Evaluation of ASTM Test Method D 4867, Effect of Moisture on Asphalt Concrete Paving Mixtures

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FOREWORD

The moisture sensitivities of 21 pavements were predicted in 1987 using American Society for Testing and Materials (ASTM) Test Method D 4867, Effect of Moisture on Asphalt Concrete Paving Mixtures. Tests were performed on cores taken from the pavements. In 1995 and 1996, cores were again taken from the pavements to ascertain whether ASTM D 4867 correctly predicted performance. Pavement distress surveys were also performed.

This report presents the results of the study. It recommends that a minimum air-void level of 6.0 percent be used in the test when evaluating dense-graded asphalt mixtures for moisture sensitivity, even if lower air-void levels are typically obtained in the field after construction. This recommendation should also be valid for the American Association of State Highway and Transportation Officials Test Method T 283, Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage.

This document will be of interest to research and laboratory personnel involved with testing and evaluating hot-mix asphalts for performance. This study is part of an effort by the Federal Highway Administration to validate laboratory tests that predict the performance of hot-mix asphalts used in pavements.

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NOTICE

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16. Abstract

The moisture sensitivities of 21 dense-graded asphalt pavements were predicted in 1987 using American Society for Testing and Materials (ASTM) Test Method D 4867, Effect of Moisture on Asphalt Concrete Paving Mixtures. Tests were performed on cores taken from the pavements. The air-void levels of the cores varied from pavement to pavement. In 1995 and 1996, cores were again taken from the pavements to ascertain whether the test method correctly predicted performance. Pavement distress surveys were also performed.

The data indicated that air-void levels lower than 6.0 percent may not always allow the specimens to become sufficiently damaged in the laboratory test. The correlation between ASTM D 4867 and pavement performance was poor except for mixtures having air-void levels greater than 6.0 percent. Therefore, it is recommended that a 6.0-percent-minimum air-void level be used when evaluating conventional, dense-graded asphalt paving mixtures for moisture sensitivity, even if lower air-void levels are typically obtained in the field after construction. This recommendation should also be valid for the American Association of State Highway and Transportation Officials Test Method T 283, Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage.

Pass/fail criteria of 80 percent for the tensile strength retained ratio, 70 percent for the diametral modulus retained ratio, and 10 percent for visual stripping are recommended for conventional, dense-graded asphalt paving mixtures.

Dense-graded sulfur-extended asphalt (SEA) pavements were also included in the study. The 1987 laboratory test data indicated that the retained ratios of these mixtures can be significantly affected by losses in cohesion. The SEA binders themselves can be severely weakened by the conditioning processes used by ASTM D 4867. However, the performances of the SEA pavements provided no evidence that they were affected by a loss in cohesion. In this experiment, the performance of each SEA pavement was compared to the performance of an asphalt concrete control pavement. Pass/fail criteria for SEA mixtures could not be proposed due to the uncertainty of how the test data relate to pavement performance.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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1. Background

In 1985, the Federal Highway Administration (FHWA) initiated a study to compare the performances of existing sulfur-extended asphalt (SEA) pavements to that of asphalt concrete (AC) control pavements. A representative set of pavements from 18 States was chosen to provide a comprehensive evaluation of the effects of sulfur on pavement performance when used as an asphalt extender. The term "sulfur-extended asphalt" denotes that a significant quantity of sulfur was used to replace asphalt cement in hot-mix asphalt, thereby extending the supply of asphalt cement which rapidly increased in price after the oil embargo of the early 1970's. Most SEA pavements were constructed between 1973 and 1983. Twenty- to forty-percent sulfur by total mass of the binder was typically used. Distress surveys were performed on the pavements in 1986 and 1987, and a laboratory study on cores taken from many of the pavements was completed in 1990.[1,2,3]

The primary conclusion of the field study was that there was no difference in overall performance between the SEA and AC pavements. The types of distress, including rutting, fatigue cracking, low-temperature cracking, and potholes, also tended to be the same. The distress in most of the pavements was low.

An examination of the cores verified the generally good conditions of the pavements. The cores were then tested to predict whether the performances of the two types of mixtures would remain similar. In general, the laboratory test data supported the findings of the field study in that most pairs of SEA and AC mixtures had very similar mechanical properties.[3] However, because the pavements were only 3.2 to 7.4 years old when cored, it was recommended that the pavements be reevaluated in the future.

The pavements were reevaluated in 1995 and 1996 by performing a distress survey and visually examining a new set of cores.[4] Table 1 shows the locations of the pavements that still existed in 1995 and 1996 and the ages of the pavements when cored for the two evaluations, henceforth referred to as the 1987 and 1996 studies for simplicity. Table 2 shows which pavement layer(s) contained the AC and SEA mixtures. This information was obtained from the 1987 cores, although no discrepancies were found for the 1996 cores.

Mechanical tests were not performed on the 1996 cores because of the lack of adequate methods for interpreting the data. For example, measurements such as tensile strength are affected by various mechanisms that occur in a pavement, including moisture damage, age-hardening, and microcracks from fatigue. Some of these mechanisms oppose each other. Moisture damage decreases the tensile strength of a compacted mixture at 25 °C, while age-hardening increases tensile strength. Moisture damage, age-hardening, and microcracks can also vary from location to location in a given pavement.

Moisture sensitivity was evaluated in the 1987 study in accordance with the American Society for Testing and Materials (ASTM) Test Method D 4867.[5] This test was performed, not only to determine the effects of sulfur on pavement performance, but to evaluate the test itself based on future pavement performance. The 1996 distress survey and cores provided this performance. The cores were extracted from the pavements using a wet process, then split open in the laboratory and visually examined for stripping. In order to avoid the readherence of loose binder films to the aggregates, the cores were not allowed to dry before they were evaluated.

2. Objectives

The objective of this study was to evaluate ASTM D 4867 by comparing the amount of visual stripping in the AC and SEA pavements in 1996 to the damage predicted by the test in 1987.

3. ASTM D 4867

In ASTM D 4867, the indirect (splitting) tensile strengths of unconditioned and conditioned specimens are measured. A tensile strength ratio (TSR), defined as the condition strength divided by the unconditioned strength, is then computed in terms of a percentage. In the 1987 study, a diametral modulus test, which provided a diametral modulus ratio (M_dR), was included along with a visual estimate of stripping.[3]

Table 1. Pavements evaluated and age of cores.

1987 Review Number	Code	Location	Age of Cores 1987	Age of Cores 1996
860602	CA	California-Anaheim; Lincoln Ave., East Section	4.3	13.6
850601	CB	California-Baker; Barstow/Baker, I-15	3.2	12.8
851601	ID	Idaho; Elk City, State Route 14	4.0	14.8
862701	MN	Minnesota; Rochester/Zumbro Falls, TH-63	7.0	17.3
862801	MS	Mississippi; S of Phila., Neshoba Co, Rt. 15	4.4	15.0
853801	ND	North Dakota; NW of Minot, U.S. 2	5.2	14.7
853501	NM	New Mexico; Carlsbad, U.S. 62/180	3.7	14.3
854802	TC	Texas-College Station; Brazos County, MH 153	7.4	16.2
854801	TP	Texas-Pecos; Bakersfield/Ft. Stockton, I-10	4.2	13.6
865501	WI	Wisconsin; Wittenberg-Tilleda, SH 29	3.6	11.9
865601	WY	Wyoming; West of Cheyenne, SR 225	3.7	13.8

Table 2. Pavement layers and thicknesses of the 1987 cores.(3)

Code	Pavement Layer	AC Pavement Thickness, mm		SEA Pavement Thickness, mm	
CA	Surface	No AC Cores[a]		30 to 45	(SEA)
CB	Surface	65	(AC)	65	(SEA)
ID	Surface Treatment	5		5	
	Surface (2 lifts)	65 to 90	(AC)	65 to 90	(SEA)
	Leveling	0 to 40		0 to 40	
MN	Surface	40	(AC)	40	(SEA)
	Leveling	40 to 55		35 to 70	
MS	Surface	30 to 55	(AC)	30 to 55	(SEA)
	Binder	40	(AC)	40	(SEA)
	Base (top lift)	55 to 75	(AC)	55 to 75	(SEA)
	Base (bottom lift)	50 to 100	(AC)	50 to 100	(SEA)
ND	Surface Treatment	10		10	
	Overlay or Patch	0 to 40		0 to 40	
	Surface (2 lifts)	75 to 100	(AC)	70 to 90	(SEA)
NM	Open-Graded Friction Course	6		10 to 20	
	Surface	50 to 75	(AC)	50	(SEA)
	Base (2 lifts)	135	(AC)	100 to 145	(SEA)
TC	Surface	20		5 to 25	
	Base (3 lifts)	135 to 155	(AC)	140 to 155	(SEA)
TP	Surface Treatment	15		15	
	Surface	30	(AC)	30	(SEA)
	Binder	50	(AC)	50	(SEA)
WI	Surface	100 to 150	(AC)	125 to 150	(SEA)
WY	Surface Treatment			10	
	Surface	No AC Cores[a]		50	(SEA)

[a]No asphalt concrete control cores were taken.

The conditioned specimens in the 1987 study were:

- Vacuum saturated so that 55 to 80 percent of the air voids were filled with water.
- Frozen at -17.8 °C for 15 h (optional step in the method).
- Soaked in a 60 °C water bath for 24 h.
- Tested along with the unconditioned specimens at 25 °C.

The objective of testing the cores in the 1987 study was to estimate the future performance of the pavements. None of the unconditioned 1987 cores showed any visual stripping; thus, it was assumed that there was little to no moisture-related damage in the pavements at that time.

The ASTM D 4867 test method is normally performed on laboratory-prepared specimens that are compacted to either a 6- to 8-percent air-void level, or to the air-void level that is expected in the pavement after construction. The air voids of the cores tested in the 1987 study did not always meet the 6- to 8-percent air-void level. The air voids varied from pavement to pavement and were not always the same in each pair of SEA and AC pavements. The air voids of the 1987 cores taken in and out of the wheelpath from a given pavement were not statistically different; thus, it was assumed that the air voids were close to the levels after construction. ASTM D 4867 does not account for any changes in pavement air voids over time, or whether the air voids in and out of the wheelpath will eventually become different.

The average air-void levels of the cores are given in table 3 and are shown graphically in figure 1. The SEA designations in table 3 (for example, 30/70) are the proportion of sulfur to asphalt by mass in the binder. The air voids in the 1987 cores ranged from 1.9 to 10.7 percent. Although ASTM D 4867 allows the use of air-void levels outside the 6- to 8-percent range, the test was primarily developed using air-void levels within this range. The degree of damage in this test and in other similar tests for moisture sensitivity is a function of the temperature of the hot-water soak, the soaking period, and the amount of water that enters the specimen. The amount of water in the specimen is a function of the air-void level and permeability. Therefore, it was hypothesized during the 1987 evaluation that the damage provided by the test may be less than what would eventually occur in the pavements when the air voids were less than 6.0 percent.

In the 1987 study, all of the cores could be vacuum saturated with water to a level above the 55-percent minimum saturation level specified by ASTM D 4867 regardless of the air-void level. (It was realized that some water may have been absorbed into the cut aggregate faces of the cores during vacuum saturation and hot-water soak.) Although all of the cores could be saturated to the required level, the water content of the cores, in terms of mass, varied widely because of the different air-void levels. For a given mixture, a low air-void level and low water intrusion should lead to less moisture damage in the field. However, it is again postulated that some minimum volume

Table 3. Maximum specific gravity of the mixtures and air-void levels.

Code	Pavement Layer	Material	1987 Cores: Maximum Specific Gravity	1987 Cores: Air Voids, Percent	1996: Air Voids, Percent
CA	Surface	SEA (30/70)	2.452	9.0	11.4
CB	Surface	AR-4000	2.408	7.6	7.3
	Surface	SEA (20/80)	2.455	10.6	8.4
	Surface	SEA (40/60)	2.413	5.0	3.2
ID	Surface, Location #1	AR-4000	2.507	4.8	5.0
	Surface, Location #2	AR-4000	2.495	4.4	5.5
	Surface, Location #1	SEA (30/70)	2.521	4.8	7.6
	Surface, Location #2	SEA (30/70)	2.507	5.2	8.3
MN	Surface	AC 200-300	2.432	2.4	2.5
	Surface	SEA (40/60)	2.492	6.1	5.0
MS	Surface	AC-20	2.398	6.4	8.8
	Surface	SEA (30/70)	2.402	7.1	10.9
	Binder	AC-40	2.410	8.2	9.0
	Binder	SEA (30/70)	2.422	9.7	12.0
	Base	AC-40	2.411	9.9	11.3
	Base	SEA (30/70)	2.428	8.6	10.4
ND	Surface	AC 120-150	2.424	2.1	3.9
	Surface	SEA (30/70)	2.456	6.7	8.3
	Surface	SEA (25/75)	2.454	3.2	6.5
NM	Surface	AC-10	2.590	7.2	8.3
	Surface	SEA (30/70)	2.577	8.4	7.7
	Base	AC-10	2.556	6.3	7.3
	Base	SEA (30/70)	2.572	8.1	10.0
TC	Base, top half	AC-20	2.425	2.4	8.2
	Base, bottom half	AC-20	2.421	3.1	7.5
	Base, total	SEA (30/70)	2.460	7.5	11.5
TP	Binder	SEA (30/70)	2.422	10.7	a
WI	Surface	AC 120-150	2.418	2.0	2.6
	Surface	SEA (30/70)	2.440	1.9	2.8
WY	Surface	SEA (20/80)	2.418	4.0	3.2

[a]The cores from the Pecos, Texas (TP), pavement disintegrated.

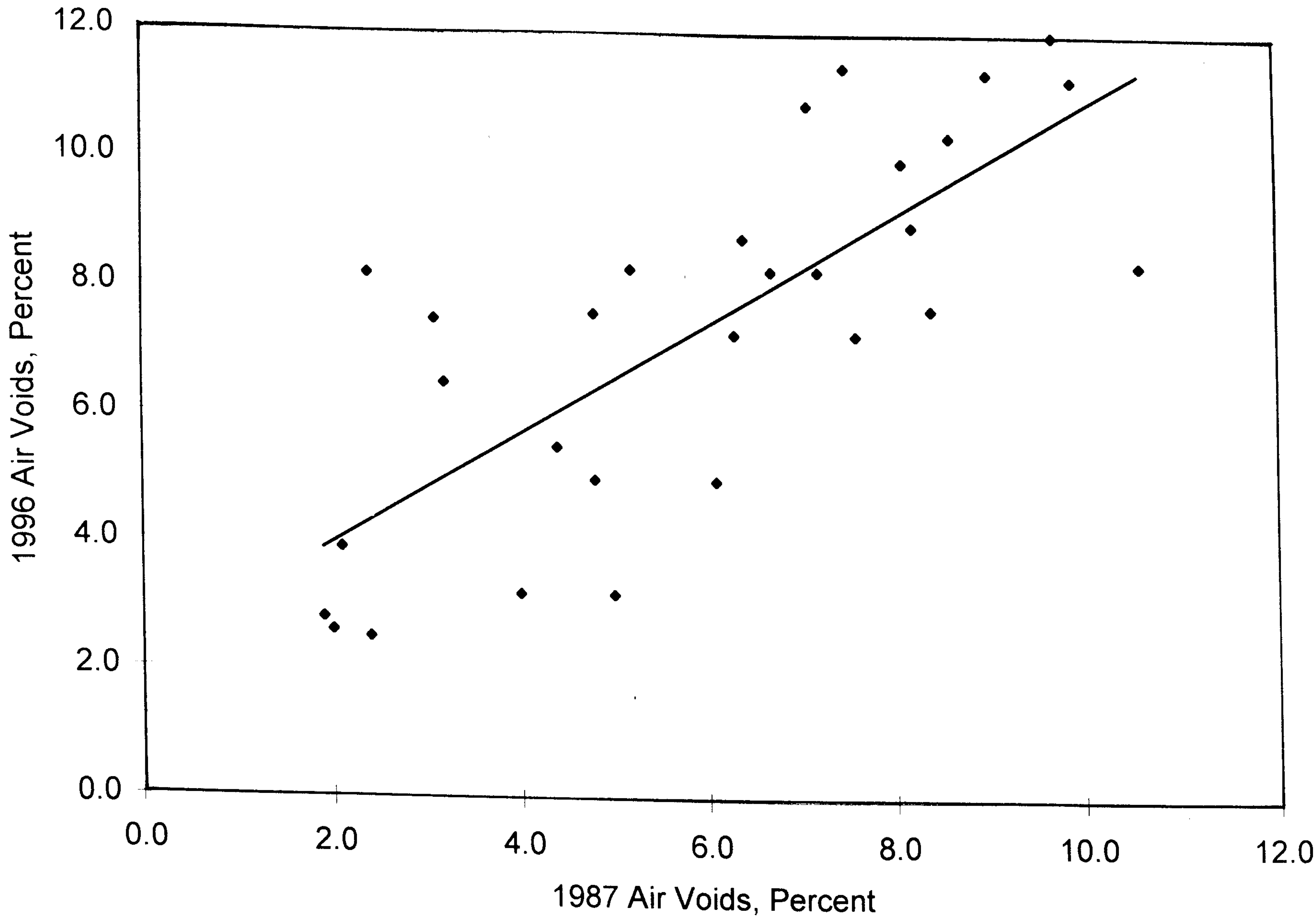

Figure 1. 1996 air voids vs. 1987 air voids.

of water may be needed in the laboratory test to accelerate moisture damage even if a relatively low air-void level is obtained in the pavement.

The coefficient of determination, r^2, for the regression line in figure 1 was found to be 0.58. This poor r^2 was expected because pavements densify to different degrees. However, table 3 shows that the average percent air voids for the 1996 cores from College Station, Texas (TC), were higher than those for the 1987 cores by 4.0 percent or greater. The maximum specific gravities for the two sets of data were found to be virtually equal; however, the 1996 SEA cores had an average binder content of 6.9 percent by total mass, compared to the 1987 value of 5.9 percent. The 1996 SEA cores also had 7.0-percent aggregate passing the 0.075-mm sieve, compared to a 1987 value of 5.0 percent. The 1996 cores from the bottom half of the AC-20 layer had a binder content of 4.9 percent by total mass, which agreed with the 1987 value of 5.1 percent; however, they had 3.6-percent aggregate passing the 0.075-mm sieve, compared to the 1987 value of 7.5 percent. These discrepancies could not be rectified, and whether the data should or should not be included in the study was not apparent.

Table 3 shows that the average air voids for the 1996 cores were also greater than those for the 1987 cores for the following pavements: Anaheim, California (CA), Idaho (ID), Mississippi (MS), North Dakota (ND), and three out of four sets of cores from New Mexico (NM). An explanation for these increases in average air voids was not apparent. It was hypothesized that these increases could be due to distress, primarily fatigue microcracks; however, this was not supported by the distress surveys.[4] Significant cracking was only observed on the following pavements: Baker, California (CB), Idaho (ID), and the AC-20 control pavement from College Station, Texas (TC). Both Mississippi (MS) surface mixtures had begun to ravel. As found during the 1987 study, the air voids in and out of the wheelpath were not statistically different for the 1996 cores for any pavement.

4. Results and Discussion

The TSR, M_dR, and average percent visual stripping for the 1987 cores are given in table 4, along with the average percent visual stripping for the 1996 cores. These average values were calculated from a range in visual stripping. The ranges were approximately the average value ±30 percent. The extensive footnotes for this table show the difficulty in trying to define pavement performance in terms of visual stripping. For example, the bottom portion of the ND AC 120-150 surface layer was severely stripped, but the top portion was not stripped. Two cores from the NM SEA (30/70) base layer were severely stripped and crumbled, while two other cores, taken at a distance not more than 1.0 m away, were not stripped. This variability is one reason why it is difficult to develop tests for predicting moisture sensitivity. Moisture damage in pavements often cannot be defined by a single number or a succinct description. The most difficult cores to examine for visual stripping were those from MS (Mississippi). Rounded, light brown aggregates were used in these pavements, and the asphalt films on the coarse aggregates were thin.

Table 4. Moisture sensitivity results.

Code	Pavement Layer	Material	TSR	M_dR	Average Visual Stripping 1987	Average Visual Stripping 1996	
CA	Surface	SEA (30/70)	60	58	40	0	
CB	Surface	AR-4000	41	55	75	12	a
	Surface	SEA (20/80)	31	31	35	2	
	Surface	SEA (40/60)	44	46	65	0	
ID	Surface, Location #1	AR-4000	82	81	0	10	b
	Surface, Location #2	AR-4000	86	99	0	12	c
	Surface, Location #1	SEA (30/70)	81	62	0	0	d
	Surface, Location #2	SEA (30/70)	71	68	0	2	e
MN	Surface	AC 200-300	86	74	12	12	f
	Surface	SEA (40/60)	78	63	5	12	f
MS	Surface	AC-20	80	104	17	2	
	Surface	SEA (30/70)	78	79	8	2	
	Binder	AC-40	80	82	17	2	
	Binder	SEA (30/70)	55	53	15	2	
	Base	AC-40	54	57	30	15	g
	Base	SEA (30/70)	72	49	35	6	g
ND	Surface	AC 120-150	103	101	0	50	h
	Surface	SEA (30/70)	57	40	0	8	i
	Surface	SEA (25/75)	77	58	2	50	j
NM	Surface	AC-10	80	87	7	2	k
	Surface	SEA (30/70)	55	45	15	2	
	Base	AC-10	30	21	10	15	
	Base	SEA (30/70)	47	36	15	25	l
TC	Base, top half	AC-20	102	103	8	50	
	Base, bottom half	AC-20	91	108	30	50	
	Base, total	SEA (30/70)	34	35	30	50	
TP	Binder	SEA (30/70)	35	26	5	50	m
WI	Surface	AC 120-150	115	141	6	35	n
	Surface	SEA (30/70)	86	85	5	35	n
WY	Surface	SEA (20/80)	81	81	2	0	

Table 4. Moisture sensitivity results (continued).

California, Barstow/Baker (CB)

a The range in visual stripping was 0 to 50 percent.

Idaho (ID)

b The range in visual stripping was 0 to 20 percent, with one end of the pavement having 0- to 10-percent visual stripping and the other end having 10 to 20 percent.

c The range in visual stripping was 5 to 25 percent. One core showed extreme aggregate segregation.

d Although there was no visual stripping in this SEA pavement, the lower SEA lift crumbled in five out of the eight cores. Sulfur had separated from the asphalt binder and settled to the bottom of these cores. The higher air-void levels for the 1996 cores in table 3 may have resulted from this separation or from the fatigue cracks observed in the pavement.

e The lower lift crumbled in two out of the eight cores, while both lifts of a third core crumbled. Sulfur had separated from the asphalt binder and settled to the bottom of these cores. The higher air-void levels for the 1996 cores in table 3 may have resulted from this separation or from the fatigue cracks observed in the pavement.

Minnesota (MN)

f The range in visual stripping was 0 to 30 percent; however, the cores either had no visual stripping or greater than 15-percent visual stripping. This difference in visual stripping was not only found for cores taken from different locations, but also for cores taken from the same location. The distress in most of the cores that were stripped appeared to have started at the interface between the surface layer and the leveling course, and was proceeding upward. The bottom portions of some cores were more than 50-percent stripped, while the top portions showed no stripping.

Mississippi (MS)

g Both the AC and SEA base mixtures tended to crumble even though the amount of visual stripping was not extensive. The range in visual stripping for the SEA base mixture was 0 to 15 percent.

North Dakota (ND)

h Stripping had started at the bottom of the AC 120-150 layer and was proceeding upward. Approximately 50 percent of the cross-sectional area of the cores was stripped at a very high level, around 80 percent. There was very little to no stripping above these areas.

Table 4. Moisture sensitivity results (continued).

i Six SEA (30/70) cores were examined. Stripping had started at the bottom of the SEA layer and was proceeding upward. Approximately 8 percent of the cross-sectional area of five cores was stripped at a very high level, approximately 80 percent. There was little to no stripping above these areas. The remaining core was stripped at approximately 15 percent throughout the SEA layer. This core, along with one of the other five cores, was cracked from top to bottom.

j Stripping had started at the bottom of the layer and was proceeding upward. The amount of stripping was extremely variable. Cores taken at one end of the pavement were 100-percent stripped and fell apart. Cores taken at the other end of the pavement had either stripped very little or had moderate amounts of stripping at their bottoms.

New Mexico (NM)

k The asphalt binder had many pits, but virtually no stripping was observed.

l Eight cores, numbered 1 through 8, were taken from this SEA pavement. The 135-mm-thick base layers of cores 2 and 3 were 100-percent stripped and crumbled. Visual stripping in the other six cores was virtually non-existent, including cores 1 and 4, which were taken at the same location as cores 2 and 3. Cores 1 and 2 were taken from the wheelpath, while cores 3 and 4 were taken between the wheelpaths. A reason for the difference in performance is not known. The top 25- to 40-mm portion of the SEA base layer in cores 2 and 3 appeared to be an asphalt mixture when the cores were first split open. Crystalline sulfur was not observed in this portion of the cores. Crystalline sulfur was observed in the lower portions and in all parts of the other six SEA cores. After 24 h, a whitish bloom was observed in cores 2 and 3 where no crystalline sulfur had been observed. This bloom was found to be sulfate. Sulfate was also observed at the bottom of the cores.

Texas, Pecos (TP)

m The sand fraction of this mixture was completely stripped and the cores fell apart.

Wisconsin (WI)

n Stripping had started at the bottom of the layer and was proceeding upward. Fifty-five to sixty-five percent of the cross-sectional area of the cores was stripped at a level of 35 percent. The top portions of the cores were not stripped. These pavements had been milled before they were obtained. It was estimated that 40 to 50 percent of the original cross-sectional area was stripped prior to milling.

Table 5. Moisture sensitivity results by type of binder, AC or SEA.

Code	Pavement Layer	Material	TSR	M_dR	Visual Stripping 1987	Visual Stripping 1996	
CB	Surface	AR-4000	41	55	75	12	a
ID	Surface, Location #1	AR-4000	82	81	0	10	b
ID	Surface, Location #2	AR-4000	86	99	0	12	c
MN	Surface	AC 200-300	86	74	12	12	f
MS	Surface	AC-20	80	104	17	2	
MS	Binder	AC-40	80	82	17	2	
MS	Base	AC-40	54	57	30	15	g
ND	Surface	AC 120-150	103	101	0	50	h
NM	Surface	AC-10	80	87	7	2	k
NM	Base	AC-10	30	21	10	15	
TC	Base, top half	AC-20	102	103	8	50	
TC	Base, bottom half	AC-20	91	108	30	50	
WI	Surface	AC 120-150	115	141	6	35	n
CA	Surface	SEA (30/70)	60	58	40	0	
CB	Surface	SEA (20/80)	31	31	35	2	
CB	Surface	SEA (40/60)	44	46	65	0	
ID	Surface, Location #1	SEA (30/70)	81	62	0	0	d
ID	Surface, Location #2	SEA (30/70)	71	68	0	2	e
MN	Surface	SEA (40/60)	78	63	5	12	f
MS	Surface	SEA (30/70)	78	79	8	2	
MS	Binder	SEA (30/70)	55	53	15	2	
MS	Base	SEA (30/70)	72	49	35	6	g
ND	Surface	SEA (30/70)	57	40	0	8	i
ND	Surface	SEA (25/75)	77	58	2	50	j
NM	Surface	SEA (30/70)	55	45	15	2	
NM	Base	SEA (30/70)	47	36	15	25	l
TC	Base, total	SEA (30/70)	34	35	30	50	
TP	Binder	SEA (30/70)	35	26	5	50	m
WI	Surface	SEA (30/70)	86	85	5	35	n
WY	Surface	SEA (20/80)	81	81	2	0	

Footnotes: See table 4.

Table 5 presents the same data as table 4, but the AC and SEA mixtures are listed in separate groups. Table 4 allows visual comparisons to be made between the SEA and companion AC mixtures. Table 5 is more beneficial for evaluating ASTM D 4867. Highway agencies are currently more interested in learning how the test predicts the performance of asphalt mixtures. The degree of correlation between the test and SEA pavement performance, and any peculiarities found for SEA mixtures, are of less interest because SEA mixtures are not used at this time.

The degree of correlation among the data in table 5 was determined using linear regression analyses. The correlations between the TSR's and M_dR's were good. The r^2 for TSR versus M_dR for all pavements, AC pavements alone, and SEA pavements alone were 0.82, 0.84, and 0.80, respectively. The data are shown graphically in figures 2 through 4. Poor correlations were found for TSR versus either set of visual stripping, M_dR versus either set of visual stripping, and for the two sets of visual stripping compared to each other. All calculated r^2 were below 0.25. Both linear and exponential regressions were tried. The data for the AC pavements are shown graphically in figures 5 through 9.

The regressions were then repeated using the highest percentage of visual stripping for those 1996 pavements that had a large range in visual stripping. These values are shown in table 6. They are also given in the footnotes for table 4. These data did not provide better correlations. The variability of visual stripping was a confounding factor in this study.

The data were evaluated using pass/fail criteria of 80 percent for TSR, 70 percent for M_dR, and 10 percent for visual stripping.[6] The results are given in table 7. If the 1996 visual stripping ratings in the table are a measure of pavement performance, then ASTM D 4867 is a poor test.

Table 8 is a variation of table 7 where the pavements are grouped according to the air-void levels of the cores when tested in the 1987 study. The pavements were divided at a 6.0-percent air-void level because the test is normally performed at a 6- to 8-percent air-void level. Comparisons between the TSR, M_dR, and 1996 visual stripping for the AC pavements indicate that the hypothesis that air voids greater than 6.0 percent are needed in ASTM D 4867 to properly accelerate damage may be valid. The six AC pavements that had passing TSR and M_dR, but failed according to the 1996 visual ratings, had air-void levels below 6.0 percent. The three pavements that had failing TSR and M_dR and had failed according to the 1996 visual rating had air voids above 6.0 percent. These pavements were CB Surface, MS Base, and NM Base. The agreement is quite remarkable (or perhaps just lucky) because visual stripping is difficult to determine and often has a high degree of variability from evaluator to evaluator. In general, the 1987 visual ratings for the AC pavements did not agree with the TSR, M_dR, or 1996 visual ratings.

Table 8 shows that poor correlations were provided by the SEA pavements. An examination of the 1987 data in table 5 showed that some SEA pavements had low levels of visual stripping coupled with low TSR and M_dR. The three pavements with the most discrepant data were the North Dakota (ND) surface layer with SEA (30/70), New Mexico (NM) surface layer with SEA (30/70), and the Texas at Pecos (TP) binder layer with SEA (30/70). For example, the TSR and M_dR for the ND surface layer with SEA (30/70) were 57 and 40 percent, respectively, but there was no visual stripping according to the 1987 rating. This indicated that the mechanical ratios of SEA mixtures can be significantly affected by decreases in cohesion. The SEA binders themselves can be severely weakened by the conditioning processes used in ASTM D 4867. Therefore, good correlations between the TSR or M_dR and the 1996 visual stripping data should not be expected. Although losses of cohesion occurred in the laboratory test, the pavement performances of the SEA mixtures compared to their AC control mixtures provided no evidence that losses in cohesion occurred in the SEA pavement.[4] The distresses in the SEA and AC pavements tended to be similar and roughly the same degree.

Other pass/fail criteria for TSR, M_dR, and visual stripping were evaluated to determine if better correlations between the data could be obtained. No reasonable pass/fail criteria (previous criterion ±10 percent) provided better correlations. Table 9 shows the results if a 20-percent pass/fail criterion for visual stripping is used. Twenty percent divided the moderate to severely stripped mixtures from the mixtures with slight to no stripping. Based on the 1996 visual stripping ratings, ASTM D 4867 is a poor test for judging moisture sensitivity even if the data for the questionable College Station, Texas (TC), pavements are removed. Based on this finding, the 10-percent criterion appears to be a better criterion.

5. Conclusions

- Tests on cores from the asphalt concrete control pavements indicated that air-void levels greater than 6.0 percent should be employed when using ASTM Test Method D 4867, Effect of Moisture on Asphalt Concrete Paving Mixtures. The data indicated that air-void levels lower than 6.0 percent may not allow the specimens to become sufficiently damaged.

- Tests on cores from the sulfur-extended asphalt pavements indicated that the retained ratios of these mixtures can be significantly affected by losses of cohesion. The SEA binders themselves can be severely weakened by the conditioning processes. It is not known whether the pavement performances of these mixtures are affected by losses of cohesion or if ASTM D 4867 is not appropriate for SEA mixtures. The pavement performances of the SEA mixtures provided no evidence that the SEA binders were weakened by a loss of cohesion. One reason for this may be that seven out of eleven pavements with SEA binder (ID, MN, MS, ND, NM, WI, and WY) had medium to low traffic levels. These seven pavements had total traffic levels of less than 5,000,000 equivalent single axle loads.

6. Recommendations

- A 6.0-percent minimum air-void level should be used when evaluating dense-graded asphalt paving mixtures using ASTM D 4867, even if lower levels are typically obtained in the field after construction. This recommendation should also be valid for American Association of State Highway and Transportation Officials Test Method T 283, Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage.[7]

- Pass/fail criteria of 80 percent for TSR, 70 percent for M_dR, and 10 percent for visual stripping are recommended for conventional, dense-graded hot-mix asphalt. Criteria for SEA mixtures cannot be proposed at this time due to the uncertainty of how the laboratory test data from these mixtures relate to pavement performance.

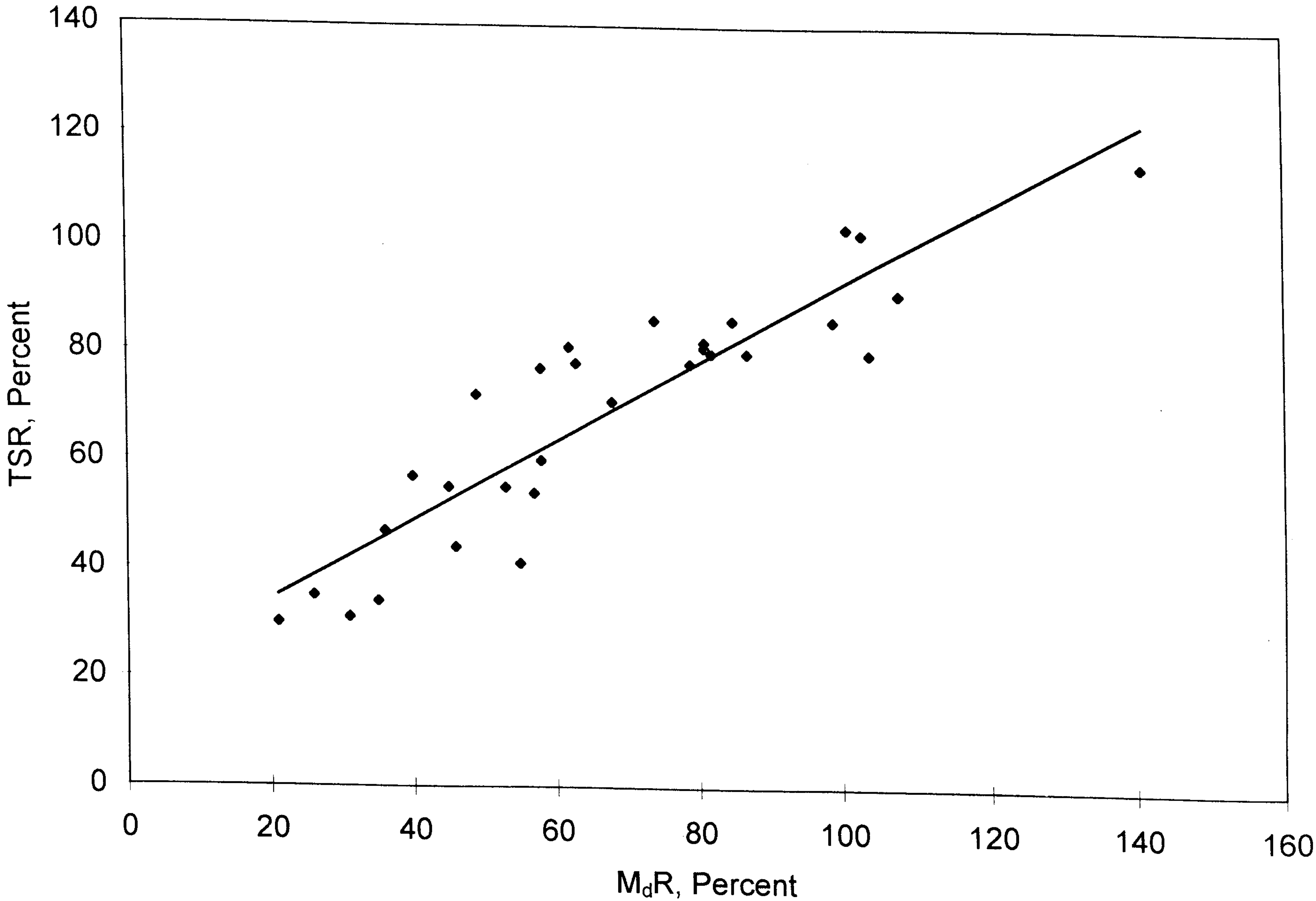

Figure 2. TSR vs. M_dR for all pavements.

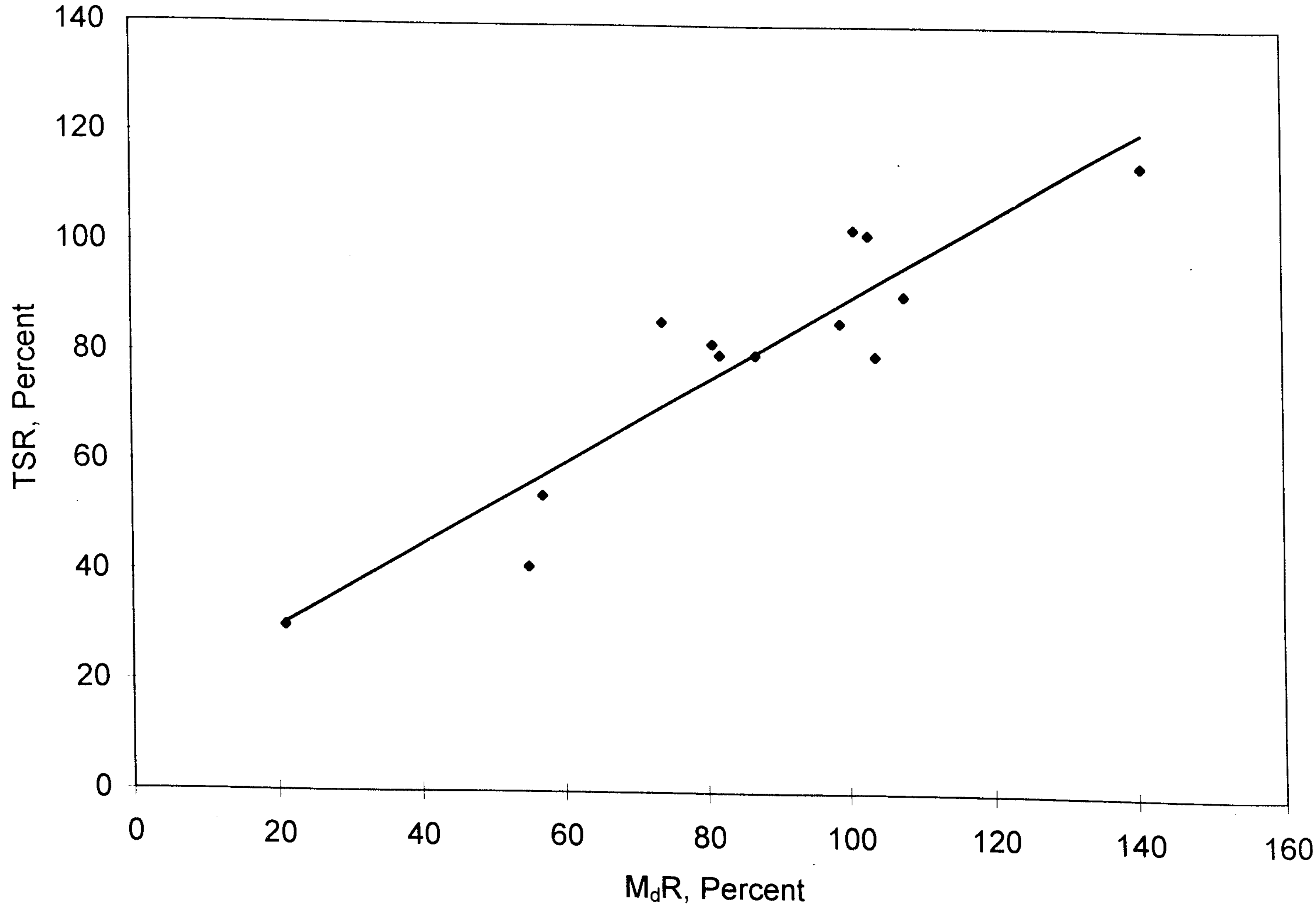

Figure 3. TSR vs. M_dR for the AC pavements.

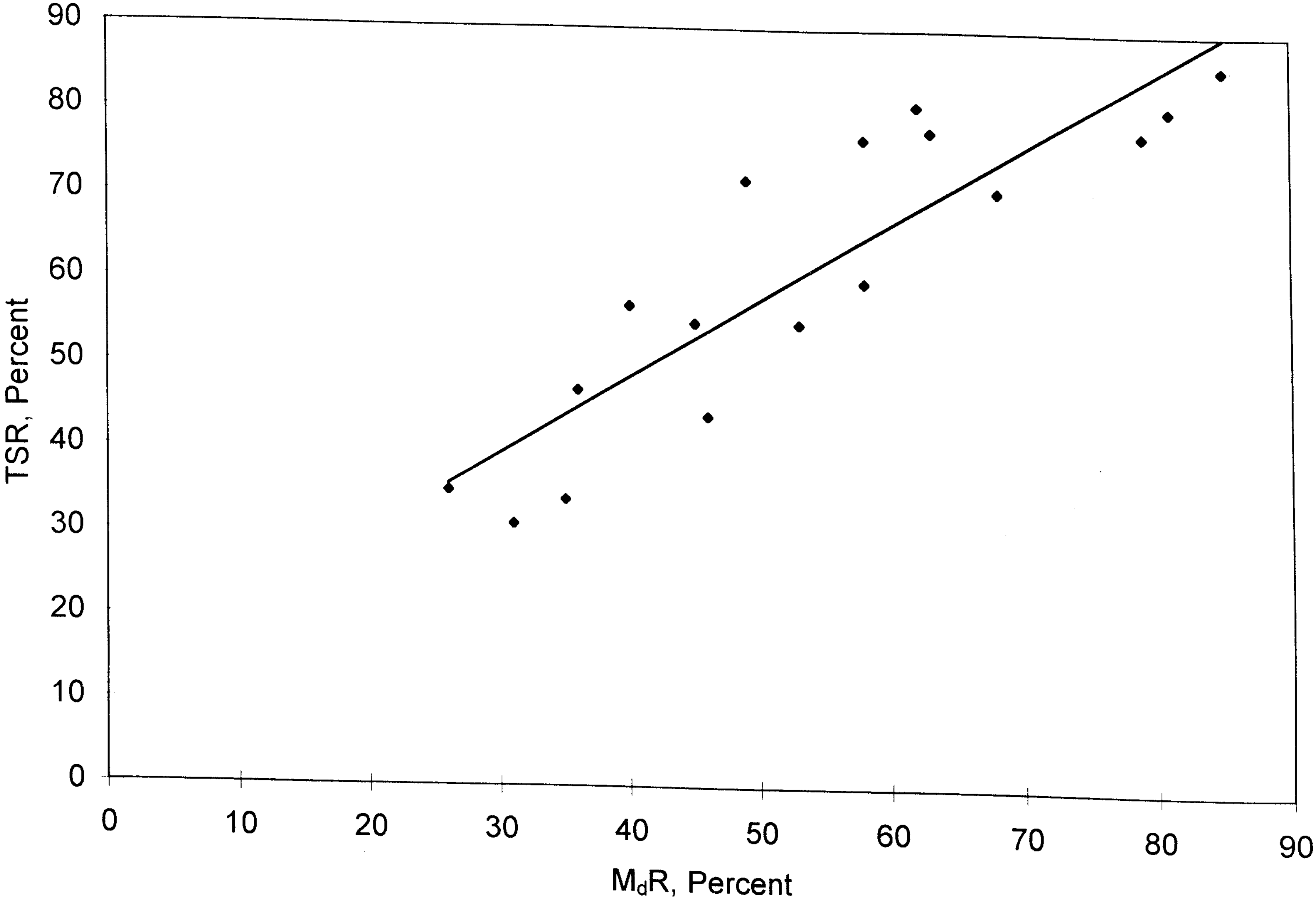

Figure 4. TSR vs. M_dR for the SEA pavements.

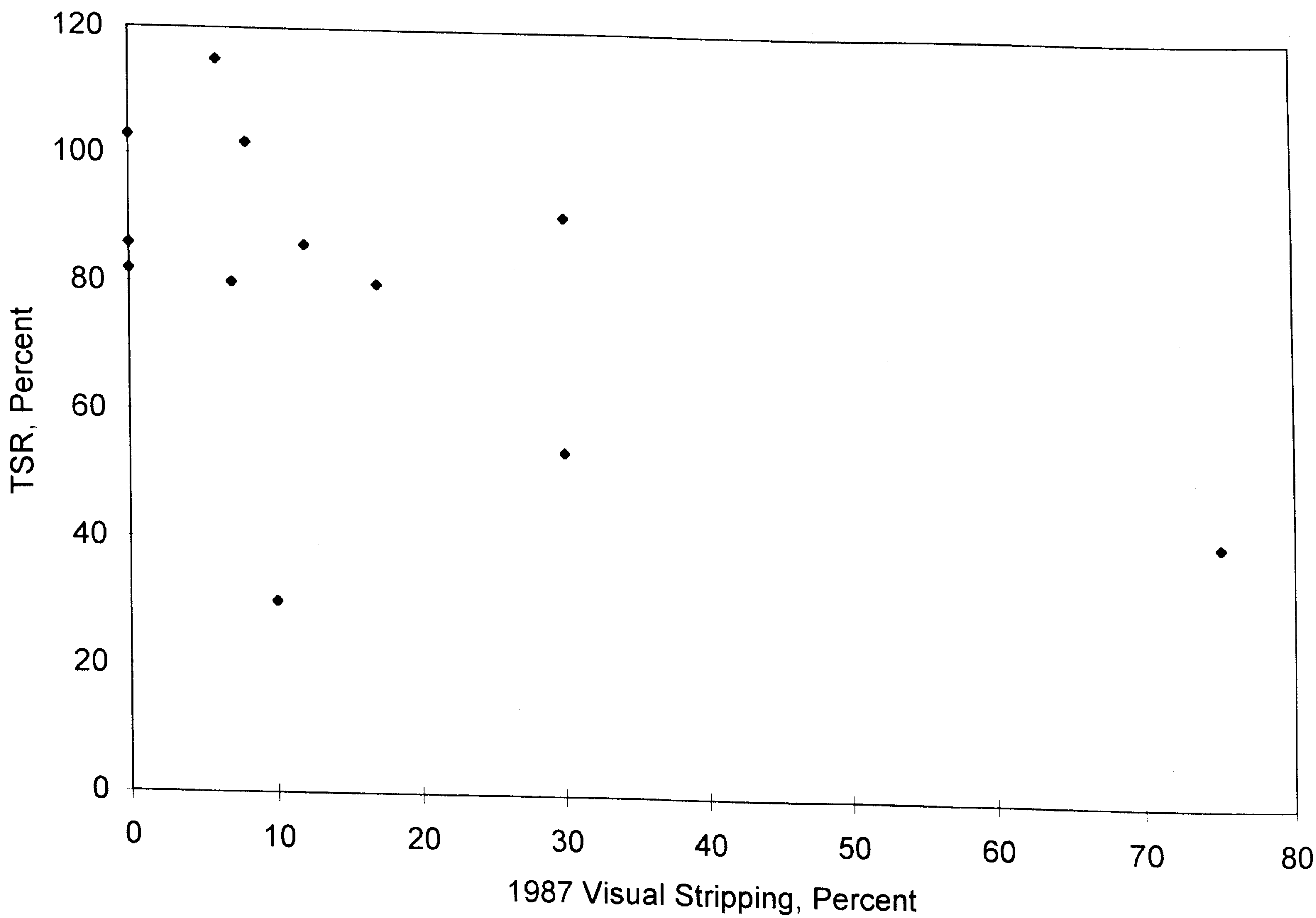

Figure 5. TSR vs. 1987 visual stripping for the AC pavements.

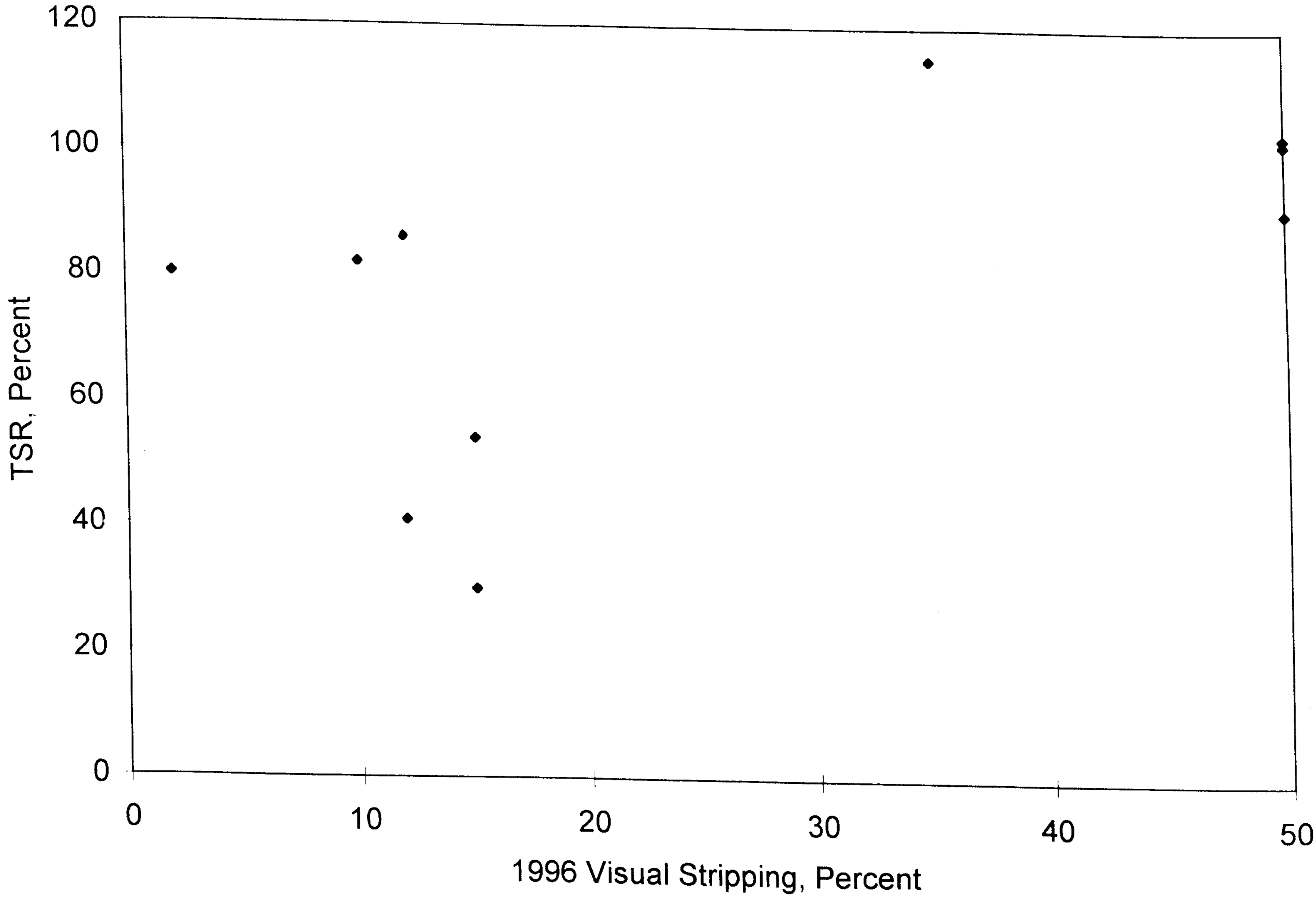

Figure 6. TSR vs. 1996 visual stripping for the AC pavements.

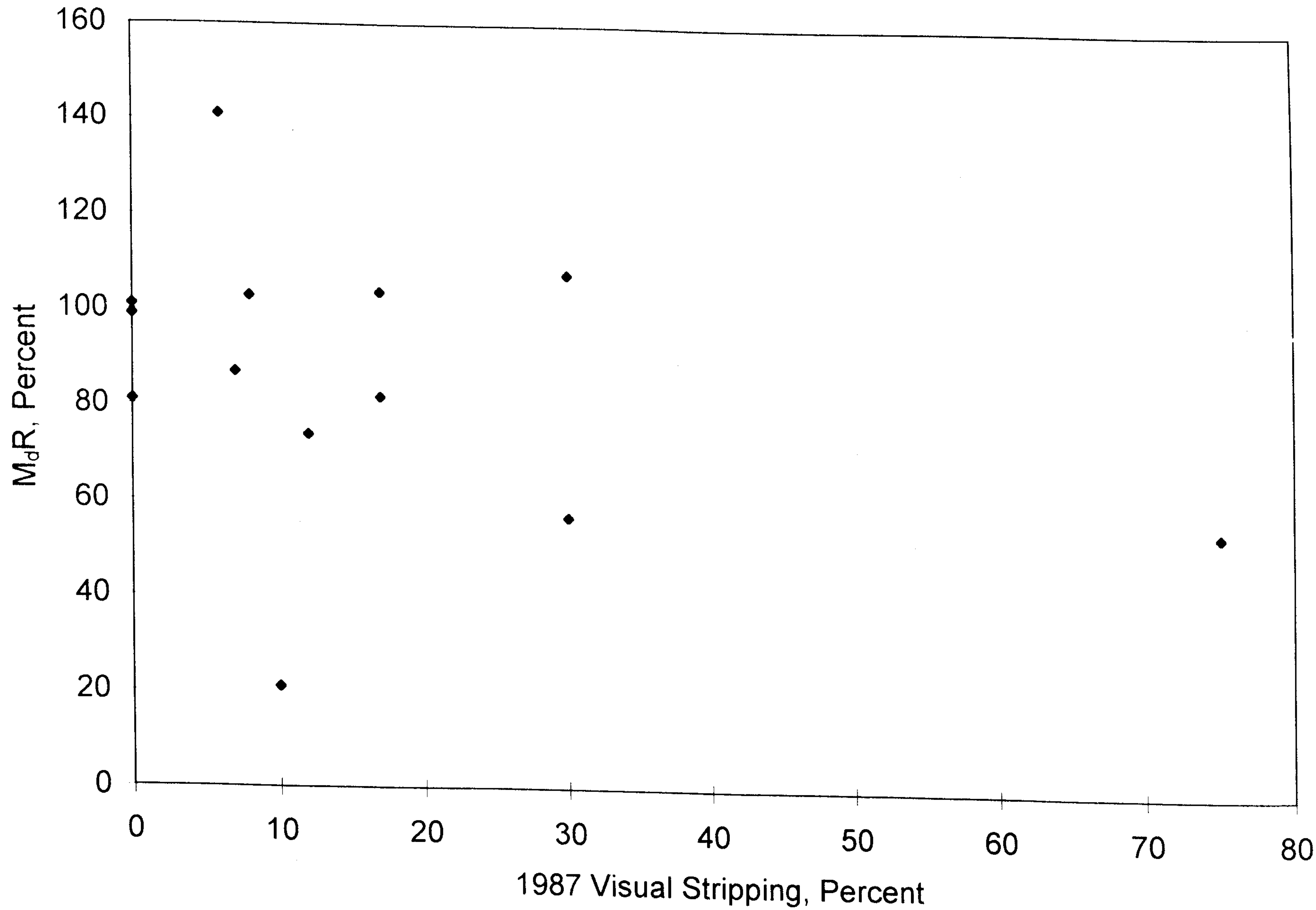

Figure 7. M_dR vs. 1987 visual stripping for the AC pavements.

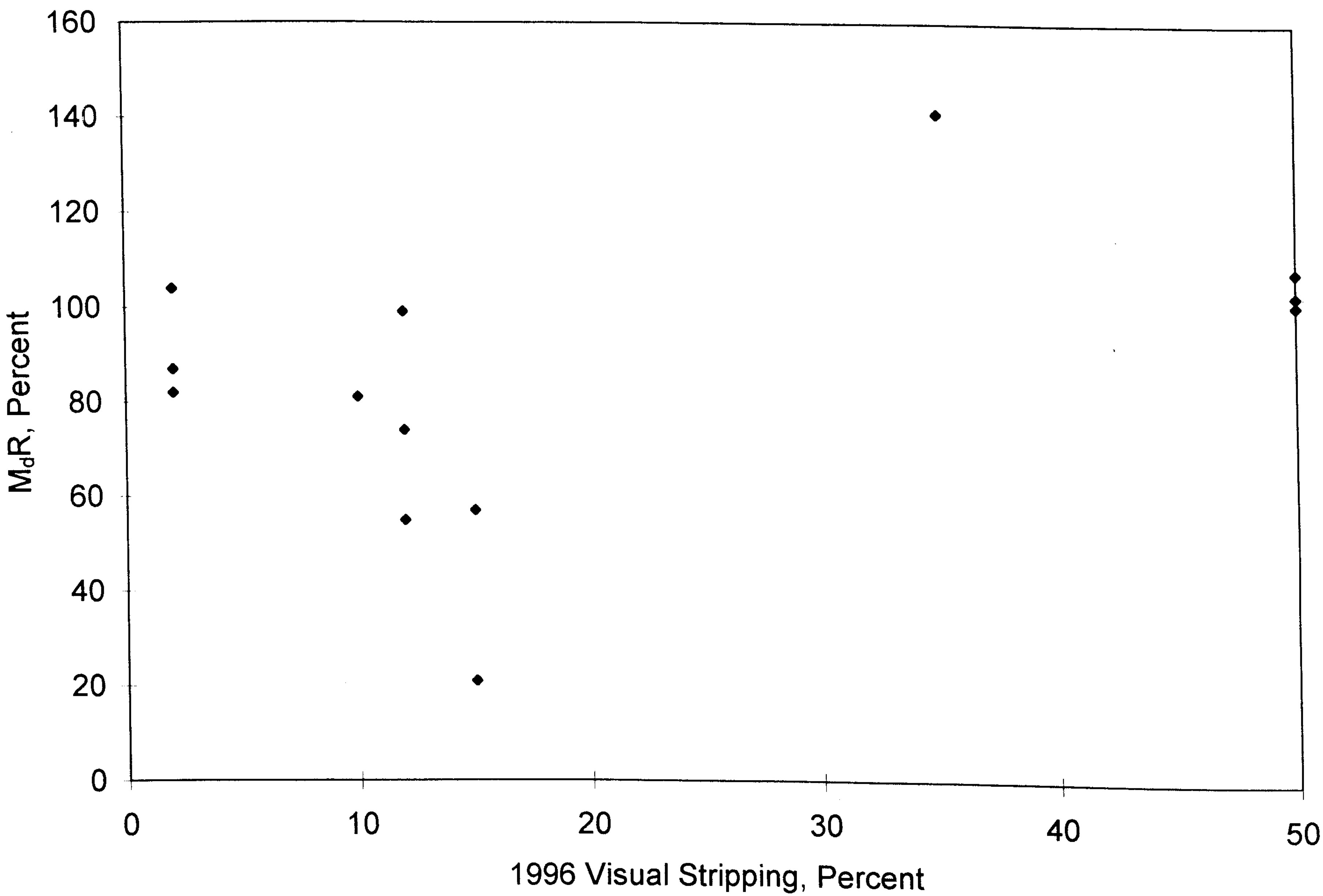

Figure 8. M_dR vs. 1996 visual stripping for the AC pavements.

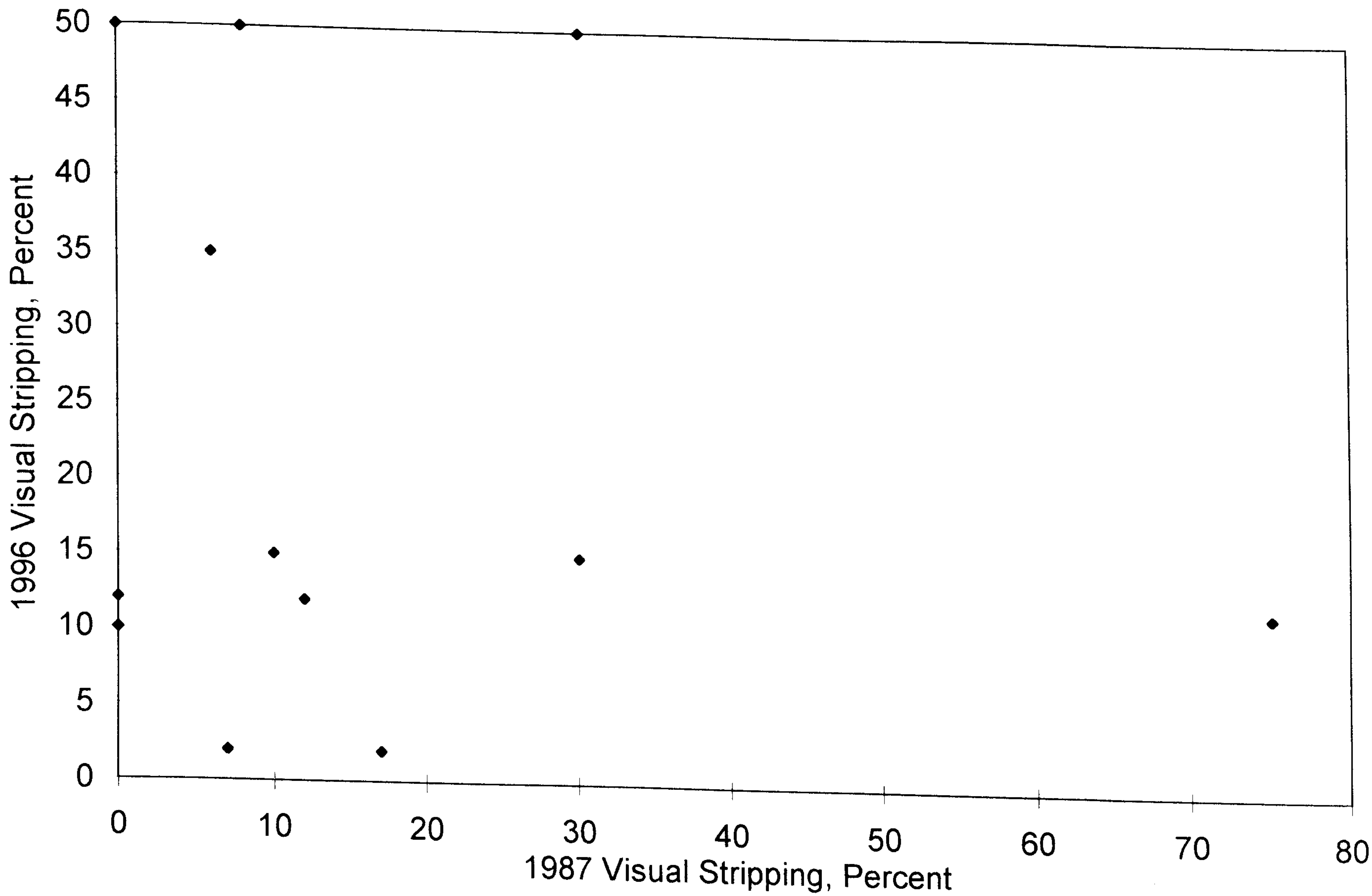

Figure 9. 1996 visual stripping vs. 1987 visual stripping for the AC pavements.

Table 6. Moisture sensitivity results using the highest amount of visual stripping found for the 1996 cores.

Code	Pavement Layer	Material	TSR	M_dR	Visual Stripping 1987	Visual Stripping 1996
CB	Surface	AR-4000	41	55	75	50
ID	Surface, Location #1	AR-4000	82	81	0	20
ID	Surface, Location #2	AR-4000	86	99	0	25
MN	Surface	AC 200-300	86	74	12	30
MS	Surface	AC-20	80	104	17	2
MS	Binder	AC-40	80	82	17	2
MS	Base	AC-40	54	57	30	15
ND	Surface	AC 120-150	103	101	0	80
NM	Surface	AC-10	80	87	7	2
NM	Base	AC-10	30	21	10	15
TC	Base, top half	AC-20	102	103	8	50
TC	Base, bottom half	AC-20	91	108	30	50
WI	Surface	AC 120-150	115	141	6	35
CA	Surface	SEA (30/70)	60	58	40	0
CB	Surface	SEA (20/80)	31	31	35	2
CB	Surface	SEA (40/60)	44	46	65	0
ID	Surface, Location #1	SEA (30/70)	81	62	0	0
ID	Surface, Location #2	SEA (30/70)	71	68	0	2
MN	Surface	SEA (40/60)	78	63	5	30
MS	Surface	SEA (30/70)	78	79	8	2
MS	Binder	SEA (30/70)	55	53	15	2
MS	Base	SEA (30/70)	72	49	35	15
ND	Surface	SEA (30/70)	57	40	0	80
ND	Surface	SEA (25/75)	77	58	2	100
NM	Surface	SEA (30/70)	55	45	15	2
NM	Base	SEA (30/70)	47	36	15	100
TC	Base, total	SEA (30/70)	34	35	30	50
TP	Binder	SEA (30/70)	35	26	5	50
WI	Surface	SEA (30/70)	86	85	5	35
WY	Surface	SEA (20/80)	81	81	2	0

Table 7. Pass/fail results using a TSR of 80 percent, M_dR of 70 percent, and 10-percent visual stripping.

Code	Pavement Layer	Material	TSR	M_dR	Visual Stripping 1987	Visual Stripping 1996
CB	Surface	AR-4000	**Fail**	**Fail**	**Fail**	**Fail**
ID	Surface, Location #1	AR-4000	Pass	Pass	Pass	Pass
ID	Surface, Location #2	AR-4000	Pass	Pass	Pass	**Fail**
MN	Surface	AC 200-300	Pass	Pass	**Fail**	**Fail**
MS	Surface	AC-20	Pass	Pass	**Fail**	Pass
MS	Binder	AC-40	Pass	Pass	**Fail**	Pass
MS	Base	AC-40	**Fail**	**Fail**	**Fail**	**Fail**
ND	Surface	AC 120-150	Pass	Pass	Pass	**Fail**
NM	Surface	AC-10	Pass	Pass	Pass	Pass
NM	Base	AC-10	**Fail**	**Fail**	Pass	**Fail**
TC	Base, top half	AC-20	Pass	Pass	Pass	**Fail**
TC	Base, bottom half	AC-20	Pass	Pass	**Fail**	**Fail**
WI	Surface	AC 120-150	Pass	Pass	Pass	**Fail**
CA	Surface	SEA (30/70)	**Fail**	**Fail**	**Fail**	Pass
CB	Surface	SEA (20/80)	**Fail**	**Fail**	**Fail**	Pass
CB	Surface	SEA (40/60)	**Fail**	**Fail**	**Fail**	Pass
ID	Surface, Location #1	SEA (30/70)	Pass	**Fail**	Pass	Pass
ID	Surface, Location #2	SEA (30/70)	**Fail**	**Fail**	Pass	Pass
MN	Surface	SEA (40/60)	**Fail**	**Fail**	Pass	**Fail**
MS	Surface	SEA (30/70)	**Fail**	Pass	Pass	Pass
MS	Binder	SEA (30/70)	**Fail**	**Fail**	**Fail**	Pass
MS	Base	SEA (30/70)	**Fail**	**Fail**	**Fail**	Pass
ND	Surface	SEA (30/70)	**Fail**	**Fail**	Pass	Pass
ND	Surface	SEA (25/75)	**Fail**	**Fail**	Pass	**Fail**
NM	Surface	SEA (30/70)	**Fail**	**Fail**	**Fail**	Pass
NM	Base	SEA (30/70)	**Fail**	**Fail**	**Fail**	**Fail**
TC	Base, total	SEA (30/70)	**Fail**	**Fail**	**Fail**	**Fail**
TP	Binder	SEA (30/70)	**Fail**	**Fail**	Pass	**Fail**
WI	Surface	SEA (30/70)	Pass	Pass	Pass	**Fail**
WY	Surface	SEA (20/80)	Pass	Pass	Pass	Pass

Table 8. Pass/fail results according to the air-void level, using a TSR of 80 percent, M_dR of 70 percent, and 10-percent visual stripping.

Code	Pavement Layer	Material	TSR	M_dR	Visual Stripping 1987	Visual Stripping 1996
	AC Cores With Air Voids Less Than 6 Percent					
ID	Surface, Location #1	AR-4000	Pass	Pass	Pass	Pass
ID	Surface, Location #2	AR-4000	Pass	Pass	Pass	**Fail**
MN	Surface	AC 200-300	Pass	Pass	**Fail**	**Fail**
ND	Surface	AC 120-150	Pass	Pass	Pass	**Fail**
TC	Base, top half	AC-20	Pass	Pass	Pass	**Fail**
TC	Base, bottom half	AC-20	Pass	Pass	**Fail**	**Fail**
WI	Surface	AC 120-150	Pass	Pass	Pass	**Fail**
	AC Cores With Air Voids Greater Than or Equal to 6 Percent					
CB	Surface	AR-4000	**Fail**	**Fail**	**Fail**	**Fail**
MS	Surface	AC-20	Pass	Pass	**Fail**	Pass
MS	Binder	AC-40	Pass	Pass	**Fail**	Pass
MS	Base	AC-40	**Fail**	**Fail**	**Fail**	**Fail**
NM	Surface	AC-10	Pass	Pass	Pass	Pass
NM	Base	AC-10	**Fail**	**Fail**	Pass	**Fail**
	SEA Cores With Air Voids Less Than 6 Percent					
CB	Surface	SEA (40/60)	**Fail**	**Fail**	**Fail**	Pass
ID	Surface, Location #1	SEA (30/70)	Pass	**Fail**	Pass	Pass
ID	Surface, Location #2	SEA (30/70)	**Fail**	**Fail**	Pass	Pass
ND	Surface	SEA (25/75)	**Fail**	**Fail**	Pass	**Fail**
WI	Surface	SEA (30/70)	Pass	Pass	Pass	**Fail**
WY	Surface	SEA (20/80)	Pass	Pass	Pass	Pass
	SEA Cores With Air Voids Greater Than or Equal to 6 Percent					
CA	Surface	SEA (30/70)	**Fail**	**Fail**	**Fail**	Pass
CB	Surface	SEA (20/80)	**Fail**	**Fail**	**Fail**	Pass
MN	Surface	SEA (40/60)	**Fail**	**Fail**	Pass	**Fail**
MS	Surface	SEA (30/70)	**Fail**	Pass	Pass	Pass
MS	Binder	SEA (30/70)	**Fail**	**Fail**	**Fail**	Pass
MS	Base	SEA (30/70)	**Fail**	**Fail**	**Fail**	Pass
ND	Surface	SEA (30/70)	**Fail**	**Fail**	Pass	Pass
NM	Surface	SEA (30/70)	**Fail**	**Fail**	**Fail**	Pass
NM	Base	SEA (30/70)	**Fail**	**Fail**	**Fail**	**Fail**
TC	Base, total	SEA (30/70)	**Fail**	**Fail**	**Fail**	**Fail**
TP	Binder	SEA (30/70)	**Fail**	**Fail**	Pass	**Fail**

Table 9. Pass/fail results according to the air-void level, using a TSR of 80 percent, M_dR of 70 percent, and 20-percent visual stripping.

Code	Pavement Layer	Material	TSR	M_dR	Visual Stripping 1987	Visual Stripping 1996
AC Cores With Air Voids Less Than 6 Percent						
ID	Surface, Location #1	AR-4000	Pass	Pass	Pass	Pass
ID	Surface, Location #2	AR-4000	Pass	Pass	Pass	Pass
MN	Surface	AC 200-300	Pass	Pass	Pass	Pass
ND	Surface	AC 120-150	Pass	Pass	Pass	**Fail**
TC	Base, top half	AC-20	Pass	Pass	Pass	**Fail**
TC	Base, bottom half	AC-20	Pass	Pass	**Fail**	**Fail**
WI	Surface	AC 120-150	Pass	Pass	Pass	**Fail**
AC Cores With Air Voids Greater Than or Equal to 6 Percent						
CB	Surface	AR-4000	**Fail**	**Fail**	**Fail**	Pass
MS	Surface	AC-20	Pass	Pass	Pass	Pass
MS	Binder	AC-40	Pass	Pass	Pass	Pass
MS	Base	AC-40	**Fail**	**Fail**	**Fail**	Pass
NM	Surface	AC-10	Pass	Pass	Pass	Pass
NM	Base	AC-10	**Fail**	**Fail**	Pass	Pass
SEA Cores With Air Voids Less Than 6 Percent						
CB	Surface	SEA (40/60)	**Fail**	**Fail**	**Fail**	Pass
ID	Surface, Location #1	SEA (30/70)	Pass	**Fail**	Pass	Pass
ID	Surface, Location #2	SEA (30/70)	**Fail**	**Fail**	Pass	Pass
ND	Surface	SEA (25/75)	**Fail**	**Fail**	Pass	**Fail**
WI	Surface	SEA (30/70)	Pass	Pass	Pass	**Fail**
WY	Surface	SEA (20/80)	Pass	Pass	Pass	Pass
SEA Cores With Air Voids Greater Than or Equal to 6 Percent						
CA	Surface	SEA (30/70)	**Fail**	**Fail**	**Fail**	Pass
CB	Surface	SEA (20/80)	**Fail**	**Fail**	**Fail**	Pass
MN	Surface	SEA (40/60)	**Fail**	**Fail**	Pass	Pass
MS	Surface	SEA (30/70)	**Fail**	Pass	Pass	Pass
MS	Binder	SEA (30/70)	**Fail**	**Fail**	Pass	Pass
MS	Base	SEA (30/70)	**Fail**	**Fail**	**Fail**	Pass
ND	Surface	SEA (30/70)	**Fail**	**Fail**	Pass	Pass
NM	Surface	SEA (30/70)	**Fail**	**Fail**	Pass	Pass
NM	Base	SEA (30/70)	**Fail**	**Fail**	Pass	**Fail**
TC	Base, total	SEA (30/70)	**Fail**	**Fail**	**Fail**	**Fail**
TP	Binder	SEA (30/70)	**Fail**	**Fail**	Pass	**Fail**

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