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Study of Rutting Resistance of Asphalt Mixes

Robert P. Elliott, Miller C. Ford, Jr., Sing Kuok Wong

Final Report

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Fayetteville, Arkansas 72701
Report No. UAF-AHTRC-92-001

In cooperation with

Arkansas State Highway and Transportation Department

Federal Highway Administration

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by

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Conducted by

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16. Abstract

The objective of this study was to investigate the effects of limiting the amount of natural sand on the relative rut resistance of Arkansas asphalt concrete mixes. Two mixes were tested with natural sand and with the natural sand replaced with a crushed stone sand. The mix gradations were also varied. In addition to the project job mix formula, each combination of aggregates was used in mixes with a standard fine gradation and a standard coarse gradation. All combinations were tested both in simple (static) creep and in a repeated load, dynamic permanent deformation test. The use of crushed stone sand in place of natural sand was shown to improve rut resistance and the dynamic test was found to be the better method for evaluating rutting potential.

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SI CONVERSION FACTORS

1 inch = 25.4 mm

1 foot = 0.305 m

1 pcf = 16 kg/m^2

1 psi = 6.9 kN/m^2

1 ksi = 6.9 MN/m^2

1 lb = 4.45 N

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CHAPTER 1
INTRODUCTION

1.1 PROBLEM AND OBJECTIVES

Rutting has long been recognized as a major failure mode in asphalt pavements. In the mid to late 1970's, mix design practices in Arkansas were modified in an attempt to alleviate a rutting problem being experienced at that time. Despite these changes severe, early rutting continued to occur on some Arkansas highways. Significant factors involved in this early rutting seems to be increased truck volumes, heavier truck loads, and perhaps most significantly, higher tire pressures.

The recent early rutting has occurred predominantly in the southern part of the state. This suggests that the asphalt mixes used in south Arkansas are less rut resistant than the mixes used elsewhere. The major difference in these mixes is the types of fine and coarse aggregate used. Aggregate type, therefore, may be a significant factor in the relative rut resistance of Arkansas mixes.

The fine aggregate is believed to be the more significant aggregate fraction. Because of this, AHTD adopted specifications that limit the use of natural sand to being no greater than 15 percent of the mix.

The primary objective of this study was to investigate the effects of limiting the amount of natural sand on the relative rut resistance of Arkansas asphalt concrete mixes. A secondary objective was to compare the simple creep test and a repeated, dynamic load permanent deformation test to determine which test provides the more realistic measure of rutting resistance.

1.2 STUDY PLAN

To meet these objectives, the original study plan called for testing mixes that used the five major types of Arkansas coarse aggregate and various percentages of natural sand. The mixes to be tested in the study were to be AHTD mixes from current construction projects. All mixes and mix variations were to be designed by AHTD. However, because of delays in identifying mixes and materials and because AHTD was not able to perform the mix designs as, the number of mixes was reduced to 2 with the provision that the project could be extended later to additional mixes. The study, however, was never extended.

As proposed, the selected mixes were to be tested with three levels of natural and manufactured sand - 1) the blend of natural and manufactured sand used in the AHTD job mix, 2) all natural sand and 3) all manufactured sand. Nevertheless, no testing was done with with a sand blend since neither of the mixes tested used a blend of natural and manufactured sand.

To isolate the effects of aggregate type from the effects of gradation, three mix designs were to be tested for each of the AHTD mixes. The first of these was the "normal" AHTD design in which the mix gradation was to be the natural gradation of the aggregates. The second and third mixes were to be "standard gradation" designs in which the aggregates were first to be screened and then recombined to standard gradations. A fine and a coarse standard gradation was selected with the same standard gradations to be used for all AHTD mixes.

Two types of tests were used to measure the relative rutting potential of each mix: 1) the simple creep test and 2) a repeated dynamic load, permanent deformation test. The simple creep test was used to provide data consistent with the Shell rut prediction scheme and consistent with the data from an earlier AHTD study (TRC 8801). The repeated load test was used in an attempt to establish a test approach that would more closely simulate "real world" rutting.

CHAPTER 2
LITERATURE REVIEW

Pavement rutting develops gradually as a combination of densification and shear deformation. The ruts that appear at the surface can be the result of rutting in any of the layers in the pavement system including the subgrade. This study was concerned only with the rutting that develops within the asphalt layers and, in particular, was concerned with the influence of the aggregate in the asphalt mix.

A literature review was made to identify the findings of previous research relative to the influence of aggregate on the rut resistance of asphalt mixes. This review reveals that the major aggregate parameters that relate to rutting are aggregate type, angularity, surface texture, gradation, amount of fines, and VMA.

2.1 INFLUENCE OF AGGREGATE PROPERTIES

Herrin and Goetz (1) studied the effects of aggregate angularity on asphalt concrete by varying the percentage (0, 55, and 100%) of crushed particles. They tested three types of mix gradation with a static triaxial test. The three mix gradations were: 1) one-sized with 0% fine aggregate (material passing the #4 sieve), 2) open-graded with 39.7% fine aggregate, and 3) dense-graded with 68% fine aggregate. The dense-graded and open-graded showed no gain in strength as the percentage of crushed particles increased. On the other hand, the strength of the one-sized gradation mix increased as the percent of crushed particles increased. The sieve analysis for Herrin and Goetz's research is shown in Table 1. The results of their testing is tabulated in Table 2.

Wedding and Gaynor (2) conducted a study on the effects of using crushed gravel as the coarse and fine aggregate in dense graded bituminous mixtures. All crushed particles had at least two crushed faces. The crushed fine aggregates was obtained by recrushing the finer material from the process of making crushed gravel. They found that, when the coarse aggregate was uncrushed, the replacement of natural sand with a crushed gravel sand provided a significant increase in stability; but, they found little change in the stability of mixes having 1005 of the coarse aggregates crushed. They also found that the substitution of natural sand by crushed sand is as effective as using 25 percent crushed coarse aggregates. When all the aggregates used in a mix were crushed particles, the stability was 45 percent greater than a similar mix that used all natural (uncrushed) aggregates.

In contradiction to the Wedding and Gaynor findings, Shklarsky and Liveneh (3) found that replacement of round coarse aggregates by crushed coarse aggregates had no significant impact on rutting potential of asphalt concrete. However, Shlarsky and Liveneh did find that the use of crushed sand reduced rutting potential.

Leech and Selves (4) compared rutting depth for three different aggregates - crushed limestone, crushed granite, crushed gravel, and uncrushed gravel. They found that rut depth was the lowest for the crushed granite and the highest for the uncrushed

Table 1. Sieve Analysis of Mixes by Herrin and Goetz.

Material	SIEVE ANALYSIS				
	Sieve		Percentage by Weight		
	Passing	Retain	Grading		
			Dense	Open	One-Sided
Coarse - Aggregate		3/4"	0	0	0
	3/4"	1/2"	7.0	17.5	29.2
	1/2"	3/8"	9.0	21.4	35.4
	3/8"	#4	16.0	21.4	35.4
Fine - Aggregate	#4	#6	7.0	2.9	0
	#6	#8	6.0	1.7	0
	#8	#16	10.0	10.5	0
	#16	#50	19.0	20.7	0
	#50	#100	9.5	3.6	0
	#100	#200	10.0	0.3	0
Cement	#200		6.5	0	0

Table 2. Test Results Obtained by Herrin and Goetz (1).

RESULTS FOR DENSE-GRADED MIXTURES

Fine Aggregate	Coarse Aggregate	Average Density	Av. Comp. Strength Ph = 15 psi.	Av. Comp. Strength Ph = 45 psi.	Angle of internal friction	Cohesion
		pcf.	*psi.*	*psi.*	*deg.*	*psi.*
Natural Sand	0% Cr. Gvl.	147.0	202.6	300.3	32.0	42.6
	55% Cr. Gvl.	147.3	216.6	317.7	32.8	45.2
	70% Cr. Gvl.	148.1	209.7	311.9	33.1	43.0
	100% Cr. Gvl.	145.3	205.5	306.3	32.8	42.3
	Crushed Stone	147.3	227.3	328.1	32.8	48.3
Crushed Stone	0% Cr. Gvl.	149.6	349.9	446.8	31.8	83.9
	55% Cr. Gvl.	148.9	354.7	452.8	32.8	84.5
	70% Cr. Gvl.	148.8	347.3	450.0	33.2	80.0
	100% Cr. Gvl.	146.7	349.4	447.6	32.2	83.0
	Crushed Stone	148.9	380.0	458.9	26.7	105.0

RESULTS FOR OPEN-GRADED MIXTURES

Fine Aggregate	Coarse Aggregate	Average Density	Av. Comp. Strength Ph = 15 psi.	Av. Comp. Strength Ph = 30 psi.	Angle of Internal Friction	Cohesion
		pcf.	*psi.*	*psi.*	*deg.*	*psi.*
Natural Sand	0% Cr. Gvl.	142.2	116.1	177.6	37.4	13.5
	55% Cr. Gvl.	140.8	127.4	189.5	37.7	16.0
	70% Cr. Gvl.	139.3	132.8	196.4	38.2	16.8
	100% Cr. Gvl.	140.3	132.1	197.1	38.7	16.1
	Crushed Stone	141.3	152.4	215.8	38.1	21.6
Crushed Stone	0% Cr. Gvl.	145.2	198.8	247.3	31.9	41.8
	55% Cr. Gvl.	145.4	211.8	261.6	32.5	44.5
	70% Cr. Gvl.	145.0	213.7	259.5	30.5	48.1
	100% Cr. Gvl.	145.7	215.5	265.3	32.5	45.5
	Crushed Stone	147.3	288.6	315.0	16.0	98.8

RESULTS FOR ONE-SIZE MIXTURES

Coarse Aggregate	Average Density	Av. Comp. Strength Ph = 15 psi.	Av. Comp. Strength Ph = 30 psi.	Angle of Internal Friction	Cohesion
	pcf.	*psi.*	*psi.*	*deg.*	*deg.*
0% Cr. Gvl.	113.6	39.1	74.3	23.7	1.3
55% Cr. Gvl.	110.5	49.3	90.5	27.8	2.4
70% Cr. Gvl.	110.6	51.3	97.2	30.5	1.5
100% Cr. Gvl.	110.1	58.7	108.7	32.6	2.4
Ar. Gr. (10,000 rev.)	115.5	49.9	77.6	17.3	7.8
Ar. Gr. (5,000 rev.)	113.7	54.8	90.0	23.7	6.4
Crushed Stone	114.6	70.8	118.2	31.3	6.6

gravel case. Rut depth was found to be linearly related to the initial VMA with the slope of the relationship relatively constant.

Hicks, Allbright, and Lundy (5) investigated the effect of increasing the crushed aggregate percentage on permanent deformation behavior. They found that an increase in percent crushed from 50% to 70% resulted in a decrease in the permanent deformation rate of 45 to 70%. A further increase from 70 to 90% resulted in a decrease of only 15 to 30%. Hicks, Allbright, and Lundy also studied the effect of the fines content (percent passing the #200 sieve) on permanent deformation. This effect was found to be more pronounced with lower percentages of crushed coarse aggregate. For 90% and 70% crushed, an increase in fines content from 3 to 6% resulted in a 45 to 65% increase in the permanent strain rate. However, when the percentage of crushed aggregate was reduced to 50%, the same increase in fines content resulted in 100 to 200% increase in the permanent strain. This suggests that mixes having a low crushed aggregate percentage is much more sensitive to changes in the fines content than are mixes with high crushed particle percentages.

Kalcheff and Tunnicliff (6) investigated the effect of aggregate shape, gradation, and filler content on rut resistance. They found that mixes composed of manufactured sand is more rut resistant than are mixes composed on natural sands. With the manufactured sands, filler content did not significantly effect rutting resistance while it was quite significant with natural sands. The manufactured sand mixes were also found to be less sensitive to the effect of changes in the quantity of coarse aggregate.

In summary, most researchers have concluded that the use of crushed aggregates improves the rut resistance of asphalt concrete. Rut resistance of asphalt concrete increases primarily due to the increase in internal friction as crushed aggregate is substituted for the natural aggregate. However, the degree to which the crushed aggregate affects the rut resistance of asphalt concrete remains unclear.

2.2 EFFECT OF AGGREGATE GRADATION

Researchers (7,8,9,10,11) have generally concluded that a coarse gradation of aggregate provides greater rut resistance than a fine gradation. This is especially true for a fine gradation with a hump in the gradation curve around the #30 or #40 sieve. Goode and Lufsey (7) tested a band of mix gradations as shown in Figure 1. They found that the gradations that show a higher hump at the #30 sieve (above the theoretical maximum density line) will have higher voids in the mineral aggregates (VMA) and lower Marshall stabilities than those mixes which have a lower hump at sieve #30. Deformation of asphalt concrete has been found to be very sensitive to amount of VMA. Deformation increases as the VMA increase.

Carpenter and Enockson (8) also found that a fine gradation mix with a hump in the gradation curve in the vicinity of #40 sieve will produce asphalt concrete having low Marshall stabilities and

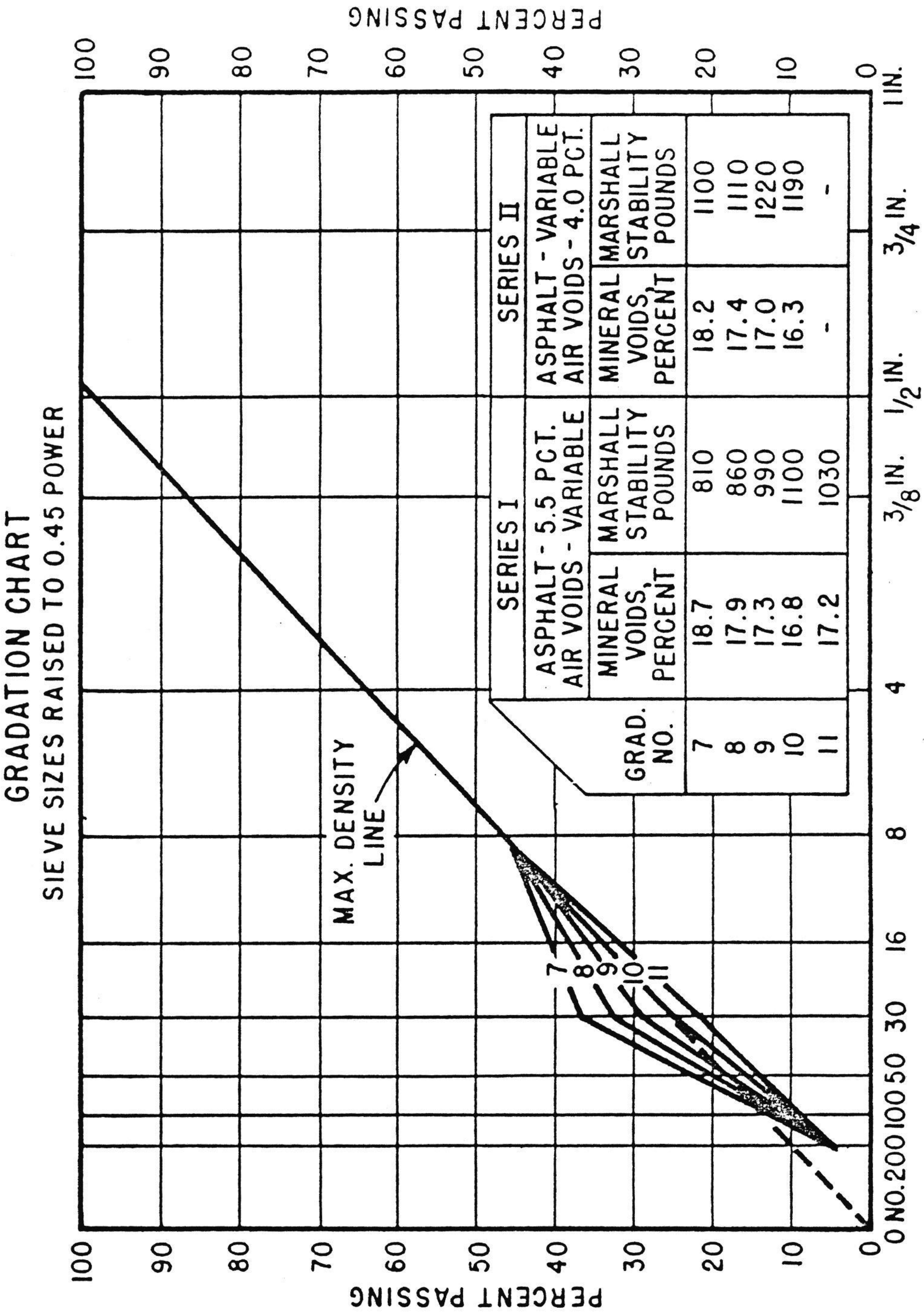


Figure 1. Gradation of Mixes Tested by Goode and Lufsey (7).

low VMA. They said that a hump in the vicinity of sieve #40 is a predominate factor affecting rutting. This indicates that the gradation of the sand fraction is the primary gradation factor contributing to rutting in asphalt mixes.

Ford (9) made a extensive study of the parameters governing rutting on Arkansas highways. Characteristics of cores were studied in detail. The cores were taken from 24 sites, all of high-type asphalt concrete that ranged in age from 3 to 22 years. A regression equation was established for the relationships between rut depth, air voids, Marshall Stability, and hump at # 40 sieve. The resulting equation was:

$$RUT = -73.8 + 0.937\ VF + 0.582\ D40 + 2.33\ BAV - 0.0236\ STAB$$

where

RUT = rut depth, 1/32 in;

VF = Voids filled (percent);

D40 = hump in grading curve (percent);

BAV = Air voids between wheelpath (percent);

STAB = Marshall stability.

However, Ford suggested that additional factors such as traffic speed, traffic character, environmental conditions, and support from the underlying pavement structure and subgrade are required to predict a rut more accurately.

Brown, Cooper and Pooley (10) conducted a study relative to mix gradations. They discovered that to maximize deformation resistance for a particular type of asphalt concrete, it was necessary to minimize VMA. to achieve low VMA, higher amounts of filler materials were required; but as the filler materials increase, the amount of binder also must increase to coat the mix completely. An increase in binder content will result in greater deformation. They argued that the equivalent fines content should be 80 to 90 percent of that required for minimum VMA to ensure that the final mix is not susceptible to overcompaction in the field. They sated that the minimum VMA mix gradation requires that 20 to 30 percent of the aggregate passing through a size that is 0.03 times the maximum particle size.

McLeod (11) tested a band of mix gradations (Figure 2) to study how gradation and asphlat content variation affected the mix properties of asphalt concrete. The gradation band was the upper (coarse mix) and lower limits (fine mix) of the ASTM specifications for gradation (Table 3). He made five mix gradations from the band namely job mix formula, lower, upper, lower-upper, and upper-lower. He compacted the specimens with standard Marshall Design method at asphalt content of 5.15%, 5.65% and 6.15% for each mix gradation. The results (Table 4) obtained from his research showed that upper-lower mixes had higher values of air voids and VMA. The job mix formula had the highest stability values. The result also indicated that upper-lower mixes showed higher stiffness modulus (stability/flow) values and that lower-upper mixes had higher flow values. It is believed that higher stiffness modulus in Marshall test and higher VMA would mean that the asphalt concrete is more

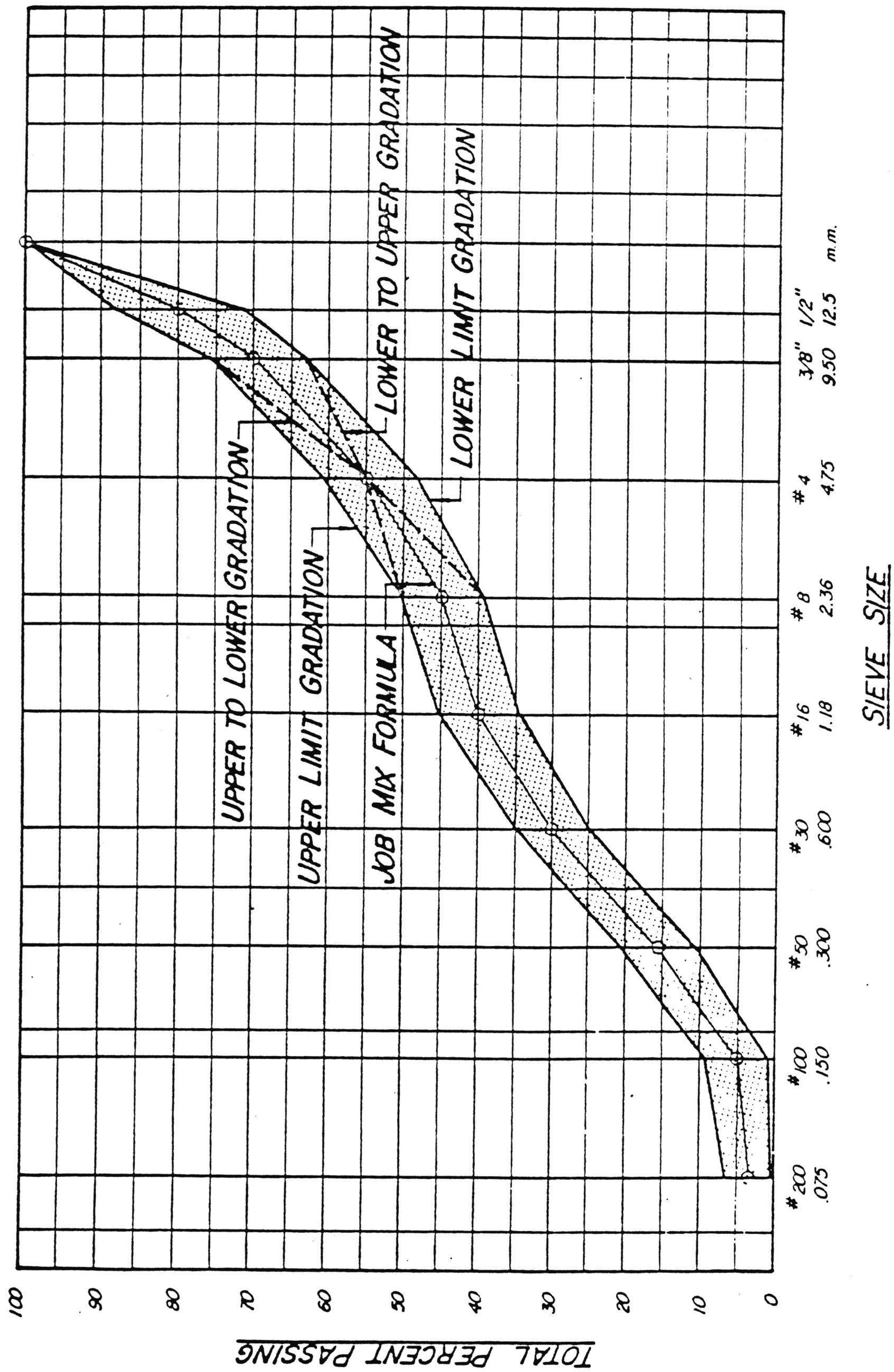


Figure 2. Gradation Variations Tested by McLeod (11).

Table 3. ASTM Tolerances Used in Study by McLeod (11).

Sieve Size Fraction	Tolerance, Aggregate Weight Basis
Greater than 1/2"	+/- 8%
3/8" to #4	+/- 7%
#8 to #16	+/- 6%
#30 to #50	+/- 5%
Passing #200	+/- 3%
Asphalt Content, Total Mix Weight Basis	+/- 0.5%

Table 4. Effect of Mixture Variation on Mix Properties in Tests by McLeod (11).

Test \ Gradation	Job-Mix Formula			Lower ‡			Upper ‡			Lower - Upper ‡			Upper - Lower ‡		
Asphalt Content % (total mix)	5.15	5.65	6.15	5.15	5.65	6.15	5.15	5.65	6.15	5.15	5.65	6.15	5.15	5.65	6.15
* Air Voids %	3.5	2.9	2.5	5.2	3.9	2.6	3.5	2.6	1.8	3.3	2.6	2.5	5.1	4.0	3.0
**VMA %	13.3	13.9	14.7	14.7	14.8	14.8	13.6	14.0	14.4	13.2	13.7	14.8	15.0	15.2	15.4
Bulk Spec. Grav.	2.420	2.416	2.408	2.379	2.389	2.401	2.416	2.417	2.418	2.425	2.424	2.406	2.373	2.381	2.389
100% Lab. Density lb/ft^3	151.1	150.8	150.3	148.5	149.1	149.9	150.8	150.9	150.9	151.4	151.3	150.2	148.1	148.6	149.1
Theor. Max. Spec. Gr.	2.509	2.489	2.468	2.509	2.487	2.466	2.503	2.483	2.462	2.507	2.489	2.468	2.501	2.481	2.464
Marshall Stability lb at 140°F	2690	2183	1853	1811	1652	1896	2367	2047	1567	2382	2025	1305	1987	1845	2407
Flow Index (units of 0.01 inch)	10.8	10.3	12.8	8.8	9.3	10.3	9.3	12.0	17.0	10.3	12.5	16.5	8.6	8.7	11.3
***Stiffness Modulus at 140°F, psi	9963	8478	5791	8232	7105	7363	10181	6823	3687	9250	6480	3164	9242	8483	8520
Ave. Aggregate Spec. Gr.	2.648	2.648	2.648	2.645	2.645	2.645	2.651	2.651	2.651	2.651	2.651	2.651	2.649	2.649	2.649
% Asphalt Absorption (wt. of aggregate)	1.1	1.1	1.1	1.2	1.1	1.1	0.99	0.97	0.94	1.1	1.1	1.1	0.84	0.96	0.99
Filler/Bitumen Ratio by weight	0.66	0.60	0.55	0.11	0.10	0.092	1.22	1.10	1.01	1.22	1.10	1.01	0.11	0.10	0.092

* % Air voids derived from ratio of bulk specific gravity to theoretical maximum specific gravity.
** % VMA based on the aggregate's ASTM bulk specific gravity.
*** Calculated from - Modulus of stiffness = $\frac{40 \text{ Marshall Stability}}{\text{Flow Index}}$

NOTE - Compaction by 75 blows on each face by Marshall double compactor.

rut resistant (7). Thus, job mix formula and upper-lower mix would be the most likely candidates to produce better rut resistant asphalt concrete.

Barksdale (12) studied the effect of gradation variation on asphalt concrete by testing the specimens with simple creep test. He compared two mix gradations, fine and coarse, whose gradations are shown in Table 5. The specimens used in the test were four inches in diameter by eight inches in height and were compacted with 50 blows of a Marshall hammer. The test was conducted at 95 F with an axial stress of 15 psi, and with no confining pressure. From the research, Barksdale found that the fine gradation mix exhibited about 33 percent more deformation than did the coarse gradation mix.

Elliott and Herrin (13) studied the effect of gradation variations on split tensile and creep behavior of asphalt concrete. Three mix gradations, Job Mix Formula, Coarse gradation, and Fine gradation were tested. The gradations of the three mixes are shown in Table 6. Unlike other research, however, Elliott and Herrin did not find any significant relationship between gradation variations and creep behavior.

In summary, all size fractions appear to have some influence on the rutting potential of an asphalt mix. Gradation and angularity have been shown to be important parameters in virtually all studies. Of particular interest is the finding of some investigators that the significance of both the coarse aggregate and filler fractions diminish as the angularity of the sand

Table 5. Fine and Coarse Gradations used in Barksdale' Research.

Sieve Size	Percent Passing Fine	Coarse
1"	100	65
1/2"	77	40
3/8"	70	36
#4	55	30
#16	37	20
#50	25	12
#200	14	5

Table 6. Example of Gradation Variation Used by Elliott and Herrin (13).

Sieve Size Fraction	Percent Pass-Retain, Total Weight Basis Job Mix Formula	Coarse Gradation	Fine Gradation
1/2" to #4	38.2	43.9	32.5
#4 to #10	21.5	25.3	17.7
#10 to #40	12.0	10.6	14.7
#40 to #80	11.0	6.8	14.2
#80 to #200	5.9	3.9	7.8
passing #200	5.7	3.8	7.6

fraction increase. This suggests that a desired level of rut resistance might be achieved by controlling either the coarse or the sand fraction and that control of the filler fraction can be critical with some combinations.

2.3 SIMPLE CREEP VERSUS REPEATED LOAD TESTING

Several researchers (15,16,17,18) have compared the behavior of asphalt concrete in the simple creep and repeated dynamic load tests. Leahy (14) documented Snaith's (15) research in her dissertation. Snaith used the same vertical stress and temperature for both the simple creep and the dynamic load tests. At low stress levels, she found the magnitude of permanent deformation for the two tests to be very close at equal total times of load duration. However, for total load duration times at higher stress levels, the static stress had to be reduced to about 65 percent of the dynamic value for the deformations to be equal. Leahy also documented Barksdale's research (16) which compared the strain of asphalt concrete obtained by simple creep and dynamic load tests. Barksdale suggested that the deformations predicted by the dynamic load test were more conservative than the results obtained from the static test.

Brown and Snaith (17) claimed that the permanent strain, which gradually accumulates under repeated loading is essentially a creep phenomenon. They concluded that the total time of load duration, rather than the number of load applications, is the parameter controlling the amount of permanent strain. Their results also indicate that frequency of loading between 1 and 10 cycles per second (equivalent to 3.75 and 40 mph) does not affect the relationship between permanent strain and time. The variation of resting time between loading periods was also investigated. Brown and Snaith concluded that the amount of time between loads does not affect the basic permanent strain versus time relationship.

This conflicts, however, with conclusions drawn by P.J. Van de Loo (18). In his research, Van de Loo ran simple creep and dynamic load tests on both pure asphalt cement and dry aggregates. He found that when dry aggreagtes are loaded the strain increases only at the beginning of the load applications; strain does not increase while the load is applied. Van De Loo, therefore, concluded that the deformations on the aggregate fraction of an asphalt mix are independent of loading time, but are strongly dependent on the number of load repetitions. This "dynamic" effect is believed to be the result of slippage or reorientation of aggregate particles.

Asphalt strain, on the otherhand, is very time dependent due to its visco-elastic nature and is not influenced by numbers of repetitions. This suggests that the simple creep test focuses primarily on the rut resistance of the asphalt fraction of the mix and provides little if any information on the contribution of the aggregate fraction.

In the same research, Van de Loo compared the simple creep with Amsterdam Laboratory Test Track (LTT) and Tracking Machine. He ranked the mixes according to stiffness of asphalt concrete to compare the tests. The tests were conducted at 20 C and with no confining pressure exerted. The stress applied was 0.2 MN/m^2 (29 psi). The composition of mixes is shown in Table 7.

The rankings of the mixes by comparing simple creep with LTT and simple creep with Track Machine are shown in Figure 3. It is obvious from the figure that the rankings of different mixes according to simple creep are not consistent with the rankings from the test track (LTT). However, rankings for variation of a single mix by simple creep are consistent.

Based on Van de Loo's work, the simple creep test appears to be a useful test for the comparison of rutting resistance between mixes containing different amounts or grades of asphalt if the aggregates were nearly identical. However, it does not appear to be a good test for comparisons between mixes containing different aggregates or gradations.

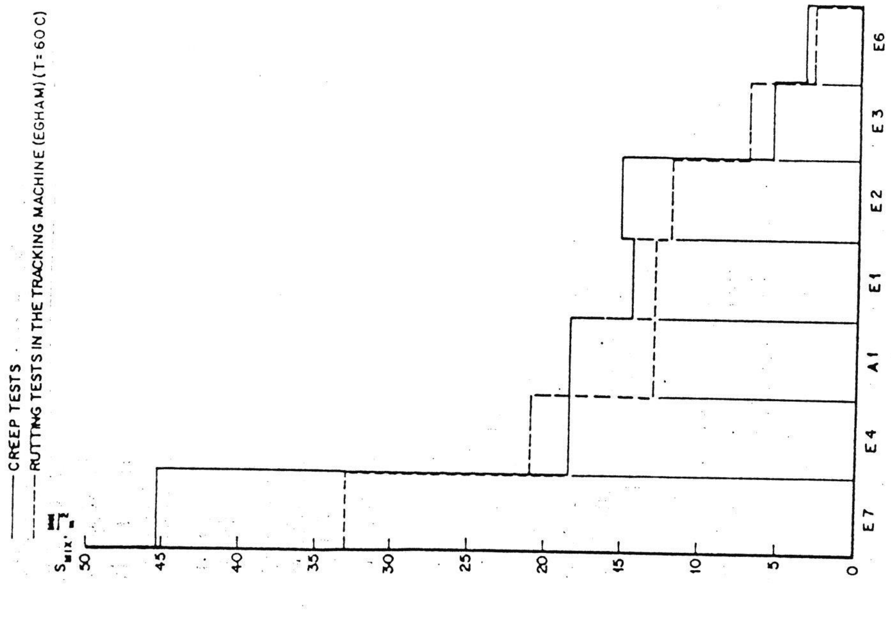
Monismith and Tayebali (19) made a thorough investigation comparing the behavior of asphalt concrete in creep and dynamic loading. Specimens of four-inches diameter by eight-inches high were prepared by kneading compaction. The average air void content for the specimens was eight percent. The loading time for the creep test was at least one hour unless the specimens failed sooner. Dynamic loading as applied pneumatically with a load duration of 0.1 second and a period of two seconds. All the tests were carried out at 100 F with at least two specimens tested at each test condition. The test conditions were:

Table 7. Data for Mixes Tested by Van de Loo (18).

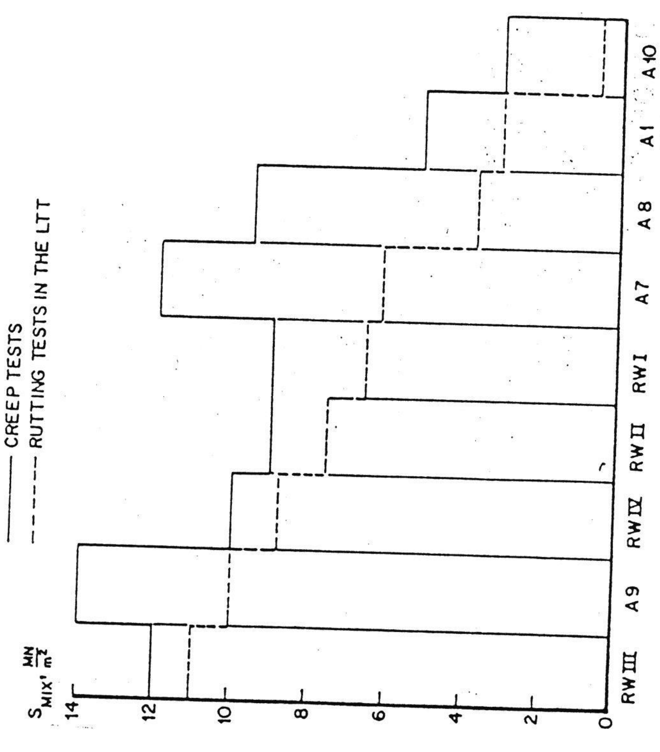
Column	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Mix No.	HM 1	HM 2	HM 3	HM 4	RW I	RW II	RW III	RW IV	A 1*	A6/A9**	A7/A8***
Description	Gravel Sand Asphalt	Gravel Sand Asphalt	Gravel Sand Asphalt	Gravel Sand Asphalt	Gravel Sand Asphalt	Gravel Sand Asphalt	Gravel Sand Asphalt	Gravel Sand Asphalt	Asphaltic Concrete	Sand Sheet Crushed Sand	Sand Sheet Round Sand
Bitumen content, pha****	5.0	4.6	4.1	5.5	5.3	5.2	5.1	6.0	6.0	7.0	6.9
Grade	50/60	50/60	50/60	50/60	50/60	50/60	50/60	50/60	various grades	40/50	40/50
Penetration at 25 °C, 0.1 mm	32	32	32	32	37	39	38	39		35	35
Softening Point, °C	56	56	56	56	60.5	59	61	58.5		63	59
Stone content, %wt	56.8	58.8	65	50.6	49	53.6	54.3	46.4	55	–	–
Sand content, %wt	37.3	36	29.9	44.5	42.9	37.8	37.9	45.5	35	82.4	83.1
Filler content, %wt	5.9	5.2	5.1	4.9	8.1	8.6	7.8	8.1	10	17.6	16.9
VIM, %v	3.8	3.8	4.4	4.0	4.4	5.0	6.4	–	–	10	4.4
VMA, %v	–	–	–	–	16.1	16.2	17.5	–	–	23.8	19.1
VFB, %v	–	–	–	–	72.4	69.4	63.1	–	–	58	76.8
C_v	–	–	–	–	88	88	88	88	86	85	84.6

Column	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Mix No.	A10	E1	E2	E3	E4	E6	E7	KW 146
Description	Sand Sheet Round Sand	Hot Rolled Asphalt (BS 594)	Gussasphalt (Stable)	Gussasphalt (Unstable)	Asphaltic Concrete (French)	Sand Sheet (Rich) Round Sand	Sand Sheet (Lean) Crushed	Asphaltic Concrete
Bitumen content, pha	9.0	8.6	8.7	9.0	5.5	11.7	5	9.9
Grade	40/50	40/50	40/50	40/50	40/50	40/50	40/50	80/100
Penetration at 25 °C, 0.1 mm	39	28	19	29	23	35	34	73
Softening Point, °C	58	64	64	64	62	58	58	49
Stone content, %wt	–	32.6	41	31.5	50	–	–	65.7
Sand content, %wt	83	57.7	33	45	50	81.5	81.5	27.5
Filler content, %wt	17	9.7	26	23.5	–	18.5	18.5	6.8
VIM, %v	5	4.2 to 6.6	1.5	0.7	8.0	6.6 to 8.7	18.0 to 18.9	3.7
VMA, %v	23	21.8 to 23.7	17.4	17.2	19.8(est.)	28.9 to 30.6	27.4 to 28.2	23.0
VFB, %v	78	80.7 to 72.1	91.4	95.9	59.5	77.2 to 71.5	34.7 to 32.9	83.9
C_v	85	80	84	83	87	72	88	80

* This mix was used as a reference mix in each test run in the LTT. Different grades have been applied, too.
** A6 and A9 had the same composition, but different compaction (as a slab and in the LTT, resp.)
*** A7 and A8 had the same composition. A7 was aged in the LTT by static compaction.
**** pha = parts by weight per hundred parts by weight of aggregate.



Ranking of Asphalt Mixes in Terms of the Stiffness of the Mix Derived from Creep Tests and Rutting Tests in the Tracking Machine (Egham) at Values of $S_{bit} = S_{bit, visc} = 10^4$ N/m.^{2}.



Ranking of Asphalt Mixes in Terms of the Stiffness of the Mix Derived from Creep Tests and Rutting Tests in the LTT at Values of $S_{bit} = S_{bit, visc} = 10^3$ N/m.^{2} (for Description of Mixes, See Table I).

Figure 3. Ranking of Mixes Tested by Van de Loo (18).

Confining Pressure (PSI)	Creep Stress (PSI)	Dynamic Stress (PSI)
0	20	15,20
15,30	30	30

From the research, it was found that the creep test produces greater strain at the beginning of the test but that as the testing progressed (say one hour for creep test or 36,000 repetitions for dynamic load test), the unconfined repeated load test produced substantially greater strains. The difference in strain measured by simple creep and dynamic load tests after one hour of loading decreased as the confining pressure increased. Note that Van de Loo's particle reorientation theory agrees with the observed effect of increased in confining pressure. As the confining pressure increases, it is harder for the aggregates to reorientate themselves. Since it is harder for the aggregates to reorientate themselves, less deformation occurs.

Monismith and Tayebali (19) found that although the magnitudes of deformation differed, the two unconfined testing modes (creep and dynamic) ranked the mixes tested in the same order. In another word, specimens which produce the largest deformations in creep at longer times of loading will also show the largest deformations in dynamic loading at the numbers of repetitions which produce comparable times of loading.

The general conclusion found by most of the researchers is that the dynamic repeated load test produces more deformation in asphalt concrete than does the simple creep test. The dynamic test also is believed to produce more consistent results. However, no solid evidence has been established to demonstrate which method of testing is superior.

CHAPTER 3
TESTING PROGRAM

3.1 MIXES TESTED

The two mixes tested in this study are surface mixes used on: 1) Route I-40 near Forest City and 2) Route US 63 near Jonesboro. The mixes are referred to hereafter as the Forrest City mix and the Jonesboro mix. Both mixes contained natural sand for the sand fractions and have had field performance problems. The Forrest City mix has exhibited excessive early rutting. The Jonesboro mix was extremely prone to segregation.

To examine the effect of sand type, the mixes were tested both with the natural sand and with the natural sand replaced by a crushed, manufactured sand. The mix gradations were also varied to isolate the effect of gradation from the effect of sand type. The project plan called for testing each mix using three gradation variations. One variation was to be the Job Mix Formula (JMF) gradation. The other two were to be "standard" gradations selected to represent the extremes of fine and coarse mixes commonly used.

Figure 4 is a plot of the "standard" gradations selected. The FINE gradation represents a typical, fine surface mix while the COARSE gradation represents the coarse surface gradation some state highway departments are using as a solution to the rutting problem.

The JMF gradations for the Forrest City and Jonesboro mixes are plotted on Figures 5 and 6 respectively. For comparison, the "standard" gradations are shown on these figures as dashed lines. Note that the Forrest City JMF gradation is very close to the

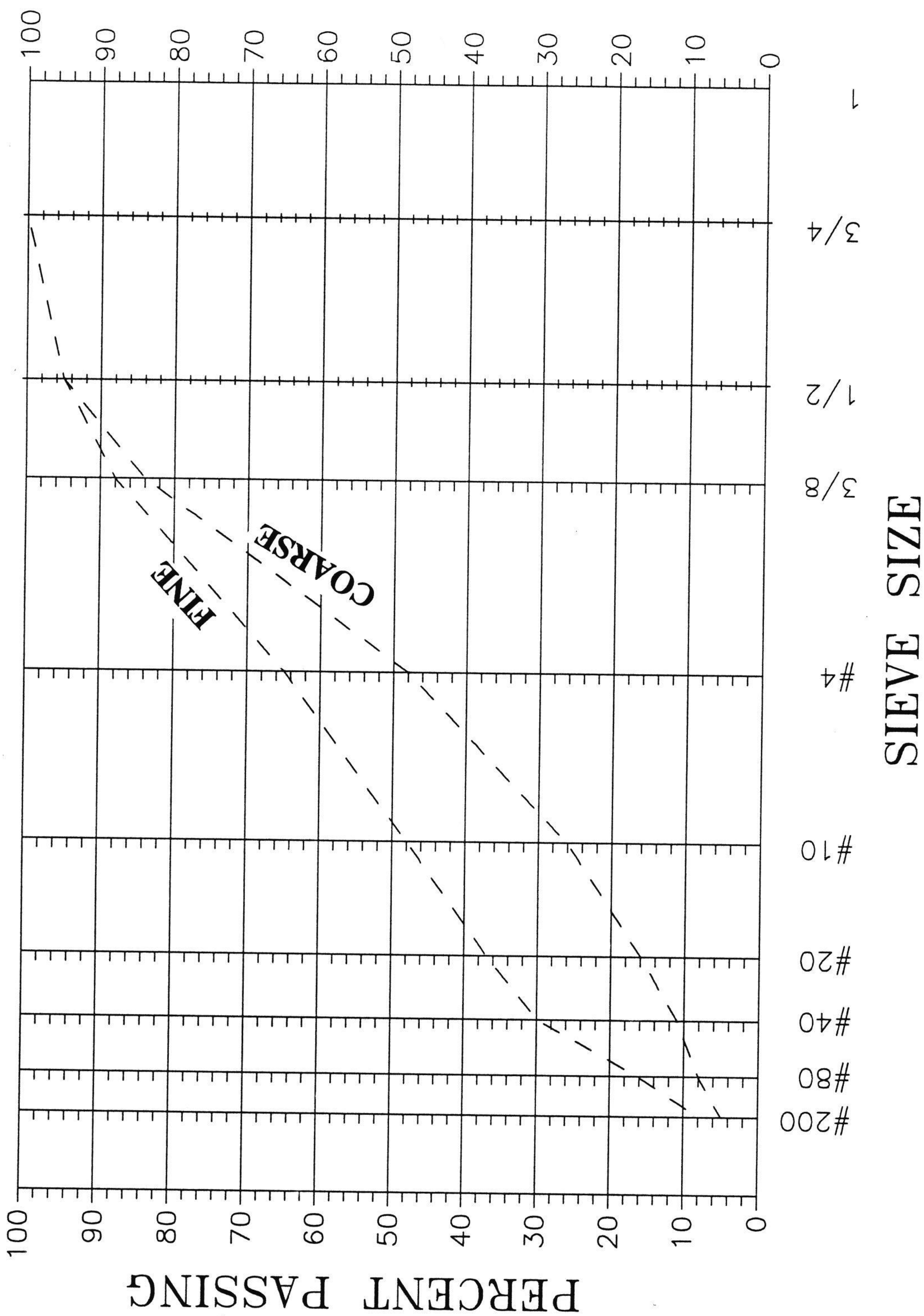


Figure 4. Standard FINE and COARSE Gradations.

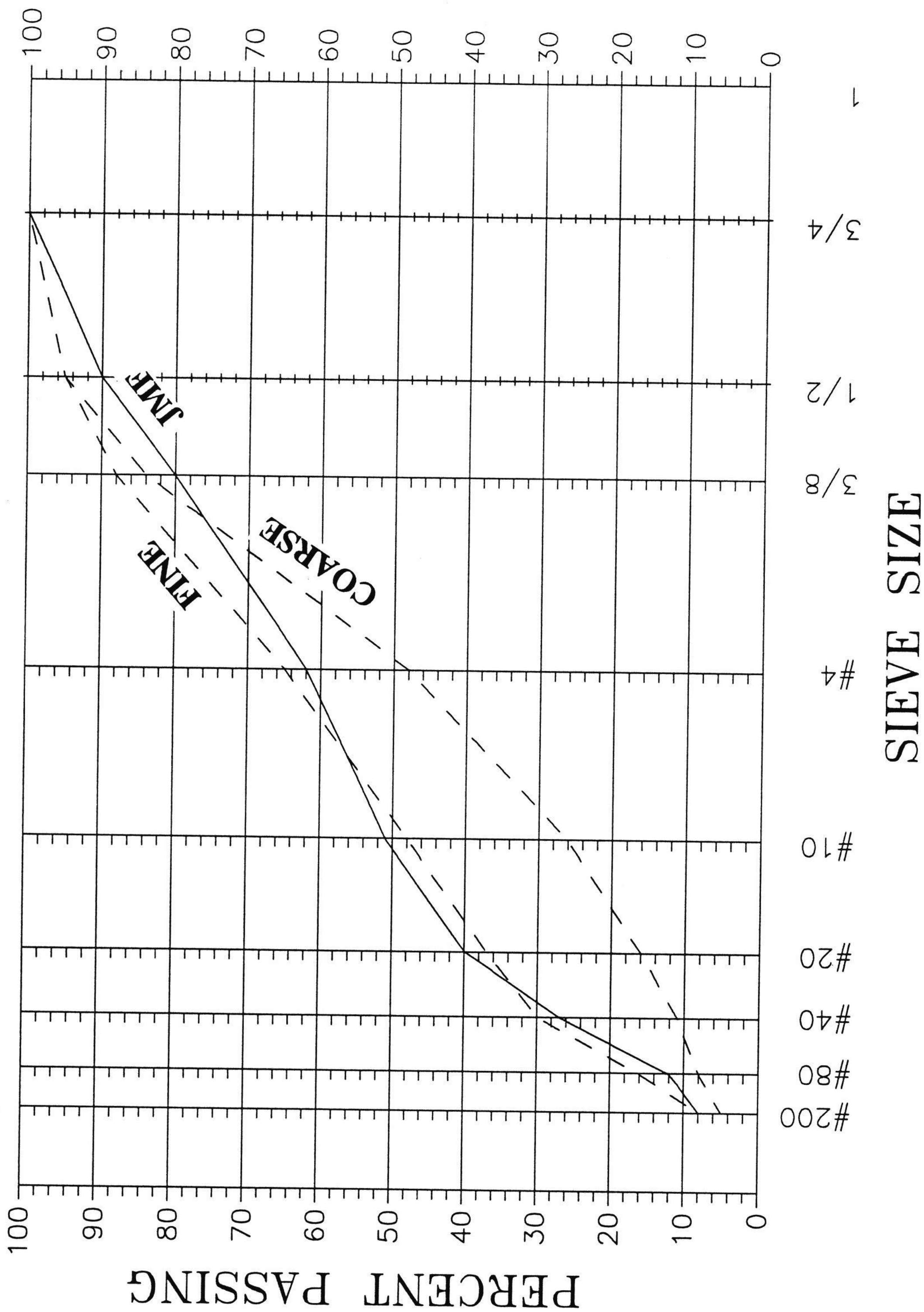


Figure 5. Gradation of the Forrest City Mix.

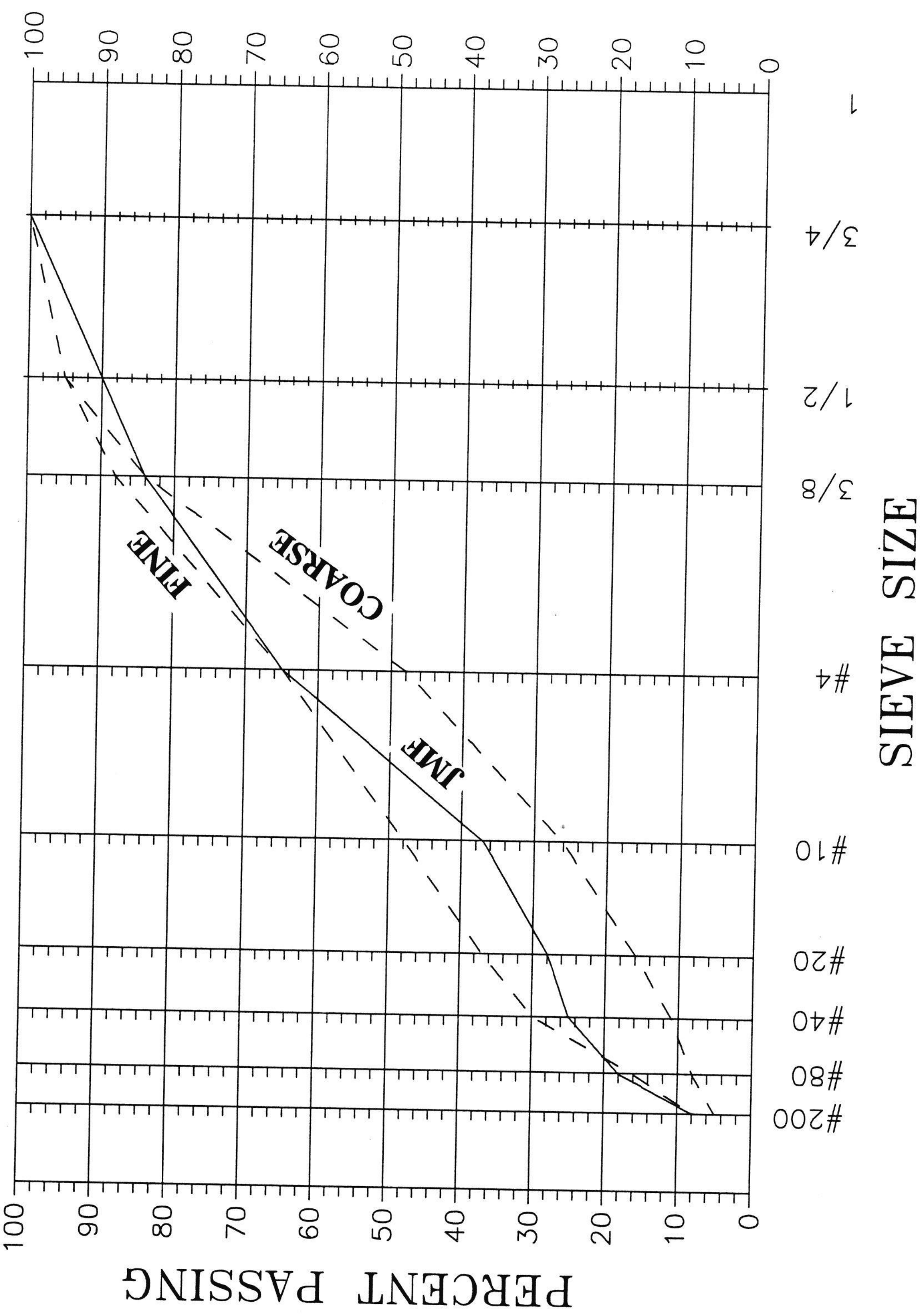


Figure 6. Gradation of the Jonesboro Mix.

standard FINE gradation. Because of this closeness, only two gradations were tested using the Forrest City mix aggregates - JMF and COARSE. All three gradations (FINE, JMF, and COARSE) were used in testing the Jonesboro mix.

The manufactured sand used in this research to replace the natural sand is Donnafil. Donnafil is a fine crushed Syenite, an igneous rock consisting principally of feldspar.

The substitution of manufactured sand (Donnafil) for natural sand in the Forrest City JMF gradation as accomplished in two stages with each stage being tested. This mix used a coarse sand and a fine sand. In the first stage, Donnafil was substituted for the fine sand. For the second stage, crushed limestone sand and Donnafil were substituted for both the fine and coarse sands. The two stage substitution was not necessary for the COARSE gradation. Similarly, two stages were not used with the Jonesboro mix since this mix only a fine sand.

To control the gradation of each test specimen, the aggregates were sieved into the various size fractions and stored in separate containers. Each test specimen was batched individually with appropriate amount of each aggregate being weighed out for each gradation fraction.

So that the rut resistance test results would reflect only the influence of aggregate variation, each mix variation was tested using the optimum asphalt content determined using the Marshall mix design procedure (75 blow). Tables 8 and 9 summarize the mix variations tested.

Table 8. Summary of Forrest City Mix Variations Tested.

ABBREVIATION	MIX DESCRIPTION	ASPHALT CONTENT
JMF	Job Mix Formula as used in construction	5.1%
J+D	Job Mix Formula with Donnafil in place of the fine sand	4.8%
J+D+C	Job Mix Formula with Donnafil and crushed limestone in place of all sand	5.4%
C	Coarse gradation using natural sand	4.5%
C+D	Coarse gradation with Donnafil in place of natural sand	4.5%

Mix Compositions by aggregate source (percent of total aggregate fraction)

	COARSE AGGREGATES			NATURAL SANDS		MANUF. SANDS
Mix/ Agg	Razor Rock	Reed Stone	Three Rivers	Bourham Fields	Ingram Pit	Donnafil
JMF	35.0	15.0	20.0	15.0	15.0	0.0
J+D	35.0	15.0	20.0	15.0	0.0	15.0
J+D+C	35.0	15.0	29.8	0.0	0.0	20.2
C	47.8	19.0	19.6	7.0	6.6	0.0
C+D	47.8	19.0	19.6	7.0	0.0	6.6

Gradation of Aggregates

	Razor Rock	Reed Stone	Three Rivers	Bourham Fields	Ingram Pit
3/4"	100	100	100	100	100
1/2"	84.5	63.5	100	100	100
3/8"	65.9	41.9	100	100	100
#4	34.1	6.8	98.3	99.6	100
#10	16.6	2.7	71.3	97.1	99.6
#20	9.9	1.7	46.7	80.3	94.4
#40	5.7	1.4	34.3	34.3	68.8
#80	2.7	1.3	22.9	4.7	19.9
#200	1.3	1.0	17.1	1.7	16.2

Note: Kling Beta anti-strip agent was used Asphalt was Ergon AC30

Table 9. Summary of Jonesboro Mix Variations Tested.

ABBREVIATION	MIX DESCRIPTION	ASPHALT CONTENT
JMF	Job Mix Formula as used in construction	5.0%
J+D	Job Mix Formula with Donnafil in place of the natural sand	5.0%
F	Fine gradation using natural sand	5.0%
F+D	Fine gradation with Donnafil in place of natural sand	5.0%
C	Coarse gradation using natural sand	4.5%
C+D	Coarse gradation with Donnafil in place of natural sand	4.5%

Mix Compositions by aggregate source.

	COARSE AGGREGATES			NAT. SAND	MANUF. SAND	
Mix/ Agg	Boorhem Fields	Clean Black Rock	Dirty Black Rock	Graham Pit	Donnafil	Hydraded Lime
JMF	34.0	18.5	31.0	15.0	0.0	1.5
J+D	34.0	18.5	31.0	0.0	15.0	1.5
C	40.1	21.6	30.4	6.4	0.0	1.5
C+D	40.1	21.6	30.4	0.0	6.0	1.5
F	27.9	14.9	40.7	15.0	0.0	1.5
F+D	27.9	14.9	40.7	0.0	15.0	1.5

Gradation of Aggregates

	Boorhem Fields	Dirty Black Rock	Clean Black Rock	Graham Pit	Hydraded Lime
3/4"	100	100	100	100	100
1/2"	70.3	100	100	100	100
3/8"	52.9	100	100	100	100
#4	27.7	88.5	61.2	100	100
#10	12.9	48.7	4.9	100	100
#20	6.6	27.7	3.0	99.9	100
#40	4.4	19.5	2.7	99.8	100
#80	3.5	18.2	2.6	63.1	100
#200	1.6	9.9	2.4	17.9	99.5

Note: Hydrated line was used as an anti-strip additive Asphalt was Ergon AC30.

3.2 SAMPLE PREPARATION

The initial activity in preparing the test specimens was to dry the aggregates at a temperature of 220° F for 24 hours. After the aggregates were cooled, they were sieved into their individual size fractions. The sieved aggregates were then stored in separate containers.

During batching the aggregates were re-combined according to the mixture compositions and gradations necessary to produce the desired mix. As a check on the sieving and batching, washed sieve analyses were performed on trial aggregate batches.

The optimum asphalt content for each mix gradation was determined using Marshall mix design procedure in accordance with AASHTO T245. Mixes of each gradation were prepared at three asphalt contents and Marshall specimens were made using 75 blows of the Marshall hammer on both sides. The specimens were subsequently tested for air voids, stability and flow. The optimum asphalt content for each mix gradation was selected with respect to air voids, V.M.A, Marshall stability, Flow and unit weight. Table 10 summarizes the Marshall mix properties for each mix.

The specimens for research testing were prepared at the optimum asphalt content but were compacted using a gyratory compactor. The gyratory method was used because it simulates field roller compaction better than does the Marshall hammer compaction. The compactive effort was adjusted to produce test specimens with air voids of five to six percent. To achieve air voids in this

Table 10. Marshall Mix Design Properties (75 blow).

Forrest City Job (Job R10009)

Mix	Optimum %AC	Stability (lb)	Flow (in.)	Air Voids	V.M.A
JMF	5.1	1980	11.0	2.8	14.6
J+D	4.8	2850	10.2	3.8	14.8
J+C+D	5.4	2850	10.8	4.2	16.4
C	4.5	2150	11.0	6.6	16.6
C+D	4.5	2330	12.8	6.8	16.7

Jonesboro Job (Job R00015)

Mix	Optimum %AC	Stability (lb)	Flow (in.)	Air Voids	V.M.A
JMF	5.0	2660	10.0	3.8	15.3
J+D	5.0	3110	13.0	2.8	14.3
C	4.5	2200	14.0	8.7	19.0
C+D	4.5	2150	13.2	8.0	18.2
F	5.0	2720	11.0	2.8	14.5
F+D	5.0	4580	12.4	2.1	14.1

range, trial compaction was required.

The specimens were 4 inches in diameter and 2.5 inches in height. A total of six specimens were molded for each mix at the optimum asphalt content. Replicates were made to allow selection of test specimens having air voids close to the target value. The properties of the specimens tested are shown in Tables 11 and 12.

3.3 SIMPLE CREEP TESTING

The simple creep test was conducted using a Retsina Resilient Modulus Apparatus produced by the Retsina Co.(20). A steady air pressure from pneumatic load applicator (Bellfram) provided a static load for the creep tests. The delivered load was measured with the load cell and displayed on the electric digital readout. The axial deformation of the specimen was measured with two linear variable differential transformers (LVDT) mounted vertically on the clamps on top of the specimen. The deformation of the specimen was recorded manually from the LVDT reading displayed on the electric digital readout.

To control temperature during the test, an environmental chamber was placed on the pneumatic load applicator. The chamber surrounded the test area and was of sufficient size to permit storage of other specimens awaiting testing. Temperature inside the chamber was controlled by a hair dryer connected to a thermostat.

Before testing, the specimens were stored in an oven at 104 F for at least 24 hours. To make sure that the correct temperature (104 F) was uniformly achieved, the specimens were removed from the

Table 11. Tested specimens properties for Forrest City Job.

Mix Spec.	Test Type	%AC	Unit Weight	V.M.A	%AV	Strain (60m)
JMF						
1	RL		142.0	17.7	6.3	0.0075
2	RL	5.1	142.8	17.2	5.8	0.0098
3	CR		141.9	17.7	6.4	0.0030
4	CR		143.1	17.0	5.6	0.0033
J+D						
1	RL		144.3	16.2	5.4	0.0057
2	RL	4.8	143.6	16.6	5.8	0.0021
3	CR		143.8	16.5	5.7	0.0025
4	CR		144.2	16.3	5.4	0.0023
J+D+C						
1	RL		143.9	17.3	5.2	0.0023
2	RL	5.4	143.1	17.7	5.6	0.0026
3	CR		143.3	17.6	5.5	0.0022
4	CR		143.8	17.3	5.2	0.0023
C						
1	RL		144.1	15.8	5.7	0.0063
2	RL	4.5	143.6	16.1	6.0	0.0072
3	CR		144.1	15.9	5.7	0.0027
4	CR		143.9	16.0	5.9	0.0029
C+D						
1	RL		144.0	15.9	5.5	0.0052
2	RL	4.6	144.0	15.9	5.6	0.0047
3	CR		143.5	16.1	6.0	0.0028
4	CR		143.7	16.0	5.9	0.0026

RL -- Repeated Load Test
CR -- Creep Test

Table 12. Tested specimens properties for Jonesboro mix.

Mix Spec.	Test Type	%AC	Unit Weight	V.M.A	%AV	Strain (60m)
JMF						
1	RL		147.4	15.5	4.0	0.0062
2	CR	5.0	146.5	16.0	4.6	0.0024
3	CR		145.9	16.4	5.0	0.0023
J+D						
1	RL		143.6	17.3	6.1	0.0019
2	CR	5.0	143.3	17.5	6.3	0.0023
3	CR		142.9	17.7	6.5	0.0024
C						
1	RL		147.0	15.5	5.2	0.0046
2	CR	4.5	147.8	15.0	4.6	0.0030
3	CR		147.9	15.0	4.6	0.0022
C+D						
1	RL		147.6	15.2	4.7	0.0039
2	CR	4.5	147.5	15.2	4.8	0.0021
3	CR		147.2	15.3	5.0	0.0022
F						
1	RL		147.8	15.5	4.0	0.0032
2	CR	5.0	146.5	16.3	4.8	0.0023
3	CR		147.6	15.7	4.1	0.0023
F+D						
1	RL		146.3	15.9	4.4	0.0027
2	CR	5.0	146.5	15.8	4.3	0.0022
3	CR		145.0	16.7	5.3	0.0022

RL -- Repeated Load Test
CR -- Creep Test

oven and stored at least one hour before testing in the environmental chamber on the Retsina device. (This chamber had more precise and accurate temperature control than did the oven.) The test loading consisted of a constant 15 psi vertical stress with no confining pressure. Prior to testing, the top and bottom surfaces of the specimens were coated with silicon grease and graphite to reduce the friction with the loading plate.

To minimize the effects of minor surface irregularities, the specimens were preconditioned by applying the 15 psi load for 10 minutes prior to testing. After the preconditioning, the specimens were allowed to rebound for ten minutes. Immediately following the rebound, the specimens were subjected to the creep test. The recommended total loading time for this test is one hour. Van de Loo (21) reported that the creep curve after one hour is known with enough accuracy to allow comparison of mixes. Also, during an international conference held in Zurich in 1977, an agreement was made to standardize the temperature at 40 C° (104° F) and to take one hour as the maximum time. (22)

Periodic deformation readings were manually recorded after 5 seconds, 30 seconds, 1 minute, 15 minutes, 30 minutes, 45 minutes and 60 minutes. Creep strain and creep stiffness were calculated for each recording times. Creep strain was calculated as the axial deformation measured to that time divided by the original specimen height. Creep stiffness was calculated by dividing the applied deviator stress (15 psi) by the creep strain calculated for the time of loading. Typical graphs of creep strain and stiffness versus loading times are shown in Figure 7 and 8.

3.4 DYNAMIC LOAD TESTING

The repeated dynamic load test was conducted with a MTS "closed loop" servo control hydraulic testing system. To control temperature during the test, an environmental chamber was placed on the MTS load frame. The chamber surrounded the test area and was of sufficient size to permit storage of other specimens awaiting testing. Temperature inside the chamber was controlled by a heat tape connected to a thermostat. The specimens deformation during the test was monitored with a strain gauge. A half-inch strain gauge was attached at one end to an iron bar which in turn was mounted to the MTS frame, the other end of the strain gage was attached to the loading piston of the MTS machine. The loading piston moved with the deformation of the specimens, while the iron bar attached to the main frame of the MTS system did not move. The deformation of the specimens was measured by the relative movement between the iron bar and the piston.

The tests were conducted at 104° F. Prior to testing, the specimens were kept in an oven at 104° F for at least 24 hours. At least one hour before testing, the specimens were moved from the oven to the environmental chamber on the MTS. Generous amounts of silicone grease and graphite powder were applied on both flat circular surfaces of the specimens to reduce friction between the contact surfaces. The load impulses applied by the dynamic load test were selected to simulate the "actual load" pulses on

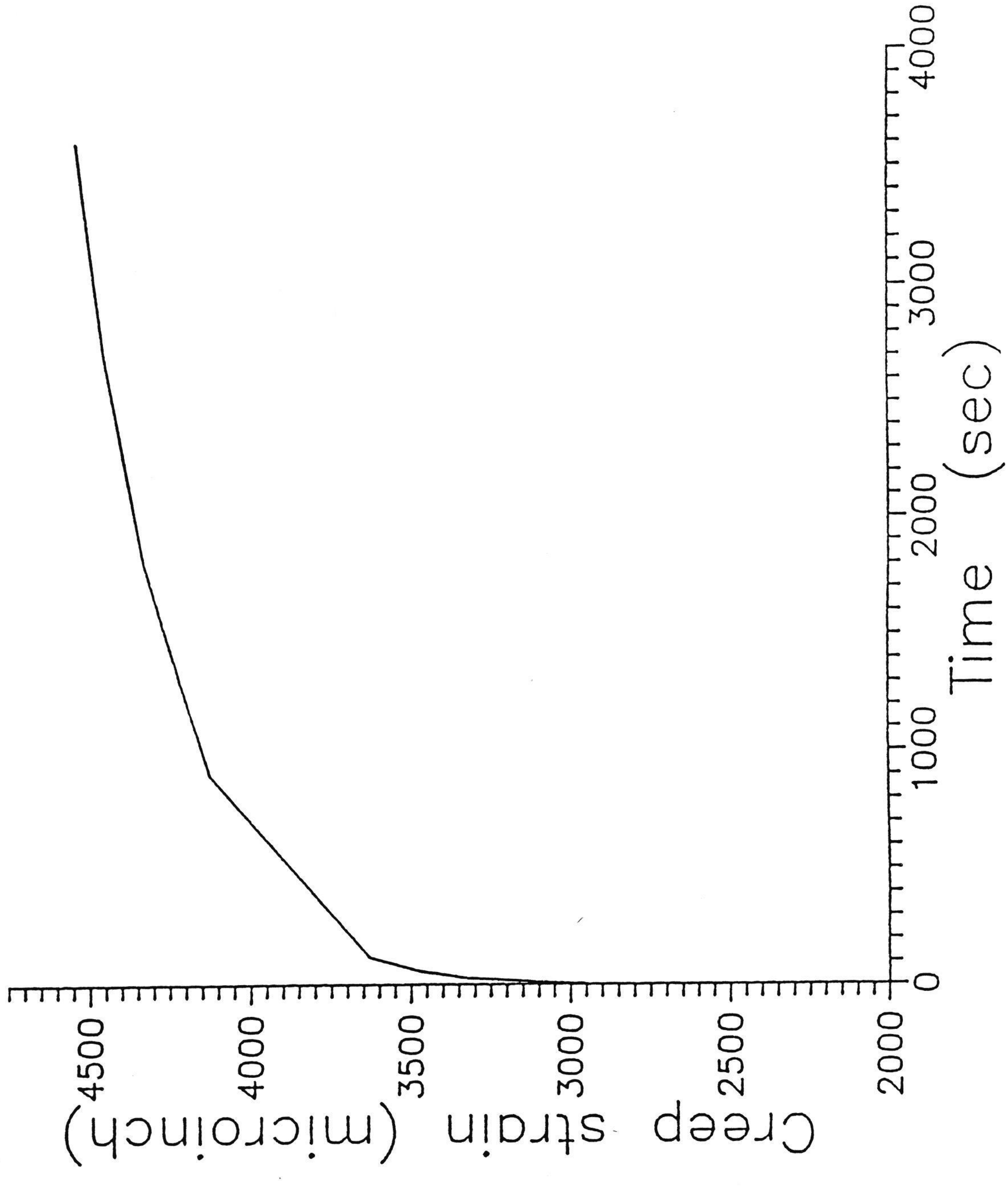


Figure 7. Typical Plot of Creep Strain versus Time.

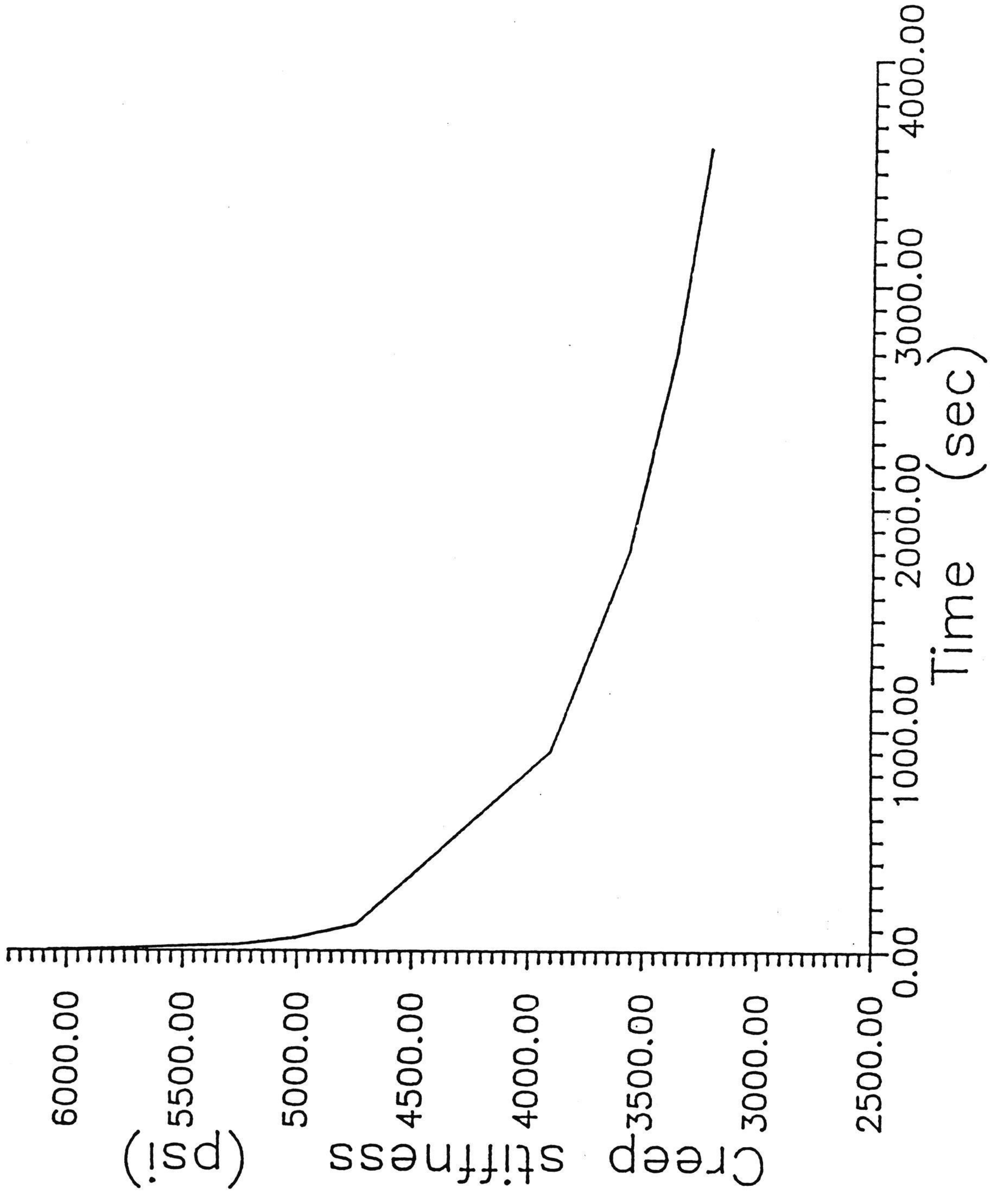


Figure 8. Typical Plot of Creep Stiffness versus Time.

pavements by vehicles. In this research, a deviator stress was applied to reach peak load of 15 psi in 0.02 second, maintained at 15 psi for 0.06 second, and relieved in the next 0.02 second. The deviator stress was then left off for 1.9 seconds as a rest period. This made the total loading time 0.1 second with the load repeated every two seconds. The "average" load duration per cycle was considered to be 0.08 seconds (0.06 + 0.04/2).

To prevent hammering, a constant preload or seating load of 0.5 psi was applied to the specimens. No confining pressure was used in this test.

Data from the test were recorded automatically on a computer. The recording interval was 20 seconds for the first 300 repetitions and 600 seconds for the rest of the test - 100000 repetitions. The data were analyzed using Lotus 1-2-3.

Two measures of rutting potential were calculated from these data -- permanent strain and permanent deformation stiffness. Similar to creep strain, permanent strain was calculated by dividing the permanent deformation recorded to a given number of load repetitions by the original specimen height. Permanent deformation stiffness for a given number of load repetitions is the applied deviator stress (15 psi) divided by the permanent strain. A plot of the permanent strain versus repetitions is shown in Figure 9, and a plot of stiffness versus repetitions is shown in Figure 10. Note that the rate of strain decreased as the test progressed (Figure 9). Also note that the patterns of the graphs for strain and stiffness versus repetitions are similar to the

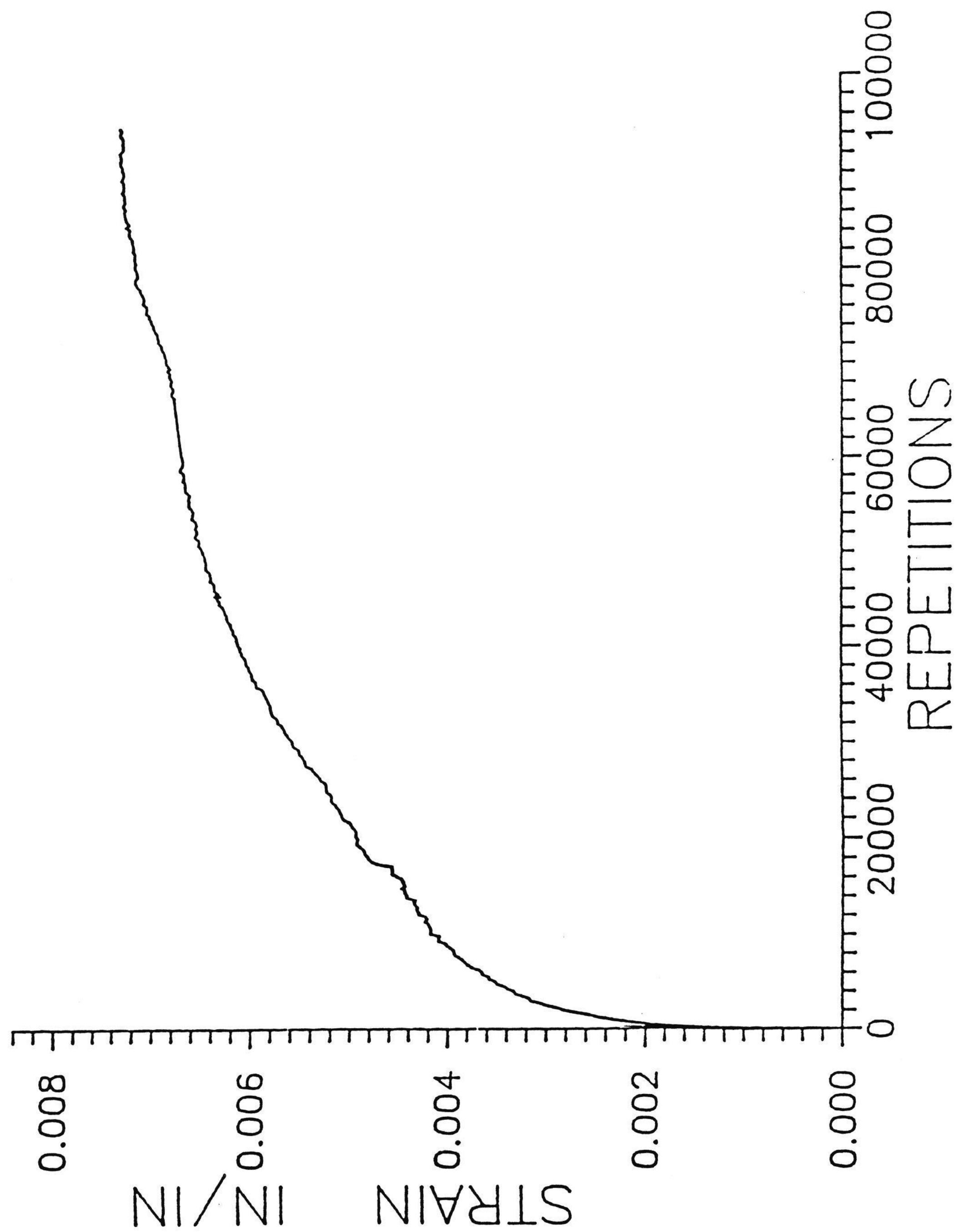


Figure 9. Typical Plot of Permanent Strain versus Load Repetitions.

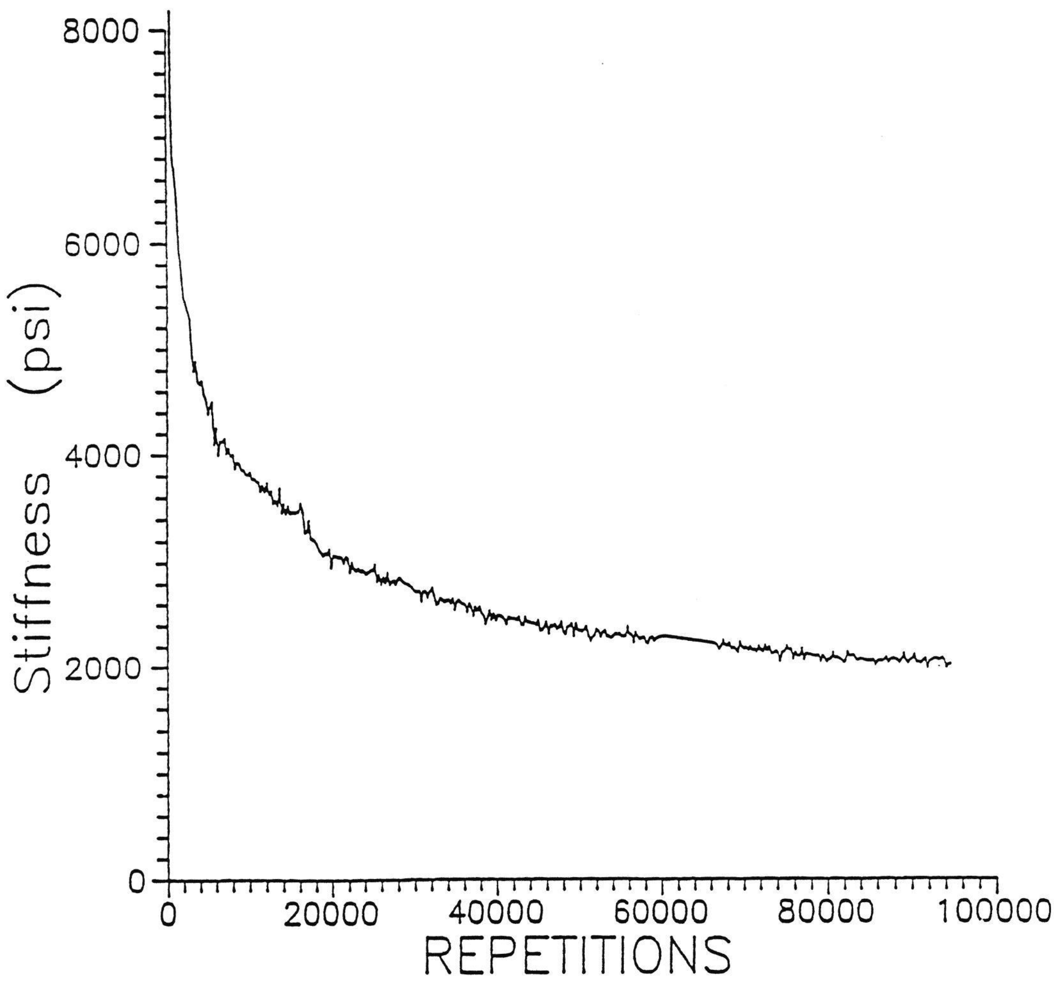


Figure 10. Typical Plot of Permanent Deformation Stiffness versus Load Repetitions.

graphs of strain and stiffness versus time obtained by simple creep test (Figures 7 and 8).

When the rate of strain was plotted against repetitions on a log-log scale, a linear relationship was obtained. Rate of strain is defined as permanent strain divided by the number of repetitions. Figure 11 shows a typical graph for the rate of strain versus repetitions on a log-log plot. The linear relationship can be expressed by the following equation (23):

$$\epsilon/N = AN^{-m}$$

where

ϵ/N = rate of permanent strain,

m = material parameter,

A = material and stress-state parameter,

N = repetitions,

ϵ = permanent strain.

With this relationship, the permanent strain of the specimens can be estimated at some larger number of repetitions. The linear relationship suggests that the time of testing can be reduced. For an example, from the Figure 11, a constant slope was achieved by 10000 repetitions; thus it would not have been necessary to run the test from 10,000 to 100,000 repetitions. Use of this relationship could reduce the time of testing in future studies by 90 percent.

Difficulties were encountered in running the repeated, dynamic

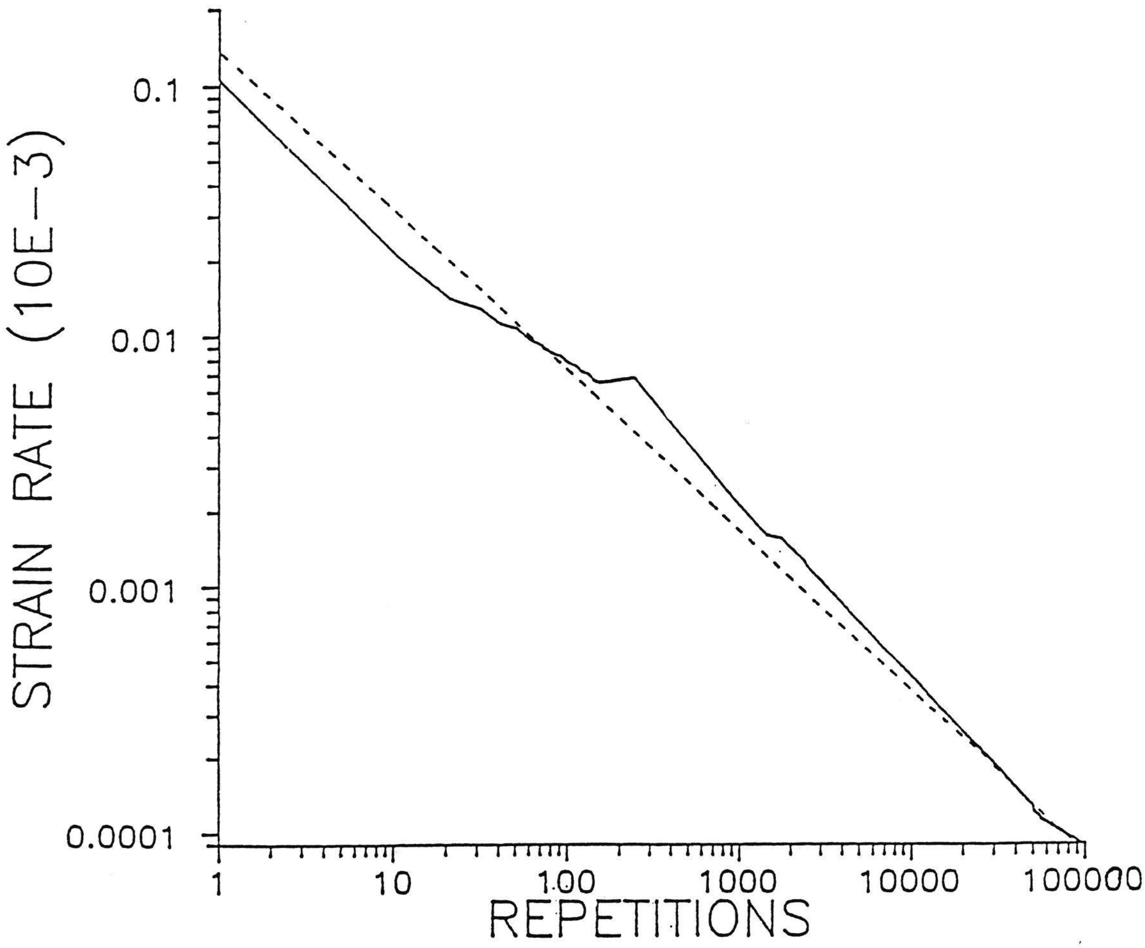


Figure 11. Log-log Plot of Strain Rate versus Load Repetitions.

load test. The dynamic load applied to the piston sometimes fluctuated between 175 and 198 pounds. When the dynamic load was allowed to fluctuate with no adjustment, it generally to increased to more than the intended 188.5 lb (15 psi). Higher stress would increase the strain of the specimens. The degree of damage done to the specimens by having higher deviator stress was unknown and the ability to analyze data with fluctuating loads was thus limited.

The load fluctuations made it necessary to manually control the dynamic load. The manual load adjustments caused a piston movement that was recorded as a sudden jump in the strain versus repetitions graph. To compensate for this, the graphs were retraced to do away the sudden jump.

Examples of the retracing of the graphs are shown in Figures 12 and 13. Figure 12 shows the retracing of the graph when the dynamic load was more than the 188.5 lb. When the load was more than 188.5 lb., the adjustment was to move the piston higher up. As the piston was moved higher, the strain gauge registered a sudden decrease in deformation. Therefore, the graph "jump" downward. When the load was less than 188.5 lb., the adjustment was to lower the piston. As the piston lowered, the strain gauge registered a sudden increase in deformation. Thus, the graph "jump" upward (Figure 13). The retracing of the graphs did not completely solve the problem, but is believed to have compensated for it so that the resulting analyses are acceptable.

To obtain data that could be compared with the creep data, dynamic strain and stiffness values were interpolated fromthe plots

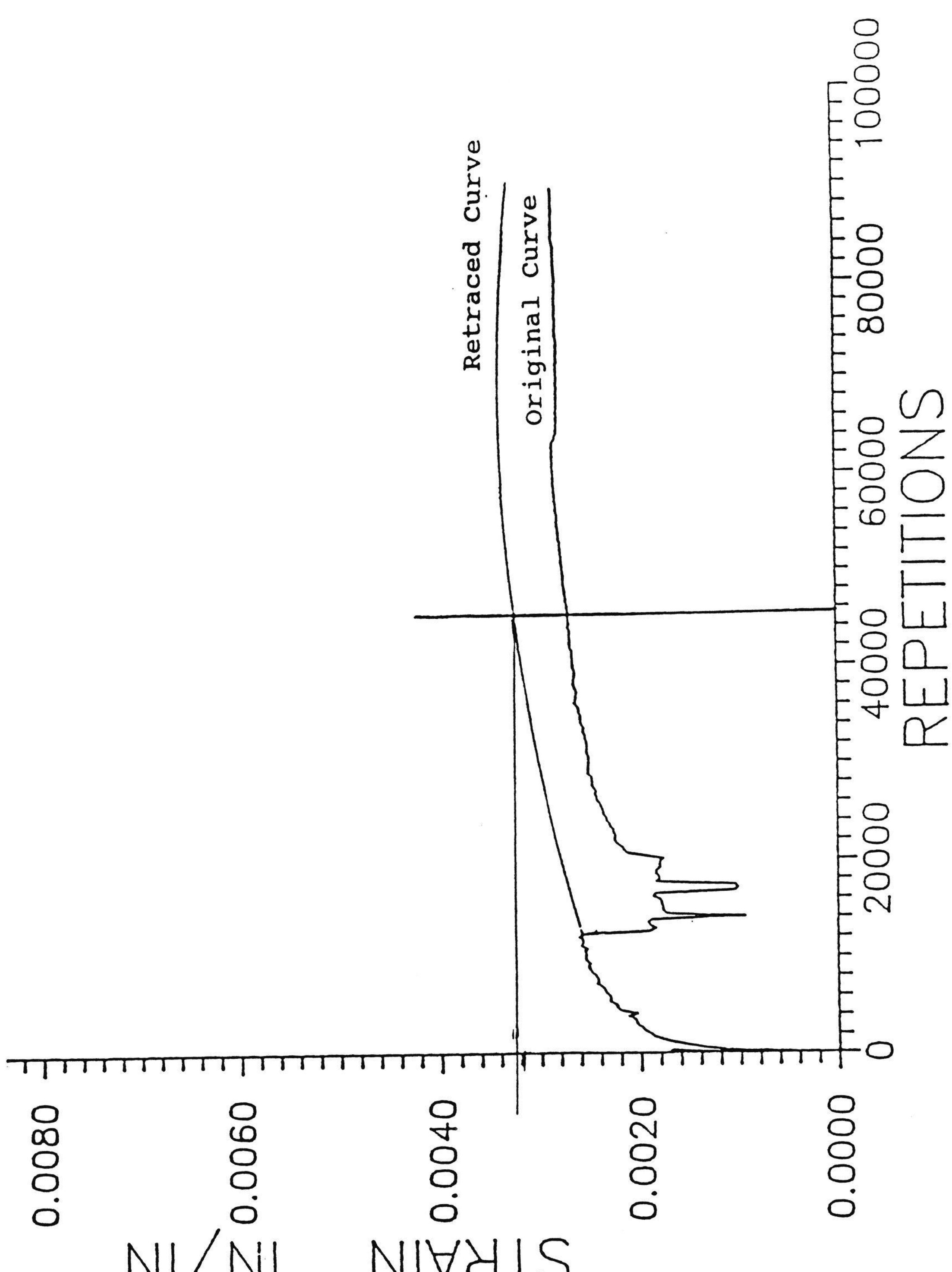


Figure 12. Example of Retracing Strain Curve to Compensate for Effect of Manual Adjustment of High Load.

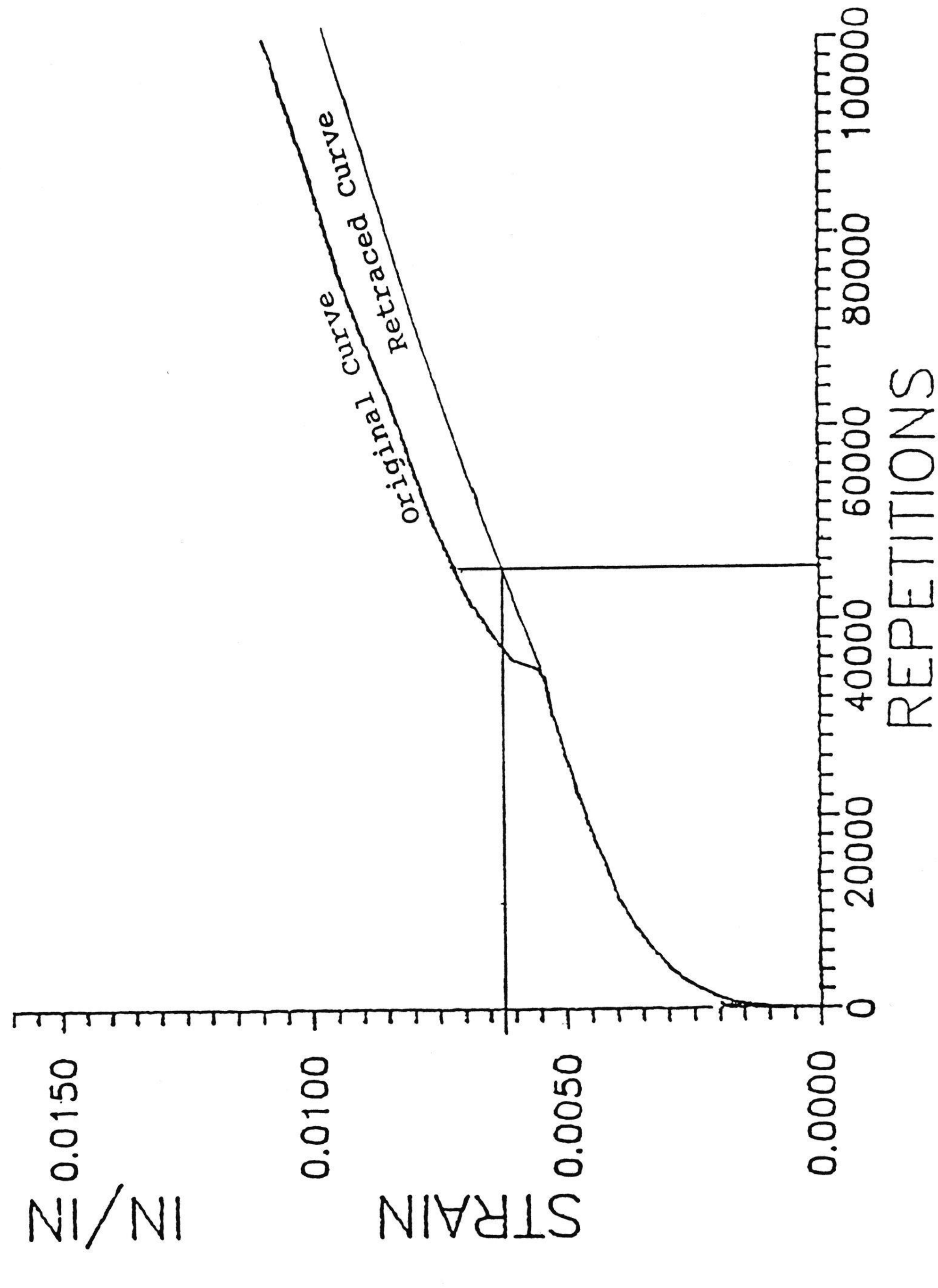


Figure 13. Example of Retracing Strain Curve to Compensate for Effect of Manual Adjustment of a Low Load.

at 45,000 load repetitions. This number of repetitions was selected because it represented one hour of cumulative loading at the 0.08 second "average" load duration per cycle (45000 * 0.08 = 3600 seconds).

CHAPTER 4

ANALYSES, CONCLUSIONS, AND RECOMMENDATIONS

4.1 ANALYSES OF TEST DATA

Circumstances beyond the control of the research staff caused significant delays in the study and reduced the number of mixes tested from five, as planned, to two. In a meeting held near the end of the project time, the project subcommittee recommended that the study be extended and requested that the principal investigator prepare a request for the extension. Based on this recommendation, the project staff continued testing up to and beyond the project completion date without initiating analyses or report preparation. The extension recommendation and request, however, was never approved. As a result the study time and funding expired with only two mixes tested and without the analyses originally intended. The following analyses were subsequently made after the expiration of the project.

Since only two mixes were tested, the conclusions from the analyses may not be universally valid. There are also limitations to the findings because of the limited number of specimens tested. (For the Forrest City job, two specimens were tested with the simple creep test and two specimens were tested with the dynamic load test; however, for the Jonesboro job, because of time constraints, two specimens were conducted for the simple creep test but only one specimen for the dynamic load test.) Nevertheless, there are trends of evidence that appear to be conclusive at least for the mixes tested.

For example, the strain recorded on both jobs shows that the dynamic load test produces a greater magnitude of deformation than does the static load test. The differences in strain obtained by the two tests increase gradually as the deformation resistance of the specimens decrease. The differences in the strain vary from 13% (Forrest City job, J+D+C) to 176% (Forrest City job, JMF).

A major effort during the analyses was the comparison of the two test methods so as to identify the more reliable measure of rutting potential. To compare the two tests, the number of loading applications from the dynamic test were converted to a total load duration. To do this the average load duration per cycle was taken to be 0.08 seconds (0.4/2 + 0.6). With this value, one hour of static loading was considered to be comparable to 45,000 repetitions (3600/0.08 = 45000) in the dynamic load test. Table 11 and Table 12 describe the properties of the tested specimens of each mix and list the strain values after 60 minutes of loading (or 45,000 repetitions of the dynamic load).

Comparison of simple creep and dynamic tests shows that at the beginning of the test, the dynamic test produces less strain than the static test; but at the end of an hour or 45000 repetitions of testing, the dynamic load test produces the greater strain (Figures 14 and 15). Notice also the linearity on a logarithmic scale for the static test, but a rather curvilinear relationship for the dynamic test (Figure 14).

Based on the test data, the dynamic test appears to be the

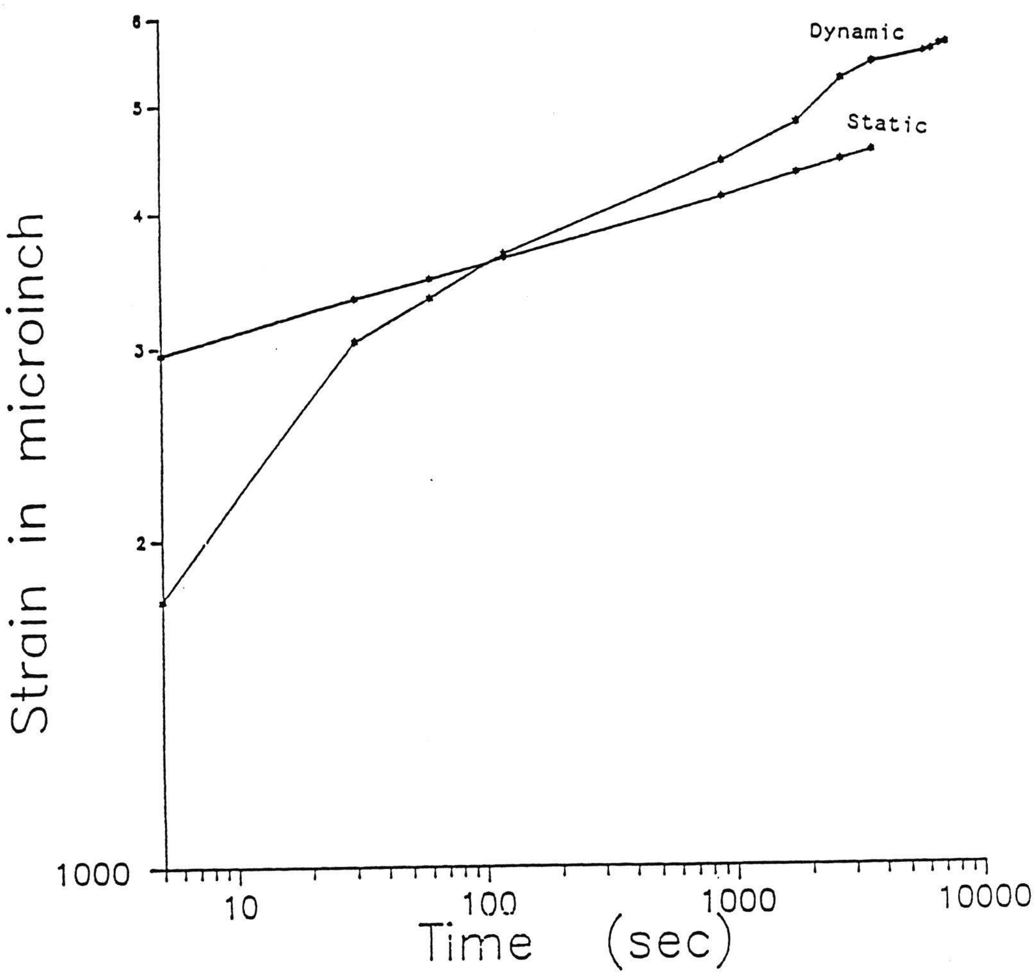


Figure 14. Log of Strain versus Time for Simple Creep and Dynamic Load Tests.

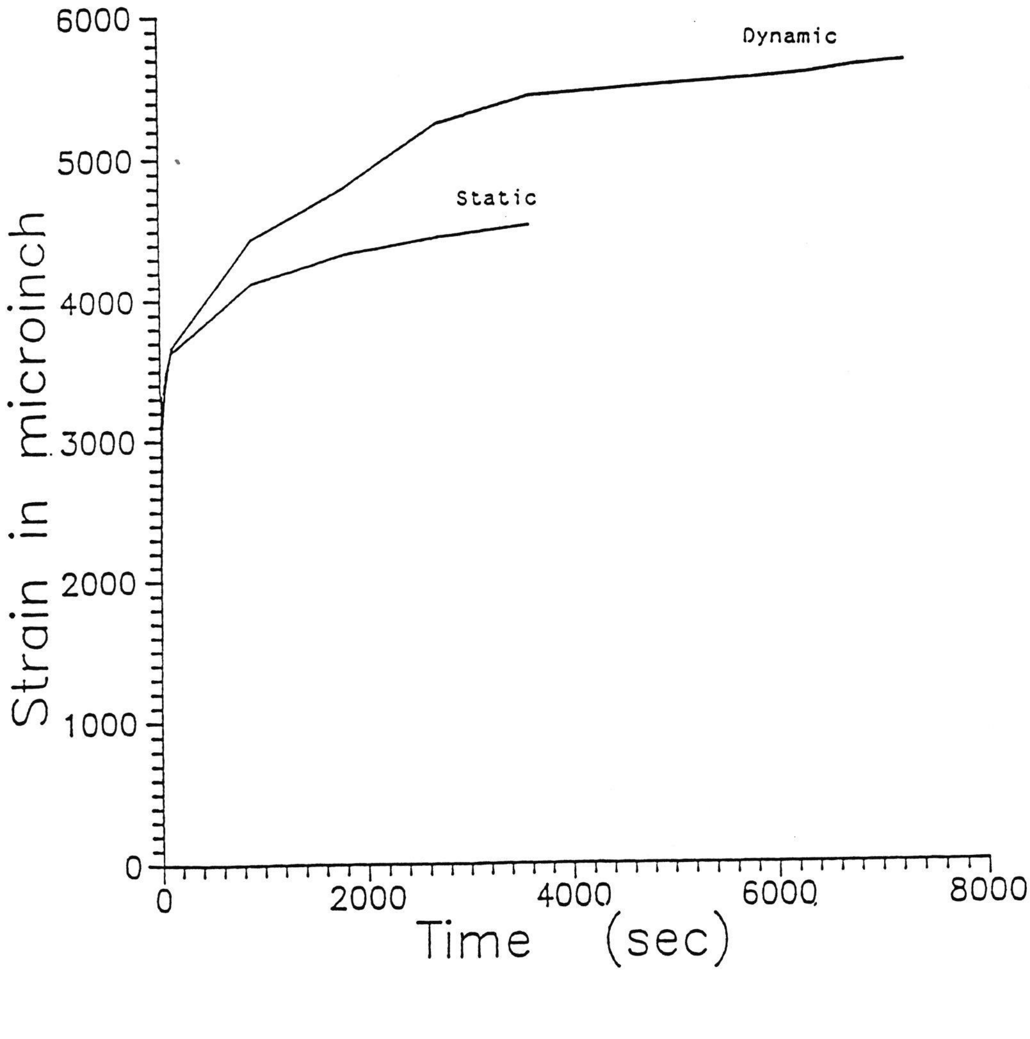


Figure 15. Strain versus Time for Simple Creep and Dynamic Load Tests.

better method for evaluating rutting potential. The ranking of the mixes for the Forrest City job according to the strain is the same by both tests. For the Jonesboro job, however, the ranking of mixes differ. Table 13 tabulates the results ranked in order according to the measured dynamic strain. Notice that the range of strain magnitudes of the Jonesboro job by simple creep test are small and cluster around 0.0023. Because of this small range it is very hard to rank the mixes or to evaluate which mix is more rut resistant. This conclusion is in agreement with Van De Loo's statement that static creep test does not produce consistent results when compared with an impulse load test (18).

The data also shows that the Job Mix Formula (JMF) gradation with natural sand used by the Arkansas State Highway and Transportation Department is less deformation resistant than the other gradations and aggregate combinations tested. JMF gradation of both mixes ranked the poorest in rutting resistant (Table 13). However, when the natural sand of the JMF was replaced with Donnafil, it ranks as the best in rut resistant.

The results of the testing for both jobs give strong support for concluding that crushed sand improves the rutting resistance of asphalt concrete. For example, mixes F+D and F for the Jonesboro job have the same mixture compositions and gradation except that, the natural sand in F was substituted with Donnafil in F+D. Mix F+D experienced 69% less permanent deformation indicating greater rut resistance (Table 13). Other mixes with Donnafil were also found to be more rut resistance than mixes that have the same

Table 13. Ranking of Mix Gradation Variations According to Average Strain.

Forrest City Job

Rank	Mix Variation	Dynamic Load Strain	Simple Creep Strain
1	J+D+C	0.0026	0.0023
2	J+D	0.0039	0.0024
3	C+D	0.0050	0.0027
4	C	0.0068	0.0028
5	JMF	0.0086	0.0033

Jonesboro Job

Rank	Mix Variation	Dynamic Load Strain	Simple Creep Strain
1	J+D	0.0019	0.0023
2	F+D	0.0027	0.0022
3	F	0.0032	0.0023
4	C+D	0.0039	0.0022
5	C	0.0046	0.0026
6	JMF	0.0062	0.0024

gradations but with the natural sand.

4.2 CONCLUSIONS

Based on the data from this project and the above discussion, the following conclusions were made:

1. The dynamic load test causes the greater magnitude of deformation for the same total time of loading.
2. The dynamic load test appears to be the better method for evaluating rutting potential.
3. The least rut resistant gradation and aggregate combinations are the Job Mix Formula gradation with natural sand aggregate.
4. Crushed sand improves the rutting resistance of asphalt concrete.
5. The coarse gradation provides only marginal improvement over the job mix formula gradation in terms of rutting resistance.

4.3 RECOMMENDATIONS

The limited testing in this study provided valuable information regarding the rutting resistance of Arkansas mixes. The data suggest changes that can be made to improve rutting resistance and provide a relative measure of the degree of improvement. However, it can be dangerous to reach broad conclusions from such limited data. In particular, there is considerable concern regarding the apparent rutting resistance of the coarse gradations. This seems to be in direct conflict with the practices of others and deserves further study.

From this viewpoint, it is unfortunate that the project was not extended to include at least two additional mixes. It is strongly recommended that another similar study be undertaken in the near future. However, some changes should be made in the testing.

There appears to be no reason for including the simple creep testing. All additional rut resistance testing can be limited to repeated load testing.

Also the number of repeated loads can be reduced. The testing to date has involved 100,000 load repetitions. At 2 seconds per cycle, this requires nearly 55 hours of continuous testing. Over this long a time, some testing error is almost inevitable. A shorter time (fewer cycles) would be beneficial.

Examination of the test results shows that the relationship between the rate of permanent deformation and load cycles is logarithmic (Figure 11). This being the case the number of cycles can be reduced to 10,000 with no significant loss. This will allow a test specimen to be completely tested in one working day.

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APPENDIX A

MARSHALL MIX DESIGN DATA.

Table A-1. Marshall design data for Forrest City Job. (R1009)

Mix	%AC	%AV	V.M.A	Unit Weight	Stab.	Flow
JMF	5.1	2.8	14.6	147.3	1980	11.0
J+D	4.5	4.9	15.1	145.4	2650	9.20
	5.0	3.0	14.4	147.1	2900	10.4
	5.5	2.0	14.8	147.8	2600	12.6
J+D+C	4.5	7.4	17.3	141.6	3050	10.1
	5.0	5.4	16.7	144.1	2950	10.4
	5.5	3.9	16.4	145.4	2850	11.0
C	3.5	9.8	17.4	140.8	2110	10.0
	4.0	8.4	17.1	141.9	2400	9.80
	4.5	7.0	17.2	142.8	2130	10.0
C+D	3.5	9.1	16.6	140.8	2540	11.6
	4.0	7.5	16.4	142.0	2480	11.4
	4.5	6.7	16.7	140.8	2340	12.0

Table A-2. Marshall design data for Jonesboro Job. (R0015)

Mix	%AC	%AV	V.M.A	Unit Weight	Stab.	Flow
JMF	5.0	3.8	15.3	147.8	2660	10.0
J+D	4.6	3.8	14.8	147.6	3400	12.0
	5.1	2.6	14.4	148.5	3110	13.1
	5.6	2.0	15.0	148.2	2800	15.0
C	3.5	11.8	19.1	138.8	2030	11.0
	4.0	9.1	17.8	141.9	2780	11.8
	4.5	8.7	18.7	140.9	2350	13.6
C+D	3.5	9.8	17.4	142.0	2000	12.0
	4.0	8.8	17.7	142.3	2200	11.8
	4.5	8.0	18.1	142.6	2160	13.2
F	4.5	3.8	14.4	148.6	3400	10.5
	5.0	2.8	14.5	148.8	2720	11.0
	5.5	1.8	14.7	149.3	2480	12.8
	6.0	0.8	15.1	149.4	2400	16.0
F+D	4.5	3.9	14.4	148.2	5150	11.4
	5.0	2.1	14.0	149.6	4550	12.4
	5.5	1.7	13.8	149.8	3600	15.0

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