. The common terminology that uses years as the measure of pavement life is simply the practical period of time for which the design assumptions are considered valid. The FAA pavement thickness design procedures refer to the determination of the thickness of a pavement structure and its components (surface, base, and subbase layers) not to the design of the materials in a pavement (e.g., hot mix asphalt or Portland cement concrete mixes). The intent is, for flexible pavements, to protect the lower layers, particularly the subgrade, from shear failure, and for rigid pavements, to protect the Portland cement concrete top layer from fatigue cracking.

The Section 705 of Vision 100 – Century of Aviation Reauthorization Act required FAA to review the standards used to determine the appropriate thickness for airfield pavements. The objective of this study was to evaluate whether the FAA thickness design standards for flexible and rigid pavements are consistent with the FAA's standard for a 20-year pavement design life requirement using the most up-to-date available information on the life of airfield pavements. This was a congressionally (United States Congress) mandated study.

Constructing and maintaining a structurally and functionally sound pavement requires strict adherence to FAA standards and practices pertaining to pavement thickness design, material selection, construction, inspection, and maintenance. The FAA standards related to various aspects of airport pavements are as follows:

- AC 150/5320-6D—Structural design requirements
- AC 150/5370-10A—Construction and material requirements
- AC 150/5320-12C—Friction requirements
- AC 150/5360-8B—Maintenance requirements
- Title 14 Code of Federal Regulations (CFR) Part 139—Operational Requirements

If any of these standards are not followed, a pavement's full design life will not be realized. Interaction and proper application of each of these standards can have a significant impact on pavement life. The standards recognize that pavements fail for different reasons, e.g., deficiencies in performance related to structure, materials, construction, environment, and other. These can be broadly classified as structural (e.g., thickness), functional (e.g., skid resistance, material durability), and operational (e.g., surface condition) factors. For this study, it was assumed that the pavement's functional, operational, and structural requirements were addressed and the pavement was properly maintained over its design life. Therefore, this study emphasized a review of a pavement's structural performance with respect to the FAA's thickness design standards.

Consistent with the FAA's scope for this study, no new data were collected. Rather, currently available information from published reports and papers, as well as other available data, was used for analysis. This study introduces a procedure to calculate Structural Condition Index (SCI) for flexible pavements using two distresses—alligator cracking and rutting. The Pavement Condition Index (PCI) data from the airport pavement field surveys were used to calculate SCI for flexible pavements at the end of 20 years of use.

2 PAVEMENT LIFE AND FAILURE

An airport pavement is a complex engineering structure. Pavement analysis and design involves the interaction of four equally important components, which are often difficult to quantify: (1) the subgrade (naturally occurring soil), (2) the paving materials (surface layer, base, and subbase), (3) the characteristics of applied loads, and (4) climate. According to AC 150/5320-6D (FAA, 1995) paragraph 302 a., "Pavements designed in accordance with these standards are intended to provide a structural life of 20 years that is free of major maintenance if no major changes in forecast traffic are encountered. It is likely that rehabilitation of surface grades and renewal of skid resistant properties will be needed before 20 years due to destructive climatic effects and deteriorating effects of normal usage." The FAA pavement design procedure refers to the determination of the thickness of pavement and its components (surface, base, and subbase layers) not to the design of the materials in pavements (e.g., HMA or PCC mixes). The material and construction requirements are specified in AC 150/5370-10E (FAA, 2009).

Failure in pavements is not a phenomenon of chance, but a phenomenon that has a definite mechanical cause. When the pavement is incapable of performing the task it was designed for, it has failed. Failure could be structural (deep structure rutting, alligator cracking, longitudinal or transverse cracks in slabs, etc.) or functional (surface rutting, roughness, loss of skid resistance, etc.). A unique definition of pavement failure does not exist. ASTM International D 5340 (ASTM, 1998) uses PCI to rate a pavement. A pavement with a PCI value less than 10 is defined as failed. The current FAA design specification, AC 150/5320-6D Change 3, 2004, paragraph 708 b., states, "An SCI of 80 is consistent with the current FAA definition of initial failure of a rigid pavement, i.e., 50 percent of the slabs in the traffic area exhibit initial structural cracking. The SCI allows a more precise and reproducible rating of a pavement's condition than previous FAA condition factor ratings, Cb and Cr." It is also important to point out that the decision to take a pavement out of service (or end of pavement life) depends not only on pavement condition, but also on the pavement functional type (runway, taxiway, or apron) and other subjective parameters.

Since the objective of this report was to evaluate the FAA design specification, the pavement structural life was defined as the period from when the pavement starts its service (SCI = 100) to the time when SCI = 80. The use of SCI = 80 is understood as the definition of the end of structural life for PCC pavements; however, the use of SCI = 80 to define the end of structural life of flexible pavement is a new concept that is not well established. Alligator cracking and rutting (load-related distresses) were used in this study to calculate the SCI of flexible pavements.

3 FLEXIBLE PAVEMENT DISTRESSES

Distresses in a pavement structure leads to all types of pavement failure. Pavement distresses are external indicators of pavement deterioration caused by loading, environmental factors, construction deficiencies, or combinations thereof. Pavement failure could be structural or functional. Structural failure requires careful and detailed examination of the failure mechanism and the pavement layer contributing to the failure. Repairs are generally very expensive and the pavement may need reconstruction. Functional failures are generally easier and less expensive to fix. The type of distress in the pavement gives an insight to the type of failure, either structural or functional. In some cases, the two types of distresses interact with each other. For example, if untreated, functional failures may lead to or accelerate the structural failure of the pavement. The different types of distresses for HMA (flexible pavements) as considered in an airfield pavement evaluation are described in ASTM D 5340-03 (ASTM, 1998).

One of the major problems in pavement evaluation is determining when the pavement has failed. According to the ASTM Standard Test Method for Airport Pavement Condition Surveys (ASTM, 1998), a PCI value is computed based on the amount and severity of distresses. The PCI value is a numerical rating of the pavement condition that ranges from 0 to 100, with 0 being the worst possible condition and 100 being the best possible condition. A pavement is defined as failed when the PCI value drops below 10. However, the reduction in the PCI value could be caused by distresses that lead to structural failure or distresses that lead to functional failure, or both, and airport pavements are typically considered to be unusable well before the PCI has reached a value of 10.

The FAA design procedure is based on the structural failure of pavements observed in full-scale tests (Ahlvin, 1971). For rigid pavements, the failure criterion is initial crack, which is defined as the condition when at least 50 percent of the slabs contain one or more cracks due to loading of the slab (FAA, 1995). This corresponds to an SCI of 80, where the SCI is defined as the structural component of the PCI. The failure criterion for flexible pavements is based on 1 inch of upheaval (shear failure in the subgrade) outside the traffic path or significant cracking (cracking in HMA layer has occurred to such an extent that the pavement is no longer waterproof).

Since the FAA thickness design procedure is based on structural failure (rather than functional failure), only those factors or distresses that lead to structural failure were included in the evaluation of pavement life in this study. Table 1 summarizes the distresses in flexible pavements with the typical failure mechanism for each distress.

Table 1: Distress mechanisms.

Distress	Mechanism	Failure Mode
Alligator Cracking	Load	Structural
Bleeding	Materials	Functional
Block Cracking	Climate	Functional
Corrugation	Materials	Functional
Depression	Construction	Functional
Jet Blast	Operational	Functional
Joint Reflection Cracking	Climate	Functional
Longitudinal/Transverse Cracking	Climate	Functional
Oil Spillage	Operational	Functional
Patching	Other	Functional
Polished Aggregate	Materials	Functional
Weathering and Raveling	Climate	Functional
Rutting	Load	Structural
Shoving	Materials	Functional/Structural
Slippage Cracking	Construction	Functional
Swell	Other	Functional

For flexible pavements, alligator cracking and rutting are characterized as the structural distresses and will be used to convert surveyed PCI data into SCI data for evaluation of airport pavement life.

4 DESCRIPTION OF SURVEYED HMA PAVEMENTS

Because of the time limitation for completion of project, only distress survey data readily available to the authors was used. All of this data was collected before 1996, and although all of the distress survey reports contained PCI information, only a portion of them had detailed information on the types of distresses, with densities, suitable for calculating SCI values. Therefore, PCI had to be used for pavement operational life analysis in the following sections. Eckrose/Green Associates provided all the field data used in this section of the report. The detailed procedures for surveying pavements may be found in reference (Green, 1996). The data represent 30 airports from 10 states. There are a total of 2,423 features with a combined area of 161 million square feet (msf), which is equivalent to the area of 107 standard runways (10,000 feet by 150 feet = 1.5 msf). The details about distribution of surveyed pavements can be found in reference (Garg et al. 2004).

Table 2 categorizes the surveyed data by airport size and area in relation to the total area in the United States.

Table 2: General information on HMA runways in the U.S.A.

Airport Size	Total Area in US Million sq.ft	Surveyed Area Million sq.ft	Percentage
Large Hub	88.7	9.03	10.2
Medium Hub	91.6	21.6	23.6
Small Hub	164.4	19.3	11.7
Total Hubs	344.7	49.93	14.5
Commuter	405.9	13.6	3.4

5 ANALYSES OF AVAILABLE DATA FOR HMA PAVEMENTS

Figure 1 shows the average PCI for runways, taxiways, and aprons without differentiating the overlaid and non-overlaid pavements. The figure shows that a higher PCI is observed for younger pavements. The average PCI of pavements less than or equal to 15 years old are similar in all three groups. However, for the pavements older than 15 years, runways had the highest PCI and aprons had the lowest PCI.

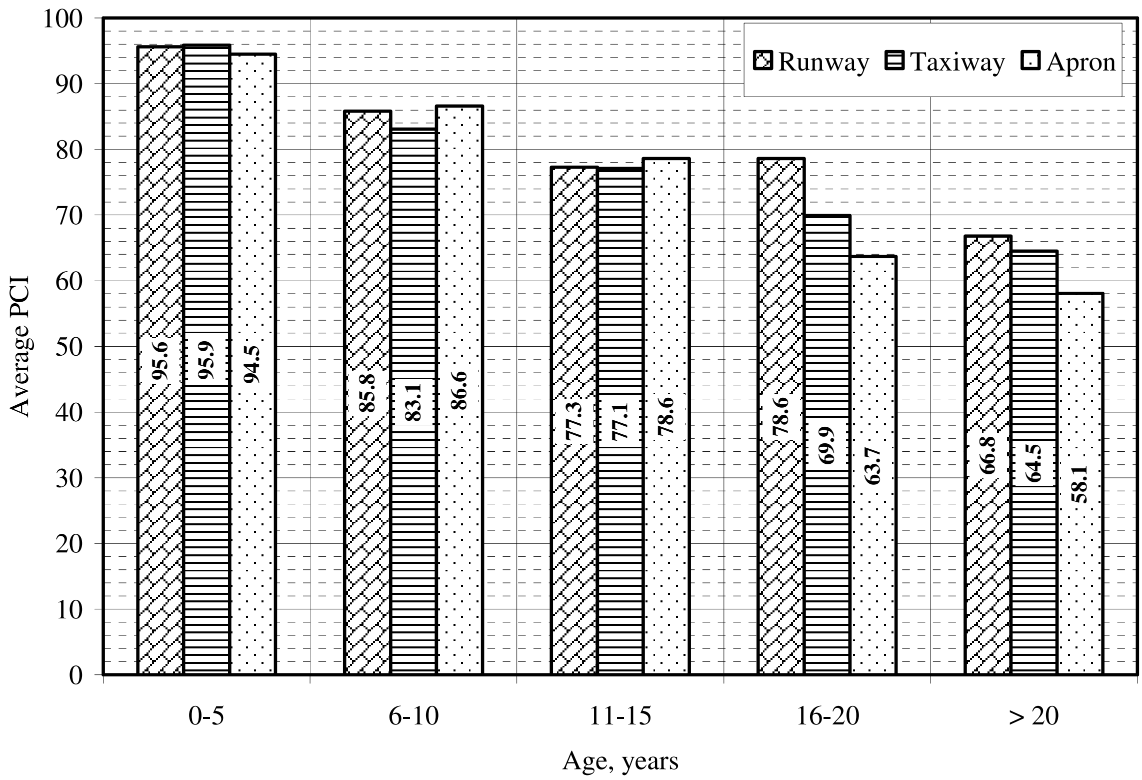

Figure 1: Average PCI for HMA runways, taxiways, and aprons.

If the pavements are separated into pavements with no overlay and pavements with an overlay, the average PCI seems to be independent of the number of overlays for the same functional pavement type (runway, taxiway, or apron) in different age groups.

AC 150/5380-6A (FAA, 2003) requires that PCI be determined based on the guidelines and procedures in ASTM D 5340 (ASTM, 1998) for both PCC and HMA pavements. Sixteen distresses are identified for HMA pavements (Table 1). For the purpose of this study, the distresses were divided into five groups as follows:

- Group-1: Cracking - Includes longitudinal and transverse cracks, alligator (or fatigue) cracking, block cracking, slippage cracking, and reflection cracking.

• Group-2: Disintegration - Includes raveling and weathering.
• Group-3: Distortion - Includes rutting, corrugation, shoving, depression, and swelling.
• Group-4: Loss of Skid Resistance - Includes bleeding, polished aggregate, and fuel spillage.
• Group-5: Others - Includes jet blast and patching distresses.

The accumulated deduct values due to distresses in a group are defined as the reduction of PCI for the group. Figure 2 shows the importance of different distress groups in HMA pavements. For example, about 82 percent of the group PCI reduction for runway pavements were contributed by distress group 1 (cracking), and 8.1 percent of it was contributed by distress group 3 (distortion).

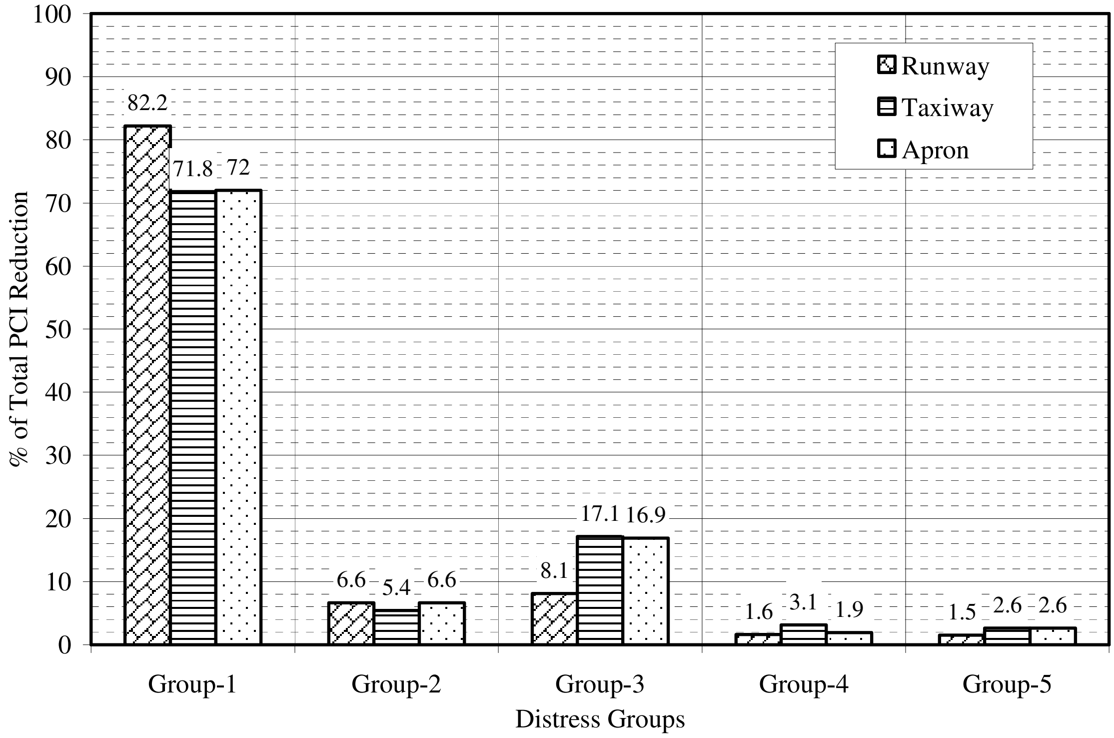

Figure 2: PCI reduction by distress groups for HMA pavements.

Figure 2 shows that

• Group 1 distresses (cracking) are the main source of PCI reduction for all three types of flexible pavements (runways-82.2%, taxiways-71.8%, and aprons-72%).
• Group 3 distresses (distortion) are the second most important reason for PCI reduction. The PCI reduction for runways, taxiways, and aprons are 8.1, 17.1, and 16.9 percent, respectively, or one-tenth to one-fifth of group 1 distresses.
• The runways have more cracks than taxiways and aprons, whereas taxiways and aprons have more distortion distresses, such as rutting.
• The loss of skid resistance (group 4) causes PCI reductions of 1.6, 3.1, and 1.9 percent for the runways, taxiways, and aprons, respectively.
• Disintegration distresses (group 2) PCI reductions for runways, taxiways, and aprons are 6.6, 5.4, and 6.6 percent, respectively.
• The PCI values reduced by jet blast and patching (group 5) distresses for the three types of pavements are 1.5, 2.6, and 2.6 percent, respectively.

Table 3 shows the PCI reduction from the total deduct PCI value by the 16 distresses. Only 5 distresses among the 16 caused PCI reductions higher than 2. Each of the five distresses cause the PCI deduct values to be higher than 5 or 10 percent or more of the total surveyed area. They are longitudinal and transverse cracking, alligator cracking, rutting, block cracking, and raveling. The deduct value used to calculate the PCI of pavements not only depends on the sum of the deduct values of all distresses observed, but also on the number of distresses that cause deduct values of PCI greater than 5. Therefore, the above five distresses may be defined as the most often observed and influential distresses among the sixteen. The total percent of PCI reduction attributed to these five distresses is 88.2 percent for all pavement types (runways, taxiways, and aprons). Table 4 shows the effect of six major distresses on different pavement groups (runways, taxiways, and aprons).

Table 3: PCI reduction by individual distresses.

Distress	PCI Deduct	PCI Deduct by %	% of Area with PCI Deduct > 5
Alligator Cracking	12.27	29.69	43.8
Bleeding	0.81	1.96	3.3
Block Cracking	2.91	7.04	10.6
Corrugation	0.01	0.02	0.1
Depression	0.81	1.95	5.1
Jet Blast	0.01	0.02	0.0
Joint Reflection Cracking	1.61	3.89	6.8
Longitudinal/Transverse Cracking	14.16	34.25	62.1
Oil Spillage	0.13	0.32	0.2
Patching	0.93	2.26	5.2
Polished Aggregate	0.01	0.03	0.2
Raveling/Weathering	2.52	6.08	11.5
Rutting	4.62	11.17	20.7
Shoving from PCC	0	0	0.0
Slippage Cracking	0.05	0.12	0.4
Swell	0.49	1.18	3.2

Table 4: PCI reduction by six major distresses.

PCI Reduction		Long./ Tran. Cracks	Alligator Cracking	Rutting	Block Cracking	Raveling	Joint Reflection Cracks	Area, msf	Ave. PCI	Ave. Age
Runway	Value	15.5	8.6	2.0	2.0	2.2	1.3	54.1	83.2	10.7
	%	46.4	25.8	5.9	6.0	6.6	3.9			
Taxiway	Value	12.5	13.0	6.0	2.4	2.2	1.2	63.0	81.3	11.0
	%	30.9	32.0	14.7	5.9	5.4	2.9			
Apron	Value	15.3	17.7	6.7	5.8	3.8	3.1	28.3	76.0	14.1
	%	26.2	30.4	11.5	10.0	6.6	5.4			

Table 4 shows that alligator cracking (load-induced distress) caused the highest reduction of PCI for aprons, followed by taxiways and runways. In other words, aircraft load-induced problems are more serious on aprons and taxiways compared to runways. Longitudinal and transverse cracking is the major source of PCI reduction on runways. This type of distress is mainly caused by construction and environmental factors. Less rutting was observed on runways compared to taxiways and aprons. Further analyses of the data showed that non-overlaid pavements experienced more rutting and alligator cracking compared to overlaid pavements. The longitudinal and transverse cracking and reflection cracking cause more PCI reduction on overlaid pavements than on non-overlaid pavements.

6 STRUCTURAL CONDITION INDEX

SCI is defined as the structural component of the PCI. For rigid pavements, SCI is clearly defined, and there is a procedure to calculate it (Rollings, 1988). Currently, for flexible pavement, there is no definition for SCI or a procedure to calculate it. This study used two distresses, alligator cracking and rutting, to calculate deducts of SCI for flexible pavements (Garg et al. 2004). Alligator cracking is load-related and is a structural problem. Rutting is a structural problem but could be caused by non-load-related mechanisms (such as poor asphalt mix design, inadequate compaction in the asphalt, base, or subbase layer). The procedure developed to calculate SCI for flexible pavements is described below.

Figure 1 shows the PCI values for runways, taxiways, and aprons. Table 4 lists the PCI reduction by six major distresses for all types of pavements (runways, taxiways, and aprons). It is assumed that the PCI deduct for a given pavement type (runway, taxiway, or apron) is the same for the pavement of all ages. For runway pavements, from Table 4, the SCI deduct (DSCI) is calculated as the sum of PCI reduction due to alligator cracking and rutting (25.8+5.9 = 31.7 percent). For taxiways and aprons, the DSCI is calculated as 46.7 percent (32+14.7) and 41.9 percent (30.4+11.5) respectively.

The SCIs were calculated for flexible pavements using equation 1.

$$SCI = 100 - (100 - PCI) \times \frac{DSCI(\%)}{100} \qquad (1)$$

where DSCI(%) is the area-weighted distress deducts due to the load related distresses. The results are shown in Table 5 and Figure 3.

Table 5. SCI computation for HMA airfield pavements.

Pavement	Age, years	PCI	DSCI, %	SCI
Runway	0-5	95.6	31.7	98.6
	6-10	85.8		95.5
	11-15	77.3		92.8
	16-20	78.6		93.2
	> 20	66.8		89.5
Taxiway	0-5	95.9	46.7	98.1
	6-10	83.1		92.1
	11-15	77.1		89.3
	16-20	69.9		85.9
	> 20	64.5		83.4
Apron	0-5	94.5	41.9	97.7
	6-10	86.6		94.4
	11-15	78.6		91.0
	16-20	63.7		84.8
	> 20	58.1		82.4

Only load-related distress deducts were considered for computing the SCI. The load-related distresses for flexible pavements are alligator cracking and rutting. Figure 3 shows that the average SCI for pavements older that 20 years is higher than 80. The average SCI for age > 20 years for runways is approximately 90. This is higher than the taxiways (≈ 83) and aprons (≈ 82). Therefore, in general, the SCI of runways is higher than the SCI of aprons and taxiways. The slow speed of aircraft on taxiways and aprons results in lower HMA stiffness, since HMA is a visco-elastic material, and longer load durations. Both these factors are related to HMA fatigue (alligator cracking) and pavement rutting. The flexible pavement SCI includes rutting, a portion of which was probably contributed by rutting in the surface HMA layer. This would represent material and construction defects rather than structural defects. HMA rutting is difficult to extract from the total rutting obtained from routine condition survey data. Consequently, the SCI values for flexible pavements are probably understated.

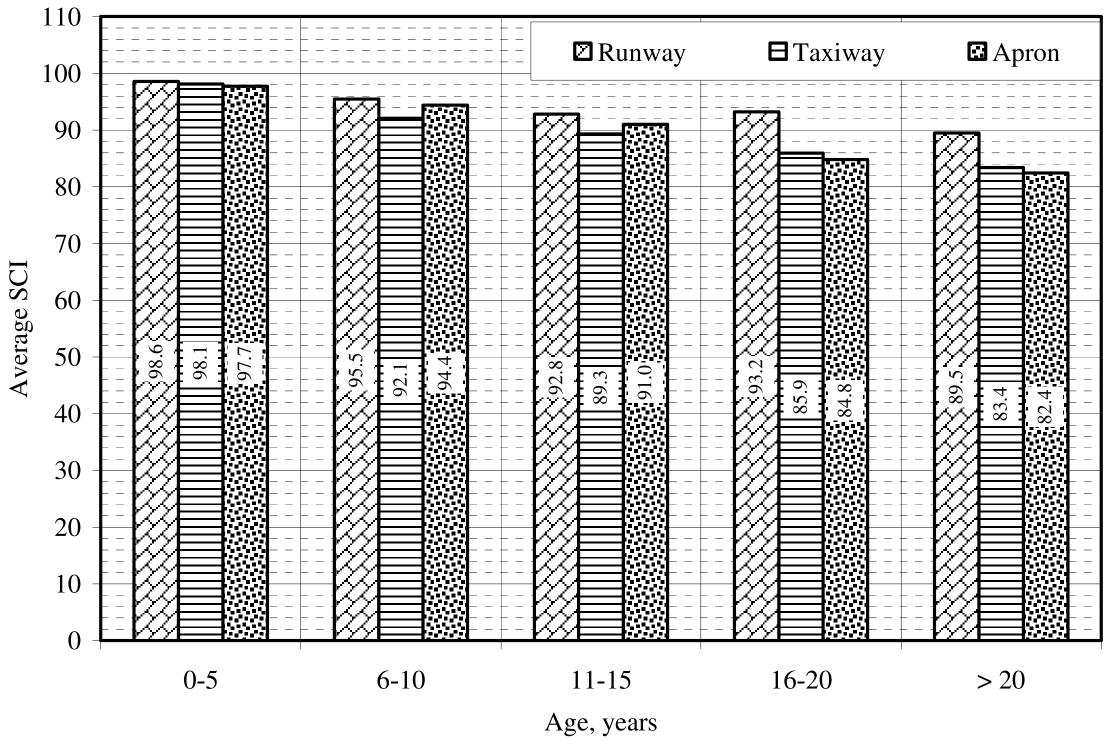

Figure 3: Average SCI for HMA runways, taxiways, and aprons.

7 CONCLUSIONS

The objective of this study was to evaluate whether the FAA's thickness design standards for flexible pavements are consistent with the FAA's standard for 20-year pavement design life requirement. Numerical analysis using structural and failure models and the analysis of surveyed pavement data (available from published and unpublished resources) was performed to achieve the objective. Based on the analysis of the surveyed data of airport pavements and using a Structural Condition Index (SCI) value of 80 as the minimum acceptable index for structurally sound pavement, it was concluded that the FAA thickness design standards for flexible pavements are adequate and are consistent with the 20-year design life requirements, if other related standards for material preparation, construction, and maintenance are appropriately applied. Available data from airport pavement condition surveys indicated that the average SCIs of HMA pavements in all age groups were higher than 80. Based on the definition adopted in this study, the average pavement structural lives for runways, taxiways, and aprons were greater than 20 years. In other words, airport pavements designed following AC 150/5320-6D have sufficient thickness to provide the required 20-year structural life.

The concept of SCI for flexible pavements was introduced in this study. Two distresses, alligator cracking and rutting, are recommended in this study to calculate SCI for HMA pavement and to evaluate the FAA design standards for HMA pavement thickness determination. The flexible pavement SCI includes rutting, which may include a portion that was probably contributed by rutting in the surface HMA layer. This distress was related to material and construction defects rather than structural defects. HMA rutting was difficult to extract from the total rutting obtained from routine condition survey data. Consequently, the SCI values for flexible pavements were probably understated. SCI provides the potential to further improve airport evaluation in the future, and further study and evaluation of the concept is recommended.

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