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TRC8801

Asphalt Gradation Variation

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Final Report

1989

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Arkansas Highway and Transportation Research Center

Dept. of Civil Engineering
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ASPHALT GRADATION VARIATION

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16. Abstract
Six asphalt concrete mixes were tested to examine the effect of variations in aggregate gradations. The properties investigated were creep behavior as a measure of rutting potential, spit tensile strength as an indicator of fatigue resistance, and the Marshall mix parameters. Each mix was tested with five gradation variations that were selected to represent the maximum variations typically encountered on a paving project. The job mix formula (JMF) gradation served as the control. Two other gradations represented the extreme fine (FINE) and coarse (COARSE) deviations from the JMF. The remaining two gradations crossed from one extreme (e.g. coarse) on the largest aggregate size to the other extreme (e.g. fine) on the smallest (#200 sieve) size). These were called the COARSE-FINE and FINE-COARSE gradations.

The greatest effect to mix properties was observed with the COARSE-FINE and FINE-COARSE gradations that caused a change in the shape of the gradation curves. This suggests that, in addition to the individual sieve size tolerance limits normally included in asphalt construction specifications, consideration should be given to including a control on the shape of the gradation curve.

Also included in the study are relative life analyses that can be used as the basis for the development of pay adjustment schedules for Quality Assurance specifications and for mix that does not quite comply with the tolerance limits under traditional specifications.

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FINAL REPORT

TRC-8801

ASPHALT GRADATION VARIATION

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The contents of this report reflect the view of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Arkansas State Highway and Transportation Department or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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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EXECUTIVE SUMMARY

FINAL REPORT, TRC-8801

ASPHALT GRADATION VARIATION

This study was performed to investigate the effect of variations in the gradation of aggregates on the properties of asphalt concrete mixes. The specific properties investigated were the creep behavior as it relates to rutting, split tensile strength as an indicator of mix fatigue resistance, the mix resilient modulus, and the Marshall mix properties.

Six mixes were tested. These were selected by AHTD as representative of the mixes commonly used on Arkansas highways. The mixes were identified by the type of coarse aggregate used. These were: 1) limestone, 2) syenite, and 3) gravel. For each coarse aggregate type, a surface mix and a binder mix were tested.

Each mix was tested with five gradation variations. The gradation variations were selected after an analysis of field extraction data to be representative of the maximum variation typically encountered in the field. These variations were generally about the same as the AHTD specification limits.

The job mix formula (JMF) served as the control gradation. Two other gradations represented the extreme fine (FINE) and coarse (COARSE) gradations. The remaining two gradations were categorized as crossover gradations in that they crossed from one extreme (e.g. coarse) on the largest aggregate size to the other extreme (e.g. fine) on the smallest aggregate size. These were called COARSE-FINE and FINE-COARSE gradations.

The study provided information and findings that should be useful in four areas: 1) the review and modification of quality control practices, 2) specification maximum tolerance levels, 3) mix design gradation adjustments, and 4) pay adjustments for mix produced that does not quite comply with the specification tolerance limits.

Quality Control Practices

The data and analyses from the study demonstrate that improvements in construction quality control that would result in a reduction in gradation variability should also result in an improvement in pavement performance. However, the data also suggests that, within the range of variability normally encountered, improved density control is more critical than improved gradation control.

Specification Maximum Tolerance Limits

In general, the mix properties tested in this study were not drastically affected by the gradation variations. The greatest effect was observed with the gradation variations that changed the shape of the gradation curve (i.e. FINE-COARSE and COARSE-FINE). This suggests that the current AHTD maximum tolerance limits are reasonable but that some additional requirement to control the shape of the gradation curve would be beneficial.

Gradation Adjustment Decisions

The results of the study suggest that care should be exercised in making decisions regarding mix gradation adjustment without first performing mix design tests. In particular, no change should be made that results in a change in the shape of the gradation curve unless backed up by laboratory test results.

Pay Adjustments

Relative life analyses were performed to examine the predicted effects of gradation variation on pavement life. These analyses can be used as the basis for the development of pay adjustment schedules for Quality Assurance specifications and for mix produced under current specifications that does not quite comply with the gradation maximum tolerance limits. However, the analyses cannot be applied directly but must consider both the normal degree of construction variability and the degree of variability on the job in question. Additional analyses are needed to develop technically sound, defensible pay adjustment schedules.

CHAPTER 1

PROBLEM STATEMENT AND STUDY OBJECTIVES

PROBLEM STATEMENT

All highway agencies recognize the need to control the degree of variability of asphalt pavement construction. Specifications controlling the quality of construction typically include limits of acceptability on factors such as asphalt content, density, and gradation. These limits have generally been established over many years and represent the collective experience and opinions of many engineers. Nevertheless, the relationship between mix variation and service life is not well known and has not been studied extensively. Such relationships are needed to assure that specification limits are realistic and consistent. The relationships are also needed to establish pay adjustments for construction that does not meet the specification requirements but is not so poor as to warrant removal and replacement.

One study(1) developed a procedure for estimating the relative effect of variations in asphalt concrete mix composition and density. This procedure was used to examine the effect of variations in asphalt content, density, and gradation. From the study significant relationships were identified between relative life and variations in asphalt content and density. However, because only a limited amount of testing included gradation variations, no significant relationship was found for the gradation variation.

STUDY OBJECTIVES

This study was performed to investigate the effect of variations in the gradation of aggregates on the properties of asphalt concrete mixes. In accordance with the procedures from a previous study for estimating relative life effects, specific objectives of the study were:

1) Determine the effect of gradation variation on the creep behavior of six selected asphalt concrete mixes.

2) Use the creep behavior relationships to identify the relative life effects of gradation variation in terms of rutting.

3) Determine the effect of gradation variation on the split tensile strength of six selected asphalt concrete mixes.

4) Use the split tensile strength relationships to identify the relative life effects of gradation variation in terms of fatigue.

In addition to these specific objectives, the study also examined the effect of gradation variation on the Marshall mix design properties (stability, flow, air voids, and VMA) and on resilient modulus.

CHAPTER 2

LITERATURE REVIEW

GRADATION VARIATION STUDIES

A review of the literature reveals that little research has been reported dealing directly with the effect of gradation variation on asphalt mix behavior. Many studies report on the relative differences between different gradations but these typically deal with mixes of different gradation not with gradation variations within a given mix. Two studies that did deal specifically with gradation variation were reported by McLeod(2) and Elliott and Herrin(1).

McLeod tested asphalt concrete mixtures with the aggregate gradations and asphalt contents varying between the upper and lower limits of the ASTM specifications (Table 2-1). Marshall mix design tests were performed on specimens prepared with gradation variations as illustrated in Figure 2-1 and with asphalt contents at the job mix formula and at the upper and lower extremes permitted by the tolerances. The results from one of the mixes tested is shown in Table 2-2.

Mcleod made no attempt to relate the results to mix behavior or to examine the results in terms of the specific variations. Instead he examined the ranges of test results for each mix. Table 2-3 lists the mean and standard deviation of the range of test values. Based on these ranges, McLeod concluded that the ASTM tolerances are too broad.

Elliott and Herrin(1) examined the effect of gradation variation on split tensile strength and creep behavior. The objective of their study was to identify relative pavement life effects and to develop a rational basis for quality assurance pay adjustment schedules. The gradation variations used in the study (Table 2-4) were based on the 90% pay limits included in the Illinois Department of Transportation quality assurance pay schedule. Elliott and Herrin did not find any consistent or significant relationship between gradation

Table 2-1. ASTM Tolerances Used in Study by McLeod (2).

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%

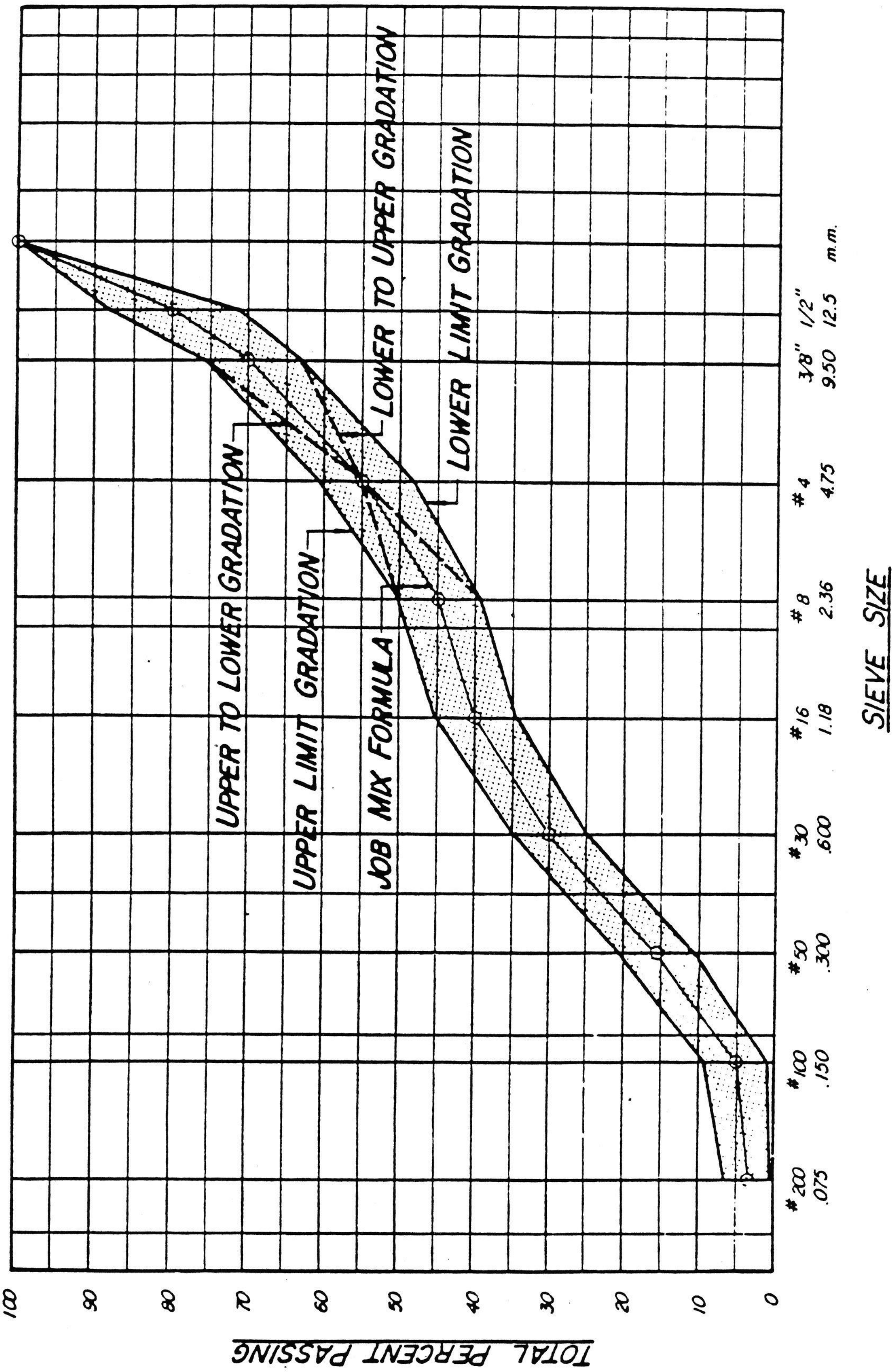


Figure 2-1. Gradation Variations Tested by McLeod (2).

Table 2-2. Mixture Property Variations Found by McLeod (2).

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 Specific Gravity	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. Grav.	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 = 40 Marshall Stability / Flow Index

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

Table 2-3. Range of Mixture Property Values Found by McLeod (2).

Mixture Test Property	Mean Range of Measured Values	Standard Deviation of Measured Values
Air Voids, %	3.76	0.93
VMA, %	2.77	0.90
Marshall Stability	937	235
Marshall Flow	7.7	1.25
Marshall Density, pcf	4.6	1.6
Theoretical Maximum Specific Gravity	0.047	0.005
Bulk Specific Gravity	0.074	0.026

Table 2-4. Example Gradation Variation Used by Elliott and Herrin (1).

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

variation and the creep behavior. However, they did report that the average tensile strength of the fine and coarse mixes were about 10% lower than the tensile strength of the job mix formula gradations.

A study of construction variability was reported by Zenewitz and Welborn[3]. Data from 53 asphalt pavement projects in 19 states were analyzed. At the time of the study the pavements were 11 to 13 years old. The pavements were categorized as "survivors" and "nonsurvivors" depending upon whether or not they had been overlaid or had received a surface treatment since the time of their construction. The data were analyzed to identify statistically significant differences between the two categories. No significant relationships were identified for the average values of mix properties; but there were several significant relationships identified relative to the variability (standard deviation) of mix properties (Table 2-5).

Because no relationships were identified based on average values, Zenewitz and Welborne concluded that the average mix design requirements for the projects were generally satisfactory but that the degree of deviation from those requirements substantially affected performance. Based on their finding, they recommended that asphalt mix specifications include controls on uniformity.

OTHER STUDIES RELATED TO GRADATION EFFECTS

Many other studies have examined the differences between mixes of different gradation. These have led to conclusions regarding the effect of gradation on stiffness, rut resistance, and fatigue resistance. In general these may be summarized as:

1. Fine graded mixes tend to rut more rapidly than do coarser graded mixes[4].
2. Increasing the maximum aggregate size increases the stiffness of dense graded mixes[5,6] and may improve the fatigue resistance slightly[7].
3. Reducing the quantity of coarse aggregate in the mix reduces the fatigue resis-

Table 2-5. Significant Standard Deviations of Mix Properties Identified in Study of Pavement Performance by Zenewitz and Welborn (3).

MIX PROPERTY	SURVIVING PAVEMENTS	NON-SURVIVING PAVEMENTS	PROBABILITY OF CHANCE OCCURRENCE
Asphalt Content, %	0.1 or less	0.3 or more	< 0.01
Air Voids, %	none	1.5 or more	0.02 to 0.05
VMA, %	0.6 or less	0.7 or more	< 0.01
Bulk Specific Gravity	0.17 or less	0.34 or more	0.05
Maximum Specific Gravity	.001 or less	.013 or more	0.01 to 0.02
Effective Aggregate Specific Gravity	.010 or less	.011 or more	0.05
Gradatiion, % Passing			
3/8"	2.0 or less	2.1 or more	< .01
#4	1.6 or less	none	0.02 to 0.05
#8	1.0 or less	none	0.01 to 0.02
#16	1.2 or less	1.3 or more	0.05

tance[6].

4. Increasing the filler content (% passing the #200 sieve) up to a filler:bitumen ratio of 2 increases the fatigue resistanc[6,8] and stiffness[9,10,11].

5. Dense graded mixes possess better fatigue resistance than do open graded mixes[12].

6. Gap graded mixes may exhibit better fatigue resistance than do dense graded mixes[12].

CHAPTER 3

TESTING PROGRAM

SIGNIFICANCE OF TESTS

The tests performed in this study were: 1) split tensile strength, 2) simple creep, 3) resilient modulus, and 4) Marshall mix stability, flow, air voids, and VMA. The split tensile and simple creep tests were performed to provide the basis for the relative life analyses as established by Elliott and Herrin(1).

The relative life analyses are based on the two most prevalent load associated modes of failure in asphalt pavements - fatigue cracking and surface rutting. The split tensile strenght test was selected as an indicator of fatigue characteristics based on research by Maupin and Freeman(16). The simple creep was selected as measure of rut resistance based on the procedures used in the Shell Pavement Design Manual(17).

The Marshall mix and resilient modulus tests were performed to provide additional information on the effect of gradation variation in terms consistent with the pavement design and mix design processes used by AHTD. AHTD uses the Marshall method of mix design and the AASHTO Guide for Design of Pavement Structures. In the AASHTO Guide resilient modulus is used as the basis for selecting the structural layer coefficient for asphalt concrete. The data from these tests provide information more familiar to AHTD engineers than would be provided by the spit tensile and creep tests.

SELECTION OF MIXES AND GRADATION VARIATIONS

Six asphalt concrete mixes were tested in the study. Three were surface mixes and three were binder mixes. The mixes were selected by the project subcommittee to be representative of mixes typically used in Arkansas. The principal difference between the mixes was in the type of coarse aggregate.

Three types of coarse aggregate were used with one surface and one binder using each type. The three coarse aggregates were: 1) crushed limestone, 2) crushed syenite, and 3) crushed gravel. Consequently, the mixes are hereafter referred to as limestone surface, limestone binder, syenite surface, syenite binder, gravel surface, and gravel binder. The job mix formulas for the mixes are listed in Table 3-1.

The gradation variations used in the study were selected to represent the extreme variations typically encountered in construction. To identify "typical, maximum" variations, field extraction data were obtained from 11 surface mixes and 10 binder mixes. Standard deviations of the gradation percentage for each sieve size were computed for each mix. From these the "typical" standard deviations were selected and "typical, maximum" variations were calculated as three standard deviations. The variations to be used in the test program (Table 3-2) were selected based on these and an examination of the actual maximum variations from the field data. The selected variations are generally about the same as the AHTD specification limits.

Each of the six mixes included in the study was tested with 5 variations in the aggregate gradation (Figure 3-1). The control gradation for each mix was the job mix formula (JMF) supplied by AHTD. Two other gradations were the job mix formula plus or minus the maximum variations described above. These produced gradation variations that are referred to as FINE and COARSE. The remaining two gradations were crossover gradations that were categorized as FINE-COARSE and COARSE-FINE.

The FINE-COARSE gradation had the maximum gradation variation to the fine side for the largest aggregate size fraction (1/2" for surface and 3/4" for binder) and the maximum gradation variation to the coarse side for the smallest size fraction (#200 sieve). The variations from the job mix formula for the other sieve sizes were prorated based on the 0.45 power gradation scale. The COARSE-FINE gradation was similar to the FINE-COARSE gradation but with the sign of the deviations from the job mix formula reversed.

Table 3-1. Job Mix Formulas of the Mixes Tested.

AGGREGATE GRADATION, % PASSING AGGREGATE ONLY

SIEVE SIZE,	SURFACE COURSE MIXES LIMESTONE	SYENITE	GRAVEL
3/4"	100	100	100
1/2"	93	93	96
3/8"	81	84	81
#4	60	61	60
#10	45	42	43
#20	36	28	31
#40	28	21	22
#80	13	12	12
#200	6	7	7
ASPHALT CONTENT % OF TOTAL MIX	5.6	5.3	5.4

SIEVE SIZE	BINDER COURSE MIXES LIMESTONE	SYENITE	GRAVEL
1"	100	100	100
3/4"	88	90	88
1/2"	66	75	69
3/8"	56	62	59
#4	43	40	44
#10	31	30	32
#20	23	25	26
#40	18	19	21
#80	10	11	11
#200	6	6	6
ASPHALT CONTENT % OF TOTAL MIX	4.3	4.5	4.4

Table 3-2. Selection of Gradation Variations.

SIEVE SIZE	AHTD SPEC. LIMITS		FIELD VARIATIONS STD. DEV.		THREE STANDARD DEVIATIONS		SELECTED VARIATIONS	
	SURFACE	BINDER	SURFACE	BINDER	SURFACE	BINDER	SURFACE	BINDER
3/4"	-	+/- 7	-	2.5	-	7.5	-	+/- 8
1/2"	-	-	1.8	3.5	5.4	10.5	+/- 6	+/- 12
3/8"	-	-	2.5	3.5	7.5	10.5	+/- 8	+/- 12
#4	+/- 5	+/- 5	2.0	2.7	6.0	8.1	+/- 6	+/- 8
#10	+/- 5	+/- 5	1.6	2.0	4.8	6.0	+/- 5	+/- 6
#20	-	-	1.5	1.8	4.5	5.4	+/- 5	+/- 6
#40	+/- 4	+/- 4	1.2	1.5	3.6	4.5	+/- 4	+/- 5
#80	-	-	1.0	1.0	3.0	3.0	+/- 3	+/- 4
#200	+/- 2	+/- 2	0.6	0.8	1.8	2.4	+/- 2	+/-2.5

NOTE: Based on analysis of data on a total percent passing basis.

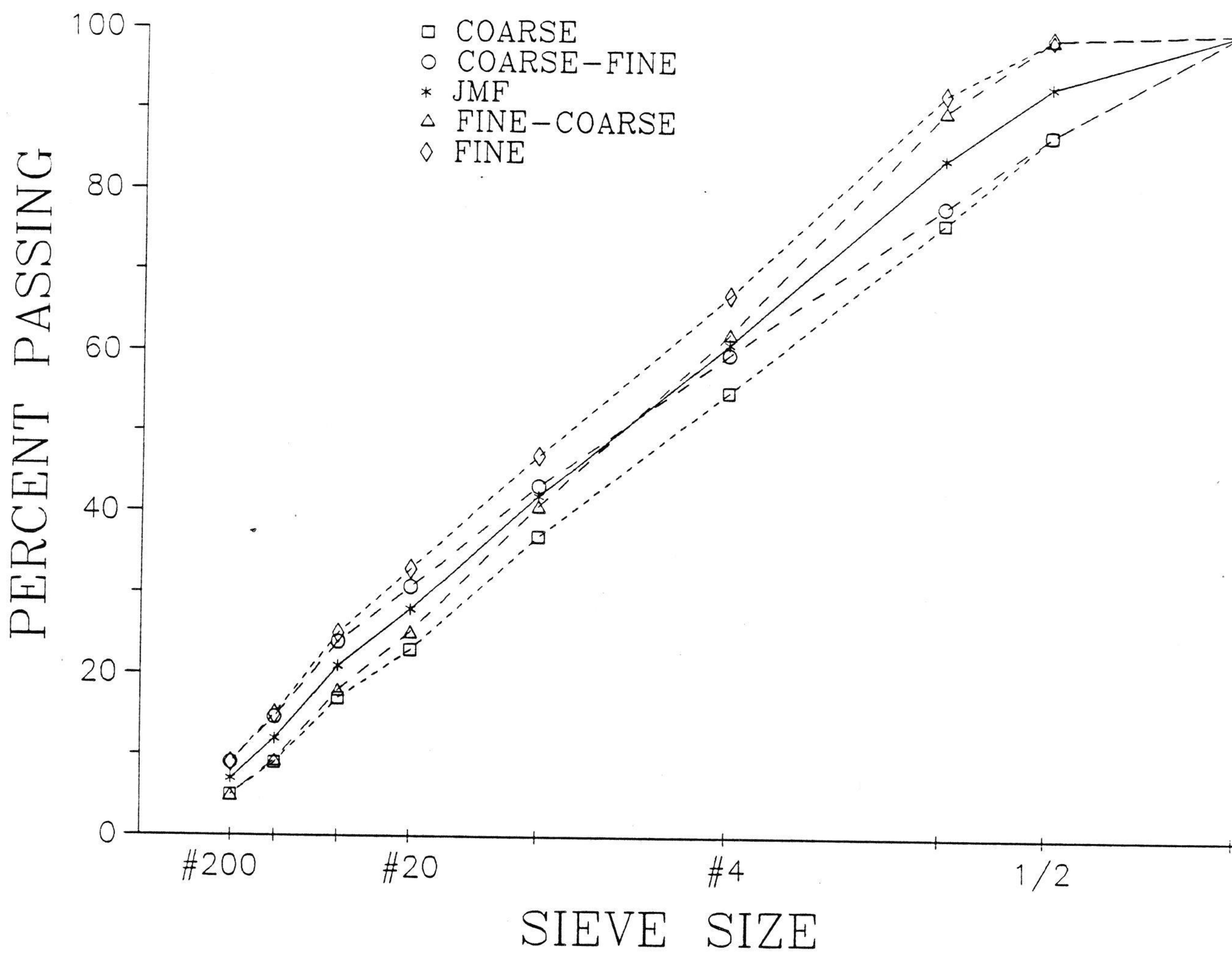


Figure 3-1. Illustration of the Gradation Variations Tested.

The method of prorating is depicted in Figure 3-2 for the FINE-COARSE gradation. In the figure, the X axis represents the sieve size scale, the Y axis represents the deviation from the job mix formula, and F represents the full deviation from the job mix formula for the sieve being prorated. Note that Y is equal to -F at X = 0 and +F at X = A. These points on the X axis represent the smallest and largest sieve size respectively. The prorated deviations from the job mix formula used in the study are listed in Table 3-3.

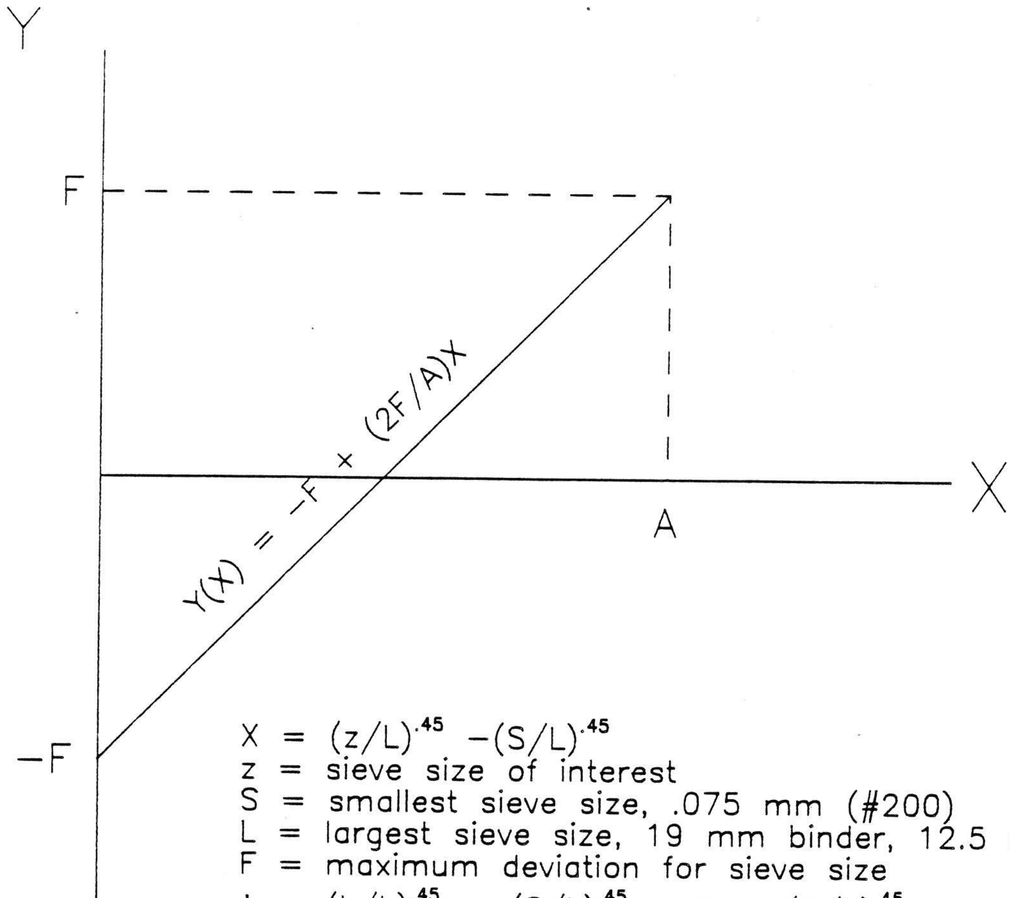
SPECIMEN PREPARATION

To control the gradation of the test specimens, all aggregates were separated into the various size fractions (i.e. 1/2" to 3/8", 3/8" to #4, etc.) and stored in metal buckets. When preparing test specimens, the aggregates were recombined to provide the desired gradation. In the recombination, the composition of each size fraction relative to aggregate sources was held constant. Thus, if the #4 to #10 material of the job mix formula was composed of 18% from the coarse aggregate source, 37% from the coarse sand, and 45% from the fine sand, these same percentages were used for the #4 to #10 fraction in all gradation variations of that mix. In this manner, all effects observed from the testing are the result of variations in the gradation rather than the result of variations in aggregate composition.

The mix for each test specimen was batched separately. The aggregate and asphalt were heated to approximately 300^{o} F for mixing and molding.

Two types of test specimens were prepared - standard Marshall specimens and 4X4 (4" diameter by 4" high) cylindrical specimens. The Marshall specimens were molded in accordance with AASHTO T245(13) using 75 blows of the compaction hammer on each face of the specimens. The 4X4 specimens were prepared using rodding and static compaction.

The cylindrical molds for the 4X4 specimens were designed to provide a fixed volume for density control. This was accomplished by having end caps that extended into the mold a



$X = (z/L)^{.45} - (S/L)^{.45}$
z = sieve size of interest
S = smallest sieve size, .075 mm (#200)
L = largest sieve size, 19 mm binder, 12.5 mm surface
F = maximum deviation for sieve size
$A = (L/L)^{.45} - (S/L)^{.45} = 1 - (S/L)^{.45}$

PRORATION EQUATION:

$$Y = -F + 2F \frac{(z/L)^{.45} - (S/L)^{.45}}{1 - (S/L)^{.45}}$$

Figure 3-2. Method Used to Prorate FINE-COARSE and COARSE-FINE Gradations.

Table 3-3. Gradation Variations Used in Study.

CHANGE IN PERCENT PASSING FROM JOB MIX FORMULA

SIEVE SIZE	SURFACE COURSE MIXES				
	FINE	FINE-COARSE	JMF	COARSE-FINE	COARSE
1/2"	+6	+6	0	-6	-6
3/8"	+8	+5.93	0	-5.93	-8
#4	+6	+1.29	0	-1.29	-6
#10	+5	-1.24	0	+1.24	-6
#20	+5	-2.80	0	+2.80	-5
#40	+4	-2.95	0	+2.95	-4
#80	+3	-2.68	0	+2.68	-3
#200	+2	-2	0	+2	-2

SIEVE SIZE	BINDER COURSE MIXES				
	FINE	FINE-COARSE	JMF	COARSE-FINE	COARSE
3/4"	+8	+8	0	-8	-8
1/2"	+12	+7.51	0	-7.51	-12
3/8"	+12	+4.99	0	-4.99	-12
#4	+8	-0.10	0	+0.10	-8
#10	+6	-2.33	0	+2.33	-6
#20	+6	-3.85	0	+3.85	-6
#40	+5	-3.93	0	+3.93	-5
#80	+4	-3.65	0	+3.65	-4
#200	+2.5	-2.50	0	+2.50	-2.5

fixed distance. The distance was controlled by a lip extending beyond the cap. A spacer was used with the bottom end cap to hold it partially out of the mold during rodding. This provided for both end caps to be pushed into the mold during the static compaction. In this way compaction was obtained from both ends.

In preparing the 4X4 specimens, the amount of mix required to produce a specimen having 5% air voids was weighed out and divided into thirds. Each third was placed in the mold and rodded in place. After all three layers had been rodded, compaction was completed on a compression test device by pushing the end caps until the volume control lips were seated on the mold. The objective was to produce specimens having 5% air voids that were uniform top to bottom. As will be shown later, this objective was not achieved.

MARSHALL SPECIMEN TESTING

Four Marshall specimens were made of each gradation variation for each mix. These specimens were tested for air voids, VMA, resilient modulus, Marshall stability, and Marshall flow. Air voids and VMA were determined based on specimen bulk specific gravities (AASHTO T166) and Rice maximum specific gravities (AASHTO T209).

Resilient modulus was determined using the diametral test developed by Schmidt[14]. The test temperature was 77° F. The dynamic pulse load was 75 pounds and the radial displacement due to the load was measured at 0.05 seconds of loading. Measurements were made on three axes 120 degrees apart and the average was used as the specimen resilient modulus.

4X4 SPECIMEN TESTING

Two 4X4 specimens were made for each gradation variation. These specimens were used for creep testing and split tensile strength testing.

The creep testing was conducted at 104° F using the apparatus depicted in Figure 3-3.

Figure 3-3. Apparatus Used for Creep Testing.

The specimens were placed in an oven set at 104° F for at least 24 hours prior to testing. For temperature control during testing, an insulated chamber was placed on the test apparatus around the loading head. Temperature was controlled using a thermal couple temperature probe which was attached as a thermostat to a hair dryer. The test specimens were stored in the chamber at least one hour prior to testing for temperature stabilization.

The top and bottom surfaces of the specimens were coated with graphite prior to testing to reduce surface friction. Prior to creep testing, each specimen was conditioned with a set loading history to reduce any influence due to small surface irregularities. The conditioning consisted of applying the creep loading (15 psi) for 10 minutes followed by 10 minutes of no load.

The creep load (15 psi) was then applied for one hour with the creep deformation being measured at 5 seconds, 30 seconds, 2 minutes, 30 minutes, and 60 minutes. The creep stiffness was calculated for each measurement time as:

$$S_x = l * h/d$$

where

S_x = the creep stiffness at time x

l = the creep loading stress, 15 psi

h = the original height of the specimen

d = the specimen vertical deformation at time x.

After creep testing, each 4X4 specimen was sawed in half to provide two specimens for the split tensile strength test. The split tensile strength was determined at 77° F using the Marshall test apparatus but with the Marshall breaking head replaced by loading caps that would apply the diametral load over a half-inch bearing width. The rate of loading was the same as the Marshall loading rate, 2 inches per minute.

CHAPTER 4

DATA ANALYSES

ANALYSES OF MARSHALL SPECIMEN DATA

Methods of Analysis

The data from testing the Marshall specimens are listed in Appendix A. These data were analyzed to identify the effect of gradation variation. Two types of analyses were used - analysis of variance and T-test groupings.

Analysis of variance examines the variation in the test parameters (i.e. air voids, VMA, stability, flow, and resilient modulus). It compares the variation observed between replicate mix specimens (specimens having the same gradation) with the variation observed between mix specimens having the different gradations. If gradation has no effect, the degree of variation will be the same for both replicate specimens and for specimens of different gradation. However, if gradation does affect the value of the test parameter, the degree of variation for all the test specimens will be greater than the degree of variation for test specimens from a single gradation.

The measure of statistical significance in the analysis of variance is the F ratio. The level of significance is indicated by the probability of finding a higher F ratio when in fact no effect due to gradation exists. Low probabilities of a higher F indicate a high probability of an effect attributable to gradation. In this study, probabilities less than 0.05 were judged as being indicative of a statistically significant effect due to gradation.

Analysis of variance provides a statistical determination of whether or not differences exist in the test parameter values that might be due to the gradation variation. However, if differences are identified, analysis of variance does not indicate where those differences occur (i.e. which gradations cause the differences). To make this type of determination, the T-test groupings were employed.

The T-test groupings examine the mean values of the test parameters relative to the various mix gradation categories. The means are compared one by one using the standard T-test. Based on the individual comparisons the gradations are are placed in groups having similar means. The separation of the various gradations into two or more groups indicate a significant difference between the mean values of the test parameter being examined. This, then, is an indication of an effect attributable to the gradation variation.

These two methods of analysis were used to analyze the Marshall specimen data from each of the mixes individually and to analyze all of the data together. When all of the data were analyzed together, the analysis of variance was performed to also identify effects attributable to the type of aggregate (limestone, gravel, and syenite) and the type of mix (surface and binder). The analyses for all the data are presented with the following discussions. The individual mix analyses are listed in Appendix B.

Air Void Analyses

Analysis of variance (Table 4-1) showed that air voids were affected by gradation variation, mix type, and aggregate type. The T-test groupings (Table 4-1 and Tables A-1 through A-3) showed that the FINE-COARSE gradation had the highest air voids for each of the 6 mixes while the COARSE-FINE mix had the lowest. The other gradation variations (i.e. FINE, COARSE, and JMF) tended to have nearly equal air void contents.

These data show that the crossover gradation variations (i.e. COARSE-FINE or FINE-COARSE) have the greatest effect on air voids. Gradation variations that tend to parallel the job mix gradation do not cause significant changes in the mix air void contents. However, gradation variations that cross from coarse on the large size fractions to fine on the small size fractions cause a significant decrease in air voids. Conversely, gradation variations that cross from fine to coarse cause an increase in the air voids. For the mixes tested, the COARSE-FINE gradation would be judged to be most detrimental since it

Table 4-1. Analyses of Air Voids in All Marshall Specimens.

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. of > F
Gradation (G)	4	60.102	15.025	84.99	0.0001
Aggregate (A)	2	29.119	14.559	82.35	0.0001
Mix Type (M)	1	7.047	7.047	39.86	0.0001
G*A	8	4.450	0.556	3.15	0.0035
G*M	4	1.061	0.265	1.50	0.2088
A*M	2	2.347	1.173	6.64	0.0020
G*A*M	8	4.913	0.614	3.47	0.0016
Error	90	15.911	0.177		
Total	119	124.950			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean (%)	Gradation Variation
A	3.591	FINE-COARSE
B	2.298	FINE
B	2.202	JOB MIX FORMULA
B	2.126	COARSE
C	1.405	COARSE-FINE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

resulted in air void contents that would be unacceptably low.

VMA Analyses

Analyses of the VMA data produced results nearly identical to the air void analyses. VMA was found to be affected by gradation variation, mix type, and aggregate type (Table 4-2). The T-test groupings for each of the 6 mixes (Tables B-4 through B-6) showed the FINE-COARSE gradation to have the highest VMA with COARSE-FINE having the lowest. The other gradation variations (i.e. FINE, COARSE, and JMF) tended to have nearly equal VMA contents.

Similar to the air void analyses, the crossover gradation variations are seen to (i.e. COARSE-FINE or FINE-COARSE) have the greatest effect on VMA. No significant changes in VMA were observed for gradation variations that tend to parallel the job mix gradation. However, COARSE-FINE gradations cause a significant decrease in VMA while FINE-COARSE gradations cause an increase in VMA. The COARSE-FINE gradation would be judged to be most detrimental since it resulted in VMA content that would be unacceptably low.

Stability Analyses

Analysis of variance (Table 4-3) of the Marshall stability data from all the mixes showed significant effects due to gradation, aggregate type, and mix type. In general, the FINE gradation had the highest stability and the FINE-COARSE gradation had the lowest stability.

These trends, however, were not observed in every mix (Tables B-7 through B-9). The highest stability occurred with the FINE gradation in 5 of the 6 mixes and was second highest in the sixth mix. Similarly, the FINE-COARSE gradation had the lowest stability in 4 of the 6 mixes and was second lowest in the other two.

Table 4-2. Analyses of VMA of All Marshall Specimens.

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. of > F
Gradation (G)	4	45.101	11.275	83.23	0.0001
Aggregate (A)	2	17.834	8.917	65.82	0.0001
Mix Type (M)	1	226.051	226.051	1668.61	0.0001
G*A	8	4.712	0.589	4.35	0.0002
G*M	4	0.877	0.219	1.62	0.1764
A*M	2	1.718	0.859	6.34	0.0027
G*A*M	8	3.548	0.443	3.27	0.0025
Error	90	12.193	0.135		
Total	119	312.033			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean (%)	Gradation Variation
A	14.721	FINE-COARSE
B	13.575	FINE
B	13.508	JOB MIX FORMULA
B	13.454	COARSE
C	12.829	COARSE-FINE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

Table 4-3. Analyses of Stability Data from All Marshall Specimens.

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. of > F
Gradation (G)	4	12869657	3217414	25.70	0.0001
Aggregate (A)	2	18954544	9477272	75.69	0.0001
Mix Type (M)	1	9403521	9403521	75.10	0.0001
G*A	8	2741912	342739	2.74	0.0095
G*M	4	1249571	312393	2.50	0.0484
A*M	2	4854283	2427141	19.39	0.0001
G*A*M	8	1550071	193759	1.55	0.1522
Error	90	11268529	125206		
Total	119	62892086			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean (lb)	Gradation Variation
A	4206.7	FINE
A & B	3966.5	COARSE-FINE
B & C	3807.3	JOB MIX FORMULA
C & D	3471.8	COARSE
D	3302.8	FINE-COARSE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

It should be noted that the stabilities of all the mixes were quite high and that the lowest stabilities observed would not be considered to be indicative of a mixture problem. Consequently, the effect of gradation variation on the stability of these mixes does not appear to be significant.

Flow Analyses

Marshall flow was also found to be affected by gradation, aggregate type, and mix type (Table 4-4). The T-test groupings showed that for 5 of the 6 mixes the COARSE-FINE gradation had the highest flow while the FINE-COARSE gradation had the lowest flow (Tables B-10 through B-12). The other gradation variations (i.e. FINE, JMF, and COARSE) did not show any consistent pattern.

The T grouping analysis for all the data showed the flow data to fit into three gradation groups. The COARSE-FINE gradations were alone in the high flow group and the FINE-COARSE gradations were alone in the low flow group. The other gradations were grouped together.

Thus, similar to the air voids and VMA data, the flow data suggests that gradation variations that parallel the job mix gradation do not significantly affect the mix. The crossover variations that change the shape of the gradation curve do have a significant affect. It should also be pointed out that the flow values of some of the COARSE-FINE gradations approached and exceeded the maximum value[16] generally considered to be acceptable for heavy traffic conditions.

Resilient Modulus Analyses

Analysis of variance found no significant differences in the resilient modulus values that might be attributed to the gradation variation. Analysis of all the data (Table 4-5) indicated significant effects attributable to aggregate type and mix type but no significant effect

Table 4-4. Analyses of Flow Data from All Marshall Specimens.

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. of > F
Gradation (G)	4	221.686	55.421	19.76	0.0001
Aggregate (A)	2	86.565	43.283	15.43	0.0001
Mix Type (M)	1	71.765	71.765	25.59	0.0001
G*A	8	70.329	8.791	3.13	0.0036
G*M	4	33.529	8.382	2.99	0.0229
A*M	2	25.817	12.909	4.60	0.0125
G*A*M	8	15.674	1.959	0.70	0.6920
Error	90	252.430	2.805		
Total	119	777.795			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean (.01")	Gradation Variation
A	15.893	COARSE-FINE
B	13.858	JOB MIX FORMULA
B	13.554	FINE
B	13.346	COARSE
C	11.633	FINE-COARSE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

Table 4-5. Analyses of Resilient Modulus Data from All Mixes.

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. of > F
Gradation (G)	4	54785	13696	1.43	0.2298
Aggregate (A)	2	521449	260724	27.27	0.0001
Mix Type (M)	1	4443671	4443671	464.71	0.0001
G*A	8	283344	35418	3.70	0.0009
G*M	4	52188	13047	1.36	0.2526
A*M	2	275998	137999	14.43	0.0001
G*A*M	8	266125	33266	3.48	0.0015
Error	90	860602	9562		
Total	119	6758162			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean, ksi	Gradation Variation
A	812	JOB MIX FORMULA
A	809	FINE
A	803	COARSE
A	780	COARSE-FINE
A	755	FINE-COARSE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

due to gradation. Although analyses of the individual mixes (Tables B-13 through B-15) indicated some effects attributable to gradation, no general trends were apparent. Overall. within the range used in this study gradation variation appears to have little affect on the resilient modulus of the mix.

ANALYSES OF 4X4 SPECIMEN DATA

Methods of Analysis

The data from the 4X4 specimens are listed in Appendix C. These data were analyzed in much the same manner as used with the Marshall specimen data. However, analysis of covariance was used in lieu of analysis of variance for some of the analyses.

Analysis of covariance is quite similar to analysis of variance except that it is used when some of the variables being analyzed are continuous, measured values as opposed to classifications. Gradation category, aggregate type, and mix type are all classification variables. Data from a given mix fits into specific categories of gradation, mix, and aggregate. Air voids, on the other hand, is a measured value that covers a continuous range.

Because air voids could not be controlled precisely but have a strong impact on strength, the analyses of the 4X4 specimen data included examination of the effects of air voids. This was done using the analysis of covariance which, in effect, provides a means to compensate for the influence of differences in air void contents.

The analyses of covariance listings are somewhat different from the listings for analysis of variance. The analyses of covariance show both Type I and Type III sums of squares. The Type I sums of squares pertain to the model analysis and the corresponding F ratios relate to the significance of the mix parameters as they are added sequentially in the analysis. In this respect, they do not necessarily reflect the level of significance for the individual parameters (i.e. gradation, mix type, or aggregate type). The Type III sums of squares and corresponding F ratios provide a measure of the significance of the individual parameters.

Similar to the analysis of variance, the measure of statistical significance in the analysis of covariance is the F ratio. However, for the individual mix parameters the F ratio from the Type III sums of squares should be examined. The level of significance is indicated by the probability of finding a higher F ratio when in fact no effect due to gradation exists. Low probabilities of a higher F indicate a high probability of an effect attributable to gradation. In this study, probabilities less than 0.05 were judged as being indicative of a statistically significant effect due to gradation.

The analysis of covariance was used primarily with the split tensile strength data. Preliminary analyses of the creep data using analysis of covariance revealed that air void variation did not have a significant effect on the creep stiffnesses. Therefore, analysis of variance was used and is reported for the creep data.

The T-test groupings were again used to examine the mean values of the test parameters relative to the various mix gradation categories. In addition, the split tensile strength data were examined with the mean strengths adjusted for the effects of density.

These methods of analysis were used to analyze the 4X4 specimen data from each of the mixes individually and to analyze all of the data together. When all of the data were analyzed together, the analysis was performed to also identify effects attributable to the type of aggregate (limestone, gravel, and syenite) and the type of mix (surface and binder). The analyses for all the data are presented with the following discussions. Individual mix analyses are listed in Appendix D.

Split Tensile Strength Analyses

The analysis of covariance showed split tensile strength to be affected by gradation variation and air void content (Tables 4-6 and D-1 through D-3). Aggregate type and mix type were not found to be significant as individual parameters but the interaction between them (A*M) was found to be significant. An examination of the strength data reveals the

Table 4-6. Split Tensile Strength Data Analyses for All Mixes.

ANALYSIS OF COVARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. of > F
Model					
Gradation (G)	4	6781.7	1695.4	15.02	0.0001
Aggregate (A)	2	9084.8	4542.4	40.25	0.0001
Mix Type (M)	1	3809.4	3809.4	33.75	0.0001
G*A	8	1253.1	156.6	1.39	0.2131
G*M	4	591.6	147.9	1.31	0.2725
A*M	2	5632.7	2816.4	24.95	0.0001
G*A*M	8	696.9	87.1	0.77	0.6284
Air Voids	1	19022.5	19022.5	168.55	0.0001
Error	87	9818.7	122.9		
Total	117	56691.5			
TYPE III SUM OF SQUARES					
Gradation (G)	4	9864.2	2466.0	21.85	0.0001
Aggregate (A)	2	25.5	12.7	0.11	0.8935
Mix Type (M)	1	25.7	25.7	0.23	0.6347
G*A	8	371.1	46.4	0.41	0.9115
G*M	4	1064.5	266.1	2.36	0.0597
A*M	2	3800.2	1900.1	16.84	0.0001
G*A*M	8	703.4	87.9	0.78	0.6222
Air Voids	1	19022.5	19022.5	168.55	0.0001

The level of significance is indicated by the probability of greater F. The Type III sum of squares is indicative of individual effects. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean (psi)	Gradation Variation
A	144.1	JOB MIX FORMULA
A & B	139.0	COARSE-FINE
B & C	134.8	FINE
C	129.5	FINE-COARSE
D	122.0	COARSE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

reason for this. With the limestone and gravel aggregate, the binder mixes had higher strengths than did the surface mixes. However, the surface mix was stronger with the syenite aggregate. Also, the syenite aggregate had the highest strength for surface mixes but the lowest for binder mixes.

The T groupings from all the data (Table 4-6) show the JMF gradation to have the highest strength. The COARSE gradation had the lowest strength and is grouped alone indicating that its strength is significantly lower than any of the other gradation variations. In the individual mix analyses, JMF was found to have the highest strength for 4 of the 6 mixes and COARSE was found to be lowest for 5 of the 6. However, because of the very strong influence of air void content on strength, additional analyses were performed to compensate for the influence of differences in air void content.

This was done by performing regression analyses on the data for each gradation variation. These analyses produced a series of equations that can be used to predict the split tensile strength for any given air void content. The regression equations and the predicted strengths for air void contents of 4 to 7 percent air voids are shown in Table 4-7. Note that at 6 and 7 percent air voids the FINE gradation is predicted to have the highest strength and the JMF gradation is second highest. The COARSE gradation has the lowest predicted strength at each air void content.

Creep Data Analyses

Preliminary analyses of the creep data examined the effect of air voids. These analyses showed that air void content variation was not a significant factor relative to creep stiffness. As an example, the analysis of covariance for the 60 minute creep stiffness for all the data had a probability of greater F of 0.1474 (Table 4-8). Similar results were obtained for each of the other time intervals and in the analyses of the data from the individual mixes.

Subsequent analyses employed analysis of variance and examined the influence of

Table 4-7. Split Tensile Strengths Adjusted for Air Void Content.

Gradation Variation	Mix Air Void Content 4%	5%	6%	7%
	Predicted Split Tensile Strength, psi			
JMF	181	164	148	132
FINE	172	161	150	139
FINE-COARSE	171	158	144	130
COARSE-FINE	167	154	140	126
COARSE	142	133	124	114

Prediction Equation: ST = a + b*AV

where ST = predicted strength

a & b = regression constants that have the following values

	a	b
JMF	245.8	-16.30
FINE	215.5	-10.92
FINE-COARSE	226.0	-13.65
COARSE-FINE	222.7	-13.81
COARSE	180.1	- 9.41

(R^2 = .74, Std. Error of Est. = 11.7)

Table 4-8. Analysis of Covariance of 60 Minute Creep Data.

ANALYSIS OF COVARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. of > F
Model					
Gradation (G)	4	2933400	733350	2.84	0.0421
Aggregate (A)	2	24890594	12445297	48.21	0.0001
Mix Type (M)	1	372740	372740	1.44	0.2392
G*A	8	3493348	436668	1.69	0.1430
G*M	4	287244	71811	0.28	0.8897
A*M	2	800213	400107	1.55	0.2293
G*A*M	8	6545629	818204	3.17	0.0105
Air Voids	1	572154	572154	2.22	0.1474
Error	29	7486454	258154		
Total	59	47381776			
TYPE III SUM OF SQUARES					
Gradation (G)	4	3026974	756744	2.93	0.0376
Aggregate (A)	2	2947324	1473662	5.71	0.0081
Mix Type (M)	1	139284	139284	0.54	0.4685
G*A	8	4065483	508185	1.97	0.0871
G*M	4	566694	141673	0.55	0.7013
A*M	2	538552	269276	1.04	0.3652
G*A*M	8	7063870	882984	3.42	0.0069
Air Voids	1	572154	572154	2.22	0.1474

The level of significance is indicated by the probability of greater F. The Type III sum of squares is indicative of individual effects. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

gradation variation, aggregate type, and mix type. Table 4-9 displays the analyses for the 60 minute creep stiffness. The analysis of variance shows that gradation variation and aggregate type have a significant effect on creep stiffness but that mix type is not significant. Analyses of the creep stiffnesses at the other time intervals (Tables D-4 through D-7) were similar except gradation was not significant at the 5 second interval and mix type was significant at 2 minutes, 30 seconds, and 5 seconds.

For each time interval, the T groupings for all the data show that the JMF had the highest creep stiffness and the COARSE-FINE and FINE-COARSE gradations had the lowest creep stiffnesses. FINE and COARSE had about the same stiffnesses and alternated with one another for second and third highest. Thus, similar to the results from the Marshall specimens, the crossover gradation variations were found to have greater impact on the properties of the mix than do gradation variations that result simply in a finer or coarser mix.

However, the differences between creep stiffnesses for the various gradations are not great and the relative rankings are not consistent when the data from the individual mixes are examined. At the 60 minute, 30 second, and 5 second intervals four gradations are placed in a single group indicating no significant difference. When the individual mixes are examined (Table D-8), JMF is found to have the highest creep stiffness only in 2 cases; COARSE-FINE is lowest or second lowest in 4 cases; and FINE-COARSE is lowest or second lowest in only 3 cases.

Comments on Air Voids

Although this study was not intended to study the effect of air voids, the inability to control the air voids in the 4X4 specimens and the impact of air voids on the test results warrant comment. The 4X4 specimens were molded in a manner intended to produce uniform specimens of controlled (5%) air void content. Examination of the creep data (Tables

Table 4-9. Analyses of 60 Minute Creep Data from All Mixes.

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. of > F
Gradation (G)	4	2933400	733350	2.73	0.0475
Aggregate (A)	2	24890594	12445297	46.33	0.0001
Mix Type (M)	1	372740	372740	1.69	0.2481
G*A	8	3493348	436668	1.63	0.1592
G*M	4	287244	71811	0.27	0.8966
A*M	2	800213	400107	1.49	0.2417
G*A*M	8	6545629	818204	3.05	0.0125
Error	30	8058608	268620		
Total	59	47381776			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean, psi	Gradation Variation
A	5994	JOB MIX FORMULA
A & B	5702	FINE
A & B	5680	COARSE
B	5442	COARSE-FINE
B	5367	FINE-COARSE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

C-3 and C-4) shows that the control of air voids was not successful. After the creep testing the 4X4 specimens were sawed in half and used for the split tensile testing. The split tensile data (Tables C-1 and C-2) shows that the specimens were also not uniform. In all cases, the top half of the specimen had lower air voids than did the bottom half. In all cases, the top half also had the higher split tensile strength.

Regression analysis of all the split tensile strength data showed that in general a 1% decrease in air voids results in a 12.7 psi increase in split tensile strength. For the individual gradation variations (Table 4-7), this effect ranged from 9.4 psi/% for the COARSE gradations to 16.3 psi/% for the JMF gradations. This suggests that, within the typical range of variation encountered on asphalt construction projects, split tensile strength (and by extension fatigue life) is more sensitive to the density achieved than it is to gradation variation.

Although air voids was not found to be significant in the creep data analyses, the creep data do indicate an effect due to air voids (and density). Correlation analyses of the creep data reveal a significant negative correlation between creep stiffness at each of the testing time intervals and air void content. The negative correlations mean that lower air voids (higher density) result in a higher creep stiffness or lower rut development potential. However, since air voids was not found to be a significant parameter in the creep data analyses (Table 4-8), creep stiffness appears to be less sensitive to density variation than it is to gradation variation.

RELATIVE LIFE EFFECTS

The split tensile strength and creep tests were performed to provide data that could be used to examine the relative effects of gradation variation on the life of an asphalt pavement. The relative life analyses were to follow procedures established by Elliott and Herrin[1]. Since the various gradations were examined relative to the job mix formula, the JMF gradation was assigned a relative life of 100%.

Fatigue Life Analyses

The split tensile strength data was to be used to estimate the effect of gradation variation on the fatigue life of an asphalt pavement. The fatigue procedure is based on work by Maupin[16] who showed that the split tensile strength can provide a reasonable estimate of the fatigue properties of a mix. Using Maupin's relationships, Elliott and Herrin developed the following relative life equation:

$$\log (N_a/N_b) = SF * (ST_a - ST_b)$$

where

N_a/N_b = the relative life ratio for two mix variations, a and b

ST_a and ST_b = the split tensile strengths of the two mix variations

SF = a strain factor which Elliott and Herrin found to be 0.0163 for typical asphalt pavements.

The relative life equation was applied to both the mean strength data and to the split tensile strengths adjusted for air void content. Table 4-10 lists the relative life predictions based on the mean strength data and on the strengths predicted for 5% air voids which was the target air voids for the study. The relative life predictions for air void contents of 4 to 7 percent are shown in Figure 4-1.

These results indicate that the relative life prediction is quite sensitive to variations in split tensile strength. They show that the COARSE gradation variation can be expected to have a significantly greater detrimental impact on fatigue life than do the other variations. The results also suggest that, within the normal range of air void and gradation variation, fatigue life is generally more sensitive to air void content (i.e. compaction) than it is to gradation.

Rut Depth Analyses

The creep data were to be used to examine relative life effects in terms of rut development. The simple creep data are used in the Shell method[17] of asphalt pavement design

Table 4-10. Relative Fatigue Life Analyses Using Mean Strength Data and Predicted Strength at 5% Air Voids.

Gradation Variation	Mean Strength	Relative Life	Predicted Strength, 5% AV	Relative Life
JMF	144 psi	100%	164 psi	100%
FINE	139 psi	83%	161 psi	88%
FINE-COARSE	135 psi	71%	158 psi	78%
COARSE-FINE	130 psi	58%	154 psi	67%
COARSE	122 psi	44%	133 psi	31%

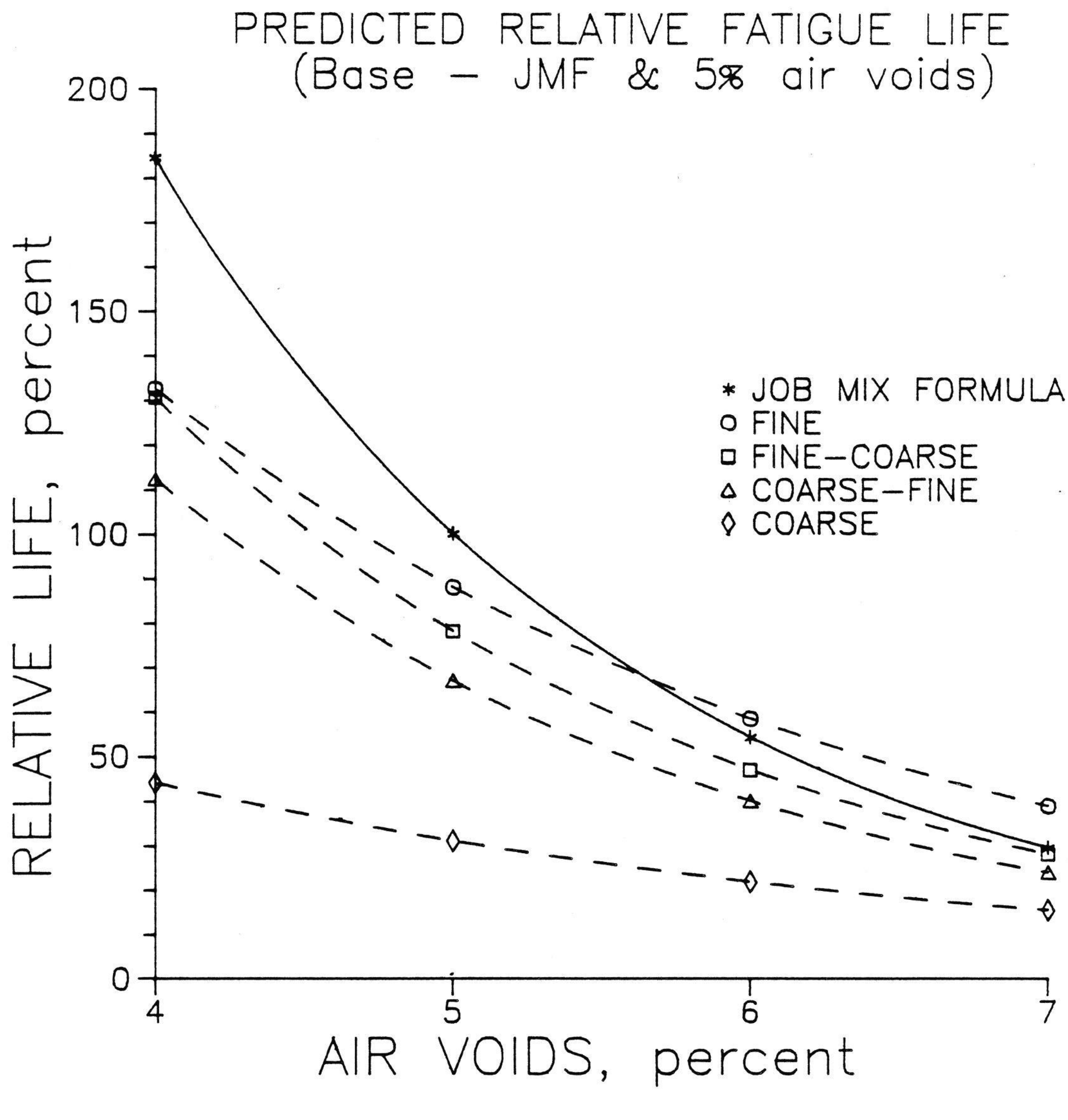


Figure 4-1. Fatigue Relative Life Effects of Gradation and Air Voids.

to predict rutting in asphalt layers. In its simplest form, the Shell rut prediction equation is:

$$RD = h * s/S_{mix}$$

where

RD = the predicted depth of rutting
h = the thickness of the asphalt layer
s = the average load induced stress in the layer
S_{mix} = the stiffness of the mix at the total (accumulated) time of all axle loadings applied.

The stiffness of the mix used in the prediction is for the mix at a temperature "representative" of local climatic conditions and at the accumulated total time of heavy vehicle applications. The stiffness is selected based on a relationship developed from the simple creep test between the stiffness of the mix and the stiffness of the asphalt cement.

Shell has shown that a linear logarithmic relationship exists between mix stiffness and asphalt stiffness. The specific relationship for a given mix is developed by: 1) measuring the mix stiffness at various time intervals using the simple creep test, 2) determining the asphalt stiffness at those time intervals and the creep test temperature using Van der Poel's nomograph (Figure 4-2), and 3) performing a best fit linear logarithmic regression analysis on the stiffness values.

In the rut depth prediction for a given mix, the total time of axle loading and the "representative" mix temperature are determined. These are used with Van der Poel's nomograph to determine the asphalt cement stiffness. This asphalt mix stiffness is then used with the linear logarithmic relationship to determine the mix stiffness that goes into the rut depth prediction equation.

The data from this study were analyzed to develop the "typical" linear logarithmic relationships for each gradation variation. The resulting relationships were subsequently used with the Shell method of rut prediction to examine the effect of the gradation variations on rut development in a 6 inch asphalt layer. Two types of analyses were made: 1) relative depth of rutting for a fixed number of axle loads and 2) relative life in terms of the number of axle loads to a fixed depth of rutting. Both analyses were made for two levels of

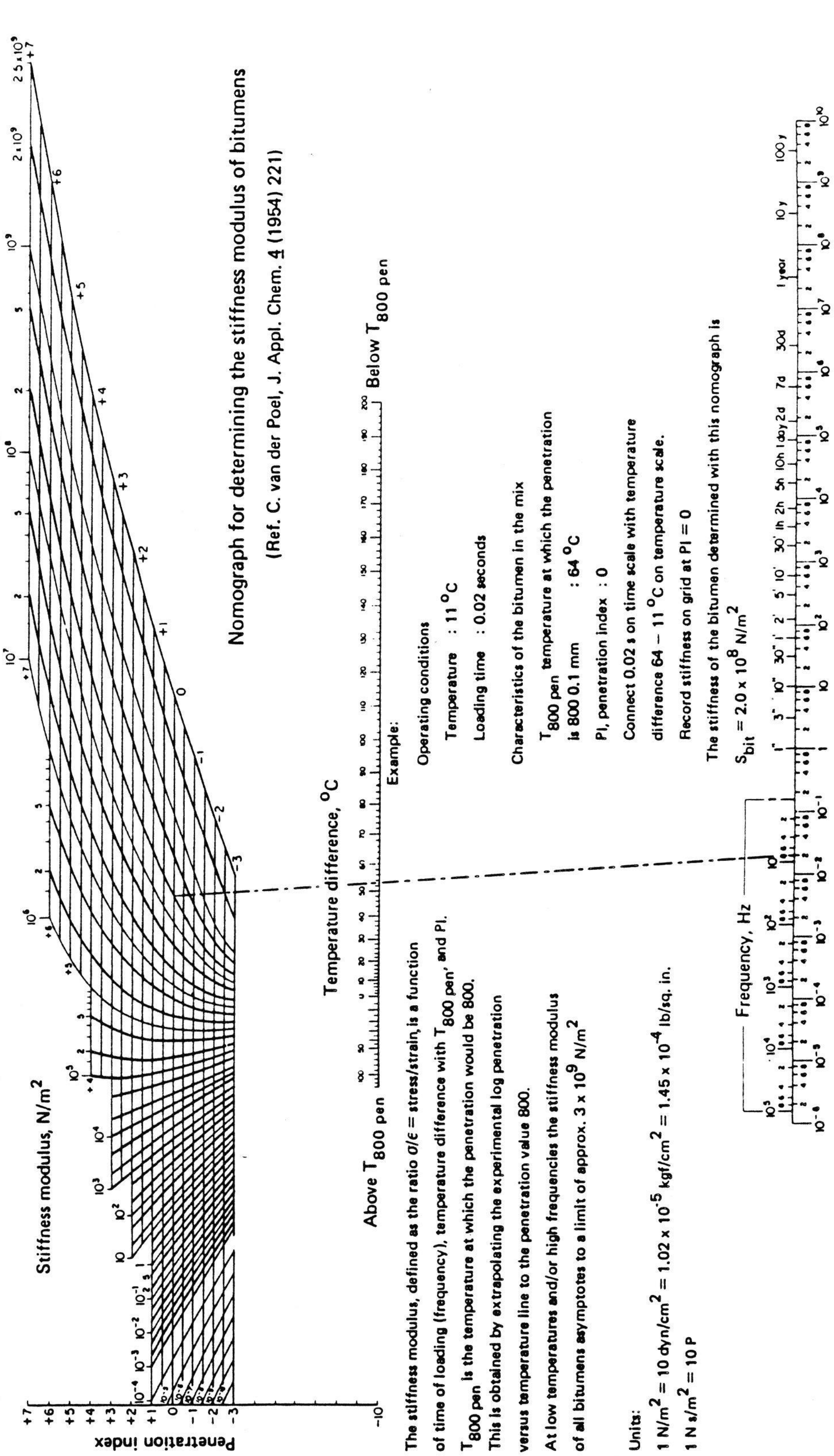


Figure 4-2. Van der Poel's Asphalt Stiffness Nomograph (17).

traffic - 1 million and 50 million axle applications. The rut depth in the JMF gradation at the two traffic levels served as the fixed depth of rutting for the relative life analysis.

The results of the rut depth analyses are presented in Table 4-11. The upper portion of the table shows the relative depth of rutting for the two traffic levels (one million and fifty million axle applications). These anayses indicate that, in comparison with the JMF gradation, the FINE and COARSE gradation variations would experience 7 to 10% greater depth of rutting and the COARSE-FINE and FINE-COARSE gradation variations would experience 13 to 19% greater depth of rutting.

The lower half of Table 4-11 displays the results of the relative life analyses. The relative life is based on the number of load applications to fixed depths of rutting. The depths of rutting in these analyses were the depths predicted in the JMF mix for one million and fifty million axle applications. These analyses indicate that the relative life of the FINE and COARSE gradations are only 30 to 40% that of the JMF gradation and that the COARSE-FINE and FINE-COARSE relative lives are only 11 to 23%.

Comments Regarding Relative Life Analyses

The relative life analyses demonstrate that predicted fatigue life and rut development is quite sensitive to seemingly minor variations in split tensile strength and creep behavior. For example, the difference between the creep stiffnesses of the JMF, FINE and COARSE gradations are not statistically significant; yet, the relative life analysis indicates a 60 to 70% reduction in relative life based on rut development. Similarly, the differences in the split tensile strengths of the JMF and FINE gradations are not statistically significant; and the relative life analysis indicates a fatigue life reduction of 17% for the FINE gradation.

This does not suggest that the relative life analyses are in error but it does show that they must be viewed with caution and should not be applied to an individual case without due consideration of the influence of normal construction variability. Bear in mind that the

Table 4-11. Relative Rut Depth Prediction Analyses.

Gradation Variation	DEPTH OF RUTTING TO FIXED NUMBER OF AXLE LOADS One Million Axle Loads Rut Depth	One Million Axle Loads % of JMF	Fifty Million Axle Loads Rut Depth	Fifty Million Axle Loads % of JMF
JOB MIX FORMULA	.160"	100	.210"	100
FINE	.172"	107	.230"	109
COARSE	.172"	107	.232"	110
COARSE-FINE	.180"	113	.246"	117
FINE-COARSE	.186"	116	.249"	119

Gradation Variation	PREDICTED APPLICATIONS TO FIXED DEPTH OF RUTTING Rut Depth = .160" Applications	Rut Depth = .160" % of JMF	Rut Depth = .210" Applications	Rut Depth = .210" % of JMF
JOB MIX FORMULA	1,000,000	100	50,000,000	100
FINE	401,000	40	14,960,000	30
COARSE	389,000	39	13,540,000	27
COARSE-FINE	226,000	23	6,810,000	14
FINE-COARSE	165,500	17	5,360,000	11

variability tested in this study reflects the extremes encountered on typical construction projects. Consequently the extremes of relative life predicted should also represent typical extremes. The observed sensitivity may account for the variability of performance that is normal to most pavements.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This study investigated the effect of aggregate gradation variation on the behavior of asphalt concrete hot mixes. The gradation variations tested were selected to represent the extremes typically encountered on actual construction projects. Six mixes were tested, three surfaces and three binders. Each mix was tested at 5 different aggregate gradations (Figure 3-1) - 1) the job mix formula (JMF), 2) a coarse gradation (COARSE), 3) a fine gradation (FINE), 4) a gradation that crossed from coarse on the large size fractions to fine on the small size fractions (COARSE-FINE), and 5) a gradation that crossed from fine on the large size fractions to coarse on the small size fractions (FINE-COARSE).

The measures of effect were the Marshall mix design parameters (i.e. stability, flow, air voids, and VMA), resilient modulus, tensile strength, and creep stiffness. The tensile strength data and creep stiffness data were used to estimate the relative pavement life effects of the variations.

Based on analysis of the data from this study, the following conclusions are in order.

1) Gradation variations within the magnitude tested have the greatest effect when they result in a change in the general shape of the gradation curve (i.e. the FINE-COARSE and COARSE-FINE gradations).
2) FINE-COARSE gradation variations cause the highest Marshall air voids and VMA. COARSE-FINE gradation variations cause the lowest Marshall air voids and VMA.
3) COARSE-FINE gradation variations produce the highest Marshall flow and FINE-COARSE gradation variations produce the lowest.
4) Creep stiffness is lowest for COARSE-FINE and FINE-COARSE gradation variations.

5) Relative to air voids, VMA, and flow, the COARSE-FINE gradation produced the most detrimental effect on the mixes tested. Some of the air void and VMA values were less than those normally considered to be acceptable and some of the flow values were greater than those normally acceptable.

6) Marshall stability is affected by gradation variations with the FINE gradations producing the highest stability and the FINE-COARSE gradations producing the lowest. However, for the mixes tested all of the gradations were found to have stabilities that are considered to be more than adequate.

7) COARSE gradation variations produce the lowest tensile strengths. The JMF gradation generally produced the highest strength but, when adjusted for differences in air voids, all gradations except COARSE had about the same strength.

8) Within the range of variations normally encountered, tensile strength is more sensitive to air void content (i.e. compaction) than it is to gradation variation.

IMPLEMENTATION RECOMMENDATIONS

This study has provided information and findings that should be useful in four areas: 1) the review and modification of quality control practices, 2) specification maximum tolerance levels, 3) mix design gradation adjustments, and 4) pay adjustments for mix produced that does not quite comply with the specification tolerance limits. The following are brief discussions regarding each of these potential uses.

Quality Control Practices

The data and analyses from this study demonstrate that improvements in construction quality control that would result in a reduction in gradation variability should also result in an improvement in pavement performance. However, the data also suggests that, within the range of variability normally encountered, improved density control is more critical than improved gradation control.

Specification Maximum Tolerance Limits

The gradation variations tested in this study represent the maximum variations typically encountered on construction projects and closely correspond with the AHTD specification maximum tolerance limits. In general, the mix properties tested in this study were not drastically affected by these variations and the greatest effect was observed with the gradation variations that changed the shape of the gradation curve (i.e. FINE-COARSE and COARSE-FINE). This suggests that the current AHTD maximum tolerance limits are reasonable but that some additional requirement to control the shape of the gradation curve would be beneficial. Some thought was given to the form such a requirement could take, but no satisfactory form was identified.

Gradation Adjustment Decisions

The results of this study suggest that care should be exercised in making decisions regarding mix gradation adjustment without first performing mix design tests. In particular, no change should be made that results in a change in the shape of the gradation curve unless backed up by laboratory test results.

Pay Adjustments

The relative life analyses can be used as the basis for the development of pay adjustment schedules for Quality Assurance specifications and for mix produced under current specifications that does not quite comply with the gradation maximum tolerance limits. However, the analyses cannot be applied directly but must consider both the normal degree of construction variability and the degree of variability on the job in question.

For the proper development of a pay adjustment schedule, analyses must be performed to identify the degree and sources of variation under current construction and material testing practices. From these analyses, a statistically sound acceptance sampling plan would need to be established. The plan must be designed to assure that the pay schedule and its use are unbiased ("fair" to both AHTD and the contractor) and technically defensible. The effort needed to develop such schedules is beyond the scope of this project.

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APPENDIX A

MARSHALL SPECIMEN DATA

Table A-1. Marshall Specimen Test Results - Limestone Surface Mix.

PROJECT NO. TRC-8801
MATERIAL TYPE: LIMESTONE
MIX TYPE: SURFACE
AHTD JOB # 90043

GRADE AC: AC-30
SP. GR. AC: 1.029
COMPACTION: 75 BLOWS

SP. GR. AG: JMF 2.600
COARSE 2.590
FINE 2.605
CRSE-FIN 2.608
FIN-CRSE 2.598
AVG: 2.600

DATE:
10 MAY 1989

GRAD.	% A.C.	HT. CORR.	WEIGHT (GRAMS) AIR	WATER	SSD	SP. GRAVITY ACTUAL	THEOR.	AGG. %VOL.	% VOIDS AIR	VMA	VOIDS FILLED	STAB. (LB.) MEAS.	ADJ.	FLOW (1/100 IN.)
JMF:														
	5.6	0.986	1213.4	698.5	1213.6	2.356	2.395	85.5	1.65	14.5	88.6	3375	3328	14.2
	5.6	0.976	1213.7	697.9	1214.1	2.351	2.395	85.4	1.84	14.6	87.4	3280	3201	14.8
	5.6	0.984	1205.1	690.9	1205.5	2.342	2.395	85.0	2.23	15.0	85.1	3030	2982	13.7
	5.6	0.982	1213.9	699.9	1214.4	2.359	2.395	85.7	1.50	14.3	89.6	3070	3015	14.0
COARSE:														
	5.6	0.976	1199.4	686.4	1200.9	2.331	2.387	84.6	2.35	15.4	84.7	3030	2957	11.0
	5.6	0.980	1216.5	699.0	1217.0	2.348	2.387	85.3	1.62	14.7	89.0	3460	3391	13.6
	5.6	0.967	1212.8	697.1	1213.8	2.347	2.387	85.2	1.68	14.8	88.7	3300	3191	12.5
	5.6	0.990	1206.8	695.2	1207.4	2.356	2.387	85.5	1.30	14.5	91.0	3230	3198	11.5
FINE:														
	5.6	0.998	1211.3	699.2	1211.7	2.364	2.399	85.8	1.49	14.2	89.5	3090	3084	15.0
	5.6	1.000	1213.8	700.2	1214.1	2.362	2.399	85.8	1.55	14.2	89.1	3450	3450	15.1
	5.6	0.953	1210.9	702.2	1211.2	2.379	2.399	86.4	0.84	13.6	93.8	3635	3464	14.9
	5.6	0.987	1215.8	701.3	1216.2	2.361	2.399	85.7	1.58	14.3	88.9	3380	3336	13.9
CRSE-FIN:														
	5.6	0.994	1214.7	703.1	1215.3	2.372	2.402	85.8	1.25	14.2	91.2	3050	3032	14.0
	5.6	1.000	1211.6	700.9	1212.1	2.370	2.402	85.8	1.31	14.2	90.8	2800	2800	15.0
	5.6	1.012	1210.3	702.5	1210.5	2.382	2.402	86.2	0.80	13.8	94.2	3095	3132	16.4
	5.6	1.027	1208.3	702.8	1208.4	2.390	2.402	86.5	0.49	13.5	96.4	2680	2752	15.5
FIN-CRSE:														
	5.6	0.961	1221.6	696.7	1222.0	2.326	2.394	84.5	2.84	15.5	81.6	3240	3114	11.5
	5.6	0.969	1209.8	689.5	1210.2	2.323	2.394	84.4	2.93	15.6	81.2	3080	2985	11.4
	5.6	0.961	1215.5	693.3	1215.7	2.327	2.394	84.5	2.79	15.5	81.9	3070	2950	11.4
	5.6	0.982	1197.7	682.2	1193.0	2.345	2.394	85.2	2.04	14.8	86.2	3140	3083	10.2

Table A-2. Marshall Specimen Test Results - Syenite Surface Mix.

PROJECT NO. TRC-8801
MATERIAL TYPE: SYENITE
MIX TYPE: SURFACE
AHTD JOB # 60275

GRADE AC: AC-30
SP. GR. AC: 1.029
COMPACTION: 75 BLOWS

SP. GR. AG: JMF 2.628
COARSE 2.623
FINE 2.629
CRSE-FIN 2.630
FIN-CRSE 2.627
AVG: 2.627

DATE:
10 MAY 1989

GRAD.	% A.C.	HT. CORR.	WEIGHT (GRAMS) AIR	WATER	SSD	SP. GRAVITY ACTUAL	THEOR.	AGG. %VOL.	% VOIDS AIR	VMA	VOIDS FILLED	STAB. (LB.) MEAS.	ADJ.	FLOW (1/100 IN.)
JMF:														
	5.3	1.000	1194.7	689.9	1195.1	2.365	2.428	85.2	2.60	14.8	82.4	3490	3490	11.6
	5.3	0.999	1193.1	685.8	1194.1	2.347	2.428	84.6	3.33	15.4	78.4	2730	2727	12.8
	5.3	0.999	1197.0	688.1	1197.7	2.349	2.428	84.6	3.26	15.4	78.8	2850	2847	12.4
	5.3	1.024	1199.2	694.0	1199.8	2.371	2.428	85.4	2.35	14.6	83.8	3390	3471	14.0
COARSE:														
	5.3	1.047	1184.6	684.8	1184.9	2.369	2.424	85.5	2.28	14.5	84.3	3090	3235	10.5
	5.3	0.998	1194.1	685.9	1195.1	2.345	2.424	84.7	3.26	15.3	78.8	3055	3049	10.2
	5.3	1.024	1192.6	687.4	1193.0	2.359	2.424	85.2	2.69	14.8	81.9	2930	3000	10.4
	5.3	0.997	1200.7	691.3	1201.0	2.356	2.424	85.0	2.82	15.0	81.2	3280	3270	12.5
FINE:														
	5.3	1.000	1190.5	683.0	1191.1	2.343	2.429	84.4	3.53	15.6	77.4	3500	3500	14.5
	5.3	1.001	1207.8	695.8	1208.2	2.357	2.429	84.9	2.95	15.1	80.4	4110	4114	15.0
	5.3	1.000	1196.7	690.3	1197.4	2.360	2.429	85.0	2.84	15.0	81.1	4230	4230	14.0
	5.3	1.000	1199.3	692.7	1200.0	2.364	2.429	85.2	2.67	14.8	82.0	3920	3920	12.5
CRSE-FIN:														
	5.3	1.053	1194.9	696.8	1195.1	2.398	2.430	86.3	1.30	13.7	90.4	3470	3654	15.5
	5.3	1.053	1191.3	693.6	1192.1	2.390	2.430	86.0	1.64	14.0	88.2	3390	3570	15.6
	5.3	1.040	1196.4	696.8	1197.2	2.391	2.430	86.1	1.60	13.9	88.5	3300	3432	16.6
	5.3	1.040	1200.3	698.8	1200.7	2.392	2.430	86.1	1.57	13.9	88.7	3140	3266	13.0
FIN-CRSE:														
	5.3	0.993	1188.5	676.6	1189.3	2.318	2.427	83.6	4.49	16.4	72.6	2670	2651	10.2
	5.3	1.000	1186.8	677.1	1187.4	2.326	2.427	83.8	4.18	16.2	74.1	2890	2890	13.0
	5.3	0.987	1192.1	680.9	1192.8	2.329	2.427	83.9	4.06	16.1	74.7	2740	2704	10.8
	5.3	1.019	1180.3	673.5	1180.9	2.326	2.427	83.9	4.16	16.1	74.2	2900	2955	11.5

Table A-3. Marshall Specimen Test Results - Gravel Surface Mix.

PROJECT NO. TRC-8801
MATERIAL TYPE: GRAVEL
MIX TYPE: SURFACE
AHTD JOB # 3989

GRADE AC: AC-30
SP. GR. AC: 1.029
COMPACTION: 75 BLOWS

SP. GR. AG: JMF 2.611
COARSE 2.599
FINE 2.617
CRSE-FIN 2.619
FIN-CRSE 2.604
AVG: 2.61

DATE:
10 MAY 1989

GRAD.	% A.C.	HT. CORR.	WEIGHT (GRAMS) AIR	WATER	SSD	SP. GRAVITY ACTUAL	THEOR.	AGG. %VOL.	% VOIDS AIR	VMA	VOIDS FILLED	STAB. (LB.) MEAS.	ADJ.	FLOW (1/100 IN.)
JMF:														
	5.4	0.995	1192.6	683.9	1193.0	2.343	2.411	84.9	2.83	15.1	81.3	3970	3950	12.4
	5.4	0.987	1193.6	685.2	1194.4	2.344	2.411	84.9	2.77	15.1	81.6	4100	4047	12.8
	5.4	0.998	1191.5	681.5	1192.0	2.334	2.411	84.6	3.19	15.4	79.3	3900	3892	12.2
	5.4	0.978	1196.4	683.6	1197.7	2.327	2.411	84.3	3.47	15.7	77.9	3500	3423	12.0
COARSE:														
	5.4	0.976	1189.8	678.4	1190.6	2.323	2.401	84.6	3.26	15.4	78.9	3590	3504	11.8
	5.4	1.000	1188.6	681.4	1189.2	2.341	2.401	85.2	2.52	14.8	83.0	3870	3870	12.7
	5.4	1.011	1190.2	684.7	1190.4	2.354	2.401	85.7	1.98	14.3	86.2	3730	3771	14.5
	5.4	0.985	1189.7	680.5	1190.4	2.333	2.401	84.9	2.83	15.1	81.2	3680	3625	
FINE:														
	5.4	1.000	1192.6	681.8	1193.1	2.332	2.416	84.3	3.44	15.7	78.0	4050	4050	14.0
	5.4	1.009	1188.3	680.0	1188.6	2.336	2.416	84.5	3.28	15.5	78.9	4475	4515	11.0
	5.4	1.000	1193.6	682.6	1193.9	2.334	2.416	84.4	3.36	15.6	78.5	4830	4830	12.1
	5.4	0.994	1190.6	686.7	1191.0	2.361	2.416	85.3	2.27	14.7	84.5	4110	4085	11.1
CRSE-FIN:														
	5.4	1.013	1196.0	691.3	1196.6	2.367	2.417	85.5	2.08	14.5	85.6	4900	4964	12.5
	5.4	1.025	1181.7	683.2	1182.4	2.367	2.417	85.5	2.07	14.5	85.7	4340	4449	11.8
	5.4	1.024	1195.4	692.0	1195.6	2.374	2.417	85.7	1.80	14.3	87.4	4750	4864	13.0
	5.4	1.020	1187.1	685.5	1187.6	2.364	2.417	85.4	2.19	14.6	85.0	4680	4774	13.2
FIN-CRSE:														
	5.4	0.976	1187.7	670.5	1188.2	2.294	2.405	83.3	4.62	16.7	72.3	3200	3123	10.3
	5.4	0.966	1193.8	673.0	1194.5	2.289	2.405	83.2	4.82	16.8	71.3	3625	3502	11.1
	5.4	0.958	1202.3	679.6	1202.9	2.298	2.405	83.5	4.48	16.5	72.9	3640	3487	11.6
	5.4	0.960	1187.0	667.1	1187.8	2.280	2.405	82.8	5.22	17.2	69.6	3250	3120	10.4

Table A-4. Marshall Specimen Test Results - Limestone Binder Mix.

PROJECT NO. TRC-8801
MATERIAL TYPE: LIMESTONE
MIX TYPE: BINDER
AHTD JOB # 90043/B

GRADE AC: AC-30
SP. GR. AC: 1.029
COMPACTION: 75 BLOWS

SP. GR. AG: JMF 2.581
COARSE 2.573
FINE 2.594
CRSE-FIN 2.590
FIN-CRSE 2.578 AVG: 2.583

DATE:
10 MAY 1989

GRAD.	% A.C.	HT. CORR.	WEIGHT (GRAMS) AIR	WATER	SSD	SP. GRAVITY ACTUAL	THEOR.	AGG. %VOL.	% VOIDS AIR	VMA	VOIDS FILLED	STAB. (LB.) MEAS.	ADJ.	FLOW (1/100 IN.)
JMF:														
	4.3	1.012	1186.0	697.8	1187.9	2.420	2.424	89.7	0.16	10.3	98.4	3825	3871	16.0
	4.3	1.031	1186.5	692.0	1188.1	2.392	2.424	88.7	1.33	11.3	88.3	4040	4165	14.7
	4.3	1.021	1185.4	694.0	1187.5	2.402	2.424	89.1	0.90	10.9	91.8	4750	4850	22.0
	4.3	1.039	1188.5	692.3	1189.6	2.390	2.424	88.6	1.40	11.4	87.7	4500	4676	14.6
COARSE:														
	4.3	0.982	1184.9	685.0	1187.7	2.357	2.417	87.7	2.48	12.3	79.9	4180	4105	19.1
	4.3	0.991	1180.4	684.2	1183.7	2.363	2.417	87.9	2.23	12.1	81.6	3600	3568	14.4
	4.3	1.000	1180.7	686.5	1183.9	2.374	2.417	88.3	1.79	11.7	84.7	3845	3845	16.0
	4.3	1.000	1190.1	696.4	1192.7	2.398	2.417	89.2	0.79	10.8	92.7	3075	3075	11.7
FINE:														
	4.3	1.030	1186.8	693.3	1188.0	2.399	2.435	88.5	1.47	11.5	87.2	3850	3966	15.5
	4.3	1.037	1197.5	701.3	1198.3	2.409	2.435	88.9	1.04	11.1	90.6	4000	4148	15.5
	4.3	1.026	1190.0	694.6	1191.4	2.395	2.435	88.4	1.62	11.6	86.1	5025	5156	15.1
	4.3	1.047	1189.3	697.0	1190.6	2.409	2.435	88.9	1.04	11.1	90.6	4350	4554	13.1
CRSE-FIN:														
	4.3	1.030	1185.2	694.3	1187.5	2.403	2.431	88.8	1.16	11.2	89.6	4330	4460	16.0
	4.3	1.057	1180.2	694.0	1181.6	2.420	2.431	89.4	0.45	10.6	95.7	3765	3980	18.7
	4.3	1.042	1186.5	696.5	1188.3	2.413	2.431	89.1	0.77	10.9	92.9	4500	4689	22.5
	4.3	1.055	1186.8	696.9	1187.9	2.417	2.431	89.3	0.59	10.7	94.5	4190	4420	26.0
FIN-CRSE:														
	4.3	0.972	1183.1	679.7	1185.9	2.337	2.421	86.8	3.47	13.2	73.8	3720	3616	12.1
	4.3	1.000	1182.2	682.1	1185.0	2.351	2.421	87.3	2.91	12.7	77.1	4230	4230	15.5
	4.3	0.966	1189.1	684.2	1192.2	2.341	2.421	86.9	3.33	13.1	74.6	4150	4009	13.9
	4.3	0.999	1180.1	680.3	1183.4	2.346	2.421	87.1	3.12	12.9	75.8	3900	3896	12.3

Table A-5. Marshall Specimen Test Results - Syenite Binder Mix.

PROJECT NO. TRC-8801
MATERIAL TYPE: SYENITE
MIX TYPE: BINDER
AHTD JOB # 60280

GRADE AC: AC-30
SP. GR. AC: 1.029
COMPACTION: 75 BLOWS

SP. GR. AG: JMF 2.614
COARSE 2.610
FINE 2.617
CRSE-FIN 2.616
FIN-CRSE 2.616
AVG: 2.615

DATE:
10 MAY 1989

GRAD.	% A.C.	HT. CORR.	WEIGHT (GRAMS) AIR	WATER	SSD	SP. GRAVITY ACTUAL	THEOR.	AGG. %VOL.	% VOIDS AIR	VMA	VOIDS FILLED	STAB. MEAS.	(LB.) ADJ.	FLOW (1/100 IN.)
JMF:														
	4.5	1.005	1200.9	703.5	1202.8	2.405	2.445	87.9	1.61	12.1	86.7	3580	3598	15.0
	4.5	1.000	1202.4	703.3	1203.9	2.402	2.445	87.8	1.74	12.2	85.8	3760	3760	14.3
	4.5	1.008	1204.2	704.9	1206.7	2.400	2.445	87.7	1.83	12.3	85.1	3870	3901	14.7
	4.5	1.018	1198.5	701.2	1200.1	2.402	2.445	87.8	1.73	12.2	85.9	3245	3303	12.3
COARSE:														
	4.5	0.999	1202.3	703.9	1204.2	2.403	2.441	87.9	1.56	12.1	87.1	2900	2897	12.2
	4.5	1.000	1203.9	705.9	1205.3	2.411	2.441	88.2	1.25	11.8	89.4	3400	3400	12.2
	4.5	1.023	1169.9	684.0	1172.1	2.397	2.441	87.7	1.82	12.3	85.2	2390	2445	11.0
	4.5	0.978	1208.8	707.4	1211.2	2.399	2.441	87.8	1.71	12.2	86.0	3500	3423	14.6
FINE:														
	4.5	0.978	1204.4	690.0	1205.0	2.339	2.447	85.3	4.43	14.7	69.8	3520	3443	11.6
	4.5	0.997	1216.1	708.5	1217.2	2.391	2.447	87.2	2.31	12.8	81.9	4480	4467	14.0
	4.5	0.99[illegible]	1205.6	702.6	1206.9	2.391	2.447	87.2	2.31	12.8	81.9	3430	3427	12.6
	4.5	1.012	1205.7	703.5	1206.7	2.396	2.447	87.4	2.08	12.6	83.4	3950	3997	13.4
CRSE-FIN:														
	4.5	1.030	1201.0	705.8	1202.1	2.420	2.446	88.3	1.08	11.7	90.8	3050	3142	16.6
	4.5	1.032	1205.9	707.4	1206.7	2.415	2.446	88.2	1.27	11.8	89.3	3880	4004	17.8
	4.5	1.014	1205.7	707.5	1207.5	2.411	2.446	88.0	1.42	12.0	88.1	3420	3468	14.8
	4.5	1.023	1204.6	705.8	1205.9	2.409	2.446	87.9	1.53	12.1	87.3	3130	3202	13.7
FIN-CRSE:														
	4.5	0.962	1202.1	693.3	1203.9	2.354	2.446	85.9	3.76	14.1	73.3	2845	2737	11.4
	4.5	0.984	1201.6	695.4	1203.3	2.366	2.446	86.4	3.29	13.6	75.9	3170	3119	12.4
	4.5	0.984	1204.7	698.3	1206.5	2.371	2.446	86.5	3.09	13.5	77.0	2845	2799	12.0
	4.5	0.964	1206.3	700.0	1208.6	2.372	2.446	86.6	3.04	13.4	77.3	2680	2584	10.0

Table A-6. Marshall Specimen Test Results - Gravel Binder Mix.

PROJECT NO. TRC-8801
MATERIAL TYPE: GRAVEL
MIX TYPE: BINDER
AHTD JOB # 3857

GRADE AC: AC-30
SP. GR. AC: 1.029
COMPACTION: 75 BLOWS

SP. GR. AG: JMF 2.563
COARSE 2.558
FINE 2.570
CRSE-FIN 2.569
FIN-CRSE 2.563
AVG: 2.565

DATE:
10 MAY 1989

GRAD.	% A.C.	HT. CORR.	WEIGHT (GRAMS) AIR	WATER	SSD	SP. GRAVITY ACTUAL	THEOR.	AGG. %VOL.	% VOIDS AIR	VMA	VOIDS FILLED	STAB. (LB.) MEAS.	ADJ.	FLOW (1/100 IN.)
JMF:														
	4.4	1.012	1167.4	669.0	1169.6	2.332	2.405	87.0	3.04	13.0	76.6	4460	4514	13.0
	4.4	0.995	1164.1	669.5	1166.6	2.342	2.405	87.3	2.64	12.7	79.1	4410	4388	12.1
	4.4	1.007	1167.0	672.8	1171.3	2.341	2.405	87.3	2.67	12.7	78.9	4400	4431	13.2
	4.4	1.008	1165.7	671.1	1169.6	2.338	2.405	87.2	2.78	12.8	78.3	5500	5544	14.0
COARSE:														
	4.4	0.963	1162.4	672.3	1165.7	2.356	2.401	88.0	1.88	12.0	84.3	4880	4699	14.8
	4.4	0.991	1160.5	669.9	1163.8	2.350	2.401	87.8	2.14	12.2	82.4	4465	4425	19.3
	4.4	0.979	1161.9	669.4	1165.7	2.341	2.401	87.5	2.49	12.5	80.1	3120	3054	13.7
	4.4	0.981	1162.6	670.9	1166.4	2.346	2.401	87.7	2.28	12.3	81.5	4410	4326	13.6
FINE:														
	4.4	1.037	1161.4	672.2	1163.1	2.366	2.411	88.0	1.88	12.0	84.3	4930	5112	13.4
	4.4	1.024	1172.5	677.7	1174.0	2.362	2.411	87.9	2.02	12.1	83.4	5900	6042	14.0
	4.4	1.023	1171.7	674.2	1172.6	2.351	2.411	87.5	2.50	12.5	80.1	5000	5115	12.1
	4.4	1.017	1167.0	671.6	1168.8	2.347	2.411	87.3	2.65	12.7	79.1	4875	4958	11.9
CRSE-FIN:														
	4.4	1.007	1166.1	674.5	1170.0	2.353	2.410	87.6	2.36	12.4	81.0	5060	5095	16.8
	4.4	1.030	1169.6	679.8	1171.0	2.381	2.410	88.6	1.21	11.4	89.4	4820	4965	16.6
	4.4	1.000	1165.9	674.8	1168.2	2.363	2.410	87.9	1.96	12.1	83.7	4010	4010	16.0
	4.4	1.033	1166.2	676.2	1169.0	2.366	2.410	88.1	1.82	11.9	84.8	4910	5072	13.8
FIN-CRSE:														
	4.4	0.989	1159.7	662.6	1162.2	2.321	2.405	86.6	3.49	13.4	74.0	4145	4099	13.4
	4.4	1.008	1164.9	667.0	1166.6	2.332	2.405	87.0	3.06	13.0	76.5	3950	3982	11.5
	4.4	1.008	1156.4	659.7	1158.0	2.321	2.405	86.6	3.51	13.4	73.8	3930	3961	10.9
	4.4	0.984	1170.7	668.5	1173.5	2.318	2.405	86.5	3.62	13.5	73.3	3730	3670	10.4

APPENDIX B

ANALYSES OF MARSHALL SPECIMEN DATA

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	6.023	1.506	9.41	0.0005
Error	15	2.399	0.160		
Total	19	8.422			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	2.615	Fine-Coarse
B	1.805	Job Mix Formula
B	1.737	Coarse
B & C	1.365	Fine
C	0.963	Course-Fine

Means with the same T Grouping letter are not significantly different.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	15.557	3.889	17.31	0.0001
Error	15	3.369	0.225		
Total	19	18.926			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	3.208	Fine-Coarse
B	1.822	Coarse
B & C	1.292	Fine
C	0.947	Job Mix Formula
C	0.742	Coarse-Fine

Means with the same T Grouping letter are not significantly different.

Table B-1. Analysis of Air Void Data from Limestone Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	14.637	3.659	30.70	0.0001
Error	15	1.788	0.119		
Total	19	16.425			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	4.222	Fine-Coarse
B	2.998	Fine
B	2.885	Job Mix Formula
B	2.762	Coarse
C	1.528	Coarse-Fine

Means with the same T Grouping letter are not significantly different.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	11.557	2.889	10.08	0.0004
Error	15	4.300	0.287		
Total	19	15.857			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	3.295	Fine-Coarse
A	2.783	Fine
B	1.727	Job Mix Formula
B	1.585	Coarse
B	1.325	Coarse-Fine

Means with the same T Grouping letter are not significantly different.

Table B-2. Analysis of Air Void Data from Syenite Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	16.707	4.177	25.17	0.0001
Error	15	2.489	0.166		
Total	19	19.196			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	4.785	Fine-Coarse
B	3.088	Fine
B	3.065	Job Mix Formula
B & C	2.648	Coarse
C	2.035	Coarse-Fine

Means with the same T Grouping letter are not significantly different.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	6.046	1.512	14.48	0.0001
Error	15	1.567	0.104		
Total	19	7.612			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	3.420	Fine-Coarse
B	2.782	Job Mix Formula
C	2.263	Fine
C	2.200	Coarse
C	1.837	Coarse-Fine

Means with the same T Grouping letter are not significantly different.

Table B-3. Analysis of Air Void Data from Gravel Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	5.553	1.388	12.45	0.0001
Error	15	1.673	0.112		
Total	19	7.226			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	15.375	Fine-Coarse
B	14.850	Coarse
B	14.600	Job Mix Formula
C	14.075	Fine
C	13.925	Coarse-Fine

Means with the same T Grouping letter are not significantly different.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	11.278	2.820	15.66	0.0001
Error	15	2.700	0.180		
Total	19	13.978			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	12.975	Fine-Coarse
B	11.725	Coarse
B & C	11.325	Fine
C	11.075	Job Mix Formula
C	10.850	Coarse-Fine

Means with the same T Grouping letter are not significantly different.

Table B-4. Analysis of VMA Data from Limestone Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	10.917	2.730	31.37	0.0001
Error	15	1.305	0.087		
Total	19	12.222			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	16.200	Fine-Coarse
B	15.125	Fine
B	15.050	Job Mix Formula
B	14.900	Coarse
C	13.875	Coarse-Fine

Means with the same T Grouping letter are not significantly different.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	9.568	2.392	10.32	0.0003
Error	15	3.478	0.232		
Total	19	13.046			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	13.650	Fine-Coarse
A	13.225	Fine
B	12.200	Job Mix Formula
B	12.100	Coarse
B	11.900	Coarse-Fine

Means with the same T Grouping letter are not significantly different.

Table B-5. Analysis of VMA Data from Syenite Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	12.275	3.069	24.98	0.0001
Error	15	1.843	0.123		
Total	19	14.118			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	16.800	Fine-Coarse
B	15.375	Fine
B	15.325	Job Mix Formula
B & C	14.900	Coarse
C	14.475	Coarse-Fine

Means with the same T Grouping letter are not significantly different.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	4.647	1.162	14.58	0.0001
Error	15	1.195	0.080		
Total	19	5.842			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	13.325	Fine-Coarse
B	12.800	Job Mix Formula
C	12.325	Fine
C	12.250	Coarse
C	11.950	Coarse-Fine

Means with the same T Grouping letter are not significantly different.

Table B-6. Analysis of VMA Data from Gravel Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	375469.00	93867.25	3.66	0.0285
Error	15	384888.75	25659.25		
Total	19	670357.75			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	3333.5	Fine
A & B	3184.3	Coarse
A, B & C	3131.5	Job Mix Formula
B & C	3033.0	Fine-Coarse
C	2929.0	Coarse-Fine

Means with the same T Grouping letter are not significantly different.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	2014375.70	503593.93	3.03	0.0510
Error	15	2489359.25	165975.28		
Total	19	4503734.95			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	4456.0	Fine
A	4390.5	Job Mix Formula
A	4387.3	Coarse-Fine
A & B	3937.8	Fine-Coarse
B	3648.3	Coarse

Means with the same T Grouping letter are not significantly different.

Table B-7. Analysis of Stability Data from Limestone Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	2988699.00	747174.75	11.20	0.0002
Error	15	1000508.75	66700.58		
Total	19	3989207.75			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	3941.0	Fine
B	3480.5	Coarse-Fine
B & C	3138.5	Coarse
B & C	3133.8	Job Mix Formula
C	2800.0	Fine-Coarse

Means with the same T Grouping letter are not significantly different.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	286427.70	716006.93	4.86	0.0103
Error	15	2209947.50	147329.83		
Total	19	5073975.20			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	3833.5	Fine
A	3640.5	Job Mix Formula
A & B	3454.0	Coarse-Fine
B & C	3041.3	Coarse
C	2809.8	Fine-Coarse

Means with the same T Grouping letter are not significantly different.

Table B-8. Analysis of Stability Data from Syenite Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	5285566.00	1321391.50	19.56	0.0001
Error	15	1013537.75	67569.18		
Total	19	6299103.75			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	4762.8	Coarse-Fine
B	4370.0	Fine
C	3828.0	Job Mix Formula
C & D	3692.5	Coarse
D	3308.0	Fine-Coarse

Means with the same T Grouping letter are not significantly different.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	4883073.30	1220768.33	4.39	0.0151
Error	15	4170286.50	278019.10		
Total	19	9053359.80			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	5306.8	Fine
A & B	4785.5	Coarse-Fine
A, B & C	4719.3	Job Mix Formula
B & C	4126.0	Coarse
C	3928.0	Fine-Coarse

Means with the same T Grouping letter are not significantly different.

Table B-9. Analysis of Stability Data from Gravel Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	49.572	12.393	19.16	0.0001
Error	15	9.700	0.647		
Total	19	59.272			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	15.225	Coarse-Fine
A	14.725	Fine
A	14.175	Job Mix Formula
B	12.150	Coarse
B	11.125	Fine-Coarse

Means with the same T Grouping letter are not significantly different.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	127.508	31.877	3.55	0.0313
Error	15	134.518	8.968		
Total	19	262.026			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	20.800	Coarse-Fine
A & B	16.825	Job Mix Formula
B	15.300	Coarse
B	14.800	Fine
B	13.450	Fine-Coarse

Means with the same T Grouping letter are not significantly different.

Table B-10. Analysis of Flow Data from Limestone Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	50.907	12.727	8.93	0.0007
Error	15	21.375	1.425		
Total	19	72.282			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	15.175	Coarse-Fine
A & B	14.000	Fine
B & C	12.700	Job Mix Formula
C & D	11.375	Fine-Coarse
D	10.900	Coarse

Means with the same T Grouping letter are not significantly different.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	42.797	10.699	5.76	0.0052
Error	15	27.865	1.858		
Total	19	70.662			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	15.725	Coarse-Fine
A & B	14.075	Job Mix Formula
B & C	12.900	Fine
B & C	12.500	Coarse
C	11.450	Fine-Coarse

Means with the same T Grouping letter are not significantly different.

Table B-11. Analysis of Flow Data from Syenite Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	18.973	4.743	3.31	0.0394
Error	15	21.515	1.434		
Total	19	40.488			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	13.875	Coarse
A & B	12.625	Coarse-Fine
A & B	12.300	Job Mix Formula
B	12.050	Fine
B	10.850	Fine-Coarse

Means with the same T Grouping letter are not significantly different.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	51.460	12.865	5.15	0.0082
Error	15	37.458	2.497		
Total	19	88.918			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	15.800	Coarse-Fine
A & B	15.350	Coarse
B & C	13.075	Job Mix Formula
C	12.850	Fine
C	11.550	Fine-Coarse

Means with the same T Grouping letter are not significantly different.

Table B-12. Analysis of Flow Data from Gravel Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	68350.498	17087.625	4.40	0.0149
Error	15	58226.570	3881.771		
Total	19	126577.068			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	677.83	Coarse
A & B	632.50	Job Mix Formula
B & C	579.23	Fine-Coarse
B & C	558.82	Coarse-Fine
C	509.43	Fine

Means with the same T Grouping letter are not significantly different.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	66001.860	16500.465	0.62	0.6572
Error	15	401249.070	26749.938		
Total	19	467250.930			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	1139.0	Fine-Coarse
A	1064.1	Coarse-Fine
A	1026.0	Job Mix Formula
A	1004.5	Coarse
A	971.6	Fine

Means with the same T Grouping letter are not significantly different.

Table B-13. Analysis of Resilient Modulus Data from Limestone Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	32759.528	8189.882	4.86	0.0103
Error	15	25289.240	1685.949		
Total	19	58048.768			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	637.80	Fine
A & B	593.05	Coarse
A & B	588.55	Job Mix Formula
B & C	538.85	Coarse-Fine
C	525.55	Fine-Coarse

Means with the same T Grouping letter are not significantly different.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	65320.372	16330.093	2.39	0.0974
Error	15	102642.230	6842.815		
Total	19	167962.602			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	871.52	Job Mix Formula
A	864.80	Fine
A	856.73	Coarse
A & B	819.58	Fine-Coarse
B	717.53	Coarse-Fine

Means with the same T Grouping letter are not significantly different.

Table B-14. Analysis of Resilient Modulus Data from Syenite Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	181542.197	45385.549	29.16	0.0001
Error	15	23345.925	1556.395		
Total	19	204888.122			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	787.60	Coarse-Fine
B	686.50	Fine
C	579.55	Job Mix Formula
C	565.28	Fine-Coarse
C	526.92	Coarse

Means with the same T Grouping letter are not significantly different.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob > F
Gradation	4	242467.923	60616.981	3.64	0.0290
Error	15	249849.055	16656.604		
Total	19	492316.978			

T-TEST GROUPINGS

T Grouping	Mean	Gradation Variation
A	1180.7	Fine
A	1172.1	Job Mix Formula
A	1156.2	Coarse
A & B	1015.5	Coarse-Fine
B	900.6	Fine-Coarse

Means with the same T Grouping letter are not significantly different.

Table B-15. Analysis of Resilient Modulus Data from Gravel Mixes.

APPENDIX C

SPLIT TENSILE AND CREEP DATA

Table C-1. Split Tensile Strength Data - Surface Mixes.

GRADATION VARIATION	SPLIT TENSILE STRENGTH, psi TOP HALF	BOTTOM HALF	AIR VOIDS, % TOP	BOTTOM
***	LIMESTONE SURFACE MIX		***	
JOB MIX FORMULA	138.9	111.6	5.72	7.60
COARSE	133.7	113.6	5.28	6.75
	130.1	110.6	5.40	6.95
FINE	154.2	134.7	5.34	6.88
	152.4	114.1	5.29	7.59
COARSE-FINE	147.9	137.6	5.08	6.70
	158.4	123.9	4.75	6.79
FINE-COARSE	144.7	112.4	5.60	7.02
	141.5	112.0	5.60	7.48
***	SYENITE SURFACE MIX		***	
JOB MIX FORMULA	142.6	131.3	6.10	7.66
	145.2	136.6	6.05	7.83
COARSE	138.3	110.9	5.94	7.72
	140.1	117.4	5.36	7.43
FINE	150.9	140.6	6.22	8.15
	145.6	133.0	6.26	7.74
COARSE-FINE	135.2	122.6	6.00	7.93
	149.6	130.9	5.59	7.40
FINE-COARSE	142.4	120.1	6.43	8.12
	132.3	114.3	6.30	8.57
***	GRAVEL SURFACE MIX		***	
JOB MIX FORMULA	142.2	122.4	6.39	8.09
	148.8	114.1	5.89	8.38
COARSE	126.4	105.2	6.71	8.66
	113.2	98.6	6.29	8.00
FINE	118.5	104.5	8.65	10.72
	119.3	94.6	8.94	11.55
COARSE-FINE	133.0	106.4	6.62	8.85
	128.8	112.1	6.50	8.94
FINE-COARSE	131.1	100.5	7.03	9.02
	123.6	101.8	7.11	9.23

Table C-2. Split Tensile Strength Data - Binder Mixes.

***	LIMESTONE	BINDER MIX	***	
JOB MIX FORMULA	187.3	133.2	3.92	5.24
	205.3	162.4	4.62	5.36
COARSE	164.7	140.4	5.21	6.00
	140.1	115.0	4.39	5.83
FINE	179.4	148.9	5.09	7.02
	170.2	150.1	5.05	6.65
COARSE-FINE	205.1	143.9	3.54	3.99
	173.3	144.3	4.24	4.53
FINE-COARSE	165.5	140.5	5.45	7.27
	157.3	137.9	6.44	7.39
***	SYENITE	BINDER MIX	***	
JOB MIX FORMULA	157.1	120.1	5.07	7.32
	146.9	124.1	5.15	7.12
COARSE	123.3	108.0	5.20	6.96
	137.7	99.1	4.79	6.47
FINE	151.2	124.2	6.38	8.54
	125.4	102.8	7.44	9.32
COARSE-FINE	158.7	114.2	4.70	7.11
	149.4	98.0	5.11	7.24
FINE-COARSE	136.9	110.4	5.97	8.10
	142.9	111.9	6.01	8.26
***	GRAVEL	BINDER MIX	***	
JOB MIX FORMULA	161.6	134.1	5.11	7.07
	185.8	119.1	4.62	6.90
COARSE	126.7	107.9	5.25	6.16
	108.2	119.3	4.87	6.41
FINE	130.0	134.6	6.55	8.05
	131.7	123.7	6.14	7.88
COARSE-FINE	146.4	111.0	4.77	7.68
	179.3	126.4	4.48	6.89
FINE-COARSE	147.1	118.5	5.66	7.48
	148.1	114.8	6.03	8.03

Table C-3. Creep Stiffness Data - Surface Mixes.

GRADATION VARIATION	CREEP STIFFNESS (IN PSI) MEASURED AT : 5 sec	30 sec	2 min	30 min	60 min	AIR VOIDS %
			LIMESTONE SURFACE MIX			
JOB MIX FORMULA	13380.9	11472.3	10230.2	7521.6	6515.4	5.80
	12150.7	10623.2	9428.0	8417.5	7612.3	5.80
COARSE	13599.3	11801.7	10668.6	7788.2	6623.3	5.28
	13611.6	11776.3	10672.4	8140.0	7647.2	5.79
FINE	12401.8	10706.6	9572.4	6865.8	6032.0	5.75
	13106.2	11509.7	10312.8	7238.5	6233.8	5.84
COARSE-FINE	11614.4	9783.1	8688.1	5914.8	5338.1	5.45
	12275.0	10431.2	9245.0	6494.9	5735.0	5.16
FINE-COARSE	11693.6	9772.0	8714.6	6454.4	5787.6	5.85
	11848.3	9803.9	8688.1	6394.5	5715.4	6.14
			SYENITE SURFACE MIX			
JOB MIX FORMULA	7598.8	6741.6	6079.0	4832.1	4518.8	6.51
	7367.4	6543.8	6330.5	6060.6	6049.6	6.38
COARSE	8068.9	6950.1	6400.0	5712.1	5494.0	6.11
	8498.6	7071.3	6339.8	4883.2	4537.9	5.98
FINE	7853.4	6533.1	6012.0	5467.5	5318.7	6.55
	7410.2	6953.3	6646.7	5909.0	5698.0	6.55
COARSE-FINE	7934.4	6804.3	6200.3	5452.6	5184.9	6.21
	8698.2	7479.4	6788.9	5657.2	5434.8	5.96
FINE-COARSE	8427.0	6861.9	6118.7	4987.5	4834.4	6.26
	8011.8	6653.4	5913.7	4807.7	4345.9	6.76
			GRAVEL SURFACE MIX			
JOB MIX FORMULA	8581.2	7286.0	6579.0	5511.2	5358.6	6.51
	9322.6	8015.0	7248.1	6123.7	5970.2	6.59
COARSE	8510.6	7112.4	6271.6	4878.8	4265.3	6.75
	8379.9	7029.9	6237.0	4765.7	4296.5	6.62
FINE	8440.0	7078.8	6269.6	5245.7	4909.2	7.37
	8112.5	6954.1	6743.1	6194.5	5670.0	7.48
COARSE-FINE	8915.3	7609.4	6755.2	5660.9	5633.8	6.99
	8473.4	7187.4	6413.0	5141.8	4847.7	6.99
FINE-COARSE	7580.5	6402.7	6003.6	5811.1	5805.0	7.36
	8187.8	6969.5	6227.9	5424.0	5336.2	7.57

Table C-4. Creep Stiffness Data - Binder Mixes.

GRADATION VARIATION	CREEP STIFFNESS (IN PSI) MEASURED AT : 5 sec	30 sec	2 min	30 min	60 min	AIR VOIDS %
		LIMESTONE BINDER MIX				
JOB MIX FORMULA	10737.3	9516.3	8849.6	7708.1	7392.8	4.13
	10387.8	9215.2	8520.3	6988.1	6731.7	4.62
COARSE	9715.0	8613.3	8068.9	7214.1	7026.6	4.47
	8658.0	7808.4	7337.7	6924.4	6888.6	4.59
FINE	8738.7	7657.0	7213.3	6790.4	6680.8	6.04
	10822.5	9066.2	8250.8	6885.5	6547.4	5.83
COARSE-FINE	8533.6	7762.0	7276.3	6494.9	6309.2	3.77
	9099.2	7936.5	7369.2	6437.1	6203.5	4.20
FINE-COARSE	10080.7	8867.9	8227.1	7231.5	7024.1	5.87
	9927.2	8894.2	8178.8	6996.3	6730.2	6.46
		SYENITE BINDER MIX				
JOB MIX FORMULA	7561.4	6575.3	6230.5	5779.8	5657.2	6.05
	7394.6	6424.0	5891.6	5108.1	5002.5	5.89
COARSE	8645.5	7380.1	6639.4	5188.5	4906.8	5.94
	7335.0	6257.8	5695.3	4573.5	4283.9	5.41
FINE	8235.0	7194.2	7012.6	6581.8	6450.9	6.70
	8759.1	7345.7	6460.0	4725.9	4292.5	7.52
COARSE-FINE	8121.3	6958.9	6265.0	5039.5	4686.0	5.45
	7741.9	6597.8	5923.0	5099.4	4595.6	6.10
FINE-COARSE	8086.3	6726.5	5994.0	5248.0	5115.1	6.46
	7725.0	6380.3	5708.9	5208.3	5075.3	6.70
		GRAVEL BINDER MIX				
JOB MIX FORMULA	8192.2	6809.7	6211.8	5921.8	5836.6	5.65
	8282.7	7067.1	6399.3	5427.9	5284.5	5.45
COARSE	7064.6	6738.5	6563.1	6157.6	5989.2	5.67
	7389.2	7043.9	6816.6	6331.8	6203.5	5.62
FINE	8253.1	7125.9	6472.5	5413.2	5173.3	6.49
	7416.6	6402.1	6037.4	5547.9	5417.1	6.55
COARSE-FINE	7914.5	6790.4	6161.4	5242.0	5017.6	5.67
	7420.2	7069.6	6872.9	6435.7	6319.1	5.51
FINE-COARSE	7575.8	6400.0	5758.2	4695.9	4362.1	5.91
	5782.6	5479.5	5278.0	4574.2	4275.0	6.52

APPENDIX D

ANALYSES OF SPLIT TENSILE AND CREEP DATA

Table D-1. Split Tensile Strength Analyses for Limestone Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. > F
Gradation	4	1151.723425	287.930856	14.08	0.0002
Air Voids	1	3194.143626	3194.143626	156.24	0.0001
Error	12	245.332549	20.444379		
Total	17	4591.199600			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean, psi	Gradation Variation
A	141.9	COARSE-FINE
A	138.9	FINE
B	127.6	FINE-COARSE
B	125.2	JOB MIX FORMULA
B	122.5	COARSE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. > F
Gradation	4	2687.148270	671.787067	1.90	0.1656
Air Voids	1	2994.627649	2994.627649	8.49	0.0113
Error	14	4937.360501	352.668607		
Total	19	10619.136420			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean, psi	Gradation Variation
A	172.04	JOB MIX FORMULA
A & B	166.66	COARSE-FINE
A & B	162.14	FINE
A & B	150.28	FINE-COARSE
B	140.02	COARSE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

Table D-2. Split Tensile Strength Analyses for Syenite Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. > F
Gradation	4	783.036930	195.759232	7.86	0.0015
Air Voids	1	1446.918279	1446.918279	58.06	0.0001
Error	14	348.897571	24.921255		
Total	19	2578.852780			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean, psi	Gradation Variation
A	142.510	FINE
A & B	138.918	JOB MIX FORMULA
B & C	134.565	COARSE-FINE
C & D	127.270	FINE-COARSE
D	126.683	COARSE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. > F
Gradation	4	846.157150	211.539287	4.36	0.0170
Air Voids	1	5628.245495	5628.245495	115.92	0.0001
Error	14	679.721055	48.551504	115.92	0.0001
Total	19	7154.123700			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean, psi	Gradation Variation
A	137.050	JOB MIX FORMULA
A & B	130.060	COARSE-FINE
B & C	125.893	FINE
B & C	125.512	FINE-COARSE
C	117.110	COARSE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

Table D-3. Split Tensile Strength Analyses for Gravel Mixes.

SURFACE MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. > F
Gradation	4	1342.293000	335.573250	11.21	0.0003
Air Voids	1	2440.661385	2440.661385	81.55	0.0001
Error	14	418.982115	29.927294		
Total	19	4201.936500			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean, psi	Gradation Variation
A	131.867	JOB MIX FORMULA
B	120.048	COARSE
B & C	114.278	FINE
C	110.850	COARSE.
C	109.232	FINE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

BINDER MIX

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. > F
Gradation	4	2667.334300	666.833575	4.22	0.0191
Air Voids	1	4291.486743	4291.486743	27.13	0.0001
Error	14	2214.802532	158.200181		
Total	19	9173.623575			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean, psi	Gradation Variation
A	150.160	JOB MIX FORMULA
A & B	140.770	COARSE-FINE
A,B & C	132.112	FINE-COARSE
B & C	130.035	FINE
C	115.535	COARSE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

Table D-4. Analyses of 30 Minute Creep Data from All Mixes.

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. > F
Gradation (G)	4	3127727.76	781931.94	3.83	0.0125
Aggregate (A)	2	35617088.99	17808544.50	87.16	0.0001
Mix Type (M)	1	53157.31	53157.31	0.26	0.6137
G*A	8	3551038.22	443879.78	2.17	0.0593
G*M	4	241811.49	60452.87	0.30	0.8783
A*M	2	191573.85	95786.93	0.47	0.6303
G*A*M	8	5067343.05	633417.88	3.10	0.0113
Error	30	6129705.54	204323.52		
Total	59	53979446.22			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean, psi	Gradation Variation
A	6283.4	JOB MIX FORMULA
A & B	6072.1	FINE
A & B	6046.5	COARSE
B & C	5755.9	COARSE-FINE
C	5652.8	FINE-COARSE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

Table D-5. Analyses of 2 Minute Creep Data from All Mixes.

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. > F
Gradation (G)	4	3145237.26	786309.31	6.32	0.0008
Aggregate (A)	2	81944247.80	40972123.90	329.22	0.0001
Mix Type (M)	1	6743151.46	6743151.46	54.18	0.0001
G*A	8	2887821.34	360977.67	2.90	0.0161
G*M	4	370360.99	92590.25	0.74	0.5697
A*M	2	7872925.31	3936462.66	31.63	0.0001
G*A*M	8	4363074.62	545384.33	4.38	0.0014
Error	30	3733539.6	124451.3		
Total	59	111060358.4			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean, psi	Gradation Variation
A	7333.2	JOB MIX FORMULA
A	7309.2	COARSE
A & B	7250.3	FINE
B & C	6996.5	COARSE-FINE
C	6734.3	FINE-COARSE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

Table D-6. Analyses of 30 Second Creep Data from All Mixes.

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. > F
Gradation (G)	4	2724962.8	681240.7	4.31	0.0072
Aggregate (A)	2	102843605.9	51421802.9	325.10	0.0001
Mix Type (M)	1	12892808.9	12892808.9	81.51	0.0001
G*A	8	4137046.2	517130.8	3.27	0.0085
G*M	4	823069.6	205767.4	1.30	0.2921
A*M	2	13209130.8	6604565.4	41.76	0.0001
G*A*M	8	4059572.6	507446.6	3.21	0.0094
Error	30	4745119.4	158170.6		
Total	59	145435316.2			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean, psi	Gradation Variation
A	8024.1	JOB MIX FORMULA
A	7965.3	COARSE
A	7877.2	FINE
A & B	7700.8	COARSE-FINE
B	7434.3	FINE-COARSE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

Table D-7. Analyses of 5 Second Creep Data from All Mixes.

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Prob. > F
Gradation (G)	4	1984253.5	496063.4	1.71	0.1735
Aggregate (A)	2	131243163.5	65621581.7	226.40	0.0001
Mix Type (M)	1	24649911.5	24649911.5	85.04	0.0001
G*A	8	6956453.2	869556.6	3.00	0.0135
G*M	4	2558347.9	639587.0	2.21	0.0921
A*M	2	21594122.9	10797061.4	37.25	0.0001
G*A*M	8	3106246.8	388280.9	1.34	0.2627
Error	30	8695606.8	289853.6		
Total	59	200788106.1			

The level of significance is indicated by the probability of greater F. Probabilities less than 0.05 are generally judged as being indicative of a significant effect.

T-TEST GROUPINGS

T Grouping	Mean, psi	Gradation Variation
A	9246.5	JOB MIX FORMULA
A & B	9129.1	FINE
A & B	9123.0	COARSE
A & B	8895.1	COARSE-FINE
B	8743.9	FINE-COARSE

Means in the same T Grouping are not significantly different at alpha equal to 0.05.

Table D-8. T Groupings of Creep Stiffnesses of Limestone Mixes.

LIMESTONE SURFACE			LIMESTONE BINDER		
T Grouping	Mean, psi	Gradation	T Grouping	Mean, psi	Gradation
5 Second Creep Stiffness			5 Second Creep Stiffness		
A	13605.5	COARSE	A	10562.5	JMF
A & B	12765.8	JMF	A	10004.0	FINE-CRSE
A & B	12754.0	FINE	A	9780.6	FINE
B	11944.7	CRSE-FINE	A	9186.5	COARSE
B	11771.0	FINE-CRSE	A	8816.4	CRSE-FINE
30 Second Creep Stiffness			30 Second Creep Stiffness		
A	11789.0	COARSE	A	9365.7	JMF
A & B	11108.2	FINE	A	8881.0	FINE-CRSE
A, B & C	11047.7	JMF	A	8361.6	FINE
B & C	10107.2	CRSE-FINE	A	8210.8	COARSE
C	9788.0	FINE-CRSE	A	7849.3	CRSE-FINE
2 Minute Creep Stiffness			2 Minute Creep Stiffness		
A	10670.5	COARSE	A	8685.0	JMF
A & B	9942.6	FINE	A & B	8203.0	FINE-CRSE
A, B & C	9829.1	JMF	A & B	7732.0	FINE
B & C	8966.5	CRSE-FINE	A & B	7703.3	COARSE
C	8701.3	FINE-CRSE	B	7322.8	CRSE-FINE
30 Minute Creep Stiffness			30 Minute Creep Stiffness		
A	7969.6	JMF	A	7348.1	JMF
A	7964.1	COARSE	A	7113.9	FINE-CRSE
A & B	7052.1	FINE	A	7069.3	COARSE
B	6424.5	FINE-CRSE	A & B	6838.0	FINE
B	6204.9	CRSE-FINE	B	6466.0	CRSE-FINE
60 Minute Creep Stiffness			60 Minute Creep Stiffness		
A	7135.3	COARSE	A	7062.3	JMF
A	7063.9	JMF	A	6957.6	COARSE
A & B	6132.9	FINE	A	6877.1	FINE-CRSE
A & B	5751.5	FINE-CRSE	A & B	6614.1	FINE
B	5536.6	CRSE-FINE	B	6256.4	CRSE-FINE

Table D-9. T Groupings of Creep Stiffnesses of Syenite Mixes.

SYENITE SURFACE			SYENITE BINDER		
T Grouping	Mean, psi	Gradation	T Grouping	Mean, psi	Gradation
5 Second Creep Stiffness			5 Second Creep Stiffness		
A	8316.3	CRSE-FINE	A	8497.0	FINE
A & B	8283.7	COARSE	A	7990.3	COARSE
A & B	8219.4	FINE-CRSE	A	7931.6	CRSE-FINE
A & B	7631.8	FINE	A	7905.6	FINE-CRSE
B	7483.1	JMF	A	7478.0	JMF
30 Second Creep Stiffness			30 Second Creep Stiffness		
A	7141.9	CRSE-FINE	A	7270.0	FINE
A	7010.7	COARSE	A	6819.0	COARSE
A	6757.6	FINE-CRSE	A	6778.4	CRSE-FINE
A	6743.2	FINE	A	6553.4	FINE-CRSE
A	6642.7	JMF	A	6499.6	JMF
2 Minute Creep Stiffness			2 Minute Creep Stiffness		
A	6494.6	CRSE-FINE	A	6736.3	FINE
A	6369.9	COARSE	A	6167.4	COARSE
A	6329.4	FINE	A	6094.0	CRSE-FINE
A	6204.8	JMF	A	6061.1	JMF
A	6016.2	FINE-CRSE	A	5851.5	FINE-CRSE
30 Minute Creep Stiffness			30 Minute Creep Stiffness		
A	5688.3	FINE	A	5653.9	FINE
A	5554.9	CRSE-FINE	A	5444.0	JMF
A	5446.4	JMF	A	5228.1	FINE-CRSE
A	5297.6	COARSE	A	5069.5	CRSE-FINE
A	4897.6	FINE-CRSE	A	4881.0	COARSE
60 Minute Creep Stiffness			60 Minute Creep Stiffness		
A	5508.4	FINE	A	5371.7	FINE
A	5309.9	CRSE-FINE	A	5329.9	JMF
A	5284.2	JMF	A	5095.2	FINE-CRSE
A	5016.0	COARSE	A	4640.8	CRSE-FINE
A	4590.1	FINE-CRSE	A	4595.4	COARSE

Table D-10. T Groupings of Creep Stiffnesses of Gravel Mixes.

GRAVEL SURFACE			GRAVEL BINDER		
T Grouping	Mean, psi	Gradation	T Grouping	Mean, psi	Gradation
5 Second Creep Stiffness			5 Second Creep Stiffness		
A	8951.9	JMF	A	8237.5	JMF
A & B	8694.3	CRSE-FINE	A & B	7834.9	FINE
A & B	8445.2	COARSE	A & B	7667.4	CRSE-FINE
A & B	8276.2	FINE	A & B	7226.9	COARSE
B	7884.1	FINE-CRSE	A	6679.2	FINE-COARSE
30 Second Creep Stiffness			30 Second Creep Stiffness		
A	7650.5	JMF	A	6938.4	JMF
A & B	7398.4	CRSE-FINE	A	6930.0	CRSE-FINE
A & B	7071.1	COARSE	A	6891.2	COARSE
A & B	7016.5	FINE	A	6764.0	FINE
B	6686.1	FINE-CRSE	B	5939.8	FINE-CRSE
2 Minute Creep Stiffness			2 Minute Creep Stiffness		
A	6913.6	JMF	A	6689.9	COARSE
A & B	6584.1	CRSE-FINE	A	6517.1	CRSE-FINE
A & B	6506.4	FINE	A	6305.6	JMF
A & B	6254.3	COARSE	A	6255.0	FINE
B	6115.8	FINE-CRSE	B	5518.1	FINE-CRSE
30 Minute Creep Stiffness			30 Minute Creep Stiffness		
A	5817.5	JMF	A	6244.7	COARSE
A	5720.1	FINE	A & B	5838.9	CRSE-FINE
A	5617.6	FINE-CRSE	A & B	5674.9	JMF
A	5401.4	2 XFC	A & B	5480.5	FINE
A	4822.3	COARSE	B	4635.0	FINE-CRSE
60 Minute Creep Stiffness			60 Minute Creep Stiffness		
A	5664.4	JMF	A	6096.4	COARSE
A & B	5570.6	FINE-CRSE	A & B	5668.4	CRSE-FINE
A & B	5289.6	FINE	A & B	5560.6	JMF
A & B	5240.8	CRSE-FINE	A & B	5295.2	FINE
B	4280.9	COARSE	B	4318.6	FINE-CRSE