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By G. D. Cline and
M. C. Hironaka
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of Transportation

Performance of Recycled Asphalt Concrete Airfield Pavement Surfaces

ABSTRACT The objective of this research was to make an assessment of the relative performance of recycled versus new asphalt concrete pavement surfaces constructed for airfield facilities. To make this assessment, pavement condition index (PCI) surveys and tests on core samples from the hot-mix recycled pavements located on the airports at Needles, California, and Valley City, North Dakota were conducted. Both pavements have a condition rating of very good. The survey and test data were compared with those for recycled highway and virgin material Navy airfield pavements. The recycled pavement at Needles is performing as good as those Navy pavements constructed with virgin material. The recycled pavement at Valley City has a higher deterioration rate than the Navy pavements but this could be attributed to the harsh climate found in North Dakota. The results of this study show that hot-mix recycling was successful at these airports but additional studies are required to determine the applicability of Asphalt Concrete (AC) recycling for reconstruction at all airfields.

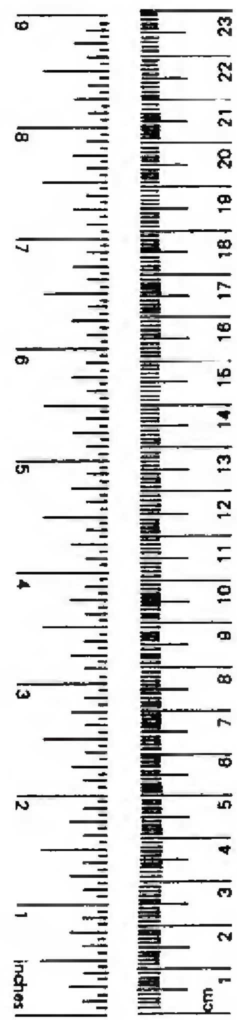
NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME, CALIFORNIA 93043

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

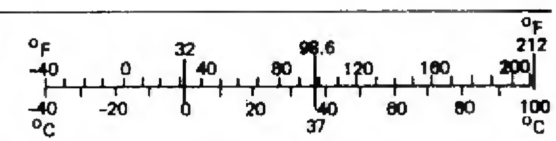
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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 (2,000 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 (1,000 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



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The objective of this research was to make an assessment of the relative performance of recycled versus new asphalt concrete pavement surfaces constructed for airfield facilities. To make this assessment, pavement condition index (PCI) surveys and tests on core samples from the hot-mix recycled pavements located on the airports at Needles, California, and Valley City, North Dakota were conducted. Both pavements have a condition rating of very good. The survey and test data were compared with those for recycled highway and virgin material Navy

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CONTENTS

INTRODUCTION

Objective

The objective of this research was to make an assessment of the relative performance of recycled Asphalt Concrete (AC) compared to new AC surface courses in airport pavements.

Background

In the late 1970's recycling evolved as an alternative for reconstructing airport AC pavements. In 1979, a laboratory study prepared for the Federal Aviation Administration (FAA) on recycling of AC airport pavement concluded that aged AC can be hot-mix and cold-mix recycled into mixtures with properties conforming to Navy and FAA specifications for new AC mixes[1]. Design procedures and guidelines for recycling AC pavements were established in Reference 1.

Contacts with FAA Regional offices provided data on projects that have incorporated recycled AC pavement in reconstruction. Numerous recycling projects have been completed on apron, taxiway, and runway pavements. Projects incorporating aged surface material recycled into new surface material were the only airports considered for this study. Recycled materials were used for pavement surfaces at five airports in the Great Lakes and Western/Pacific Regions. Other projects incorporated recycled material into base courses (Table 1).

The performance of recycled AC surface courses is unknown under actual field conditions since this practice is relatively new. Surfaces that incorporated the recycled AC are only 5 years old or less. To determine if this material was maintaining an acceptable condition, the Naval Civil Engineering Laboratory (NCEL) performed the following: (1) a pavement condition index survey (PCI) following the guidelines and procedures set forth in FAA Guidelines and Procedures for Maintenance of Airport Pavements[2], (2) a comparison of the PCI's of the recycled AC at a specific age with that of pavements constructed with virgin material, (3) laboratory tests on core samples, and (4) a comparison of recycled pavement properties with those of other recycled pavements.

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[1] Federal Aviation Administration. Report No. FAA-RD-78-58: Recycling of asphalt concrete airfield pavement - A laboratory study, by R.B. Brownie and M.C. Hironaka. Washington, D.C., Naval Civil Engineering Laboratory, May 1979. (DOT-FA77WAI-704)

[2] U.S. Department of Transportation, Federal Aviation Administration. AC No. 150/5380-6: Guidelines and procedures for maintenance of airport pavements. U.S. Government Printing Office, Washington D.C., Dec 1980.

TEST SITES

Location

Three criteria were used to select the sites where the PCI surveys were conducted: (1) hot-mix recycling of the old into new surface course, (2) high proportion of recycled material to virgin material, and (3) differing climates. Two extreme climatic conditions and maximum use of recycled material were desirable.

The sites chosen were Runway 2-20 at Needles Airport in Needles, California and a Taxiway at Barnes County Municipal Airport in Valley City, North Dakota. Needles airport has a hot and dry climate. The recycled mix proportion on the runway was 50 percent recycled and 50 percent virgin material. The Valley City airport is in a cold and wet climate. The recycled surface mix proportion used on the taxiway was 70 percent recycled and 30 percent virgin material. Figures 1 through 4 show the average monthly high and low temperatures and total precipitation for both airports since reconstruction was completed. These figures show average temperature extremes of 40 to 110 °F at Needles and -20 to 90 °F at Valley City. Needles airport has recorded 26 inches of rain since completion of reconstruction in 1981 while Valley City has recorded 98 inches of rain since 1980 and 127 inches of snow since November 1981.

Both airports serve approximately 20 aircraft per day. Most aircraft at both airports are small single-engine aircraft. Needles has occasional small private jets along with some heavier military aircraft, but both occurrences are low in number.

Needles Airport Reconstruction and Maintenance

In November 1980, C.M. Engineering Associates investigated Needles Airport to determine the condition of the existing pavement and to prepare recommendations for the overlay[3]. In general, the entire pavement had large block cracking and the pavement had shrunk and warped significantly. There was no evidence of subgrade failure, base failure, or failure due to overloading. Field sampling concluded the asphalt thickness on Runway 2-20 to be 5-1/2 inches and the average asphalt cement content of 5.8 percent by weight. The gradation fell within the limitations of the gradation for 3/4-inch maximum aggregate material under P-401 of the FAA Specifications[4]. The unit weight was calculated to be 135.6 pounds per cubic foot. This investigation concluded that recycling would be the most suitable for providing a smooth pavement and reducing reflective cracking to a minimum. The investigation also concluded that reconstruction of the old pavement would be by hot-mix recycling.

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[3] C.M. Engineering Associates. J. N. 273-055: Needles Airport Overlay, Seal & Mark Runways 2-20 & 11-29 and Parallel Taxiways, Needles, California, ADAP No. 5-06-0164-01, by Pioneer Consultants. Redlands, Calif., Nov 1980.

[4] Federal Aviation Administration. P-401, AC No. 150/5370-10: Advisory circular, standards for specifying construction of airports. Washington, D.C., Oct 1974, pp 107 - 124-8.

Reconstruction of Runway 2-20 was completed in July 1981. Two inches of the old runway was removed through a cold planning process and the salvaged material was stockpiled. A 10,000-pound Standstill conventional batch plant that was set up for a nearby highway project was used. The drum size of the plant was 9 feet in diameter by 36 feet long with a production rate of 350 to 400 tons per hour. A mix proportion of 50 percent recycled material and 50 percent virgin aggregate was used. The virgin material was first heated in the batch plant to 600 °F and old material was then added. Finally, AR 2000 was added as the bituminous material. Test results during reconstruction showed that the asphaltic concrete layer had an average asphalt cement content of 7.1 percent, layer thickness of 2.5 inches, unit weight of 144.9 pounds per cubic foot, and aggregate gradation as follows[5]:

Sieves	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
% Passing	99	92	83	67	53	41	30	19	12	8

A fog seal was applied to the pavement surface in 1985. The fog seal was scheduled for 1 year after reconstruction to help keep raveling to a minimum but was postponed until raveling became evident.

Valley City Airport Reconstruction and Maintenance

The consulting engineer's report for the reconstruction project stated that the pavement at the Valley City airport was over 30 years old[6]. The material was suitable for recycling and chosen to be the best alternative. Tests were performed on pavement samples prior to the reconstruction but the results could not be located.

Reconstruction of the taxiway, runway, and parking apron was completed in August 1980. The old material was removed with a milling machine down to the base course. The salvaged material was stockpiled at the airport. A 1979 Cedarapids recycling plant, Model 7224 ADM (drum within a drum) was assembled at the site. The drum size was 72 inches in diameter by 24 feet long with a production rate of 150 to 175 tons per hour. A 70 percent recycled material and 30 percent virgin aggregate with 200 to 300 penetration grade asphalt cement were mixed in the recycling plant. The recycled hot-mix was placed with a conventional paving machine. The contractor had some problems with the recycling plant due to the drum clogging and

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[5] C.M. Engineering Associates. J. N. 273-065: Final materials inspection report on resurfacing of Runway 2-20 & Taxiways, Needles Airport, Needles, California, ADAP No. 5-06-0164-01, by Pioneer Consultants. Redlands, Calif., Aug 1981.

[6] Veigel Engineering, P.C., Consultants. Final Engineer's Report, Barnes County Municipal Airport, Valley City North Dakota, ADAP No. 5-38-0053-01, by Ervin M. Krank. Bismarck, N.D., Feb 1982.

chutes plugging with the recycled material. Actual asphalt content, unit weight, and gradation of aggregate during the reconstruction are not available but the engineer's final report indicated the properties of the AC mix to be within FAA Specification P-401[4].

Maintenance since reconstruction includes chip sealing, and crack routing and filling. A chip seal (3/8 minus aggregate) was placed immediately after reconstruction. Crack filling with asphalt cement was completed in 1981, 1982, and 1983. Crack routing and filling with rubberized asphalt was done in 1984 and 1985.

Present Surface Conditions

The Naval Civil Engineering Laboratory contracted with Harding Lawson Associates to perform PCI surveys of both Needles and Valley City airports[7]. Figures 5 and 6 show the overall view of Runway 2-20 at Needles Airport and the taxiway at the Valley City airport, respectively.

Figure 7 illustrates the layout of Runway 2-20 and location of condition survey sample units and test cores. Seventeen of the 72 sample units were surveyed. PCI values ranged from 80 to 88 with the average being 85 (see Table 2). The overall rating of the pavement is classified as very good in accordance with FAA Guidelines[2]. The major distresses observed at Needles Airport were longitudinal and transverse cracking and raveling both of low severity. A typical view of the defects is shown in Figure 8. The primary distress mechanism is climatic effects on material durability.

Figure 9 illustrates the layout of the Valley City taxiway and the location of sample units and test cores. All eight of the sample units representing the entire area of the taxiway were surveyed, and PCI values were calculated. PCI values ranged from 71 to 77 with an average of 75 (see Table 3). The overall rating of the pavement is classified as very good in accordance with FAA guidelines[2]. Primary pavement distresses at the Valley City Airport were longitudinal and transverse cracking of the recycled AC and raveling of the aggregate seal. Both distress types are of low severity. A typical view of the defects is shown in Figure 10. The primary distress mechanism is climate and material durability.

TEST RESULTS

Comparison of Recycled Pavement Properties

Laboratory tests including Marshall stability and flow, resilient modulus, indirect tensile, Lottman water susceptibility, and asphalt content and properties were conducted on the core samples taken from Needles and Valley City Airports[7]. A brief description of the test procedures is provided in Appendix A. Tables 4, 5, and 6 show the test results. For comparative purposes, physical test properties of cores from highway recycled AC pavement projects of 1 to 5 years of age are shown in Table 7.

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[7]Harding Lawson Associates. J.N. 2176,066.05: Pavement evaluation Needles, California, Airport Runway 2-20 and Valley City, North Dakota, Airport Taxiway, by Kent Hansen and Stuart Dykins. Reno, Nev., Oct 1985. (NCEL P.O. No. 85M-R141)

Marshall stability and flow values are measures of a mixture's ability to resist plastic flow. The test method is an integral part of a mix design procedure used for selecting asphalt binder contents for asphalt-aggregate mixtures. Marshall stability and flow values at Needles Airport are higher than those obtained on the highway recycling projects listed in Table 7. The high Marshall stability value of 3,160 pounds may be the result of rapid aging under the hot, dry climate or the use of a less effective recycling agent. Flow values are generally high in recycled mixtures but the exceptionally high value of 0.27 inches coupled with the high average density of 146.8 pcf at Needles Airport indicates an excess of binder. The Valley City Airport Marshall stability value of 773 pounds is lower than most of the highway recycled projects. This low stability is indicative of a soft binder and the high air voids indicate a somewhat lower compaction (the average density was 135.7 pcf). The flow value of 0.21 inches is typical of values found in other recycled projects.

Resilient modulus is a measure of the ability of the pavement structure to distribute traffic loads and is approximately equal to the elastic modulus. Resilient modulus values at Needles are considerably higher than those on highway recycled projects, which indicate a very stiff mixture. This type of pavement can expect transverse and longitudinal cracks and surface raveling of fine and coarse aggregates. High values at relatively high temperatures would also indicate a general resistance to rutting and shoving. Valley City resilient modulus values are generally high and are typical of highway recycled mixtures. High values at relatively low temperatures would indicate the potential for thermal transverse and longitudinal cracking and fatigue cracking.

Indirect tensile strength is a measure of the splitting tensile strength of the core but is not a parameter that is presently used in mix design methods. The values were calculated to compare past recycled projects with Needles and Valley City. The tensile strength (before Lottman) at Needles is higher than past recycled projects while the tensile strength at Valley City is a typical value.

The Lottman water susceptibility test method determines the water susceptibility of compacted asphalt-aggregate mixtures. Resilient modulus and indirect tensile strengths are obtained before and after subjecting the samples to conditioning. The values of the Lottman water susceptibility test at Needles (87 percent retention) indicate that stripping and loss of strength in the presence of water should not be a major problem. In Valley City, water susceptibility values (25 to 35 percent retention) indicate the potential exists for stripping and loss of strength in the presence of water. Performance problems could exist if the mixture was subjected to damaging moisture and freeze-thaw conditions.

Physical properties of the asphalt extracted from core samples are presented in Table 6. The high viscosity value of 12,800 poises and the low penetration value of 1.6 mm at Needles indicate a hard asphalt binder exists. This may indicate rapid aging under the hot, dry climate or the use of a less effective recycling agent. The values of 2,009 poises for viscosity and 5.8 mm for penetration at Valley City Airport are typical values expected for asphalt surfaces.

Performance of Recycled AC Pavements

PCI values for virgin material AC pavement surfaces at Navy airfields were obtained from a report[8] on the merits of the PCI procedure and numerous Navy airfield pavement condition survey reports. PCI values and age of surface were compared to each other and plotted. A regression analysis was then completed through the Statistical Package for the Social Sciences computer program using first, second, and third order equations. The evaluation of the results shows the second order regression equation is the most applicable to these data. Two parallel lines were developed by multiplying the standard error by 1.96, which is based on the 95 percent probability for normal distribution. These lines were then plotted on the graph, therefore creating a parallel confidence band of 95 percent. The 95 percent parallel confidence band indicates that 95 percent of any data collected from Navy airfields made of virgin material will fall within this band. Figure 11 represents the virgin AC pavement data. The two data points representing the condition of recycled surface material at the Needles and Valley City airports are also shown in Figure 11. Needles PCI value is well within the 95 percent confidence band while Valley City PCI is outside the band on the low side.

The recycled surfaces have low volume traffic and light aircraft while the virgin surface samples were used by heavier aircraft and subjected to higher volume. The kneading effect of traffic tends to keep an AC pavement "alive." Thus, assuming that heavier use is beneficial, PCI values at both Needles and Valley City airports should be lower than Navy airfields of the same age. This holds true for Valley City but generally in harsh climates, as is found in North Dakota, any surface materials do not perform as well as those in mild climates. The Needles airport recycled surface seems to be in the same condition as would be expected of a virgin surface.

FINDINGS

1. At the initiation of this study, inquiries made at all FAA Regional Offices revealed that recycling AC into new surface courses has been used at five airports, and recycling AC into base courses has been used at 20 other airports. The locations of the airports where the aged AC pavements were recycled into new surface courses are: Kingsford, Michigan; Valley City, North Dakota; Needles, California; Santa Maria, California; and Prescott, Arizona. The recycled pavements at Needles (Runway 2-20) and Valley City (taxiway) were selected for further investigation. Both of these airports have general aviation traffic of low volume.

2. The results of the condition survey of the recycled pavement at the two selected airports are:

[8] Naval Civil Engineering Laboratory. Technical Memorandum M-53-83-02: Comparison of PCI and weighted defect density airport pavement condition survey methods, by M.C. Hironaka and N.F. Shoemaker, Port Hueneme, Calif., Aug 1983.

	Needles, CA	Valley City, ND
Pavement surveyed	Runway 2-20	Taxiway
PCI	85	75
Condition Rating	Very Good	Very Good
Distress Types and Severity		
Longitudinal & Transverse Cracks	Low	Low
Raveling	Low	Low

3. The results of the laboratory tests on core samples taken from the two airports are:

	Needles, CA	Valley City, ND
Marshall Stability (lb)	3,160	773
Flow (0.01 in)	27	21
Asphalt Content (% by weight)	6.9	6.2
Penetration at 77°F (0.1mm)	16	58
Viscosity at 140°F (poises)	12,800	2,009

Comparing properties of recycled highway pavements with the above, the Marshall stability and flow are high for Needles Airport. The high flow value suggests an excess asphalt content and the low penetration and high viscosity indicate that this asphalt binder is hard. This hard binder may be the result of rapid aging under the hot, dry climate or the use of a less effective recycling agent. For Valley City, the Marshall stability is low but the flow is typical of other recycled pavements. The penetration and viscosity are typical values expected for asphalt surfaces.

4. A regression analysis of PCI values versus age for Navy pavements constructed with virgin AC materials was made. The comparison of the results from this analysis with the values for the two recycled pavements surveyed showed that the performance of the pavement at Needles, California is within the 95 percent parallel confidence band and the pavement at Valley City, North Dakota is slightly outside this band on the low side. The performance of this latter pavement may be due more to the harsh environment rather than the pavement being constructed out of recycled material.

CONCLUSIONS

Properties of the two recycled airport pavements investigated in this study are similar to those of previously recycled highway pavements. The performance, in terms of deterioration rate of the PCI with respect to time, of the two recycled pavements has a tendency to be lower than that for AC surfaces constructed with virgin materials at Navy airfields. The results of laboratory tests conducted on core samples showed that the pavement at Needles has been subjected to rapid aging under the hot, dry climate or that a less effective recycling agent was used. For the recycled pavement at Valley City, the high air voids, low modulus, and low percent retained values of resilient modulus and indirect tension after Lottman immersion indicate a possible asphalt stripping problem.

RECOMMENDATIONS

Based on the results of this limited study, it is recommended that the following research be performed relative to recycled AC airport pavements:

1. Long term assessment of durability and performance of recycled AC pavement with various types and amounts of recycling agent and proportions (recycled versus virgin material) used, and under various climatic conditions.

2. A comparative study on a normalized basis of the performance of recycled AC versus AC made with virgin material to positively determine the relative performance characteristics of recycled pavements.

3. Assessment of the performance of recycled AC pavements under structural loadings and repeated traffic effects.

REFERENCES

1. Federal Aviation Administration. Report No. FAA-RD-78-58: Recycling of asphalt concrete airfield pavement - A laboratory study, by R.B. Brownie and M.C. Hironaka. Washington, D.C., Naval Civil Engineering Laboratory, May 1979. (DOT-FA77WAI-704)

2. U.S. Department of Transportation, Federal Aviation Administration. AC No. 150/5380-6: Guidelines and procedures for maintenance of airport pavements. U.S. Government Printing Office, Washington D.C., Dec 1980.

3. C.M. Engineering Associates. J. N. 273-055: Needles Airport Overlay, Seal & Mark Runways 2-20 & 11-29 and Parallel Taxiways, Needles, California, ADAP No. 5-06-0164-01, by Pioneer Consultants. Redlands, Calif., Nov 1980.

4. Federal Aviation Administration. P-401. AC No. 150/5370-10: Advisory circular, Standards for specifying construction of airports. Washington, D.C., Oct 1974, pp 107 - 124-8.

5. C.M. Engineering Associates. J. N. 273-065: Final materials inspection report on resurfacing of Runway 2-20 & Taxiways, Needles Airport, Needles, California, ADAP No. 5-06-0164-01, by Pioneer Consultants. Redlands, Calif., Aug 1981.

6. Veigel Engineering, P.C., Consultants. Final Engineer's Report, Barnes County Municipal Airport, Valley City North Dakota, ADAP No. 5-38-0053-01, by Ervin M. Krank. Bismarck, N.D., Feb 1982.

7. Harding Lawson Associates. J.N. 2176,066.05: Pavement evaluation Needles, California, Airport Runway 2-20 and Valley City, North Dakota, Airport Taxiway, by Kent Hansen and Stuart Dykins. Reno, Nev., Oct 1985. (NCEL P.O. No. 85M-R141)

8. Naval Civil Engineering Laboratory. Technical Memorandum M-53-83-02: Comparison of PCI and weighted defect density airport pavement condition survey methods, by M.C. Hironaka and N.F. Shoemaker. Port Hueneme, Calif., Aug 1983.

TABLE 1. LOCATION OF RECYCLED AC AIRPORT PAVEMENTS
(as submitted by FFA Regional Offices)

FAA Region	Airport	Location	Surface Course	Base Course
Alaska	Ketchikan	Ketchikan, Alaska		X
Central	None			
Eastern	Greater Pittsburgh Intl.	Pittsburgh, Pennsylvania		X
	Allegheny County	Pittsburgh, Pennsylvania		X
Great Lakes	Ford	Kingsford, Michigan	X	X
	Marquette County	Negaunee, Michigan		X
	Houghton County Memorial	Calumet, Michigan		X
	Muskegon County	Muskegon, Michigan		X
	W.K. Kellogg Regional	Battle Creek, Michigan		X
	Kalamazoo County	Kalamazoo, Michigan		X
	Jamestown Municipal	Jamestown, North Dakota		X
	Barnes County Municipal	Valley City, North Dakota	X	X
Northwest/ Mountain	Baker Municipal	Baker, Oregon		X
	Cut Bank Municipal	Cut Bank, Montana		X
	Ephrata Municipal	Ephrata, Washington		X
	Gooding Municipal	Gooding, Idaho		X
	Ontario Municipal	Ontario, Oregon		X
	Snohomish County	Everett, Washington		X
Western/ Pacific	Needles	Needles, California	X	
	Santa Maria Public	Santa Maria, California	X	
	Mohave County	Kingman, Arizona		X
	Ernest A. Love Field	Prescott, Arizona	X	
	Window Rock	Window Rock, Arizona		X
	Winslow Municipal	Winslow, Arizona		X

TABLE 2. SUMMARY OF SAMPLE UNITS SURVEYED AND PCI VALUES FOR THE RUNWAY AT NEEDLES AIRPORT (From Reference 7)

Sample Unit Number	Sample Unit Area, ft^2	PCI Value	Rating
3	5,250	87	Excellent
7	5,250	86	Excellent
11	5,250	84	Very Good
15	5,250	84	Very Good
19	5,250	87	Excellent
23	5,250	85	Very Good
27	5,250	80	Very Good
31	5,250	81	Very Good
35	5,250	85	Very Good
39	5,250	88	Excellent
43	5,250	87	Excellent
47	5,250	84	Very Good
51	5,250	82	Very Good
55	5,250	85	Very Good
59	5,250	83	Very Good
63	5,250	88	Excellent
67	5,250	82	Very Good
Total	89,250	--	--
Mean	--	85	Very Good
Standard Deviation	--	2.43	--
Coef. of Variation, %	--	2.86	--

TABLE 3. SUMMARY OF SAMPLE UNITS SURVEYED AND PCI VALUES FOR THE TAXIWAY AT THE VALLEY CITY AIRPORT (From Reference 7)

Sample Unit Number	Sample Unit Area, ft^2	PCI Value	Rating
1	5,000	75	Very Good
2	5,000	73	Very Good
3	5,000	76	Very Good
4	5,000	75	Very Good
5	5,000	71	Very Good
6	5,000	74	Very Good
7	5,000	77	Very Good
8	5,000	75	Very Good
Total	40,000	--	--
Mean	--	75	Very Good
Standard Deviation	--	1.85	--
Coef. of Variation, %	--	2.47	--

TABLE 4. SUMMARY OF RESULTS FROM TESTS ON CORE SAMPLES FROM NEEDLES AIRPORT (FROM REFERENCE 7)

Sample Number	Compacted Core Test Data: Bulk Specific Gravity	Unit Wt., pcf	Air Voids %	Marshall: Stability lbs.	Marshall: Flow 0.01 in.	Resilient Modulus, $M_R \times 10^6$, psi: Before Lottman 10°F	Before Lottman 34°F	Before Lottman 77°F	Before Lottman 104°F	After Lottman 77°F	Splitting Tensile, psi: Before Lottman 77°F	After Lottman 77°F
A	B	C	D	E	F	G	H	I	J	K	L	M
1A	2.342	146.1	3.4	3,420	26			1.900				
1B	2.346	146.4	3.3			5.863	4.104	1.891	0.313			
2A	2.343	146.2	3.4					1.867		1.493		304
2B	2.394	149.4	1.3*			8.058	5.701	1.467	0.222		326	
3A	2.347	146.5	3.2	2,900	27			1.427				
3B	2.361	147.3	2.6					1.660		1.294		353
4A	2.325	145.1	4.1					1.846		1.740		265
4B	2.362	147.4	2.6			3.869	2.781	1.816	0.412		381	
NUMBER OF TESTS		8	7	2	2	3	3	8	3	3	2	3
MEAN		146.8	3.2	3,160	27	5.930	4.195	1.734	0.316	1.509	354	307
STANDARD DEVIA.		1.27	0.52	--	--	2.095	1.462	0.193	0.095	0.223	--	44
COEF. OF VAR., %		0.87	16.3	--	--	35.3	34.9	11.1	30.1	14.8	--	14.3

REMARKS: * Not included in statistical analysis

TABLE 5. SUMMARY OF RESULTS FROM TESTS ON CORE SAMPLES FROM BARNES COUNTY MUNICIPAL AIRPORT, VALLEY CITY, NORTH DAKOTA (FROM REFERENCE 7)

Sample Number	Compacted Core Test Data					Resilient Modulus, $M_R \times 10^6$, psi					Splitting Tensile, psi	
	Bulk Specific Gravity	Unit Wt., pcf	Air Voids %	Marshall		Before Lottman				After Lottman	Before Lottman	After Lottman
				Stability lbs.	Flow 0.01 in.	10°F	34°F	77°F	104°F	77°F	77°F	77°F
A	B	C	D	E	F	G	H	I	J	K	L	M
1AT	2.181	136.1	8.2	610	23			0.274				
1BT	2.193	136.8	7.7					0.299		0.074		39
1CT	2.194	136.9	7.7			2.028	1.647	0.277	0.077		97	
2AT	2.197	137.1	7.5	980	18			0.440				
2BT	2.188	136.5	7.9					0.484		0.123		32
2CT	2.167	135.2	8.8			1.980	2.104	0.421	0.106		104	
3AT	2.180	136.0	8.2	614	18			0.345				
3BT	2.161	134.8	9.0					0.312		0.109		40
3CT	2.159	134.7	9.1			2.615	1.798	0.232*	0.058		77	
4AT	2.159	134.7	9.1	889	23			0.562				
4BT	2.161	134.8	9.0					0.407		0.108		28
4CT	2.164	135.0	8.9			3.138	2.820	0.621	0.164		126	
NUMBER OF TESTS		12	12	4	4	4	4	11	4	4	4	4
MEAN		135.7	8.4	773	21	2.440	2.092	0.404	0.102	0.103	101	35
STANDARD DEVIA.		0.95	0.62	190	2.89	0.547	0.521	0.117	0.046	0.021	20	5.74
COEF. OF VAR., %		0.7	7.4	24.6	13.8	22.4	24.9	29.0	45.1	20.4	19.8	16.4

REMARKS: * Not included in statistical analysis

TABLE 6. AGGREGATE AND BINDER TEST DATA FROM NEEDLES AND VALLEY CITY AIRPORTS (From Reference 7)

Sieve Size	Project Description		
	Needles Airport	Valley City Airport	
		Surface AC	Base AC
	Percent Passing by Dry Weight		
3/4 in	100	100	100
1/2 in	96	90	89
3/8 in	85	76	78
No. 4	71	56	57
No. 8	56	39	44
No. 16	43	25	32
No. 30	30	15	19
No. 50	20	10	13
No. 100	11	5	8
No. 200	6	3	4
Asphalt Content, % (by weight of mix)	6.9	6.2	6.4
Penetration at 77 °F, 0.1 mm	16	58	25
Viscosity at 140 °F, poises	12,800	2,009	17,000

TABLE 7. PHYSICAL TEST PROPERTIES OF CORES FROM RECYCLED HIGHWAY PAVEMENT PROJECTS (1 TO 5 YEARS OF AGE) (FROM REFERENCE 7)

Project Description	Air Voids	Resilient Modulus, $M_R \times 10^6$, psi					Marshall		Hveem Stabilometer	Resilient Modulus $M_R \times 10^6$, psi			Indirect Tension psi		
	%	-10°F	10°F	33°F	77°F	104°F	Stability lbs.	Flow 0.01 in.		Before Lottman	After Lottman	Percent Retained	Before Lottman	After Lottman	Percent Retained
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
RYE GRASS WASHINGTON	5.1	4.66	--	2.40	0.222	0.046	1,180	20	29	0.222	0.210	—	—	421	—
ABILENE TEXAS	10.4	2.44	--	1.37	0.438	0.129	1,090	20	26	0.438	0.044	10.0	57	14	24.6
WOODBURN OREGON (IH8)	7.7	4.09	--	3.55	0.371	0.065	1,759	34	23	0.371	0.164	44.2	99	71	71.7
GILA BEND ARIZONA (IH10)	--	3.20	--	1.85	0.285	0.080	1,510	16	31	0.285	0.075*	26.3*	127	48*	37.8*
TRUNK HIGHWAY 94, MINNESOTA	3.5	2.80	--	1.52	0.460	0.180	450	19	15	0.460	0.070*	15.2*	—	—	—
KOSSUTH COUNTY IOWA	4.1	2.65	—	1.64	0.220	0.058	1,690	18	24	0.220	0.039*	17.7*	106	28*	26.4*
GRAHAM COUNTY ARIZONA (US666)	--	3.80	—	1.80	0.440	0.110	--	--	--	--	—	—	—	—	—
HENDERSON NEVADA (IH15)	--	3.80	--	2.50	1.000	0.400	—	—	--	--	—	—	—	—	—
ROSCOE TEXAS (IH20)	--	2.90	--	1.40	0.350	0.110	--	—	--	—	—	—	—	—	—
SNYDER TEXAS (US84)	--	3.60	--	1.90	0.760	0.200	--	—	—	—	--	—	—	—	—
McALLEN TEXAS (SEC 1)	--	1.70	--	0.98	0.200	0.056	--	--	--	--	—	—	—	—	—
(SEC 2)	--	1.95	--	1.40	0.300	0.084	--	--	--	--	—	—	—	—	—
ABILENE TEXAS (US277)	--	3.00	--	2.00	0.330	0.087	--	--	—	—	—	--	--	—	—
HOLDEN UTAH (SEC 17)	--	--	4.50	--	1.000	0.200	--	--	--	--	—	—	—	—	—
(SEC 18)	--	--	4.30	--	0.980	0.210	--	--	--	--	--	—	—	—	—
(SEC 19)	--	--	3.70	--	0.850	0.170	--	--	--	--	--	—	—	—	—
BLEWITT PASS WASHINTON	--	3.20	--	1.62	0.320	0.100	—	--	--	--	--	—	—	—	—

REMARKS: * Vacuum saturation and soak for 7 days (no freeze-thaw cycle) after reference 7

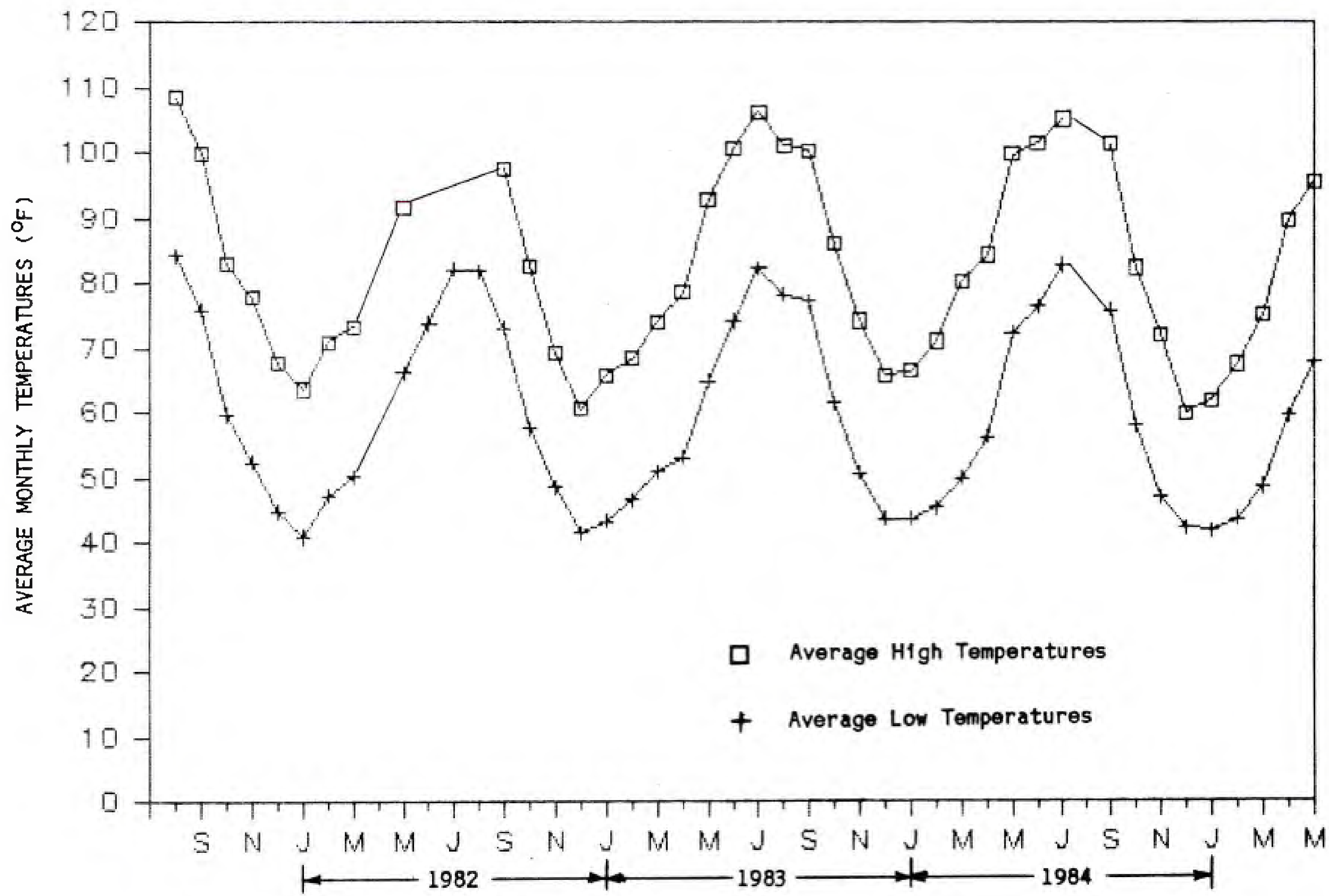

FIGURE 1. AVERAGE MONTHLY HIGH AND LOW TEMPERATURES SINCE RECYCLED SURFACE WAS PLACED AT NEEDLES AIRPORT, NEEDLES, CALIFORNIA.

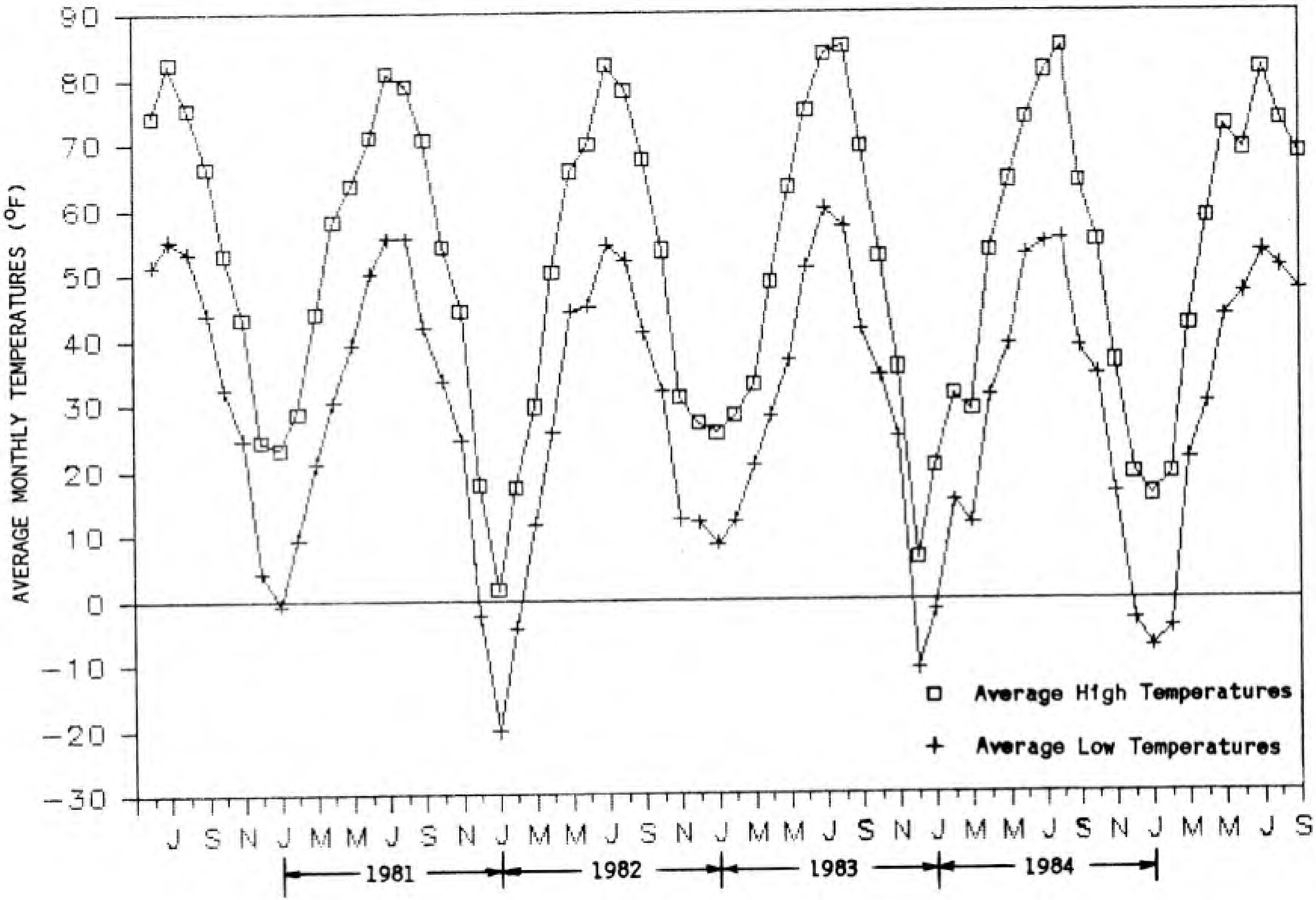

FIGURE 2. AVERAGE MONTHLY HIGH AND LOW TEMPERATURES SINCE RECYCLED SURFACE WAS PLACED AT BARNES COUNTY MUNICIPAL AIRPORT, VALLEY CITY, NORTH DAKOTA.

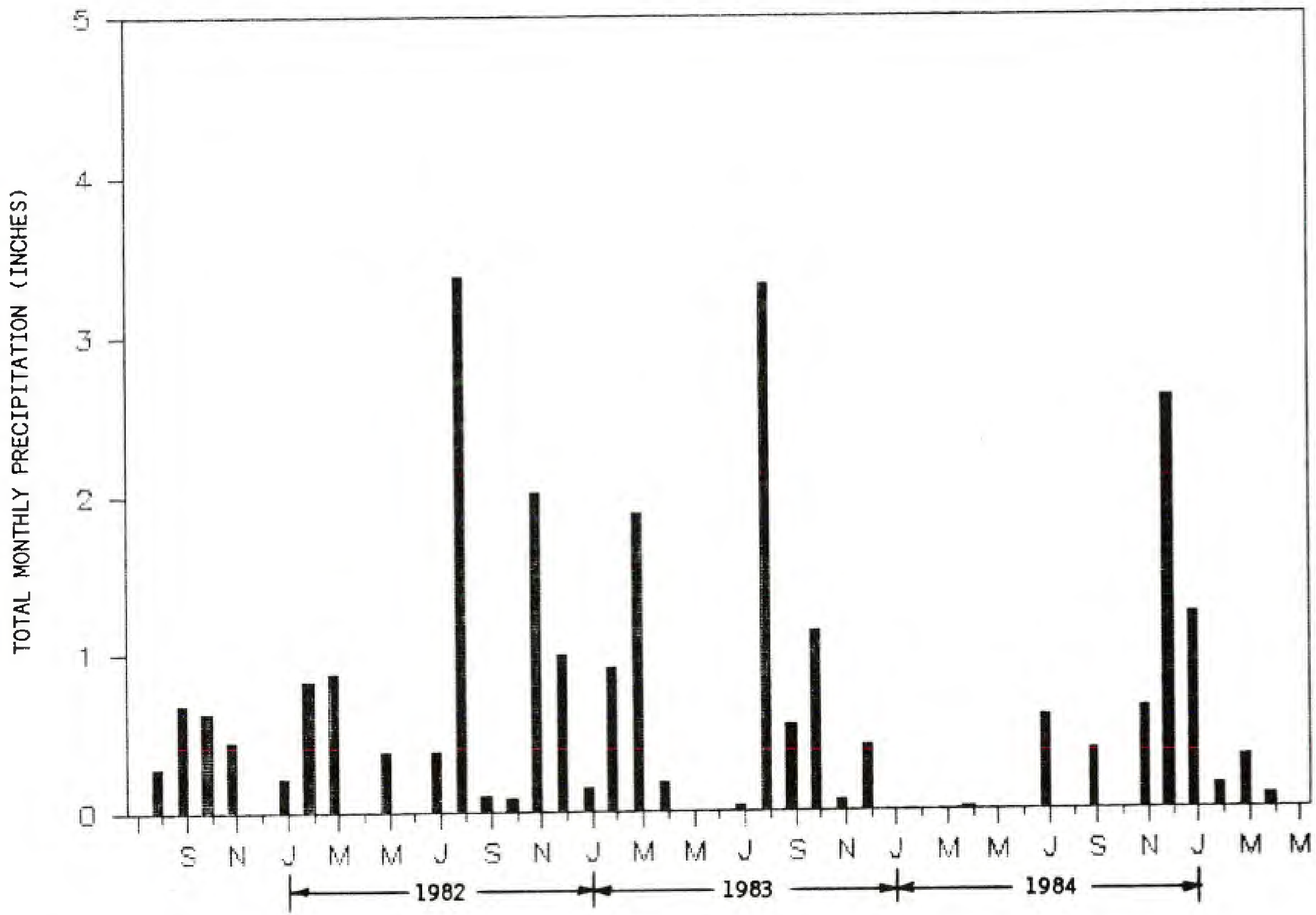

FIGURE 3. TOTAL MONTHLY PRECIPITATION SINCE RECYCLED SURFACE WAS PLACED AT NEEDLES AIRPORT, NEEDLES, CALIFORNIA.

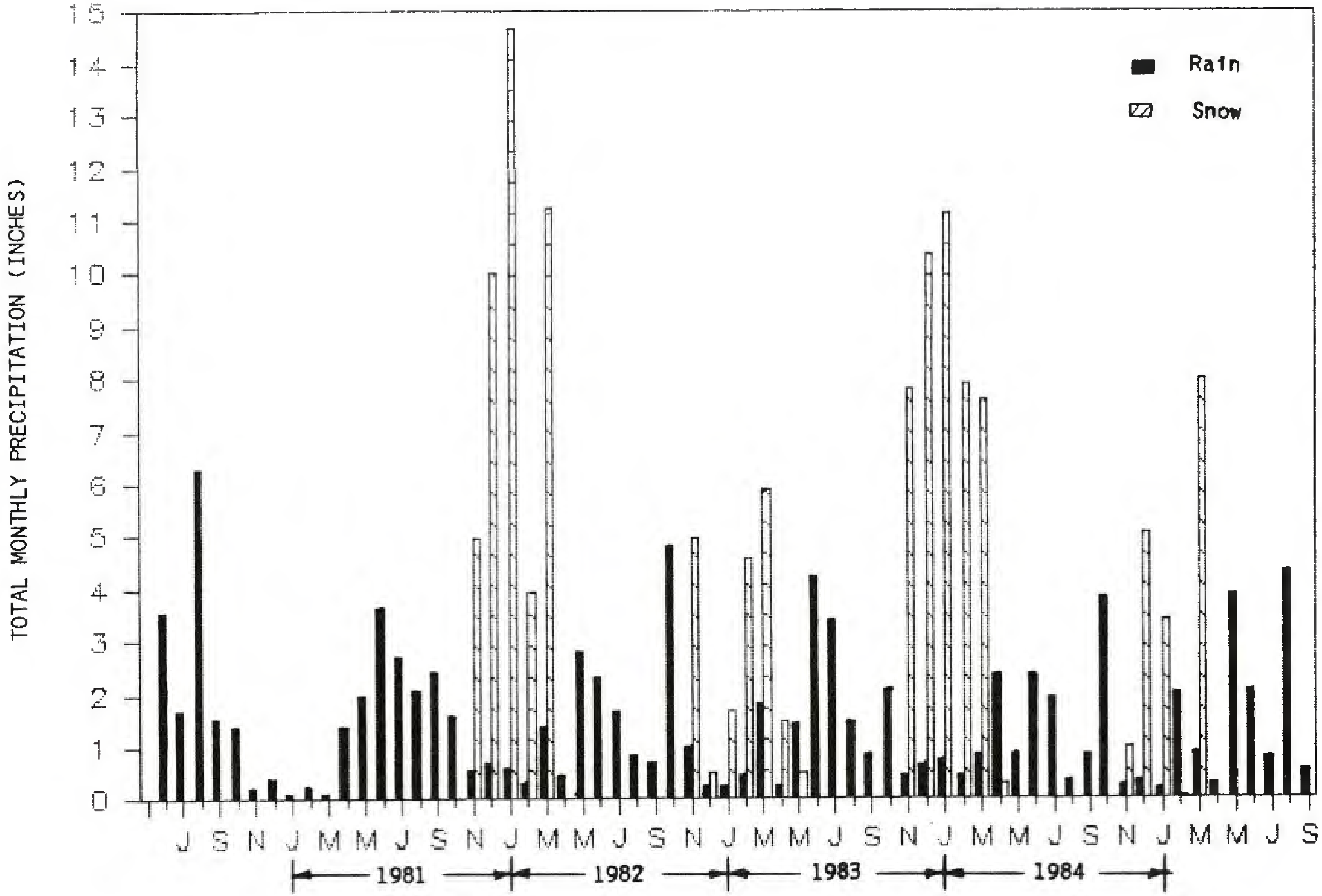

FIGURE 4. TOTAL MONTHLY PRECIPITATION SINCE RECYLCED SURFACE WAS PLACED AT BARNES COUNTY MUNICIPAL AIRPORT, VALLEY CITY, NORTH DAKOTA.

FIGURE 5. OVERALL VIEW OF RUNWAY 2-20 AT NEEDLES AIRPORT, NEEDLES, CALIFORNIA.

FIGURE 6. OVERALL VIEW OF THE TAXIWAY AT BARNES COUNTY MUNICIPAL AIRPORT, VALLEY CITY, NORTH DAKOTA.

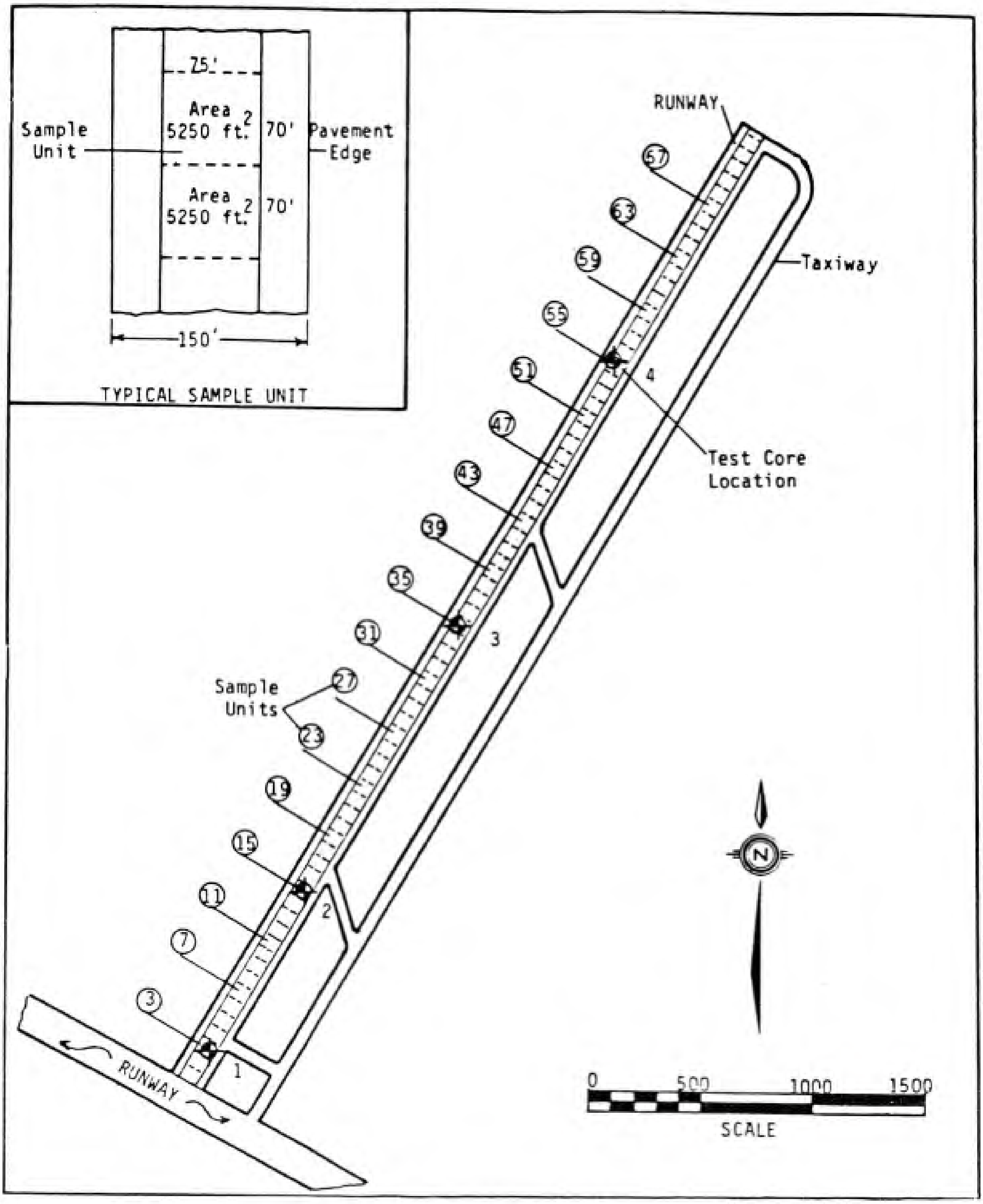

FIGURE 7. SAMPLE UNIT LOCATION PLAN, NEEDLES AIRPORT, NEEDLES, CALIFORNIA.

FIGURE 8. TYPICAL PAVEMENT DEFECTS (CRACKING AND RAVELING OF LOW SEVERITY) AT NEEDLES AIRPORT, NEEDLES, CALIFORNIA.

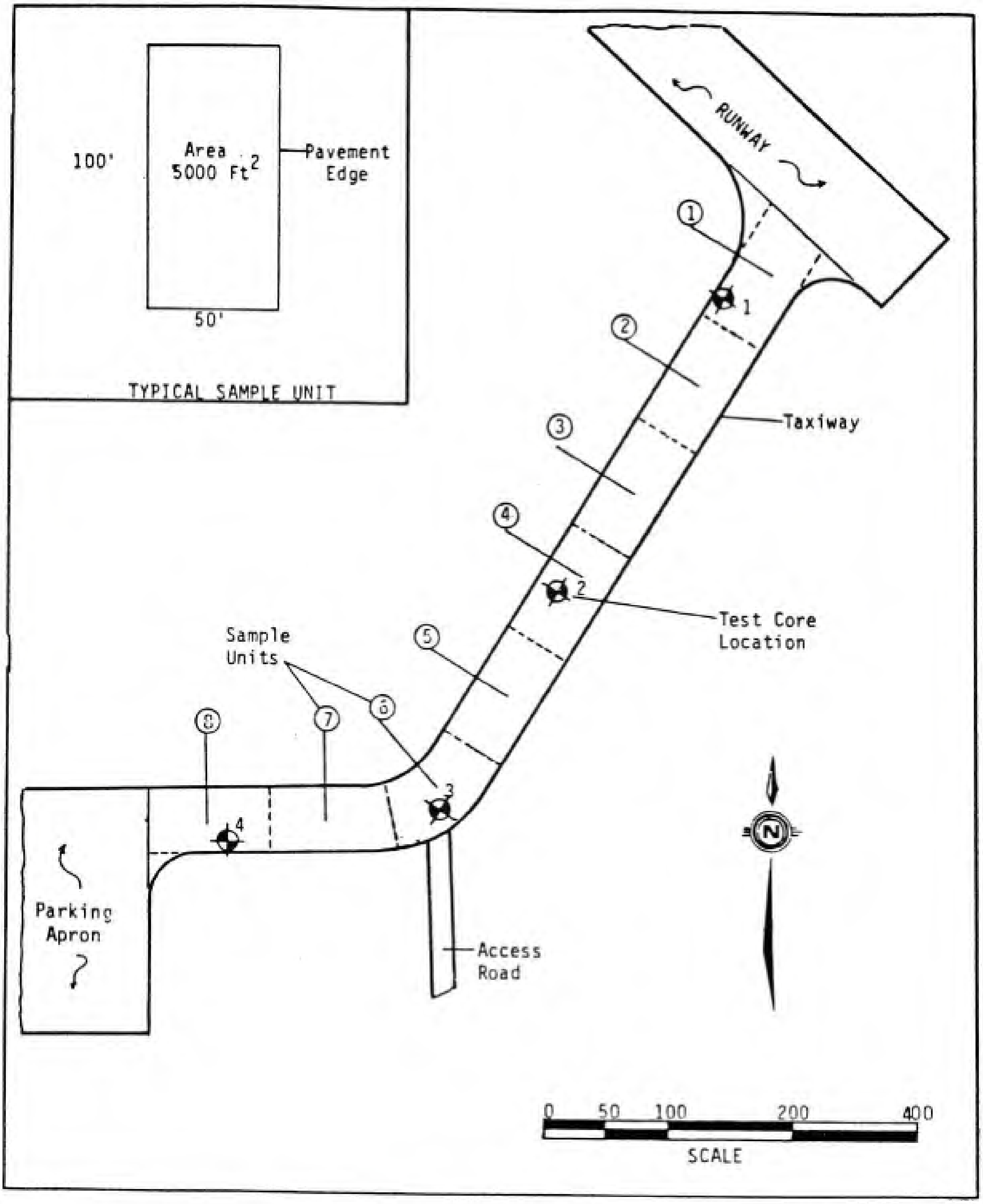

FIGURE 9. SAMPLE UNIT LOCATION PLAN, BARNES COUNTY MUNICIPAL AIRPORT, VALLEY CITY, NORTH DAKOTA.

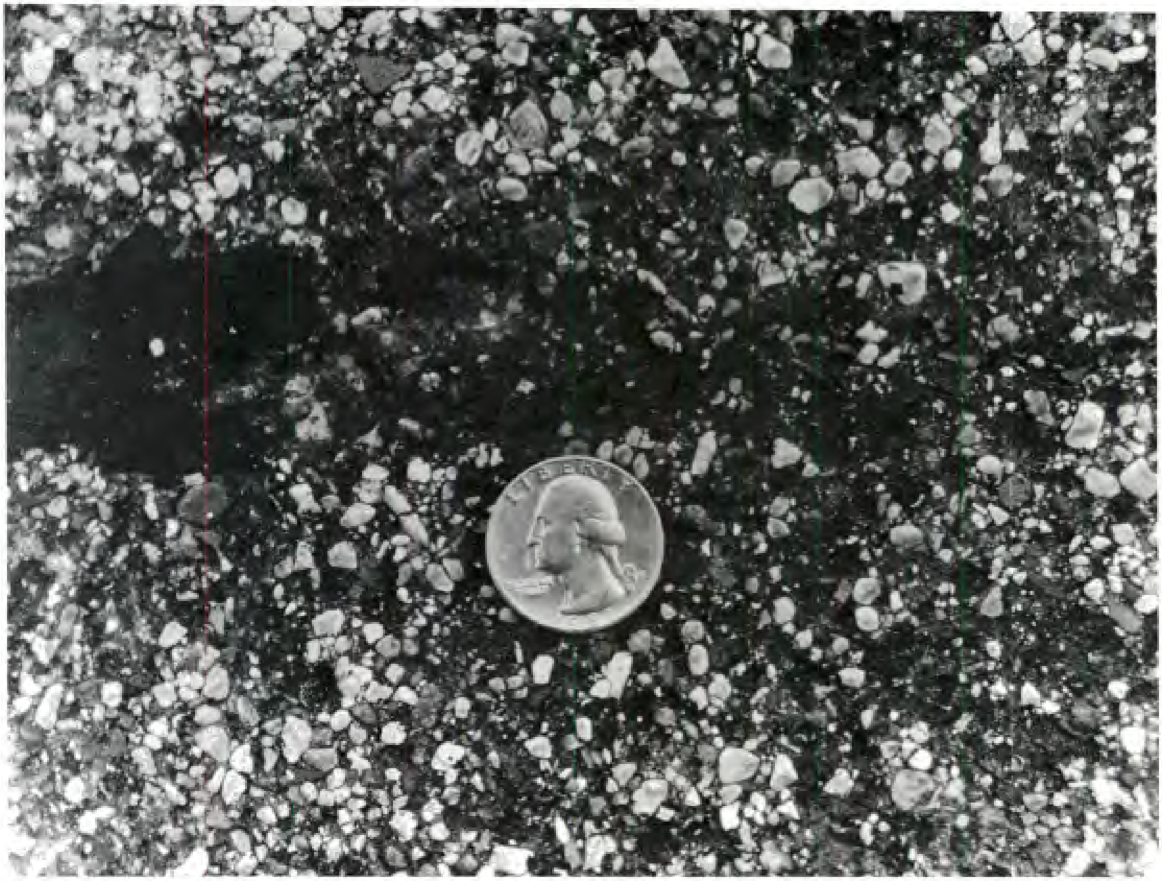

FIGURE 10. TYPICAL PAVEMENT DEFECTS (CRACKING AND RAVELING OF LOW SEVERITY) AT BARNES COUNTY MUNICIPAL AIRPORT, VALLEY CITY, NORTH DAKOTA.

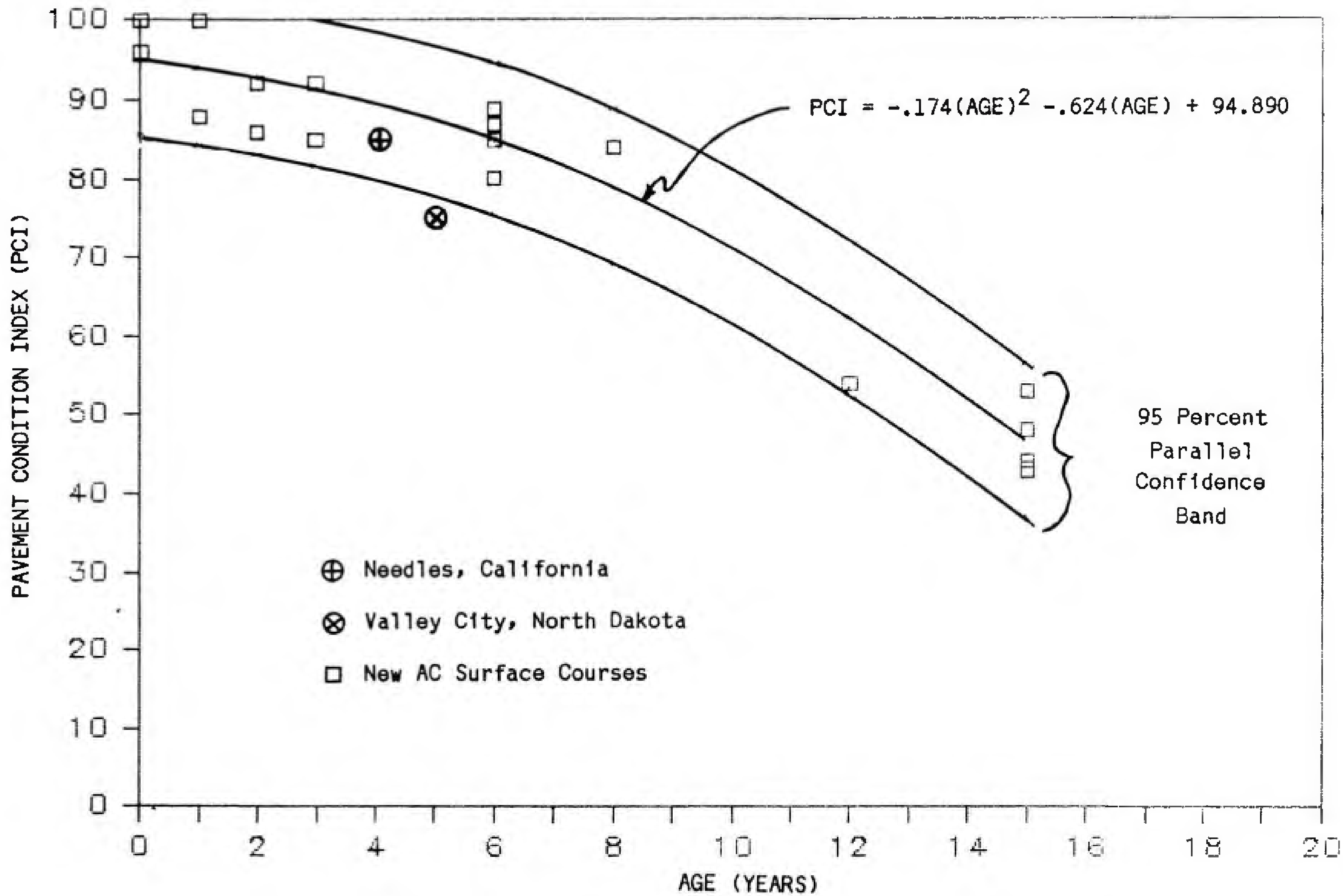

FIGURE 11. PAVEMENT CONDITION INDEX VERSUS AGE OF RECYCLED AC SURFACE COURSES AT NEEDLES, CA AND VALLEY CITY, ND AIRPORTS COMPARED TO NEW AC SURFACE COURSES AT NAVY AIRFIELDS.

APPENDIX A

TESTING PROCEDURES
(After Reference 7)

Marshall Stability and Flow

The Marshall test was developed in the late 1930s and early 1940s by the Mississippi State Highway Department and the U.S. Army Corps of Engineers. The test is used by a large number of states, the Department of Defense, and several foreign countries. The test method is an integral part of a mix design procedure used for selecting asphalt binder contents for asphalt-aggregate mixtures. Marshall stability and flow values are measures of a mixture's ability to resist plastic flow. The standard test method used is the American Society for Testing and Materials (ASTM) Designation D 1559, located in the Annual Book of ASTM Standards, Section 4, Volume 4.03. Normally, mixtures with high Marshall stability and low flow do not shove, corrugate, or rut under traffic.

Criteria for Marshall stability and flow as used for airport mix design purposes on laboratory mixed and laboratory compacted samples are 500 to 1800 pounds minimum for stability and <.20 inches for flow. Marshall stability and flow criteria for core samples have not been established. Cores obtained from newly constructed pavements will normally have stability values lower than those obtained on laboratory mixed and compacted samples. Differences in air voids, binder stiffness, and orientation of aggregate particles account for some of these differences.

Resilient Modulus

Resilient modulus is a measure of an asphalt aggregate mixture's ability to distribute traffic loads and is approximately equal to the elastic modulus (ASTM Designation D 4123). Resilient modulus can be measured over a temperature range. A Mark III Resilient Modulus Device developed by Schmidt was used for testing. A diametral repeated load is applied for a duration of 0.1 second while monitoring the lateral deformation of the specimen.

At the present time, the resilient modulus is not a parameter used in standardized mix design methods. Typical values for resilient modulus at 77 °F and 0.1 second load duration are between 200,000 and 600,000 pounds per square inch (psi) for laboratory mixes and compacted samples. Typical values of resilient modulus over a temperature range are shown in Table 7 for core samples obtained from recycled pavements 1 to 5 years of age.

High values of resilient modulus indicate a good load traffic distributing capability of materials. However, high values at low temperatures indicate a potential for thermal cracking (transverse and longitudinal cracking pattern) and fatigue cracking pavements with relatively thin sections of asphalt concrete. High values of resilient modulus at relatively high temperatures indicate a general resistance to rutting and shoving. The resilient modulus is dependent on temperature and time of loading.

Indirect Tensile Test

The indirect tensile test (splitting tensile, ASTM Designation D 4123) procedure involves loading a sample diametrically along its vertical plane which results in a nearly uniform tensile stress along the axis of loading and away from the loading strips. The tensile stress is calculated from the equation below.

$$\sigma_x = \frac{2 \quad P}{\pi \; t \; d}$$

where: P = total load applied
t = thickness of specimen
d = diameter of specimen

The indirect tensile test can be performed at various temperatures and loading of deformation rates. Typically, the test is performed at 77 °F with a deformation rate of the loading head equal to 2 inches per minute.

At the present time the indirect tensile test is not a parameter used in standardized mix design. Typical values for tensile strength at 77 °F and 2 inches per minute are 100 to 200 psi for laboratory mixed and compacted samples. Typical values for core samples obtained from recycled pavements 1 to 5 years of age are shown in Table 7.

Lottman Water Susceptibility

This test method is utilized to determine the water susceptibility of compacted asphalt-aggregate mixtures. The test procedure is defined in "Predicting Moisture-Induced Damage of Asphalt Concrete" by R.P. Lottman, NCHRP Report 192, TRB, 1978 and involves the vacuum saturation of a compacted sample and subjecting the sample to a freeze-thaw cycle. Resilient modulus and indirect tensile strengths are obtained before and after subjecting the samples to conditioning.

Several state departments of transportation utilize these methods as part of their specification for asphalt-aggregate mixture. Retained indirect tensile strength above 60 to 70 percent are usually specified for laboratory mixed and compacted samples. Typical values for core samples obtained from recycled pavements 1 to 5 years of age are shown in Table 7.

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16 Base facilities (including shelters, power generation, water supplies)
17 Expedient roads/airfields/bridges
18 Amphibious operations (including breakwaters, wave forces)
19 Over-the-Beach operations (including containerization, materiel transfer, lighterage and cranes)
20 POL storage, transfer and distribution
28 **ENERGY/POWER GENERATION**
29 Thermal conservation (thermal engineering of buildings, HVAC systems, energy loss measurement, power generation)
30 Controls and electrical conservation (electrical systems, energy monitoring and control systems)
31 Fuel flexibility (liquid fuels, coal utilization, energy from solid waste)
32 Alternate energy source (geothermal power, photovoltaic power systems, solar systems, wind systems, energy storage systems)
33 Site data and systems integration (energy resource data, energy consumption data, integrating energy systems)
34 **ENVIRONMENTAL PROTECTION**
35 Solid waste management
36 Hazardous/toxic materials management
37 Wastewater management and sanitary engineering
38 Oil pollution removal and recovery
39 Air pollution
44 **OCEAN ENGINEERING**
45 Seafloor soils and foundations
46 Seafloor construction systems and operations (including diver and manipulator tools)
47 Undersea structures and materials
48 Anchors and moorings
49 Undersea power systems, electromechanical cables, and connectors
50 Pressure vessel facilities
51 Physical environment (including site surveying)
52 Ocean-based concrete structures
53 Hyperbaric chambers
54 Undersea cable dynamics

TYPES OF DOCUMENTS

85 Techdata Sheets
86 Technical Reports and Technical Notes
82 NCEL Guide & Updates
☐ None— remove my name
83 Table of Contents & Index to TDS
91 Physical Security

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