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TECHNICAL MEMORANDUM

CIVIL ENGINEERING LABORATORY CEL PORT HUENEME, CALIF.

title: RUNWAY FRICTION MEASUREMENTS AND PAVEMENT CONDITION SURVEY, MCALF CAMP PENDLETON, CALIFORNIA

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Runway Friction Measurements and Pavement Condition Survey, MCALF Camp Pendleton, California

Technical Memorandum TM 76-53-2

by

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ABSTRACT

The results of friction tests and a condition survey on the runway at the U.S. Marine Corps Auxiliary Landing Field, Camp Pendleton, California are presented. The survey established statistically-based condtion numbers (weighted defect densities) which were direct indicators of the condition of the individual pavement facilities. The runway friction measurements showed the aircraft hydroplanning/skidding potential of the field. The results of the condition survey show no visible pavement defects on Runway 3-21. Runway friction measurements show that some portions of the runway have marginal friction resistance due to poor transverse drainage.

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INTRODUCTION

In October 1969, the Naval Facilities Engineering Command authorized a series of periodic pavement condition surveys to be conducted at Naval and Marine Corps Air Stations. The purpose of these condition surveys was to determine the suitability of the airfield pavement surfaces for aircraft operations, and to establish a uniform basis for maintenance and repair efforts. A pavement condition survey was conducted at the Marine Corps Auxiliary Landing Field, Camp Pendleton, California by the Naval Civil Engineering Laboratory* in July 1969 and reported in reference (1). Commencing in FY-75, pavement condition surveys will be performed only on active runways and increased emphasis will be placed on determining runway friction coefficients. During the month of March, 1976 a second pavement condition survey and runway friction measurements were made at MCALF Camp Pendleton by CEL. The survey consisted of a sophisticated, statistically-based procedure of pavement defect measurement which permitted the establishement of condition numbers (weighted defect densities) which are direct indicators of the condition of airfield pavement facilities. Runway friction measurements were made using a Mu-Meter, a small friction-measuring trailer. Additional survey efforts included photographic coverage of pavement defect types, preparation of a construction history of the airfield, compilation of current aircraft traffic data, summarization of climatological data, and delineation of requirements for future pavement evaluation efforts at the station.

BACKGROUND

The U.S. Marine Corps Auxiliary Landing Field, Camp Pendleton, is located in San Diego County, eight miles inland from U.S. Highway 101 and the Pacific Ocean adjacent to Oceanside, California. The airfield has one runway, Runway 3-21, which is 6,000 feet long. The field was constructed in the flood plain of the Santa Margarita River.

CONSTRUCTION HISTORY

Original construction of the asphaltic concrete (AC) runway was completed in 1942. Construction of the AC taxiways was also accomplished in 1942. Portland cement concrete additions to the parking apron were constructed in 1956 and 1965. All of the asphaltic concrete pavements were overlaid in 1972. A complete history of construction and recorded maintenance is provided in Appendix A.

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* On 1 January 1974, redesignated the Civil Engineering Laboratory (CEL) of the Naval Construction Battalion Center, Port Hueneme, California

CURRENT AIRCRAFT TRAFFIC

A tabulation of the number of aircraft operations for a 12-month period is shown in Table 1. Table 2 lists the aircraft normally based at the station and transient aircraft observed using the station.

CLIMATOLOGICAL DATA

A summary of climatological data for MCALF Camp Pendleton is presented in Appendix B.

PAVEMENT CONDITION SURVEY

Condition Survey Procedure

The condition survey procedure used at MCALF Camp Pendleton was developed by CEL in 1968. This procedure permits the establishment of condition numbers (weighted defect densities) which are direct indicators of the pavement surface condition. A complete description of the pavement condition survey procedure is presented in Appendix C. It should be noted that Appendix C describes procedures for both asphaltic concrete (AC) and portland cement concrete (PCC) pavements and includes other pavement facilities in addition to runways. At MCALF Camp Pendleton only the runway was surveyed. Discrete areas were selected after a preliminary inspection of the runway. The location of the discrete area is shown in Figure 1. Defect severity weights as used at MCALF Camp Pendleton are given in Table 3.

Results of Condition Survey

The results of the survey of each discrete area are shown in the Discrete Area Defect Summary sheet, page 21 of this report. The Discrete Area Defect Summary includes a narrative description of the pavement defects encountered. A Facility Defect Summary is shown on page 23.

The total weighted defect density for the only discrete area surveyed at MCALF Camp Pendleton is 0.00A indicating no visual defects were noted. A graphic analysis of the change is pavement condition since the last condition survey is given in the Discrete Area Condition analysis sheet on page 22.

RUNWAY FRICTION MEASUREMENTS

The skid resistance/hydroplaning characteristics of the runway surface were evaluated with a Mu-Meter friction measuring device. The test program consisted of field measurements of skid resistance/hydroplaning potential under standardized, artificially-wet conditions. In addition, both transverse and longitudinal pavement slopes were measured at intervals along the runway centerline to evaluate surface drainage characteristics.

Test Locations

Four test sections on the runway were selected to provide a representative sample of the skid resistance properties of the runway. The test section layout is shown in Figure 2. The test sections were selected to provide pavement friction data in: (a) the aircraft touchdown areas, and (b) the runway interior where maximum braking is normally developed.

Test Equipment

The principal items of test equipment used were the Mu-Meter, a tank truck for water application, and a device for measuring pavement slopes.

The Mu-Meter is a small trailer, designed and manufactured by M. L. Aviation of Maidenhead, England. It measures the side-force friction coefficient generated between the pavement surface and the pneumatic tires on the two wheels which are set at a fixed toe-out (yaw angle) to the line of drag. The Mu-Meter is a continuous recording device that graphically records the coefficient of friction, mu* versus the distance traveled along the pavement.

The water truck provided by the station was equipped with a spray bar and pumping system calibrated to place 0.1 inch of water on the skid test strip with each pass.

The slope measuring device consisted of a rectangular aluminum section (10 feet long, 1 inch thick, and 4 inches high) with machinists levels attached to define slope from 0 to 2.5 percent.

Test Procedures

The field test procedures utilized at MCALF Camp Pendleton are those outlined in NAVFAC INSTRUCTION 1132.14B. The methods were:

(1) A preliminary reconnaissance of the pavement surfaces was made and representative test areas (each 1000 feet long) were selected for skid testing.

(2) Transverse and longitudinal slope measurements were made at 500 foot intervals along the runway centerline. Transverse measurements were

* The symbol mu or μ designates the coefficient of friction which is a constant used to represent the ratio of frictional force to force normal to the pavement surface.

made at two places on each side of the centerline covering a distance of approximately 20 feet. Longitudinal measurements were made on the centerline at the same stations where the transverse measurements were made.

(3) The water truck, which had been calibrated to apply 0.1 inch of water each time it passed over a test strip, made two passes over the test strip.

(4) Mu-Meter runs at 40 miles per hour, 1.2 times the theoretical hydroplaning speed for this vehicle, were initiated immediately after completion of the second water truck pass. Mu-Meter runs were made in alternate directions at convenient time intervals until a dry pavement condition was reached or 30 minutes had elapsed.

(5) All water truck and Mu-Meter operations were measured to the nearest second using a stop watch.

Runway Friction Test Results

The pavement skid resistance results are reported in terms of mu, coefficient of friction, as measured by the Mu-Meter. The actual friction coefficient versus distance traces as recorded by the Mu-Meter during the first run after wetting for each test section are shown in Figures 3 and 4. The traces show the variation of friction coefficient within each test section. Sharp dips in the curves indicate areas of lower friction values. At MCALF Camp Pendleton the low-coefficient areas correspond to areas of localized ponded water and poor transverse drainage. Appendix D contains all test results for each Mu-Meter test section.

Figures 5 and 6 show changes in surface friction coefficient versus time after wetting for each pavement section tested. (Note that the time intervals after wetting at which skid tests were made often differed from one test to another, due to small variations in water truck speed and Mu-Meter adjustments.) These graphs demonstrate the natural drainage characteristics of the runway surface and the time required to return to an essentially dry condition or a consistently high friction coefficient.

A summary of test data and an associated Mu-Meter aircraft pavement rating guide are presented in Tables 4 and 5. The rating guide was developed from the results of an Air Force Weapons Laboratory research program and a joint NASA/AF/FAA test program using actual aircraft correlated with Mu-Meter skid coefficient results. The rating guide has been modified as the result of extensive testing by the Air Force Civil Engineering Center (Reference 2). While the current state-of-the-art does not allow a more precise delineation of exact aircraft responses, the rating guide provides a good rule-of-thumb for interpretation of test data.

Table 4 presents the average skid resistance values for each skid test section. From the curves presented in Figures 5 and 6, values of mu were determined for time periods of 3, 15, and 30 minutes after water was applied. The coefficient determined at 3 minutes after water application corresponds to a wet runway condition and the coefficient determined at 15 minutes after water application corresponds to a damp runway condition. At 30 minutes after wetting the friction coefficient can be considered a dry pavement condition. The curves in Figures 5 and 6 were extrapolated, if necessary, to obtain friction coefficients at those time intervals. These data indicate the rate the pavement skid resistance properties were recovered after the test sections were wetted. By comparing the actual values of mu shown in Table 4 with the expected aircraft response in the associated rating guide, Table 5, it is possible to evaluate aircraft hydroplaning potential.

Measured pavement slopes are shown in Figure 7. Positive transverse slopes indicate that water drains to the runway edge without crossing the centerline, while negative transverse slopes indicate that water crosses the runway centerline before draining to the edge. Positive longitudinal slopes indicate rising pavement grades in the direction of increasing runway stations while negative longitudinal slopes indicate falling grades in the direction of increasing stations.

DISCUSSION OF RESULTS

Condition Survey Results

The change in total weighted defect density on Runway 3-21 reflects the overlay placed in 1972. Although four years old at the time of this survey, the overlay surface had no visible defects.

Runway Friction Measurements

The wet (3 minute) friction coefficients given in Table 4 show that two of the four skid test sections (2 and 4) have frictional resistance which indicates a potential for hydroplaning by some aircraft. These results are attributed to localized ponding of water in these sections as shown in Figure 8. The center 20 feet of the runway has an average transverse slope of 0.3 percent with individual measurements ranging from 0.0 (level) to 0.8 percent. This variation is assumed to be the result of inadequate grade control during construction of the overlay in 1972.

RECOMMENDATIONS

Although some areas of Runway 3-21 at MCALF Camp Pendleton have the potential to cause some aircraft to hydroplane, no remedial measures are recommended at this time. The majority of aircraft operations at this facility are helicopters and light observation planes. Hydroplaning problems are, of course, nonexistent for helicopters and very unlikely for the OV-10 observation planes. Transient cargo and training aircraft, for example - T-39, C-130, C-131, have the potential to hydroplane on this runway during rainfall conditions. Pilots should be cautioned to use wet landing techniques when puddles are evident.

A evaluation of the load carrying capabilities of the airfield pavements at MCALF Camp Pendleton was made by the Western Division, Naval Facilities Engineering Command in March 1975 and reported in reference 3. No further evaluation effort is recommended at this time.

REFERENCES

1. U.S. Naval Civil Engineering Laboratory. Technical Note N-1088: Airfield Pavement Condition Survey, U.S. Marine Corps Auxiliary Landing Field, Camp Pendleton, California by D. J. Lambiotte, Port Hueneme, California, April 1970.

2. Air Force Civil Engineering Center. Technical Report TR-75-3: Analysis of the Standard USAF Runway Skid Resistance Tests by John H. Williams, CAPT., USAF, May 1975.

3. Western Division, Naval Facilities Engineering Command. Report on Airfield Pavement Load Carrying Capabilities, Marine Corps Auxiliary Landing Field, Camp Pendleton, California, March 1975.

TABLE 1. AIRCRAFT OPERATIONS DATA
USMCALF CAMP PENDLETON, CA

Date	Landings and Takeoffs	Touch and Go	Total Monthly Operations
February 1975	2,013	3,552	5,565
March	1,890	3,303	5,193
April	2,295	3,620	5,915
May	2,870	3,470	6,340
June	1,897	1,886	3,783
July	2,388	4,515	6,903
August	3,165	3,146	6,311
September	1,973	2,932	4,905
October	2,212	3,089	5,301
November	1,950	2,685	4,635
December	2,160	2,366	4,526
January 1976	2,121	2,356	4,477
Annual Totals	26,934	36,920	63,854
Average Monthly Operations	2,245	3,077	5,321

TABLE 2. AIRCRAFT USING USMCALF
CAMP PENDLETON, CA

Type of Operation	Aircraft Type
Touch and Go:	AH-1, UH-1E, OV-10
Landings and Takeoffs:	H-1, H-2, H-3, H-46, H-53, LOH-58, C-1, C-117, C-118, C-130, C-131, 0-1, OV-10 T-28, T-39, S-2, V-3, V-11

TABLE 3. DEFECT SEVERITY WEIGHTS

AIRFIELD: USMCALF CAMP PENDLETON, CALIFORNIA

Asphaltic Concrete		Portland Cement Concrete	
Defect	Weight	Defect	Weight
Depression	9.0	Depression	9.0
Rutting	9.0	Shattered Slab	9.0
Broken-up Area	9.0	Faulting	8.5
Faulting	8.5	Spalling	7.5
Raveling	7.0	Scaling	7.0
Erosion-Jet Blast	7.5	"D-Line" Cracking	6.5
Longitudinal, Transverse, or Longitudinal Construction Joint Crack	2.5	Pumping	3.5
Pattern Cracking	2.5	Poor Joint Seal	2.5
Patching	3.0	Corner Break	2.5
Reflection Crack	1.0	Intersecting Crack	2.5
Oil Spillage	1.5	Longitudinal or Transverse Crack	1.0

TABLE 4. RUNWAY FRICTION MEASUREMENT SUMMARY
USMCALF CAMP PENDLETON, CA

Test Location	Average Friction Coefficients		
	3 Min. (Mu)	15 Min. (Mu)	30 Min. (Mu)
Runway 3-21			
Test Section 1	0.60	0.85	0.85
Test Section 2	0.43	0.63	0.68
Test Section 3	0.55	0.87	0.87
Test Section 4	0.42	0.66	0.72

TABLE 5. MU-METER PAVEMENT RATING GUIDE

Three Minute Mu Value	Hydroplaning potential
Greater than 0.5	No hydroplaning problems expected
0.4 to 0.5	Hydroplaning potential for some aircraft
Less than 0.4	High hydroplaning potential

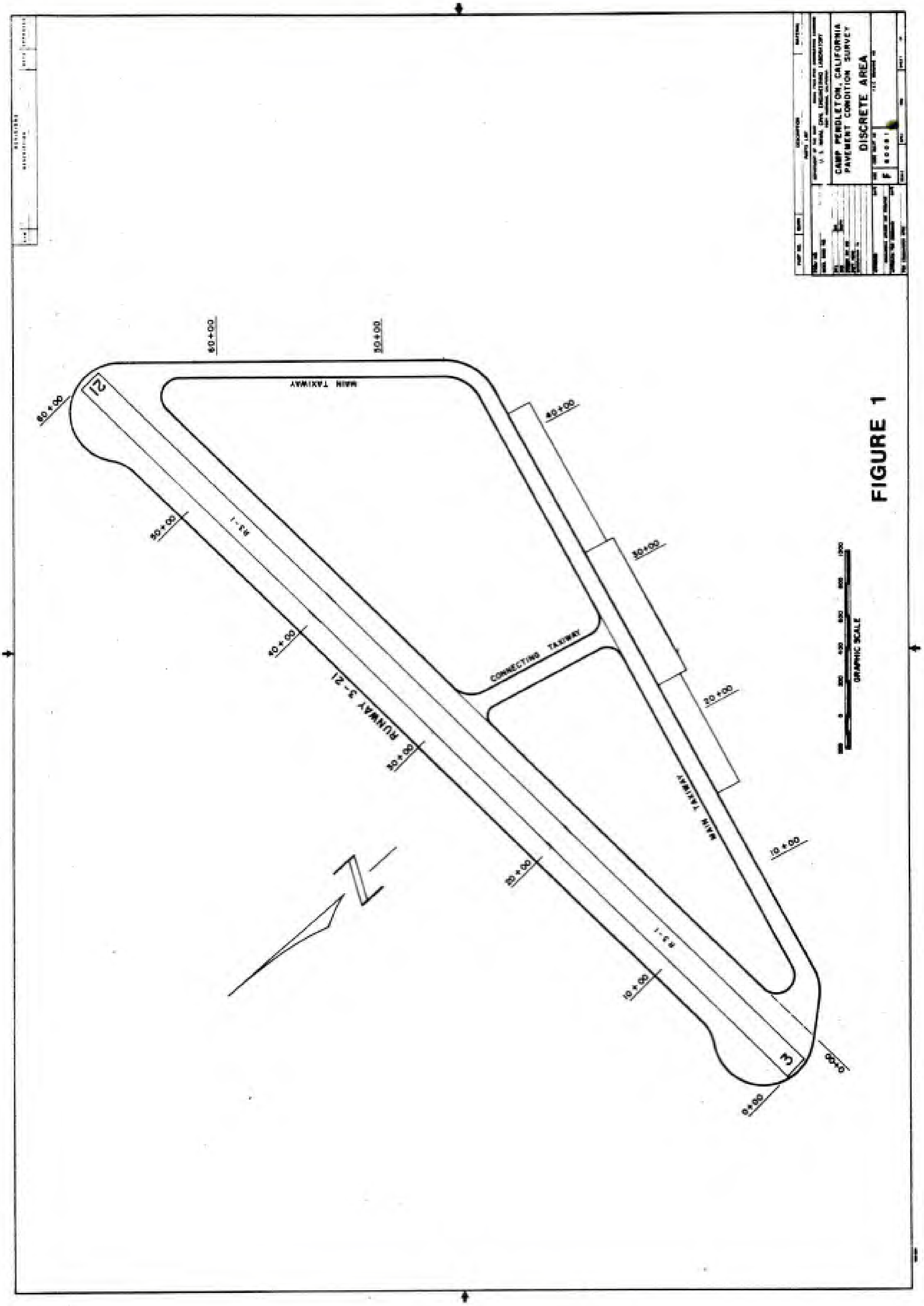
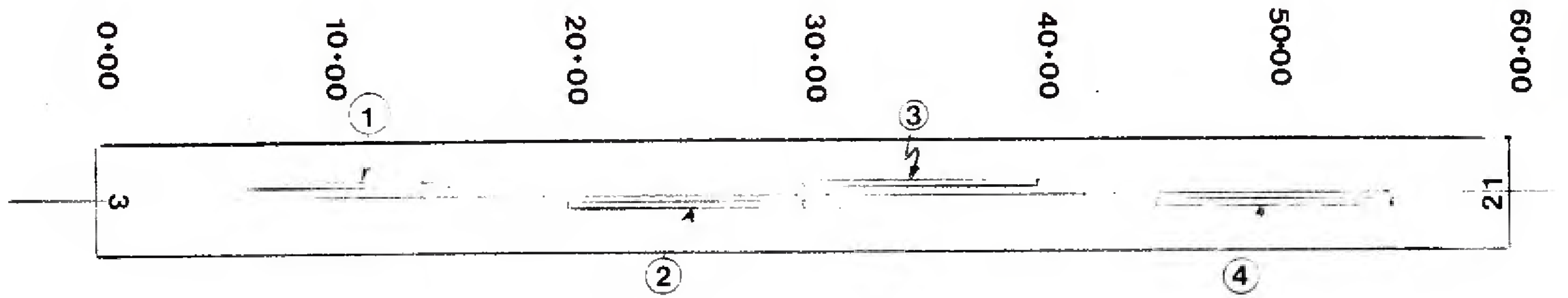

CAMP PENDLETON, CALIFORNIA
PAVEMENT CONDITION SURVEY
DISCRETE AREA
MAIN TAXIWAY
MAIN TAXIWAY
CONNECTING TAXIWAY
RUNWAY 3-21
R3-1
R3-1
21
3
0+00
10+00
20+00
30+00
40+00
50+00
60+00
GRAPHIC SCALE

FIGURE 1



No Scale

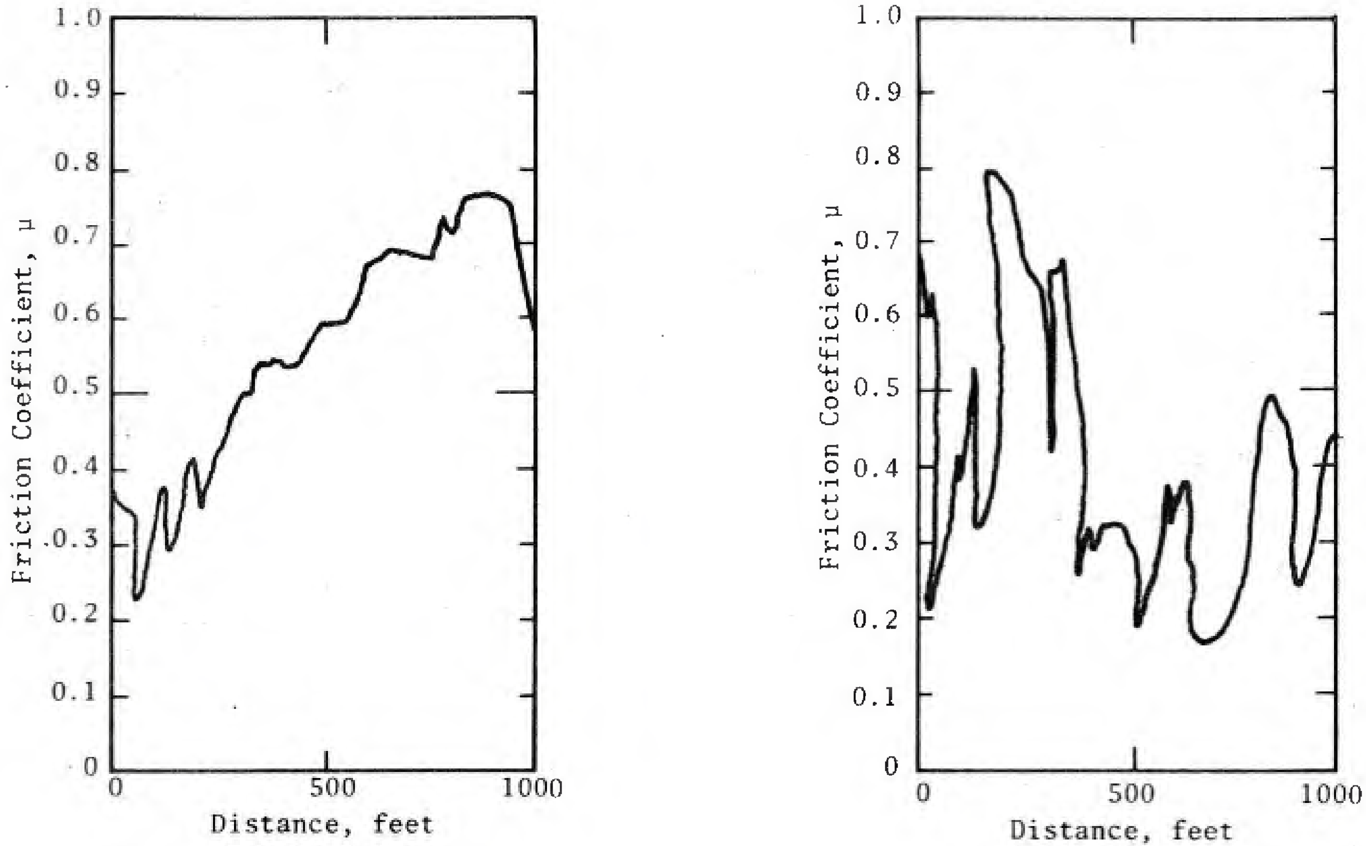
Runway	Test Location	Station	Offset From Center Line
Runway 3-21	1	5+00 to 15+00	10' Left
	2	20+00 to 30+00	10' Right
	3	30+00 to 40+00	10' Left
	4	45+00 to 55+00	10' Right

Note: Only runway shown for clarity.

FIGURE 2

FRICTION TEST LOCATIONS

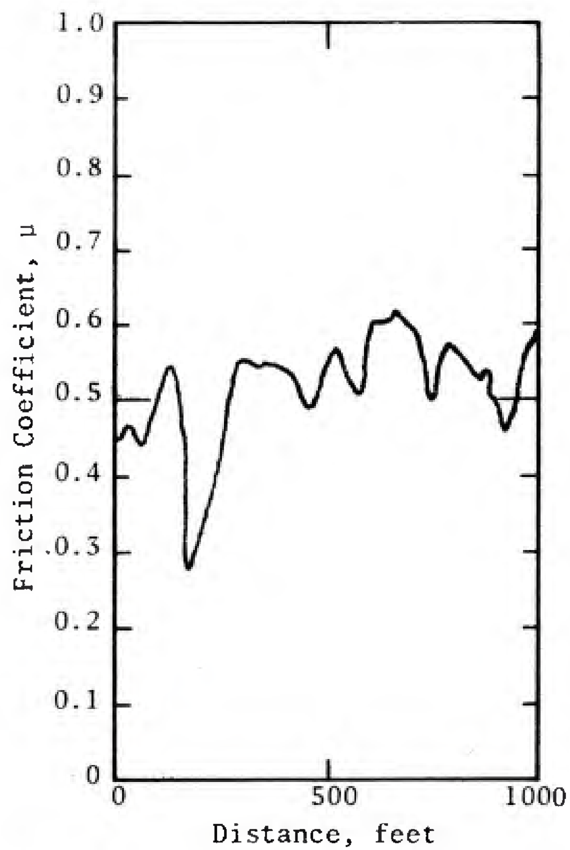
USMCALF CAMP PENDLETON, CALIF.



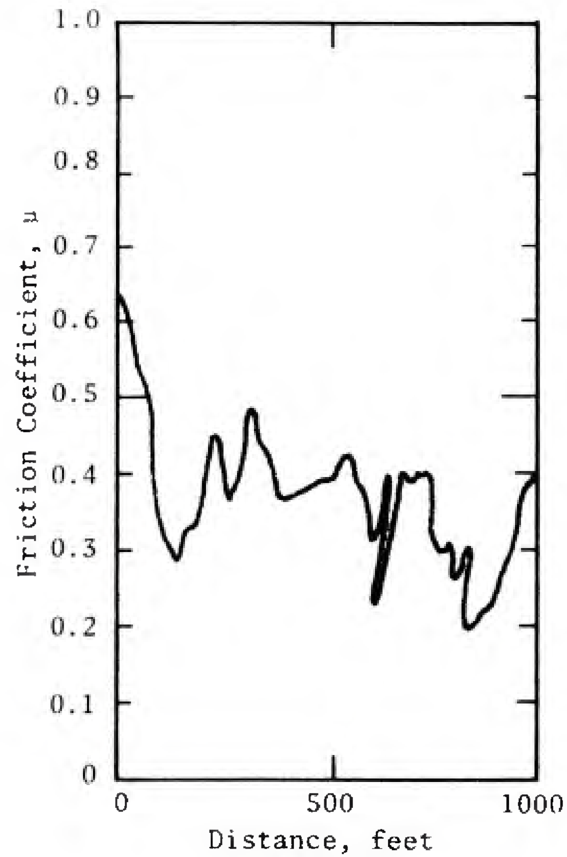
Runway 3-21
Test Section 1, Run 1

Runway 3-21
Test Section 2, Run 1

Figure 3. Friction Coefficient versus Distance
USMCALF Camp Pendleton, CA

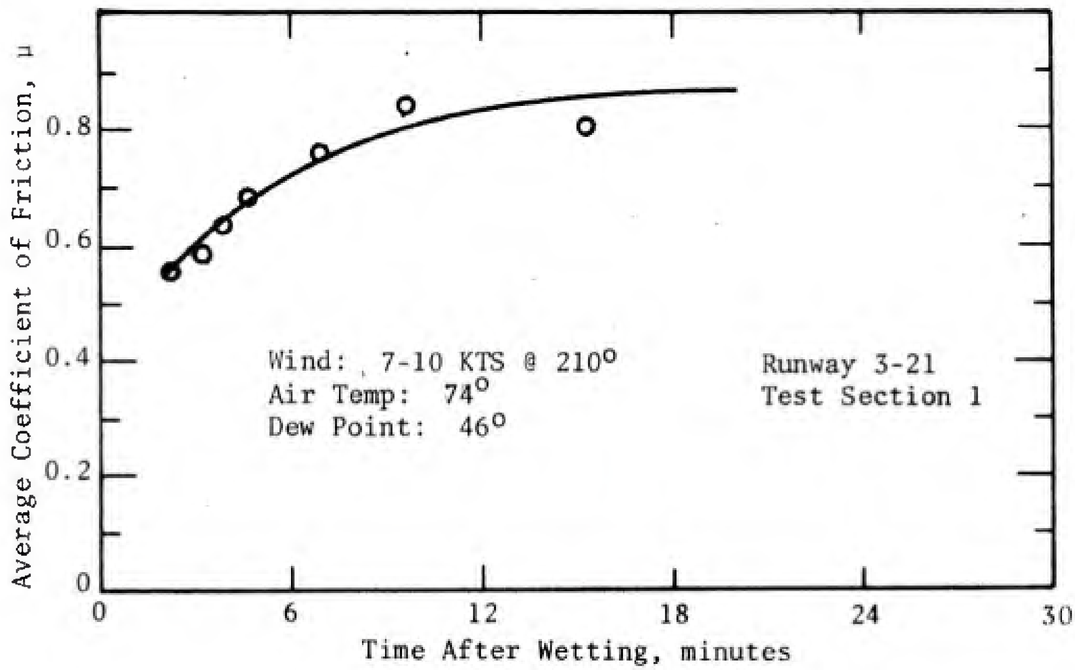


Runway 3-21
Test Section 3, Run 1



Runway 3-21
Test Section 4, Run 1

Figure 4. Friction Coefficient versus Distance
USMCALF Camp Pendleton, CA



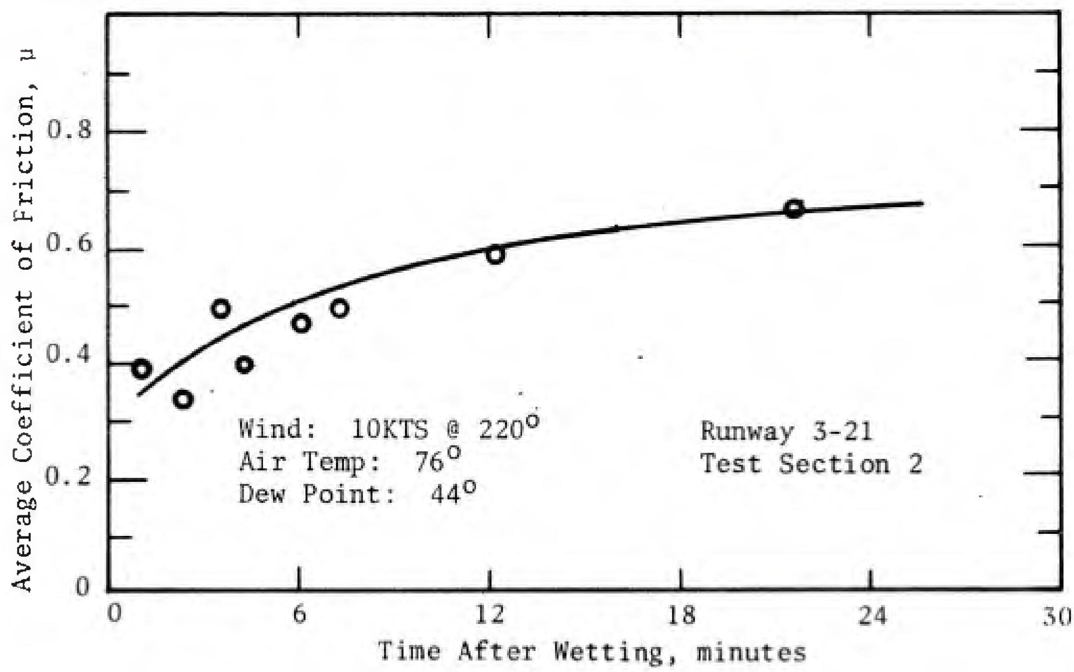
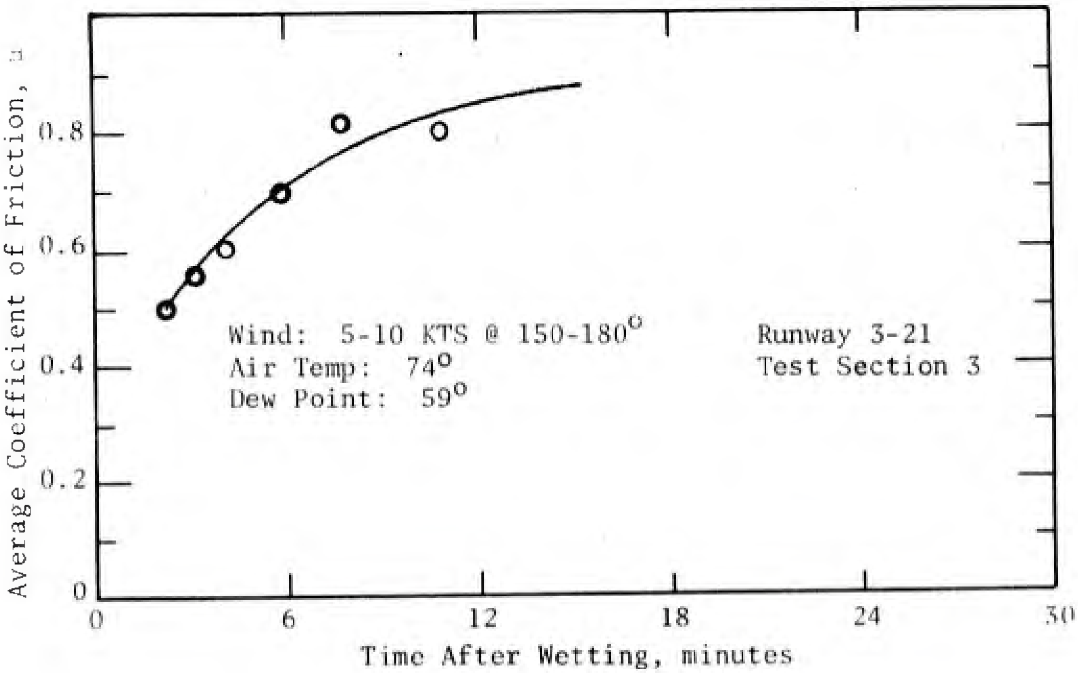


Figure 5. Average Friction Coefficient versus Time, USMCALF Camp Pendleton, CA



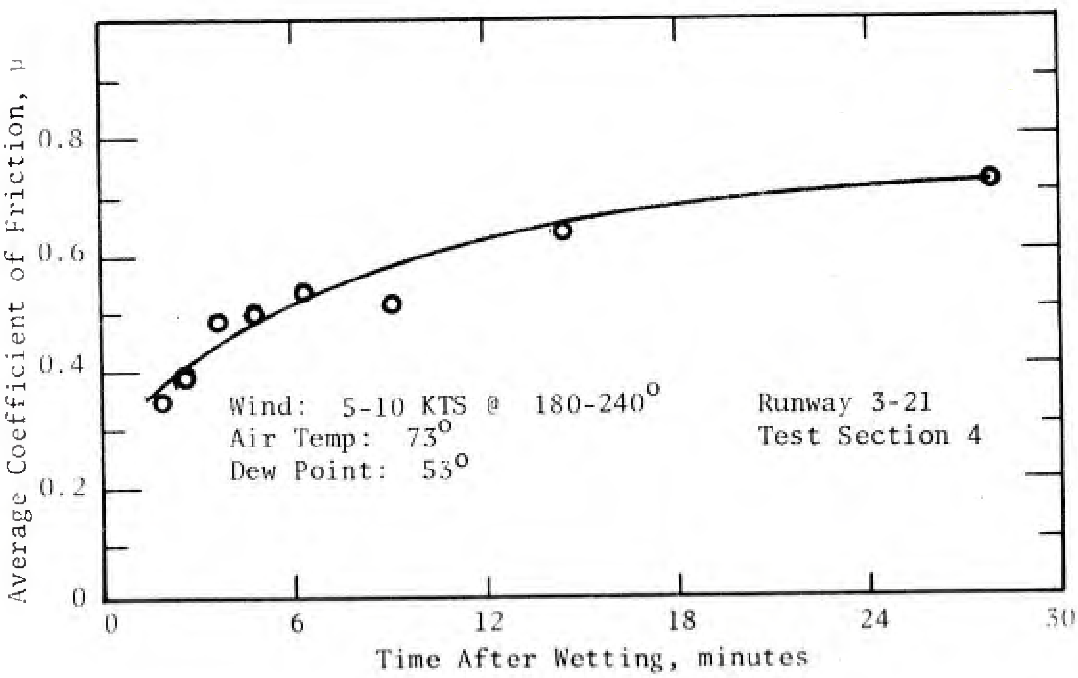
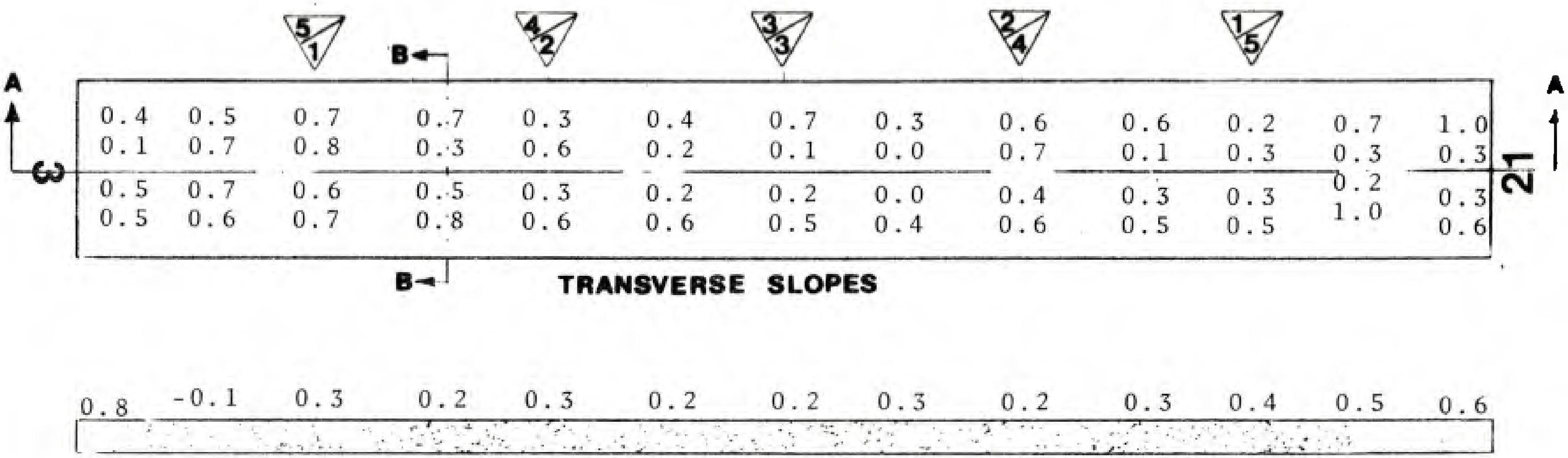
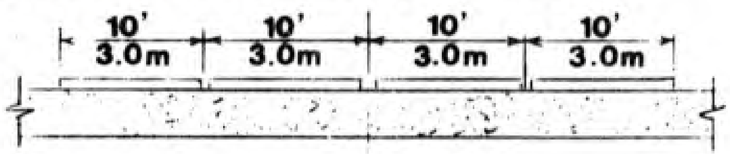


Figure 6. Average Friction Coefficient versus Time, USMCALF Camp Pendleton, CA

RUNWAY SLOPE MEASUREMENTS

RUNWAY 3-21, USMCALF CAMP PENDLETON, CALIFORNIA





SECTION "B-B" TRANSVERSE SLOPES

NOTES

1. All measurements are percent slope.
2. Positive transverse slopes indicate water drains to the runway edge without crossing the centerline, while negative transverse slopes indicate drainage across the centerline.
3. Positive longitudinal slopes indicate rising grades in the direction of increasing runway stationing, while falling grades are negative.
4. Runway stationing begins at 3 end.

Legend


10'(3.0m) Slope Measuring Device

Runway Distance Markers 1000' (304.8m) Apart

FIGURE 7

FIGURE 8. PONDED WATER REMAINING IN TEST SECTION 2 TWENTY MINUTES AFTER WATER APPLICATION

ASPHALTIC CONCRETE DISCRETE AREA DEFECT SUMMARY

Airfield MCALF Camp Pendleton, CA Facility Runway 3-21

Discrete Area R3-1 Area of Discrete Area (a) 600,000 ft^2

No. of Sample Areas (b) 15 Ratio: (a/2500b) 16.0

Defect Type	Length or Area of Sampled Defects	Total Length or Area of All Defects: (c) x Ratio	Defect Density (per 10 sq. ft.) 10 d/a	Defect Severity Weight	Weighted Defect Density: (e) x (f)
	(c)	(d)	(e)	(f)	(g)
T.C., L.C. or LCJ*					
Reflection Crack					
Faulting					
Patching					
Settlement or Depression					
Pattern Cracking					
Rutting					
Raveling					
Erosion–Jet Blast					
Oil Spillage					
Broken-up Area					
				Total	0.00A **

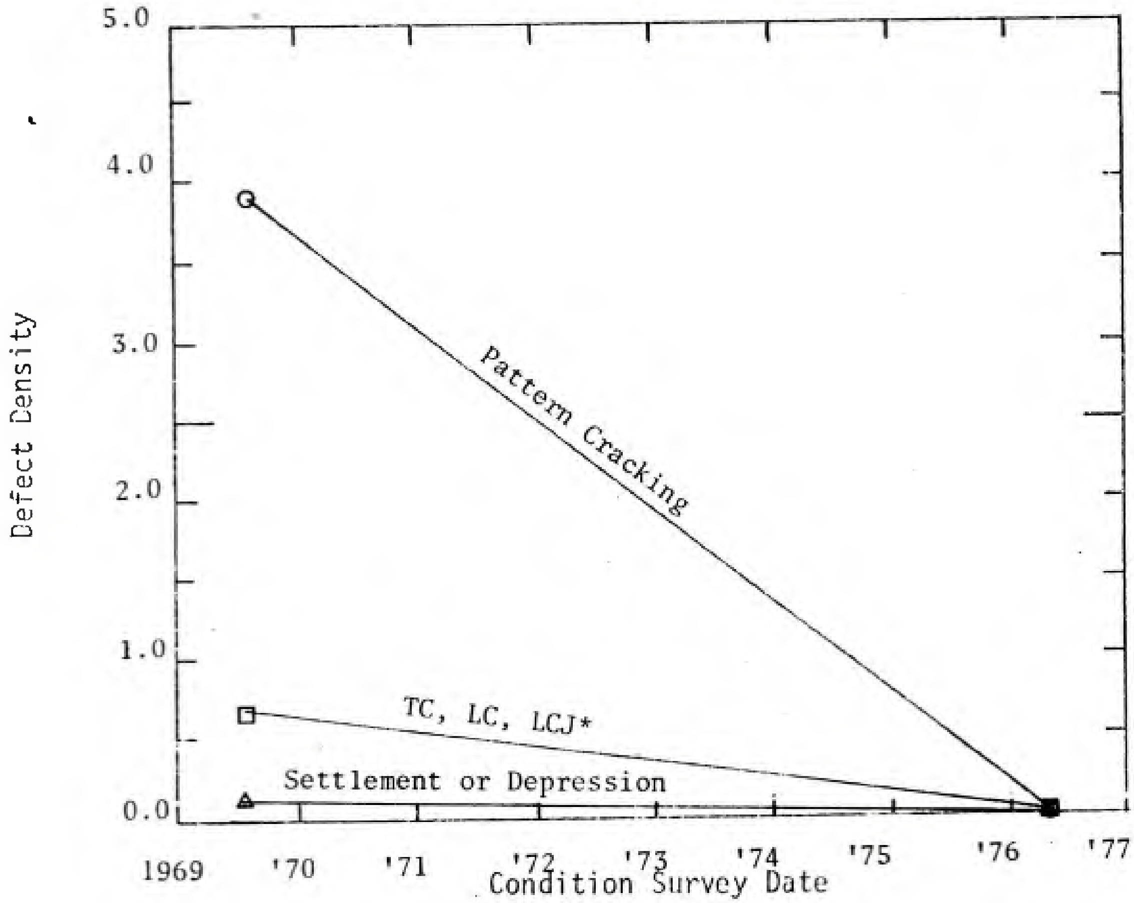
Remarks on Pavement Condition

No visible defects noted.

* Transverse crack, longitudinal crack or longitudinal construction joint crack.

** Letter suffix "A" indicates asphaltic pavement.

DISCRETE AREA CONDITION ANALYSIS



Airfield USMCALF Camp Pendleton Facility Runway 3-21
Discrete Area R3-1 Pavement Type AC
Discussion

All previous defects have been covered by the overlay placed in 1972. Two discrete areas in Reference 1 are combined in this report.

*Transverse crack, longitudinal crack, or logitudinal construction joint crack.

ASPHALTIC CONCRETE FACILITY DEFECT SUMMARY

Airfield USMCALF Camp Pendleton, CA

Date Surveyed March, 1976

Facility (or portion)	Weighted Defect Density Total	Ratio: Discrete Area / Total Facility Area*	Average Weighted Defect Density (a) x (b)
	(a)**	(b)	(c)**
1976 Survey			
Runway 3-21			
R3-1	0.00A	1.0	0.00A
1969 Survey			
Runway 3-21			
R3-1	11.74A	0.67	7.86
R3-2	14.76A	0.33	4.87
			12.73A (Total)

* If facility entirely constructed of AC, indicates total facility area. If facility only partly constructed of AC, indicates total area of AC portion of facility.

** Letter suffix "A" on weighted defect densities indicates asphaltic concrete pavements.

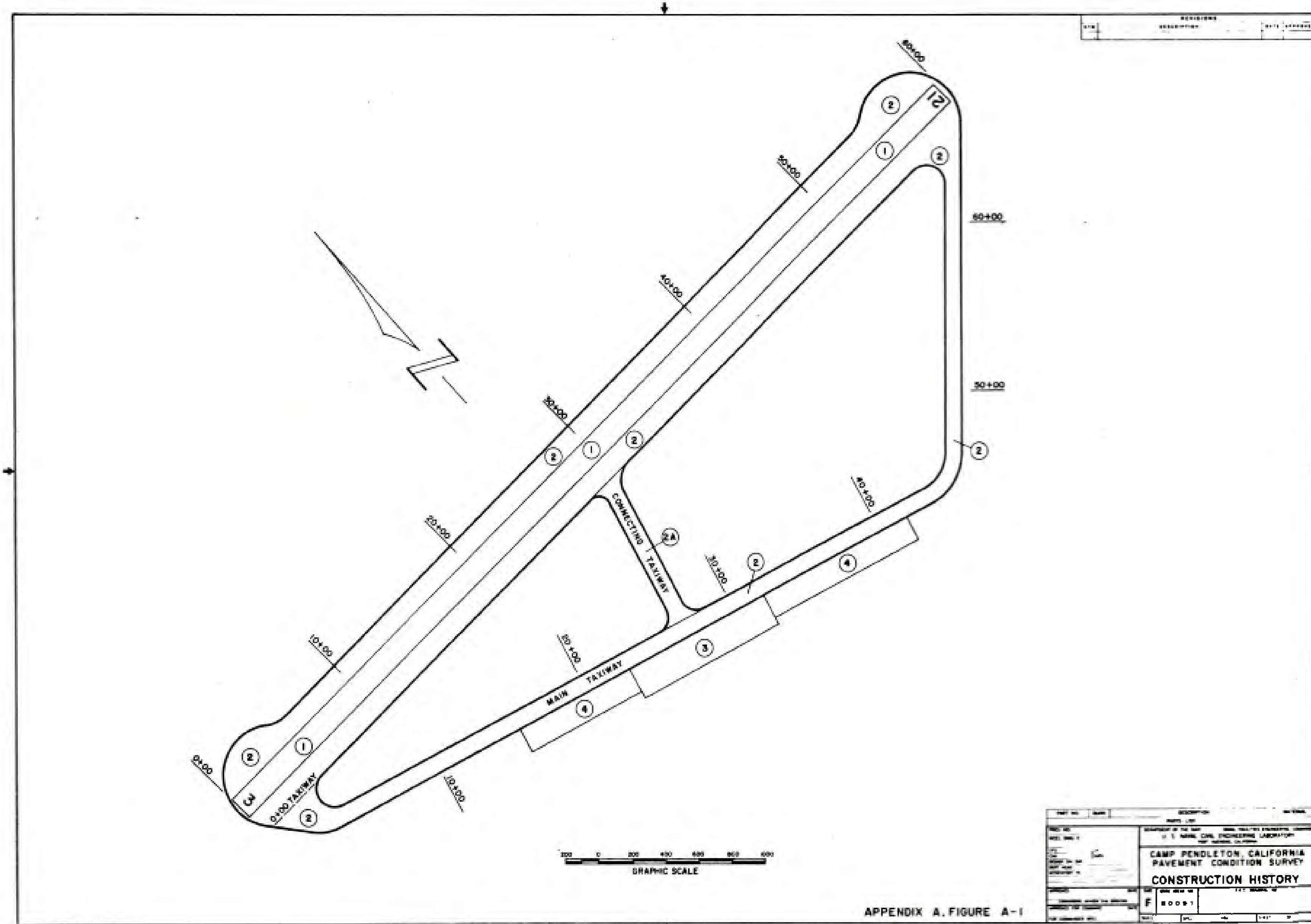
APPENDIX A

CONSTRUCTION HISTORY FOR
USMCALF CAMP PENDLETON, CA

Appendix A

CONSTRUCTION HISTORY FOR USMCALF CAMP PENDLETON
CALIFORNIA

Item No.	Section From Surface to Subgrade	Date Constructed	Date Strengthened or Sealed
1	Runway 3-21		
	AC overlay (1-½" to 8" thick)		1972
	Seal coated and cracks sealed		1964
	Seal coated		1947
	3" AC	1942	
	6" Crusher Run Base	1942	
	12" Subbase	1942	
2	Main Taxiway		
	2½" AC overlay		1972
	Seal coated and cracks sealed		1964
	Seal coated		1947
	3" AC	1942	
	6" Crusher Run Base	1942	
	3" AC	1942	
	6" Crusher Run Base	1942	
	12" Subbase	1942	
	Connecting Taxiway		
	4" AC overlay		1972
	3½" AC	1942	
	7" Base course	1942	
3	Portion of Parking Apron		
	8" PCC	1956	
	14" Crusher Run Base	1956	
4	Portion on Parking Apron		
	8" PCC unreinforced	1965	
	6" 40 CBR Material compacted to 100%	1965	
	6" Natural material compacted to 100%	1965	
	6" Natural material compacted to 95%	1965	



APPENDIX A. FIGURE A-1

APPENDIX B

CLIMATOLOGICAL DATA FOR USMCALF CAMP PENDLETON, CALIFORNIA

Appendix B

CLIMATOLOGICAL DATA FOR USMCALF CAMP PENDLETON, CALIFORNIA

Average Temperature

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	An'l.
1954	51.7	57.2	53.6	57.2	59.7	62.4	67.9	68.2	65.1	60.1	59.5	55.4	59.8
1955	52.1	51.7	55.3	54.9	58.4	61.7	65.0	68.2	67.4	60.0	55.8	54.1	58.7
1956	51.6	49.6	53.4	55.5	61.1	62.5	66.2	66.6	66.5	62.0	60.6	56.5	59.4
1957	53.6	56.3	55.2	57.1	59.4	65.3	67.2	69.5	64.8	62.0	56.4	57.0	60.3
1958	55.3	57.0	53.8	59.2	61.7	64.4	66.2	69.2	67.9	67.1	57.7	56.7	61.4
1959	54.8	52.7	57.9	59.5	60.7	64.9	69.7	69.6	68.7	63.6	60.8	58.0	61.7
1960	51.8	53.8	55.9	58.3	61.2	62.6	66.8	67.2	67.5	61.7	57.3	53.4	59.8
1961	56.0	55.1	54.4	57.2	58.1	61.6	66.8	67.8	64.7	61.0	55.7	51.5	59.2
1962	54.0	52.0	51.2	56.7	58.4	61.0	61.0	70.0	67.7	63.1	58.6	54.7	59.0
1963	54.3	60.0	55.8	57.1	63.3	64.7	67.9	69.7	71.7	66.0	59.7	57.0	62.2
1964	54.8	55.7	56.4	58.4	59.2								

Total Precipitation

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	An'l.
1954	2.20	1.12	2.89	.05	T *	T	.22	T	T	.00	1.47	.11	8.06
1955	2.72	1.10	.19	.73	.97	T	.02	.01	.01	T	.71	.24	6.69
1956	2.88	.25	.00	2.68	.23	.00	.00	.00	.00	.10	.00	.30	6.44
1957	5.74	.39	1.42	.74	1.30	.20	T	T	T	2.01	.66	1.23	13.69
1958	1.71	3.83	3.73	2.87	.38	T	T	T	.11	.07	.05	.07	12.82
1959	.26	3.11	.00	.58	.01	.01	T	T	.06	.22	.09	1.59	5.93
1960	2.61	2.13	.75	1.22	.06	.06	T	T	.62	.04	1.28	.05	8.83
1961	.88	.01	1.39	.03	.02	.01	.00	.03	.01	.17	.84	1.32	4.71
1962	2.45	3.87	1.44	.00	.38	.13	.13	.00	T	.04	.01	.10	8.55
1963	.03	2.53	1.93	.85	.10	.19	.00	T	3.09	.20	2.68	.09	11.68
1964	1.38	.27	.97	.29	.11								

* T = Trace

APPENDIX C

CONDITION SURVEY PROCEDURES

Appendix C

CONDITION SURVEY PROCEDURES

Step 1. Preliminary Survey

In the preliminary survey the evaluators make a general and personal inspection of all airfield pavement areas, during which they note the type and distribution of defects in each facility (runway, taxiway, etc.). In addition, a previously-prepared construction history is consulted and areas of different construction and different pavement type (AC or PCC) within a facility are noted. As a result of these efforts, each pavement facility is then divided into "discrete areas" of reasonably similar failure modes for performance of the subsequent sampling and tally or measurement of defects. Thus, if the type and/or number of defects found in one portion of a facility are distinctly different from those found in another portion of that facility, discrete areas are selected on this basis. If, however, the pavement facility contains few defects or if the defects found are similar in type and distribution throughout the facility, each facility is individually divided for survey according to the construction history. Under either criterion, a discrete area may vary, for example, from a 500 foot length of runway or taxiway to the entire length of the facility. All discrete areas are numbered with a system that relates the discrete area to the runway, taxiway, etc., of which it is a part. For example, discrete areas comprising Runway 11-29 are designated R 11-1 and R 11-2, etc.; discrete areas for Taxiway 2 are T 2-1 and T 2-2, etc.

A special survey of singular occurrences of serious defects is made during the preliminary survey. This is necessary because the statistical sampling techniques utilized in the subsequent survey are effective in spotting defects only when such defects are numerous and/or relatively well distributed. This abbreviated special survey provides information on those infrequent defects, if any, which may present a problem to safe aircraft operation.

Step 2. Statistical Sampling and Defect Survey

After discrete areas are selected, a number of small "sample areas" are chosen within each discrete area. The total number of sample areas is determined by statistical theory as a function of the relative size of the discrete area. Actual locations of the sample areas are selected at random from the discrete area.

Sample areas in PCC pavements basically consist of individual slabs, usually 12½ x 15 feet in size. For the convenience of the evaluators, either a single slab or a number of adjacent slabs can be considered as a sample area. Both types of sampling area are shown schematically in Figure C-1. Note from Figure C-1 that individual sample slabs and/or sample strips are selected within the center 100 feet (laterally) of runways and within the center 50 feet (laterally) of taxiways by a random selection process. For parking aprons, mats, etc., similar sample areas are selected at random over the entire pavement area.

For AC pavements, sample areas are fifty-foot-square areas located as shown in Figure C-2. For parking aprons, mats, etc.(not shown in Figure C-2) sample areas are fifty-feet square, as for other traffic areas, and randomly located over the entire pavement area.

All defects or defected slabs in each of the selected sample areas are noted on appropriate data sheets. For PCC pavement slabs or sample strips, either single or multiple occurrences of a given defect type within the slab qualify the slab as a defected slab. For example, one or more spalls qualifies a slab as a spalled slab. A crack in the same slab requires that it be counted again, this time as a cracked slab. No measurement of length, area, etc. is recorded for PCC pavement defects. When a sample slab strip is chosen for test, the above mentioned tally method (slab by slab) is still utilized.

The defects found in AC sample areas are measured and tallied, rather than merely tallied as are those for PCC pavements. Depending on the type of defect, the total length in feet (for cracks, etc.) or total area in square feet (for pattern cracking, raveling, etc.) is recorded.

The above survey of defects found in sample areas (in each discrete area) are shown in column (c) of the Discrete Area Defect Summary sheets, Figures C-3 and C-4. Separate summary sheets are provided for portland cement concrete (PCC) and asphaltic concrete (AC) pavements. Total defect counts for the entire discrete area are calculated by a linear extrapolation of the defect data in column (c), and are shown in column (d) of the Discrete Area Defect Summary sheets. To remove the influence of the size of the discrete area on the total defect count, the count is divided by either the number of slabs in the discrete area (for PCC pavements) or by the area (in 10-square-foot increments) of the discrete area (for AC pavements). This gives a defect <u>density</u> (per slab or per 10 square feet) which is listed in column (e).

Step 3. Defect Severity Weighting System

A weighting system, providing a numerical weight for each type defect in proportion to the relative severity of that defect, is applied in the following manner to each of the defect counts in the discrete area;

given defect density x $\frac{\text{weight for that}}{\text{type defect}}$ = weighted defect density

This is accomplished in columns (f) and (g) of the Discrete Area Defect Summary sheets. Next, a total weighted defect density is obtained for each discrete area by summing column (g) of these sheets. Note that a letter suffix is added to each total weighted defect density for the purpose of further distinguishing between asphaltic concrete defect densities (suffix "A") and portland cement concrete defect densities (suffix "C").

The defect weighting guide developed by NCEL assigns greater weights to defects that (1) presently affect the safe operation of aircraft or the cost of aircraft operation; (2) will lead to increased airfield pavement maintenance costs; or (3) will result in significant deterioration of load-carrying capacity of the pavements. The resultant numerical weights are further modified to reflect variations in pavement environment from station to station. For example, higher (more severe) weights are assigned to defects which are affected by factors such as freezing weather, heavy rainfall, or blow sand for surveys of airfields located in areas where these undesirable environmental effects occur. Thus, it can be seen that the higher the numerical weighted defect density, the poorer the condition of the surveyed pavement.

Remarks concerning the general pavement condition and the defects identified are given in narrative form on each Discrete Area Summary sheet. In addition, photographs of typical pavement conditions noted during the survey are used to further illustrate typical pavement defects.

Step 4. Facility Summary-- Weighted Defect Densities

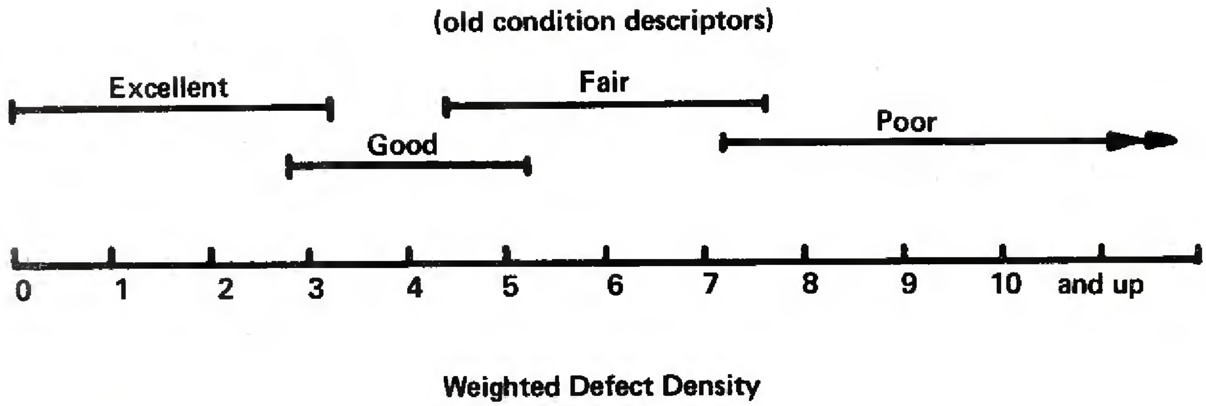
A final step in providing a numerical condition rating for each facility (runway, taxiway, etc.) is accomplished in the Facility Defect Summary sheets, Figures C-5 and C-6. Again note that separate sheets have been provided for AC and PCC pavements. In these sheets the individual weighted defect densities for all discrete areas comprising the entire AC or PCC portion of a facility (runway, taxiway, etc.) are summarized in column (a). When an AC or PCC facility (or portion) has been divided into more than one discrete area for the condition survey, the proportional contribution of each discrete area to the entire AC or PCC facility area is determined in column (b). In column (c) these proportions are applied to the individual discrete area weighted defect densities listed in column (a) and added to obtain an overall average weighted defect density for the entire AC or PCC portion of the facility (marked "total" in column (c)). When an entire AC or PCC facility (or portion) has been designated a single discrete area (as often occurs), the proportionality factor in column (b) is obviously 1.00 and the discrete area weighted defect density from column (a) becomes the average weighted defect density for the entire facility (or portion) in column (c).

GENERAL COMMENTS ON CONDITION SURVEY PROGRAM

The weighted defect densities, listed in column (a) of the Facility Defect Summary for individual discrete pavement areas and in column (c) as averaged weighted defect densities for entire AC or PCC runways, taxiways, etc. (or portions thereof) represent, numerically, the surface condition of the airfield pavements at the station. As previously stated, the larger defect density numbers indicated basically a greater number and/or severity of defects per unit area of pavement, i.e., a poorer pavement. Thus, they represent the final product of the pavement condition survey. It should be noted specifically, however, that AC and PCC pavement defect densities, although often numerically similar, are obtained by two different condition survey techniques and, as such, are not numerically compatible and must not be combined. (It is largely because of this fact that the letter suffixes "A" and "C" have been affixed to defect densities for AC and PCC pavements respectively.) As an example, consider the common case of an AC runway with PCC ends. The condition survey system presented herein provides indivdual discrete are weighted defect densities for discrete areas selected on both AC and PCC pavements, but provides a separate average weighted defect density for the entire AC portion and a separate average weighted defect density for the combined PCC end pavements. It is not possible to combine these defect densities to obtain an average AC/PCC defect density for the entire runway. Thus the defect densities for AC and PCC are reported separately, given different letter suffixes, and should include the letter suffix when reference is made to them.

Individual numerical defect densities, however accurately they indicate pavement condition, may mean little to the reader of an individual airfield condition survey report, for he has no basis upon which to judge the relative severity of pavement condition associated with the numbers obtained for his pavements. The primary value of a numerical condition survey program will be the accumulation of uniformly-obtained, comparative condition data for many airfields which can best be correlated, studied, and used in the decision-making processes at headquarters levels.

For the benefit of the individual reader, however, an effort was made during the first year of pavement condition surveys (FY-70) to relate the numerical condition (defect densities) to the basic subjective condition descriptors (excellent, good, fair, poor, etc.) used in all previous Navy pavement evaluation procedures. Although the subjective condition-descriptor approach is poorly regarded as a means of comparing pavement condition from one airfield to another, the following diagram may serve temporarily as a rudimentary bridge between the old subjective system and the new (numerical) condition approach:



The system of numerical defect densities was developed to aid in determining the suitability of airfield pavement surfaces for satisfying aircraft operational requirements and to establish an unbiased, uniform basis for initiating maintenance and repair efforts. As such, defect densities are simply visually-determined indicators of the condition of the pavement and do not represent true "condition ratings" in that they do not include factors relating to pavement strength, traffic usage, etc. It is possible that additional measurements or modifications may be considered necessary or desirable in future condition survey programs.

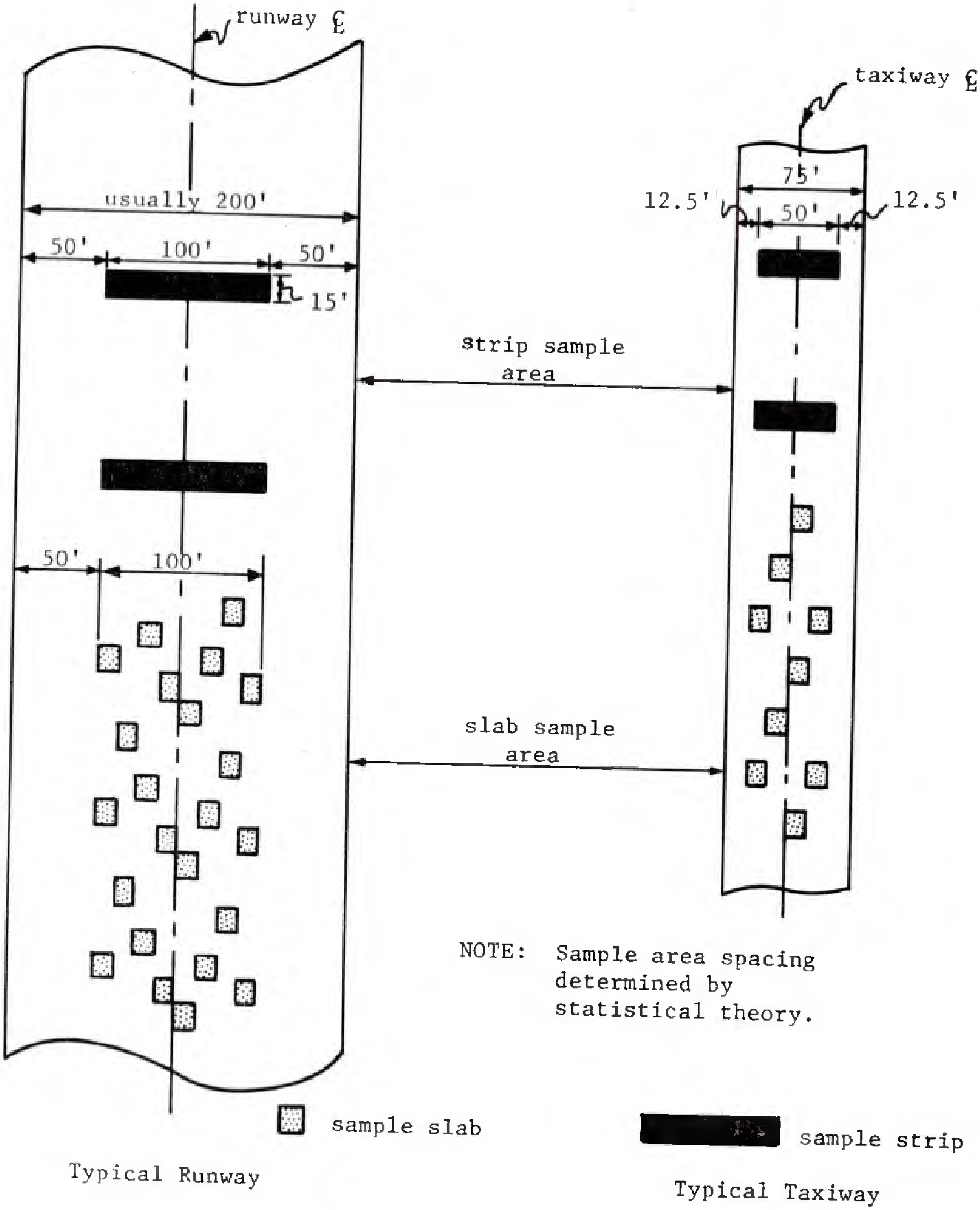
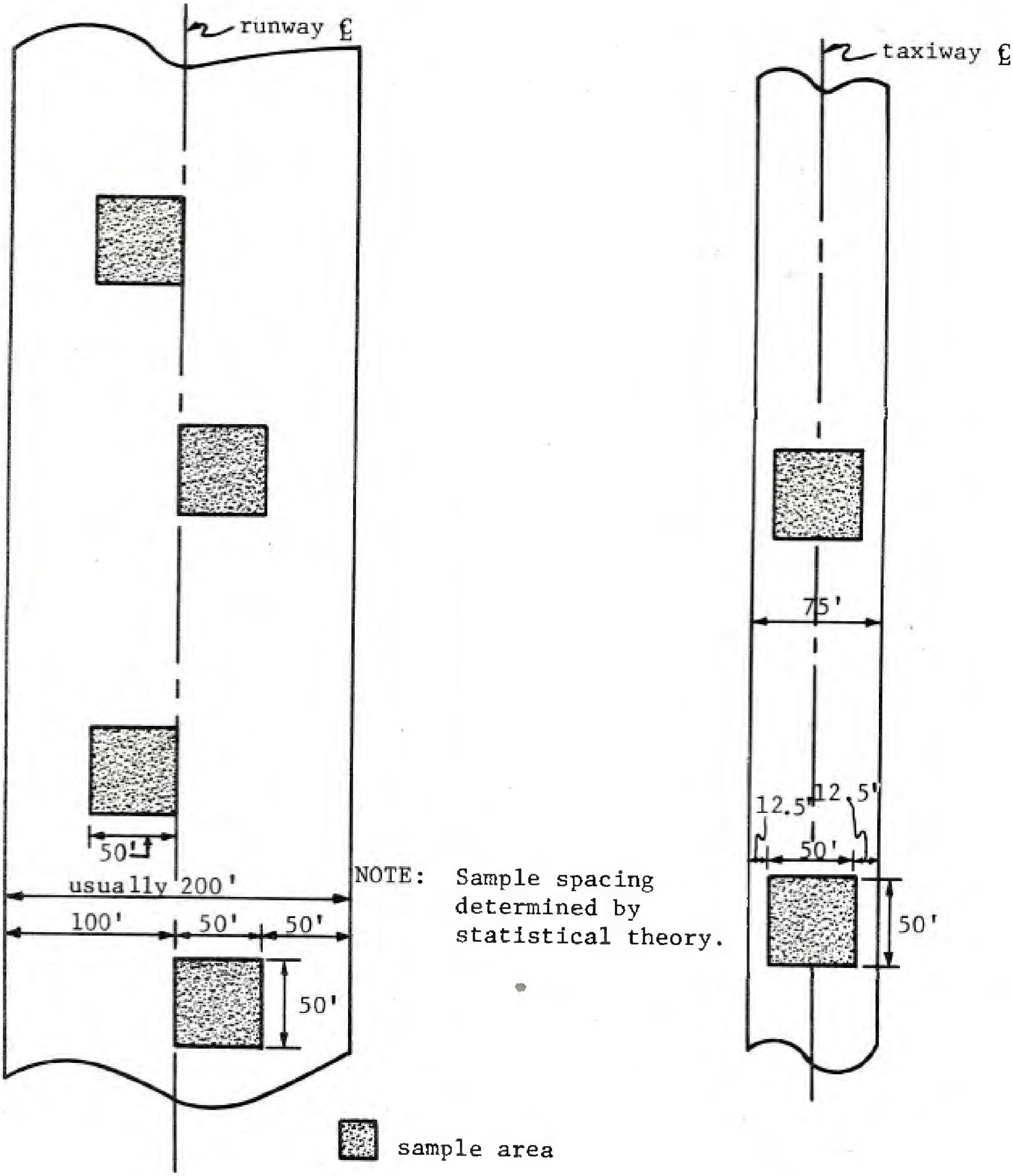


Figure C-1. Portland cement concrete sample areas.



Typical Runway

Typical Taxiway

Figure C-2. Asphaltic concrete sample areas.

ASPHALTIC CONCRETE DISCRETE AREA DEFECT SUMMARY

Airfield E X A M P L E Facility Taxiway 2

Discrete Area T2-1 Area of Discrete Area (a) 97,700 ft^2

No. of Sample Areas (b) 10 Ratio: (a/2500b) 3.9

Defect Type	Length or Area of Sampled Defects	Total Length or Area of All Defects: (c) x Ratio	Defect Density (per 10 sq. ft.) 10 d/a	Defect Severity Weight	Weighted Defect Density: (e) x (f)
	(c)	(d)	(e)	(f)	(g)
T.C., L.C. or LCJ*	80 ft	312 ft	0.0319	2.5	0.0798
Reflection Crack					
Faulting					
Patching					
Settlement or Depression	530 ft^2	2,067 ft^2	0.2116	9.0	1.9041
Pattern Cracking	126 ft^2	491.4 ft^2	0.0503	2.5	0.1257
Rutting					
Raveling					
Erosion—Jet Blast					
Oil Spillage					
Broken-up Area					
				Total	2.11 A**

Remarks on Pavement Condition

The depressions were generally 1/2" deep. Pattern cracking formed 6" to 12" polygons and was associated with the depressions. Longitudinal cracks were unsealed and 1/8" wide. (See Figure 5.)

* Transverse crack, longitudinal crack, and longitudinal construction joint

** Letter suffix "A" indicates asphaltic concrete pavement

Figure C-3. Typical Asphaltic Concrete Discrete Area Defect Summary

PORTLAND CEMENT CONCRETE DISCRETE AREA DEFECT SUMMARY

Airfield E X A M P L E Facility Taxiway 2

Discrete Area T2-2 Total Slabs in Discrete Area (a) 1,542

No. of Slabs Sampled (b) 193 Ratio a/b = 8.0

Defect Type	No. of Sample Slabs w/Defect	Total Slabs w/Defect: c x a/b	Defect Density (per slab) d/a	Defect Severity Weight	Weighted Defect Density e x f
	(c)	(d)	(e)	(f)	(g)
Faulting					
Corner Break	1	8	0.0052	2.5	0.013
L.C. or T.C. *	19	152	0.0985	1.0	0.098
I.C. **	1	8	0.0052	2.5	0.013
Depression		2***	0.0013	9.0	0.012
Spalling	59	472	0.3060	7.5	2.295
Scaling					
Disintegrated Slab					
Joint Seal	10	80	0.0518	2.5	0.130
Pumping					
				Total	2.57 C****

Remarks on Pavement Condition

Spalls were generally 1" wide by 3" long with some spalls up to 4" wide and 12" long. The longitudinal cracks found were mostly sealed. The depressions noted as singular defects consisted of two depressed and cracked slabs. The depression was approximately 1/2" deep. An attempt had been made to repair these slabs with portland cement concrete. Joint seal was missing in strips 4" to 12" long. (See Figures 25 and 26.)

* Longitudinal crack or transverse crack
** Intersecting crack
*** Counted as singular defects during the preliminary survey
**** Letter suffix "C" indicates portland cement concrete pavement

Figure C-4. Typical Portland Cement Concrete Discrete Area Defect Summary

ASPHALTIC CONCRETE FACILITY DEFECT SUMMARY

Airfield E X A M P L E

Date Surveyed ______

Facility (or portion)	Weighted Defect Density Total	Ratio: Discrete Area / Total Facility Area*	Average Weighted Defect Density (a) x (b)
	(a)**	(b)	(c)**
Taxiway 2			
T2-1	2.11 A	1.00	2.11 A
Taxiway 10			
T10-2	0.004 A	1.00	0.004 A
Towway 1			
TOW-1	3.77 A	1.00	3.77 A
Parking Apron 2			
PA2-1	7.29 A	1.00	7.29 A
Parking Apron 6			
PA6-1	7.44 A	1.00	7.44 A
Parking Apron 7			
PA7-1	4.97 A	0.79	3.93
PA7-2	23.18 A	0.21	4.87
			8.80 A (Total)
Parking Apron 8			
PA8-1	2.76 A	1.00	2.76 A
Central Mat			
CM-1	2.89 A	1.00	2.89 A

* If facility entirely constructed of AC, indicates total facility area. If facility only partly constructed of AC, indicates total area of AC portion of facility.

** Letter suffix "A" on weighted defect densities indicates asphaltic concrete pavements.

Figure C-5. Typical Asphaltic Concrete Facility Defect Summary

PORTLAND CEMENT CONCRETE FACILITY DEFECT SUMMARY

Airfield E X A M P L E

Date Surveyed

Facility (or portion)	Weighted Defect Density Total	Ratio: Discrete Area / Total Facility Area*	Average Weighted Defect Density (a) x (b)
	(a)**	(b)	(c)**
Runway 11-29			
R11-1	0.80 C	0.25	0.02
R11-2	4.43 C	0.75	3.33
			3.35 C (Total)
Runway 18-36			
R18-1	1.25 C	0.68	0.85
R18-2	0.76 C	0.32	0.28
			1.13 C (Total)
Taxiway 1			
T1-1	2.82 C	0.12	0.34
T1-2	0.98 C	0.88	0.86
			1.20 C (Total)
Taxiway 2			
T2-2	2.57 C	1.00	2.57 C
Taxiway 3			
T3-1	1.82 C	1.00	1.82 C
Taxiway 4			
T4-1	3.02 C	1.00	3.02 C
Taxiway 5			
T5-1	0.98 C	1.00	0.98 C
Taxiway 6 and Taxiway 7			
T6-1 and T7-1	0.06 C	1.00	0.06 C

* If facility entirely constructed of PCC, indicates total facility area. If facility only partly constructed of PCC, indicates total area of PCC portion of facility.

** Letter suffix "C" on weighted defect densities indicates Portland cement concrete pavements.

Figure C-6. Typical Portland Cement Concrete Facility Defect Summary

APPENDIX D

MU-METER TEST RESULTS
USMCALF CAMP PENDLETON, CA

APPENDIX D
MU-METER TEST RESULTS
USMCALF CAMP PENDLETON, CA

Test Location Run #	Runway Heading	Average Time After Wetting Min.	Average Coefficient of Friction (Mu)	Maximum Coefficient of Friction (Mu)	Minimum Coefficient of Friction (Mu)
Runway 3-21					
Test Section 1					
1	3	2.21	0.56	0.77	0.22
2	21	3.06	0.58	0.80	0.37
3	3	3.87	0.64	0.81	0.32
4	21	4.73	0.68	0.84	0.47
5	3	6.97	0.76	0.84	0.57
6	21	9.71	0.84	0.86	0.83
7	3	15.38	0.80	0.84	0.72
Test Section 2					
1	3	1.14	0.39	0.80	0.16
2	21	1.96	0.34	0.74	0.14
3	3	3.34	0.49	0.83	0.18
4	21	4.34	0.40	0.81	0.12
5	3	6.09	0.47	0.82	0.14
6	21	7.12	0.49	0.83	0.16
7	3	12.04	0,58	0.81	0.23
8	21	21.51	0.66	0.90	0.23
Test Section 3					
1	3	2.30	0.50	0.62	0.28
2	21	3.23	0.56	0.73	0.37
3	3	4.21	0.60	0.75	0.44
4	21	5.90	0.70	0.81	0.63
5	3	7.91	0.82	0.87	0.67
6	21	10.97	0.80	0.89	0.72
Test Section 4					
1	3	1.93	0.34	0.68	0.20
2	21	2.71	0.39	0.69	0.18
3	3	3.89	0.48	0.75	0.30
4	21	4.74	0.49	0.72	0.30
5	3	6.41	0.53	0.79	0.37
6	21	9.04	0.51	0.77	0.17
7	3	14.49	0.64	0.84	0.42
8	21	27.92	0.72	0.83	0.52