REHABILITATION DESIGN FOR AIRFIELD PCC PAVEMENTS

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This paper presents procedures for airfield pavement condition rating, evaluation, and rehabilitation design. The procedures are based on the Pavement Condition Index (PCI) which measures the pavement's structural integrity and surface operational conditions. The PCI is used worldwide by the U.S. Air Force and several other agencies. Models are presented for predicting PCI as a function of traffic, climate, and pavement structure. This paper emphasizes the significance of these models for use not only for PCI prediction, but also for performance-based design models. However, these models should be considered preliminary since they were being field-evaluated and improved at the time this paper was prepared.

Introduction

This paper briefly describes procedures for analyzing and designing rehabilitation alternatives for concrete airfield pavement. The procedures are: (1) determination of existing pavement condition, (2) evaluation of the pavement's past performance, (3) identification of feasible alternatives, (4) design and prediction of the future performance of the various alternatives, and (5) selection of the best alternative. These procedures are the result of several years of research and field implementation (1, 2, 3, 4, 5, 6, 7).

The in-service "performance" used in the procedures is measured by the Pavement Condition Index (PCI) used by the U.S. Air Force, U.S. Army, and several states for airport pavement evaluation and rehabilitation planning. The performance prediction models are based on field data collected from several Air Force base pavements located throughout the United States that are subjected to a variety of climates, usage (i.e., runway/taxiway/apron), and traffic. However, the models presented in this paper should be considered preliminary since the models were being evaluated and improved during the preparation of this paper.

The models enable the user to determine the consequence for each rehabilitation alternative in terms of future condition and maintenance needs. The optimum rehabilitation alternative is selected by computing the life-cycle costs and analyzing any existing management constraints for all the alternatives. A field case study which illustrates the procedures is described in this paper.

Pavement Condition Survey and Rating

The pavement condition survey and rating procedure is based on the Pavement Condition Index (PCI) used worldwide by the U.S. Air Force (5).

The Pavement Condition Index (PCI) is a numerical indicator of pavement condition that is directly related to the pavement's structural integrity (ability to resist fracture, distortion, and disintegration) and surface operational condition. The PCI is a function of (1) type of distress, (2) severity of distress, such as width and degree of spalling of cracks, and (3) density of distress, which is the number of slabs containing the distress divided by the total number of slabs surveyed; this number is expressed as a percent. If any of the three distress characteristics is ignored, the pavement condition indicator will not be consistent.

The PCI is expressed mathematically as:

$$PCI = C - \left[\sum_{i=1}^{p} \sum_{j=1}^{m_i} a(T_i, S_j, D_{ij}) \right] F(t,q) \quad (1)$$

where:

PCI = pavement condition index

C = a constant depending on the desired maximum-scale value

$a(\ )$ = deduct weighting value dependent on distress type T_i, level of severity S_j, and density of distress D_{ij}

i = counter for distress types

j = counter for severity levels

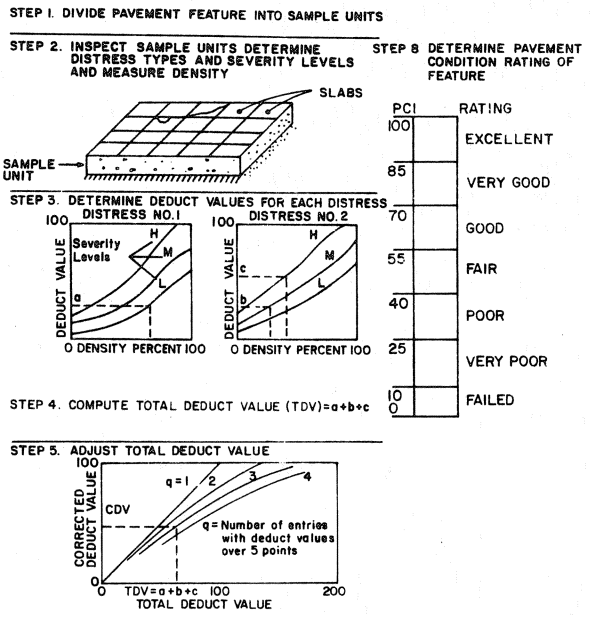
p = total number of distress types for the pavement type under consideration

m_i = number of severity levels on the ith type of distress

$F(t,q)$ = an adjustment function for multiple distresses that varies with total summed deduct value (t) and number of deducts (q).

The PCI of a given pavement feature is determined by performing the steps shown in Figure 1.

Figure 1. Steps for Pavement Condition Index (PCI) Determination.



A pavement feature is defined as a portion of pavement which (1) has consistent structural thickness and materials, (2) was constructed entirely at one time, and (3) has been subjected to the same type and approximately the same number of traffic repetitions.

A procedure for inspecting PCI by sampling has been developed to expedite inspection but still maintain accuracy (5).

Evaluation of Existing Condition and Selection of Feasible Alternatives

Selection of feasible maintenance and rehabilitation (M&R) alternatives should be based on comprehensive evaluation of factors, including existing pavement condition, rate of deterioration, and load-carrying capacity. Figure 2 shows a pavement evaluation summary sheet that has been proven in the field to be very useful in determining M&R needs. Following is a brief description of how to complete the pavement evaluation summary sheet for a pavement feature.

1. Overall condition. The overall pavement condition is determined based on its PCI rating, which represents the consensus of a group of experienced pavement engineers. The PCI is also used to determine the M&R zone from Figure 3. This zone provides a general guideline of what experienced engineers would do within 2 years of the date that the PCI was determined.

2. Variation of PCI within feature. Variation within a pavement feature occurs on both a localized random basis (i.e., from material and variability), and on a systematic basis (i.e., from traffic patterns). Determination of localized variation is based on the PCI variation of the individual sample units with respect to the overall pavement feature's PCI. Systematic variation occurs whenever the condition of a large concentrated area of the feature differs significantly from the rest. For example, in a wide runway or a large apron where traffic is channelized on a certain portion, that portion may show much more distress (or poorer condition) than the rest of the area. Whenever there is a significant degree of systematic variation within a feature, strong consideration should be given to dividing the feature into two or more features.

3. Rate of deterioration. The relative rate of long-term deterioration from initial construction is determined from Figure 4. This figure was obtained by plotting available PCI data from the features surveyed versus their respective ages. The dashed lines are intended to envelop a majority of the data in order to represent the normal deterioration rates actually occurring in the field. The data from which Figure 4 was developed are from a greater variety of pavement designs, traffic, climates, soils, and other factors and thus represent an overall average expected loss condition. A pavement feature above the dashed lines is considered to have a low deterioration rate, while a feature below the dashed lines is considered to have a high deterioration rate. Thus, a concrete pavement feature having a PCI of 40 after 20 years is considered to have a long-term high deterioration rate, but one having a PCI of 60 is considered to have a normal long-term deterioration rate.

The rate of pavement deterioration must also be checked in terms of a short-term or yearly loss of PCI. This is determined by plotting PCI versus time for the pavement feature under consideration.

4. Pavement distress. The PCI is a composite index of existing pavement distress. However, examination of the specific types, severities, quantities, and causes of individual distresses is very valuable for helping determine probable causes of deterioration and eventually selecting M&R alternatives. Distress types have been divided into three main groups: (1) those caused primarily by traffic loadings, (2) those caused primarily by material durability and climate, and (3) those caused by other factors. Conditions at each pavement will dictate which distresses go into each group. The percent deduct values attributed to each cause is the basis for determining the primary cause(s) of pavement deterioration.

5. Load-carrying capacity evaluation. Evaluation of the load-carrying capacity is based on traffic and pavement structure. The simplest evaluation procedure is a reverse process of the design procedure. Non-destructive testing may also be used.

6. Surface roughness. There are three methods of estimating surface roughness. First, pilot complaints are considered to be subjective but highly reliable sources of qualitative roughness information. Second, certain distress types contained in the PCI may be correlated with localized roughness. Third, the roughness may be quantitatively evaluated, on a relative basis, by analyzing measured profile elevation data (8).

7. Skid resistance hydroplaning potential. Pavement skid resistance, as measured by the U.S. Air Force, is reported in terms of the coefficient of friction as determined by the Mu-Meter, and the

Figure 2. Pavement evaluation summary sheet.

Facility: PARKING APRON Feature: APRON 13-TRAFFIC AREA

1. Overall Condition Rating - PCI = 35

Excellent, Very Good, Good, Fair, (Poor), Very Poor, Failed.

2. Variation of Condition Within Feature - PCI

a.	Localized Random Variation	Yes, (No)
b.	Systematic Variation	Yes, (No)

3. Rate of Deterioration of Condition - PCI

a.	Long-term period (since construction)	Low, Normal, (High)
b.	Short-term period (1 year)	Low, Normal, (High)

4. Distress Evaluation

a. Cause

Load Associated Distress	95+ percent deduct values
Climate Durability Associated	_____ percent deduct values
Other (_____) Associated Distress	_____ percent deduct values

b. Moisture (Drainage) Effect on Distress: (Minor), Moderate, Major

5. Load-Carrying Capacity Deficiency: No, (Yes)

6. Surface Roughness NOT SIGNIFICANT: Minor, Moderate, Major

7. Skid Resistance/Hydroplaning (runways only): No hydroplaning problems are expected

a. Mu-Meter NOT SIGNIFICANT
Transitional
Potential for hydroplaning
Very high probability

b. Stopping Distance Ratio
No hydroplaning anticipated
Potential not well defined
Potential for hydroplaning
Very high hydroplaning potential

c. Transverse Slope: Poor, Fair, Good, Excellent

8. Previous Maintenance: Low, (Normal), High

9. Effect on Mission (Comments): ASPHALT SURFACING SHOULD BE AVOIDED DUE TO CONSIDERABLE OIL SPILLAGE IN THE AREA.

wet-to-dry stopping distance ratio (SDR) measured by the diagonally braked vehicle (9).

8. Previous M&R applied. Permanent patching and slab replacement may be used as criteria for evaluating previous maintenance. Patching and/or slab replacement between 1.5 and 3.5 percent is considered normal, while more than 3.5 percent is considered high, and less than 1.5 percent is considered low. Some pavement features may have received an excessive amount of M&R other than patching. If the engineer feels that a feature should be evaluated as high previous maintenance, then his/her evaluation should take precedence over an evaluation based on only patching and slab replacement.

The evaluation results are used as a basis for rational determination of feasible M&R alternatives. For example, if the results showed that the primary cause of deterioration (based on distress) is load and that the load-carrying capacity is deficient, the following alternatives should be considered feasible: structural overlay, reconstruction, recycling, and replacement of the keel section (area with channelized traffic). Selection of a specific alternative is a function of its predicted future performance and of its life-cycle costing.

Performance of M&R Alternatives

There are always several M&R strategies that can be applied to a pavement. For example, the pavement could be maintained with routine M&R (e.g., patching, some slab replacement, pressure grounding), major slab replacement and patching, concrete overlay, complete removal and replacement, etc. Each strategy has its own associated costs, performance, and other factors which must be considered before recom-

mending an alternative for a specific pavement. The performance (including service life) of M&R work has always been difficult, if not impossible, to determine. However, performance can be estimated using predictive models developed from in-service pavement data. These models are a valuable tool in rehabilitation design. The distress data collected during the condition survey can also be used to determine the required overlay design thickness for various pavement conditions described later in this paper.

Figure 3. Correlation of maintenance and rehabilitation (M&R) needs with PCI and condition rating.

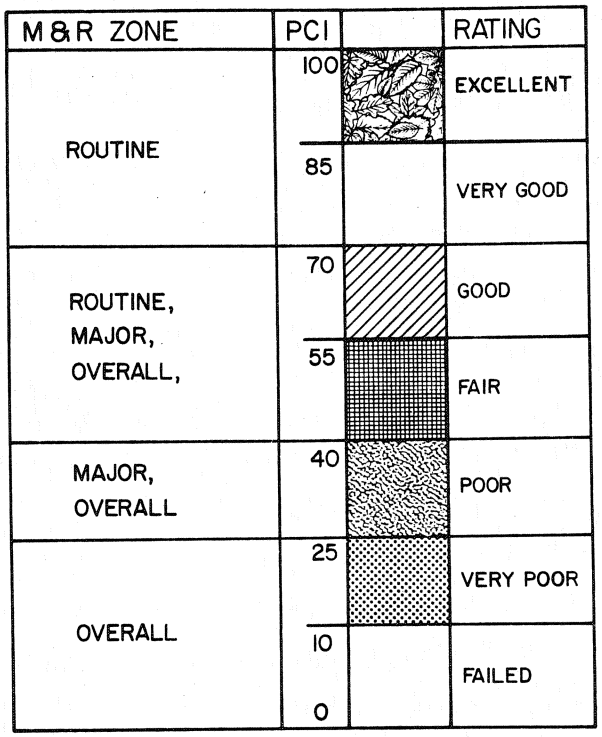
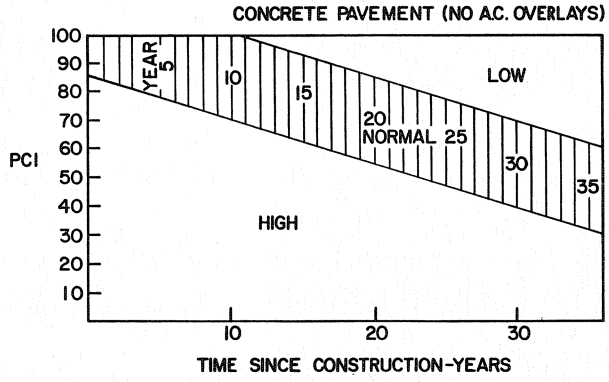


Figure 4. Average PCI decrease with age for PCC pavements, developed from field data.



Development of Predictive Models

The first step in model development was identifying all major variables believed to significantly influence pavement deterioration. This was accomplished by reviewing literature, interviewing Major Command and base pavement engineers, and reviewing previous experience of the project staff. The availability of information, the cost, and the time required to collect each variable for every airfield feature were assessed, and it was concluded that several variables could not be obtained within the available resources. Table 1 lists the independent variables considered important in the development of the concrete pavement PCI prediction models and those from which data were actually collected. The chosen data were collected from 67 concrete features having no overlay, 19 concrete features having an asphalt overlay, and 5 concrete overlay features, including runways, taxiways, and aprons. Table 2 summarizes the data obtained from the features.

Table 1. List of independent variables considered in the development of the concrete pavement PCI prediction models.

I. Variables used to develop models (data obtained from each feature):

AGE (Time Since Original Construction of Slab) -- Years
SLAB (Concrete Slab Thickness) -- Inches
BASE (Granular Subbase Thickness) -- Inches
JSL (Longest Joint Spacing) -- Feet
JSS (Shortest Joint Spacing) -- Feet
MR (Modulus of Rupture of Concrete) -- psi
K (k-Value of Slab Foundation) -- Pounds/Cubic Inch
ACWGT (Gross Maximum Weight of Critical Aircraft Using Feature) -- kips
FAT (Ratio of Stress to Modulus of Rupture [Strength] x 100)
PEI (Pavement Evaluation Index)
FEAT (Type of Feature: Runway, Taxiway, Apron)
AREA (Traffic Area: A, B, C)
PS (Usage of Feature: Primary or Secondary)
FI (Freezing Index) -- Degree Days Below 32°F
PPT (Average Annual Precipitation) -- Inches
TEMP (Average Annual Temperature) -- °F
SR (Slab Replacement) -- Percent of Total Slabs
PATCH (Large Patching) -- Percent of Total Slabs
ACOL (Existence of AC Overlay)
PCOL (Existence of Concrete Overlay)

II. Other variables considered which had important effects on PCI data, but were not obtained because of cost, time required, or nonavailability:

Number of Aircraft Passes Over Feature
Joint Design
Joint Load Transfer Efficiency
Several Additional Climatic Variables (Number of Freeze-Thaw Cycles, Temperature Gradients Through Slab, Monthly Distribution of Precipitation, etc.)
Drainage Condition of Pavement Feature

A variable was created by dividing the stress determined for an interior loading condition of the critical aircraft by the concrete's modulus of rupture. The stress was determined using charts based on stress charts prepared by the Portland Cement Association (PCA) computer program (9). The PCA program is based on the Pickett and Ray influence charts (10). This variable is multiplied by 100 and is called FAT.*

*Fatigue.

Table 2. Summary of data for plain jointed concrete airfield features.

Factor	Mean	Range
PCI	70	36-97
Cracking (% Slabs)	17	71
Age Orig. Slab (Years)	19	2-34
Age of Conc. Overlay (Years)	17	12-23
Orig. Slab Thickness (In.)	12	6-22
Conc. Overlay Thickness (In.)	9	8-10
Modulus of Rupture (psi)	739	520-922
k-value	163	30-500
Freezing Index (Degree Days Below 30°F)	99	0-678
Avg. Annual Rainfall (In.)	31	3-56
Avg. Annual Temp. (°F)	58	46-57
Stress/Strength	0.37	0.15-0.80
Slab Size (Ft)	--	12.5 x 12.5 to 25 x 25
Asphalt Overlay Thickness (In.)	3	1.5 to 8.0
Age of Asphalt Overlay (Years)	10	4-21

The distress data collected during the condition surveys were used to compute the mean PCI of each feature, using the standard Air Force procedures (5). A tentative linear model was selected, and a stepwise regression program was run many times to obtain the best predictive PCI model as a function of the independent variables listed in Table 1. The model was constrained so that it would fit the important boundary condition of the PCI = 100 just after initial construction or overlay. This boundary condition would occur since there would normally be no observable distress just after construction. The final predictive model selected after extensive analysis of the data was:

$$PCI = 100.0 - AGE\,[0.01967FAT - 0.02408SR + 0.001051\,(JSL \times JSS) + 0.94191ACOL + 0.03475PATCH + 2.91238 - 0.001775FI - 0.04066TEMP] \quad (2)$$

Standard Error = 10.5 N = 91 features

where:

PCI = Pavement Condition Index at time AGE since construction or overlay with asphalt or concrete

AGE = time since construction of slab or, if overlaid, time since overlay construction (years)

FAT = (ratio of interior slab stress/modulus of rupture) x 100

SR = slab replacement (percent total slabs)

JSL = longest joint spacing (feet)

JSS = shortest joint spacing (feet)

ACOL = 1 if asphalt overlay exists

= 0 if no asphalt overlay exists

PATCH = slabs containing large patches (5 square feet), percent of total slabs, or percent area of total area patched if overlaid with asphalt

TEMP = average annual temperature (°F)

FI = freezing index (degree days below 32°F)

The models show that the PCI decreases as the ratio of stress/modulus of rupture x 100, or FAT, increases. This is a very logical trend, because the higher the ratio, the greater the fatigue damage from repeated aircraft traffic, which means that slab cracking will occur sooner. When an asphalt overlay is placed, its PCI decreases more rapidly than the PCI of the original concrete slab. This result is expected, since all of the cracks and joints in the concrete slab will soon reflect through the asphalt overlay and generally begin spalling.

While equation 2 contains several variables that affect PCI, many others also known to influence it are not included. However, the equation is expected to reproduce or model some of the major aspects of pavement deterioration. The following analysis shows that the equation has several important potential uses. A sensitivity analysis was conducted using the equation to show the general influence of the variables on PCI. The following typical pavement feature was selected:

	Mean	Range
SLAB	16 inches	6-23 inches
K	350 pounds/ cubic inch	50-500 pounds/ cubic inch
MR	700 psi	500-700 psi
JSL & JSS	25 x 25 feet	25 x 25 to 15 x 12.5 feet
ACWGT	--	light, medium, heavy
TEMP	63°F	--
FI	0 degree days below 32°F	--
SR	0%	0

As shown below, PATCH varied according to PCI:

PCI	PATCH
0-29	10
30-39	8
40-49	4
50-59	2
60-100	0

Using equation 2, graphs were prepared in which slab thickness, modulus of rupture, k-value, slab size, and aircraft type (and weight) were varied over typical values found in the field (see Figures 5 through 8). It was noted that after 25 years of service, slab thickness dramatically influences the PCI, particularly slabs that are less than 15 inches thick. The aircraft type (or weight) also greatly influences the PCI, particularly for thinner slabs. As the slab becomes thicker, the influence of aircraft greatly diminishes, because the damage caused by high-load stress is much less significant on a

thicker slab. The k-value has a smaller influence than slab thickness on PCI (although its influence is much greater for values that are less than 200 pounds/cubic inch than for those more than 200 pounds/cubic inch and for medium to heavy aircraft). Slab size significantly influences the PCI; i.e., the larger the slab is, the less the PCI will be, because larger slabs display an increased tendency to crack when subjected to increased thermal and moisture gradient stresses. These stresses increase greatly as joint spacing increases, e.g., from 15 to 25 feet (11). Decreasing the spacing from 25 to 15 feet will make the PCI approximately 18 points higher after 25 years. Increased cracking will lower the PCI. The concrete modulus of rupture is a significant influence for the medium- and heavy-load aircraft, but not for the light-load aircraft because of the higher load-fatigue damage resulting from the heavier aircraft. These results appear to be reasonable.

Figure 5. Influence of slab thickness on the PCI after 15 years of service.

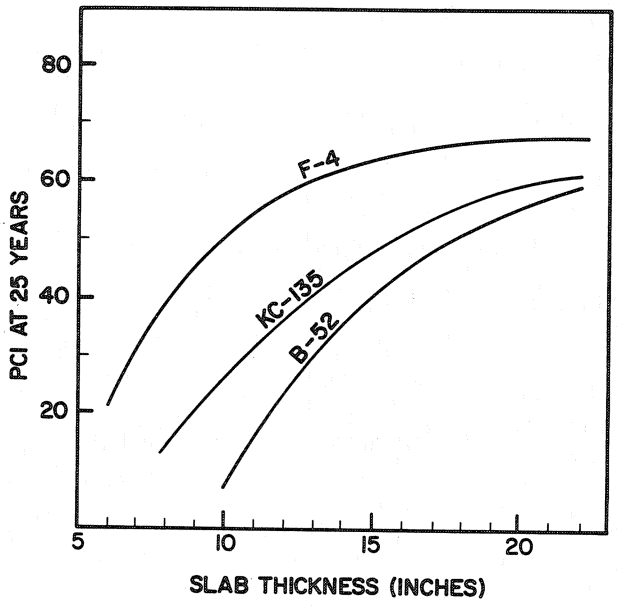


Figure 6. Influence of modulus of rupture and the PCI after 25 years of service.

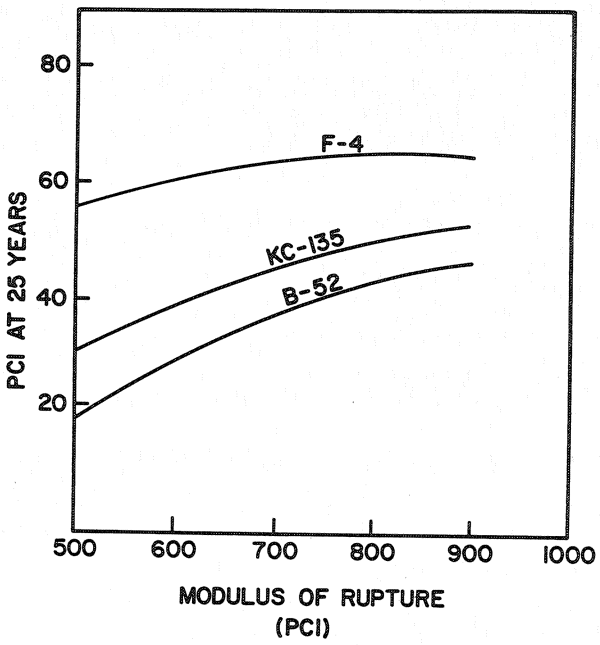


Figure 7. Influence of k-value on the PCI after 25 years of service.

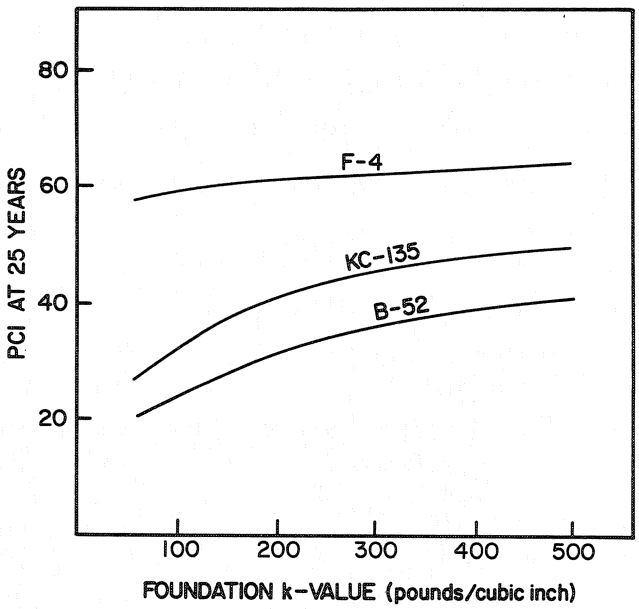
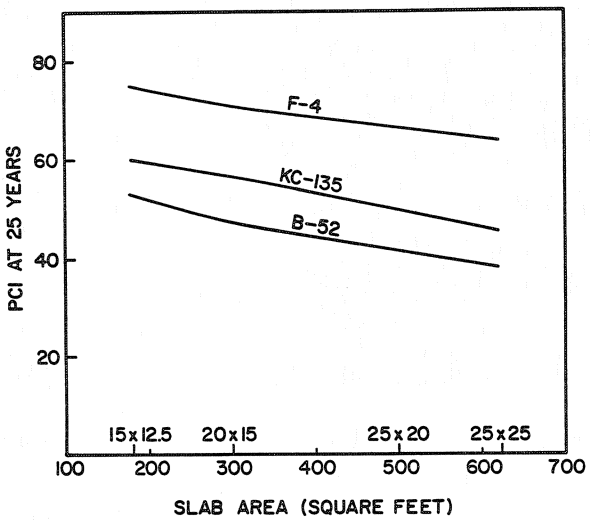


Figure 8. Influence of slab size on the PCI after 25 years of service.



Application to Design

The predictive equation 2 can be used to estimate the consequences of M&R decisions. The distress data measured during the condition survey can also be used to help design a concrete overlay.

The following typical pavement feature was used to illustrate the design application of equation 2.

AGE = 15 years
PCI = 75 (existing pavement)
SLAB = 10 inches
K = 200 pounds/cubic inch
JSL = 15 feet
JSS = 12.5 feet
MR = 700 psi
ACWGT = 60 kips (fighter)
PATCH = 0%
SR = 0%
FI = 0 degree days below 32°F
TEMP = 55°F

1. If routine maintenance were continued as in previous years, when would the pavement require rehabilitation? Assume that rehabilitation is needed when the PCI = 40.

First calculate the FAT:

$$FAT = \frac{\text{interior stress}}{\text{modulus of rupture}} \times 100 = \frac{320 \times 100}{700} = 46.$$

Adjust equation 2 to "fit" the specific age and PCI of the pavement:

$$PCI = 100 - AGE\,[0.01967FAT - 0.02408SR + 0.9419ACOL + 0.001051(JSL \times JSS) - 0.001775FI - 0.04066TEMP + 0.034748PATCH + 2.91238]C$$

where: PCI = 75, SR = 0, TEMP = 55, AGE = 15, FAT = 46, FI = 0, JSL = 15, PATCH = 0, ACOL = 0, JSS = 12.5, SLAB = 10

Thus, an adjustment factor, C = 0.937. (This factor must be used with equation 2 for this particular pavement feature, so that the PCI at 15 years is 75.)

Now using equation 2 and including C, the AGE when the PCI = 40 can be computed (PATCH = 5 percent, which is assumed for a PCI of 40):

$$40 = 100 - AGE\,[1.9517]\,0.937$$

AGE = 33 years.

Thus, the pavement is expected to need rehabilitation in approximately 33 - 15 = 18 years from the present.

2. If 15 percent of the slabs are replaced, when will the pavement need rehabilitation? Using SR = 15 percent, equation 2 is resolved for the time when PCI = 40:

$$40 = 75 - TIME\,[0.01967 \times 46 - 0.02408 \times 15 + 0.001051 \times 15 \times 12.5 - 0.04066 \times 55 + 0.034748 \times 5 + 2.91238]\,0.937$$

TIME = 23 years from present.

Thus, the slab replacement program extends the life of 23 - 18 = 5 years, or 28 percent. Note that 75 was used instead of 100 because this is the existing PCI of the pavement.

3. If the mission aircraft is changed from fighter (light load) to medium-load cargo with a gross aircraft load of 335 kips, when will the pavement need rehabilitation? First, calculate the FAT for the new aircraft:

$$FAT = \frac{650}{700} \times 100 = 93$$

Equation 2 is now solved for TIME until PCI = 40:

$$40 = 75 - TIME\,[0.01967 \times 93 - 0.02408 \times 0 + 0.9419 \times 0 + 0.001051 \times 15 \times 120.5 - 0.001775 \times 0 - 0.04066 \times 55 + 0.034748 \times 5 + 2.91238]\,0.937$$

TIME = 13 years from present.

Thus, with the medium-load traffic, the time until rehabilitation is now expected to be 13 years instead of 18 years, a life decrease of 28 percent.

4. If the mission aircraft was changed from the fighter to the C-141, with a gross weight of 300 kips, and a bonded concrete overlay of 5 inches was proposed, would this design last another 20 years until the PCI = 40?

The time until PCI = 40 is now computed as:

$$40 = 100 - AGE\,[0.01967 \times 51 + 0.001051 \times 15 \times 12.5 - 0.04066 \times 55 + 0.034748 \times 5 + 2.91238]\,0.937$$

AGE = 31 years from present.

Note that 100 is used because the PCI will be 100 after the overlay is placed. Thus, for the C-141, a bonded overlay of 5 inches will extend the pavement

life more than 20 years. Much additional work is needed to study this important aspect more adequately, so that life predictions of overlays can be conducted more accurately.

Concrete overlay design for airfields has largely used the empirical equations that the Corps of Engineers developed many years ago. Slab thickness is calculated for unbonded, partially bonded, and fully bonded concrete overlays by the following expression:

$$h_c = \left[h^p - C_r h_e^p \right]^{1/p} \quad (3)$$

where: h_c = required thickness of concrete overlay, inches
h = required single-slab thickness determined from design curves, inches
h_e = thickness of existing concrete slab, inches
C_r = condition factor of existing pavement (based on structural distress)
p = 2.0 for unbonded overlay
1.4 for partially bonded overlay
1.0 for fully bonded overlay

The condition factor, C_r, is selected after the condition survey. In the past, the value assigned to C_r has been largely left up to the designer with very little guidance provided.

A procedure was developed for estimating C_r based on measured structural distress data. The condition survey is conducted as described previously, and the PCI is calculated as usual; however, the only distresses considered are those associated with structural load. These include (1) corner breaks of any severity, (2) longitudinal, transverse, and diagonal cracks of medium to high severity, (3) large patches of load-associated failures, (4) pumping, (5) settlement or faulting of any severity, (6) shattered slabs of any severity, and (7) certain types of joint spalls believed to be load-associated (e.g., keyway failures).

A correlation between PCI (computed from structural distress only) and C_r is believed to exist. In fact, the only guidelines on selecting C_r are based on a subjective description of the pavement condition in terms of structural distress. These descriptions of condition can be approximately matched to the PCI structural rating as follows:

C_r = 1.0 for existing pavement in good condition; some minor cracking but no structural defects are evident. The PCI_{STR} (PCI based on load-associated distress) would equal 100 if there were no structural distress.

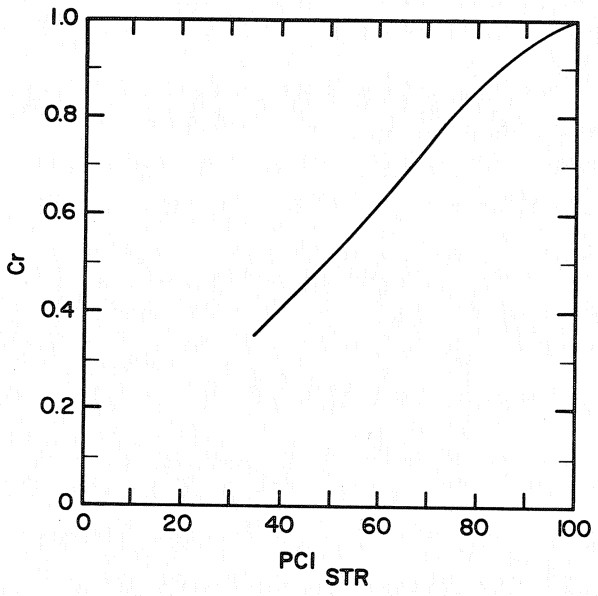
C_r = 0.75 for existing pavement containing initial corner cracks due to loading but no progressive cracking or joint failure. The PCI_{STR} could range between about 60 and 80 for this amount of distress.

C_r = 0.35 for existing pavement to poor structural condition, with badly cracked or crushed and faulted joints. The PCI_{STR} would be less than 40 for this condition.

Using this information and various analyses, the relationship shown in Figure 9 was developed; however, this relationship is tentative and needs further verification. No curve is given below a PCI of 35. Any pavement having a PCI of less than 35 must be extensively repaired to raise its PCI above 35 before an overlay can be considered. Figure 10 shows a sensitivity analysis for a set of given conditions.

For example, the existing pavement, which has a PCI of 50, would require a partially bonded overlay thickness of 10.5 inches; however, if the pavement were repaired so that the PCI after patching and slab replacement was 80, the overlay thickness required would be 8.7 inches, providing a savings of 1.8 inches of concrete. Thus, there are design cost tradeoffs between the repair of existing pavement before overlay and the overlay thickness required. However, certain distresses should always be repaired before the overlay is placed (e.g., shattered slabs of medium to high severity).

Figure 9. Approximate relationship between C_r and the PCI computed by only considering structural distresses.



Field Case Study

This section provides an example field application of procedures for pavement condition survey, evaluation, identification of feasible M&R alternatives, design and prediction of future performance of each alternative, and selection of the best alternatives.

Background

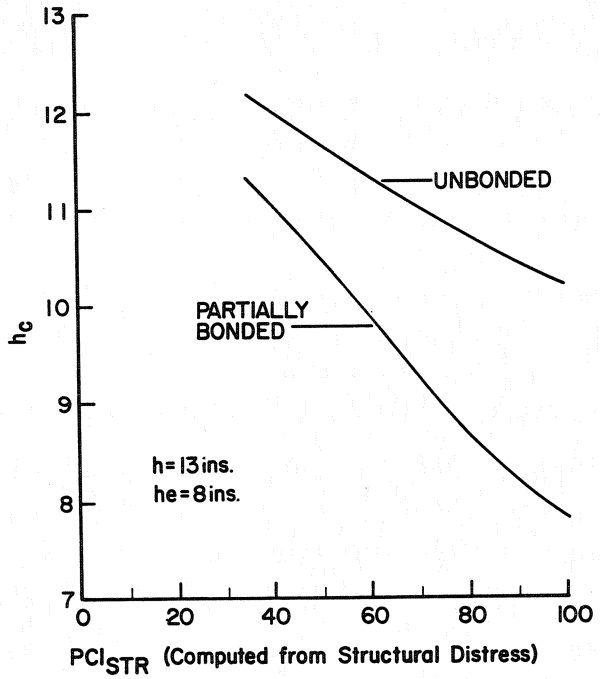
The pavement used in this example is a concrete apron located in Louisiana. The primary traffic using the pavement is B-52 aircraft. This pavement feature serves as the immediate access to the three B-52 maintenance hangars shown in Figure 11. The pavement was originally constructed in 1945 with 11 inches of plain-jointed PCC over a lean clay and silt having a k-value of 50 pounds per cubic inch. The pavement was overlaid in 1955 with an additional 8 inches of PCC.

Pavement Condition Survey

The concrete apron, which consisted of 48 sample units, was surveyed in March 1978. Each unit was surveyed and its PCI determined (see Figure 11).

Each sample unit consisted of 24 slabs, except for sample units 33 through 36, which each contained 18 slabs. Slab size was 12 1/2 x 15 feet. A random survey of several units revealed that the PCI ranged from 10 to 98; thus, the standard deviation was very high. Every sample unit was therefore surveyed individually in order to obtain accurate information for analyzing various M&R alternatives. Figure 12 is a representative photograph of the distress found in the apron. Figure 13 shows the key structural distresses found in the individual slabs.

Figure 10. Illustration of the influence of the existing pavement condition on the required concrete overlay thickness.



Identification of Feasible M&R Alternatives

The overall PCI of the feature was 35, which put the pavement in the major localized/overall rehabilitation zone (see Figure 3). The following four alternatives were considered feasible.

Alternative 1. Perform major localized repair (including slab replacement) as needed.

Alternative 2. Replace slabs in traffic area as outlined in Figure 13, and continue routine maintenance for the rest of the apron.

Alternative 3. Replace bad slabs and place a fully bonded PCC overlay.

Alternative 4. Replace bad slabs and place a partially bonded PCC overlay.

Asphalt overlay was not considered because of the large amount of oil spillage in the area.

Design and Prediction of Future Performance of Selected M&R Alternatives

Alternative 1: Localized Repair. Based on PCI calculations, it was determined that the pavement can be maintained in fair to good condition through an extensive program of slab replacement, patching, and crack/joint sealing. A 20-year life-cycle cost was determined (see Table 3), assuming that within 20 years, all slabs in the traffic area would be replaced.

Alternative 2: Replace Slabs in Traffic Area. As indicated earlier, the 11-inch pavement was originally constructed in 1945 and overlaid with 8 inches in 1955. This alternative calls for removing the concrete (19 inches deep), recompacting the subgrade, and placing new 19-inch concrete slabs. The performance of 19-inch reconstructed slabs was determined, using the PCI prediction model (equation 2) and is plotted in Figure 14.

The users and engineering staff determined that the predicted performance would be acceptable. It was also decided that the overlay alternatives be designed to provide the same performance.

Alternative 3: Fully Bonded Overlay. The overlay thickness of this alternative was designed to maintain an interior stress of 260 psi in order to insure a performance similar to that of alternative 2. To determine the overlay thickness, it was first necessary to determine the equivalent existing thickness. Field investigations (coring) showed that the 8-inch overlay placed in 1955 had become unbonded from the lower 11 inches. This finding was confirmed by determining the stress value that would cause the PCI to be 35 in 23 years (1955 to 1978). It was found that an 8-inch PCC over subgrade modulus K of 500 pci would produce this result. Therefore, the existing pavement was considered to have an effective thickness of 8 inches and a k-value of 500 pci. From the design charts, it was determined that approximately 15 inches PCC over k-value of 500 pci is required to produce an interior stress of 260 psi. The bonded overlay thickness was therefore determined to be 15 minus 8, or 7 inches. A major slab replacement program (approximately 20 percent of the slabs) was also determined to be necessary before the overlay.

Alternative 4: Partially Bonded Overlay. As determined in alternative 3, the existing pavement was considered to have an effective thickness of 8 inches and a k-value of 500 pci. The required thickness (for K = 500 pci) to produce a 260 psi was also determined in alternative 3 to be 15 inches. In order to determine the required overlay thickness, the C_r value (see equation 3) had to be determined first. To determine the C_r value, the PCI caused by structural distress was recomputed assuming the following: slab replacement of medium- and high-severity corner break and shattered slabs, replacement of slabs with high-severity cracks, and crack filling of slabs with medium-severity cracks. The PCI caused by structural distress after repair was computed to be 80. The C_r value was then determined from Figure 9 to be 0.85.

The required overlay thickness was determined using equation 3 as follows:

$$h_c = [15^{1.4} - .85(8)^{1.4}]^{\frac{1}{1.4}} = 11 \text{ inches}$$

Figure 11. Pavement feature layout showing PCI for individual sample units.

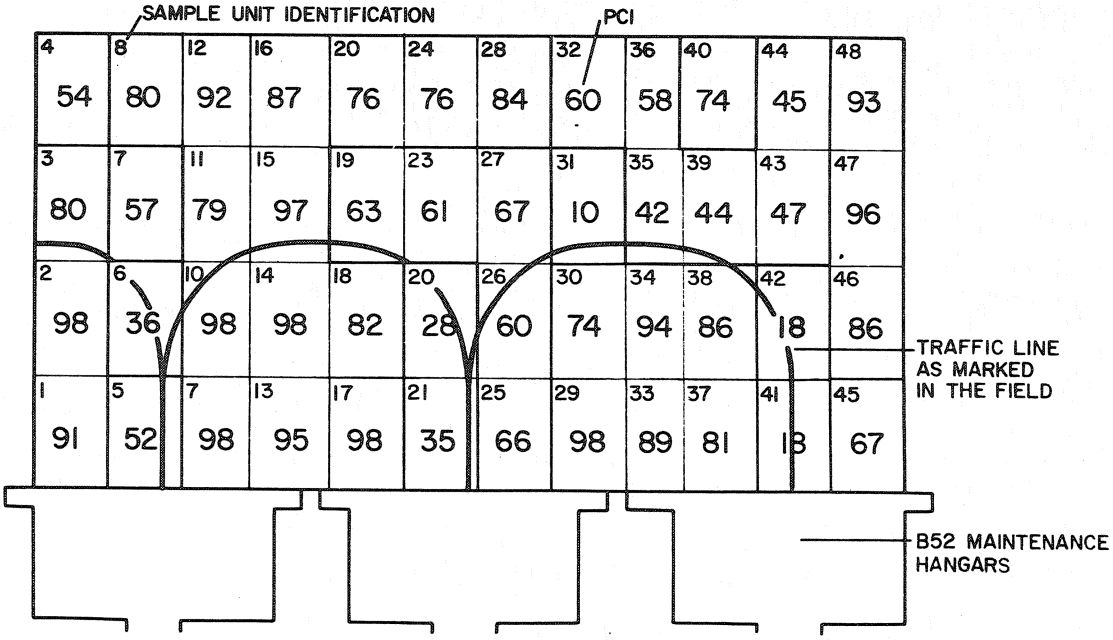


Figure 12. Pavement damage along traffic lines.

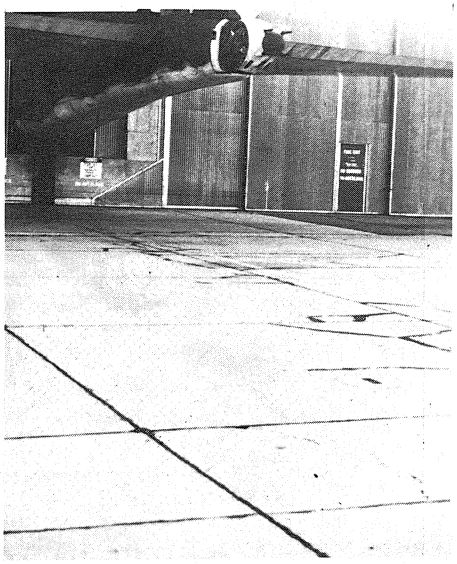


Table 3. Summary comparison of M&R alternatives (all costs are to the nearest $1000).

Alternative	1978 Cost	Total Present Disc. Cost	Salvage Value	Pres. Worth	Ratio to Most Econ. Altern.
1 (Localized)	138	546	279	267	5.1
(Reconstruct Traffic Area)	445	592	540	52	1.00
3 (Fully Bonded Overlay)	683	711	656	54	1.04
4 (Partially Bonded Overlay)	894	922	662	260	5.0

Selection of Best Alternative

Alternatives 2, 3, and 4 are all expected to provide the same performance (see Figure 14), since all were designed to produce the same slab interior stress.

A 20-year life-cycle cost analysis was also performed on all the alternatives. Table 3 shows the results of this analysis. Alternatives 2 and 3 were found to be the most economical. Alternative 2 was selected, since it did not require any additional drainage adjustments to the inside of the maintenance hangars.

Summary and Conclusions

This paper has described procedures for analyzing and designing rehabilitation alternatives for concrete airfield pavements. The procedures were developed as part of an overall U.S. Air Force program on pavement maintenance management. The following procedures were presented: pavement condition survey and rating, evaluation of existing condition and selection of feasible alternatives, and performance determination of M&R alternatives. A field case study was presented to illustrate the application of the procedures.

Figure 13. Slabs containing key structural distress and outline of newly defined features.

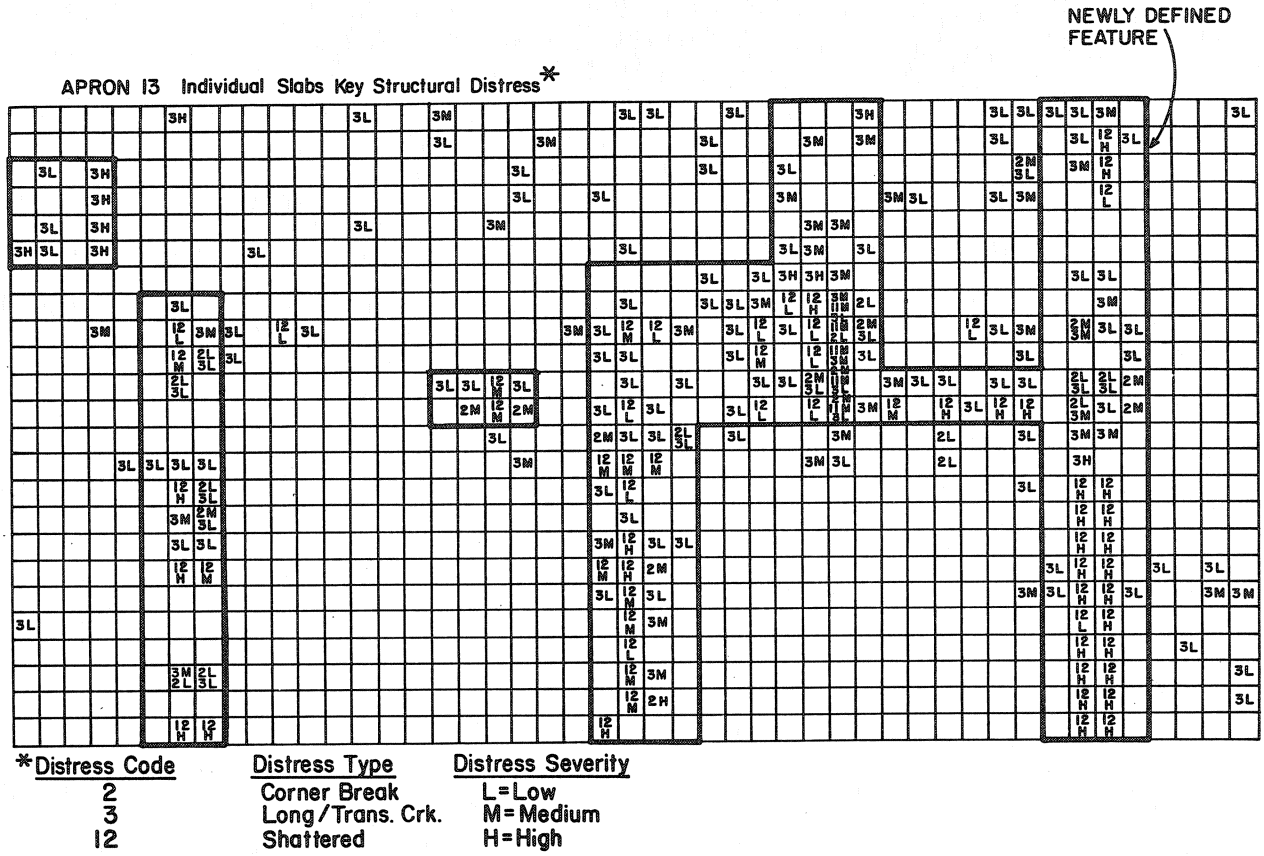
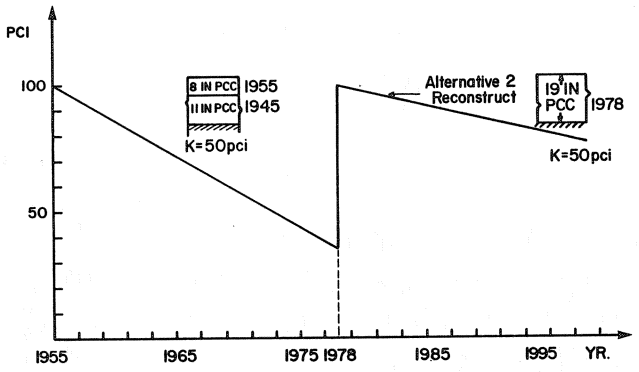


Figure 14. Performance prediction assuming reconstruction of traffic area.



Pavement performance used in the procedures is measured by the Pavement Condition Index (PCI). The PCI is used worldwide by the U.S. Air Force and several other airport agencies. Its value for rehabilitation analysis and design has been field-tested and proven over several years. Models have also been presented for predicting PCI as a function of traffic, climate, and pavement structure. These models are a very significant tool, not only as PCI prediction models, but also as design models based on performance. One major emphasis of this paper was to illustrate such an application. However, the models should be considered preliminary since they are currently being field-evaluated and improved.

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