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EVALUATION OF METHODS TO CONTROL DEBONDING

Final Report

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16. Abstract

The purpose of the research was to evaluate various test methods for obtaining a measure of resistance to debonding of asphaltic concrete. The work was done in two phases. Phase 1 was involved principally with laboratory prepared specimens and Phase 2 with the changes in susceptibility to debonding of pavement cores as the pavement increased in service time. In Phase 1, the test methods were the immersion-compression, the University's double-punch, and a modified Lottman split-cylinder. The treatment included portland cement, lime, silane, BA-2000, and increasing the sand equivalent value. The results indicated that overall the portland cement treatment generally increased the "wet" strength and the "retained" strength and so was rated as the best. The double-punch procedure always yielded the highest wet and retained strength and also had the lowest standard deviation values; and it was rated as the best of the three test methods. In Phase 2, the plant mixtures and cores from surfaces containing no treatment, BA-2000, and portland cement were evaluated with the immersion-compression test, the double-punch method, and the Tunnicliff split-cyclinder procedure. The double-punch method rated the untreated plant mixture as being acceptable, but the split-cylinder procedure rated it as not acceptable. Tests of cores by the immersion-compression test and double-punch method indicated good resistance to debonding; the split-cylinder procedure did not up to the first year. The pavement sections have shown no failures after 19.8 months of service.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

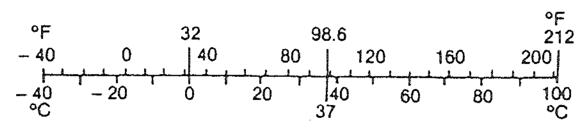
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	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	Mg
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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ABSTRACT

The purpose of the research was to evaluate various test methods for obtaining a measure of resistance to debonding of asphaltic concrete. The work was done in two phases. Phase 1 was involved principally with laboratory prepared specimens and Phase 2 with the changes in susceptibility to debonding of pavement cores as the pavement increased in service time. In Phase 1, the test methods were the immersion-compression, the University's double-punch, and a modified Lottman split-cylinder. The treatment included portland cement, lime, silane, BA-2000, and increasing the sand equivalent value. The results indicated that overall the portland cement treatment generally increased the "wet" strength and the "retained" strength and so was rated as the best. The double-punch procedure always yielded the highest wet and retained strength and also had the lowest standard deviation values; and it was rated as the best of the three test methods. In Phase 2, the plant mixtures and cores from surfaces containing no treatment, BA-2000, and portland cement were evaluated with the immersion-compression test, the double-punch method, and the Tunnicliff split-cylinder procedure. The double-punch method rated the untreated plant mixture as being acceptable, but the split-cylinder procedure rated it as not acceptable. Tests of cores by the immersion-compression test and double-punch method indicated good resistance to debonding; the split-cylinder procedure did not up to the first year. The pavement sections have shown no failures after 19.8 months of service.

INTRODUCTION

During the early 1980's, one of highway's most pressing problems was the concern of asphaltic concrete pavement failures caused by debonding of the asphalt from the aggregate in the mixture. The concern was not a new one since the matter of adhesion of asphalt to aggregate surfaces has been studied since the 1920's as reported by Nicholson (1) and Rice (2). In 1965, the Highway Research Board reported the responses by highway agencies to a questionnaire related to the evaluation and occurrence of asphaltic paving mixtures susceptible to the destructive effects of waters.

The performance of an asphaltic concrete pavement surface is dependent on its capability to function as a structural member of a road and also as a water barrier for subsurface soils and to provide for a smooth but skid-resistant surface. The "debonding" or "stripping" that may occur will result in the impairment of those required functions and, thus, it is imperative that these paving mixtures be resistant to the combined action of water and traffic. As a consequence, laboratory evaluations or designs of these paving mixtures include a measurement of resistance to debonding.

It is not the purpose of this report to describe the mechanism of debonding nor of the many, many methods that have been proposed for determining the susceptibility to debonding. That function has been adequately covered by other investigators and more recently by Khosla (4) and Brown (5). However, the basis for the test methods used in this investigation will be presented in later sections.

The Arizona Department of Transportation (ADOT) had and is still conducting research in the use of additives and test methods for improving the resistance and its measurement of a mixture to debonding in its service function. To this end, the research work presented in this report had the objectives to determining:

a. the most effective additive or treatment to improve the resistance to debonding of various aggregate types in Arizona, and

b. in using three different laboratory evaluation procedures (tests) to determine which method would be the most predictable of service performance.

For these objectives, the work was separated into two phases. Phase I was devoted to a laboratory investigation involving (a) three aggregate blends, (b) three test methods, and (c) six treatments to the materials. Phase 2 was developed to determine the change of resistance to debonding of cores from a field test site resulting from age in the roadway. The results were affected by variations in additives used in the paving mixture and by the method of testing.

SCOPE OF WORK

The resistance to debonding of the paving mixtures evaluated was to be determined on the value of a "retained strength". This value is based on the ratio of a "wet" strength divided by a companion "dry" strength and then multiplied by 100; it is expressed as a percent of the dry strength. The dry strength is a base strength of the unexposed specimens and the wet strength is the strength of companion specimens that have undergone some environmental exposure and being wet at the time of strength determination.

Preliminary work in mixture design was performed to determine a design or optimum asphalt content for the paving mixtures. The exceptions were for those containing a liquid additive to the asphalt. It was felt that the small amounts of these liquid additives were such that the asphalt content for the control blends (no additives) would not be affected.

The scope of work for the laboratory and field investigations are shown on the following tables and discussions.

Phase 1

Table 1 shows the variables included in the determinations for retained strength. The numbers and symbols are defined as follows:

Asphaltic Concrete

#1 - Aggregate from the Salt River in Phoenix

#2 - Aggregate from Tanner's plant located by the Santa Cruz River in Tucson

#3 - Aggregate from the vicinity of Holbrook

Test Method

I-C - The immersion-compression method for debonding by ARIZ-802G procedure (6)

D-P - The double-punch repeated pore water pressure method developed at the University of Arizona (7)

S-C - The split-cylinder indirect tensile strength, a modification to the method developed by Lottman (8)

TABLE 1. Variables for Standard Procedures for Retained Strength Tests.

Asphaltic Concrete		#1			#2			#3		
Test Method / Treatment		IC	DP	SC	IC	DP	SC	IC	DP	SC
Control	1	*								
Lime	2									
P.C.	3									
Silane	4									
BA-2000	5									
S.E.	6									

*There are 6 specimens per cell

Treatment

1 - Control-no additive or treatment

2 - Lime

3 - Portland Cement

4 - Silane

5 - BA-2000

6 - Sand Equivalent - produced by washing

Table 2a was proposed to determine the effects of the amount of air voids and portland cement on the wet strengths of selected paving mixtures. The variables were selected to determine the importance of air voids and the difference of 0.5 percent of portland cement on the wet strength of the paving mixtures. It was anticipated that along with retained strength, a minimum wet strength might be required for the design of paving mixtures with reference to the resistance to debonding. The reason for a requirement on minimum wet strength is illustrated in the following example. Compare the data between Mixtures A and B listed.

Mixture	A	B
Wet strength	80	120
Dry strength	100	240
Retained strength, %	80	50

If a minimum of 70 percent for retained strength were the requirement, then Mixture A passes and Mixture B fails. However, note that the wet strength of Mixture B is 1-1/2 times higher than for Mixture A. The question then is, if Mixture B is much stronger under a "worse" condition than Mixture A, why wold it not perform as well or better than Mixture A in service?

The symbols in Table 2a are defined as shown below:

Aggregate

A - From Salt River in Phoenix

B - From Tanner's plant in Tucson

Test Methods - These are the same as for Table 1.

TABLE 2a. Variables for Wet Strength of Two Asphaltic Concrete Mixtures-Double Plunger Compaction.

AGGREGATE	A									B								
TEST METHOD	I-C			DP			SC			I-C			DP			SC		
AIR VOID	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
P.C. TREATMENT																		
1½%																		
1%																		

TABLE 2b. Effects of Two Compaction Methods on Air Voids Distribution and Their Influence on Wet Strength of Aggregate A.

COMPACTION METHOD	Marshall						Vibratory					
TEST METHOD	DP			SC			DP			SC		
AIR VOID	H	M	L	H	M	L	H	M	L	H	M	L
P.C. TREATMENT												
1½%												
1%												

Air Voids

H - High

M - Medium

L - Low

P.C. Treatment - Amount of portland cement in total blend.

The principal variable in Table 2b is that of compaction method. It was believed that the method of compaction would affect the distribution of air voids and also the surface texture of the specimen and thus have an influence on the amount of water saturation and also on wet strength of the specimens. The description of the symbols have been given in the preceding sections.

Phase 2

This portion of the research was concerned with the field performance of a paving mixture's resistance to debonding. Variables for this evaluation were treatment, test method, and age of cores taken from the pavement surface.

Figure 1 shows the total length of the test site was 3,000 feet; subdivided into sections 120 feet long; and to be cored on the outer-wheel path (OWP) on a random location basis. The test section was located on I-40 east of Holbrook on the eastbound traffic lane.

The investigation was planned to follow the changes in resistance to debonding of a paving mixture during a portion of its service life in a roadway. Originally, it had been planned to design and evaluate mixtures in the laboratory of materials to be used in the construction of a pavement. Further evaluations were to be performed for specimens made with component materials obtained at the hot-mix plant as well as on asphaltic mixtures obtained from the laydown machine. Following the testing of the original materials for resistance to debonding, cores were to be taken from the pavement surface at specified intervals of time. The mixtures were to contain no additive, BA-2000, or portland cement, and three test methods were to be utilized in testing for debonding.

Unfortunately, there was no complete pre-evaluation of the paving mixtures and so the only testing done was of the field cores and of the plant mixtures. Table 3 shows the test methods to be used and the planned time intervals for taking the cores after construction.

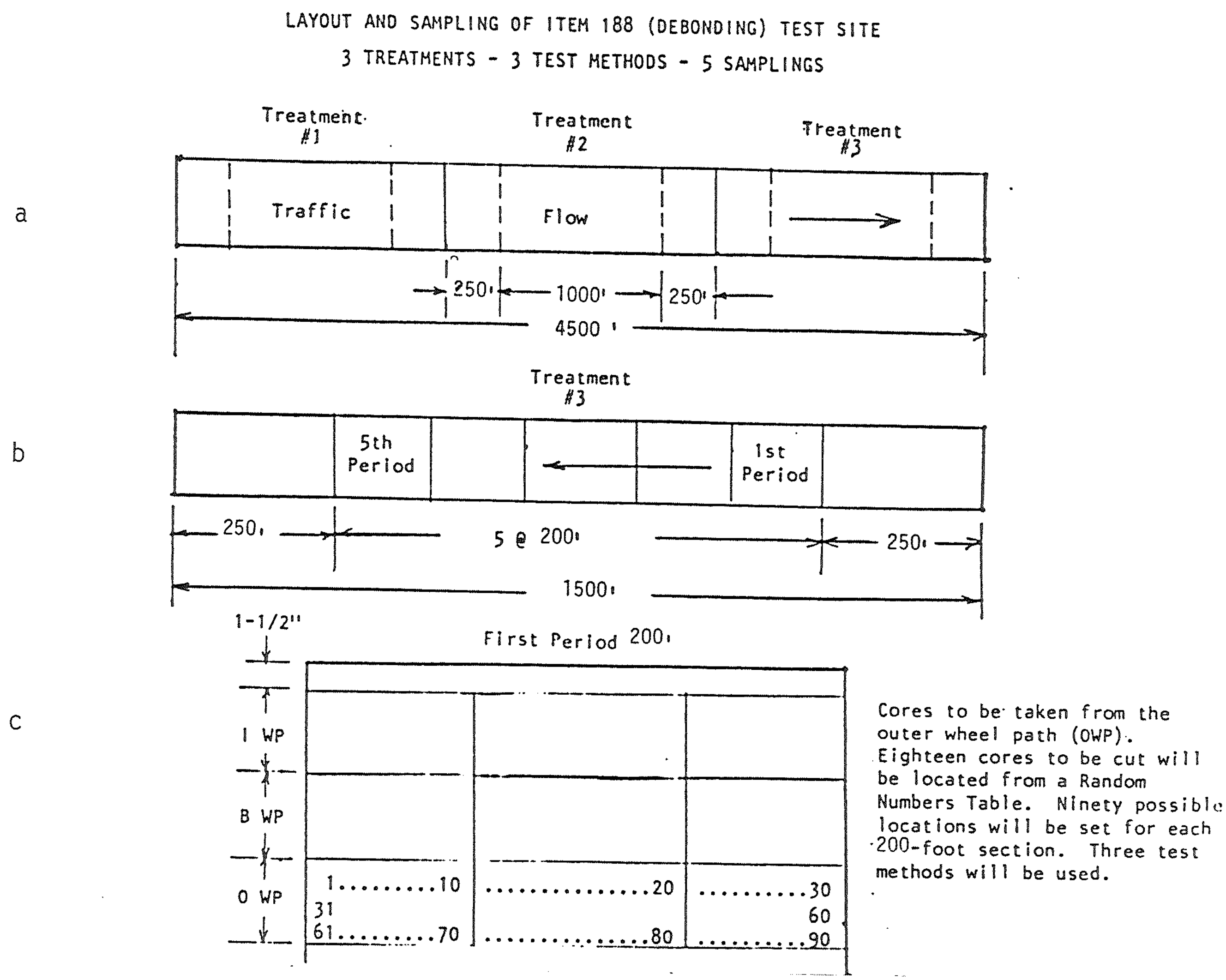

Figure 1. Layout for Sampling Pavement on I-40

Table 3. Variables of Time Interval for Testing Pavement Cores* with Different Test Methods.

Age of Cores (mos)	Test Method		
	Immersion Compression	Double Punch	Split Cylinder**
0-0.4	6***	6	6
0.5	6	6	6
1.5	6	6	6
6.5	6	6	6
12.0	6	6	6
18.0	6	6	6

* Cores to be 4" diameter and taken from the outer-wheel-path.
** Split cylinder test as per Tunnicliff-Root (10).
***A minimum of 6 specimens per cell.

Cores taken from the test site were to be tested with a modified immersion- compression test; with the double-punch method of the University of Arizona; and with the Tunnicliff method (10). ADOT requested that the Lottman method be replaced with the Tunnicliff procedure, since the test site was going to be incorporated into the NCHRP work program of Tunnicliff and Root.

MATERIALS FOR ASPHALTIC MIXTURES

General

The laboratory asphaltic concrete mixtures were made with aggregates obtained from different parts of the State. These are to be described later.

The portland cement and lime were obtained from a commercial source and were assumed to meet ADOT's requirements as given in their book of specifications (9). The use of portland cement and also lime has a long use and history as an additive to asphaltic concrete for improving its resistance to debonding.

In the past, ADOT has used liquid additives incorporated into the asphalt for investigating it's effects on the resistance to moisture damage of asphaltic concrete Two of these liquids were used in this study; one is referred to as silane and the other as BA-2000.

Silane is a chemical coupling agent named Dow Corning Z-6020 Silane. It is claimed that this agent possesses "both organic and inorganic reactivity" so that one end of the molecular chain reacts with a resin (organic) and another end of the chain reacts with a silicious (inorganic) surface In an asphaltic paving mixture the bond between the asphalt and aggregate would expectedly be enhanced with the addition of this agent since most aggregates contain silicon and all asphalts contain resin as a compound. DiVito and Morris (11) have reported on the use of silane to prevent stripping in asphaltic concrete.

The other liquid additive used is identified here as BA-2000, but it is named CARSTAB BA-2000 by its manufacturer, Thiokol Carstab Corporation. Gilmore et al. (12) discuss its use as an antistrip additive to improve asphaltic concrete durability.

Characteristics of the aggregates and mixtures used in Phases 1 and 2 are given in the next sections.

Phase 1

As indicated earlier, the aggregates used in the first part of the research came from various parts of the State. The aggregates had been identified as having resistance to debonding from good to bad in-service conditions unless given some treatment to resist moisture damage.

Table A-1 in Appendix A shows basic properties of the aggregate blends. The inclusion of the asphaltic content design values in this table is due to a desire to compare them based on three different methods. The amount determined by laboratory tests by the University of Arizona and ADOT were based on the Marshall method using 75 blows per face (B/F). The amount shown as "by theory" was based on knowing only the gradation and specific gravities of the aggregate and asphalt. That procedure has been described by Jimenez in References 13 and 14. Table A-2 lists those characteristics of the aggregate blends modified with the addition of portland cement, lime, and by washing to increase the sand equivalent values. It is noted that washing the aggregate blends significantly changed the gradation of the aggregation as shown by the differences in surface area values.

Tables A-3 to A-5 present the Marshall test data for the three aggregates plus their blends with the five treatments. The data show that all blends had adequate stability, flow values, and generally, VMA values. Of concern were the air void values obtained by measurement of the specimens. The results shown indicate that the design asphalt content for several of the mixtures was established by extrapolation of the plotted data.

Figures B-1 to B-3 in Appendix B illustrate the effects of asphalt content on the properties of the specimens made with the control aggregates. As stated, the compaction was by 75-blow Marshall and stability was obtained on specimens that had been brought to test temperature by placing in a 140°F waterbath for 45 minutes prior to testing.

From Tables A3-A5 and Figures B1-B3, it can be seen that the asphalt contents used for testing the aggregate-asphalt mixtures for resistance to debonding did meet the Asphalt Institute's (5) and ADOT's (6) specification for stability, air voids, and flow. The data show that the treatments having the most important effects on mixtures' design were portland cement and lime in that they resulted in a reduced air-void content and required that asphalt content be reduced approximately 0.2 percent.

The addition of portland cement and lime increased the surface area of the aggregate blends and the reduction of asphalt content would in combination reduce the accompanying asphalt film thicknesses for these blends. However, the decrease in permeability (air voids) would counteract the adverse condition of reduced film thickness. Of course, it is assumed that these small changes can cause measurable changes in test results.

Phase 2

The original plans for this portion of the research were for the aggregates, proposed for making the asphaltic concrete for use in the construction of the test site, to be evaluated in the University's laboratory. The proposed mixture design to be used as the control would have been proportioned to show an early failure and to have inadequate resistance to debonding. That portion of the research was abandoned, and the control asphaltic concrete along with the amounts of additives of portland cement and BA-2000 were selected by ADOT. The design worksheets representing the mixture designs are shown in Tables A-6 to A-8 in Appendix A. It is noted that the aggregate blend consisted principally of basalt and ± 38 percent field sand. The control mixture had 5.6 percent asphalt; the mixture with BA-2000 had 5.5 percent; and the one with portland cement had 5.5 percent asphalt. Those three mixtures were tested by ADOT for I-C resistance to debonding and had retained strength values of 43, 60 and 88, respectively. It is noted that ADOT's values for retained strength indicated that the control (untreated) mixture did not meet specifications; the BA-2000 mixture just did meet specification values; and the portland cement mixture exceeded the specification value of 60 percent.

TEST METHODS

The testing methods used for evaluating the susceptibility for debonding of the paving mixtures are fully described in the references cited. However, for reasons of practicability and immediate information, brief descriptions of the test methods will be given for both phases of the research program.

Phase 1

As indicated earlier in this report, the testing methods for debonding were (a) the immersion-compression (I-C), (b) the double-punch (D-P), and (c) the split-cylinder (S-C). The laboratory procedures used followed the specifications as closely as practicable.

Immersion-Compression

The compaction test specimens varied some from that specified by AASHTO T167-84 (16); the mixing was done at ±300°F and double-plunger compaction at ±255°F. Also, the six specimens of 4-inch diameter by 4-inch height were compacted to obtain a density of 95 to 97 percent of the Marshall design density. The resulting density was expected to be the density of the field mixture after construction compaction. After curing of the specimens at 140°F and density determination, they were divided into two sets of essentially equal density. The control or "dry" set was tested at a temperature of ±77°F under an unconfined compression condition. The other set of three specimens was placed in a 140°F waterbath for 24 hours and then transferred to a 77°F waterbath for two hours. After cooling to 77°F, the "wet" set was tested in the same manner as the dry set. The retained strength was expressed as a percent after dividing wet strength by the dry strength.

Double-Punch

The six specimens of 4-inch diameter and 2-1/2 inch height were made at the same temperatures as used for the immersion-compression samples; however, they were compacted using the Marshall method except for the number of blows per face. The compaction energy, the number of blows per face, ranged from 17 to 20 for the 18 mixtures evaluated in this phase for resistance to debonding. The specimens were stored in a ±77°F room for approximately 18 hours and then density measurements were made. The specimens were divided into two sets of dry and wet and the retained strength was obtained. The strength test was of indirect tensile loading effected through two axial and concentrically loaded punches.

The wet condition was one developed at the University of Arizona to simulate traffic loadings on a saturated surface course. The specimens were placed in a 122°F waterbath for 40 minutes, then "saturated" under a vacuum of 20 inches of mercury for five minutes. Following the saturation, the specimens were subjected to 5,800 cycles of pore water pressure ranging sinusoidally from 5 to 30 pounds per square inch within a period of ten minutes. After pore-water stressing, the specimens were placed in a 77°F waterbath. Prior to strength testing, the saturated-surface-dry weights were obtained for calculation of the amount of water saturation. The calculated value for saturation may exceed 100 percent. This is possible since pockets of air become permeable, clay may become wet and swell, or aggregates are stripped of asphalt and water enters the stones' pores. The retained strength was calculated in the same manner as for the immersion-compression method.

Split-Cylinder

The mixtures and specimens were prepared as for the double-punch method. The exposed (wet) set was vacuum saturated under 20 inches of mercury for ten minutes (rather than 26 inches for 30 minutes); then the set was wrapped and frozen at 0°F for 15 hours; then soaked in a waterbath of 140°F for 24 hours; and then brought to test temperature by soaking in water at 77°F. The tensile strength of the specimens, both dry and wet, was obtained using the split cylinder (diametral loading) test with curved loading bars and a loading rate of one inch per minute deformation. The retained strength was calculated as described before. It is to be noted that several modifications to the standard Lottman procedure were used. Both ADOT and the University of Arizona personnel felt the modifications to be appropriate for the objectives of the research.

Phase 2

As indicated earlier, the original plans for this portion of the research were modified; however, some of each of the construction paving mixtures was obtained for debonding tests. The mixtures were evaluated several months after they had been produced at the plant; however, these had been stored in air-tight containers at room temperature to minimize possible changes in them.

The mixtures were compacted using the Marshall method and 75 blows per face to establish an air-void datum. The immersion-compression, double-punch, and split-cylinder tests were performed at air voids content ranging from 10 to 13 percent for the mixtures.

In the new program, only pavement cores were to be taken and tested for debonding resistance. Since the cores from the pavement surface would be trimmed to a height of 2-1/2 inches, a height-correction factor had to be established for converting these retained strengths to comparable 4-inch high specimens for immersion-compression testing. As shown later, the retained strengths for laboratory-prepared specimens 2-1/2 inches high were 116 percent higher than for those 4 inches in height. It should be noted that this value was obtained and used only for retained strengths ranging form 65 to 77 percent for 4-inch high specimens.

The 4-inch diameter cores were taken dry using air as the coolant and along the outer wheel path. The use of air as the coolant in the coring operation was considered to be appropriate and especially at an early age of the asphaltic concrete when water under pressure might cause some damage to the core.

At least 24 cores were taken from each subsection by personnel from ADOT. These were sent to the Asphalt Laboratory at The University of Arizona for processing. After trimming and density measurements, the cores were divided into three groups of essentially equal density. Each group was then tested for debonding using the immersion-compression, double-punch, and the split-cylinder method of Tunnicliff.

The immersion-compression and double-punch sets were tested as described previously except that the immersion-compression specimens were loaded for strength at a lower rate (0.125 inch per minute) than had been used for the 4-inch high ones. The split-cylinder set was tested as described below.

Split-Cylinder

This version of the split-cylinder method for debonding evaluation was that as reported in Reference (10), and as presented for the other methods, a brief description follows.

The set of specimens to be exposed to the environmental conditioning (wet) were submerged in ±77°F water and subjected to a vacuum so as to obtain a saturation between 55 and 80 percent.

They then were placed in a 140°F waterbath for 24 hours. The specimens were brought to testing temperature by placing them in a 77°F waterbath for one hour. Prior to testing, the saturated-surface-dry weight was determined to calculate the degree of saturation. The strength test was that of the split-cylinder using curved loading bars and a displacement rate of two inches per minute. The loading device was a standard Marshall frame and had the loading bars secured to the testing heads.

The other group of specimens was brought to test temperature in a dry condition for 40 minutes although 20 minutes in 77°F water is allowed. The retained strength was calculated in the standard manner.

DEBONDING TEST RESULTS AND DISCUSSIONS

Phase 1

The discussions on the results from the tests performed will be centered towards determining the most effective treatment for improving the mixtures' resistance to debonding and also towards finding the best test of the three methods used in Phase 1 of the research.

Tables A-9 to 11 in Appendix A list the results of the laboratory testing for resistance to debonding or, in a sense, for durability.

Tables 4 and 5 show a summary and are a compact way for determining characteristics and effects of the variables on test results for mixture properties and strengths.

Table 4 shows that the air-void content was fairly uniform for any one mixture but varied from about 7.5 to 8.7 percent among the three different aggregate mixtures. The difference of 1.2 percent is not considered excessive nor significant since gradation and asphalt contents were different. The variability in the degree of saturation was expected because of the small size of the value for air-void content. A one-gram difference of water absorption would correspond to a sizeable percentage of an air-void content of seven percent (14.3). It is noted that the specimens subjected to the split-cylinder exposure had the largest values for saturation, even though the saturation for the double-punch specimens was calculated after being subjected to nearly 6,000 applications of a pore water pressure cycling from 5 to 30 pounds per square inch. The retained strengths shown in the table indicate that the highest values were associated with the double-punch method of testing and that the most severe test was the split-cylinder one.

In Table 5 wet strength and retained strength values are shown for comparison of effects of treatment as determined by the three test methods. The wet strengths were highest for the treatment with portland cement, especially for the Tanner and Cameron aggregates. The BA-2000 treatment was the most effective when used with the Salt River aggregate. The lowest wet strengths were found generally with the sand equivalent (S.E.) treatment. An examination of Tables A-9 to 11 will show that those specimens had air-void values generally higher than the control that had no additive.

Table 4. Summary of Average Values for All Six Treatments and Test Methods.

Aggregate	Range: High	Range: Medium	Range: Low
		Air Voids, %	
Salt River	7.7 (I-C)	7.5 (D-P)	7.1 (S-C)
Tanner	9.0 (I-C)	8.7 (D-P)	8.4 (S-C)
Cameron	8.3 (S-C)	8.2 (I-C)	8.7 (D-P)
		Saturation, %	
Salt River	95 (S-C)	88 (D-P)	61 (I-C)
Tanner	134 (S-C)	103 (D-P)	82 (I-C)
Cameron	146 (S-C)	111 (D-P)	83 (I-C)
		Retained Strength, %	
Salt River	81 (D-P)	73 (I-C)	64 (S-C)
Tanner	66 (D-P)	52 (I-C)	26 (S-C)
Cameron	64 (D-P)	61 (I-C)	39 (S-C)

TABLE 5. Range of Treatment Effects on Test Values for Wet Strength and Retained Strength for Debonding Methods.

Aggregate	Test	Range		
		High	Medium	Low
		Wet Strength, psi		
Salt River	I-C	475 (BA-2000)	340 (PC)	214 (Lime)
	D-P	148 (BA-2000)	105 (Silane)	81 (SE)
	S-C	133 (Lime)	105 (BA-2000)	35 (SE)
Tanner	I-C	236 (PC)	192 (BA-2000)	124 (Control)
	D-P	91 (PC)	79 (Lime)	62 (SE)
	S-C	48 (PC)	40 (Silane)	19 (Control)
Cameron	I-C	341 (PC)	221 (Silane)	124 (SE)
	D-P	115 (PC)	83 (Lime)	63 (SE)
	S-C	104 (Lime)	54 (Silane)	12 (SE)
		Retained Strength, %		
Salt River	I-C	95 (PC)	73 (Control)	60 (BA-2000)
	D-P	98 (Lime)	84 (BA-2000)	72 (Control)
	S-C	97 (Silane)	62 (PC)	31 (SE)
Tanner	I-C	81 (PC)	50 (Silane)	36 (Control)
	D-P	87 (Silane)	59 (Control)	52 (BA-2000)
	S-C	41 (Silane)	26 (Silane)	13 (Control)
Cameron	I-C	82 (PC)	65 (Silane)	45 (SE)
	D-P	75 (PC)	62 (Silane)	50 (Control)
	S-C	64 (Lime)	33 (Silane)	15 (Control)

Table 5 also shows that the most effective treatment for retained strength was portland cement followed by silane. As would be expected, the control and sand equivalent treatments had the lowest values for retained strength.

It is to be emphasized that the above comments are based on average values and that there may not have been a significant difference between the highest and next-highest values for any of the properties discussed.

The summary of average values presented in Tables 4 and 5 for the individual values shown in Tables A-9 to 11 in Appendix A was presented for a rough and more "visual" analysis of the data. The test results obtained from the listing of Table 1 (Tables A-9 to 11) were analyzed using a computer program entitled "statistical package for the social science" (SPSS). The program yielded the analysis of variance shown on Tables A-14 and A-15 and the program was utilized to answer three questions listed below:

1. Question. Which treatment was the most effective relative to the highest wet strength and also to the highest retained strength?

   Answer. The output of the SPSS program gave values for tabulation of the mean values for wet and retained strength and further broken down by treatment and source of aggregate to test if method differed and also if the test method was a large source of variation, that is, had a large effect on test value. An example of this is shown as follows:

Treatment	Aggregate	Mean Wet Strength, psi
	Combined	107.4
Control	Salt River	131.3
	Tanner	69.9
	Cameron	121.2
Portland	Combined	164.1
Cement	Salt River	183.9
	Tanner	124.9
	Cameron	183.4

It is to be noted that the mean wet strength values shown are averages of both compressive (I-C) and tensile (D-P and S-C) stresses.

A summary of the above information is given next and shows detailed relationships presented in Table 5.

Highest			to			Lowest
	Portland Cement	BA-2000	Lime	Silane	Control	Sand Equivalent
Wet Strength, psi	164.2	159.3	143.9	130.9	107.4	83.5
	Portland Cement	Silane	Lime	BA-2000	Control	Sand Equivalent
Retained Strength, %	71.6	68.4	65.6	58.7	44.9	44.7

The entire population had a mean retained strength value of 59 percent for a combination of treatment, aggregate, and test method. It is apparent the most effective treatment with respect to both wet and retained strengths was portland cement. However, the second best treatment depended on whether one considers wet strength or retained strength.

2. Question. Which test method was the most repeatable?

Answer. The following listing of mean values and standard deviations obtained from the SPSS program was used to reach a decision.

Wet Strength, psi	Immersion-Compression	241.8	90.1
	Double-Punch	90.0	22.5
	Spit-Cylinder	62.8	38.7
Retained Strength, psi	Immersion-Compression	63.4	17.0
	Double-Punch	70.5	13.9
	Split-Cylinder	43.1	25.7

From the above, it is noted that the double-punch method was the most repeatable due to having the lowest standard deviation values for both wet and retained strengths. The double-punch method had the highest retained strength values which would imply it had the least severe exposure. How that would be related to performance is not known at this time.

3. Question. Did the source of aggregate and treatment have an influence on wet and retained strength values?

Answer. Two analyses of variance (ANOVA) were run on wet strength values and also on retained strength to test the hypotheses that

a. test methods had no effects,

b. the source of aggregate had no effect,

c. the treatment had no effects, and

d. there was no interaction between source of aggregate and treatment.

Examination of both the results of the ANOVA and with reference to wet and retained strength the data indicated that:

a. the test method was highly significant at a level near 100 percent,

b. the source of aggregate was significant near the 100 percent level,

c. the treatment was also significant near the 100 percent level, and

d. the interaction between source of aggregate and treatment was not important since the level of significance was near 60 percent.

The above analyses indicate that the double-punch procedure to evaluate debonding responded to the effects of treatment and aggregate source, and also that it was the most repeatable test method used for this program. It is noted that an ADOT evaluation report in 1980 of the double-punch method by Scott and Ritter (18) had recommended that " ... this method, with some minor modifications should be incorporated into the mix design methods of the Arizona Department of Transportation."

Table 2a indicates variables of amounts of portland cement and air voids on the wet strengths of Salt River and Tanner aggregates. Test results obtained by the three debonding methods for the two aggregates are shown in the Appendix Tables A-12 and A-13. Although the initial plan had been to look at wet strength only, the appendix tables show that the work was extended to include calculations for retained strengths. Examination of the data on the two tables shows that the range of air voids was from 5.4 to 10.3 percent, which is considered somewhat limited. The data also show that except for the Tanner mixture at high air voids, the retained strength values were relatively high, that is, above the common specification value of a minimum of 60 percent.

The effects of the variables on wet strength are presented in graphical form on Figure 2. A study of the curves indicates that the effects of air void content on wet strength was relatively the same for each test method in consideration of aggregate and also cement content; the slopes of the corresponding curves are essentially the same. The wet strengths of the specimens for the Salt River aggregate were generally higher than for the Tanner aggregate as well as the values for retained. The same relative values for wet strength and retained strength for the two aggregates are found in Tables A-9 and A-10. The curves of Figure 2 show that air void content had a greater effect on wet strength than did the increase in portland cement content from 1.0 to 1.5 percent.

The results of the testing outlined in Table 2b are listed in the Appendix Table A-16. The variables were again air void content and amount of cement plus method of compaction to determine their effects on wet strength of the Salt River aggregate. The two compaction methods of Marshall and the University's vibratory kneading compactor (VKC) were used to form the test specimens. The vibratory kneading compactor was the one developed by Jimenez (17) and has been used in other research projects for ADOT.

As was done for the work proposed in Table 2a, additional testing was performed to obtain retained strength values. The long run significance of the variables was somewhat minimized since the majority of the retained strength values were above 80 percent and Arizona specifications suggest a minimum of 60 percent.

A study of the data in Table A-16 showed that the wet strength values at the low air void content were generally higher than those at high air void content; overall averages being 205 and 139 pounds per square inch, respectively. The same relative retained strength values related to air void contents were 92 and 75 percent for low to high air voids.

In order to verify the above "eyeballed" relationships, standard statistical methods were used to obtain numerical expressions for the relationships among the variables of the study. Values of retained strength versus air void content were plotted for the variables of compaction method, test, method, and treatment. Linear regression was performed on each set of data to obtain the best fit line (R = .99). The reason for that was to find the values of retained strength that corresponded to the medians of the three ranges of air void content. For example, the range of the "low" air void

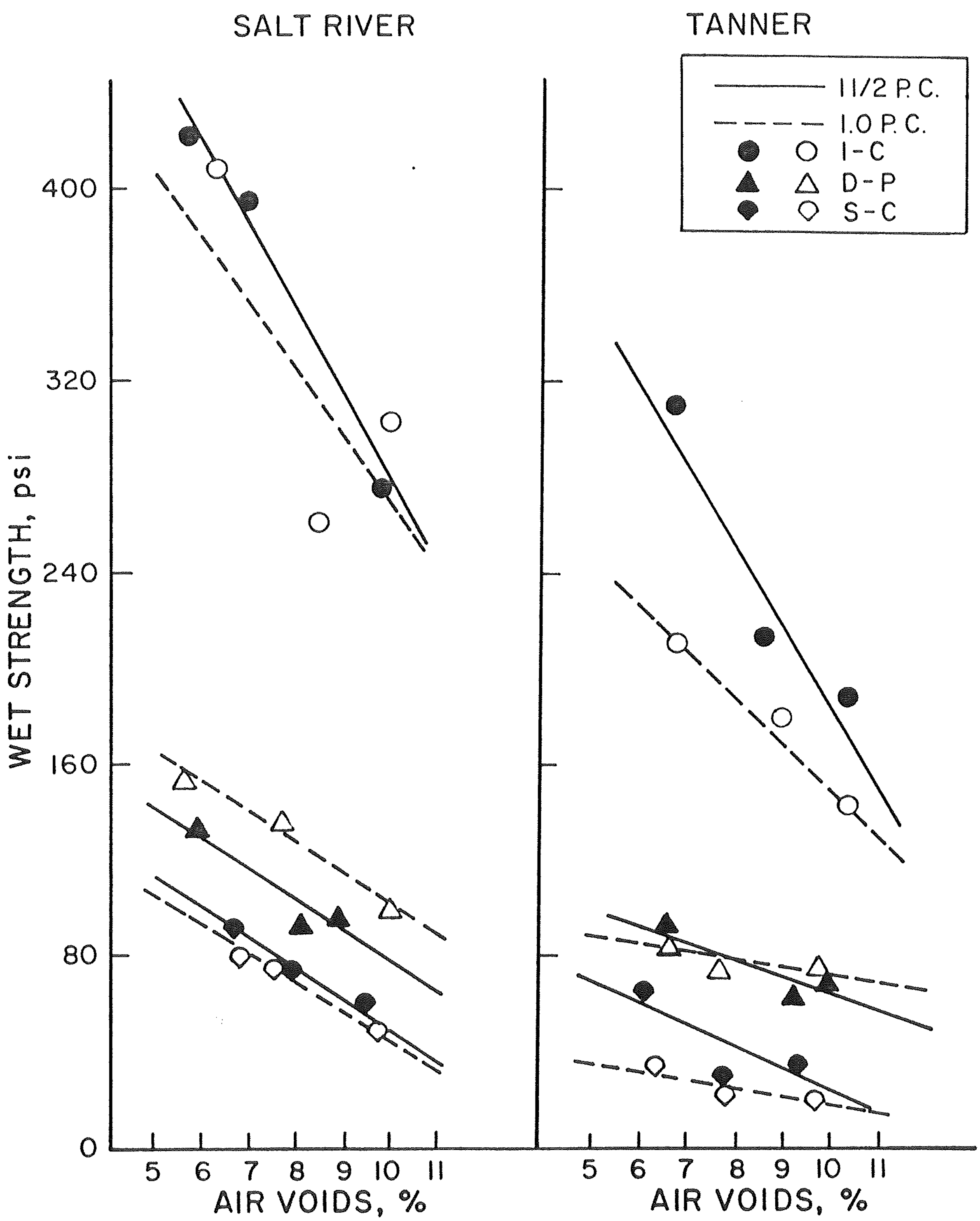

Figure 2. Effects of Air Voids and Cement Content on Wet Strength (Table 2a)

content was 2.0 to 4.0 percent, then the value of the retained strength that corresponded to the median of that range (3.0 percent) was picked off the graph. This was done for each of the low, medium, and high ranges of air void content.

After all of the median values of retained strength were obtained by interpolation, an analysis of variance was performed. The ANOVA made possible the study of effects of compaction method, air void content, treatment, and their interactions between these sources and the retained strength values.

Table A-17 shows the results of the ANOVA, and the following conclusions were made:

a. Compaction method had no significant effect on the retained strength; level of significance was 77 percent,

b. Treatment had no significant effect on retained strength,

c. Air voids had a significant effect on retained strength at a level of 99 percent, and

d. The two-way interactions between compaction and treatment, compaction and air voids, and treatment and air voids had levels of significance of around 77, 77 and 29 percent, respectively. Therefore, none of these two-way interactions was significant.

Air void content was the only source of variation that had a significant effect on the retained strength. Further examination of the three levels (2.8, 4.8, and 6.8 percent) of air void content showed that an increase or decrease of 2 percent in air voids caused a change of 12 percent in the overall retained strength. In order to determine if this relationship was significant, a separate ANOVA was performed. Table A-18 shows the sample means and standard deviations of the retained strengths for the three levels of air void content. From the data, it was indicated that at least two means were significantly different than the other. The Least Significant Difference (LSD) test was run to determine which of the three levels of air voids differed significantly. From the same table, it was determined that only the high and the low levels of air voids changed the retained strength significantly. In other words, a change of more than 2 percent in air voids was needed to have a significant change in the retained strength. It is to be reiterated that these conclusions apply to retained strength levels that generally are considered to be above specification minimum values of retained strength.

Phase 2

The construction of the test site was started on September 18, 1986 on Interstate 40 east of Holbrook. The construction on I-40 required a treatment with lime to meet ADOT requirements. However, the test sections had treatments of control (no treatment), portland cement, and BA-2000. All of the mixture design variables were investigated and selected by ADOT. As indicated earlier, the debonding tests to be used on the cores were the immersion-compression, double-punch, and the Tunnicliff split-cylinder.

At the request of Tunnicliff, ADOT sampled and tested cores taken from the test site at the same time as those for this research. However, the cores were taken from in between the wheel path and water was used as a coolant during the coring operation.

Table 6 shows the variation of densities with service time and treatment. Except for the location of outer-wheel-path, the cores were taken in a randomized position within a section. The data show that all three core mixtures had a relatively uniform distribution of density for each sampling period as well as for all five periods of sampling.

Table A-19 in Appendix A has the results from testing the cores with all three treatments and with all three procedures.

The results for the "plant" mixtures were obtained several months after being produced for the construction. These mixtures were used to obtain a measure of the initial resistance to debonding. All three tests were used for that evaluation except as shown and follows. The untreated plant mixture was compacted only to the 4-inch height condition. The portland cement mixture was used along with another one for developing a relationship between 2-1/2 and 4-inch high specimens in the immersion-compression test. As a consequence, there was not enough mixture left for performing the double-punch test on that plant mixture.

The data on Table A-19 indicate that for the untreated plant mixture, the double-punch method yielded the highest retained strength at 53 percent followed by the immersion-compression with 43 percent, and then by the split-cylinder at 23 percent. Note that these specimens had relatively high air void contents of 11.9 percent while the cores after 1/2 month had air voids of 7.2 percent. The results of the double-punch test suggests that the untreated paving mixture would not fail by debonding, but the split-cylinder data suggests that the mixture would certainly fail by debonding.

The results shown for the BA-2000 plant mixture again shows the same direction of severity of the test methods in that the retained strengths were 75, 42, and 32, respectively for the double-punch, immersion-compression, and split-cylinder methods.

Table 6. Summary of Core Densities and Their Variations for the Holbrook Test Site.

Treatment	Age Mos.	Number of Cores	Average Density g/cc	Standard Deviation	Coefficient of Variation, %
	0.5	13	2.417	0.019	0.8
	1.5	24	2.399	0.019	0.8
Untreated	6.7	24	2.413	0.011	0.5
	12.9	24	2.461	0.018	0.7
	19.8	24	2.461	0.018	0.7
	0.5	24	2.404	0.028	1.2
	1.5	24	2.428	0.023	0.9
BA-2000	6.7	24	2.049	0.024	1.0
	12.9	24	2.426	0.028	1.1
	19.8	24	2.447	0.019	0.8
	0.5	--	--	--	--
	1.5	24	2.458	0.016	0.7
Portland	6.7	24	2.446	0.020	0.8
Cement	12.9	24	2.486	0.013	0.5
	19.8	24	2.493	0.013	0.5

As indicated previously, the portland cement plant mixture was not evaluated for debonding by the double-punch method. However, since the other two methods (I-C and S-C) suggest that the mixture was not susceptible to debonding, it is imagined that similar results would have been obtained with the double-punch procedure.

The retained strengths obtained for all three mixtures by the immersion-compression and the double-punch methods were all above 70 percent starting at an age of 1/2 month. The results from the split-cylinder test show relatively low retained strength values for the cores from the untreated pavement sections; the highest value being 42 percent after 19.8 months in service.

Table A-20 in the Appendix shows the results obtained by ADOT on the cores taken from the Holbrook site. That table shows a different age of cores than Table A-19; however, it is known for a certainty that the last three periods of coring are identical. That is that 6.7 month sampling is labeled 6 months in Table A-20 and the same for the 12.9 and 19.8 months periods.

A direct comparison can not be made between the two tables since the location (OWP vs. BWP), the method of coring (dry vs. wet) and laboratory (U.A. vs. ADOT) were not the same. A study of the two sets of data will not be made. However, it is observed that the ADOT data show higher values for saturation than for the University and yet also higher values for retained strength. We would not expect such a correspondence since higher saturation generally are associated with lower retained strength.

A plot of core values for air voids and voids-in-the-mineral-aggregate (VMA) versus age in service is presented in Figure 3. As expected, both values of A.V. and VMA were decreasing with time in service. The broken horizontal lines shown in the VMA plot are the calculated terminal values after about 5 years of service. These theoretical values were calculated with the method described by Jimenez in reference 13.

The test site has been examined by ADOT personnel during the time of coring. At the 12.9 months of service, the test site was visited by the writer and found no evidence of debonding in any of the three paving mixtures. There was only one crack in the test site and that was a transverse reflection one across both east bound lanes in the section containing BA-2000. The photograph of Figure 4 illustrates the texture of the untreated (#1) mixture at 12.9 months of age. The numbers 1-85 and 1-93 represent the cores of earlier sampling.

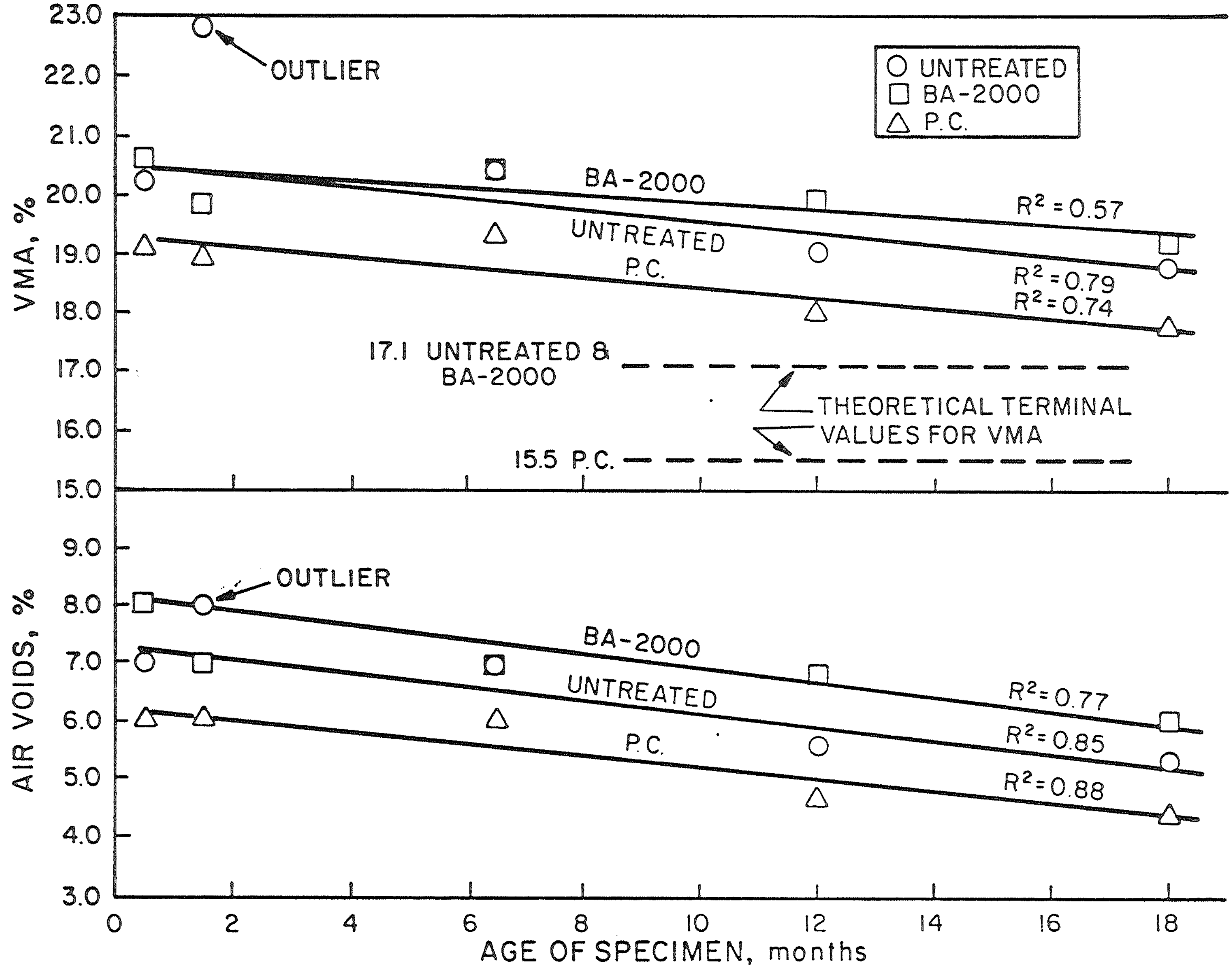

Figure 3. Relationships Between Air Voids and Voids in the Mineral Aggregate with Age in Service for Three Paving Mixtures

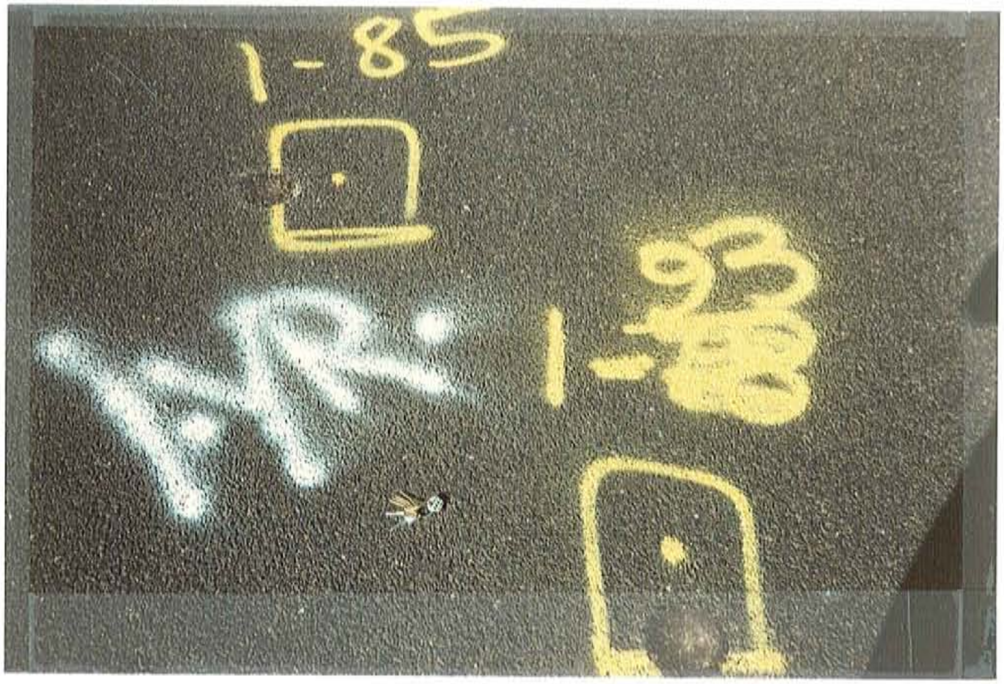

Figure 4. Photograph of the Untreated Paving Mixture at 12.9 Months Age of the Surface.

CONCLUSIONS AND RECOMMENDATIONS

The investigation was aimed towards determining the best of three debonding methods for the evaluation of asphaltic concrete. Also, the effectiveness of various treatments to three aggregate blends was examined to establish the best one for improving the resistance to moisture damage (debonding) of asphaltic concrete. Most of the work was done on laboratory prepared mixture; however, a test site on Interstate-40 was examined to determine effectiveness of treatment and test methods for detecting the changes in resistance to debonding as service time progressed. The following conclusions are warranted from the data obtained in the laboratory (Phase 1) and field (Phase 2) work done on the paving mixtures.

1. The treatment with portland cement was the most effective for improving wet strength and retained strength for most of the aggregate mixtures. However, BA-2000 yielded the highest wet strength for the Salt River aggregate and silane was somewhat effective in improving the retained strength for the Tanner blend. It is apparent that the effectiveness of the treatments used were dependent on the aggregate treated.

2. The low ranking of the sand equivalent treatment is attributed to the good values (50-61) of the untreated (control) aggregates. The increases effected in S.E. values (62-84) were by washing which resulted in significant reductions in the amounts passing the No. 200 sieve.

3. The highest retained strength values were obtained with the University of Arizona's double-punch procedure. Statistical analyses of wet strength and retained strength showed that the double-punch method had the lowest standard deviation values for both measurements. The split-cylinder method of the modified Lottman had the highest standard deviation method for retained strength.

4. Air void content were found to have a significant influence on the value of retained strength regardless of compaction method. The data indicated that a 2 percentage point difference in air void can cause a 12 percentage point change in retained strength.

5. The evaluation of the untreated plant mixture used for the field test indicated that the double-punch method of the U.A. rated the mixture highest with reference to resistance to

debonding with a retained strength value of 53 percent. The split-cylinder method of Tunnicliff rated the mixture lowest with a retained strength value of 23 percent.

6. Ratings of cores taken from the test sections after 1/2 month in service showed that all treatments (control, BA-2000, and portland cement) evaluated with the immersion- compression and double-punch methods had good (above 70 percent) values for retained strength. The split-cylinder method showed poor retained strength values for the untreated and BA-2000 mixtures.

7. At 19.8 months of age there was no debonding failure of any of the three treatments. The double-punch method predicted the highest performance of the untreated plant mixture; therefore, in this study, it is considered to be the test of the four test methods.

The objectives of the research program were to determine the best test method to evaluate the debonding susceptibility of paving mixtures and to determine the most effective treatment for improving resistance to debonding. Based on the findings of this work reported, the following recommendations are made:

1. As stated by Scott and Ritter in 1980, " ... this method (double-punch) with minor modifications, should be incorporated into the mix design methods of the Arizona Department of Transportation" (18). It is repeated here; however, modifications were not identified.

2. The Arizona Department of Transportation should support efforts towards modifying the double-punch equipment so that the method can be used for field control of paving mixtures.

3. The effectiveness of portland cement for improving retained strength has been shown to be a fact. However, other treatments such as lime slurry or silane may be as effective with a particular aggregate and be more cost effective.

4. The study of treatments for improving the resistance to debonding should continue as new products and methods of introduction (portland cement to wet aggregate) are presented to the design of paving mixtures.

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APPENDIX A

LISTING OF TABLES

TABLE A-1. Characteristics of Control Aggregate Mixtures.

Gradation Sieve Size	Percent Passing Salt River	 Tanner	 Cameron
1 1/2"	100	100	100
3/4"	95	100	100
3/8"	71	81	80
#4	47	59	66
#8	42	48	45
#16	32	34	31
#30	22	22	23
#50	12	13	13
#100	7	8	8
#200	4.7	5.7	5.6
Surface Area ft^2/lb	25.6	28.4	28.5
Eff. S.G.	2.68	2.59	2.79
Sand Equiv.	53	50	61
U.A. Design, by Lab Test, A.C., %	4.8	5.3	5.2
by Theory A.C., %	5.1	4.8	4.5
F.T., μ	9.8	8.2	7.8
ADOT Design, A.C., %	4.9	NA	5.1

TABLE A-2. Characteristics of Treated Aggregate Mixtures.

Gradation	Percent Passing								
	Salt River			Tanner			Cameron		
Sieve Size	+1.5% P.C.	+1.5% lime	S.E.	+1.5% P.C.	+1.5% lime	S.E.	+1.5% P.C.	+1.5 lime	S.E.
1 1/2"	100	100	100	100	100	100	100	100	100
3/4"	95	95	93	100	98	100	86	86	86
3/8"	71	71	70	81	81	85	80	80	80
#4	47	47	47	59	59	61	66	66	66
#8	42	42	43	48	48	47	45	45	45
#16	33	33	33	34	35	31	31	31	30
#30	23	23	22	22	23	19	23	23	21
#50	13	13	12	13	14	10	13	13	9
#100	9	9	6	8	9	5	8	9	4
#200	6.0	5.8	2.7	6.9	6.9	2.4	6.2	6.0	3.0
Surface Area ft^2/lb	29.3	28.9	21.9	30.8	31.9	20.1	29.4	29.9	20.4
Eff. S.G.	2.68	2.68	2.68	2.59	2.59	2.59	2.79	2.79	2.79
S.E.			62			70			84
U.A. Design, by Lab Test, A.C., %	4.8	4.6	5.1	5.2	5.0	5.4	5.0	5.0	5.5
by Theory A.C., %	4.8	4.6	5.1	4.9	4.6	5.4	4.4	4.3	5.2
F.T., μ	8.0	7.8	11.5	7.9	7.1	13.4	7.3	7.1	12.6

TABLE A-3. Marshall Mixture Design Data for Salt River Aggregate and Additives.

A.C. %	Density pcf	Air Void %	Stability lbs	Flow in, 10^{-2}	V.M.A. %
			Control		
5.0	151.0	2.5	2980	10.7	14.4
5.5	151.0	1.6	3010	11.3	14.7
6.0	150.5	1.3	2290	13.5	15.5
4.8*					
			+1.5% Portland Cement		
5.0	151.0	2.3	2830	10.7	14.2
5.5	152.0	0.9	2770	14.7	14.1
6.0	151.5	0.7	2060	17.0	15.0
4.8*					
			+ 1.5% Lime		
5.0	151.5	2.0	3050	13.0	13.9
5.5	151.0	1.5	2610	15.0	14.6
6.0	151.0	0.9	2100	21.0	15.2
4.6*					
			+ 1.0 % Silane		
4.0	147.0	6.3	3170	9.0	15.6
4.5*	148.0	5.8	3040	10.0	15.6
5.0	148.5	4.1	2740	11.7	15.8
5.5	149.5	2.7	2540	10.3	15.7
			+ 0.5% B.A. 2000		
4.0	148.0	5.6	3093	9.5	15.0
4.5	148.0	4.9	3270	9.4	15.4
5.0	148.0	4.2	2690	14.2	16.0
5.5	148.0	2.5	2756	14.0	15.5
4.8*					
			Sand Equivalent		
4.5	144.0	6.9	2510	7.0	17.2
5.0	144.5	6.0	2410	9.0	17.4
5.5	147.5	3.3	2900	11.0	16.1
6.0	148.0	2.4	2520	7.7	16.4
5.1*					

* Design Asphalt Content

TABLE A-4. Marshall Mixture Design Data for Tanner Aggregate and Additives.

A.C. %	Density pcf	Air Void %	Stability lbs	Flow in, 10^{-2}	V.M.A. %
			Control		
5.0	141.0	5.8	2183	9.0	16.9
5.5	142.5	4.3	2460	9.0	16.6
6.0	143.0	3.1	2443	9.0	16.7
5.3*					
			+1.5% Portland Cement		
5.0	143.0	4.5	2960	9.0	15.8
5.5	143.5	3.4	2750	11.0	15.9
6.0	145.0	1.7	2730	15.0	15.4
5.2*					
			+ 1.5% Lime		
5.0*	149.0	3.8	3200	11.0	15.2
5.5	144.5	2.5	2750	10.0	15.4
6.0	145.0	1.9	2660	10.0	15.6
			+ 1.0 % Silane		
4.5	140.0	7.0	2990	10.0	17.0
5.0	139.0	7.0	2210	9.0	18.2
5.5	142.0	4.6	2880	8.5	16.9
6.0	141.5	4.4	2270	8.2	17.7
5.2*					
			+ 0.5% B.A. 2000		
4.5	140.0	7.4	2580	10.0	17.6
5.0	139.5	6.8	2590	10.0	17.8
5.5	142.5	4.2	2840	8.0	16.6
6.0	143.0	3.1	2710	9.0	16.7
5.2*					
			Sand Equivalent		
4.5	138.0	8.7	2310	7.5	18.5
5.0	137.5	8.1	2140	8.2	19.0
5.5	138.5	6.8	1890	7.0	18.8
6.0	139.5	5.4	2010	7.8	18.6
5.4*					

* Design Asphalt Content

TABLE A-5. Marshall Mixture Design Data for Cameron Aggregate and Additives.

A.C. %	Density pcf	Air Void %	Stability lbs	Flow in, 10^{-2}	V.M.A. %
			Control		
4.5	151.0	5.6	3410	7.8	16.3
5.0	150.0	5.4	2880	8.2	17.2
5.5	152.5	3.0	3000	9.0	16.2
6.0	152.0	2.5	2820	8.5	17.0
5.2*					
			+1.5% Portland Cement		
4.5	152.5	4.8	3200	8.7	15.6
5.0*	153.5	3.3	3090	9.0	15.4
5.5	154.0	2.3	2680	8.3	15.6
6.0	153.0	2.0	2580	10.7	16.5
			+ 1.5% Lime		
4.5	151.0	5.2	2580	9.0	15.9
5.0*	151.0	4.4	2440	13.3	16.3
5.5	153.5	2.1	2700	9.3	15.4
6.0	154.0	1.0	2280	10.3	15.5
			+ 1.0 % Silane		
4.5	149.0	7.0	2840	7.3	17.5
5.0*	150.5	5.1	2540	9.0	17.0
5.5	152.0	3.3	2740	7.7	16.5
6.0	152.5	2.4	2780	7.5	16.8
			+ 0.5% B.A. 2000		
4.5	149.0	6.9	2660	8.2	17.5
5.0*	150.0	5.5	2660	9.5	17.4
5.5	152.0	3.5	2200	10.3	16.6
6.0	153.0	2.2	2400	11.7	16.6
			Sand Equivalent		
4.5	144.0	10.0	1630	9.0	20.2
5.0	146.5	7.8	2030	8.0	19.4
5.5*	146.5	7.0	1870	8.0	19.7
6.0	145.5	7.0	1830	7.0	20.8

* Design Asphalt Content

TABLE A-6. Copy of ADOT's Worksheet for the Design of the Control Paving Mixture.

44-2901 R7/81

MATERIALS SECTION
LABORATORY BITUMINOUS MIXTURE DESIGN

Pit No. 5588
Blend Francis Day (Richfield)
Asphalt Source Sahuaro - Edgington

☐ INITIAL ☐ FINAL ☒ Verification

Received	9-3-86	Test Commenced	9-3-86	Material	3/4" AC
Identification		Sampled	9-2-86	Lab. No.	86-437A
Submitted by		Sampled by	Adair	Project No	IR-40-5(67)(69)(74)
Source of Sample	Stockpiles			Quantity	
Location of Supply	Pit 5588 & Francis Day (Richfield)				
Project Name	Holbrook - Lupton Highway			Contractor	Corn
Specifications Governing				Mix Design ~~Request No.~~	ATL

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Sieve	Materials Survey (PE) Preliminary Design Grading: Orig. Pit Average % Ret	Orig. Pit Average % Pass	Crushed Gradation % Ret	Crushed Gradation % Pass	Adj. Crush Gradation % Ret	Adj. Crush Gradation % Pass	As Produced (Construction) Final Adjusted Design Grading: As Crushed on Project (Composite) % Ret	As Crushed on Project % Pass	As Adj. in Laboratory (Composite) % Ret	As Adj. in Laboratory % Pass	~~Spec. Limits~~
							%		Coarse 30%		
							%		Inter 14%		
							%		Crush fine 18%		
							%		Wash Sand 38%		
							%		- %		
3" Slot											
3"											
2½"											
2"											
1½"											
1"										100	100
¾"										100	97-100
½"									4	96	
⅜"									14	82	79-85
¼"									15	67	
No. 4									8	59	
8									13	46	42-46
10									3	43	
16									8	35	
30									12	23	
40									7	16	15-19
50									6	10	
100									6	4	
200									2	2.5	2.1-3.1

O.D. SP. GR. COARSE	3.005	O.D. SP. GR. FINE	2.696	O.D. SP. GR. COMB.	2.815
S.S.D. SP. GR. COARSE	3.042	S.S.D. SP. GR. FINE	2.742	S.S.D. SP. GR. COMB.	2.858
APP. SP. GR. COARSE	3.120	APP. SP. GR. FINE	2.829	APP. SP. GR. COMB.	2.941
ABSORP. COARSE AGGR.	1.23 %	ABSORP. FINE AGGR.	1.71 %	ABSORP. COMB. AGGR	1.53 %

	Liquid Limit	Plastic Limit	Plasticity Index	Sand Equiv.
Natural Fines				
Crushed Fines				
Combined Fines				84

ABRASION (A, B, C, D): 100 REV. 3 % LOSS 500 REV. 12 % LOSS CRUSH.FACES 97 % LIMESTONE %

REMARKS Abrasion from Proj. F-077-1-505 (3), Lab # 84-682A
A minimum of 38% washed sand shall be used.

DESIGN DATA (SEE BACK FOR CHARTS)

Specimen	A	B	C	D	E	F	~~Design Spec.~~
Bit. Grade/Specific Gravity	AC 30 - 1.021						
% of Bit.	5.6	5.6					
Bulk Density Lbs. per Cu. Ft.	150.7	152.1					
Marshall Stability	2668	2710					1750 min
Flow	11	12					7-17
~~Method of Compaction~~	Mech	Hand					
Max SP. GR.	2.419	2.442					
% Air Voids	7.1	6.2					4.5-7.5
% V.M.A.	18.9	18.1					16.6-19.
% Air Voids Filled	62.5	65.8					
% Effect Asphalt Total Mix	4.98	4.98					

Sample	Air PSI	H_2O PSI	Retention	ARIZ 802 Minimum Retention 35 %; H_2O PSI Minimum ~~150~~ 140
No. 1	(468)	(202)	(43)%	5.6 % AC 30 Asphalt
No. 2	(This test being repeated due to			%
No. 3	not having at least two wet breaks			
No. 4	within ± 10% of avg. of three results.			%
No. 5			%	%
No. 6			%	%

MAX. DENSITY 162.2 LBS. PER CU. FT @ 5.6 % ~~ARIZ 806 (RICE TEST)~~
ASPHALT ABSORP. ON DRY AGGREGATE 0.66 %
AGG. SURFACE AREA= SQ.FT./LB. FILM THICKNESS MICRONS
C.K.E. VALUES - ARIZ 805 F = F(CORR.)= C = C(CORR)=
Kf = Kc = Km =
BIT GRADE RECOMMENDED BITUMEN %
RECOMMENDED BITUMEN CONTENT CONSIDERING ALL TEST DATA %

MIX DESIGN GRADATION TARGET VALUES

Sieve	% Pass
1"	100
¾"	
½"	
⅜"	
No. 4	
8	
40	
200	

TABLE A-7. Copy of ADOT's Worksheet for the Design of the Paving Mixture with BA-2000.

† 44-2901 R7/81

☐ INITIAL ☐ FINAL ☒ VERIFICATION

MATERIALS SECTION
LABORATORY BITUMINOUS MIXTURE DESIGN

Pit No. 5588
Blend FRANCIS DAY (Richfield)
Asphalt Source SAHUARO- EDDINGTON

Received	9-3-86	Test Commenced	9-3-86	Material	3/4" AC
Identification		Sampled	9-2-86	Lab. No.	86-437C
Submitted by		Sampled by	ADAIR	Project No	TR-40-5(67)(69)(74
Source of Sample	STOCKPILE			Quantity	
Location of Supply	PIT 5588 & FRANCIS DAY (RICHFIELD)				
Project Name	HOLBROOK - LUPTON HIGHWAY			Contractor	CORN
Specifications Governing				Mix Design Request No.	ATL

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Sieve	Orig. Pit Average % Ret	Orig. Pit Average % Pass	Crushed Gradation % Ret	Crushed Gradation % Pass	Adj. Crush Gradation % Ret	Adj. Crush Gradation % Pass	As Crushed on Project (Composite) % Ret	As Crushed on Project (Composite) % Pass	As Adj. in Laboratory (Composite) % Ret	As Adj. in Laboratory (Composite) % Pass	Spec. Limits
3" Slot								%	Coarse	30 %	
3"								%	Inter	14 %	
2½"								%	Crush Fine	18 %	
2"								%	Wash. Sand	38 %	
1½"								%		%	
1"										100	100
¾"										100	97-100
½"									4	96	
⅜"									14	82	79-85
¼"									15	67	
No. 4									8	59	
8									13	46	42-46
10									3	43	
16									8	35	
30									12	23	
40									7	16	15-19
50									6	10	
100									6	4	
200									2	2.5	2.4-3.1

O.D. SP. GR. COARSE	3.005	O.D. SP. GR. FINE	2.696	O.D. SP. GR. COMB.	2.815
S.S.D. SP. GR. COARSE	3.042	S.S.D. SP. GR. FINE	2.742	S.S.D. SP. GR. COMB.	2.858
APP. SP. GR. COARSE	3.120	APP. SP. GR. FINE	2.829	APP. SP. GR. COMB.	2.941
ABSORP. COARSE AGGR.	1.23 %	ABSORP. FINE AGGR.	1.71 %	ABSORP. COMB. AGGR	1.53 %

	Liquid Limit	Plastic Limit	Plasticity Index	Sand Equiv.
Natural Fines				
Crushed Fines				
Combined Fines				84

ABRASION (A Ⓑ C, D): 100 REV. 3 % LOSS 500 REV. 12 % LOSS CRUSH.FACES 97 % LIMESTONE %

REMARKS Abrasion from Proj. F-077-1-505 & (3) Lab # 84-682A
A minimum of 38% washed sand shall be used.
This design requires the use of 0.5% BA 2000 by weight of asphalt.
Project to initiate C.O. to reduce verification requirement for index of retained strength to 60%.

DESIGN DATA (SEE BACK FOR CHARTS)

Specimen	A	B	C	D	E	F	Design Spec.
Bit. Grade/Specific Gravity	AC 30 - 1.021						
% of Bit.	5.5	5.5					
Bulk Density Lbs. per Cu. Ft.	150.6	152.5					
Marshall Stability	2842	3031					1750 Min
Flow	12	12					7-17
	Mech	Hand					
SP. GR.	2.417	2.448					
% Air Voids	7.3	6.1					4.5-7.3
% V.M.A.	18.9	17.8					16.1-19.
% Air Voids Filled	61.2	65.6					
% Effect Asphalt Total Mix	4.88	4.88					

Sample	Air PSI	H_2O PSI	Retention	
No. 1			%	5.5 % AC 30 ASPHALT
No. 2	583	351	60 %	0.5 % BA 2000
No. 3			%	%
No. 4			%	%
No. 5			%	%
No. 6			%	%

ARIZ 802 MINIMUM RETENTION 65 %
H_2O PSI MINIMUM ~~150~~ 140

MAX. DENSITY 162.4 LBS. PER CU. FT @ 5.5 % ~~ARIZ 806 (RICE TEST~~
ASPHALT ABSORP. ON DRY AGGREGATE 0.66 %
AGG. SURFACE AREA= SQ.FT./LB. FILM THICKNESS MICRON
C.K.E. VALUES - ARIZ 805 F = F(CORR.)= C = C(CORR)=
Kf = Kc = Km =
BIT GRADE RECOMMENDED BITUMEN %
RECOMMENDED BITUMEN CONTENT CONSIDERING ALL TEST DATA %

MIX DESIGN GRADATION TARGET VALUES

Sieve	% Pass
1"	100
¾"	
½"	
⅜"	
No. 4	
8	
40	
200	

TABLE A-8. Copy of ADOT's Worksheet for the Design of the Paving Mixture with Portland Cement.

†●49-2901 R7/81

☐ INITIAL ☐ FINAL ☒ VERIFICATION

MATERIALS SECTION
LABORATORY BITUMINOUS MIXTURE DESIGN

Pit No. 5588
Blend Francis Day (Richfield)
Asphalt Source Sahuaro - Edgington

Received	9-3-86	Test Commenced	9-3-86	Material	3/4" AC
Identification		Sampled	9-2-86	Lab. No.	86-437B
Submitted by		Sampled by	Adair	Project No	IR-40-5(67)(69)(74)
Source of Sample	Stockpile			Quantity	
Location of Supply	Pit 5588 & Francis Day (Richfield)				
Project Name	Holbrook - Lupton Highway			Contractor	Corn
Specifications Governing				Mix Design Request No.	ATL

Sieve	MATERIALS SURVEY (PE) PRELIMINARY DESIGN GRADING: ORIG. PIT AVERAGE % Ret	% Pass	CRUSHED GRADATION % Ret	% Pass	ADJ. CRUSH GRADATION % Ret	% Pass	AS PRODUCED (CONSTRUCTION) FINAL ADJUSTED DESIGN GRADING: AS CRUSHED ON PROJECT (COMPOSITE) % Ret	% Pass	AS ADJ. IN LABORATORY (COMPOSITE) % Ret	% Pass	~~SPEC. LIMITS~~
3" Slot							Coarse 29 %		Coarse 30 %		
3"							Inter 14 %		Inter 14 %		
2½"							Crush Fine 16 %		Crush Fine 16 %		
2"							Washed Sand 39 %		Wash Sand 40 %		
1½"							Cement 2 %		%		
1"								100		100	100
¾"								100		100	97-100
½"							4	96	4	96	
⅜"							14	82	14	82	79-85
¼"							14	68	15	67	
No. 4							7	61	7	60	
8							13	48	13	47	43-47
10							3	45	3	44	
16							8	37	8	36	
30							12	25	13	23	
40							6	19	6	17	15-19
50							6	13	6	11	
100							8	6	7	4	
200							-2	4.3	2	2.4	2.0-3.0

WORK COPY NOT OFFICIAL

O.D. SP. GR. COARSE	3.005	O.D. SP. GR. FINE	2.685	O.D. SP. GR. COMB.	2.804
S.S.D. SP. GR. COARSE	3.042	S.S.D. SP. GR. FINE	2.731	S.S.D. SP. GR. COMB.	2.847
APP. SP. GR. COARSE	3.120	APP. SP. GR. FINE	2.816	APP. SP. GR. COMB.	2.930
ABSORP. COARSE AGGR.	1.23 %	ABSORP. FINE AGGR.	1.53 %	ABSORP. COMB. AGGR	1.53 %

	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SAND EQUIV.
NATURAL FINES				
CRUSHED FINES				
COMBINED FINES				78

ABRASION (A/Ⓑ/C, D): 100 REV. 3 % LOSS 500 REV. 12 % LOSS CRUSH.FACES 97 % LIMESTONE %

REMARKS Abrasion from Proj. F-077-1-505 & (3) Lab #84-682A

This design requires the use of 2.0% Type II Cement, mixed with aggregate with approx. 2% water, by weight of aggregate.

DESIGN DATA (SEE BACK FOR CHARTS)

SPECIMEN	A	B	C	D	E	F	DESIGN SPE
BIT.GRADE/SPECIFIC. GRAVITY	AC 30 - 1.021						
% OF BIT.		5.5					
BULK DENSITY LBS. PER CU. FT.		153.5					
MARSHALL STABILITY		2595					1750 m
FLOW		12					7-17
~~HVEEM STABILITY~~		Hand					
~~COHESION~~ Rice Sp. Gr.		2.464					
% AIR VOIDS		5.0					4.5-7.
% V.M.A.		17.1					16.2-19.
% AIR VOIDS FILLED		70.6					
% EFFECT ASPHALT TOTAL MIX		5.02					

SAMPLE	AIR PSI	H_2O PSI	RETENTION	ARIZ 802 MINIMUM RETENTION (65) % H_2O PSI MINIMUM ~~150~~ 140
No. 1			%	5.5 % AC 30 ASPHALT
No. 2	502	440	88 %	2.0 % Type II Cement (Ideal)
No. 3			%	%
No. 4			%	%
No. 5			%	%
No. 6			%	%

MAX. DENSITY 161.6 LBS. PER CU. FT @ 5.5 % ~~ARIZ 806 (RICE TEST~~

ASPHALT ABSORP. ON DRY AGGREGATE 0.52 %

AGG. SURFACE AREA= SQ.FT./LB. FILM THICKNESS MICRON

C.K.E. VALUES - ARIZ 805 F = F(CORR.)= C = C(CORR)=

Kf = Kc = Km =

BIT GRADE RECOMMENDED BITUMEN %

RECOMMENDED BITUMEN CONTENT CONSIDERING ALL TEST DATA %

MIX DESIGN GRADATION TARGET VALUES

Sieve	% Pass
1"	100
¾"	
½"	
⅜"	
No. 4	
8	
40	
200	

TABLE A-9. Results of Durability Tests on Salt River Aggregate.

Treatment	Control	P. Cement	Lime	Silane	BA 2000	S.E.
			Immersion Compression			
Design A.C., %	4.8	4.8	4.6	4.5	4.8	5.1
Density, pcf	144.0	144.0	142.0	143.0	143.0	142.0
Air Void, %	7.3	7.0	8.6	8.2	7.8	7.7
Saturation, %	59	44	40	66	63	61
Wet Strength, psi	257	340	214	319	475	304
Dry Strength, psi	351	359	326	407	789	345
Retained Strength, %	73	95	66	78	60	73
			Double Punch			
Density, pcf	142.5	145.5	143.0	143.5	145.0	141.0
Air Void, %	8.3	6.3	8.0	7.8	6.6	7.5
Saturation, %	75	87	75	92	93	88
Wet Strength, psi	86	90	124	105	148	106
Dry Strength, psi	120	101	126	143	177	113
Retained Strength, %	72	89	98	73	84	81
			Split Cylinder			
Density, pcf	144.0	145.0	145.5	144.0	144.5	141.0
Air Void, %	7.0	6.5	6.5	7.5	7.0	7.1
Saturation, %	100	103	74	96	95	95
Wet Strength, psi	51	122	133	113	105	35
Dry Strength, psi	158	197	152	116	142	93
Retained Strength, %	32	62	87	97	74	64

TABLE A-10. Results of Durability Tests on Tanner Aggregate.

Treatment	Control	P. Cement	Lime	Silane	BA 2000	S.E.
			Immersion Compression			
Design A.C., %	5.3	5.2	5.0	5.2	5.2	5.4
Density, pcf	137.0	136.5	136.5	136.5	137.0	133.0
Air Void, %	8.3	8.7	9.0	8.5	8.5	9.6
Saturation, %	92	70	68	93	95	82
Wet Strength, psi	124	236	197	157	192	133
Dry Strength, psi	341	291	329	317	466	316
Retained Strength, %	36	81	60	50	41	52
			Double Punch			
Density, pcf	136.5	137.5	136.0	137.5	138.0	133.5
Air Void, %	8.6	8.0	9.2	8.1	7.8	8.7
Saturation, %	100	98	100	122	105	103
Wet Strength, psi	66	91	79	84	69	62
Dry Strength, psi	111	110	139	96	133	111
Retained Strength, %	59	83	57	87	52	66
			Split Cylinder			
Density, pcf	137.5	138.5	138.0	137.0	137.0	133.5
Air Void, %	8.0	7.5	7.8	8.4	8.5	8.4
Saturation, %	150	145	134	137	139	134
Wet Strength, psi	19	48	48	40	34	22
Dry Strength, psi	151	146	167	98	141	125
Retained Strength, %	13	33	29	41	24	26

TABLE A-11. Results of Durability Tests on Cameron Aggregate.

Treatment	Control	P. Cement	Lime	Silane	BA 2000	S.E.
			Immersion Compression			
Design A.C., %	5.2	5.0	5.0	5.0	5.0	5.5
Density, pcf	147.5	148.0	146.0	144.5	144.5	141.5
Air Void, %	6.9	6.6	8.1	8.9	8.9	8.2
Saturation, %	111	90	70	85	92	93
Wet Strength, psi	244	341	315	221	255	124
Dry Strength, psi	460	417	455	340	476	275
Retained Strength, %	53	82	69	65	53	61
			Double Punch			
Density, pcf	147.5	149.0		146.5	146.5	141.5
Air Void, %	6.9	6.0		7.8	7.6	7.2
Saturation, %	135	78		110	123	111
Wet Strength, psi	97	115	83	74	101	63
Dry Strength, psi	193	154	135	119	134	102
Retained Strength, %	50	75	61	62	75	64
			Split Cylinder			
Density, pcf	148.0	149.0	145.5	143.5	143.5	140.5
Air Void, %	6.4	6.1	7.8	9.5	9.4	8.3
Saturation, %	205	166	119	116	135	146
Wet Strength, psi	29	94	104	69	54	12
Dry Strength, psi	195	206	161	113	164	78
Retained Strength, %	15	46	64	61	33	39

TABLE A-12. Effects of Level of Static Compaction on Results of Debonding Tests for Salt River Aggregate Treated with Portland Cement.

Test Method	I-C		D-P		S-C	
			Low Air Voids			
P.C. %	1.0	1.5	1.0	1.5	1.0	1.5
A.C. %	4.6	4.8	4.6	4.8	4.6	4.8
Density, pcf	145.5	147.0	146.5	146.0	144.5	145.5
Air Void, %	6.3	5.3	5.6	5.8	6.7	6.1
Saturation, %	68	64	79	87	111	111
Wet Strength, psi	408	421	156	122	79	122
Dry Strength, psi	494	560	171	165	148	146
Retained Strength, %	83	75	91	73	54	84
			Medium Air Voids			
P.C. %	1.0	1.5	1.0	1.5	1.0	1.5
A.C. %	4.6	4.8	4.6	4.8	4.6	4.8
Density, pcf	144.0	143.5	141.5	143.0	143.5	143.0
Air Void, %	7.0	7.6	8.7	7.9	7.5	7.8
Saturation, %	75	56	71	58	102	90
Wet Strength, psi	333	367	130	105	74	75
Dry Strength, psi	445	401	136	119	145	119
Retained Strength, %	75	91	96	88	51	63
			High Air Voids			
P.C. %	1.0	1.5	1.0	1.5	1.0	1.5
A.C. %	4.6	4.8	4.6	4.8	4.6	4.8
Density, pcf	140.0	140.0	139.5	141.0	140.0	140.0
Air Void, %	9.7	9.6	10.1	9.1	9.6	9.4
Saturation, %		40	147	69	93	76
Wet Strength, psi	305	275	99	107	50	59
Dry Strength, psi	399	380	119	131	98	99
Retained Strength, %	76	72	83	82	51	60

TABLE A-13. Effects of Level of Static Compaction on Results of Debonding Tests for Tanner Aggregate Treated with Portland Cement.

Test Method	I-C		D-P		S-C	
	Low Air Voids					
P.C. %	1.0	1.5	1.0	1.5	1.0	1.5
A.C. %	5.5	5.2	5.5	5.2	5.5	5.2
Density, pcf	139.0	139.5	138.5	139.0	139.5	140.0
Air Void, %	6.7	6.8	6.8	6.8	6.4	6.6
Saturation, %	98	100	103	119	170	169
Wet Strength, psi	211	312	86	94	34	67
Dry Strength, psi	427	560	115	133	147	49
Retained Strength, %	49	56	74	71	23	54
	Medium Air Voids					
P.C. %	1.0	1.5	1.0	1.5	1.0	1.5
A.C. %	5.5	5.2	5.5	5.2	5.5	5.2
Density, pcf	135.5	136.5	137.0	135.0	137.0	138.0
Air Void, %	8.9	8.6	7.9	9.5	7.9	7.8
Saturation, %	86	96	93	104	149	102
Wet Strength, psi	178	213	75	64	22	31
Dry Strength, psi	318	350	103	86	87	51
Retained Strength, %	56	61	73	74	25	54
	High Air Voids					
P.C. %	1.0	1.5	1.0	1.5	1.0	1.5
A.C. %	5.5	5.2	5.5	5.2	5.5	4.8
Density, pcf	133.5	134.0	134.0	134.0	134.0	136.0
Air Void, %	10.3	10.3	9.9	10.3	9.8	10.0
Saturation, %	75	90	71	97	127	120
Wet Strength, psi	141	189	76	70	21	38
Dry Strength, psi	306	367	114	102	105	44
Retained Strength, %	46	52	67	68	20	51

TABLE A-14. Analysis of Variance for Debonding Study "Wet Strength".

Source	df	SS	MS	F	Level of Significance	Significant
Test Method	2	334,985	167,493	98.85	100 %	Yes
Source of Material	2	47,735	23,868	13.37	99.99%	Yes
Treatment	5	43,901	8,780	4.92	99.83%	Yes
Source of Treatment	10	19,700	1,970	1.10	61.28%	No

Error	34	60,679	1,785			
Total	53	507,000				

SS (Model) = SS (test method) + SS (source) + SS (treatment) + SS (source by treatment) = 446,322

Ss (Total) = SS (model) + SS (error) = 507,000

$$R^2 = \frac{SS(model)}{SS(total)} = \frac{446,322}{507,000} = 0.88 \quad (0 < R^2 < 1)$$

Note: This means that about 88 percent of the variability of the wet strength results is explained by "Model" sources of variation, namely the test method, source of materials, treatment, and interaction between source and treatment. Only 12 percent was due to experimental error.

TABLE A-15. Analysis of Variance for Debonding Study "Retained Strength".

Source	df	SS	MS	F	Level of Significance	Significant
Test Method	2	15.4	7.69	11.57	99.98%	Yes
Source of Material	2	21.1	10.56	15.88	100 %	Yes
Treatment	5	18.4	3.67	5.52	99.92%	Yes
Source of Treatment	10	2.8	0.28	0.41	0.07%	No

Error	34	22.6	0.65			
Total	53	80.3				

$$R^2 = \frac{SS(Model)}{Ss(Total)} = \frac{57.65}{80.30} = 0.72$$

TABLE A-16. Effect of Compaction Methods on Results of Debonding Tests for Salt River Aggregate Treated with Portland Cement.

Compaction Method	Marshall				V.K.C.			
Test Method	D-P		S-C		D-P		S-C	
				Low Air Void				
P.C., %	1.0	1.5	1.0	1.5	1.0	1.5	1.0	1.5
A.C., %	4.6	4.8	4.6	4.8	4.6	4.8	4.6	4.8
Density, pcf	149.5	151.0	150.5	150.0	149.0	151.0	149.0	151.5
Air Void, %	3.6	2.7	3.0	3.3	3.8	2.8	3.7	2.4
Saturation, %	79	115	59	97	84	71	82	70
Wet Strength, psi	193	161	193	136	194	268	225	276
Dry Strength, psi	204	175	219	173	215	260	250	261
Retained Strength, %	95	92	88	79	90	103	90	106
				Medium Air Void				
P.C., %	1.0	1.5	1.0	1.5	1.0	1.5	1.0	1.5
A.C., %	4.6	4.8	4.6	4.8	4.6	4.8	4.6	4.8
Density, pcf	145.5	148.0	149.5	147.0	148.5	147.5	146.5	148.0
Air Void, %	6.2	4.5	3.6	5.2	4.3	4.9	5.4	4.7
Saturation, %	75	49	79	91	94	68	75	75
Wet Strength, psi	189	161	241	144	232	161	149	156
Dry Strength, psi	229	185	290	206	254	171	216	196
Retained Strength, %	83	87	83	70	91	94	69	80
				High Air Void				
P.C., %	1.0	1.5	1.0	1.5	1.0	1.5	1.0	1.5
A.C., %	4.6	4.8	4.6	4.8	4.6	4.8	4.6	4.8
Density, pcf	144.5	144.0	144.0	145.0	145.0	146.5	145.5	147.0
Air Void, %	6.8	7.3	7.0	6.5	6.3	5.6	6.1	5.1
Saturation, %	65	68	90	74	78	79	82	77
Wet Strength, psi	188	183	81	114	130	156	114	152
Dry Strength, psi	241	229	130	165	171	184	165	179
Retained Strength, %	78	80	62	69	76	85	69	85

TABLE A-17. Statistical Analysis of Variance vs. Retained Strength (Table 26).

Source	df	SS	MS	F	Level of Significance	Significant
Main Effects	4	2,540	635	9.81	99.9%	Yes
Compaction	1	104	104	1.61	77.1%	No
Treatment	1	10	10	0.165	30.8%	No
Air Voids	2	2,426	1,213	18.70	99.9%	Yes
2-Way Interactions	5	367	73	1.14	60.6%	No
Compaction-Treatment	1	104	104	1.61	77.1%	No
Compaction-Air Voids	2	217	109	1.68	77.3%	No
Treatment-Air Voids	2	46	23	0.35	29.0%	No
3-Way Interactions	2	23	11	0.174	15.8%	No
Compaction/ Treatment/Air Voids	2	23	11	0.174	15.8%	No
Error	12	777	65			
Total	23	3,707	161			

TABLE A-18. Statistical Analysis of Air Voids vs Retained Strength (Table 26).

Retained Strength for

High Air Voids	Medium Air Voids	Low Air Voids
Mean = 70.88	Mean = 83.12	Mean = 95.50
Standard Dev. = 8.31	Standard Dev. = 6.56	Standard Dev. = 8.43

Source	df	SS	MS	F(calculated)	$F_{0.05,2,21}$	Significant
Treatment	2	2,426	1,213	19.87	3.47	Yes
Error	21	1,282	61			
Total	23	3,707				

Since $F_{cal} > F_{tab}$: reject H_0 and accept H_1

$H_0 : \mu_1 = \mu_2 = \mu_3$

$H_1 : \mu_1 = \mu_2 = \mu_4$

Least Significant Difference (LSD) = $t_{\sigma/2,df} \frac{2MSE}{n}$

$$d = Y_i - Y_j$$

$$LSD(0.05) = t_{0.025,21} \sqrt{\frac{2MSE}{n}} = 2.08 \sqrt{\frac{2(61.04)}{8}} = 18.60$$

$$\left|\bar{Y}_1 - \bar{Y}_2\right| = \left|70.88-83.12\right| = 12.24 \langle \text{ LSD} = 18.60 \text{ .. Not Significant}$$

$$\left|\bar{Y}_1 - \bar{Y}_3\right| = \left|70.88-95.50\right| = 24.62 \rangle \text{ LSD} = 18.60 \text{ .. Significant}$$

$$\left|\bar{Y}_2 - \bar{Y}_3\right| = \left|83.12-95.50\right| = 12.38 \langle \text{ LSD} = 18.60 \text{ .. Not Significant}$$

$\bar{Y}_1$ (High)	$\bar{Y}_2$ (Medium)	$\bar{Y}_3$ (Low)
70.88	83.12	95.50

/——————————/——————————/

Not Significant   Not Significant

TABLE A-19. Results From Debonding Tests for Cores Taken at Various Ages, Holbrook Site.

UNTREATED

			I.C.				D.P.			S.C.		
Age (Months)	Air Voids %	VMA %	SW psi	SR H = 2-1/2 %	SR* H = 4" %	SAT %	SW psi	SR %	SAT %	SW psi	SR %	SAT %
Plant**	11.9	24.3	208	--	43	73	88	53	94	50	23	53
0.5	7.2	20.2	632	83	72	62	76	67	97	54	27	80
1.5	7.7	22.8	466	87	75	56	71	72	101	45	23	59
6.7	7.3	20.4	521	82	71	59	101	78	88	60	36	58
12.9	5.6	19.1	759	82	71	64	160	91	89	74	28	68
19.8	5.3	18.8	749	100	--	48	136	86	90	95	42	58

BA-2000

Plant**	12.9	25.1	315	--	42	105	135	75	106	72	32	77
0.5	7.6	20.6	772	86	74	74	123	100+	81	--	--	--
1.5	6.7	19.8	720	100+	--	63	122	99	78	95	38	66
6.7	7.5	20.4	565	80	69	69	118	100	88	94	63	70
12.9	6.8	19.9	950	93	--	44	165	88	100	120	47	71
19.8	6.0	19.2	789	99	--	46	141	90	96	128	57	72

PORTLAND CEMENT

Plant**	9.9	22.6	430	78	67	73	--	--	--	159	72	54
0.5	5.7	19.1	730	100+	--	61	137	100+	88	140	64	89
1.5	5.6	18.9	615	100+	--	63	124	100+	109	136	70	52
6.7	6.2	19.3	666	100+	--	68	125	100+	97	134	75	60
12.9	4.7	18.0	794	86	74	44	161	99	84	215	69	56
19.8	4.4	17.8	930	100+	--	34	138	83	101	155	57	92

* Corrected from H = 2-1/2" to H = 4" for SR within the range 65-77% of 4" high specimens.

** Plant mixture compacted by Marshall Method at 15-20 B/F.

TABLE A-20 ADOT RESULTS OF TESTING HOLBROOK CORES FOR TUNNICLIFF

No.	Age of Core Mos.	Density g/cc	AV %	Saturation Final, %	Wet Stgth psi	Dry Stgth psi	Sr %	
			Control - MTSG =2.610					
1.	0*	2.426	8.2	101.0	76.6	249.1	30.8	MTSG 2.642
2.	1st Day	2.412	7.6	—	—	100.2	—	
3.	1 Week	2.415	7.5	89.6	52.5	107.8	48.7	
4.	6 Month	2.428	7.0	78.8	54.6	100.4	54.4	
5.	12 Month	2.441	6.5	88.0	90.5	195.8	46.2	
6.	18 Month	2.430	6.9	83.7	77.0	184.9	41.6	
			+ BA 2000 - MTSG = 2.611					
1.	0*	2.432	8.0	98.7	116.6	275.6	42.3	MTSG 2.642
2.	1st Day	2.417	7.4	—	—	123.6	—	
3.	1 Week	2.432	6.9	92.3	84.2	125.4	67.1	
4.	6 Month	2.434	6.8	84.3	78.5	127.2	61.7	
5.	12 Month	2.453	6.0	84.1	151.0	204.4	73.9	
6.	18 Month	2.467	5.5	82.6	123.9	201.4	61.5	
			+ 1 1/2 % PC - MTSG =2.617					
1.	0*	2.402	8.1	97.9	135.9	226.7	59.9	MTSG 2.614
2.	1st Day	2.447	6.5	—	—	136.1	—	
3.	1 Week	2.452	6.3	87.6	133.4	145.6	91.6	
4.	6 Month	2.447	6.5	82.3	137.5	158.9	86.5	
5.	12 Month	2.486	5.0	86.3	177.7	207.3	85.7	
6.	18 Month	2.481	5.2	87.0	169.4	208.2	81.4	

Respondent's Name

*0 months refers to plant mixture prior to placement

(Plant mix values from Dick Root, Chicago Testing Laboratory)

APPENDIX B

LISTING OF FIGURES

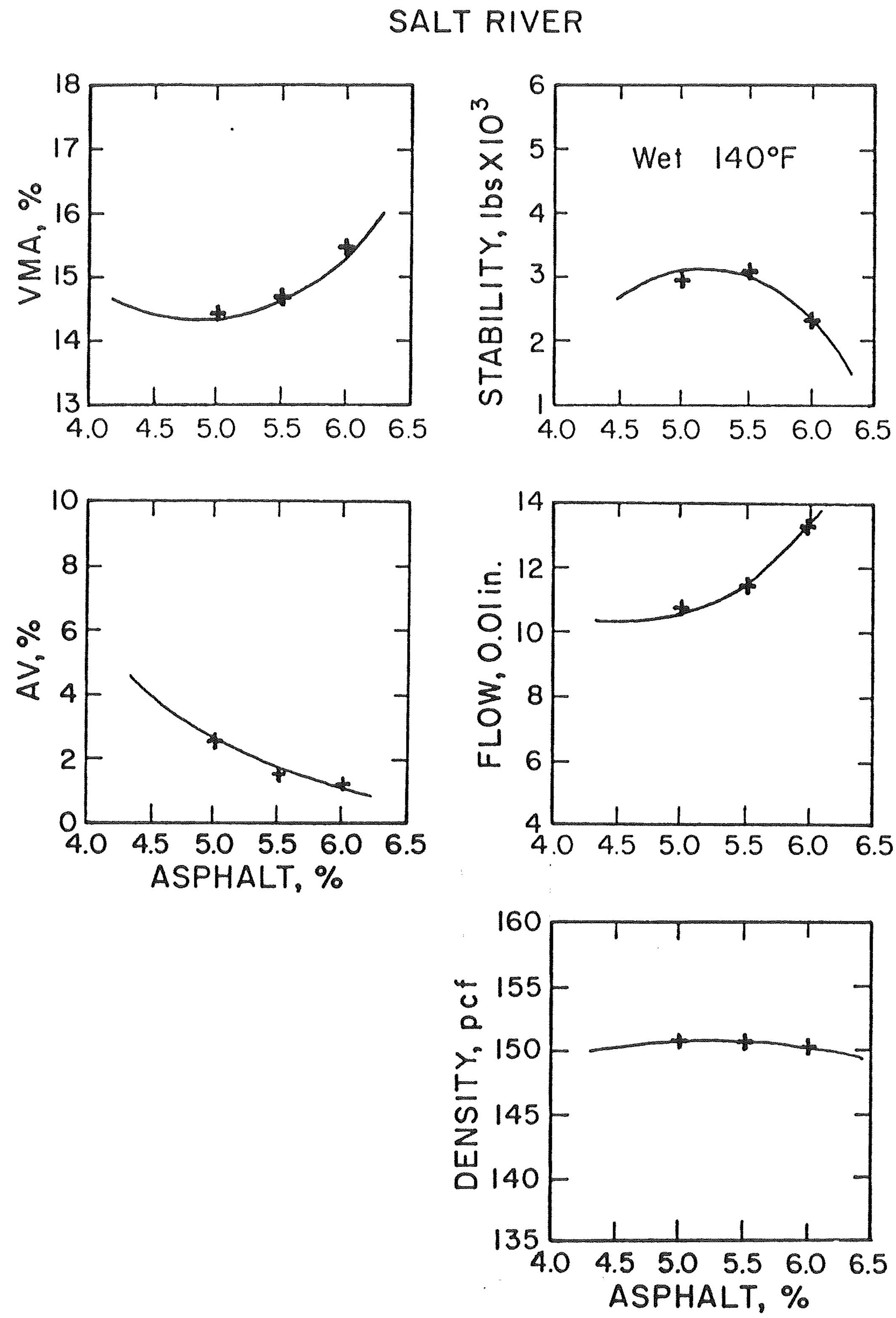

Figure B-1. Marshall Method Design Relationships for Salt River Aggregate

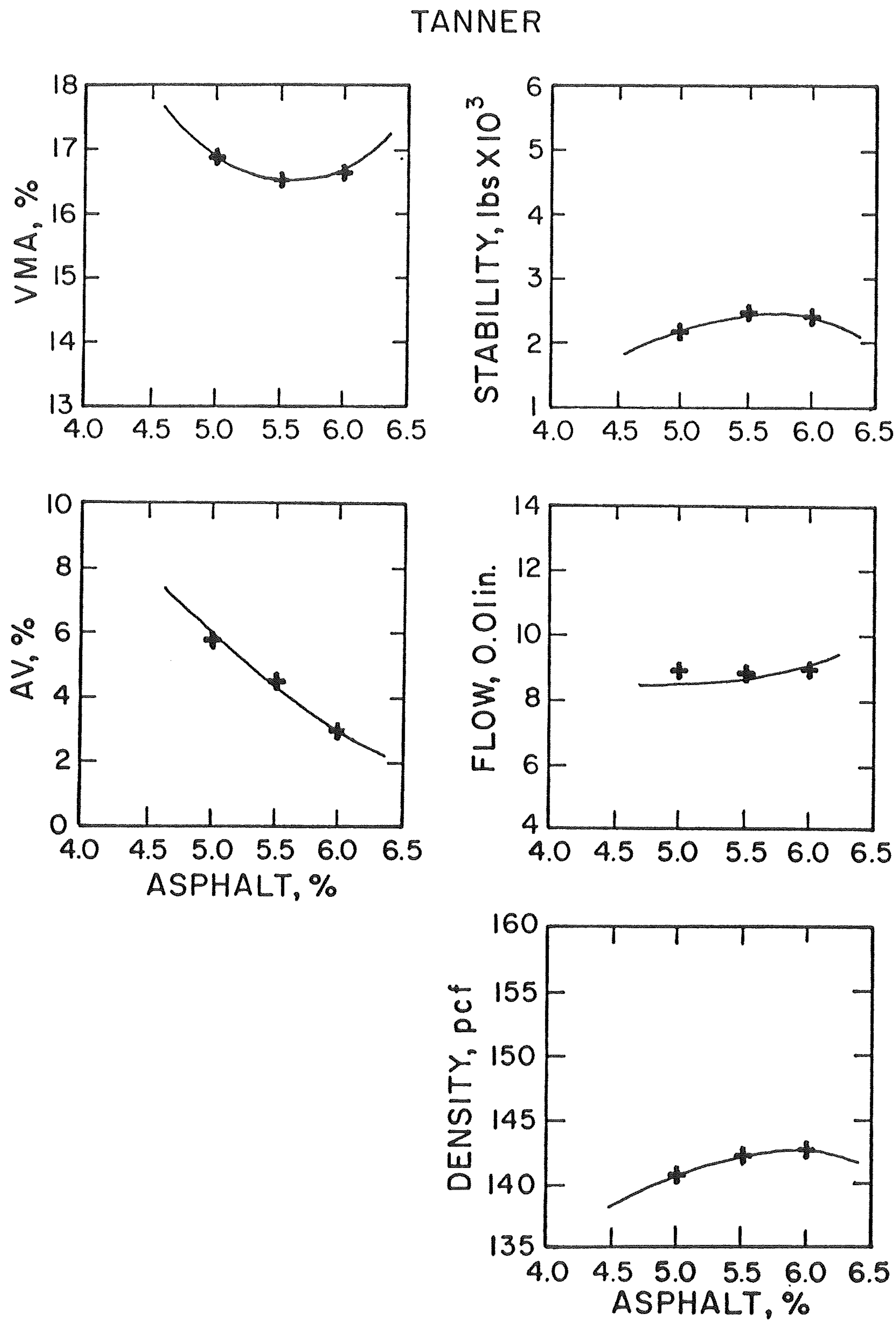

Figure B-2. Marshall Method Design Relationships for Tanner Aggregate

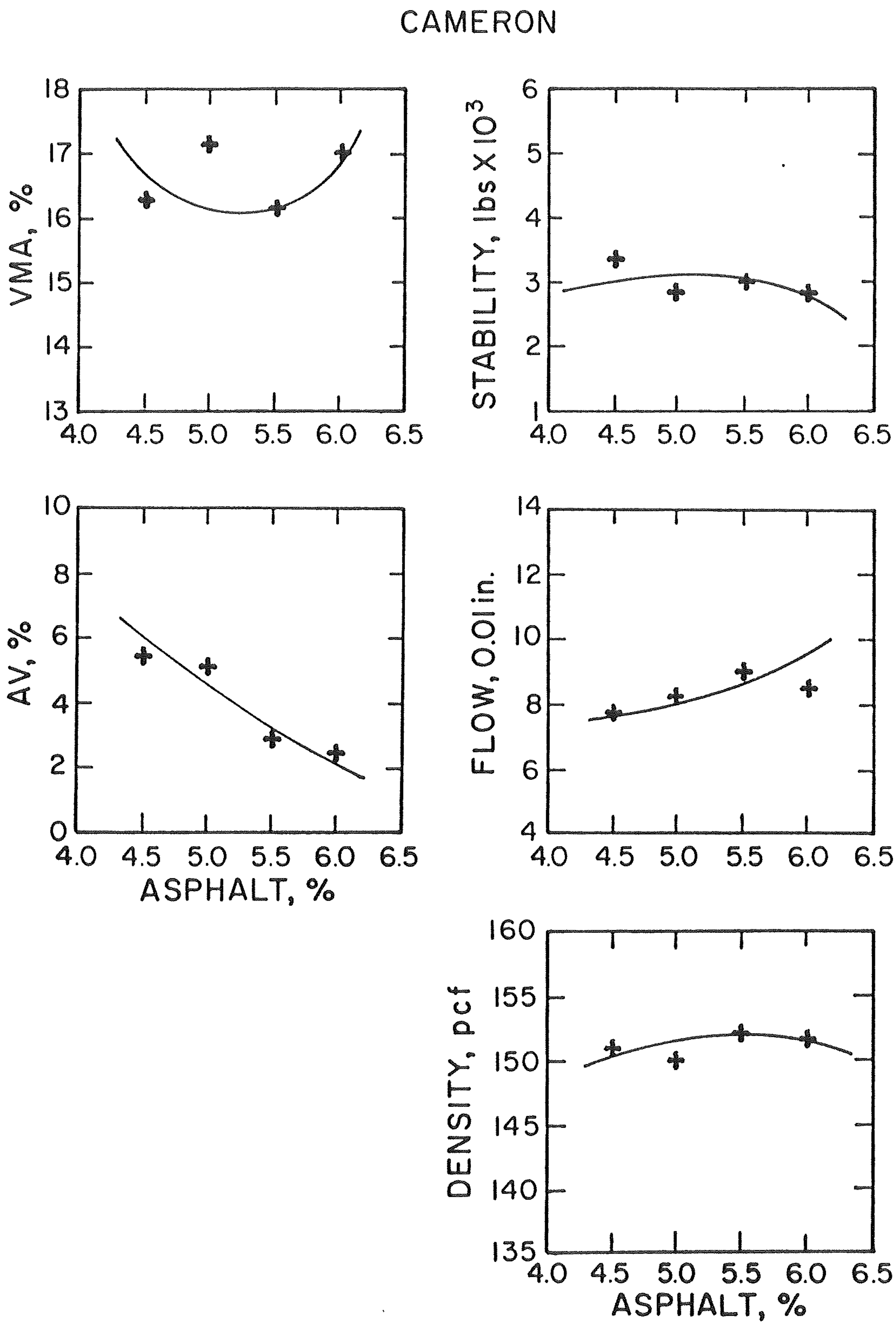

Figure B-3. Marshall Method Design Relationships for Cameron Aggregate