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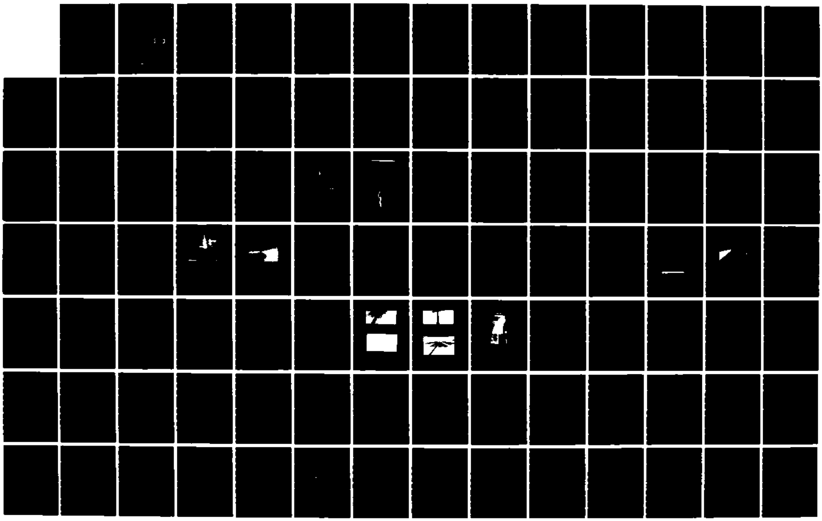

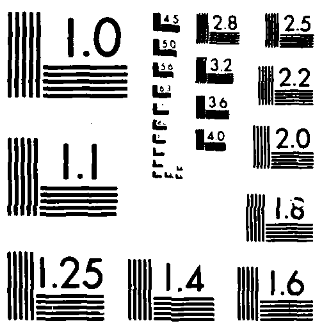

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Evaluation of the FAA Design Procedures for High Traffic Volume Pavements

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16. Abstract
The results of a field study of the performance of high traffic volume airfield pavements is presented. Both rigid (portland cement concrete) and flexible (asphalt concrete) pavements were included in the study. Condition surveys and nondestructive testing were performed on the pavement sections in order to measure present performance and estimate load-carrying capacity. Traffic and material properties data were also collected for each pavement section. These parameters were used to compare thicknesses obtained using the current FAA design procedure and the thicknesses of the existing sections in order to evaluate the adequacy of the current design procedures. In general it was found that the design procedures are adequate; however, further field study has been recommended in order to verify collected data.

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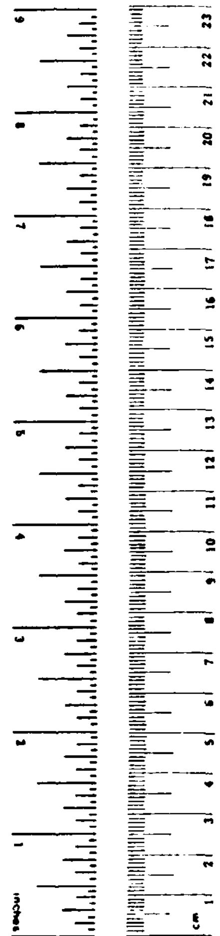
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

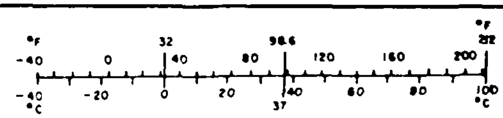
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This investigation was conducted by the Pavement Systems Division, US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., for the US Department of Transportation, Federal Aviation Administration, under Inter-agency Agreement Number DTFA01-81-Y-10555. The field work was performed from January 1983 to May 1984. Mr. H. Tomita was the technical representative for this project.

The nondestructive testing and condition survey work was performed by WES evaluation team. The team consisted of Messrs. S. D. Kohn, R. A. Bentsen, D. R. Alexander, D. D. Mathews, and Ms. M. D. Alexander, Pavement Systems Division (PSD), Geotechnical Laboratory (GL); Mr. S. W. Guy, Instrumentation Services Division; and Mr. L. B. Vanlandingham, Engineering and Construction Services Division.

Personnel of the PSD actively engaged in the preparation of this report were Messrs. Bentsen and Alexander under the supervision of Mr. R. W. Grau, Chief, Prototype Testing and Evaluation Unit, PSD; Mr. J. W. Hall, Jr., Chief, Engineering Investigations, Testing, and Validation Group, PSD; and Mr. H. H. Ulery, Jr., Chief, PSD. The work was under the general supervision of Dr. W. F. Marcuson III, Chief, GL, WES. This report was prepared by Mr. Kohn. Ms. Odell F. Allen, Publications and Graphic Arts Division, edited the report.

COL Allen F. Grum, USA, was Director of WES during the preparation and publication of this report. Dr. Robert W. Whalin was Technical Director.

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INTRODUCTION

BACKGROUND

Over the past two decades the average annual growth rate for United States domestic airline traffic in terms of passengers carried has been about 8 percent. Along with this increase in passengers, an increase in the speed, weight, and number of aircraft operating has been realized.[1] Traffic levels at several of the major hub airports are presently exceeding 100,000 total annual departures. For example, Dallas-Fort Worth Airport has averaged 157,000 annual departures from 1974 to 1983, and the Atlanta Hartsfield Airport has averaged 288,500 annual departures during the past 3 years.

This increase in traffic volume has caused concern over the adequacy of the Federal Aviation Administration's (FAA) pavement design curves. In 1974 the FAA's Advisory Circular, AC 150/5320-6B (FAA 6B), on pavement design and evaluation included design curves for pavements receiving up to 25,000 annual departures. A revised Advisory Circular, AC 150/5320-6C (FAA 6C) dated December 7, 1978, includes a method to extrapolate the thickness required for pavements receiving up to 200,000 annual departures. Any pavement section receiving over the 25,000 annual departure level has been defined as a high traffic volume pavement. This limit is set by the point at which one must use the extrapolation procedure outlined in the current Advisory Circular FAA 6C.

The FAA design procedures are based on accelerated traffic tests performed by the US Army Corps of Engineers.[2] The highest traffic levels achieved in the tests were approximately 30,000 coverages of a given gear load for rigid pavements and approximately 5,000 coverages for flexible pavements. Converting these coverages to passes of a dual-tandem gear, the rigid pavements have been tested to 60,000 passes (departures) and the flexible pavements have been tested to 10,000 passes. In terms of a 20-year design life, these pass levels would be converted to 3,000 and 500 annual departures, respectively. Thus, the need to evaluate the adequacy of the extrapolation procedures was deemed necessary. Also, it appears that data collected on any section receiving annual departures in excess of the 3,000 and 500 departure levels would be valuable information to assess the design procedure. This fact modifies the definition of high volume traffic in terms of assessing the design procedure, and as stated above, any section receiving traffic levels in excess of the original test sections becomes important data points in evaluating the procedure.

PURPOSE

The purpose of this study is to document the present condition of in-service pavements subjected to high volumes of traffic, evaluate the structural capacity, and assess the adequacy of the present FAA design method. This report documents the findings of field surveys and nondestructive testing (NDT) performed on pavement sections at five major hub airports and presents the preliminary assessment of the FAA design method.

SCOPE

The study is limited to the analysis of flexible and rigid pavements which had not received overlays. No analysis was made regarding the adequacy of the current overlay design procedures. The preliminary results and recommendations for future research needed to fully analyze the design method are presented.

APPROACH

The basic approach of this study is as follows:

a. Selection of the airports to be included in the study.

b. Selection of the data to be collected at each site.

c. Data analysis and design comparison.

d. Compilation of the data and assessment of the adequacy of the current FAA design methods as presented in AC 150/5320-6C.

The pavement design sections obtained using the FAA 6C design procedure are 20-year design life pavements. In order to evaluate the design procedure, it would be ideal to find pavements that were 20 years old and assess their performance and compare their thicknesses to the design thicknesses using FAA 6C. However, this is not always possible. The pavements in this study ranged in age from 4 to 24 years. Pavements that were not 20 years old had to be analyzed considering their present performance and fatigue usage and extrapolate these values to the 20-year life.

DATA COLLECTION

SITE SELECTION

In order to select the sites for the study, a preliminary assessment of the traffic levels and general availability of pavement data at several sites was necessary. This was accomplished by using the questionnaire shown as Figure 1. The questionnaire was sent to the 26 airports listed in Table 1.

Because the primary purpose of the study was to evaluate pavements receiving over 25,000 annual departures, the first question of the survey was of prime importance. However, most responses to this question simply indicated the total number of annual departures. This necessitated an estimation of the traffic distribution at each airport in order to determine the locations having high traffic volumes. The remaining questions addressed the general availability of pavement data. All respondents indicated that traffic and construction data were available.

Based on the estimated traffic levels, seven preliminary sites were chosen from which five were selected for the study. The selection of five airports was based on the fiscal resources available for the project. It was thought, however, that this number would provide enough pavement sections for the preliminary analysis. The seven sites chosen for preliminary interviews were as follows:

a. Dallas-Fort Worth.

b. William B. Hartsfield-Atlanta.

c. John F. Kennedy International-New York.

d. New York La Guardia.

e. Phoenix Sky Harbor.

QUESTIONNAIRE

1. Are any of your runway, taxiway, and parking apron pavements being subjected to air carrier traffic levels in excess of:

   25,000 annual departures? Yes _____ No _____

   50,000 annual departures? Yes _____ No _____

   100,000 annual departures? Yes _____ No _____

   150,000 annual departures? Yes _____ No _____

   200,000 annual departures? Yes _____ No _____

2. Do these pavements consist of:

   Asphaltic concrete surfaces? Yes _____ No _____

   Portland cement concrete surfaces? Yes _____ No _____

3. Are traffic history data (types and frequency of aircraft movements) available? Yes _____ No _____

4. Is current traffic data being recorded? Yes _____ No _____

5. Is construction history of these pavements (construction dates, plans, and drawings, etc.) available? Yes _____ No _____

6. Are maintenance records available showing types of maintenance and when maintenance was performed? Yes _____ No _____

7. Have recent pavement evaluations been performed indicating load-carrying capacity and/or remaining life of these pavements? Yes _____ No _____

8. Would the general appearance be rated as:

   Excellent? Yes _____ No _____

   Good? Yes _____ No _____

   Fair? Yes _____ No _____

   Poor? Yes _____ No _____

9. If you have pavements and traffic levels that meet the needs of this project, would you be willing to participate by making selected portions of your pavements available for a performance monitoring program? (This program will not require disruption of traffic nor any type of destructive sampling or coring. Imposition to you and your staff will be minimal.)

   Yes _____ No _____

Airport name: ______________________________

Person who may be contacted for further information: ______________________________

Phone number of contact person: __________ ______________________________

Figure 1. Evaluation questionnaire

Table 1

Airports Receiving Questionaire

Port Authority of New York and New Jersey
Kennedy International
La Guardia
Newark
Chicago O'Hare
Phoenix Sky Harbor
Dallas-Fort Worth
Dallas Love Air Field
Houston Intercontinental
Los Angeles International
Tulsa International
Albuquerque International
New Orleans International
Miami International
William B. Hartsfield-Atlanta
Seattle-Tacoma International
Honolulu International
Boston Logan International
Detroit Metropolitan-Wayne County
Indianapolis International
Anchorage International
Lambert-St. Louis International
Stapleton (Denver) International
Washington National
Tampa International
Orlando International
San Francisco International

f. Detroit Metropolitan.

g. Seattle-Tacoma.

A preliminary visit was made to each of these sites, and the airport personnel were given a short briefing on the purpose of the project and a more detailed description of the data to be collected. Based on these preliminary visits, the following sites were selected for the study:

a. Dallas-Fort Worth.

b. William B. Hartsfield-Atlanta.

c. John F. Kennedy International-New York.

d. New York La Guardia.

e. Phoenix Sky Harbor.

The primary reason for selecting each of these sites was that the traffic levels and patterns were such that several original (not overlaid) pavement sections with high volume traffic were available at each location. This applied to all sites except Phoenix, which was selected because all pavement sections were conventional flexible pavements.

DATA SELECTION

At the same time the site selection process was being accomplished, determination of the field data to be collected was also accomplished. The main items of data to be collected at each site were as follows:

a. Construction data (materials thickness, strength, and physical properties).

b. Pavement condition (pavement condition index).

c. Traffic history.

d. Nondestructive test data (deflection basins, dynamic stiffness modulus (DSM), etc.).

In order to provide a guide for the collection of this field data, a booklet was developed which listed all the elements for possible collection. An example data book is contained in Appendix A. It was realized that all the data would not be available for each pavement section, but as much data as possible would be collected at each site.

The pavement condition data to be collected at each site consisted of performing a condition survey on each section using the Pavement Condition Index (PCI) method as outlined in Advisory Circular AC 150/5380-6. This method correlates very well with the pavement's structural integrity and surface operational condition.[11]

The nondestructive test (NDT) data collected at each site were obtained using the WES 16-kip* vibratory testing device. A standard test pattern was run on the rigid pavements; testing included center slab locations along with transverse and longitudinal joint locations. The tests on the flexible pavements were performed at 100-ft intervals along the centerline of the section and off-set distances on each side of the centerline.

PROBLEM AREAS IN DATA COLLECTION

In the preliminary interviews, it was found that the participants believed data were generally available concerning the construction of the pavements, but traffic data would only be available in terms of total annual departures. In regard to the traffic data, this was generally true. However, it was found that considerable portions of the pavement data were not available. The types of data not usually available were the as-built thicknesses of the pavement layers and in-place strength and/or materials properties.

* A table of factors for conversion of non - SI units of measurement to SI (metric) units is presented on page ii.

Thus, the pavement structure data were obtained from design documents and as-built drawings (when available). Some of the material properties were estimated from boring logs and general correlations. The traffic data for the individual pavement sections were determined based on traffic patterns estimated by airport operations and FAA air traffic control tower personnel. The traffic history, dating back to the oldest pavement section, was obtained from the finance office at each airport. The aircraft traffic mix for each airport was obtained from statistics compiled by the FAA and Civil Aeronautics Board (CAB).[3] These data (FAA and CAB) were also used to check the data obtained from the individual airports.

SUMMARY OF DATA

This section of the report presents a summary of the data collected at each airport. The physical property data for each airport summarize the material properties for each pavement layer. The data shown in this section represent the values used in the design of the pavement. These values were tabulated from either airport planning documents or engineering consultants reports regarding pavement design. Values for the in-place properties will be presented in the next section. The NDT data presented are the representative values selected for analyzing each section. The methodology used to select these properties is presented in Appendix B. The airports are referred to by the following abbreviations:

a. DFW - Dallas-Fort Worth.

b. ATL - William B. Hartsfield-Atlanta.

c. PHX - Phoenix Sky Harbor.

d. KIA - John F. Kennedy International.

e. LGA - New York La Guardia.

All pavement sections in the study were portions of primary taxiway pavements. No runway sections were obtained due to the length of time the section would be closed for the detailed condition survey and NDT.

Several sections of pavement were surveyed and tested at KIA and LGA; however, only four sections from KIA were used in this study. The remaining sections were either new construction or were overlaid. The data obtained on the overlaid sections have been compiled and will be reviewed for use in an FAA study (FAA agreement with WES DTFA01-81-Y-10523, Update Overlay Thickness Criteria) on the overlay design procedures. The data on the new construction sections will be kept for possible future surveys to monitor the performance of in-service pavements.

DALLAS-FORT WORTH

DFW was opened to air traffic in January 1974. Thus, all the pavement sections were approximately 9 years old at the time of this study. The original pavement design was for a 20-year life, and the design method used was a fatigue damage analysis. The pavements were all designed as jointed reinforced concrete slabs. The original design required doweled joints at 50-ft intervals. This was modified after placement of the first sections of pavement due to random cracks developing at the midpoint of the new slabs. The remaining pavements were constructed with doweled transverse joints at 50-ft intervals with sawed contraction joints at 25-ft intervals. The longitudinal joints were constructed as doweled (drilled and epoxied). The temperature steel in the slabs is approximately 0.07 percent. Slab thickness ranges from 15 to 18 in. All sections are supported on 9 in. of cement-treated base and 9 in. of lime-stabilized subgrade. The modulus of subgrade reaction, k , value on top of the cement-treated base was estimated to be 360 pci using elastic layer theory, and the k value on top of the lime-stabilized subgrade was estimated to be 127 pci from plate-bearing tests. These values are based on plate-bearing tests performed on test sections prior to construction.

Figure 2 is a layout of DFW with the location of the selected pavement sections shown. Each pavement section is a portion of taxiway pavement. These are the busiest sections of pavement on the airfield with the exception of the runways. Physical properties of the sections are summarized in Table 2. The properties presented are the values used in the design of the

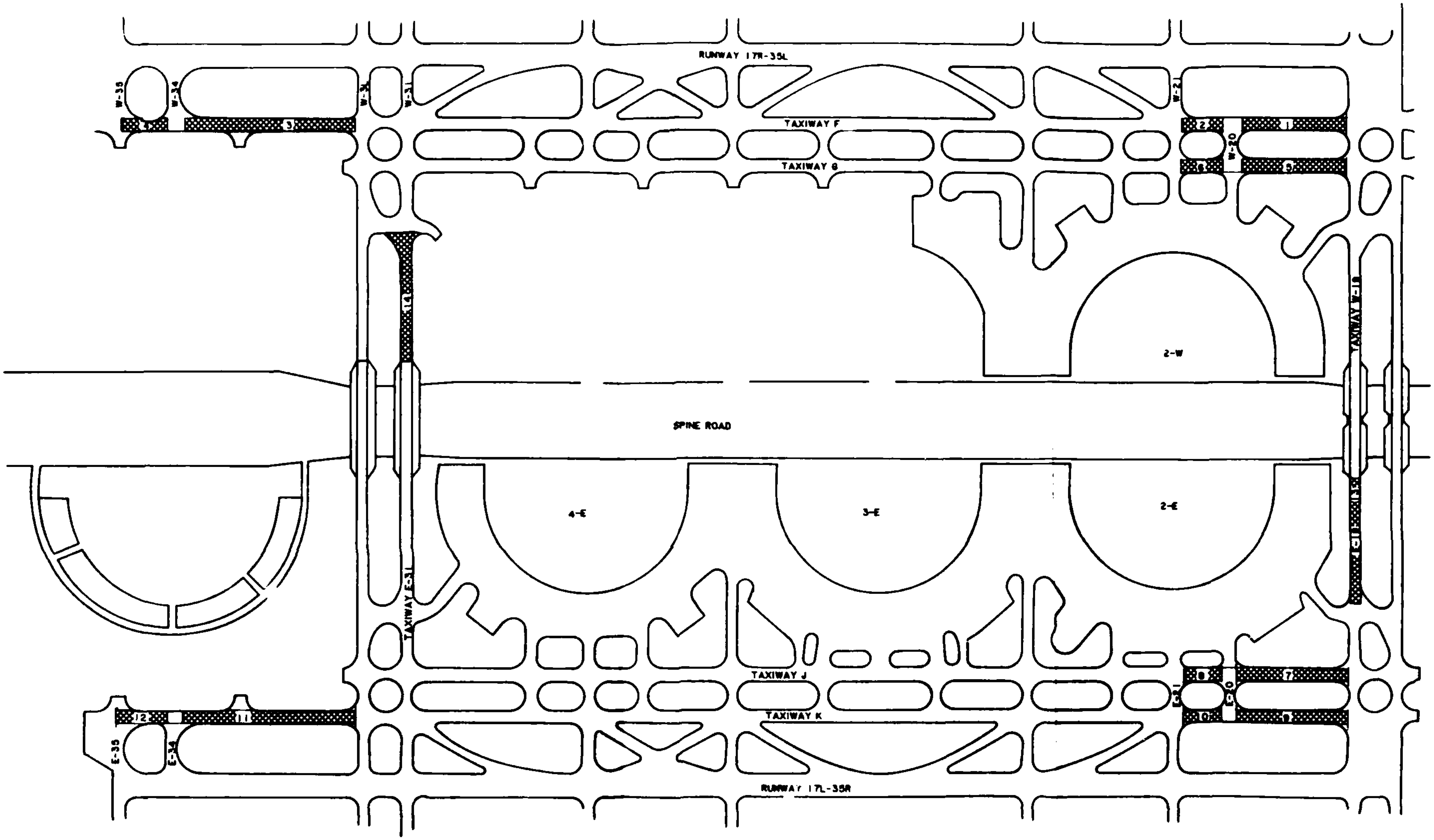

Figure 2. Layout of sections at Dallas-Fort Worth

13/14

SUMMARY OF PHYSICAL PROPERTY DATA

DALLAS-FORT WORTH

FACILITY					OVERLAY PAVEMENT			PAVEMENT			BASE				SUBBASE			SUBGRADE		
FEATURE	IDENTIFICATION	LENGTH (FT)	WIDTH (FT) *	GENERAL CONDITION PCI	THICKNESS (IN)	DESCRIPTION	FLEX STR (PSI)	THICKNESS (IN)	DESCRIPTION	FLEX STR (PSI) **	THICKNESS (IN)	DESCRIPTION	CBR+ %	K PSI/IN ++	THICKNESS (IN)	DESCRIPTION	CBR %	DESCRIPTION	CBR %	K PSI/IN ++
1	TW F between W-19 and W-20	1000	100	86				15	PCC 25' x 25'	680	9	Cement Treated Bases		360	9	Lime Stabilized Soil	100	Clay (CL-CH)		127
2	TW F between W-20 and W-21	500	100	94				15	PCC 25' x 25'	680	9	Cement Treated Bases		360	9	Lime Stabilized Soil	100	Clay (CL-CH)		127
3	TW F between W-32 and W-34	1750	100	96				16	PCC 25' x 25'	680	9	Cement Treated Bases		360		Lime Stabilized Soil	100	Clay (CL-CH)		127
4	TW F between W-34 and W-35	475	100	97				16	PCC 25' x 25'	680	9	Cement Treated Bases		360	9	Lime Stabilized Soil	100	Clay (CL-CH)		127
5	TW G between W-19 and W-20	1000	100	90				17	PCC 25' x 25'	680	9	Cement Treated Bases		360	9	Lime Stabilized Soil	100	Clay (CL-CH)		127
6	TW G between W-20 and W-21	500	100	89				17	PCC 25' x 25'	680	9	Cement Treated Bases		360	9	Lime Stabilized Soil	100	Clay (CL-CH)		127
7	TW J between E-19 and E-20	1000	100	72				17	PCC 25' x 25'	680	9	Cement Treated Bases		360	9	Lime Stabilized Soil	100	Clay (CL-CH)		127
8	TW J between E-20 and E-21	500	100	72				17	PCC 25' x 25'	680	9	Cement Treated Bases		360	9	Lime Stabilized Soil	100	Clay (CL-CH)		127
9	TW K between E-19 and E-20	1000	100	69				15	PCC 50' x 50'	680	9	Cement Treated Bases		360	9	Lime Stabilized Soil	100	Clay (CL-CH)		127

(Continued)

WES FORM 1 JAN 83 1000

* Center 50 ft used in PCI survey.
** Design flexural strength.
\+ California bearing ratio.
\++ Average 50 ft used in PCI survey.

pavement sections and are not from as-built construction or quality control data. Tables 3 and 4 summarize the PCI and NDT data. The traffic data are summarized in Tables 5 and 6.

The pavements at DFW were in very good to excellent condition. The average PCI for the 14 sections was 82.3 with a standard deviation of 10.5. The most predominant distresses were small patches and spalls. In the sections with the 50-ft joint spacing, a crack was generally found at the midpoint of the slab (25-ft). This is reflected in the lower PCI's of sections 9 and 10. Figure 3 shows some of the typical small patches, and Figures 4 and 5 show the cracking at the 25-ft midpoint in the 50-ft slabs.

Overall, there were no special conditions at DFW which would affect the evaluation of the pavements with the exception of sections 13 and 14. These two sections were both located on the approaches to the bridges used to connect the east and west side of the airport. Both sections have had major maintenance in the form of slab-jacking performed in localized areas. This maintenance was performed in areas where the fill over a drainage line had consolidated causing the slabs to settle and crack. Figures 6 and 7 show the major cracks present in these areas.

WILLIAM B. HARTSFIELD-ATLANTA

The locations of the pavement sections at ATL are shown in Figure 8. Table 7 summarizes the physical properties for each section. Tables 8 and 9 summarize the PCI and NDT data. Tables 10 and 11 summarize the traffic data for ATL.

The pavements at ATL were constructed approximately 4 years ago. All the pavements are rigid pavements with reinforcing steel. The temperature steel in the slabs is approximately 0.06 percent. The slabs in the sections

Table 3

PCI Summary, Dallas-Fort Worth

Section No.	Total No. of Sample Units	Average PCI	Standard Deviation	Percent Deduct Values Based on Distress Mechanism: Load	Environment	Other
1	4	86	7.9	0.0	12.4	87.6
2	2	94	0.7	0.0	28.4	7.6
3	7	96	2.6	0.0	5.7	43.0
4	2	97	0.0	0.0	75.5	24.5
5	4	90	2.0	8.3	17.8	73.9
6	2	89	0.0	0.0	19.5	80.5
7	4	72	6.9	71.3	6.0	22.7
8	2	72	4.2	61.4	5.7	32.9
9	4	81	2.2	64.2	6.0	29.8
10	2	72	7.1	86.9	4.9	8.2
11	7	78	11.7	58.8	6.9	34.3
12	2	85	8.5	17.0	13.6	69.4
13	4	80	10.7	39.4	7.3	53.3
14	4	73	26.1	44.9	4.4	50.7

Table 4

NDT Summary, Dallas-Fort Worth

Section No.	Age year	Geometric Average DSM kips/in.	Standard Deviation	Representative Basin, mils 0 in.	18 in.	36 in.	60 in.
1 & 2	9	6,214	644.9	2.3	1.6	1.5	1.2
3 & 4	9	6,527	621.5	2.3	1.8	1.6	1.3
5 & 6	9	6,484	1,078.2	2.1	1.5	1.4	1.2
7 & 8	9	5,989	662.9	2.3	1.7	1.5	1.2
9 & 10	9	6,266	703.7	2.3	1.7	1.6	1.3
11 & 12	9	5,981	662.1	2.3	1.8	1.7	1.5
13	9	5,893	591.4	2.4	1.6	1.4	1.2
14	9	4,893	1,373.8	2.8	2.3	2.2	1.9

Table 5

General Traffic Summary, Dallas-Fort Worth

Average Traffic Mix*		
Aircraft	Percent of Total Traffic	Maximum Gross Load, lb
B-727	77.8	190,500
DC-10	1.03	410,000
L-1011	1.8	409,000
B-707	1.0	327,000
B-747	0.8	710,000
DC-8	0.98	325,000
DC-9	13.2	98,000
CV-580	1.3	54,600
B-737	2.07	115,000

* Average annual departures (1974-1983) air carrier aircraft, 314,700.

Table 6

Equivalent Annual Departures of B-727 Aircraft,

Dallas-Fort Worth Airport

Aircraft	Fraction of Mix	Gear Factor	Wheel Load lb	Estimated Annual Departures	Equivalent Annual Departures
			Section No. 1		
B-727	.7780	1.00	45,244	5,368	5,368
DC-10	.0103	1.70	35,625	121	70
L-1011	.0180	1.70	35,625	211	116
B-707	.0100	1.70	33,240	117	59
B-747	.0080	1.70	35,625	94	56
DC-8	.0098	1.70	41,562	115	94
DC-9	.1320	1.00	25,650	911	169
CV-580	.0130	1.00	12,967	90	11
B-737	.0207	1.00	27,432	143	48
			TOTALS	6,900	5,992
			Section No. 2		
B-727	.7780	1.00	45,244	4,046	4,046
DC-10	.0103	1.70	35,625	91	55
L-1011	.0180	1.70	35,625	159	90
B-707	.0100	1.70	33,240	88	47
B-747	.0080	1.70	35,625	71	44
DC-8	.0098	1.70	41,562	87	72
DC-9	.1320	1.00	25,650	686	137
CV-580	.0130	1.00	12,967	68	10
B-737	.0207	1.00	27,432	108	38
			TOTALS	5,200	4,539
			Section No. 3		
B-727	.7780	1.00	45,244	36,021	36,021
DC-10	.0103	1.70	35,625	811	381
L-1011	.0180	1.70	35,625	1,417	626
B-707	.0100	1.70	33,240	787	304
B-747	.0080	1.70	35,625	630	305
DC-8	.0098	1.70	41,562	771	585

(Continued)

(Sheet 1 of 5)

Table 6 (Continued)

Aircraft	Fraction of Mix	Gear Factor	Wheel Load lb	Estimated Annual Departures	Equivalent Annual Departures
			Section No. 3 (Continued)		
DC-9	.1320	1.00	25,650	6,112	709
CV-580	.0130	1.00	12,967	602	31
B-737	.0207	1.00	27,432	958	210
			TOTALS	46,300	39,172
			Section No. 4		
B-727	.7780	1.00	45,244	32,443	32,443
DC-10	.0103	1.70	35,625	730	347
L-1011	.0180	1.70	35,625	1,276	570
B-707	.0100	1.70	33,240	709	278
B-747	.0080	1.70	35,625	567	278
DC-8	.0098	1.70	41,562	695	529
DC-9	.1320	1.00	25,650	5,504	655
CV-580	.0130	1.00	12,967	542	29
B-737	.0207	1.00	27,432	863	193
			TOTALS	41,700	35,322
			Section No. 5		
B-727	.7780	1.00	45,244	1,400	1,400
DC-10	.0103	1.70	35,625	32	21
L-1011	.0180	1.70	35,625	55	35
B-707	.0100	1.70	33,240	31	19
B-747	.0080	1.70	35,625	24	17
DC-8	.0098	1.70	41,562	30	26
DC-9	.1320	1.00	25,650	238	62
CV-580	.0130	1.00	12,967	23	5
B-737	.0207	1.00	27,432	37	17
			TOTALS	1,800	1,602
			Section No. 6		
B-727	.7780	1.00	45,244	2,645	2,645
DC-10	.0103	1.70	35,625	60	38
L-1011	.0180	1.70	35,625	104	62

(Continued)

(Sheet 2 of 5)

Table 6 (Continued)

Aircraft	Fraction of Mix	Gear Factor	Wheel Load lb	Estimated Annual Departures	Equivalent Annual Departures
			Section No. 6 (Continued)		
B-707	.0100	1.70	33,240	58	32
B-747	.0080	1.70	35,625	46	30
DC-8	.0098	1.70	41,562	57	48
DC-9	.1320	1.00	25,650	449	99
CV-580	.0130	1.00	12,967	44	8
B-737	.0207	1.00	27,432	70	27
			TOTALS	3,400	2,989
			Sections No. 7 & 8		
B-727	.7780	1.00	45,244	82,857	82,857
DC-10	.0103	1.70	35,625	1,865	798
L-1011	.0180	1.70	35,625	3,259	1,310
B-707	.0100	1.70	33,240	1,811	620
B-747	.0080	1.70	35,625	1,448	638
DC-8	.0098	1.70	41,562	1,774	1,300
DC-9	.1320	1.00	25,650	14,058	1,328
CV-580	.0130	1.00	12,967	1,385	48
B-737	.0207	1.00	27,432	2,205	401
			TOTALS	106,500	89,301
			Sections No. 9 & 10		
B-727	.7780	1.00	45,244	67,997	67,997
DC-10	.0103	1.70	35,625	1,530	670
L-1011	.0180	1.70	35,625	2,674	1,099
B-707	.0100	1.70	33,240	1,486	523
B-747	.0080	1.70	35,625	1,189	535
DC-8	.0098	1.70	41,562	1,456	1,076
DC-9	.1320	1.00	25,650	11,537	1,144
CV-580	.0130	1.00	12,967	1,136	43
B-737	.0207	1.00	27,432	1,809	344
			TOTALS	87,400	73,433

(Continued)

(Sheet 3 of 5)

Table 6 (Continued)

Aircraft	Fraction of Mix	Gear Factor	Wheel Load lb	Estimated Annual Departures	Equivalent Annual Departures
			Section No. 11		
B-727	.7780	1.00	45,244	49,014	49,014
DC-10	.0103	1.70	35,625	1,103	501
L-1011	.0180	1.70	35,625	1,928	822
B-707	.0100	1.70	33,240	1,071	395
B-747	.0080	1.70	35,625	857	400
DC-8	.0098	1.70	41,562	1,050	786
DC-9	.1320	1.00	25,650	8,316	894
CV-580	.0130	1.00	12,967	819	36
B-737	.0207	1.00	27,432	1,304	267
			TOTALS	63,000	53,116
			Section No. 12		
B-727	.7780	1.00	45,244	39,056	39,056
DC-10	.0103	1.70	35,625	879	410
L-1011	.0180	1.70	35,625	1,536	672
B-707	.0100	1.70	33,240	853	325
B-747	.0080	1.70	35,625	683	327
DC-8	.0098	1.70	41,562	836	632
DC-9	.1320	1.00	25,650	6,626	754
CV-580	.0130	1.00	12,967	653	32
B-737	.0207	1.00	27,432	1,039	223
			TOTALS	50,200	42,432
			Section No. 13		
B-727	.7780	1.00	45,244	32,365	32,365
DC-10	.0103	1.70	35,625	728	347
L-1011	.0180	1.70	35,625	1,273	569
B-707	.0100	1.70	33,240	707	277
B-747	.0080	1.70	35,625	566	277
DC-8	.0098	1.70	41,562	693	528
DC-9	.1320	1.00	25,650	5,491	654
CV-580	.0130	1.00	12,967	541	29
B-737	.0207	1.00	27,432	861	193
			TOTALS	41,600	35,239

(Continued)

(Sheet 4 of 5)

Table 6 (Concluded)

Aircraft	Fraction of Mix	Gear Factor	Wheel Load lb	Estimated Annual Departures	Equivalent Annual Departures
			Section No. 14		
B-727	.7780	1.00	45,244	60,139	60,139
DC-10	.0103	1.70	35,625	1,354	601
L-1011	.0180	1.70	35,625	2,365	986
B-707	.0100	1.70	33,240	1,314	471
B-747	.0080	1.70	35,625	1,051	480
DC-8	.0098	1.70	41,562	1,288	956
DC-9	.1320	1.00	25,650	10,204	1,043
CV-580	.0130	1.00	12,967	1,005	40
B-737	.0207	1.00	27,432	1,600	313
			TOTALS	77,300	65,030

(Sheet 5 of 5)

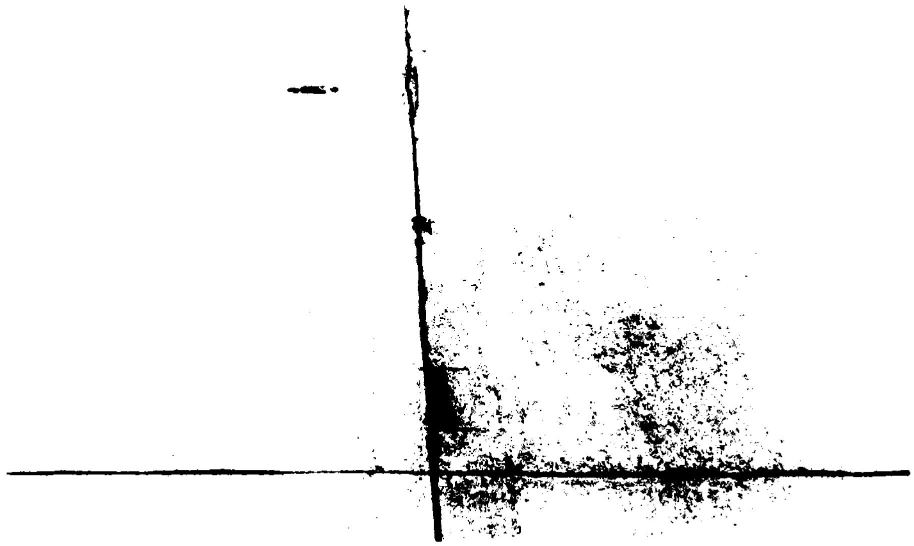

Figure 3. Typical small patches along the joints

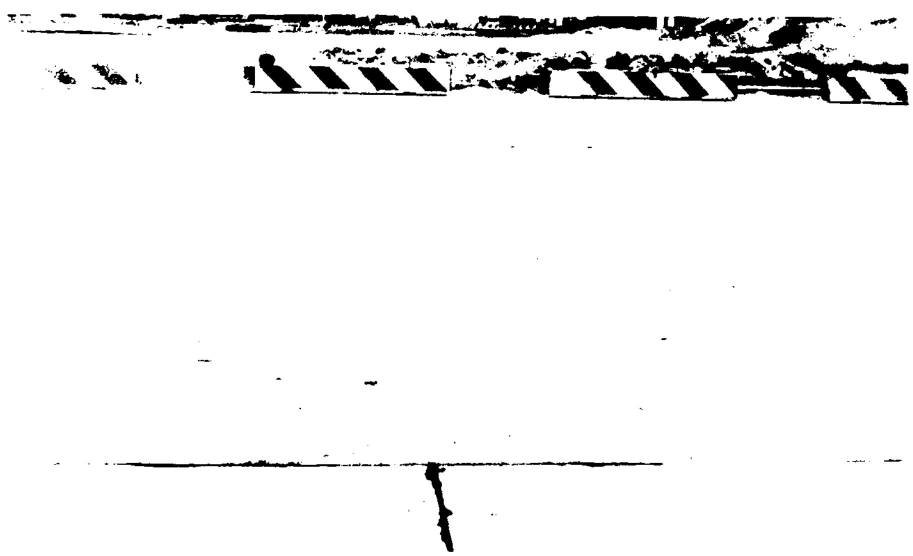

Figure 4. Shrinkage (contraction) crack in section 10

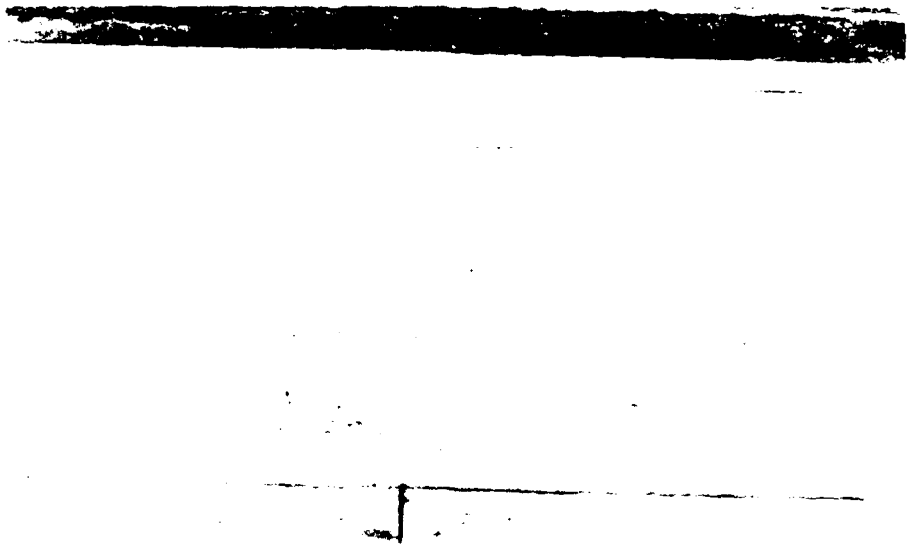

Figure 5. Contraction crack in section 9
(Note: Near slab sawed at 25-foot midpoint)

Figure 6. Medium-severity cracking in
section 14

Figure 7. High-severity cracking in section 13

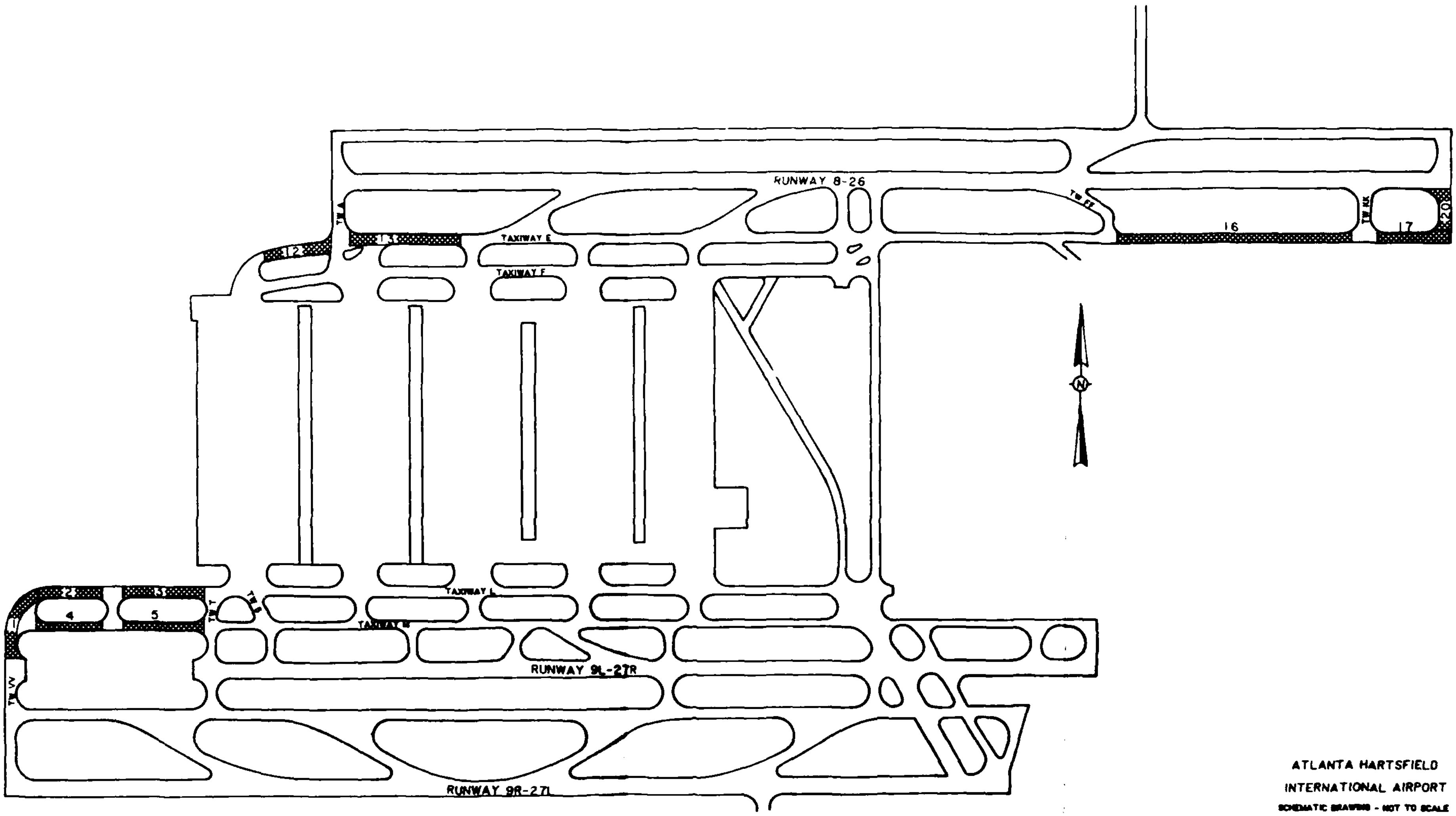

Figure 8. Layout of sections at William B. Hartsfield-Atlanta

SUMMARY OF PHYSICAL PROPERTY DATA

FACILITY					OVERLAY PAVEMENT			PAVEMENT			BASE				SUBBASE			SUBGRADE		
FEATURES	IDENTIFICATION	LENGTH (FT)	WIDTH (FT)	GENERAL CONDITION PCI	THICKNESS (IN)	DESCRIPTION	FLEX STR (PSI)	THICKNESS (IN)	DESCRIPTION	FLEX STR (PSI)	THICKNESS (IN)	DESCRIPTION	CBR %	K (PSI/IN)	THICKNESS (IN)	DESCRIPTION	CBR %	DESCRIPTION	CBR %	K (PSI/IN)
1	TW [illegible]V between [illegible]	750	[illegible]00*	8[illegible]				[illegible]	[illegible] 25' [illegible] 25'	71[illegible]	6	[illegible]		[illegible]	6	Soil Cement Subgrade	100	Sandy silt Silty sand		100
2	TW L between VV and V	500	100*	8[illegible]				16	PCC 25' x 25'	715	6	[illegible]		500	[illegible]	Soil Cement Subgrade	100	Sandy silt Silty sand		100
3	TW L between V and [illegible]	[illegible]0	[illegible]0*	76				16	PCC 25' x 25'	715	6	[illegible] Base		500	6	Soil Cement Subgrade	100	Sandy silt Silty sand		100
[illegible]	TW M between VV and V	525	75**	84				16	PCC 25' x 25'	71[illegible]	6	Cement Treated Base		50[illegible]	6	Soil Cement Subgrade	100	Sandy silt Silty sand		100
5	TW M between V and T	525	75**	82				16	PCC 25' x 25'	715	6	Cement Treated Base		500	6	Soil Cement Subgrade	100	Sandy silt Silty sand		100
12	TW E from TW A - [illegible]' west	500	100*	83				16	PCC 25' x 25'	715	6	Cement Treated Base		500	6	Soil Cement Subgrade	100	Sandy silt Silty sand		100
13	TW E from TW A - 1000' east	1000	100*	85				16	PCC 25' x 25'	715	6	Cement Treated Base		500	6	Soil Cement Subgrade	100	Sandy silt Silty sand		100
16	TW E between FF and KK	1825	75**	77				16	PCC 25' x 25'	715	6	Cement Treated Base		500	6	Soil Cement Subgrade	100	Sandy silt Silty sand		100
17	TW E between KK and K	525	75**	81				16	PCC 25' x 25'	715	6	Cement Treated Base		500	6	Soil Cement	100	Sandy silt Silty sand		100

WES FORM 1000 JAN 83

* Surveyed central 50 ft.
** Total width surveyed.

(Continued)

Table [illegible] (Concluded)

SUMMARY OF PHYSICAL PROPERTY DATA

FACILITY					OVERLAY PAVEMENT			PAVEMENT			BASE			SUBBASE			SUBGRADE	
FEATURE	IDENTIFICATION	LENGTH (FT)	WIDTH (FT)	GENERAL CONDITION PCI	THICKNESS (IN)	DESCRIPTION	FLEX STR (PSI)	THICKNESS (IN)	DESCRIPTION	FLEX STR (PSI)	THICKNESS (IN)	DESCRIPTION	CBR % / K PSI/IN	THICKNESS (IN)	DESCRIPTION	CBR %	DESCRIPTION	CBR % / K PSI/IN
20	TW K between E and 26	250	100*	80				16	PCC 25' x 25'	715	6	Cement Treated Base	K: 500	6	Soil Cement Subgrade	100	Sandy silt Silty sand	K: 100

WES FORM 1000 1 JAN 83

* Surveyed central 50 ft.

Table 8

PCI Summary, William B. Hartsfield-Atlanta

Section No.	Total No. of Sample Units	Average PCI	Standard Deviation	Percent Deduct Values Based on Distress Mechanism: Load	Environment	Other
1	3	88	1.5	0.0	0.0	100.0
2	2	80	5.7	0.0	0.0	100.0
3	3	76	7.2	0.0	0.0	100.0
4	3	84	5.5	0.0	0.0	100.0
5	3	82	4.4	0.0	0.0	100.0
12	2	83	11.3	0.0	0.0	100.0
13	4	85	5.9	0.0	0.0	100.0
16	6	77	4.5	0.0	6.8	93.2
17	3	81	0.99	6.2	0.0	93.8
20	1	80	---	0.0	0.0	100.0

Table 9

NDT Summary, William B. Hartsfield-Atlanta

Section No.	Age year	Geometric Average DSM kips/in.	Standard Deviation	Representative Basin, mils: 0 in.	18 in.	36 in.	60 in.
1	4	5,789	908	2.2	1.7	1.5	1.2
2 & 3	4	5,169	663	2.8	2.0	1.8	1.4
4 & 5	4	5,074	633	2.9	2.3	2.1	1.7
12 & 13	4	4,920	761	2.8	2.1	2.0	1.8
16 & 17	4	4,625	629	2.9	2.2	2.1	1.7
20	4	4,006	482	3.3	2.9	2.7	2.3

Table 10

General Traffic Summary, William B. Hartsfield-Atlanta

Average Traffic Mix*		
Aircraft	Percent of Total Traffic	Maximum Gross Load, lb
B-727	34.51	190,500
DC-9	39.46	98,000
C-1011	8.96	409,000
DC-8	3.99	325,000
B-737	2.76	115,000
A-300-200	2.70	364,000
B-757	2.41	221,000
DASH-7	2.19	44,000
B-767	1.80	302,000
DC-10	0.72	410,000
CV-580	0.28	54,600
B-747	0.14	710,000
TS-11	0.09	52,910

* Average annual departures (1980-1983) air carrier aircraft, 556, 365.

Table 11

Equivalent Annual Departures of B-727 Aircraft,

William B. Hartsfield-Atlanta

Aircraft	Fraction of Mix	Gear Factor	Wheel Load lb	Annual Departures	Equivalent Annual Departures
			Section No. 1		
B-727	.3500	1.00	45,244	23,933	23,933
DC-9	.3900	1.00	25,650	26,669	2,150
L-1011	.0890	1.70	35,625	10,346	3,652
DC-8	.0400	1.70	41,462	4,650	3,242
B-737	.0270	1.00	27,432	1,846	349
A-300	.0270	1.70	35,625	3,139	1,267
B-757	.0240	1.70	26,244	2,790	421
DASH-7	.0220	1.00	10,450	1,504	34
B-767	.0180	1.70	35,625	2,092	884
DC-10	.0072	1.70	35,625	837	392
CV-580	.0028	1.00	12,967	191	17
B-747	.0014	1.70	35,625	163	92
YS-11	.0009	1.00	12,827	62	9
			TOTALS	68,381	36,443
			Sections No. 2 & 3		
B-727	.3500	1.00	45,244	13,528	13,527
DC-9	.3900	1.00	25,650	15,073	1,399
L-1011	.0890	1.70	35,625	5,848	2,201
DC-8	.0400	1.70	41,462	2,628	1,878
B-737	.0270	1.00	27,432	1,044	224
A-300	.0270	1.70	35,625	1,774	764
B-757	.0240	1.70	26,244	1,577	273
DASH-7	.0220	1.00	10,450	850	26
B-767	.0180	1.70	35,625	1,183	533
DC-10	.0072	1.70	35,625	473	236
CV-580	.0028	1.00	12,967	108	12
B-747	.0014	1.70	35,625	92	55
YS-11	.0009	1.00	12,827	35	7
			TOTALS	38,650	21,134

(Continued)

(Sheet 1 of 3)

Table 11 (Continued)

Aircraft	Fraction of Mix	Gear Factor	Wheel Load lb	Annual Departures	Equivalent Annual Departures
			Sections No. 4 & 5		
B-727	.3500	1.00	45,244	13,528	13,527
DC-9	.3900	1.00	25,650	15,073	1,399
L-1011	.0890	1.70	35,625	5,848	2,201
DC-8	.0400	1.70	41,462	2,628	1,878
B-737	.0270	1.00	27,432	1,044	224
A-300	.0270	1.70	35,625	1,774	764
B-757	.0240	1.70	26,244	1,577	273
DASH-7	.0220	1.00	10,450	850	26
B-767	.0180	1.70	35,625	1,183	533
DC-10	.0072	1.70	35,625	473	236
CV-580	.0028	1.00	12,967	108	12
B-747	.0014	1.70	35,625	92	55
YS-11	.0009	1.00	12,827	35	7
			TOTALS	38,650	21,135
			Sections No. 12 and 13		
B-727	.3500	1.00	45,244	7,089	7,089
DC-9	.3900	1.00	25,650	7,889	860
L-1011	.0890	1.70	35,625	3,065	1,241
DC-8	.0400	1.70	41,462	1,377	1,012
B-737	.0270	1.00	27,432	547	135
A-300	.0270	1.70	35,625	930	430
B-757	.0240	1.70	26,244	826	167
DASH-7	.0220	1.00	10,450	446	19
B-767	.0180	1.70	35,625	620	300
DC-10	.0072	1.70	35,625	248	133
CV-580	.0028	1.00	12,967	57	9
B-747	.0014	1.70	35,625	48	31
YS-11	.0009	1.00	12,827	18	5
			TOTALS	20,255	11,431
			Sections No. 16 and 17		
B-727	.3500	1.00	45,244	28,357	28,357
DC-9	.3900	1.00	25,650	31,597	2,443
L-1011	.0890	1.70	35,625	12,258	4,245
DC-8	.0400	1.70	41,462	5,509	3,813

(Continued)

(Sheet 2 of 3)

Table 11 (Concluded)

Aircraft	Fraction of Mix	Gear Factor	Wheel Load lb	Estimated Annual Departures	Equivalent Annual Departures
			Sections No. 16 & 17 (Continued)		
B-737	.0270	1.00	27,432	2,188	399
A-300	.0270	1.70	35,625	3,719	1,473
B-757	.0240	1.70	26,244	3,306	479
DASH-7	.0220	1.00	10,450	1,782	37
B-767	.0180	1.70	35,625	2,479	1,028
DC-10	.0072	1.70	35,625	992	456
CV-580	.0028	1.00	12,967	227	18
B-747	.0014	1.70	35,625	193	107
YS-11	.0009	1.00	12,827	73	10
			TOTALS	81,019	42,864
			Section No. 20		
B-727	.3500	1.00	45,244	28,357	28,357
DC-9	.3900	1.00	25,650	31,597	2,443
L-1011	.0890	1.70	35,625	12,258	4,245
DC-8	.0400	1.70	41,462	5,509	3,813
B-737	.0270	1.00	27,432	2,188	399
A-300	.0270	1.70	35,625	3,719	1,473
B-757	.0240	1.70	26,244	3,306	479
DASH-7	.0220	1.00	10,450	1,782	37
B-767	.0180	1.70	35,625	2,479	1,028
DC-10	.0072	1.70	35,625	992	456
CV-580	.0028	1.00	12,967	227	18
B-747	.0014	1.70	35,625	193	107
YS-11	.0009	1.00	12,827	73	10
			TOTALS	81,019	42,864

(Sheet 3 of 3)

selected for this study have a transverse joint spacing of 25 ft. The longitudinal joints are keyed joints. The slab thickness is 16 in. The pavements are supported by 6 in. of cement-treated base resting on 6 in. of cement-stabilized soil. Plate-bearing tests on this material ranged from 405 to 1,000+ pci. The k value on top of the cement-treated material was estimated to be 500 pci, and the k value on top of the subgrade was estimated to be 180 pci.

It should be noted that the major distress found at ATL was spalling of the joints. This spalling was located on the longitudinal joints which are keyed. It was observed that several sections had already received patching to repair the spalling, and in some areas these patches were starting to spall again. The overall condition of the pavements was very good with an average PCI of 81.7 and a standard deviation of 3.8. Figures 9, 10, and 11 are representative photographs of the conditions at ATL.

PHOENIX SKY HARBOR

The PHX pavement sections are all conventional flexible pavements. The age of the sections varies from 2 to 16 years with a mean age of 8.5 years. The pavements generally consisted of an asphalt concrete (AC) surface layer, an aggregate base course, a select material subbase, and the natural subgrade. One section was constructed with a soil-cement subbase. The older pavements were designed using the FAA 6B, and the pavements constructed after 1978 used the FAA 6C design curves.

Figure 12 is a layout of the airport with the location of the pavement sections marked. Table 12 is a summary of the physical properties of the sections, and Tables 13 and 14 summarize the PCI and NDT data. Tables 15 and 16 present the traffic data.

Figure 9. High-severity spalling of the keyed joint

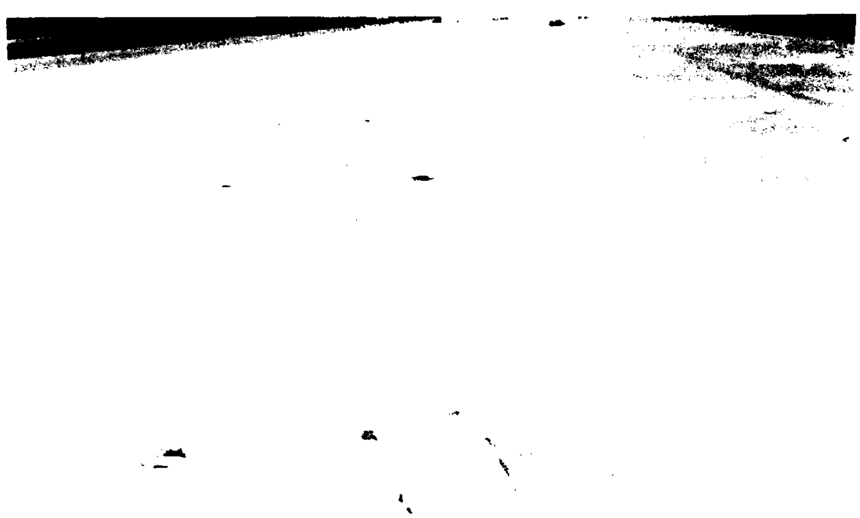

Figure 10. Low-severity patch where keyed joint has been repaired

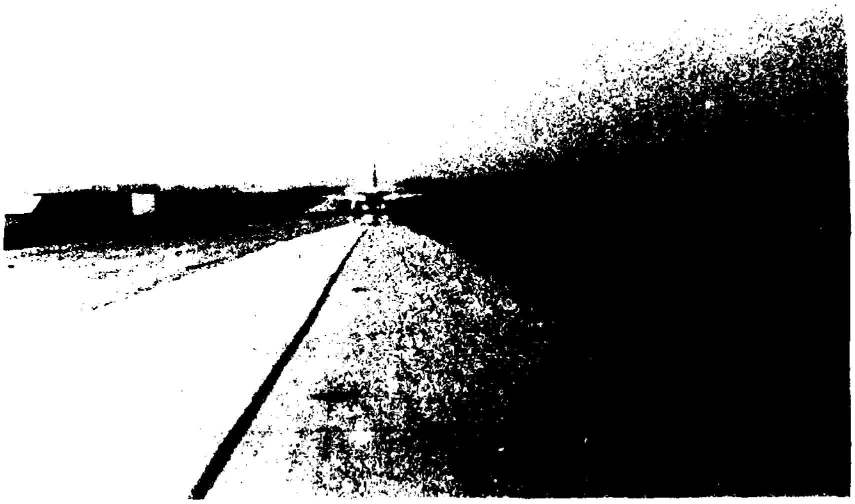

Figure 11. General view of section 16 (Note: The B-767's main gear rides the longitudinal joint)

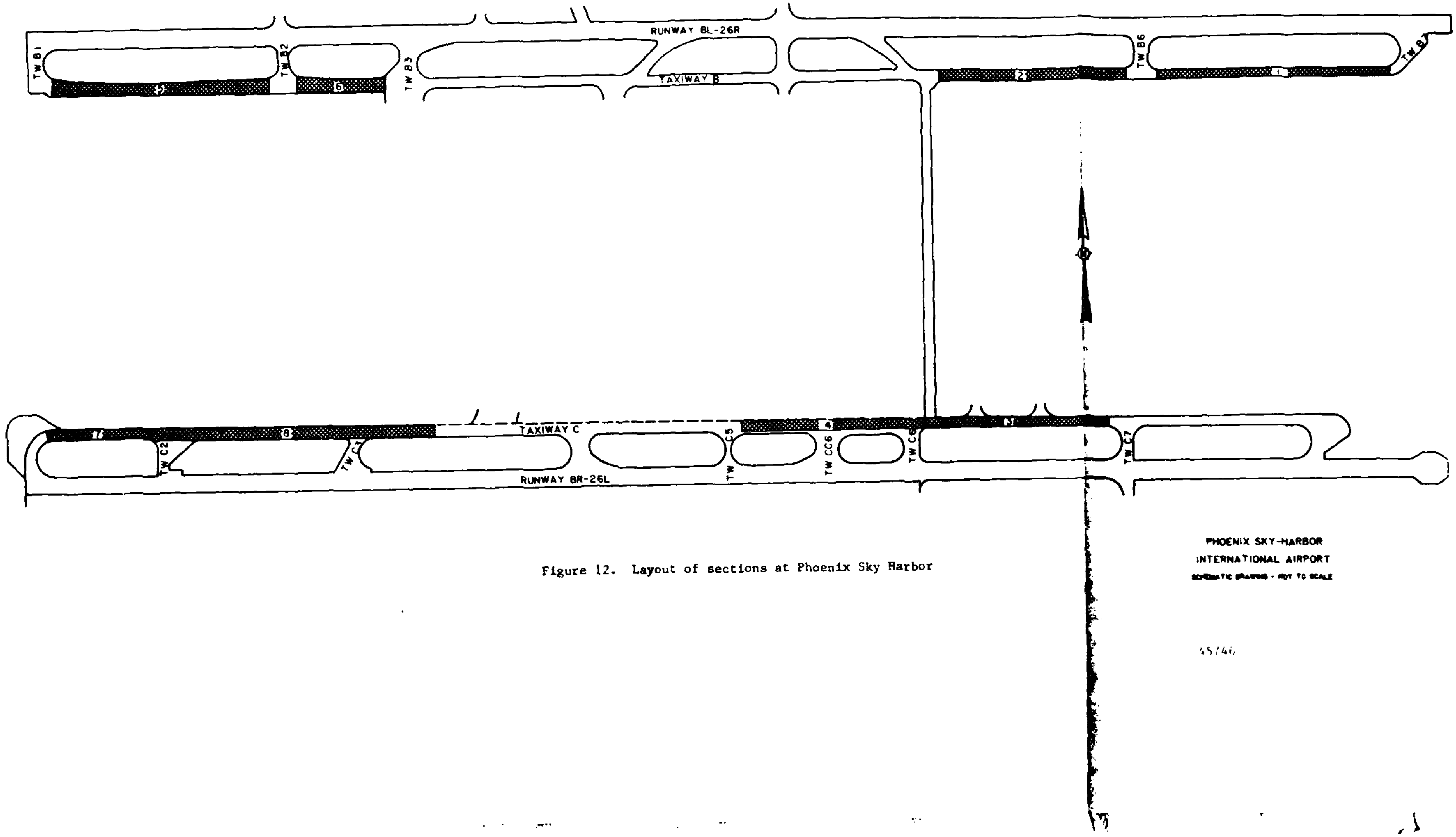

Figure 12. Layout of sections at Phoenix Sky Harbor

Table 12

SUMMARY OF PHYSICAL PROPERTY DATA

PHOENIX SKY HARBOR

FACILITY					OVERLAY PAVEMENT			PAVEMENT			BASE			SUBBASE			SUBGRADE	
FEATURE	IDENTIFICATION	LENGTH (FT)	WIDTH (FT) *	GENERAL CONDITION PCI	THICKNESS (IN)	DESCRIPTION	FLEX STR (PSI)	THICKNESS (IN)	DESCRIPTION	FLEX STR (PSI)	THICKNESS (IN)	DESCRIPTION	CBR % / K PSI/IN	THICKNESS (IN)	DESCRIPTION	CBR %	DESCRIPTION	CBR % / K PSI/IN
1	TW B from 26R - 1627' west	1627	75	29				6	AC		10.5	Crushed stone	100	24	Select river run	80	Silty sand Some gravel	15
2	TW B from B6 - TW X	1700	75	54				4	AC		11	Crushed stone	100	12 8	Select river run Soil cement	60	Silty sand Some gravel	15
3	TW C from 26L - C6	1676	75	65				6	AC		10	Crushed stone	100				Silty sand Some gravel	15
4	TW C from C6 - C5	1475	75	94	--	Slurry seal		4	AC		9	Crushed stone	100	6	Select river run	80	River run	40
5	TW B from B1 - B2	1713	75	43				6	AC		10.5	Crushed stone	100	24	Select river run	80	River run	40
6	TW B from B2 - B3	818	75	48				6	AC		10.5	Crushed stone	100	24	Select river run	60	River run	40
7	TW C from C1 - C2	909	75	70				5	AC		8	Bituminous base	--				River run	40
8	TW C from C2 - C4	1872	75	40				4	AC		9	Crushed stone	100	6	Select river run	80	River run	40

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* Center 50 ft surveyed for PCI and NDT

Table 13

PCI Summary, Phoenix Sky Harbor

Section No.	Total No. of Sample Units	Average PCI	Standard Deviation	Percent Deduct Values Based on Distress Mechanism: Load	Environment	Other
1	16	29	7.9	55.2	1.4	43.2
2	17	54	10.4	72.1	17.6	10.4
3	19	65	11.5	45.9	0.0	54.1
4	13	94	8.4	59.2	40.8	0.0
5	17	43	4.3	24.0	3.5	72.5
6	8	48	1.7	0.0	6.2	93.8
7	9	70	24.1	52.3	2.8	44.9
8	19	40	14.1	91.1	8.9	0.0

Table 14

NDT Summary, Phoenix Sky Harbor

Section No.	Age year	Geometric Average DSM kips/in.	Standard Deviation	Representative Basin, mils: 0 in.	18 in.	36 in.	60 in.
1	7	2,791	172	5.5	3.2	1.6	0.8
2	16	839	88	16.0	11.5	7.7	4.3
3	2	2,068	171	6.6	4.5	2.6	1.3
4	14	1,751	212	7.8	4.7	2.8	1.6
5	4	1,772	159	8.3	5.0	2.7	1.1
6	4	2,232	197	6.5	3.7	1.8	0.7
7	5	4,257	393	3.5	2.1	1.6	0.9
8	15	1,840	247	7.7	4.6	3.0	1.5

Table 15

General Traffic Summary, Phoenix Sky Harbor

Average Traffic Mix*		
Aircraft	Percent of Total Traffic	Maximum Gross Load, lb
B-727	62.0	190,500
B-737	8.0	115,000
B-707	4.0	327,000
DC-10	2.5	410,000
L-1011	2.0	409,000
DC-9	21.5	98,000

* Average annual departures (1967-1983) air carrier aircraft, 101, 839.

Table 16

Equivalent Annual Departures of B-727 Aircraft,

Phoenix Sky Harbor

Aircraft	Fraction of Mix	Gear Factor	Wheel Load lb	Estimated Annual Departures	Equivalent Annual Departures
			Sections No. 1 & 2		
B-727	.6200	1.00	45,244	7,577	7,577
B-737	.0800	1.00	26,312	978	191
B-707	.0400	1.70	33,240	831	318
DC-10	.0250	1.70	35,625	519	257
L-1011	.0200	1.70	35,625	416	211
DC-9	.2150	1.00	25,650	2,628	376
			TOTALS	12,221	8,929
			Sections No. 3 & 4		
B-727	.6200	1.00	45,244	17,679	17,679
B-737	.0800	1.00	26,312	2,281	364
B-707	.0400	1.70	33,240	1,939	658
DC-10	.0250	1.70	35,625	1,212	545
L-1011	.0200	1.70	35,625	970	447
DC-9	.2150	1.00	25,650	6,131	711
			TOTALS	28,515	20,403
			Sections No. 5 & 6		
B-727	.6200	1.00	45,244	11,365	11,365
B-737	.0800	1.00	26,312	1,466	260
B-707	.0400	1.70	33,240	1,247	450
DC-10	.0250	1.70	35,625	779	368
L-1011	.0200	1.70	35,625	623	302
DC-9	.2150	1.00	25,650	3,941	510
			TOTALS	18,331	13,255
			Sections No. 7 & 8		
B-727	.6200	1.00	45,244	26,494	26,494
B-737	.0800	1.00	26,312	3,419	495
B-707	.0400	1.70	33,240	2,906	930
DC-10	.0250	1.70	35,625	1,816	780
L-1011	.0200	1.70	35,625	1,453	640
DC-9	.2150	1.00	25,650	9,188	964
			TOTALS	42,733	30,303

The condition of the pavements at PHX ranged from poor to excellent with an average PCI of 55.4 and standard deviation of 20.5. This large range is due in part to the range in the age of the pavements at PHX (4 to 16 years). Two major problems were noted with the pavements at PHX. The first problem is that older pavements are exhibiting fatigue cracking of the AC surface. No rutting was noted in these areas; however, the cracking was of medium severity. This condition is most likely caused by the synergistic effects of load, aging of the asphaltic material, and the severe climate of Arizona (dramatic temperature variations between night and day). Figure 13 shows the alligator cracking in section 8. The second problem was that the newer pavements were observed to be bleeding excessively. This problem appeared to be caused by a higher than normal asphalt content in the surface material. This was orally reported by Phoenix materials engineering personnel. The AC content of the material was about 1 percent higher than normally used in the area. Figure 14 shows the rutting and bleeding occurring in section 1, and Figure 15 shows the bleeding in section 5.

JOHN F. KENNEDY INTERNATIONAL

Three of the four sections at KIA were flexible pavements with the fourth section being a rigid pavement. Two of the flexible pavements were constructed with an AC surface and a bituminous macadam base course. The third section consisted of an AC surface over a lime-cement-fly ash base course. The rigid pavement section was 13 in. of concrete over 6 in. of stone screenings. All the sections were built over a sand subgrade.

Figure 16 is a layout of KIA showing the location of the test sections. Table 17 summarizes the physical property data, and Tables 18 and 19 summarize the PCI and NDT data. Tables 20 and 21 present the traffic

Figure 13. Alligator (fatigue) cracking in section 8

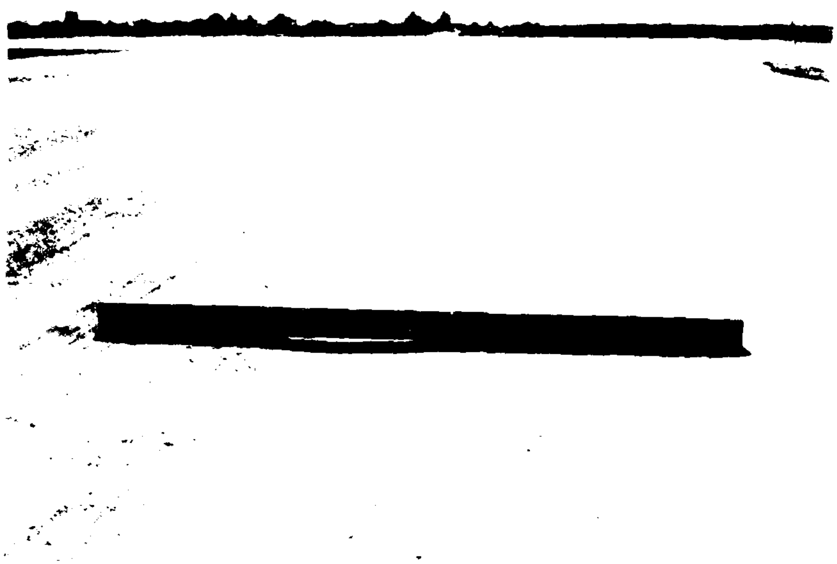

Figure 14. Rutting in section I
(Note: Bleeding on the surface)

Figure 15. Bleeding in section 5

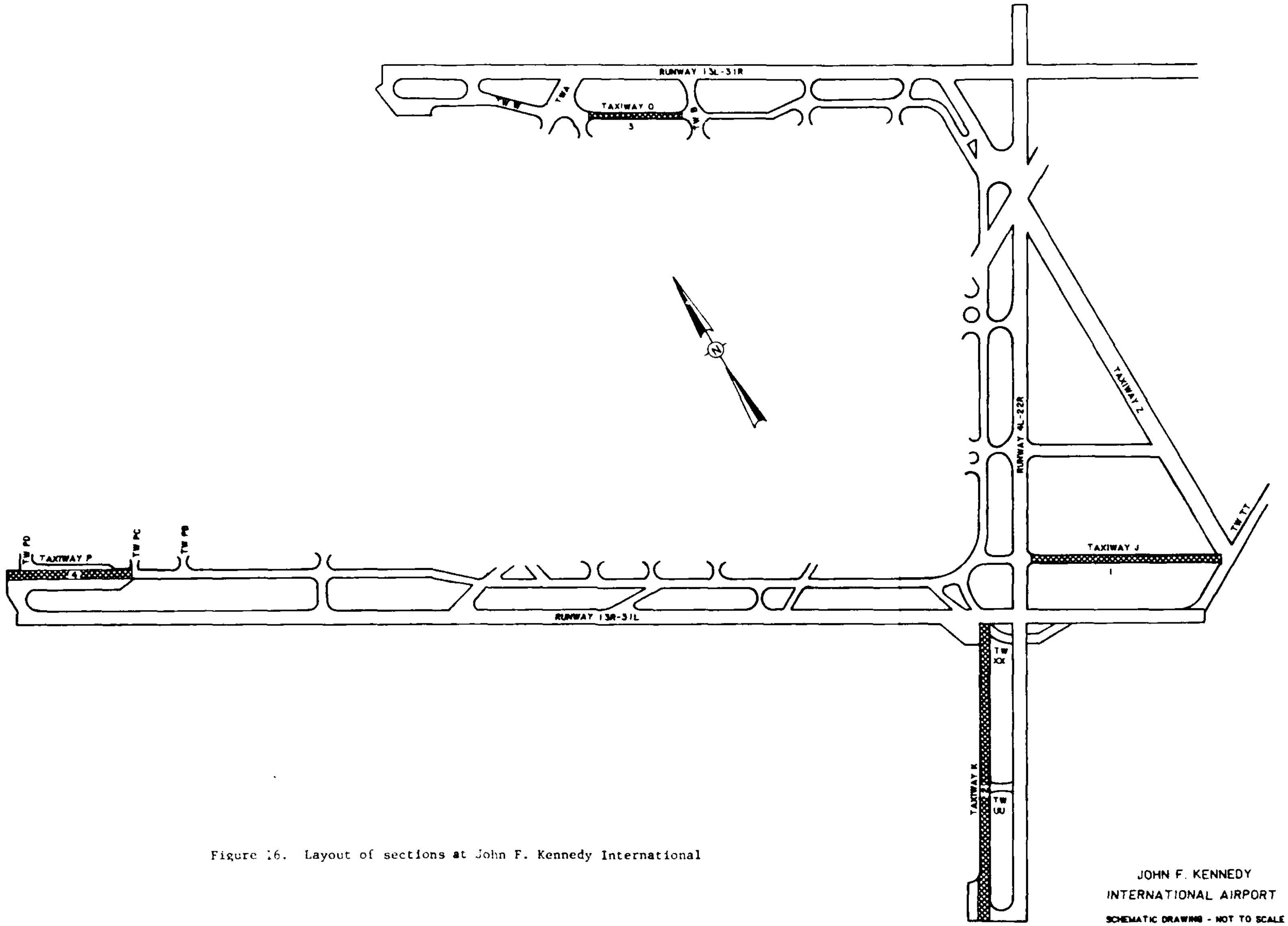

Figure 16. Layout of sections at John F. Kennedy International

Table 17

SUMMARY OF PHYSICAL PROPERTY DATA

JOHN F. KENNEDY INTERNATIONAL

FACILITY					OVERLAY PAVEMENT			PAVEMENT			BASE				SUBBASE			SUBGRADE		
FEATURE	IDENTIFICATION	LENGTH (FT)	WIDTH (FT)	GENERAL CONDITION PCI	THICKNESS (IN)	DESCRIPTION	FLEX STR (PSI)	THICKNESS (IN)	DESCRIPTION	FLEX STR (PSI)	THICKNESS (IN)	DESCRIPTION	CBR %	K PSI/IN	THICKNESS (IN)	DESCRIPTION	CBR %	DESCRIPTION	CBR %	K PSI/IN
1	TW J between TW C and 4L22R	2000	75	92				8	AC		17	P.M. macadam	100		13	Dense graded aggregate	80	Medium-density sand	25	
2	TW K between 13R31L and 4L22R	3400	75	50				5	AC		11	Penetrated stone course	80		6	Stone screenings	80	Medium-density sand	25	
3	TW O between TW A and TW B	1300	75	76				4	AC		8 8 8 6	Lime cement flyash	100					Medium-density sand	25	
4	TW P between TW PC and TW PD	800	75*	36				13	PCC 12-1/2'x20'	640	6	Stone screenings		300				Medium-density sand		300

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* Center 50 ft used in PCI survey.

Table 18

PCI Summary, John F. Kennedy International

Section No.	Total No. of Sample Units	Average PCI	Standard Deviation	Percent Decuct Values Based on Distress Mechanism Load	Environment	Other
1	11	92	7.1	67.5	14.4	18.1
2	25	50	9.9	69.4	27.6	3.0
3	12	76	3.2	0.0	97.9	2.1
4	8	36	8.7	3.0	0.0	97.0

Table 19

NDT Summary, John F. Kennedy International

Section No.	Age yr	Geometric Average DSM kips/in.	Standard Deviation	Representative Basin, mils 0 in.	18 in.	36 in.	60 in.
1	5	4308	539	3.3	2.4	2.0	1.4
2	20	1642	197	7.2	5.3	3.9	2.4
3	13	3451	606	3.8	2.9	2.5	1.9
4	22	2737	404	4.9	4.0	3.4	2.4

Table 20

General Traffic Summary, John F. Kennedy International

Aircraft	Percent of Total Traffic	Maximum Gross Load, lb
	Average Traffic Mix*	
B-727	29.	190,500
B-707	17.	327,000
B-747	16.	710,000
DC-10	7.	410,000
L-1011	7.	409,000
DC-8	5.	325,000
DC-9	5.	98,000

* Average annual departures air carrier aircraft, 100,000.

Table 21

Equivalent Annual Departures of Design Aircraft

John F. Kennedy International

Aircraft	Fraction of Mix	Gear Factor	Wheel Load lb	Estimated Annual Departures	Equivalent Annual Departures
			Section No. 1		
B-747*	.160	1.00	35,625	5,440	5,440
B-727	.290	0.60	45,244	5,916	17,818
DC-10	.070	1.00	35,625	2,380	2,380
L-1011	.070	1.00	35,625	2,380	2,380
B-707	.170	1.00	33,240	5,780	4,303
DC-9	.050	0.60	25,650	1,020	357
DC-8	.050	1.00	38,594	1,700	2,303
			TOTALS	34,000	34,983
			Section No. 2		
B-747*	.160	1.00	35,625	2,080	2,080
B-727	.290	0.60	45,244	2,262	6,030
DC-10	.070	1.00	35,625	910	910
L-1011	.070	1.00	35,625	910	910
B-707	.170	1.00	33,240	2,210	1,700
DC-9	.050	0.60	25,650	390	158
DC-8	.050	1.00	38,594	650	847
			TOTALS	13,000	12,635
			Section No. 3		
B-747*	.160	1.00	35,625	800	800
B-727	.290	0.60	45,244	870	2,054
DC-10	.070	1.00	35,625	350	350
L-1011	.070	1.00	35,625	350	350
B-707	.170	1.00	33,240	850	676
DC-9	.050	0.60	25,650	150	70
DC-8	.050	1.00	38,594	250	313
			TOTALS	5,000	4,613

(Continued)

* Design aircraft.

Table 21 (Concluded)

Aircraft	Fraction of Mix	Gear Factor	Wheel Load lb	Annual Departures	Equivalent Annual Departures
			Section No. 4		
B-727*	.290	1.00	45,244	4,785	4,785
B-747	.160	1.70	35,625	4,488	1,740
DC-10	.070	1.70	35,625	1,964	836
L-1011	.070	1.70	35,625	1,964	836
B-707	.170	1.70	33,240	4,769	1,422
DC-9	.050	1.00	25,650	825	157
DC-8	.050	1.70	38,594	1,403	806
			TOTALS	16,500	10,582

* Design aircraft.

data for KIA. All physical property data was obtained from design drawings provided by the Port Authority.

The average PCI for the three flexible pavements was 72.6 (very good) with a standard deviation of 21.9. The standard deviation is caused in part by the spread in the ages of the pavements (ages of 5, 20, and 13 years). The rigid pavement section had a PCI of 36 and was 22 years old. In general, the primary distress types in the flexible sections were random cracking and some small areas of fatigue cracking. These conditions are shown in Figures 17, 18, and 19. The rigid pavement was in poor condition primarily due to patching at the joints. Only four structural cracks were located in the section. Figures 20 and 21 are general photographs of this area.

Figure 17. General view of section 2

Figure 18. Small area of alligator cracking in section 2

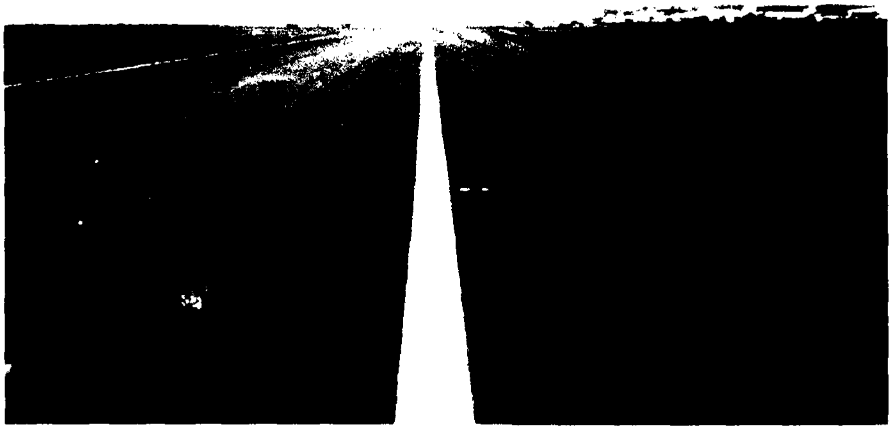


Figure 19. Overall view of section 3

Figure 20. Overall view of section 4
(Note: Patches continue all the way along the section)

Figure 21. Close-up of patches in section 4.

PAVEMENT EVALUATION AND DESIGN

This section of the report presents the results of the load-carrying capacity analysis using the NDT data and the DSM evaluation procedure.[4] Material properties based on the NDT data are also presented. Using both the design and evaluation (NDT) material properties, the FAA design procedures were used to obtain a thickness design for each pavement section. These sections were then compared to the existing pavement thicknesses. The analysis of each airport is presented separately.

In addition to the above analyses, a fatigue-damage analysis using Miner's hypothesis was performed on each section. For the rigid pavements the following fatigue equation[5] was used:

$$\log_{10} N_i = 16.61 - 17.61(R_i) \qquad (1)$$

where

N_i = allowable load applications to failure of i^{th} aircraft

R_i = ratio of edge stress of i^{th} aircraft to flexural strength

This equation represents a probability of failure of 24 percent. The edge stress was calculated using the H-51 program.[6] The maximum gross load of each aircraft was used to determine gear loads.

Two fatigue relationships were used in analyzing the flexible pavements. One was a model for allowable subgrade strain repetitions,[7] and the other was a stress-based AC model for allowable tensile stress based on laboratory beam samples at 77° F.[8] The equation used for the subgrade strain model was as follows:

$$N = 10{,}000\ (A/e_{sub})^B \qquad (2)$$

where

$A = 0.000247 + 0.000245 \log E_{subgrade}$

$B = 0.0658 (E_{subgrade})^{0.559}$

N = allowable repetitions

e = vertical subgrade strain, in./in.

E = elastic modulus of subgrade, psi

The tensile stress fatigue equation for the AC was as follows:

$$\log N = 10.812913 + 4.54 (\log(1/\sigma)) \qquad (3)$$

where

σ = radial tensile stress, psi

N = allowable repetitions

The calculation for the number of allowable load repetitions was based on a relationship derived from laboratory beam samples. This number was multiplied by a factor of 20 to convert to field fatigue performance.[12] This factor accounts for the crack propagation to the surface of the layer. No factors were added to account for rest periods between loads.

In order to evaluate the accumulated damage based on these parameters, it was necessary to evaluate the tensile stress in the bottom of the AC surface and the vertical strain at the top of the subgrade. The BISAR elastic layer computer program was used to calculate these values. The inputs for the modulus of elasticity for each layer were estimated based on the material type and back calculation using the NDT deflection basins. The back calculation procedure used was the CHEVDEF program developed by Bush.[13]

DALLAS-FORT WORTH

The pavements at DFW were evaluated using the B-727 as the design aircraft at a maximum gross weight of 191,000 lb. The k values determined from the NDT data were used in the evaluation. The evaluation data are summarized in Table 22. All sections with the exception of section 14 are rated at an allowable load of 191 kips and require no overlays. Section 14 was rated as having an allowable load of 185 kips. It would require an unbonded rigid overlay of 2 in. (5 in. is the minimum allowed) to be rated at the 191-kip load level. The evaluation data indicate the design was adequate for the existing conditions.

A thickness design was performed for each section using the FAA rigid pavement design procedure. The material properties used in the original design and the properties determined from the NDT tests were used as inputs to the design procedure. The design results are presented in Table 23. Using the design parameters and comparing the thickness required by the FAA method to the existing thicknesses, three sections (sections 9, 10, and 11) of pavement were found to be thinner than what the FAA 6C design procedure indicates is necessary. The design method was also used with the material properties obtained from the NDT tests. These results indicate that the existing pavements are generally thicker than necessary. However, it should be noted that the k values computed from the NDT are generally lower than the value assumed in the design, and that the modulus of rupture, MR, based on the NDT are generally higher than the MR assumed in design. The higher MR values are supported by quality control beam tests performed on the new runway and taxiway pavements. A sample of 20 beam tests indicated a mean flexural strength of 820 psi at 28 days. The mix design for these pavements was essentially the same as the pavements constructed in 1973. These higher MR values are the controlling parameters of the thickness design based on the NDT data which results in the thinner pavement sections.

Table 22

Pavement Evaluation Data, Dallas-Fort Worth

Section No.	Age year	Equivalent Annual Departures*	DSM kips/in.	k NDT pci	Allowable Gross Load kips	Overlay** in.
1	9	5,992	6,214	229	191	0
2	9	4,539	6,214	229	191	0
3	9	39,172	6,527	305	191	0
4	9	35,322	6,527	305	191	0
5	9	1,602	6,484	177	191	0
6	9	2,989	6,484	177	191	0
7	9	89,301	5,989	415	191	0
8	9	89,301	5,989	415	191	0
9	9	73,433	6,266	199	191	0
10	9	73,433	6,266	199	191	0
11	9	53,116	5,981	127	191	0
12	9	42,432	5,981	127	191	0
13	9	35,239	5,893	324	191	0
14	9	65,030	4,893	92	185	2

* Design aircraft, B-727.
** PCC overlay is required to extend life 20 years (minimum of 5 in. required).

Table 23

Pavement Design Data, Dallas-Fort Worth

			Required Design Thickness					
			NDT Properties			Design Properties		
Section No.	Existing Thickness in.	Equivalent Annual Departures*	k pci	MR psi	Thickness in.	k pci	MR psi	Thickness in.
1	15.0	5,992	229	900	12.0	360	680	14.0
2	15.0	4,539	229	900	12.0	360	680	14.0
3	16.0	39,172	305	900	13.0	360	680	16.0
4	16.0	35,322	305	900	13.0	360	680	16.0
5	17.0	1,602	177	900	12.0	360	680	13.0
6	17.0	2,989	177	900	12.0	360	680	14.0
7	17.0	89,301	415	885	13.0	360	680	17.0
8	17.0	89,301	415	885	13.0	360	680	17.0
9	15.0	73,433	199	900	15.0	360	680	17.0
10	15.0	73,433	199	900	15.0	360	680	17.0
11	16.0	53,116	127	900	15.0	360	680	17.0
12	16.0	42,432	127	900	15.0	360	680	16.0
13	17.0	35,239	324	900	13.0	360	680	16.0
14	17.0	65,030	92	867	16.0	360	680	17.0

* Design aircraft, B-727.

As a check on the design procedure, a fatigue damage analysis was performed for each section. Two methods were used to perform the analysis. The first method was a mixed traffic analysis where the edge stress was computed for each aircraft, and the damage was totalled over the life of the section. The second method used the equivalent annual departures of the design aircraft and the stress from that aircraft. The stresses were computed using the k values from both design and evaluation. The values for the MR from both procedures were also used. The damage data are summarized in Table 24. The damage values are low for all sections of pavement using the evaluation parameters. The damage values using the design parameters are higher, but within an acceptable limit with the exception of sections 9 and 10, which have damage values in excess of 100 percent. It should be noted that 100 percent of the edge stress was used in the fatigue analysis and that all aircraft were considered to cause an edge load. This is the most conservative analysis. The FAA criteria are based on 75 percent of the maximum edge stress (accounting for 25 percent load transfer) and use the Corps of Engineers coverage concept to account for stress repetitions.

The pavements at DFW are just short of the midpoint in terms of a 20-year design life. Thus, it would be expected to have damage values near the 50 percent level (assuming constant traffic levels). The fatigue analysis shows values far less than this level, which indicates the existing pavements were designed on the conservative side. Another factor supporting this is the fact that the deflection transfer values determined from the NDT tests averaged 69 percent over all the pavement sections. The individual results are presented in Table 25. Using the relationship shown in Figure 22, developed by Sawan and Darter,[9] a deflection transfer value of 69 percent

Table 24

Summary of Damage Values, Dallas-Fort Worth

Section No.	NDT Properties MR psi	NDT Properties Design Aircraft Damage Percent	NDT Properties Mixed Traffic Damage Percent	Design Properties MR psi	Design Properties Design Aircraft Damage Percent	Design Properties Mixed Traffic Damage Percent
1	1,213	0.0	0	680	16.7	15.3
2	1,213	0.0	0	680	12.6	11.5
3	1,107	0.0	0	680	14.6	13.8
4	1,107	0.0	0	680	13.1	12.4
5	1,067	0.0	0	680	0.1	0.1
6	1,067	0.0	0	680	0.2	0.2
7 & 8	885	0.0	0	680	5.5	5.4
9 & 10	1,245	0.0	0	680	204.2	193.6
11	1,131	0.1	0.1	680	19.7	18.8
12	1,131	0.0	0.1	680	15.8	15.0
13	899	0.0	0	680	2.2	2.1
14	867	4.9	7.3	680	4.0	3.9

Table 25

Deflection Transfer Percentages, Dallas-Fort Worth

	Average Deflection Transfer Percentages					
	Transverse Sawed		Joints Doweled		Longitudinal Joints Doweled	
Section No.	Mean Percent	Standard Deviation	Mean Percent	Standard Deviation	Mean Percent	Standard Deviation
1 & 2	78.5	4.6	58.2	9.4	57.3	7.6
3 & 4	80.9	4.9	82.6	4.5	77.8	12.2
5 & 6	78.5	7.4	56.0	21.5	78.8	17.7
7 & 8	64.4	16.2	73.4	8.1	66.1	20.9
9 & 10	--	--	59.7	10.6	51.9	20.3
11 & 12	73.7	0.7	78.9	8.7	86.0	8.6
13	78.8	9.6	68.1	9.4	78.9	28.3
14	70.6	22.9	64.5	13.1	57.3	23.7
Average Overall	75.1		67.7		69.3	

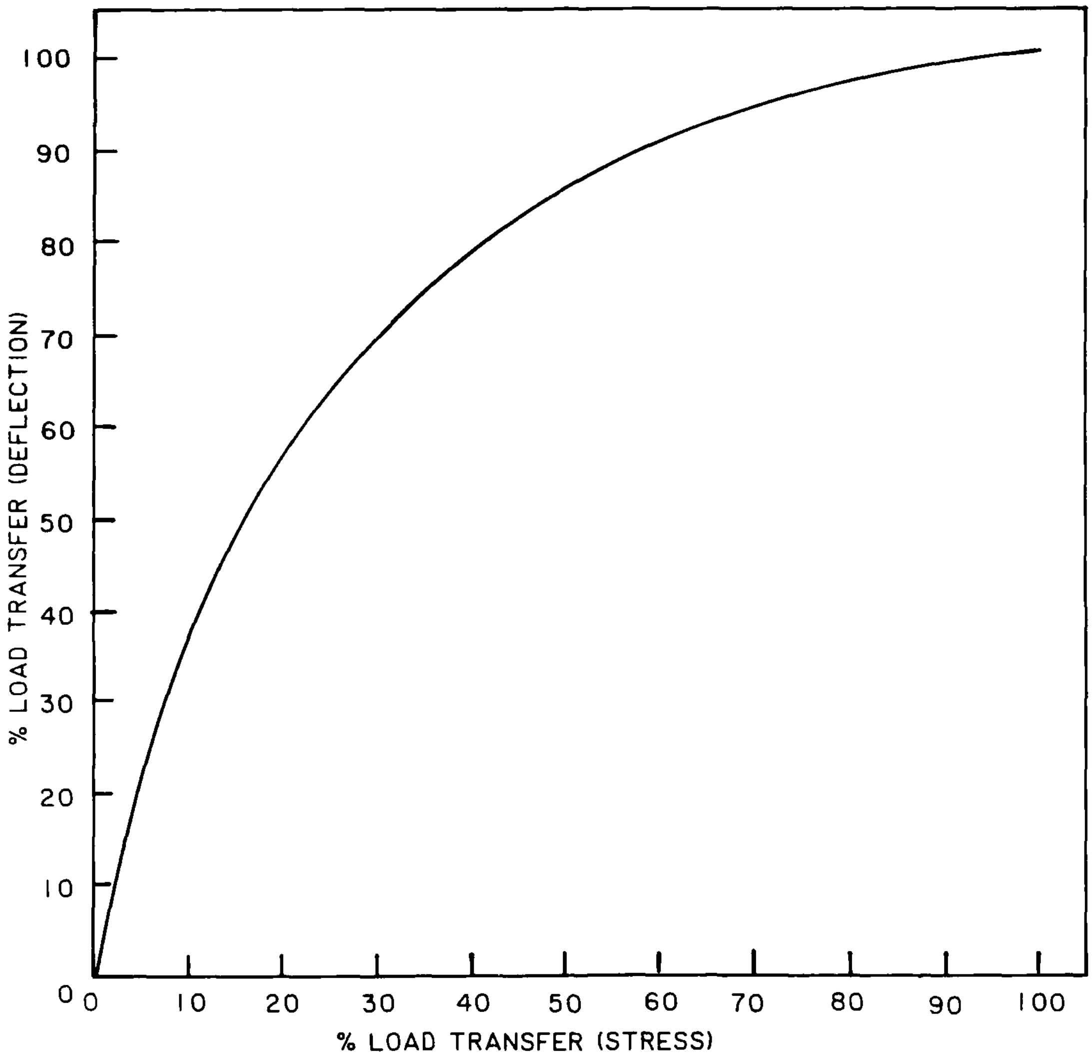


Figure 22. Load transfer efficiency based on deflection versus efficiency based on stress (ref 9)

relates to a load transfer value of 28 percent. Thus, the edge stresses would be on the order of 72 percent of the maximum values used in the fatigue analysis.

WILLIAM B. HARTSFIELD-ATLANTA

The controlling aircraft at ATL was the B-727; the evaluation was performed using the B-727 at a gross weight of 191,000 lb. As with the DFW pavements, all but three sections at ATL were evaluated as being able to carry the maximum gross weight. The three sections at ATL which were found to be deficient are sections 16, 17, and 20. Sections 16 and 17 are estimated to have a load-carrying capacity of 187 kips each and would require a 2 in. overlay to carry the maximum 191 kip load. Section 20 was estimated to have a load-carrying capacity of 161 kips and would require a 4.7 in. overlay to carry the maximum 191 kip load. These evaluations are based on NDT data that indicate k values much lower than the k of 500 pci used in the original design. The evaluation data are presented in Table 26.

A thickness design was performed for each section using the FAA 6C design procedure. Two designs were performed for each section, one using the original design values of k and MR and the other using the values determined from the NDT procedure. These designs are summarized in Table 27. Based on the design inputs, the existing sections are thicker than required by the FAA procedure. The designs based on the NDT parameters indicate the same except for section 20. This section requires a 17-in. thickness using the FAA 6C method.

The fatigue damage results for the ATL pavements are summarized in Table 28. Extrapolating these four fatigue values to 20 years, the analysis indicates all the pavements would be below the 100 percent level at the

Table 26

Pavement Evaluation Data, William B. Hartsfield-Atlanta

Section No.	Age year	Equivalent Annual Departures*	DSM kips/in.	k NDT pci	Allowable Gross Load kips	Overlay** in.
1	4	36,443	5,789	440	191	0
2	4	21,134	5,169	285	191	0
3	4	21,134	5,169	285	191	0
4	4	21,135	5,074	265	191	0
5	4	21,135	5,074	265	191	0
12	4	11,431	4,920	290	191	0
13	4	11,431	4,920	290	191	0
16	4	42,864	4,625	255	187	2
17	4	42,864	4,625	255	187	2
20	4	42,864	4,006	205	161	4.7

* Design aircraft, B-727.
** PCC overlay required to extend life 20 years (minimum of 5 in. required).

Table 27

Pavement Design Data, William B. Hartsfield-Atlanta

			Required Design Thickness					
			NDT Properties			Design Properties		
Section No.	Existing Thickness in.	Equivalent Annual Departures*	k pci	MR psi	Thickness in.	k pci	MR psi	Thickness in.
1	16.0	36,443	440	900	13.0	500	715	14.0
2 & 3	16.0	21,134	285	884	13.0	500	715	14.0
4 & 5	16.0	21,135	265	876	13.0	500	715	14.0

(Continued)

Table 27 (Concluded)

Section No.	Existing Thickness in.	Equivalent Annual Departures*	Required Design Thickness: NDT Properties k pci	MR psi	Thickness in.	Design Properties K pci	MR psi	Thickness in.
12 & 13	16.0	431	290	840	13.0	500	715	13.0
16 & 17	16.0	42,864	225	802	15.0	500	715	14.0
20	16.0	42,864	205	715	17.0	500	715	14.0

* Design aircraft, B-727.

Table 28

Summary of Damage Values, William B. Hartsfield-Atlanta

	Total Damage Percent					
	NDT Properties			Design Properties		
Section No.	MR psi	Design Aircraft Damage Percent	Mixed Traffic Damage Percent	MR psi	Design Aircraft Damage Percent	Mixed Traffic Damage Percent
1	933	0.6	0.0	715	0.5	0.4
2 & 3	884	0.0	0.0	715	0.3	0.2
4 & 5	876	0.1	0.1	715	0.3	0.2
12 & 13	840	0.1	0.0	715	0.2	0.1
16 & 17	802	0.0	0.7	715	0.6	0.5
20	714	14.1	16.2	715	0.6	0.4

present rate of damage accumulation. This also assumes that each aircraft pass causes an edge load condition which is the most conservative case. These results are in conflict with the evaluation results which indicate that sections 16, 17, and 20 have allowable loads less than the design maximum load. Also, the average deflection transfer value for the ATL pavements was 70.7 percent. This relates to a load transfer value of 29 percent, which implies the edge load is 71 percent of the maximum. A summary of the deflection transfer values is shown in Table 29. This fact further complicates the conflict with the NDT evaluation.

PHOENIX SKY HARBOR

The NDT evaluation data for the PHX pavements are summarized in Table 30. Four of the eight sections have a load-carrying capacity of 191 kips. All others are rated as having a load-carrying capacity less than the maximum. Section 2 requires the largest overlay and is rated for only 71 kips. This is the oldest section. The other sections are rated over 149 kips and require overlays varying from 1 to 4 in. of overlay.

The FAA thickness designs are presented in Table 31. The designs based on the NDT properties are very close to the existing designs with the exception of sections 2 and 5. The FAA thicknesses for these sections are 22 and 13.5 in., respectively, greater than the existing thicknesses. Using the design values, the thicknesses obtained from the FAA procedure are generally less than the thickness of the existing pavements (section 3 requires an additional 6 in. of material).

Table 29

Deflection Transfer Percentages, William B. Hartsfield-Atlanta

Section No.	Average Deflection Transfer Percentages: Transverse Doweled, Mean	Transverse Doweled, Standard Deviation	Longitudinal Keyed, Mean	Longitudinal Keyed, Standard Deviation
1	75.8	8.4	68.9	15.0
2 & 3	70.8	14.5	65.2	13.2
4 & 5	82.9	8.4	66.5	22.0
12 & 13	86.0	5.8	78.5	13.1
16 & 17	79.4	6.8	64.1	19.2
20	52.9	20.5	81.0	7.7
Overall Average	74.6		70.7	

Table 30

Pavement Evaluation Data, Phoenix Sky Harbor

Section No.	Age yr	Equivalent Annual Departures*	DSM kips/in.	CBR percent	Allowable Gross Load kips	Overlay** in.
1	7	8,929	2,791	5.5	191	0
2	16	8,929	839	4.6	71	17
3	2	20,403	2,068	26.1	191	0
4	14	20,403	1,751	17.0	149	4
5	4	13,255	1,772	3.5	158	3
6	4	13,255	2,232	4.4	191	0.1
7	5	30,303	4,257	76.0	191	0
8	15	30,303	1,840	17.9	183	.4

* Design aircraft, B-727.
** AC overlay required to extend life 20 years (minimum of 5 in. required).

Table 31

Pavement Design Data, Phoenix Sky Harbor

				Required Total Design Thickness					
				NDT Properties			Design Properties		
Section No.	Existing T* in.	Existing Surface in.	Equivalent Annual Departures**	Subgrade CBR percent	Required Surface in.	T in.	Subgrade CBR percent	Required Surface in.	T in.
1	40.5	6.0	8,929	5.5	4.0	41.0	15.0	4.0	20.0
2	24.0	4.0	8,929	4.6	4.0	46.0	15.0	4.0	20.0
3	16.0	6.0	20,403	26.1	4.0	14.0	15.0	4.0	22.0
4	19.0	4.0	20,403	17.0	4.0	20.0	40.0	4.0	10.0
5	40.5	6.0	13,255	3.5	4.0	54.0	40.0	4.0	10.0
6	40.5	6.0	13,255	4.4	4.0	47.0	40.0	4.0	10.0
7	21.0	5.0	30,303	76.0	5.0	8.0	40.0	5.0	11.0
8	19.0	4.0	30,303	17.9	5.0	20.0	40.0	5.0	11.0

* T - total thickness of section; stabilized materials converted to equivalent thickness of granular material.

** Design aircraft, B-727.

The damage values for the sections are presented in Table 32. All the damage values for the AC material are well in excess of 100 percent. This wide range of values can be in part attributed to the selection of the modulus values. However, the sections with damage values in excess of 1,000 all are exhibiting fatigue cracking. Section 4 has been slurry sealed in the past year, but the section was reported to be cracked prior to this maintenance. The subgrade strain damage values are not overall as high, yet they are as widespread as the AC fatigue. Section 2, which has a damage value of 4 percent, is exhibiting a considerable amount of rutting. Section 3 is a new pavement (2 years old). The damage value for this section is extremely high (>140,000); however, the section is only exhibiting a small amount of rutting. This may indicate that the appearance of distress is not far away. Also, the relationship between laboratory fatigue tests and field performance is very scattered for AC materials.

JOHN F. KENNEDY INTERNATIONAL

Of the four sections at KIA, two sections were evaluated as needing an overlay. These sections, however, are at the end of their design lives. The evaluation data are presented in Table 33.

The FAA design data are presented in Tables 34 and 35. The comparison between the thickness of existing sections and the design sections using the CBR's calculated in the NDT procedure is very close for two of the flexible sections. The third section showed a difference of 24 in. The section was constructed with 30 in. of a lime-cement-fly ash base course. A conversion factor of 1.6 was used to convert this to equivalent granular thickness. The section, however, is rated as having a load-carrying capacity of 710 kips, and it is presently 13 years old. This indicates the design inputs

Table 32

Summary of Damage Analysis, Phoenix Sky Harbor

Section No.	Age year	Equivalent Annual Departures*	Asphalt Concrete Damage percent	Subgrade Damage percent
1	7	8,929	829.0	0.18
2	16	8,929	2,289.0	4.0
3	2	20,403	137.0	140,710.0
4	14	20,403	1,292.0	230.0
5	4	13,255	402.0	0.0
6	4	13,255	402.0	0.0
7	5	30,303	454.0	479.0
8	15	30,303	2,057.0	366.0

* Design aircraft, B-727.

Table 33

Pavement Evaluation Data, John F. Kennedy International

Section No.	Age year	Equivalent Annual Departures*	DSM kips/in.	CBR/k percent pci	Allowable Gross Load kips	Overlay** in.
1	5	34,983	4,274	8.9	710	0
2	20	12,635	1,630	12.2	522	4.5
3	13	4,613	3,396	10.8	710	0
4	22	10,582	2,707	300	125	11.0

* Design aircraft, B-747, sections 1-2; B-727, section 4.

** Overlay required to extend life 20 years; AC for sections 1-3, PCC for section 4 (minimum of 5 in. required).

Table 34

Pavement Design Data, John F. Kennedy International,

Flexible Pavements

				Required Total Design Thickness					
				NDT Properties			Design Properties		
Section No.	Existing T* in.	Existing Surface in.	Equivalent Annual Departures**	Subgrade CBR percent	Required Surface in.	T in.	Subgrade CBR percent	Required Surface in.	T in.
1	38.0	8.0	34,983	8.9	6.0	33.0	25	6.0	16.0
2	22.0	5.0	12,635	12.2	5.0	25.0	25	5.0	16.0
3	49.0	4.0	4,613	10.8	5.0	25.0	25	5.0	15.0

* Stabilized material converted to equivalent granular material.
** Design aircraft, B-747.

Table 35

Pavement Design Data, John F. Kennedy International

Rigid Pavement

			Required Design Thickness				
			NDT Properties			Design Properties	
Section No.	Existing Thickness in.	Equivalent Annual Departures*	k pci	MR psi	T in.	k pci	MR psi
4	13.0	10,582	300	640	16.0	N/A	N/A

* Design aircraft, B-727.

may have been overestimated. The rigid pavement (section 4) shows that the existing thickness is 3 in. less than the required 16 in. Again, this section is 22 years old.

The damage analysis is presented in Tables 36 and 37. The damage values for both the flexible and rigid pavement surfaces exceed the 100 percent value. In the flexible sections, a small amount of fatigue cracking was found during the condition survey. The rigid pavement did not exhibit any cracking, but a considerable amount of patching was present. The subgrade damage values for the flexible sections were all less than 100 percent. No major rutting was encountered in the condition survey.

Table 36

Summary of Damage Values, John F. Kennedy International,

Flexible Pavements

Section No.	Equivalent Annual Departures*	Pass-to-Coverage Ratio	Asphalt Concrete Tensile Strength Damage percent	Vertical Subgrade Strain Damage percent
1	34,983	1.85	927	0
2	12,635	1.85	3049	12.1
3	4,613	1.85	6483	0

* Design aircraft, B-747.

Table 37

Summary of Damage Values, John F. Kennedy International,

Rigid Pavement

	Total Damage, Percent					
	NDT Properties			Design Properties		
Section No.	MR psi	Design Aircraft	Mixed Traffic	MR psi	Design Aircraft	Mixed Traffic
4	640	>10,000	>10,000	N/A	N/A	N/A

ASSESSMENT OF THE DESIGN PROCEDURE

This section presents the assessment of the design procedures based on the data collected to date. An analysis of the findings as they pertain to each pavement type will be presented. Observations based on the entire data set are presented thereafter.

A major problem in the field of pavement design and evaluation is determining when a pavement has failed. It has been realized that pavements fail in two basic modes. One is the structural failure where the pavement no longer has the ability to carry the load; and two, the functional failure where the pavement no longer provides the level of service it was intended to provide through the loss of some quality such as ride comfort or skid resistance. Each design method available for any pavement type is based on one of these basic failure modes.

In order to assess the adequacy of the FAA design procedure, an analysis of the pavement sections must be made in terms of the failure criteria upon which the design procedures are based. The failure criteria that the FAA design procedures are based on are the same as the Corps of Engineers criteria.[2,10] The rigid pavement failure criterion is the initial crack criterion that is defined as the condition when at least 50 percent of the slabs contain one or more cracks due to loading of the slab. The flexible pavement criteria are based on rutting or cracking of the section. The rutting criterion is a 1-in. rut depth due to shear deformation, and the cracking criterion is defined as the condition when the cracking has occurred to such an extent that the pavement is no longer waterproof.

RIGID PAVEMENTS

As shown in the design section, the pavements at DFW are performing well, and none of the sections is underdesigned when comparing the existing thickness to the thicknesses obtained using the design or NDT material properties. The pavements are about halfway through their design lives, and no major distress has occurred except in those areas with special conditions (sections 13 and 14). The data set, however, does not lend itself to the assessment of the design procedure. The pavements are not underperforming (which they should not be by the present design standards), since all the sections are at least as thick as or thicker than the FAA design thickness and in at least good condition. None of the sections was found to be in any condition close to the failure criteria. Even though the sections with the 50-ft slab lengths did have cracking, the cracks were not of a structural nature. However, it should be noted that the sections with the 50-ft slabs had PCI values considerably lower than the other sections. This was due to not only the cracks, but also some increase in the amount of spalling.

In comparing the loss of PCI points on an annual basis, the DFW pavements compare to the normal deterioration found on US Air Force (USAF) pavements. A general relationship for the PCI with the age of the pavement is shown in Figure 23. As shown, a rigid pavement that is 9 years old would be expected to have a PCI of about 83. The pavements at DFW averaged a PCI of 82.3. Comparison of pavements at DFW with the USAF pavements is reasonable since the design failure criteria for these pavements are the same.

The typical distresses at DFW were not generally load associated. Most of the distresses were spalling and small patches of joint spalls.

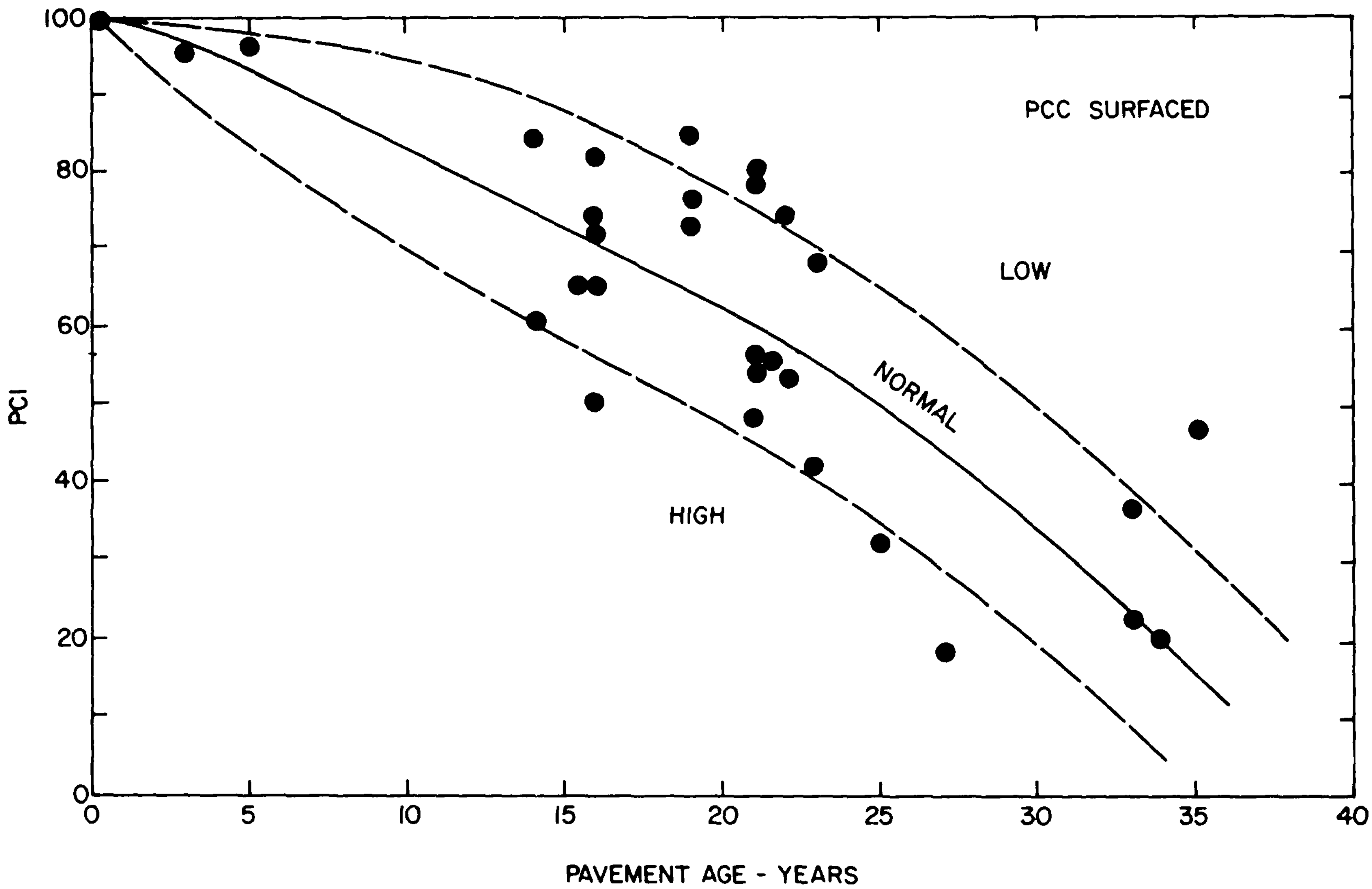


Figure 23. PCI of concrete-surfaced pavements versus time since construction (ref 3)

Some of these patches were reported to have been placed right after construction to repair spalls caused by the sawing of the joints. Taking this into consideration, the overall loss in PCI points on an annual basis is really less since the pavement did not begin its life in a 100-pci condition.

If the FAA procedure were used to design these same pavements, the design thicknesses would be thinner than the existing pavements (using the traffic estimates contained in this report). However, it must be remembered that the traffic used in this report is not the same as used in the original design. Whether or not these sections would perform under these conditions is not known. The current sections with the highest traffic levels are not overperforming when compared to typical USAF pavements of the same age, but the distresses that are appearing are not generally load-related problems. Thus, the thinner sections may have performed as well under the same traffic conditions. The damage calculations in the previous chapter (Pavement Evaluation and Design) certainly indicate that the existing sections are not being overstressed. The pavements at ATL are in similar condition as the pavements at DFW. The ATL pavements are only 4 years old, and the average PCI of these sections is 81.7, which is low for concrete pavements of this age. However, the distresses which are appearing at ATL are not structural in nature. The major distress type was spalling of the joints, and in the case of the ATL pavements, the keyed longitudinal joint was showing the most problems. However, this failure could be considered structural if the failures are not key caused by construction problems such as misshaped keys or poor consolidation at the key.

As with the DFW pavements, using the FAA design procedure and the traffic estimated in this study, the pavements at ATL are thicker than required with the exception of section 20 (using the NDT inputs). However, the ATL pavements, if constructed at the thinner level, would most likely not be performing as well since the keyed joints are showing problems on the thicker sections. From a structural cracking point of view, the pavements presently have no structural cracks. Reviewing the damage values of the previous section, no structural distress is expected on these pavement sections.

The rigid pavement section at KIA is the oldest section in the data set. The section is 22 years old and has a PCI of 36. Comparing this value with the average PCI of USAF pavements of the same age, the KIA section's PCI is much lower than expected. The average value for the USAF pavements is 57. However, most of the distresses encountered were patching and spalling near the slab joints. In particular, most of the patches were found at the slab corners and appeared to be patches of spalls rather than corner breaks. Maintenance of these slabs would raise the PCI of the section close to the expected value for a pavement of this age. Of the 160 slabs surveyed, only 4 slabs exhibited any kind of structural distress. One slab was found to be in a shattered condition, and the other three slabs were cracked (two with corner breaks). This condition is not failed by the cracking criteria (less than 50 percent cracking).

The damage values calculated for this section would indicate that a considerable amount of structural distress would be expected. However, the traffic used in the analysis was estimated from traffic records for the past 10 years. In the years prior to the early 70's the traffic using the airport was most likely lighter than the mix used in the analysis, since wide-body aircraft were not flying during this period. Thus, the damage calculated for the section is an overestimate of the actual damage.

The FAA design procedure indicates that the section needed to be 16 in. of pavement to last 20 years. However, the 13 in. has lasted for 22 years. The overestimate of the traffic can account for some of this discrepancy. Also, the exact material properties are not known for the section. A small difference in the thickness could make a large difference in the performance of this section. The stress curves for the large aircraft are steep in the 12- to 14-in. thickness range. Thus, any error in the thickness parameter in this range greatly affects the damage calculation.

In summary, a majority of the rigid pavement sections are as thick as or thicker than the current FAA procedure would require to carry the current traffic. None of the sections was found to be in any condition close to the failure condition used in the design procedure. Generally, the damage values calculated for the sections support this finding. The sections at DFW and ATL are expected to last for at least a total of 20 years extrapolating the damage calculations. Since the sections were as thick as or thicker than required by the design method, a damage calculation was performed for the thicknesses determined from the procedure. These values are presented in Tables 38 and 39. The damage values for these sections are also within the limit of 100 percent damage. Thus, the design method appears to be adequate from a thickness point of view.

To complete the analysis of the data set, a comparison of the existing traffic levels, allowable traffic levels, design thicknesses, and existing thicknesses has been made. These values were then used along with the PCI data to evaluate the design method. The data are shown in Table 40.

Table 38

Summary of Damage Values for FAA Design

Sections Using NDT Properties*

Section No.	Equivalent Annual Departures	Design Thickness in.	Total Damage, Percent** 100% Takeoff Weight	80% Takeoff Weight	50% Takeoff Weight
DFW 1	5,992	12.0	2.568	0.014	0.0
DFW 2	4,539	12.0	1.935	0.011	0.0
DFW 3	39,172	13.0	0.330	0.004	0.0
DFW 4	35,322	13.0	0.298	0.004	0.0
DFW 5	1,602	12.0	2.032	0.008	0.0
DFW 6	2,989	12.0	3.838	0.016	0.0
DFW 7 & 8	89,301	13.0	.0199	0.003	0.0
DFW 9 & 10	73,433	15.0	0.053	0.001	0.0
DFW 11	53,116	15.0	0.204	0.003	0.0
DFW 12	42,432	15.0	0.163	0.002	0.0
DFW 13	35,239	13.0	0.250	0.000	0.0
DFW 14	65,030	16.0	0.344	0.004	0.0
ATL 1	36,443	13.0	0.022	0.000	0.0
ATL 2 & 3	21,134	13.0	0.074	0.001	0.0
ATL 4 & 5	21,135	13.0	0.196	0.002	0.0
ATL 12 & 13	11,431	13.0	0.177	0.002	0.0
ATL 16 & 17	42,864	15.0	0.047	0.001	0.0
ATL 20	42,864	17.0	0.031	0.000	0.0
JFK 4	10,582	16.0	0.679	0.007	0.0

* NDT properties for k and MR used as input to FAA design procedure.
** Damage percentage calculated by summing damage of each aircraft.

Table 39

Summary of Damage Values for FAA Design

Sections Using Design Properties*

Section No.	Equivalent Annual Departures	Design Thickness in.	Total Damage, Percent** 100% Takeoff Weight	80% Takeoff Weight	50% Takeoff Weight
DFW 1	5,992	14.0	1.771	0.010	0.0
DFW 2	4,539	14.0	1.335	0.008	0.0
DFW 3	39,172	16.0	0.127	0.002	0.0
DFW 4	35,322	16.0	0.114	0.002	0.0
DFW 5	1,602	13.0	6.724	0.023	0.0
DFW 6	2,989	14.0	0.873	0.005	0.0
DFW 7 & 8	89,301	17.0	0.040	0.001	0.0
DFW 9 & 10	73,433	17.0	0.033	0.001	0.0
DFW 11	53,116	17.0	0.024	0.001	0.0
DFW 12	42,432	16.0	0.138	0.002	0.0
DFW 13	35,239	16.0	0.114	0.002	0.0
DFW 14	65,030	17.0	0.029	0.001	0.0
ATL 1	36,443	14.0	0.186	0.002	0.0
ATL 2 & 3	21,134	14.0	0.105	0.001	0.0
ATL 4 & 5	21,135	14.0	0.105	0.001	0.0
ATL 12 & 13	11,431	13.0	0.694	0.004	0.0
ATL 16 & 17	42,864	14.0	0.223	0.002	0.0
ATL 20	42,864	14.0	0.223	0.002	0.0
JFK 4	N/A	N/A	N/A	N/A	N/A

* Design properties for k and MR used as input to FAA design procedure.
** Damage percentage calculated by summing damage of each aircraft.

Table 40

Comparison of Existing versus Calculated Traffic

and Thickness Values For Rigid Pavements

Section No.	Design Parameters: Flexural Strength psi	Design Parameters: k-Value psi/in.	Existing Thickness, in.	Thickness For 25000 Departures	Allowable Departures	Current Departures	Design Thickness For Current Dept.	Thickness Ratio
DFW 1	680	360	15	15.5	15,000	5,992	14	1.07
DFW 2	680	360	15	15.5	15,000	4,539	14	1.07
DFW 3	680	360	16	15.5	60,000	39,172	16	1.00
DFW 4	680	360	16	15.5	60,000	35,322	16	1.00
DFW 5	680	360	17	15.5	150,000	1,602	13	1.31
DFW 6	680	360	17	15.5	150,000	2,989	14	1.21
DFW 7	680	360	17	15.5	150,000	89,301	17	1.00
DFW 8	680	360	17	15.5	150,000	89,301	17	1.00
DFW 9	680	360	15	15.5	15,000	73,433	17	0.88
DFW 10	680	360	15	15.5	15,000	73,433	17	0.88
DFW 11	680	360	16	15.5	60,000	53,116	17	0.94
DFW 12	680	360	16	15.5	60,000	42,432	16	1.00
DFW 13	680	360	17	15.5	150,000	35,239	16	1.06
DFW 14	680	360	17	15.5	150,000	65,030	17	1.00
ATL 1	715	500	16	14.2	200,000	36,433	14	1.14
ATL 2	715	500	16	14.2	200,000	21,124	14	1.14
ATL 3	715	500	16	14.2	200,000	21,134	14	1.14
ATL 4	715	500	16	14.2	200,000	21,135	14	1.14
ATL 5	715	500	16	14.2	200,000	21,135	14	1.14
ATL 12	715	500	16	14.2	200,000	431	13	1.23
ATL 13	715	500	16	14.2	200,000	431	13	1.23
ATL 16	715	500	16	14.2	200,000	42,864	14	1.14
ATL 17	715	500	16	14.2	200,000	42,864	14	1.14
ATL 20	715	500	16	14.2	200,000	42,864	14	1.14
JFK 4	640	300	13	20	1,200	10,582	16	0.81

As shown, only 6 of the 25 sections are presently carrying traffic that would not be considered high volume traffic. In terms of allowable traffic levels based on the current advisory circular design procedure, only 3 sections are carrying traffic in excess of what the design procedure indicates as the allowable traffic level. The existing thicknesses were compared to the thicknesses obtained from the 6C Advisory Circular; this is shown in the column labeled "Thickness Ratio." A review of these values shows that the existing thickness of 21 of the 25 sections exceeds the thickness found using the design procedure.

To analyze this data, a two-way classification table was established grouping the thickness ratio in three groups and categorizing them in three groups of condition rating. Table 41 shows the classification table with each cell containing the information obtained from groups of data in the respective cell. Table 42 presents the comparison of the data using the design parameters, and Table 43 is a comparison of the data using the NDT data as the input parameters to the design procedure. Both data sets divide the data between the cells evaluating the design as good and unconservative. In general, the data contained in the cell tending to rate the design as unconservative fall in the upper end of the range such that the balance leans toward the cell providing no information on the design. Thus, the data could be interpreted as being split between the good and no information cells. The data in the no information cell gives no information about the design method, but indicates that some parameter was overestimated in the design procedure.

As another check on the designs, takeoff weight (TOW) data were solicited from the major airlines servicing these airports. In general, the actual TOW's of the aircraft are considerably less than the maximum. The TOW

Table 41

Evaluation Key

T Existing / T Design	Pavement Condition Excellent	Very Good - Good	<Good
>1	No information obtained	Design method may be unconservative	Design method is unconservative
=1	Design method is conservative	Good	Design method is conservative
<1	Design method is very conservative	Design method may be conservative	Good

Table 42

Comparison of FAA Rigid Pavement Design Thicknesses with

In-Place Thicknesses Based on Design Properties

T Existing / T Design	Pavement Condition PCI >85 Excellent	PCI 85-56 Very Good - Good	PCI <55 <Good
>1	20%	40%	
=1	8%	16%	
<1	4%	8%	4%

Table 43

Comparison of FAA Rigid Pavement D^sign Thicknesses with

In-Place Thicknesses Based on NDT Properties

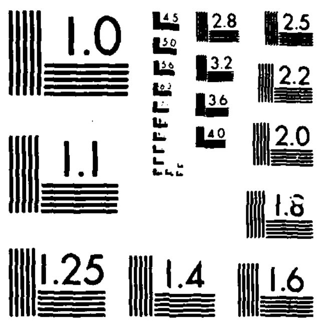
T Existing / T Design	Pavement Condition PCI >85 Excellent	PCI 85-56 Very Good - Good	PCI <55 <Good
>1	28%	56%	
=1		8%	
<1		4%	4%

AD-A163 341 EVALUATION OF THE FAA (FEDERAL AVIATION ADMINISTRATION) DESIGN PROCEDURES..(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIR.. S D KOHN 2/2

UNCLASSIFIED OCT 85 DOT/FAA/PM-84/14 DTFA01-81-Y-10555 F/G 13/2 NL

END

FILMED


1.0
2.8
2.5
3.2
2.2
3.6
2.0
4.0
1.1
1.8
1.25
1.4
1.6

is a function of the stage length of the flight. A plot of the TOW for several aircraft versus the stage length of the flight is shown in Figure 24. These data were obtained from one of the major airlines and represent flights originating at several airports. As shown, the actual TOW is generally in the region of 70 to 80 percent of the maximum. Using this data, damage calculations were performed for the design sections at 80 and 50 percent of maximum TOW. It is realized that 50 percent is low. The analyses were performed in order to obtain the relationship between TOW and damage. These values are also presented in Tables 38 and 39. The damage percentages for these weights are substantially less than those for the 100 percent TOW. Thus, if the pavement is designed for the maximum gross load of the aircraft, there is an unquantified factor of safety in the design.

The calculation of the damage for these sections using each aircraft and the equivalent annual departures calculated using the FAA conversion technique indicates that the technique is a practical way to handle mixed traffic analysis. As shown in Tables 38 and 39, the values using the summation of damage from each aircraft and the damage values from the equivalent annual departures are very close.

One disturbing factor found during the study was the performance of the keyed joints at ATL. Corps of Engineers studies have indicated that keyed joints perform well under heavy traffic if the pavement is supported by high-strength subgrades and traffic is not highly channelized. The NDT tests at ATL indicate that the subgrade k values are fairly high (generally greater than 250 pci). However, the joints are exhibiting some major problems. Two differences in the Corps test sections and the ATL pavements are that the ATL pavements are slipformed and the test sections are formed

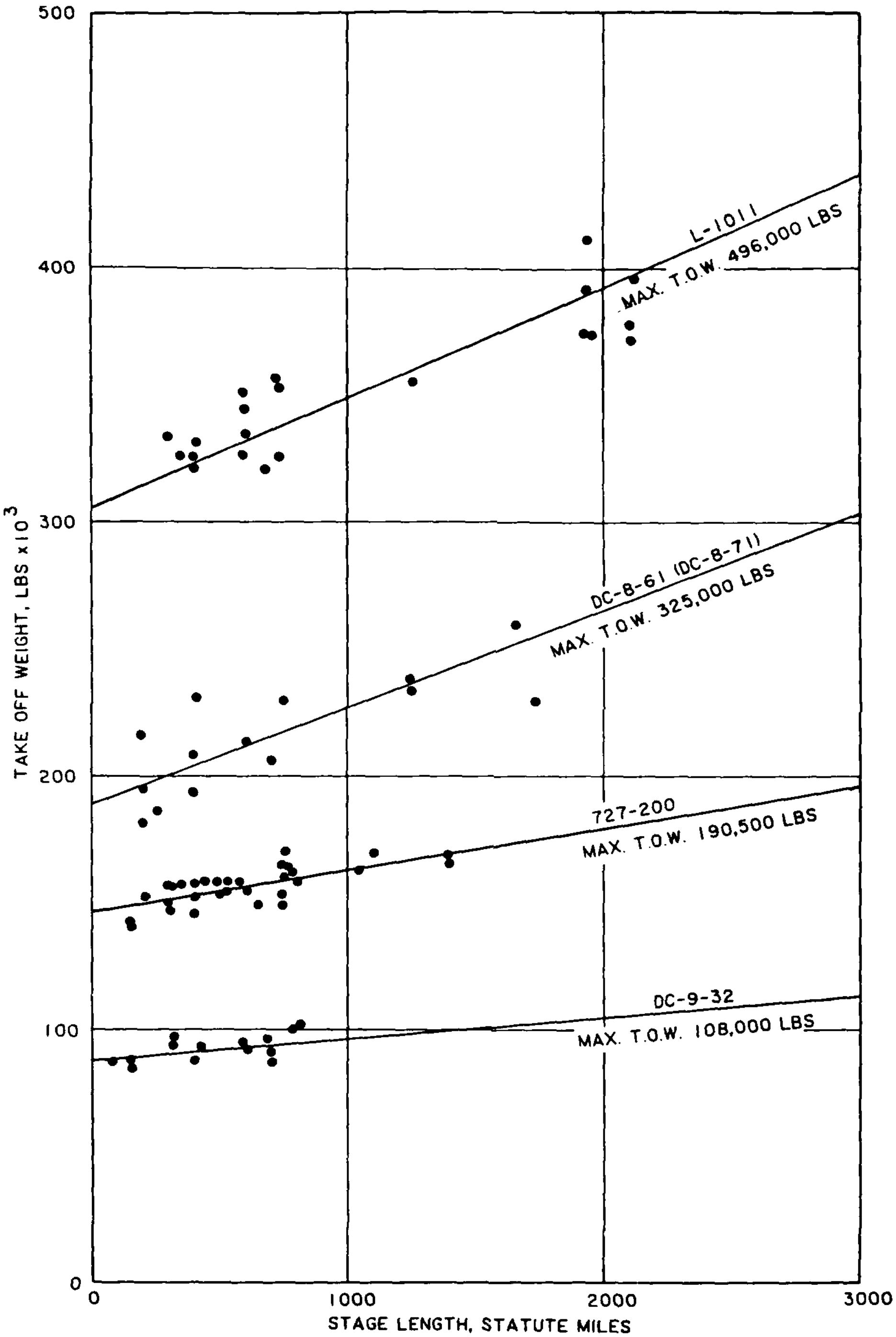


Figure 24. Takeoff weights versus stage length of flight for various aircraft

construction and the traffic on the ATL pavements is channelized. Thus, the performance of keyed joints in slipformed pavements should be investigated. It is recommended that the use of these types of joints be limited in highly channelized areas.

The DFW pavements have performed very well. One problem was noted which relates to the construction techniques used (spalling at the transverse joints which occurred during the sawing of the joints). This distress was observed on some of the new pavements being constructed at DFW during the time of this investigation. This distress could possibly be eliminated by close regulation of the time of sawing these joints.

FLEXIBLE PAVEMENTS

The eight sections at PHX are generally not performing as well as expected based on a comparison to typical USAF pavements. Figure 25 shows a plot of the PCI versus the age of the pavement for several USAF pavement sections. Comparing the PHX pavements with these data, it was found that the PCI's of the PHX pavements are generally lower than would be expected. However, none of the sections was found to be failed by the Corps rutting criteria which under the CBR method of design implies adequate protection of the subgrade. It should be noted that some rutting was encountered, but it was thought that most of this rutting was due to the consolidation of the AC material. Another problem which has caused the lower PCI's at PHX was the bleeding encountered in several sections. This problem is definitely related to the AC mix design and the environmental conditions at PHX. Sections 7 and 8 were exhibiting some alligator cracking with section 8 having the most cracking. These sections would be considered failed under the cracking criteria. The environment at PHX is such that this loss of waterproofing has

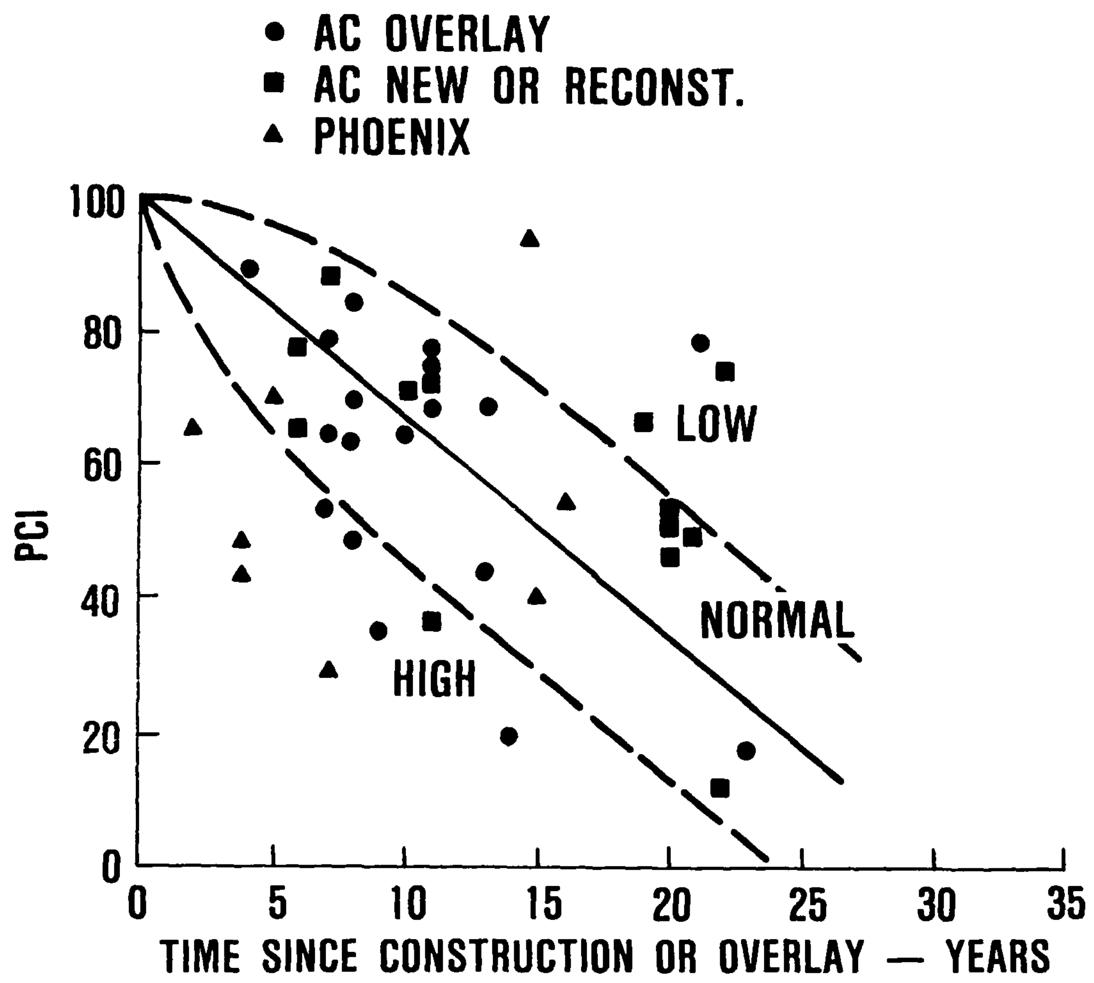


Figure 25. PCI of asphalt-surfaced pavements versus time since construction or last overlay (ref 3)

not affected the underlying base course material. If these pavements were subjected to a wet environment in this condition, it would only be a short time before the pavement surface would be lost. It should be noted that no rutting was found in these sections, which indicates that an asphalt aging problem is most likely contributing to the present condition.

Comparing the FAA design thicknesses with the existing section thicknesses, it was found that the values were very close when the NDT inputs were used in the design. Considering the age of the pavements, it appears that the design procedure is adequate, especially from the rutting criteria. However, a method to check the fatigue life of the asphalt surfacing should be developed and incorporated into the method.

In performing the FAA design on these sections, it was necessary to extrapolate the thickness beyond the 25,000-annual-departure level. The present FAA design method specifies that the same procedure used to determine the extra thickness required for rigid pavements be used for the flexible pavements with the additional requirement of an extra 1 in. of surfacing added. Currently, the Corps uses flexible pavement design curves which have been extrapolated to 100,000 annual departures. This extrapolation was performed for the dual-wheel FAA design curve, and a comparison was made with the percent thickness increase found in the rigid pavement procedure. It was found that at the lower California bearing ration (CBR) levels the required thickness is greater using the extrapolated design curve rather than the percentages specified in the rigid pavement procedure.

The three sections at KIA were in good condition and performing as would be expected when compared to average USAF pavements (based on the PCI's of the sections). The pavement sections were exhibiting some alligator cracking of the AC material. This would be expected from the damage values calculated for the sections. No rutting was encountered on any of the sections which was caused by shearing of the subgrade. This would also be expected based on the damage values from the vertical subgrade strain criteria.

The FAA design sections were close to the existing thicknesses for sections 1 and 2, but the thicknesses were thinner for section 3. This is based on using the NDT properties for input to the FAA design. Section 3 includes stabilized materials as the base course of the system. The thickness of an equivalent granular section was computed using the midpoint of the FAA equivalency factors. Some error may be associated with this approach. Thus, it appears that the design is adequate for the KIA pavements. However, this is from the standpoint of subgrade deformation. The KIA sections are exhibiting some alligator cracking.

A two-way comparison of the flexible pavement data was also performed. The evaluation of the data is the same as shown in Table 41. The design information is summarized in Table 44. As presented in this table, only 1 out of the 11 sections included is carrying traffic in excess of the traffic level estimated based on the design procedurby This is also the only section with a thickness ratio less than 1. By placing this data in the classification table, (Table 45) one can see that the design method is unconservative. Using the NDT data as input to the design procedure a different picture is portrayed by the data (Table 46). The data in this case is split between unconservative and good. It is felt that this is the more appropriate analysis since the NDT properties represent the field conditions. However, as discussed in previous sections, there does appear to

Table 44

Comparison of Existing versus Calculated Traffic

and Thickness Values For Flexible Pavements

Section No.	Design Subgrade CBR percent	Thickness For 25,000 Departures	Existing Thickness in.	Allowable Annual Departures	Actual Departures	Design Thickness in.	Thickness Ratio
PHX 1	15.0	23.0	40.5	200,000	8,929	20.0	2.03
PHX 2	15.0	23.0	24.0	54,000	8,929	20.0	1.20
PHX 3	15.0	23.0	16.0	1,200	20,403	22.0	0.73
PHX 4	40.0	10.5	19.0	200,000	20,403	10.0	1.90
PHX 5	40.0	10.5	40.5	200,000	13,255	10.0	4.05
PHX 6	40.0	10.5	40.5	200,000	13,255	10.0	4.05
PHX 7	40.0	10.5	21.0	200,000	30,303	11.0	1.91
PHX 8	40.0	10.5	19.0	200,000	30,303	11.0	1.73
JFK 1	25.0	15.0	38.0	200,000	34,983	16.0	2.38
JFK 2	25.0	15.0	22.0	200,000	12,635	14.5	1.52
JFK 3	25.0	15.0	49.0	200,000	4,613	14.0	3.50

Table 45

Comparison of FAA Flexible Pavement Design Thicknesses with

In-Place Thicknesses Based on Design Properties

T Existing / T Design	Pavement Condition		
	PCI >85 Excellent	PCI 85-56 Very Good - Good	PCI <55 <Good
>1	18%	18%	55%
=1			
<1	9%		

Table 46

Comparison of FAA Flexible Pavement Design Thicknesses with

In-Place Thicknesses Based on NDT Properties

T Existing / T Design	Pavement Condition		
	PCI >85 Excellent	PCI 85-86 Very Good - Good	PCI <55 <Good
>1	9%	27%	
=1			
<1	9%	9%	46%

be a problem in designing for the fatigue of the surface material. This problem is what is causing the shift in the data to the unconservative side of the classification table.

Based on the eight sections reviewed in this study, it appears that the flexible pavement design procedure is adequate from the standpoint of the rutting criteria (subgrade deformation). However, it was found that several of the sections were exhibiting alligator or fatigue cracking. The occurrence of this distress was expected based on the damage calculations performed. The damage values computed for these sections were very high for the AC fatigue. However, the same factor of reduced TOW affects these results as well as the rigid pavements. Using the reduced TOW in the damage analysis would reduce the total damage percent for these sections. In the analysis of the PHX pavements it was found that extrapolating the flexible pavement design curves results in thicker sections than those that would be selected using the rigid pavement procedure to determine the thickness of the flexible sections. The design curve using the extrapolated CBR equation for the dual-wheel aircraft is shown in Figure 26. As an illustration of this fact, the design thickness for a 200,000-lb aircraft was determined for subgrade CBR's ranging from 5 to 20 at the 50,000-departure level. The percent increase in thickness over the 25,000-departure level was then determined. The percentage ranged from 6.4 percent at the 5-CBR level to 5.3 percent at the 20-CBR level. These percentages are opposed to the 4 percent increase specified in the rigid pavement procedure. These percentages are not constant over the range of CBR values and gross weights; however, it is reasonable to assume that these values would provide reasonable values for the design of the flexible pavements.

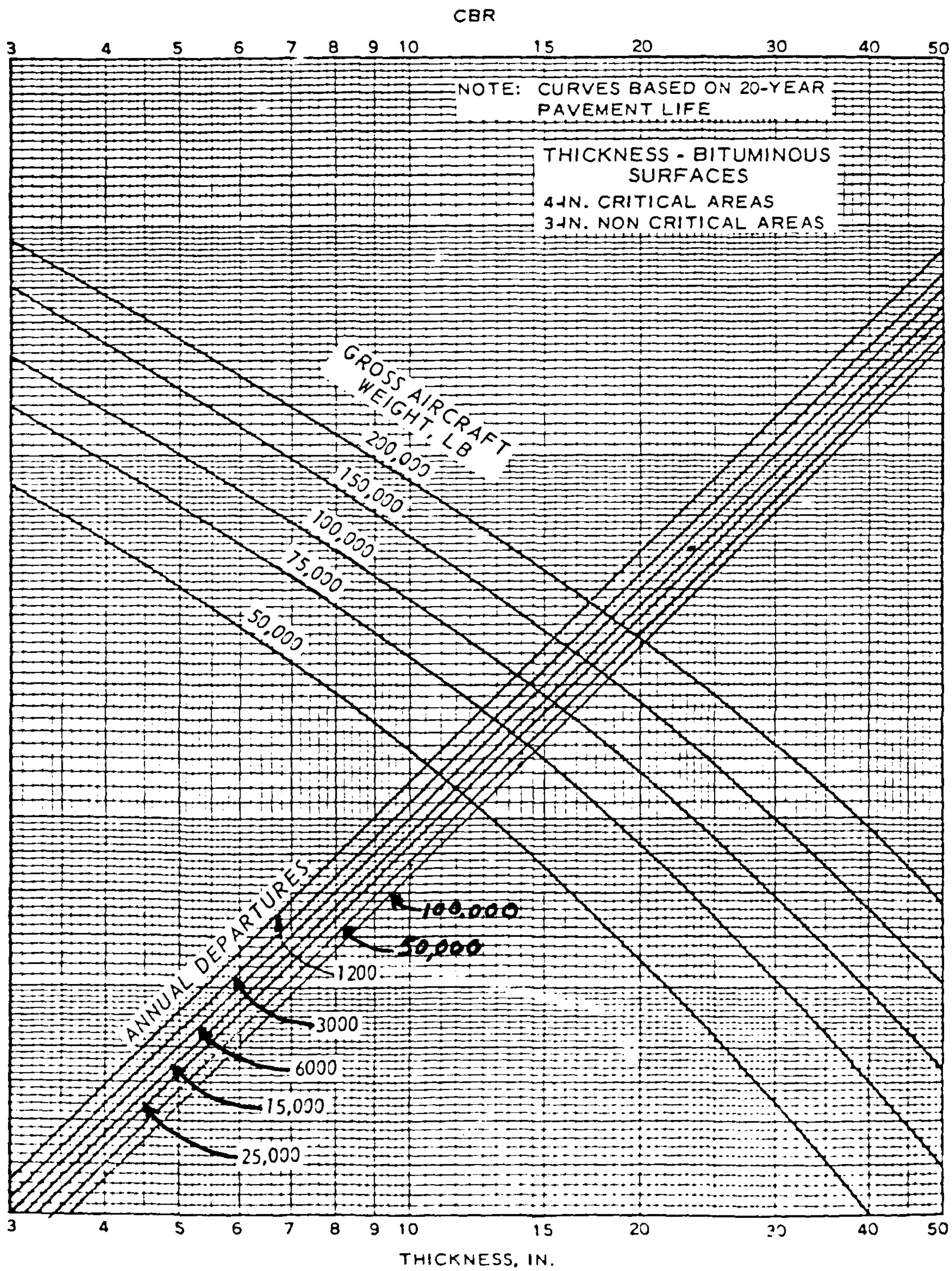


Figure 26. Flexible pavement curve for dual-wheel gear including 50,000 and 100,000 annual departures

Thus, it is recommended that a set of design curves extrapolating the CBR equation to the higher pass levels be issued for use in designing high-volume flexible pavements. Also, a method to check the fatigue of the AC surface material should be developed.

The condition survey of the PHX pavements revealed a limitation to the construction specifications used in conjunction with the design method. The pavements at the airport were constructed using the P-401 bituminous concrete specifications. Several of the sections were found to be bleeding considerably, while other pavements in the area (city streets and streets at the airport) were not observed to be bleeding. It may be reasonable to include some method of using local material specifications when environmental considerations can have a dramatic effect on the pavement's performance.

SUMMARY

Overall, both the rigid and flexible pavement design methods appear to be adequate. This statement must be slightly qualified for both procedures. The following paragraphs present these limitations.

For the rigid pavements the statement of adequacy is based on conservative damage calculations. Even though the computations are on the conservative side, any small errors in the input values for k, MR, and thickness would affect the results. In some cases this could be a dramatic effect. No sections were found to be in a failed condition, but the design procedure indicated thinner pavements could have been used. The actual performance of these thinner sections cannot be predicted.

The flexible pavement sections surveyed were found to be much closer to design thickness when the NDT properties were used in the design procedure. None of the sections was found to be failed using the rutting criteria. Some of the sections were failed under the cracking criteria. This fact presents a problem in the design method since the cracking encountered was alligator- or fatigue-type cracking. The current method specifies minimum thicknesses for critical pavement sections, but no method is present to check the fatigue life of the surface for a given set of conditions.

Other factors which affect the performance of the pavements were found during this study, but these factors are not related to the design method in terms of thickness determination. For the rigid pavements the main problem encountered was the use of keyed joints. Although this problem was only encountered at ATL, it was thought to be of sufficient magnitude to require caution. The keyed longitudinal joints were found not to be performing as expected. The k values estimated for the ATL pavements are considered good, yet the joints were found to be spalling. Based on this observation, it is recommended that any information on the performance of keyed joints in slipformed pavements be collected and that the use of these joints on high-volume channelized pavements be limited.

The flexible pavement designs are based on having an AC surface material meeting certain minimum material properties. In some cases, these properties may not be the properties which perform well in a given geographic area. This was demonstrated for the sections which were found to be bleeding considerably at PHX.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The data collected during this study represents the beginning of a large data base regarding the performance of in-service airfield pavements. The collection of as-built data and traffic history for a given pavement section was found to be a difficult and time-consuming task. In many cases the data must be estimated from design information and the knowledge of individuals associated with a facility for many years. However, the data are a starting point from which future investigations can proceed.

Although many problems were encountered in the data collection process, the data collected to date represent the best available data for each airport in the study. It is realized that the estimation of the parameters used as input to the design can cause errors in the analysis. However, all the data analyses performed were always compared with the field performance of the sections in question. The intention of this methodology was to prohibit any conclusions being drawn from calculated values alone. The analysis of the data collected during this phase of the study did tend to indicate the general adequacy of the current design procedures in terms of obtaining a design thickness. Factors were discovered which indicate improvements are needed in areas other than the determination of thickness.

In general, it can be said that the FAA6C design method is adequate from the standpoint of thickness design. This must be viewed with the limitations of the data set in mind. A majority of the pavements were only half way (or less) through the design life. Extrapolating the damage values however indicated that a majority would over perform. A fact that tends to support the adequacy of the design is that no sections were encountered where premature load failures had occurred.

RECOMMENDATIONS

The major recommendations of this study involve verification of the field data collected. It is recommended that field cores be obtained from the pavement sections included in this study. These cores would provide valuable information in order to support or negate the findings of this report. Along with the cores of the pavement sections, it is recommended that a traffic survey be performed at each airport. The traffic survey would consist of monitoring the number, type, and flight number (where possible) of aircraft passing over the test sections. Subsequent to the traffic survey, weight data could be obtained from the airlines based on the traffic data. These items would provide the means to verify the analysis of this study. The last recommendation for the existing sections is to continue the monitoring of the performance of these pavements. At least one more data point should be obtained in terms of the PCI of the sections. This would provide a measure of the rate of deterioration of the pavement sections.

A final recommendation is to include two more airports in the study. The flexible pavement data are primarily limited to PHX. Another airport with flexible pavement is definitely needed in the data set. Preferably, the airport would be located in the Midwest where the pavements would be subjected to a more representative climate. Concerning the rigid pavements, an airport with both plain-jointed and reinforced pavement is needed with the emphasis on the plain sections. Again, the preferred location is a representative Midwest climate.

Recommendations which are a result of this study are as follows:

a. The flexible pavement design curves should be extended to cover the 100,000-annual-departure-level based on extension of the CBR equation.

b. The use of keyed joints in highly channelized areas subjected to high traffic volumes should be limited even when strong subgrades are anticipated. Investigation of keyed joint performance should be continued. The Corps' criteria for joint types should be incorporated into the FAA design procedure.

c. Consideration should be given to modifying the construction specifications on bituminous concrete material to allow local materials when special conditions exist.

d. A method to check the fatigue life of the AC surface material should be developed and incorporated into the flexible pavement design method. A possible interim solution would be to increase minimum thicknesses.

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APPENDIX A

DATA COLLECTION BOOK

FAA HIGH VOLUME STUDY

Airport: ____

Section No.: ____

Date Surveyed: ______________________________________

Survey Team: ____

I. SECTION INFORMATION

A. Airport Code __ __

B. Date of Survey __ __ __ __.__ __

C. Pavement Use

1. Runway 2. Taxiway 3. Apron 4. Other __

D. Section Identification Number (AP Name ____________) __ __ __

E. Station Location From __ __ __.__ __

To __ __ __.__ __

F. Section Length (ft) __ __ __ __ __

Width (ft) __ __ __ __ __

Area (ft^2) __ __ __ __ __ __ __ __

G. Design Method __

1. AC 150-5320-6C

2. AC 150-5320-6B

3. AC 150-5320-6A

4. Other

H. Design Aircraft __ __

I. Design Life __ __

J. Design Traffic Level (Annual Departures) __ __ __ __ __ __

K. Frost Design Level __

L. Subsurface Drainage __

0. None 3. Pipe Under Drain

1. Daylight 4. Other ______________

2. French Drain ______________________

M. Pavement Type __ __

N. Sketch Cross-Section (Include All Tack and Prime Coats) __

II. PAVEMENT LAYER INFORMATION

A. Third Overlay

1. Date of Construction __ __ __ __.__ __

2. FAA Material Class __ __ __

Specify if Other ______________

____

3. Thickness (in.) __ __.__

4. Design Modulus of Rupture __ __ __

5. In-Place Modulus __ __ __ __

6. Std. Dev. of Modulus __ __.__

7. Bond Type (Conc. Overlay) __

8. Asphalt Properties

a. Date of Test (Yr) __ __ __ __.

b. Percent Asphalt __ __.__

c. Percent Air Voids __ __.__

d. Marshall Stability __ __ __ __

e. Flow __ __

f. Asphalt Penetration __ __ __

g. Asphalt Grade by AC Class __ __ __

h. Asphalt Grade by AR Class __ __ __ __

II. PAVEMENT LAYER INFORMATION

B. Second Overlay

1. Date of Construction __ __ __ __.__ __

2. FAA Material Class __ __ __

   Specify if Other ______________

   ____

3. Thickness (in.) __ __.__

4. Design Modulus of Rupture __ __ __

5. In-Place Modulus __ __ __ __

6. Std. Dev. of Modulus __ __.__

7. Bond Type (Conc. Overlay) __

8. Asphalt Properties

   a. Date of Test (Yr) __ __ __ __.

   b. Percent Asphalt __ __.__

   c. Percent Air Voids __ __.__

   d. Marshall Stability __ __ __ __

   e. Flow __ __

   f. Asphalt Penetration __ __ __

   g. Asphalt Grade by AC Class __ __ __

   h. Asphalt Grade by AR Class __ __ __ __

II. PAVEMENT LAYER INFORMATION

C. First Overlay

1. Date of Construction ___ ___ ___ ___.___ ___

2. FAA Material Class ___ ___ ___

   Specify if Other ______________________

   ____

3. Thickness (in.) ___ ___.___

4. Design Modulus of Rupture ___ ___ ___

5. In-Place Modulus ___ ___ ___ ___

6. Std. Dev. of Modulus ___ ___.___

7. Bond Type (Conc. Overlay) ___

8. Asphalt Properties

   a. Date of Test (Yr) ___ ___ ___ ___.

   b. Percent Asphalt ___ ___.___

   c. Percent Air Voids ___ ___.___

   d. Marshall Stability ___ ___ ___ ___

   e. Flow ___ ___

   f. Asphalt Penetration ___ ___ ___

   g. Asphalt Grade by AC Class ___ ___ ___

   h. Asphalt Grade by AR Class ___ ___ ___ ___

II. PAVEMENT LAYER INFORMATION

D. Original or Reconstructed Surface

1. Date of Construction _ _ _ _._ _

2. FAA Material Class _ _ _

   Specify if Other ______________

   ____

3. Thickness (in.) _ _._

4. Design Modulus of Rupture _ _ _

5. In-Place Modulus _ _ _ _

6. Std. Dev. of Modulus _ _._

7. Bond Type (Conc. Overlay) _

8. Asphalt Properties

   a. Date of Test (Yr) _ _ _ _.

   b. Percent Asphalt _ _._

   c. Percent Air Voids _ _._

   d. Marshall Stability _ _ _ _

   e. Flow _ _

   f. Asphalt Penetration _ _ _

   g. Asphalt Grade by AC Class _ _ _

   h. Asphalt Grade by AR Class _ _ _ _

II. PAVEMENT LAYER INFORMATION

E. Base Course

1. Date of Placement __ __ __ __.__ __
2. FAA Material Class __
3. Thickness (in.) __ __.__
4. K-Value __ __ __
5. K_f (Frost Period) __ __ __
6. Modulus of Rupture __ __ __
7. CBR (Percent) __ __ __
8. Marshall Stability (lb) __ __ __ __
9. In-situ Density (Percent of Optimum) __ __ __.__
10. In-situ Moisture Content (Percent) __ __.__

F. Subbase Layer 1

1. Date of Construction __ __ __ __.__ __
2. FAA Material Class __
3. Thickness (in.) __ __.__
4. CBR (Percent) __ __ __
5. In-situ Dry Density (Percent Optimum) __ __ __.__
6. In-situ Moisture Content (Percent) __ __.__

G. Subbase Layer 2

1. Date of Construction __ __ __ __.__ __
2. FAA Material Class __
3. Thickness (in.) __ __.__
4. CBR (Percent) __ __ __
5. In-situ Dry Density (Percent of Optimum) __ __ __.__
6. In-situ Moisture Content (Percent) __ __.__

II. PAVEMENT LAYER INFORMATION

H. Subbase Layer 3

1. Date of Construction __ __ __ __.__ __
2. FAA Material Class __
3. Thickness (in.) __ __.__
4. CBR (Percent) __ __ __
5. In-situ Dry Density (Percent of Optimum) __ __ __.__
6. In-situ Moisture Content (Percent) __ __.__

I. Subgrade Layer

1. Date of Construction __ __ __ __.__ __
2. Unified Soil Class __ __
3. Modifier Applied __
4. CBR (Percent) __ __ __
5. K-Value (pci) __ __ __
6. PI __ __
7. LL __ __
8. Optimum Moisture Content (Percent) __ __.__
9. In-situ Moisture Content (Percent) __ __.__
10. In-situ Dry Density (Percent Optimum) __ __ __.__
11. Depth of Water Table __ __ __

J. Subgrade Layer

a. Original Soil Properties

1. Unified Soil Class __ __
2. CBR __ __ __
3. PI __ __
4. LL __ __
5. Moisture Content __ __.__

6. Density ___ ___ ___.___

7. Shear Strength (TSF) ___ ___ ___

K. Joint Design (Concrete Pavement)

1. Slab Length ___ ___.___

2. Slab Width ___ ___.___

3. Longitudinal Joint Design Paving Intermed. ___ ___

4. Transverse Joint Design ___ ___

5. Original Filler ___

6. Average Joint Width (Transverse) ___

III. TRAFFIC

A. Present Mission

1. Traffic Dates — From ____.__ To ____.__

2. Traffic Area _

3.

	Aircraft Type	Percent Traffic	Average Gross Weight
a.	__	__	______
b.	__	__	______
c.	__	__	______
d.	__	__	______
e.	__	__	______
f.	__	__	______
g.	__	__	______
h.	__	__	______
i.	__	__	______
j.	__	__	______

4. Average Annual Operations ______

III. TRAFFIC

B. Second Mission

1. Traffic Dates From _ _ _ _._ _

To _ _ _ _._ _

2. Traffic Area _

3.

	Aircraft Type	Percent Traffic	Average Gross Weight
a.	_ _	_ _	_ _ _ _ _ _
b.	_ _	_ _	_ _ _ _ _ _
c.	_ _	_ _	_ _ _ _ _ _
d.	_ _	_ _	_ _ _ _ _ _
e.	_ _	_ _	_ _ _ _ _ _
f.	_ _	_ _	_ _ _ _ _ _
g.	_ _	_ _	_ _ _ _ _ _
h.	_ _	_ _	_ _ _ _ _ _
i.	_ _	_ _	_ _ _ _ _ _
j.	_ _	_ _	_ _ _ _ _ _

4. Average Annual Operations _ _ _ _ _ _

III. TRAFFIC

C. Third Mission

1. Traffic Dates From __ __ __ __.__ __

To __ __ __ __.__ __

2. Traffic Area __

3.

	Aircraft Type	Percent Traffic	Average Gross Weight
a.	__ __	__ __	__ __ __ __ __ __
b.	__ __	__ __	__ __ __ __ __ __
c.	__ __	__ __	__ __ __ __ __ __
d.	__ __	__ __	__ __ __ __ __ __
e.	__ __	__ __	__ __ __ __ __ __
f.	__ __	__ __	__ __ __ __ __ __
g.	__ __	__ __	__ __ __ __ __ __
h.	__ __	__ __	__ __ __ __ __ __
i.	__ __	__ __	__ __ __ __ __ __
j.	__ __	__ __	__ __ __ __ __ __

4. Average Annual Operations __ __ __ __ __ __

IV. PAVEMENT MAINTENANCE

1. Joint/Crack Filling Interval (Average Time Between Projects) — —

2. Slab Replacement/Patching (Specify Construction Dates)

   a. Number of Slabs/sq ft — — — —

   b. Average Age — —

3. Surface Seals No Aggregate (Mean Age) — —

4. Surface Seal (With Aggregate) — —

5. Spall Repairs

   a. Number of Slabs Percent Area — — —

   b. Average Age — —

6. Other Maintenance (Specify)

V. CONDITION SURVEY INFORMATION

1. PCI ___ ___ ___
2. PCI Date ___ ___ ___ ___.___ ___
3. Standard Deviation ___ ___.___
4. Total Number Sample Units ___ ___ ___
5. Number of Random Units Surveyed ___ ___ ___
6. Number of Additional Units Surveyed ___ ___ ___
7. Statistical Sampling Satisfied (Y/N) ___

VI. DISTRESS DATA

A. Asphalt/Concrete	Low	Medium	High
1. Alligator/Blowup	__ __.__ __	__ __.__ __	__ __.__ __
2. Bleeding/Corner Break	__ __.__ __	__ __.__ __	__ __.__ __
3. Block Cracking/Longitudinal, Transverse and Diagonal Cracks	__ __.__ __	__ __.__ __	__ __.__ __
4. Corrugation/Durability ("D") Cracking	__ __.__ __	__ __.__ __	__ __.__ __
5. Depression/Joint Seal Damage	__ __.__ __	__ __.__ __	__ __.__ __
6. Jet Blast Erosion/Small Patching	__ __.__ __	__ __.__ __	__ __.__ __
7. Joint Reflection Cracking/Large Patching	__ __.__ __	__ __.__ __	__ __.__ __
8. Longitudinal and Transverse Cracking/Pop-outs	__ __.__ __	__ __.__ __	__ __.__ __
9. Oil Spillage/Pumping	__ __.__ __	__ __.__ __	__ __.__ __
10. Patching/Scaling, Map Cracking, and Crazing	__ __.__ __	__ __.__ __	__ __.__ __
11. Polished Aggregate/ Settlement or Faulting	__ __.__ __	__ __.__ __	__ __.__ __
12. Raveling and Weathering/ Shattered Slab, Intersecting Cracks	__ __.__ __	__ __.__ __	__ __.__ __
13. Rutting/Shrinkage Cracks	__ __.__ __	__ __.__ __	__ __.__ __
14. Shoving/Spalling (Transverse and Longitudinal Joint)	__ __.__ __	__ __.__ __	__ __.__ __
15. Slippage/Spalling (Corner)	__ __.__ __	__ __.__ __	__ __.__ __
16. Swell	__ __.__ __	__ __.__ __	__ __.__ __

VII. PAVEMENT EVALUATION INFORMATION

A. Evaluation Date __ __ __ __.__ __

B. Test Method __

C. Evaluation Method __

D. Average DSM __ __ __ __

Standard Deviation DSM __ __ __ __.__

E. Average $^{\Delta}$Basin $^{\Delta}$Sen 1 __ __.__

2 __ __.__

3 __ __.__

4 __ __.__

5 __ __.__

6 __ __.__

7 __ __.__

F. Average Load Transfer (Longitudinal) Percent __ __

G. Average Load Transfer (Transverse) Percent __ __

H. Basin Area __ __ __

I. Basin Difference __ __ __

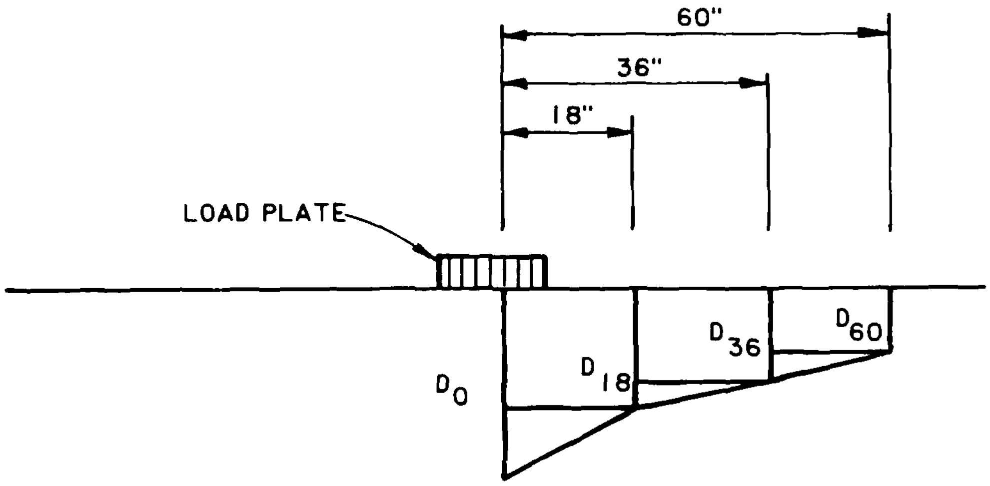
APPENDIX B

PROCEDURE FOR SELECTION OF REPRESENTATIVE DEFLECTION BASIN

In order to select a representative deflection basin to use in the evaluation of the test sections, it was necessary to develop a mathematical procedure to select a basin which was representative from a group of tests. The parameters for selecting a basin include the magnitude of the deflection values and the shape of the basin.

In previous work it was found that using the arithmetic average over a series of tests was not a good indicator of the deflection at a given point. This is due to the fact that the arithmetic average is highly influenced by individual readings which are very high or low. Thus, the first step was to determine a parameter for use in obtaining average deflection values. Since the primary concern was the effect of high or low values on the average calculation, it was decided that the geometric or logrithmic average would be a better parameter to use due to the fact that it is not affected as much by the outlying values. The next step was to determine the parameter to use which would account for the shape of the basin. Previous work in this field has shown that a parameter measuring the area of the deflection basin is an indicator of the pavement's performance. It was determined that such a parameter could be used as a measure of the basin shape. Determination of the area factor is illustrated in Figure B-1.

The data collected for this study included a deflection basin and dynamic stiffness modulus (DSM) for each test location. The DSM is the slope of the load-deflection curve. The DSM is calculated from a plot made at the time of the test. A typical plot is shown in Figure B-2. The values



$$AREA = 9(D_0 - D_{18}) + 18D_{18} + 9(D_{18} - D_{36}) + 18D_{36} + 12(D_{36} - D_{60}) + 24D_{60}$$

Figure B-1. Illustration of determining the area factor

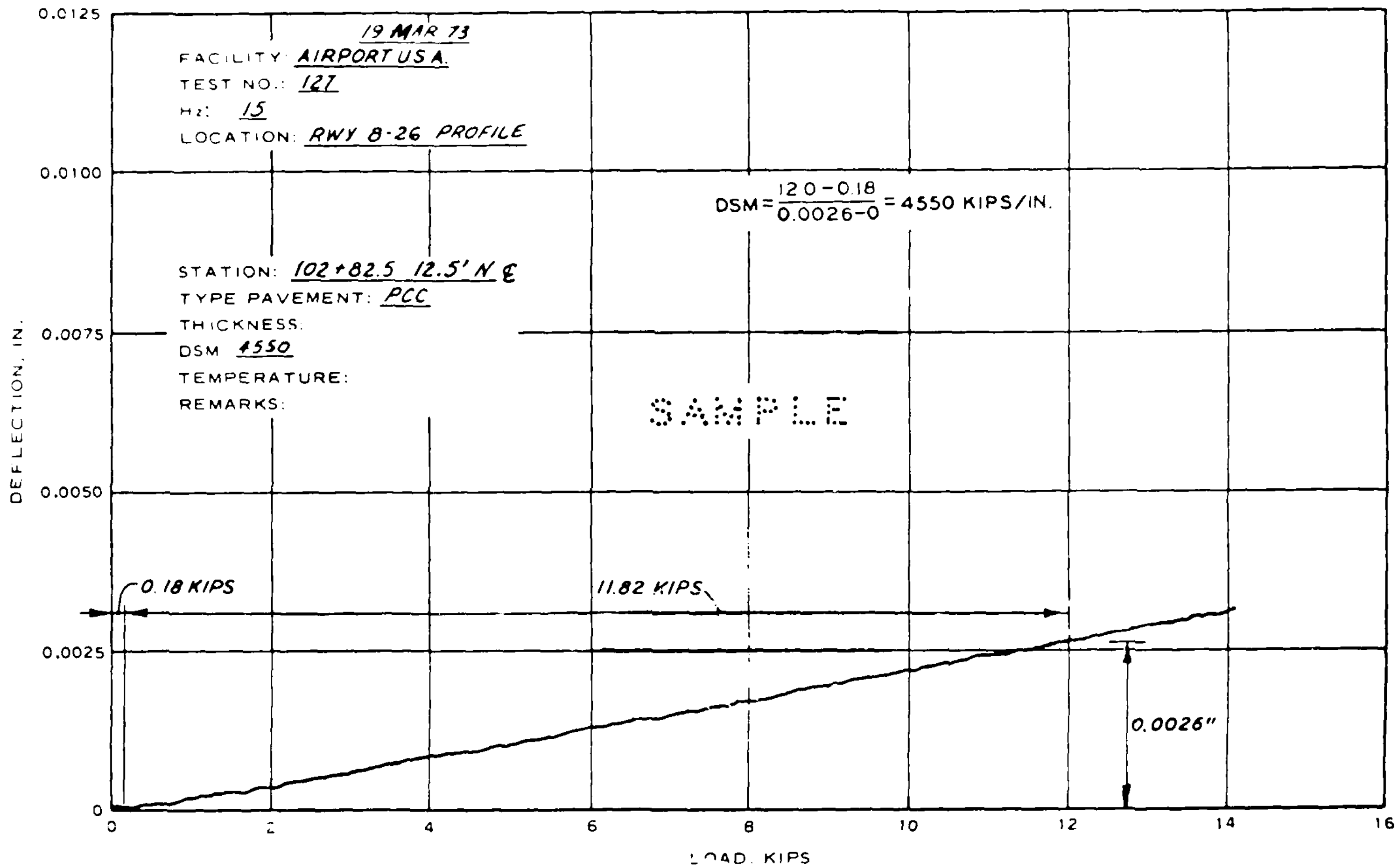


Figure B-2. Example load versus deflection plot used in determining the DSM collected on a given section are all obtained by performing the test at a frequency of 15 Hz; however, the load at each test location is not the same. Thus, it is necessary to normalize the test data so that the deflection values and DSM's can be compared. The procedure to normalize the test data was as follows:

a. The test location with the maximum load was determined.

b. The relationship between load and deflection was assumed to be linear, and the deflections for each test location were multiplied by the ratio of the maximum load to the test load. Once the normalized data was obtained, the process of obtaining the representative basin could be performed.

The selection process included the following steps:

a. Normalize the deflection basin data.

b. Calculate the area of each normalized basin.

c. Calculate the geometric average of each deflection location (deflections were taken at 0, 18, 36, and 60 in.) and the area.

d. Select the basin which was closest to the mean basin using the defined error function.

The selection of the representative basin involved selecting the test location which was closest to the mean basin. In order to make this determination, it was necessary to define an error function and select the location with the smallest error. The function used can be described as follows:

```
err = (((DSM(J) - ADSM)/ADSM)**2 + ((DO(J) - ADO)/ADO)**2 + ((D18(J) -
      AD18)/AD18)**2 + ((D36(J) - AD36)/AD36)**2 + ((D60(J) - AD60)/
      AD60)**2 + ((AREA(J) - AAREA)/AAREA)**2)*100
```

where

err = error function

DSM(J) = DSM of the j^{th} test location

DO(J) = deflection at 0 in. of the j^{th} test location

D18(J) = deflection at 18 in. of the j^{th} test location

D36(J) = deflection at 36 in. of the j^{th} test location

D60(J) = deflection at 60 in. of the j^{th} test location

AREA(J) = basin area of the j^{th} test location

ADSM = geometric average of the DSM's

AD0 = geometric average of 0-in. deflections

AD18 = geometric average of the 18-in. deflections

AD36 = geometric average of the 36-in. deflections

AD60 = geometric average of the 60-in. deflections

AAREA = geometric average of the basin areas

A computer program was written to process the information collected and select the representative basin. An output from this program is shown in Figure B-3. The test location with the smallest err function was used in the evaluation of the section.

Figure B-3. Example output from DSM sorting program

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