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16. Abstract

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by

Mansour Solaimanian
Thomas W. Kennedy

Research Report Number 468-4F

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Field Evaluation to Obtain Density in Asphalt Mixtures

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Texas State Department of Highways and Public Transportation

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by the

CENTER FOR TRANSPORTATION RESEARCH

Bureau of Engineering Research

THE UNIVERSITY OF TEXAS AT AUSTIN

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NOT INTENDED FOR CONSTRUCTION,
PERMIT, OR BIDDING PURPOSES

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There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

PREFACE

This is the fourth and final report in a series of reports dealing with density of asphalt paving mixtures in Texas. This report summarizes pavement densities obtained in the state of Texas and compares the results with past density achievements. The importance of density, the factors which influence it, and construction guidelines for compaction are discussed in CTR Research Report 468-3.

The effort required to assemble the data for this project was provided by many people. Special appreciation is extended to Paul Krugler and James Joslin of the Texas State Department of Highway and Public Transportation (SDHPT) for initiating data collection and obtaining data. Efforts of the personnel of all SDHPT districts who participated in providing The University of Texas at Austin with required data are greatly appreciated. The support of the Texas State Department of Highways and Public Transportation and of the Federal Highway Administration is acknowledged. Special thanks go to W. E. Elmore of the Center for Transportation Research and to Peter A. Kopac of the Pavements Division, HNR-20, for their proofreading and valuable technical suggestions. Appreciation is also extended to Becky McIntyre of the Center for Transportation Research who frequently performed the tremendous task of typing the manuscript.

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ABSTRACT

This report summarizes density levels and corresponding variations obtained from 57 construction projects throughout the state of Texas. Almost 80 percent of projects achieved densities higher than 92 percent based on Rice maximum theoretical specific gravity (Test Method Tex-227-F). Factors affecting density and compaction are analyzed. Poor mixture characteristics and small thicknesses of compacted layers were found to be major causes of low densities.

SUMMARY

Densities and variations in density levels in asphalt concrete mixtures in the state of Texas were investigated through 1987 HMAC field construction data. Fifty-seven construction projects, for which relative densities based on Rice maximum theoretical specific gravity (obtained according to Test Method Tex-227-F) were available, were involved in this study. Almost 80 percent of projects achieved relative densities higher than 92 percent based on the maximum theoretical specific gravity. Confidence intervals for average relative densities of different projects were established. Factors affecting density and compaction were reviewed, and the effects of factors such as mat thickness, mix temperature, mix condition, and gradation on density levels were investigated. Small mat thickness and poor mixture characteristics proved to be among the most important factors contributing to low density levels. Mixes exhibiting tender behavior or segregation and mixes compacted in thin layers generally had lower density levels than mixes reported as "good" or mixes compacted at thick layers.

IMPLEMENTATION STATEMENT

A summary of typical densities currently achieved in Texas is presented in this report. Analysis indicates that, in most cases, the new specifications of 92 to 97 percent relative density are achievable if the mix is properly designed and compacted at sufficient thickness. It is possible to establish more realistic density specifications if more density data supported by mix characteristics and construction variables are provided.

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CHAPTER 1. INTRODUCTION

In 1982, the Texas State Department of Highways and Public Transportation adopted a density specification for hot mixed asphalt concrete (HMAC). This specification required 3 to 8 percent air voids (relative densities between 92 and 97 percent of maximum theoretical density). Here, the relative density is defined as the ratio of the actual density of the pavement (e.g., in pounds per cubic foot) to the maximum theoretical density (zero-air-void density). In 1983, a study was performed by the Center for Transportation Research in cooperation with Texas State Department of Highways and Public Transportation to determine the densities obtained from 17 construction projects. It was found that the average relative density for the 17 projects was 92.7 percent, with a standard deviation of 2.3 percent. While in most projects the required densities were achieved, there were a few projects in which the required densities were not obtained.

The purpose of the study summarized in this report was to evaluate densities and their variations in a wide range of projects 5 or 6 years after experience with the density specification to determine the degree of success in achieving the required densities and to evaluate factors that influence the ability to achieve the required densities.

In a cooperative effort, 21 districts of the Texas State Department of Highways and Public Transportation provided the Center for Transportation Research with HMAC field construction data from a total of 92 projects. The data include general information concerning parameters such as mixture and compaction temperatures, weight, speed, number of passes of different rollers, amplitude and frequency of vibratory rollers, and type and condition of existing surface on which the HMAC was placed. The data also include the relative densities and air voids of field cores, aggregate gradation, asphalt cement contents, and amount of hot mix placed for each day's production. The data were entered into a database using Lotus 1-2-3 and dBase III Plus softwares. The details of the data organization are provided in Ref 2.

The importance of obtaining pavement density and the various roles played by each of the ingredients in a hot mix asphalt paving mixture have been covered in great detail in a number of previous reports. Therefore, this report will not include further discussions of these points, although the authors in no way wish to detract from their importance.

Data on relative densities of different projects and the corresponding statistical analysis are presented in Chapters 2 and 3. Chapter 2 deals with projects in which The University of Texas at Austin was directly involved in determining the relative densities. Chapter 3 concerns projects reported in 1987 HMAC construction data provided by the State Department of Highways and Public Transportation (SDHPT). Variations in densities, and the factors behind these variations, are discussed in Chapter 4. Finally, Chapter 5 presents conclusions based on analyses presented in Chapters 2, 3, and 4.

CHAPTER 2. EVALUATION OF RELATIVE DENSITIES AND SEVERAL RELATED PARAMETERS

This chapter is a summary of test results performed for the purpose of evaluating density-related properties of asphalt-aggregate mixtures from 14 construction projects within the state of Texas. All tests reported on these projects were performed at The University of Texas at Austin. The purpose of this portion of the study was to compare density levels of new projects with those studied in 1983 and reported in Ref 2. This information was also used to compare density levels obtained by The University of Texas with those reported by the contributing SDHPT districts through 1987 HMAC field construction data which are analyzed in Chapter 3.

CTR Research Report 317-2F (Ref 1), published in 1986, discusses the level of density being achieved in Texas under a previous specification of the State Department of Highways and Public Transportation which was in effect prior to December 1984. The study presented in this chapter is based on the data from hot mix asphalt concrete overlays constructed after the present specification was adopted as a standard. This specification requires the air voids to be between 3 and 8 percent based on the maximum theoretical specific gravity.

Field and Laboratory Procedures

Fourteen overlay construction projects in six districts in the state of Texas were selected for this study. The project pavements were hot mix asphalt concrete mixtures designed in accordance with the Item 340 Standard Specification of the Texas State Department of Highways and Public Transportation (Ref 3). The projects included SDHPT Types B, C, and D mixtures. Type D mixtures are dense fine-graded surface mixtures, while Types C and B are coarser and may be used for surface but are normally used for level-up and base courses. Both limestone and siliceous aggregates were included in this study. The project locations, by district, are shown in Figure 2.1.

Field Procedures

Field cores were obtained after construction to evaluate the in-place density of constructed pavements. In most cases, the research personnel participated in drilling and obtaining the cores with the aid of the district personnel. In all cases, district personnel were involved in obtaining the cores. The cores were then sent to The University of Texas at Austin asphalt laboratory for testing. The number of cores varied from project to project depending on the length of the project and the availability of personnel and equipment. The least amount of cores (12 cores) was obtained from a Type B mix placed on US Highway 77, District 21. The greatest amount of cores (106 cores) was obtained from a Type D mix placed on State Highway 6, District 12. Generally, the number of cores for most projects varied between 20 and 40.

Laboratory Procedures

All laboratory tests were performed at The University of Texas at Austin asphalt laboratory. The following is a description of the procedures followed as a standard in the testing of the cores. All tests referred to are from the Texas State Department of Highways and Public Transportation's Manual of Testing Procedures.

(1) The cores were initially dried in air for a minimum of four days.

(2) The specific gravity of each core was measured according to Test Method Tex-207-F.

(3) After being dried in air, the cores were put in the oven at a temperature of 250°F for 30 minutes in order to allow for breaking the core into an uncompacted mix.

(4) Maximum theoretical specific gravity of the loose mixture was then measured according to Test Method Tex-227-F.

(5) The mixture was then dried and the asphalt cement was extracted from the mixture and

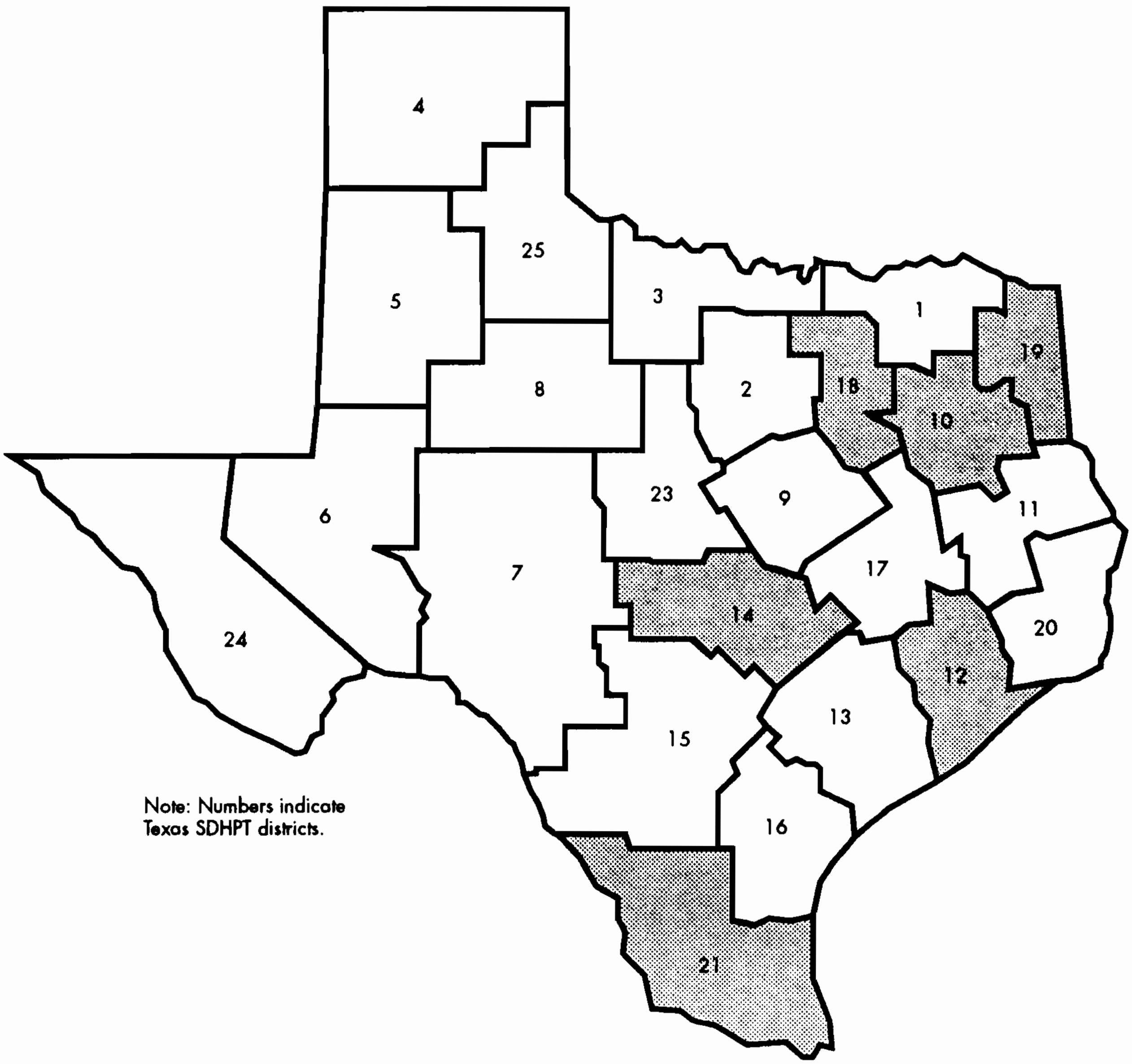


Figure 2.1 Shaded areas indicate districts where corresponding projects were investigated

measured according to the extraction procedure in Test Method Tex-210-F.

(6) A sieve analysis was performed on the aggregates after the extraction according to Test Method Tex-200-F.

The data obtained from the laboratory tests, along with the specific gravities of the aggregates and the asphalt cement, were used to calculate the following parameters of interest:

(1) relative density,
(2) voids in the mineral aggregate (VMA),
(3) percent voids filled (PVF),
(4) asphalt content,
(5) dust-to-asphalt-cement ratio, and
(6) gradation.

Evaluation of Results

The individual results were determined, and these values are given in Tables A-1 through A-14 in Appendix A. Average values were calculated for each project, and a summary of results is shown in Table 2.1. A brief discussion of each parameter is presented.

Relative Density

Relative densities were calculated as

$$R_d = \frac{G_c}{G_r}(100)$$

where

R_d = relative density,
G_c = specific gravity of the core, and
G_r = maximum theoretical specific gravity based on Text Method Tex-277-F (Rice specific gravity).

Two values for Rice specific gravity were used in calculating the relative densities. The first maximum theoretical specific gravity value was determined without being corrected for water absorption, and the second value was corrected for water absorption. Both values for relative density are reported. The first corresponds to the uncorrected Rice specific gravity and the second corresponds to the corrected value. The uncorrected Rice specific gravity, which is the procedure commonly used by the SDHPT, results in lower relative densities than does the corrected one. However, in all cases, the difference between relative densities from these two methods was found not to exceed 1 percent for the projects studied. Table 2.1 includes a summary of relative densities for different projects.

Texas specifications require that the relative densities be less than 97 percent and greater than 92 percent (i.e., allowable range for air voids is 3 to 8 percent). The data presented here for the average values indicate that four projects do not satisfy this requirement if the uncorrected relative densities are

Table 2.1 Summary of results for different projects

District	Highway	Type	Gc/Gr1 (%)	Gc/Gr2 (%)	VMA	PVF	DUST/AC
10	US 287	D	93.7	94.0	18	67	0.9
12	SH 6	D	92.4	93.1	18	62	1.1
14	IH 35	B	93.4	94.0	16	63	1.0
14	IH 35	C	90.7	91.2	18	52	1.0
14	Loop 1	C	91.9	92.7	17	58	1.2
14	Loop 1	D	89.0	89.5	20	47	0.7
14	RR 2244	C	91.7	92.4	16	54	1.0
14	Loop 360	C	94.0	94.4	19	63	1.0
18	IH 635	C, Level up	95.4	95.9			0.6
18	IH 635	C, Surface	93.2	93.4	17	60	0.2
19	SH 67	D	96.6	97.0			0.9
19	SH 67	D	96.9	97.4			1.1
21	US 77	B	93.0	93.7	17	64	0.7
21	US 77	D	92.0	92.7	19	63	0.4
		Count	14	14	11	11	14
		Average	93.1	93.7	18	59	0.8
		Std Dev	2.1	2.0	1.3	5.8	0.3
		Maximum	96.9	97.4	20	67	1.2
		Minimum	89.0	89.5	16	47	0.2

Gc: Core Specific Gravity
Gr1: Rice Specific Gravity Not Corrected for Water Absorption
Gr2: Rice Specific Gravity Corrected for Water Absorption
VMA: Percent Voids in the Mineral Aggregate
PVF: Percent Voids Filled with Asphalt

used. However, if corrected relative densities are used, only two projects do not meet the density specifications.

A histogram representing frequency distribution of relative densities for State Highway 6, District 12, is shown in Figure 2.2. This histogram closely approximates a normal distribution. The relative densities from this study are comparable with those from the previous study (Ref 1) and those from 1987 HMAC field construction data (Ref 2). The results from these three studies are compared in Table 2.2.

Voids in the Mineral Aggregate (VMA)

Percent voids in the mineral aggregate (VMA) is defined as the ratio of void space between the aggregate particles in the compacted mixture to the total volume (Ref 4).

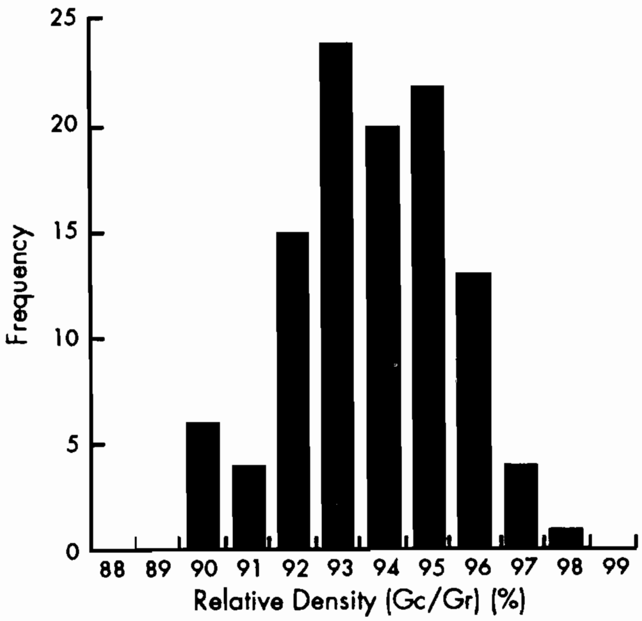


Figure 2.2 Frequency distribution of relative densities for SH 6, District 12

$$VMA = 100 - \frac{G_c \cdot P_{agg}}{G_b}$$

where

G_c = bulk specific gravity of the core,

P_{agg} = weight of aggregate as percent of total mix, and

G_b = bulk specific gravity of aggregate.

Some investigators believe that it is more reasonable to calculate VMA based on the effective specific gravity of the aggregate rather than the bulk specific gravity. When using the effective specific gravity, the total volume of asphalt is taken into account when calculating VMA (i.e., the volume of absorbed asphalt is also included).

It is important to identify which specific gravity of aggregate is used to calculate VMA since it will affect the value derived. To illustrate this, the equations for the VMA for the two specific gravities are shown below:

Using bulk specific gravity: VMA = AIR VOIDS + effective asphalt content

Using effective specific gravity: VMA = AIR VOIDS + total asphalt content

It must be noticed that asphalt content, air voids, and VMA are expressed as percents of total volume of the mix. Considering the relationship between these three measurements (VMA, air voids, and asphalt content), specifying minimum values for VMA and air voids establishes a minimum asphalt content. In other words, the mix is not allowed to be drier than a certain degree when minimum air voids and a minimum VMA are both specified.

Normally, a minimum value is specified for VMA. The minimum required VMA is generally higher for finer mixtures. Huber and Heiman (Ref 5) observed deeper rutting depths for compacted mixtures with VMA values less than 13.5. If the VMA is not sufficient, there will not be enough space to

Table 2.2 Comparison of relative densities from three different studies

Study	Number of Projects	Minimum Gc/Gr*	Maximum Gc/Gr	Average Gc/Gr	Std Dev Gc/Gr
1983 Projects (Ref 1)	17	89.7	95.9	92.7	2.3
U.T. Projects**	14	89.5	97.4	93.7	2.0
1987 HMAC Field Const Data***	57	90.1	95.8	93.0	1.3

* Gc: Specific Gravity of the Core

* Gr: Maximum Theoretical Specific Gravity Based on the Rice Method

** Projects studied in this chapter

*** Data presented in Chapter 4

accommodate the asphalt cement. Therefore, one of the following two problems may occur:

(1) Insufficient asphalt is used because of the inadequate air void content. In this case, the coating on the aggregate will be thin and durability will be reduced.
(2) Asphalt content is sufficient to provide thick coating and high durability, but air void content will then be excessively low. Such a condition results in flushing and instability.

The Asphalt Institute (Ref 4) suggests a minimum VMA ranging from 13 to 16 for a nominal maximum particle size ranging from 1 inch to 0.375 inches. These minimum values were suggested based on an evaluation of mixes designed by the Marshall Mixture Design Method. Requiring the same values for mixes designed by the Texas Gyratory Method may not be appropriate. An FHWA Technical Advisory Committee (Ref 6) also recommends the same minimum values for VMA after a study that was performed on rutting and stripping of asphalt concrete hot mixes by an FHWA Ad Hoc Task Force. Extensive research on Texas mixtures is required to determine which VMA would be appropriate for future Texas specifications. An extensive HMAC field construction database, which includes VMA values obtained from Texas mixtures, has been assembled at the Center for Transportation Research. These data could provide a primary foundation for analysis of the VMA data.

The VMA values for projects evaluated in this study are presented in Tables A-1 through A-14. Average VMA for different projects varies between 16 and 20. For most projects, the difference in the maximum and minimum values for VMA is 5. However, in all but two projects, the standard deviation is less than 1.5. All projects except one have VMA values exceeding the minimum values suggested by the Asphalt Institute. However, interpreting VMA values of Texas mixes based on the Asphalt Institute minimum VMA requirements may not be appropriate because of the difference in the Marshall and Texas Gyratory design procedures.

Percent Voids Filled (PVF)

Percent voids filled (PVF) is defined as the ratio by volume of the effective asphalt content (total asphalt content minus the asphalt absorbed into the voids of the aggregate particles) to VMA, expressed as a percent. PVF is calculated by:

$$PVF = \left[\frac{AV}{VMA}\right]*100$$

where

AV = air void content, percent, and
VMA = voids in the mineral aggregate, percent.

PVF is normally limited to a maximum value. Ford (Ref 7) suggests that PVF be between 75 and 85 percent. Huber and Heiman (Ref 5) recommend PVF values lower than 70 percent based on their field observations and tests on pavement rutting.

All projects presented in this report are below the recommended 70 percent. On the average, percent voids filled is less than 62 percent and more than 52 percent (i.e., well below the suggested maximum allowable limit of 70 percent). The percent voids filled varies significantly within a project. The standard deviation for PVF varied between 3 and 12 percent for the projects studied.

Dust-to-Asphalt-Content Ratio

Dust refers to the fine fraction passing the No. 200 sieve. The amount of dust in the mix affects the mechanical and compaction characteristics of the mix. Increase in the dust-to-asphalt-content (AC) ratio increases stiffness, resilient moduli, tensile strength, and stability (Ref 8). The amount of increase depends on type, void-filling properties, and gradation of the dust. Increase in stiffness is accompanied by decrease in tensile strain at failure—which is not desirable. The work by Santucci and Schmidt (Ref 9) suggests that density is affected by the amount of dust-to-asphalt-cement ratio. Figure 2.3 illustrates this relationship.

The FHWA Technical Advisory Committee recommends a dust-to-asphalt ratio not greater than 1.2 and not less than 0.6. These values are based on ratios obtained through weight calculations (i.e., the ratio of percent of asphalt cement to the percent of dust in the mix by weight). It should be noticed that in Figure 2.3 the ratio is based on volume. The dust-to-AC ratios presented in this report are based on weight. This study shows that two projects, District 18 (coarse surface) and District 21, have dust-to-AC ratios out of the 0.6 – 1.2 range recommended by FHWA. Both of these projects gave ratios less than 0.6. Most of the projects had ratios close to 1.0.

Aggregate Gradation

Aggregate gradation has great influence on the pavement performance. Gradation is normally plotted on a gradation chart on which sieve sizes are raised to 0.45 power. The gradations are compared with the "maximum-density line" which plots as a line from maximum nominal size to the origin (FHWA 0.45 power gradation line). This line will produce the maximum-density gradation. Typical gradation charts for different projects are given in Figures A-1 through A-12 in Appendix A. Gradations along the 0.45 line have been found to have too low a VMA and can result in unsatisfactory pavement performance. Deviations from this curve to increase VMA are recommended. Past experience has shown that gradation curves which plot farther from the maximum-density line result in higher VMA values

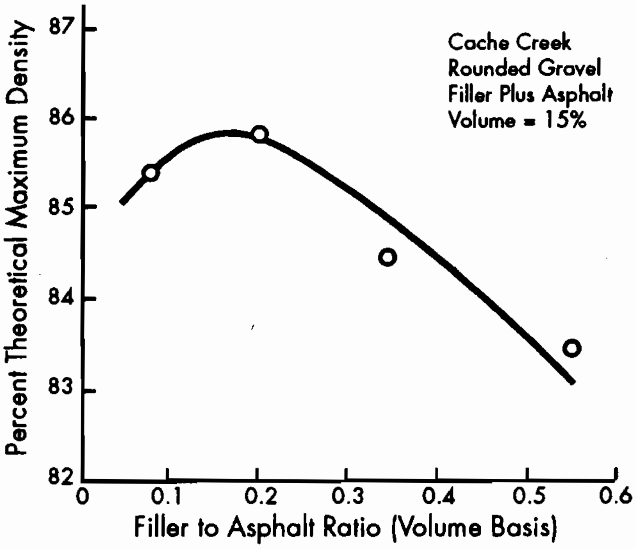


Figure 2.3 Filler-to-asphalt ratio influences compactive effort (Ref 9)

(Ref 10). However, a hump above the maximum-density line at the No. 30 sieve size has been shown to cause a reduction in stability and an increase in the VMA.

The gradations for all projects studied in this report deviate from the 0.45 line. How much deviation is required to give the best performance depends on the asphalt-aggregate interacting factors and is a question that requires further analysis. All gradations give a lower percent passing the No. 200 sieve than that given by the 0.45 line. A lower percent fines than that of the 0.45 line is desirable because percent minus sieve No. 200, given by the 0.45 line, generally results in a poor performing mixture. In almost all cases, the gradation lies below the 0.45 line in the region above the No. 10 sieve. Some gradations indicate a hump between sieves No. 10 and No. 40. A more detailed analysis of gradation will be presented in Chapter 4 following the analysis of 1987 HMAC field construction data.

CHAPTER 3. EVALUATION OF RELATIVE DENSITIES FROM THE 1987 CONSTRUCTION DATA

Projects studied in Chapter 2 were those that The University of Texas at Austin asphalt laboratory initiated for determining the relative densities and corresponding variations. This chapter deals with projects reported in 1987 HMAC field construction reports to the Materials and Tests Division. For these projects, the relative densities were reported by the districts.

For the projects in this study, the relative densities are reported based either on Rice maximum specific gravity or on a calculated specific gravity using the bulk or effective specific gravity of the aggregates. Out of the total of 92 projects available, relative densities of 57 projects are calculated based on the Rice specific gravity.

There are 32 projects for which no report of density is available. It should be noted that some projects belong to the same construction location but are considered as separate projects. This results from a change in mixture type (Type B, C, D, etc.) or from a change in mix designs which were used for the same construction project. For instance, four separate projects were considered for US 290 in Washington County, District 17, to differentiate between mix types (B and D) and different mix designs (design numbers 7, 8, and 10).

In general, relative densities based on Rice maximum specific gravity are lower than those based on a calculated maximum specific gravity. This observation is in agreement with the past experience regarding differences between the two methods.

Table B-1 shows the projects for which the relative density based on Rice specific gravity is available. In this table, the average relative density, the maximum and minimum relative densities, the standard deviation, and the number of cores used to find the relative densities for each project (N) are given.

The confidence interval for the true mean of the relative densities for various projects was determined through a statistical analysis. To perform a statistical analysis of this type, the density distribution should follow a normal distribution. For projects with large numbers of density measurements (greater than 30), a frequency plot of density should be sufficient to check the normality of the distribution. However, in many projects, the number of density measurements does not exceed 10; therefore, a frequency plot is not a proper means of checking normality. The normality of small samples is best checked by using a normal probability plot. This is a plot in which the normal scores (which are based on the number of observations) are plotted against the observations (relative densities). The plot should follow a straight line if the distribution is normal. Significant deviations from a linear pattern indicate that the underlying distribution is not normal. Therefore, the normality of density distribution for each project was checked using a normal probability plot. Normal probability plots for some samples are shown in Figure 3.1. These plots indicate that the distributions are close to normal although they do not lie perfectly on a straight line. Because of the limited number of observations (density measurements) in most cases, the student t-distribution, rather than typical normal distribution, was used to determine the ranges for true mean, the confidence levels, and the confidence tolerance for different projects. The ranges for true means are shown in Table B-2. A total of 763 relative density measurements based on Rice maximum specific gravity are reported for all the projects (i.e., 763 single measurements are obtained when data from all projects are put together). The distribution of all measurements put together closely follows a normal distribution (Figure 3.2).

The lowest and highest measurements correspond to relative densities of 86 and 95.8 percent, respectively. The average density, when all data are put together, is 93.0, and the standard deviation is 1.83. However, the standard deviation calculated in this way is probably not a useful measurement for specification purposes. It cannot be related to a typical construction project, since each project's measurements are mixed in to calculate this value. Its significance here is to indicate what magnitude of standard deviations is obtained if all random single density measurements from different projects are put together. For each project, an average density was calculated based on data available from daily construction records. In this way, 57 values were found,

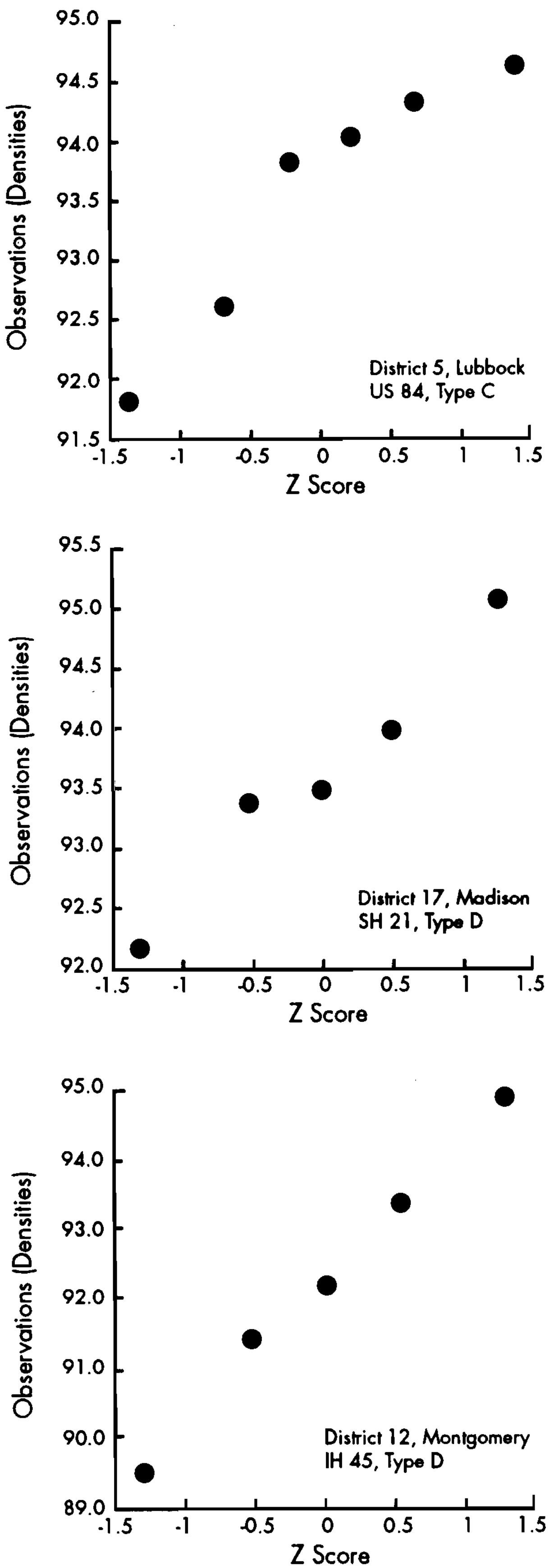


Figure 3.1 Normal probability plots for some sample projects

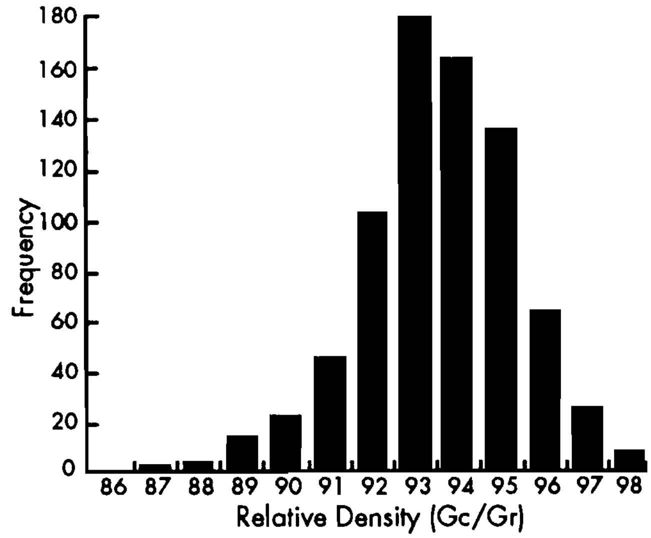


Figure 3.2 Frequency distribution of relative densities when all individual measurements are taken into account

each representing the average density for one project. The mean and standard deviation of the average relative densities were 93.0 and 1.3, respectively (Table B-1).

Therefore, a typical hot mix construction project in Texas achieves a relative density of 93 percent based on Rice maximum theoretical specific gravity with a corresponding standard deviation of 1.3. Another standard deviation reported in Table B-1 is the value of 1.23, which is the average standard deviation for a typical construction project. This should not be confused with the former standard deviation (1.3), which is an indication of how average densities of various projects in Texas deviate from 93 percent. Even though these two standard deviations have different interpretations, their magnitudes are not significantly different for all practical purposes.

The average densities of the projects, based on Rice maximum specific gravity, follow a near-normal distribution, as shown in Figure 3.3. This check for normality is required in order to establish confidence intervals and probabilities based on a normal distribution.

Average relative densities for projects involved in the present study and those studied in 1983 (Ref 1) are shown in Table 3.1. A comparison of past and present studies reveals that a slight improvement in average density was achieved (92.7 percent relative density improved to 93.0 percent). Reduction in standard deviation implies a smaller variation in densities of the current projects. However, this slight improvement could be due to the fact that a larger sample was used for the present study.

Statistical analysis of densities for projects reported in Ref 1 suggests that only 57 percent of the

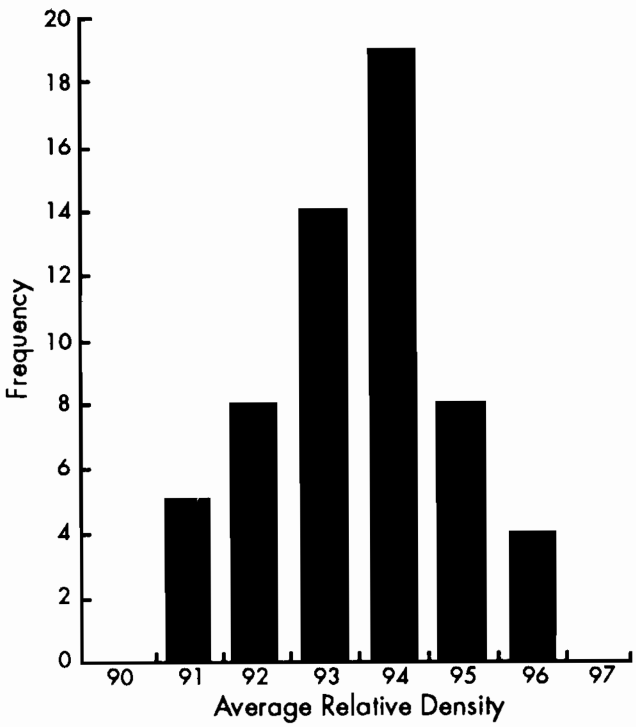


Figure 3.3a Frequency distribution of average relative densities

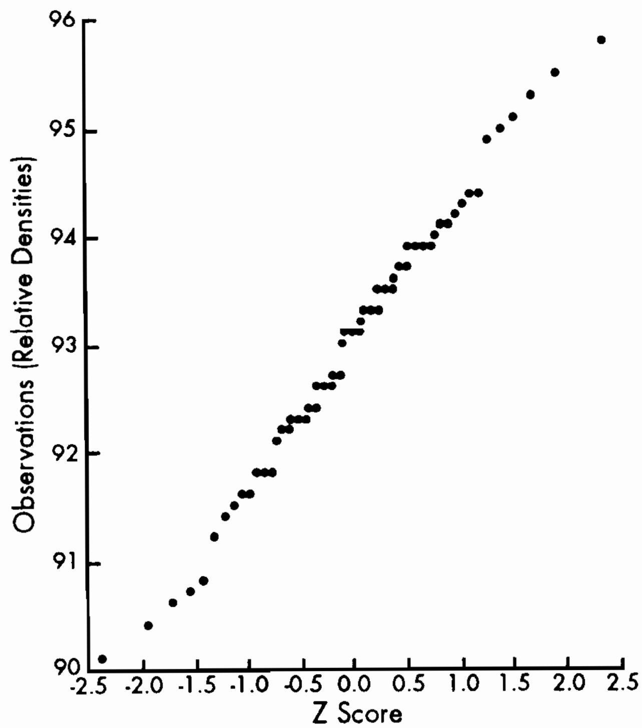


Figure 3.3b Frequency distribution of average relative densities

projects achieved densities between 92 and 97 percent. The same type of analysis on densities for projects of the present study shows that about 78 percent of projects lie within this range.

The student t-test was performed to investigate the existence of any statistical significance between the average density of previous projects (Ref 1) and the average density of projects covered in this study. Since the true means and variances of the two groups are unknown, this case is treated as the Behrens-Fisher problem, explained in Ref 11. The t-value obtained through this analysis suggests that there is no significant difference between average densities of these two groups.

Out of 18 projects for which relative densities based on the calculated maximum theoretical specific gravity are available, only one has a relative density less than 92 percent (average relative density for this project is 91.8 percent), and, in general, densities are within specification limits. The calculated maximum theoretical specific gravities are obtained using the effective specific gravity of the aggregates from the C-14 method or the bulk specific gravity of the aggregates. However, not all the relative densities based on Rice maximum specific gravity meet specification requirements concerning density. There are 57 projects for which relative densities based on Rice maximum specific gravity are available. Thirteen projects did not achieve required densities and had densities less than 92 percent. Of course, in all cases, relative densities exceeded 90 percent. Five projects had relative densities between 90 and 91 percent. The other 8 had relative densities between 91 and 92 percent. There are 13 projects with relative densities higher than 94 percent and only 5 projects with relative densities above 95 percent. Therefore the majority of projects (32 projects out of 57) had relative densities between 92 and 94 percent.

Table 3.1 Comparison of statistical data on relative densities

a) Relative Densities (Gc/Gr):

	Past Study (Ref. 1)	Present Study
Count	13	57
Average	92.7	93.0
Std Dev	2.3	1.3
Minimum	89.7	90.1
Maximum	95.9	95.8

b) Standard Deviation of Relative Densities

	Past Study (Ref. 1)	Present Study
Count	13	57
Average	2.30	1.30
Minimum	1.09	0.17
Maximum	3.76	3.37

CHAPTER 4. ANALYSIS OF PROJECT DATA

As a first step in analyzing the factors that may have contributed to variations in density, two groups of mixes are compared:

Group 1, including relative densities less than 92 percent, and

Group 2, including relative densities higher than 94 percent.

Factors affecting density for Group 1 are compared with those for Group 2. The reason for separating the two groups by a gap of 2 percent air voids is to reduce the effect of density measurement errors and to distinguish more clearly between the groups.

Tables 4.1 and 4.2 show several mix factors which affect density for these two groups, and Tables 4.3 and 4.4 give some variables which influence density during compaction. A general comparison of mixes with relative densities less than 92 percent and those with relative densities higher than 94 percent (based on Tables 4.1 through 4.4) indicates that the major difference between the two groups is in the mat thickness. Other variables do not suggest distinct differences between the two groups. However, a more detailed evaluation of density variation was performed by a closer investigation of some major variables affecting density and compaction.

Effect of Mat Thickness

The variation in mat thickness between projects ranged between 1.2 and 4.4 inches. Each project reported only a range for the layer thickness (for instance, between 2.0 and 2.5 inches). Such a range would not allow for an accurate analysis aimed at evaluating the effect of the layer thickness on density. Therefore, the layer thickness was computed from the data available on the amount of hot mix asphalt concrete used and the area paved as reported on the daily construction records. This allowed the layer thickness to be calculated for each construction day. Then, the average thickness during the construction period was determined and recorded as the average layer thickness for each project. The numbers on pages 12-13 in Tables 4.3 and 4.4, under the

Table 4.1 Some mix parameters for projects with Gc/Gr less than 92 percent

Project	Design AC	Ext AC	DUST/AC	% Pass #40	% Pass #80	% Pass #200	VMA	PVF	Mix Type
D5GAUS84	5.1	5.2	0.71	21.9	11.8	3.7	19.3	57.7	D
D12MFM13	5.3	5.3	1.26	29.7	13.4	6.7	17.0	50.3	D
D13GOSH8	4.7	4.6	0.76	26.1	11.3	3.5	N/A	N/A	D
D13GOU87	4.7	4.6	0.74	25.8	11.0	3.4	N/A	N/A	D
D13JAS11	4.5	4.6	1.48	27.3	16.4	6.8	N/A	N/A	D
D14BSH21	4.5	4.5	0.82	17.9	9.4	3.7	17.1	52.0	C
D14BSH21B	4.5	4.5	1.00	19.6	10.2	4.5	17.9	51.9	C
D14BSH71	5.0	5.0	1.30	21.9	14.6	6.5	18.6	55.9	D
D14TIH35FR	4.7	4.7	1.43	21.9	14.6	6.7	16.9	51.6	C
D17GSH6B	5.8	5.5	0.64	21.5	8.8	3.5	N/A	N/A	D
D17BSORCOM	5.4	5.6	0.57	27.1	18.5	3.2	N/A	N/A	D
D17B21COM	5.3	5.0	0.62	25.1	16.1	3.1	N/A	N/A	D
D17R79COM	6.1	5.8	0.67	27.2	19.1	3.9	N/A	N/A	D
Count	13	13	13	13	13	13			
Average	5.0	5.0	0.9	24.1	13.5	4.6			
Std Dev	0.5	0.5	0.3	3.5	3.4	1.5			
Maximum	6.1	5.8	1.5	29.7	19.1	6.8			
Minimum	4.5	4.5	0.6	17.9	8.8	3.1			

Table 4.2 Some mix parameters for projects with Gc/Gr greater than 94 percent

Project	Design AC	EXT AC	DUST/AC	% Pass #40	% Pass #80	% Pass #200	VMA	PVF	Mix Type
D1FNUS82	5.6	5.5	1.00	27.9	14.5	5.5	16.4	71.8	D
D13FAU77C	6.0	6.0	0.72	25.9	12.9	4.3	N/A	N/A	D
D16JUS28	4.9	4.9	0.84	23.7	15.5	4.1	N/A	N/A	C
D16RUS77B1	4.9	4.8	0.60	19.3	11.6	2.9	N/A	N/A	B
D16SPU18B	4.5	4.5	0.76	23.9	10.3	3.4	N/A	N/A	B
D16SPU18S	5.0	5.0	0.80	20.6	8.3	4.0	N/A	N/A	D
D17BSH36TB	5.6	5.5	1.35	28.9	17.2	7.4	N/A	N/A	B
D17GS105	5.1	4.9	1.12	24.2	13.7	5.5	N/A	N/A	D
D17WUS29D	4.2	4.2	1.43	26.3	15.2	6.0	N/A	N/A	D
D17WUS29B1	3.7	3.7	0.89	24.3	12.6	3.3	N/A	N/A	B
D19CUS59	4.8	4.7	0.77	22.2	8.8	3.6	15.0	62.8	D
D19MUS59	5.7	5.6	0.41	25.1	14.0	2.3	N/A	N/A	C
D23MUS87	3.9	3.9	1.69	17.5	11.1	6.6	N/A	N/A	GR4
Count	13	13	13	13	13	13			
Average	4.9	4.9	1.0	23.8	12.7	4.5			
Std Dev	0.7	0.7	0.4	3.3	2.7	1.5			
Maximum	6.0	6.0	1.7	28.9	17.2	7.4			
Minimum	3.7	3.7	0.4	17.5	8.3	2.3			

title "Mat Thickness," are the average thicknesses calculated using the above procedure. A general consideration of densities and corresponding mat thicknesses reveals that thicker layers tend to have higher densities than thinner layers. Statistical t-test analysis of the thickness data presented in Tables 4.3 and 4.4 supports the idea that projects with relative densities greater than 94 percent have higher thicknesses than those with relative densities less than 92 percent. This analysis was performed at a 5 percent significance level, and the results are shown in Table 4.6. Figure 4.1 presents this general conclusion. It should also be noted that out of 13 projects with relative densities higher than 94 percent, only one project has a mat thickness of less than 1.5 inches. However, out of 13 projects with relative densities less than 92 percent, there are 5 projects with mat thickness less than 1.5 inches.

A plot of relative density versus the mat thickness for projects that did not achieve minimum required densities (Figure 4.2) indicates that as the mat thickness increases, the relative density

Table 4.3 Mat thickness, mix temperature, and vibratory roller variables for projects with Gc/Gr less than 92 percent

Project	Mat Thick (in.)	Mix Temp (°F)	First Pass Temp (°F)	Last Pass Temp (°F)	Vib Speed (mph)	Vib Wt (Ton)	Vib Freq (Hz)	Vib Ampl (in.)	Vib No. of Passes
D5GAUS84	1.73	310	292	170	2.5	10.0	N/A		3
D12MFM13	1.62	300	270	200	4.0	25.0	31	LOW	4
D13GOSH8	1.28	300	240	200	3.5	10.0	36	.029	3
D13GOU87	1.26	300	240	200	3.0	9.3	28	.047	1
D13JAS11	1.19	325	230	190	N/A	N/A	N/A	N/A	N/A
D14BSH21	1.71	305	251	180	6.0	13.0	42	LOW	2
D14BSH21	2.03	305	251	180	6.0	13.0	42	LOW	2
D14BSH71	1.81	300	260	230	2.7	10.0	38	.028	2
D14TIH35	1.63	285	243	195	2.5	10.0	42	L&M	1
D17GSH6B	1.51	325	310	275	4.0	8.5	23	.060	2
D17BSORC	1.45	325	275	225	4.0	N/A	22	.060	2
D17B21CO	1.53	325	275	225	4.0	N/A	22	.060	2
D17R79CO	1.49	325	275	225	4.0	N/A	22	.060	2
Count	13	13	13	13	12	9	11		
Average	1.56	310	262	207	3.9	12.1	32		
Std Dev	0.24	14	23	28	1.1	4.8	8.7		
Maximum	2.03	325	310	275	6.0	25.0	42		
Minimum	1.19	285	230	170	2.5	8.5	22		

Table 4.4 **Mat thickness, mix temperature, and vibratory roller variables for projects with Gc/Gr greater than 94 percent**

Project	Mat Thick (in.)	Mix Temp (°F)	First Pass Temp (°F)	Last Pass Temp (°F)	Vib Speed (mph)	Vib Wt (Ton)	Vib Freq (Hz)
DIFNUS82	1.95	300	265	195	2.5	15.0	40
D13FAU77	1.65	295	280	185	2.4	10.0	35
D16JUS28	1.58	300	300	150	N/A	N/A	N/A
D16RUS77	3.11	N/A	N/A	N/A	2.5	10.0	28
D16SPU18	3.14	N/A	N/A	N/A	2.5	N/A	28
D16SPU18	1.60	N/A	N/A	N/A	2.5	N/A	28
D17BSH36	2.49	300	275	225	4.0	N/A	N/A
D17GS105	1.23	300	275	225	4.0	N/A	22
D17WUS29	1.67	315	305	275	N/A	N/A	N/A
D17WUS29	2.97	300	275	225	N/A	N/A	N/A
D19CUS59	2.68	315	300	265	6.4	10.9	N/A
D19MUS59	2.51	290	270	240	6.7	10.0	36
D23MUS87	4.43	320	290	220	N/A	N/A	N/A
Count	13	10	10	10	9	5	7
Average	2.39	304	284	221	3.7	11.2	31
Std Dev	0.89	10	14	37	1.7	2.2	6.2
Maximum	4.43	320	305	275	6.7	15.0	40
MInimum	1.23	290	265	150	2.4	10.0	22

increases. A general plot (including all projects) of density versus thickness is given in Figure 4.3a on page 14. One should not expect to see a clear trend of the effect of thickness on density in this plot, owing to the many other factors that affect density in different directions. However, if the effects of other factors are eliminated—i.e., if the effect of thickness on density is evaluated while all other conditions are the same—then a clear trend should be observed. However, no two projects have the same factors affecting density. When the projects with more or less the same mix characteristics and construction conditions are selected, the corresponding data are not sufficient to evaluate the effect of the contributing parameter (thickness) on the relative density. However, in one case, it was decided to evaluate the effect of thickness on relative density when the effect of two of the factors was reduced. These two factors were the temperature of the hot mix during the first pass of the vibratory roller and the weight of the vibratory roller. The temperature was restricted to a range between 240° and 300°F,

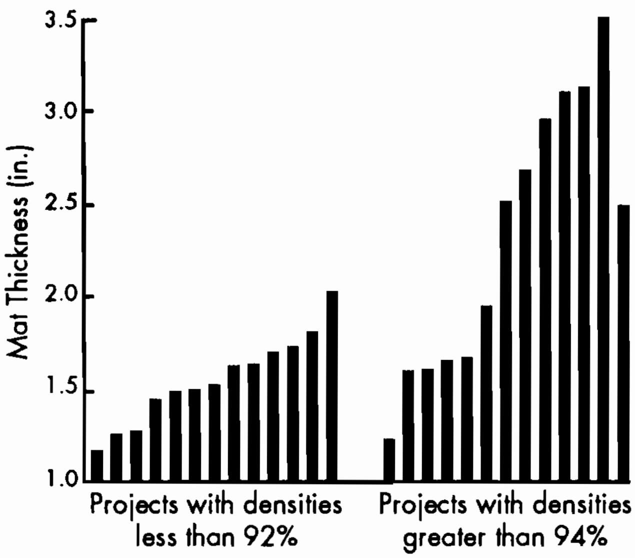


Figure 4.1 **Comparing overlay thicknesses of low-density projects with those of high-density projects**

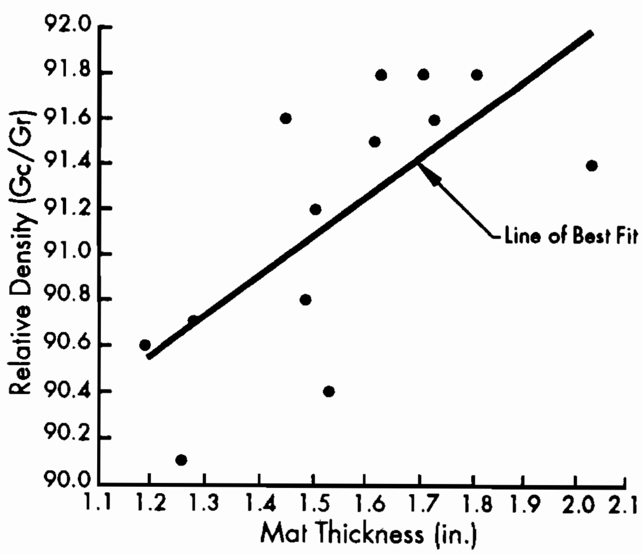


Figure 4.2 **Plot of relative density versus mat thickness for projects with relative densities less than 92 percent**

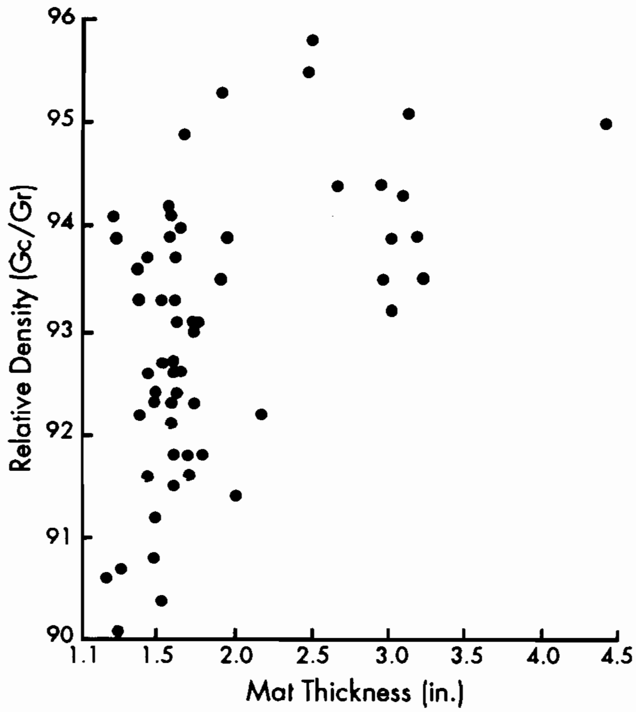


Figure 4.3a Plot of mat thickness versus relative density for all projects

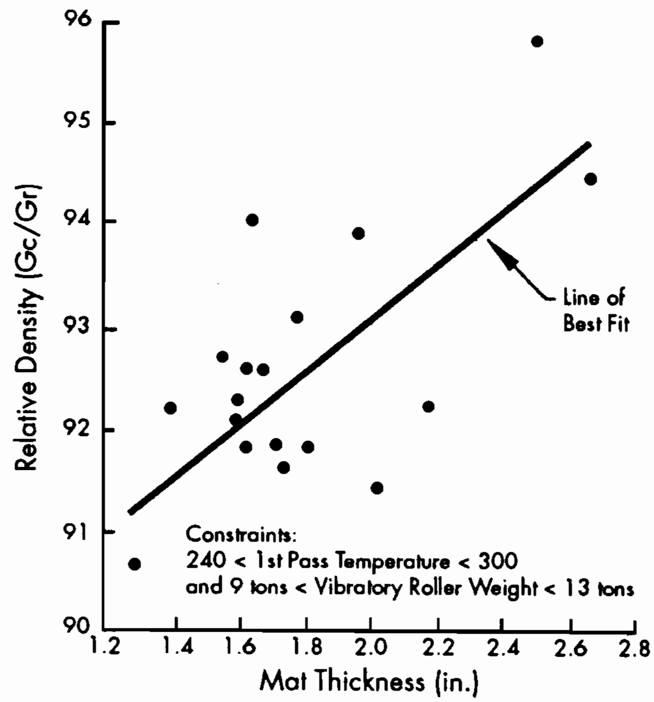


Figure 4.3b Plot of mat thickness versus relative density for projects given constraints on first-pass temperature and vibratory roller weight

and the weight of the roller was restricted to a range between 9 and 13 tons. The result is shown in Figure 4.3b. This figure supports the idea of higher densities for greater thicknesses.

Therefore, mat thickness can be considered an important factor affecting density. It is more difficult to achieve adequate density for thin layers than for thick ones.

Mix Condition

Out of the 57 projects with relative densities calculated based on Rice specific gravity, brief explanations were furnished for 31 projects concerning the mix condition; for the rest there were no remarks at all. Mix conditions for most projects were reported as either "good" or "excellent." A few projects were reported to have sticky mixes. One project had a problem with excessive bleeding of the mix. Six projects had some type of segregation-related problem with their mixes, and for 5 projects problems were reported with the tenderness of the mix. Out of these 11 projects with tenderness or segregation problems, only 2 achieved densities higher than 93 percent. Six of the remaining 9 projects had densities less than 92 percent. In fact, out of the 13 projects that did not achieve minimum required densities, explanations were furnished for only 6 concerning the mix conditions that had either tenderness or segregation problems. For the other 7 projects there were no remarks at all. For these projects, nothing was mentioned regarding the quality of the mix.

On the average, the projects with segregation or tenderness problems did not achieve densities as high as those without any mix problems. Figure 4.4 presents average relative densities for three groups of projects:

(1) those with tenderness problems;
(2) those with segregation problems; and
(3) those reported as good or excellent mixes.

The average density for the third group of projects is higher than the average densities for the other two groups.

Effect of Temperature

Table 4.5 indicates a summary of data available on average temperatures at the time of mixing, the first pass of the roller, and the last pass of the roller. The data are categorized into two groups: Group 1 (Table 4.5a) presents average temperature values for all projects for which temperature data are available, and Group 2 (Table 4.5b) summarizes temperature data for projects for which relative densities based on Rice maximum specific gravity are available. It can be seen that the average mixing temperature is

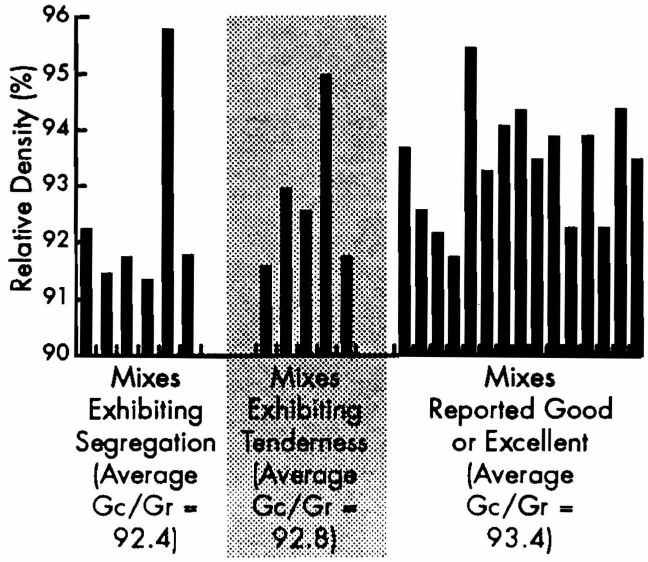


Figure 4.4 Effect of mix condition on relative densities

Table 4.5 Statistical data on mix temperature at the time of discharge, first rolling pass, and last rolling pass

	a) For All Projects		
	Temperature at Discharge	Temperature at First Pass	Temperature at Last Pass
Count	83	83	81
Average	308	276	210
Std Dev	16	25	37
Minimum	260	210	135
Maximum	340	320	290

	b) For Projects For Which Gc/Gr Is Available			
	Temperature at Discharge	Temperature at First Pass	Temperature at Last Pass	Gc/Gr
Count	53	53	52	53
Average	307	273	205	93
Std Dev	15	21	31	1
Minimum	275	225	135	90
Maximum	340	320	275	96

about 310°F. Some projects reported mixing temperature as low as 260°F and some others as high as 340°F. However, the majority of projects had mixing temperatures between 290° and 325°F. The average mix temperature at the time of the first pass of the roller was around 275°F. Although a few projects had much lower values than average (210° and 225°F) or much higher (320°F), the majority had temperatures between 270° and 300°F. The average temperature at the time of the last pass of the roller was around 205° to 210°F, although for a few of the projects it was as low as 135° to 150°F. These projects had relative densities higher than 92 percent based on Rice maximum specific gravity.

Table 4.6 Statistical data

	Group 1 (Table 4.3)				Group 2 (Table 4.4)			
	n	$\bar{x}$	S^2	nu	n	$\bar{x}$	S^2	nu
Thickness	13	1.56	0.056	12	13	2.39	0.798	12
Mix Temp	13	310	183	12	10	304	95	9
First-Pass Temp	13	262	531	12	10	284	200	9
Last-Pass Temp	13	207	794	12	10	221	1364	9

COMBINED	S_p^2	S_d^2	υ_c	t_c	$t_{0.05}$	Significant?
Thickness	0.653	0.066	24	3.23	2.064	Yes
Mix Temp	145	25.7	21	1.28	2.080	No
First-Pass Temp	389	68.9	21	2.54	2.080	Yes
Last-Pass Temp	1038	183.7	21	0.97	2.080	No

n = Number of Observations

$\bar{x}$ = Sample Mean

S^2 = Sample Variance

υ_c = Degrees of Freedom

S_p^2 = Pooled Estimate of the Common Variance: $S_p^2 = \dfrac{\upsilon_1 S^2 + \upsilon_2 S^2}{\upsilon_1 + \upsilon_2}$

S_d^2 = Variance of Difference of Means: $S_d^2 = S_p^2\left(\frac{1}{n_1} + \frac{1}{n_1}\right)$

υ_c = Degrees of Freedom Corresponding to the Pooled Estimate of Variance ($\upsilon_c = n_1 + n_2 - 2$)

t_c = Calculated t-value: $t_c = \dfrac{\bar{x}_2 - \bar{x}_1}{S_d}$

$t_{0.05}$ = t-value from the t-table at 5% significance level for υ_c degrees of freedom (a two-tailed t-test is used)

A t-test analysis was performed to compare the temperatures reported in Table 4.3 (i.e., for projects with relative densities less than 92 percent) with those reported in Table 4.4 (i.e., for projects with relative densities greater than 94 percent). The results of this statistical analysis are given in Table 4.6. No significant difference was observed between mix temperatures and last-pass temperatures of the two groups at the 5 percent significance level. However, at this level of significance, the average first-pass temperature of the projects in Table 4.4 was larger than that of the projects in Table 4.3. Considering the fact that there is not a significant difference between the mix temperatures of the two groups, the higher first-pass temperature for the second group could be the result of thicker layers. This higher compaction temperature contributes to higher densities for thicker pavements, as indicated in Tables 4.3 and 4.4.

Figure 4.5a shows a plot of relative densities versus the mix temperature at the time of the first pass of the roller. The plot generally indicates that the population of higher densities belongs to a higher range of compaction temperatures. Of course, the effect of compaction temperature on relative density may not be very clear based on this plot (mainly because of many other factors involved), and therefore a conclusion based on this plot may be premature.

It is important to keep the mix temperature sufficiently high to prevent a significant temperature drop during compaction, since adequate compaction may not be achievable at low temperatures. The lower the temperature, the more difficult it will be to reach adequate density.

Many factors contribute to temperature drop, such as original mix temperature, environment, and thickness of the pavement. Rolling operation is also a governing factor in mix temperature at the time of compaction. Obviously, longer "relax" intervals between consecutive rolling passes cause greater differences between mix temperatures during different passes. Moreover, the slower the roller speed, the lower the mix temperature during the subsequent passes.

As mentioned before, projects with smaller mat thicknesses generally had lower densities than did those with larger thicknesses. One reason for such a phenomenon is that temperature drops more rapidly for thinner mats. Thick mats are able to retain higher mixture temperatures for a longer period of time. This fact is supported by Figure 4.5b, which shows a bar plot of the temperature difference between first and last passes of the roller versus the mat thickness. Of course, ambient temperature and vibratory roller speed are also among the factors that affect the differences between compaction temperatures during different passes of rollers. The effect of vibratory roller speed was eliminated by keeping the vibratory roller speed at 3 miles per hour. Applying additional constraints could result in reducing the number of data points to so few that no meaningful plot could be obtained.

Effect of Amplitude of Vibratory Rollers

A general review of projects indicates that the vibratory amplitude for different projects varies within a wide range. Although most projects reported numerical values concerning the amplitudes, some were reported as either high or low. The lowest amplitudes were about 0.013 to 0.016 inches and the highest ranged from 0.04 to 0.06 inches. A general recommendation would be to use a higher amplitude for higher mat thicknesses and a lower amplitude for lower mat thicknesses (Ref 12). Most projects used amplitudes in the medium and high ranges. Only 6 projects with small mat thicknesses (less than 1.5 inches) used a low vibrator amplitude. Unfortunately, out of these 6, the relative density data based on Rice specific gravity is given for only 2 (both higher than 92 percent). Twelve projects with mat thickness less than 1.5 inches reported high amplitudes. Only 7 projects out of these 12 reported relative densities based on Rice specific gravity. Four of these 7 projects had relative densities less than 92 percent.

For thick mats (thicker than 2 inches), the amplitude data are available for 12 projects. Six projects reported medium to high amplitude, and all had relative densities higher than 92 percent. Of the remaining 6, which reported low amplitudes, only one contained relative density data. This project obtained a relative density of 91.4 percent. All 15 projects which achieved high densities (greater than 94 percent) used high amplitudes, and all (except one) had mat thicknesses greater than 1.5 inches.

Asphalt Content and Dust-to-Asphalt-Cement (AC) Ratio

Table B-3 summarizes the design and extracted asphalt contents for different projects. In most cases, the difference between these two did not exceed 0.5 percent. The average difference and the standard deviation were 0.0 and 0.1 percent, respectively. While some projects used asphalt contents as low as 3.7 percent, others used values as high as 7 to 7.6 percent.

Dust-to-AC ratios for projects with given relative densities are shown in Tables B-4 through B-7. Too high a ratio of dust to asphalt cement makes the mix dry and difficult to compact. Too low a ratio makes it tender and unstable.

The FHWA Task Force Technical Advisory recommends dust-to-AC ratios between 0.6 and 1.2 (Ref 6). Out of the 57 projects with relative densities

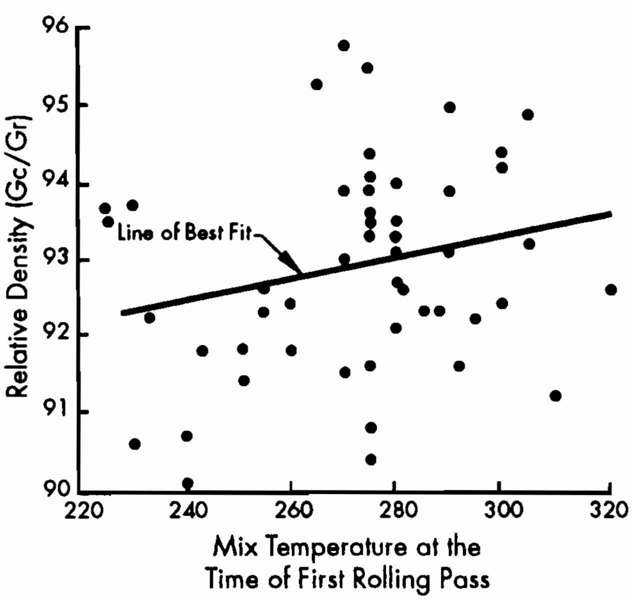


Figure 4.5a Relative density as a function of mix temperature at the time of first rolling pass

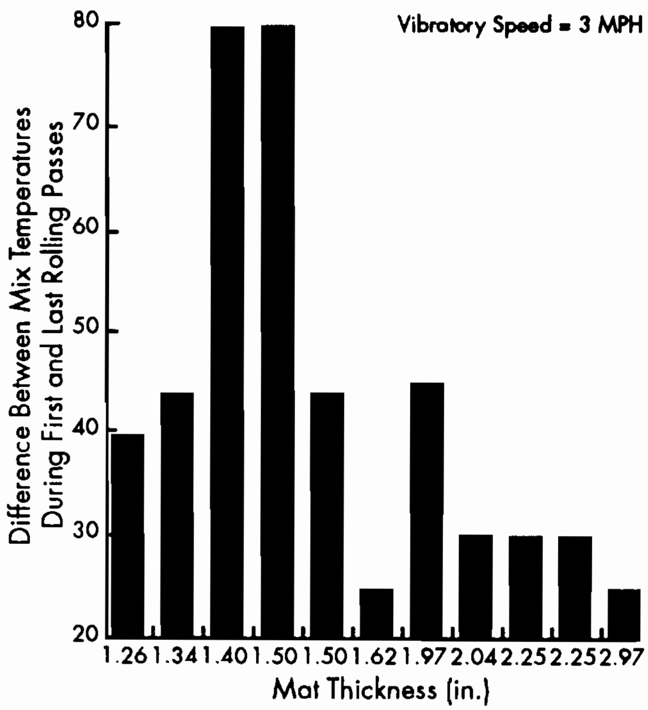


Figure 4.5b Difference between mix temperature during first and last rolling passes versus mat thickness

based on Rice specific gravity, 10 have dust-to-AC ratios exceeding 1.2 and 12 have dust-to-AC ratios below 0.6. However, these out-of-limit ratios apparently did not cause problems with achieving adequate densities. No meaningful relationship could be found between average density and dust-to-AC ratio.

Gradations and Voids in the Mineral Aggregate (VMA)

Aggregate gradations were determined by performing sieve analysis on the aggregates obtained from an extraction test. All projects reported the aggregate gradations for various construction days. A comparison of gradations within the same project did not show any significant variations as long as the mix design was not altered. The number of gradations reported for different projects varied within a wide range. For each project, the average gradation was determined and recorded. Type B gradations either follow very closely the maximum-density line on the 0.45 power gradation chart or lie above this line. Gradations above the 0.45 line are finer than that obtained with the 0.45 line. Gradations below the 0.45 maximum-density line are harsher or coarser gradations than that of 0.45 line. Most gradations of Type C mixtures closely follow the 0.45 line. Some lie below this line in the range of coarser aggregates (passing the 1/2-inch sieve and retained on sieve No. 10) and above the 0.45 line in the range of finer part (passing sieve No. 10 and retained on sieve No. 80).

Most gradations for Type D mixtures are below the maximum-density line on the 0.45 power gradation chart. Typical gradation charts for the different types are given in Figures 4.6 through 4.8. For all projects, the amount of filler (dust) passing the No. 200 sieve is less than that given by the maximum-density line. The amount of dust given by the 0.45 line is considered high and may result in a dry mix and poor performance. The amount of dust was less than that given by the 0.45 line for all projects reported. The summary of average core VMA values and percent voids filled with asphalt is given in Table B-8. Because of insufficient data concerning bulk specific gravity of aggregates or Rice specific gravity of the mixture, it was not possible to calculate the VMA value for all the projects. VMA values could be calculated for only 17 projects (11 Type D mixes, 5 Type C mixes, and 1 Type G mix). Average VMA is 17.1 for Type D mixes and 17.2 for Type C mixes. Generally, Type D mixes, on the average, have a higher VMA than Type C mixes. However, this was not the case for the reported projects. The VMA values (except two) either exceed the minimum values recommended by the Asphalt Institute or are within the range of recommended minimum values. However, care should be taken in making such a comparison since the Asphalt Institute recommendation is based on the Marshall test and laboratory-compacted specimens, not on field cores. A plot of relative density versus VMA is given in Figure 4.9. As expected, lower relative densities (high air voids) correspond to higher VMA values.

As mentioned before, it is believed that as the magnitude of departure from the maximum-density line increases, the VMA increases. The problem lies in quantifying the departure from the maximum-density line. Gradations are illustrated by plots, and the shape of a gradation line can vary significantly. It would appear impossible to use a unique numerical index to quantify the general shape of the gradation curve and its departure from the 0.45 line.

However, some indices have been developed to define the departure or relative position of the gradation line from the maximum-density line within certain ranges. One index that can be used for this purpose is the one introduced by D. E. Edge (Ref 13). This index, represented by R, is defined as the ratio of the material passing the No. 30 (or No. 40) sieve and retained on the No. 200 sieve to the material passing the No. 8 (or No. 10) sieve and retained on the No. 200 sieve. This index essentially gives the amount of fine sand as a percentage of total sand used in the gradation. For this index, sand is defined as the material passing sieve No. 10 and retained on sieve No. 200 (i.e., particles smaller than 2 mm and larger than 0.075 mm), and fine sand is considered as the material passing sieve No. 40 and retained on sieve No. 200 (i.e., particles smaller than 0.425 mm and larger than 0.075 mm).

The higher the R coefficient, the larger the amount of fine sand with respect to the total sand used in the mix. The R coefficient for the maximum-density line is a function of the sieves used to calculate R and the power used for that line. R for the maximum-density line is independent of the mix Type and the maximum aggregate size. If sieves No. 10, 40, and 200 are used for the calculations and the power is 0.45, then the R value for the maximum-density line will always be a constant value. The value of this constant is 0.35. This constant implies that the amount of fine sand in the mix for the maximum-density line based on the FHWA 0.45 power gradation chart is 35 percent of the total sand used in the mix. R values for all different projects were calculated and are given in Table B-9. All of these values are greater than 0.35, implying that all projects have a percent fine sand with respect to total sand larger than that given by the FHWA 0.45 line. To indicate the relative magnitude of R coefficients of gradation lines with respect to the R value of the 0.45 line, all these coefficients were divided by 0.35. In

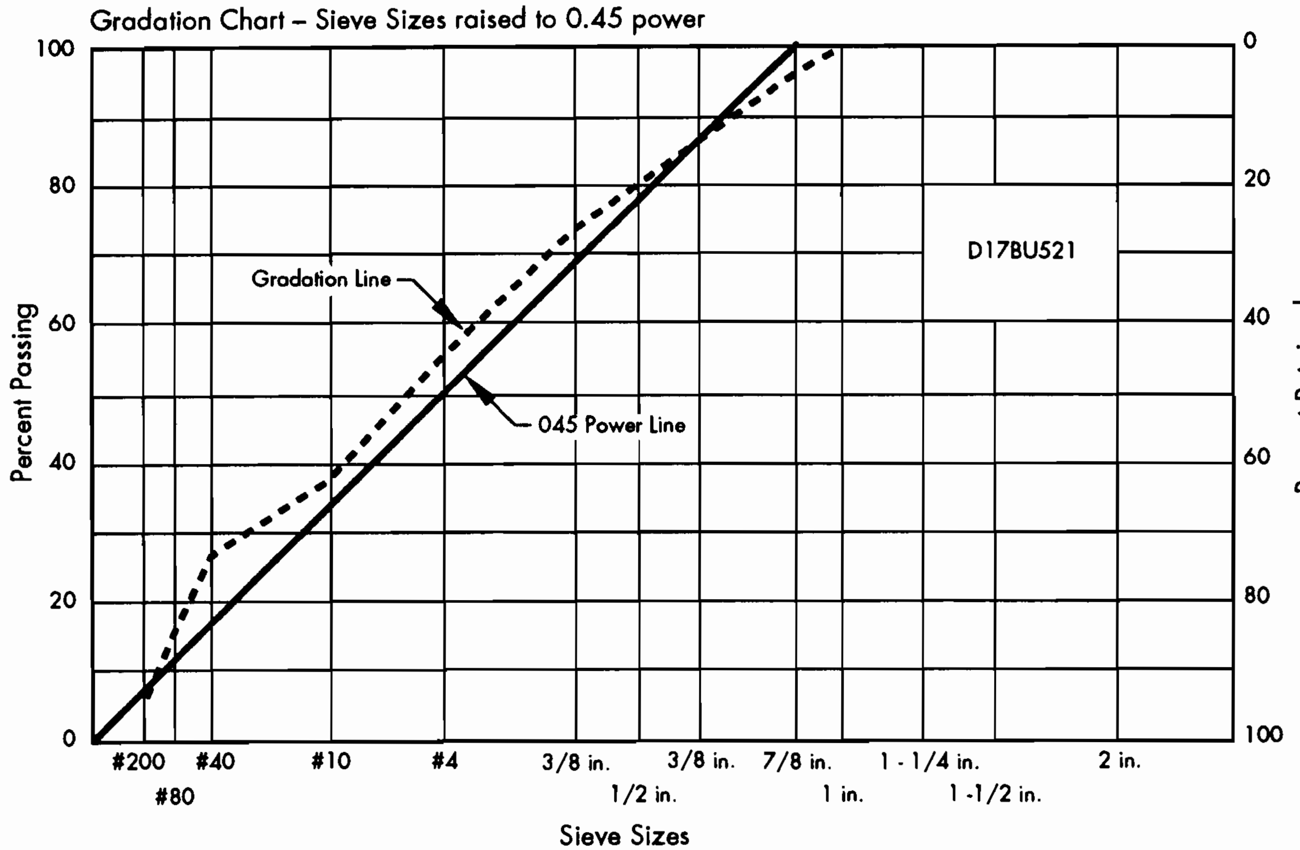


Figure 4.6 Typical gradation for a Type B mix on FHWA 0.45 power gradation chart

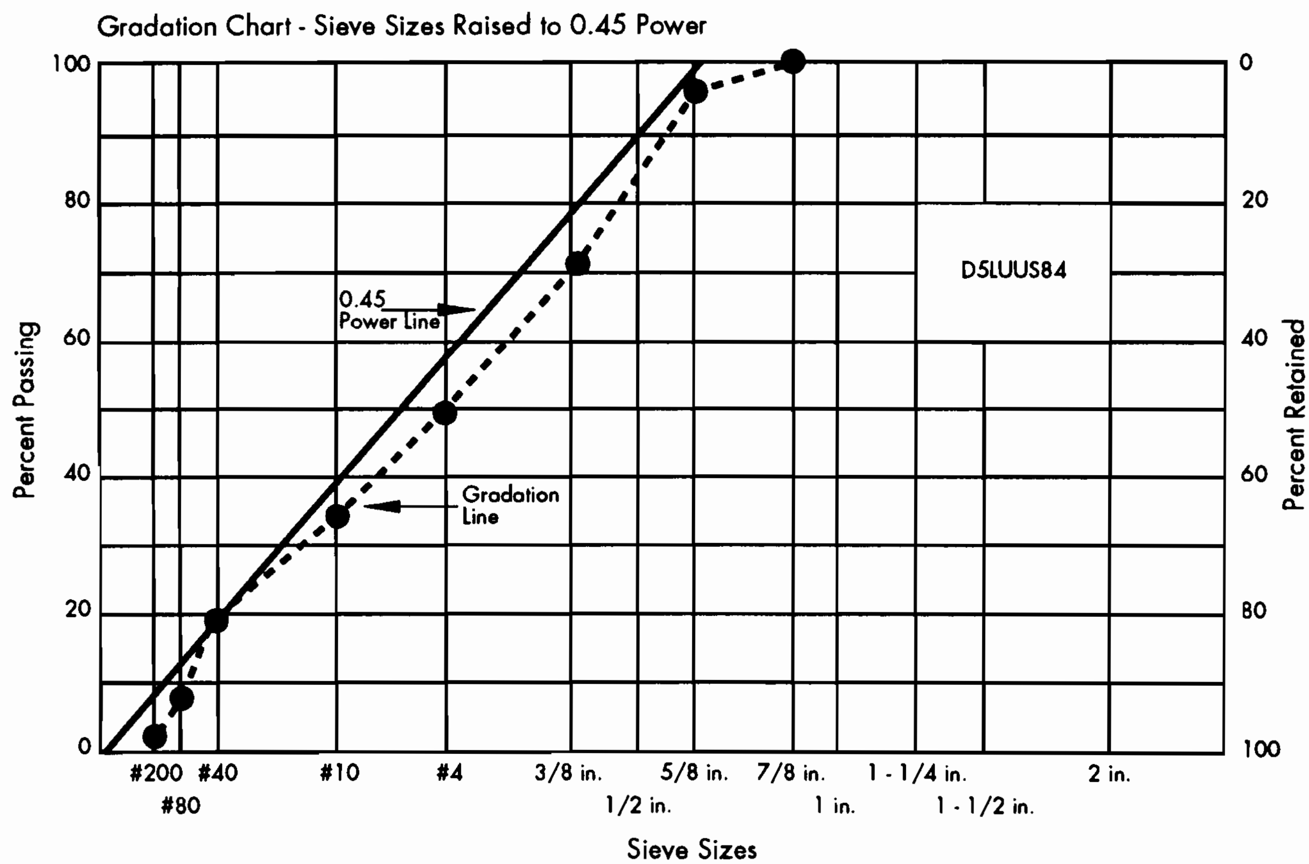


Figure 4.7 Typical gradation for a Type C mix on FHWA 0.45 power gradation chart

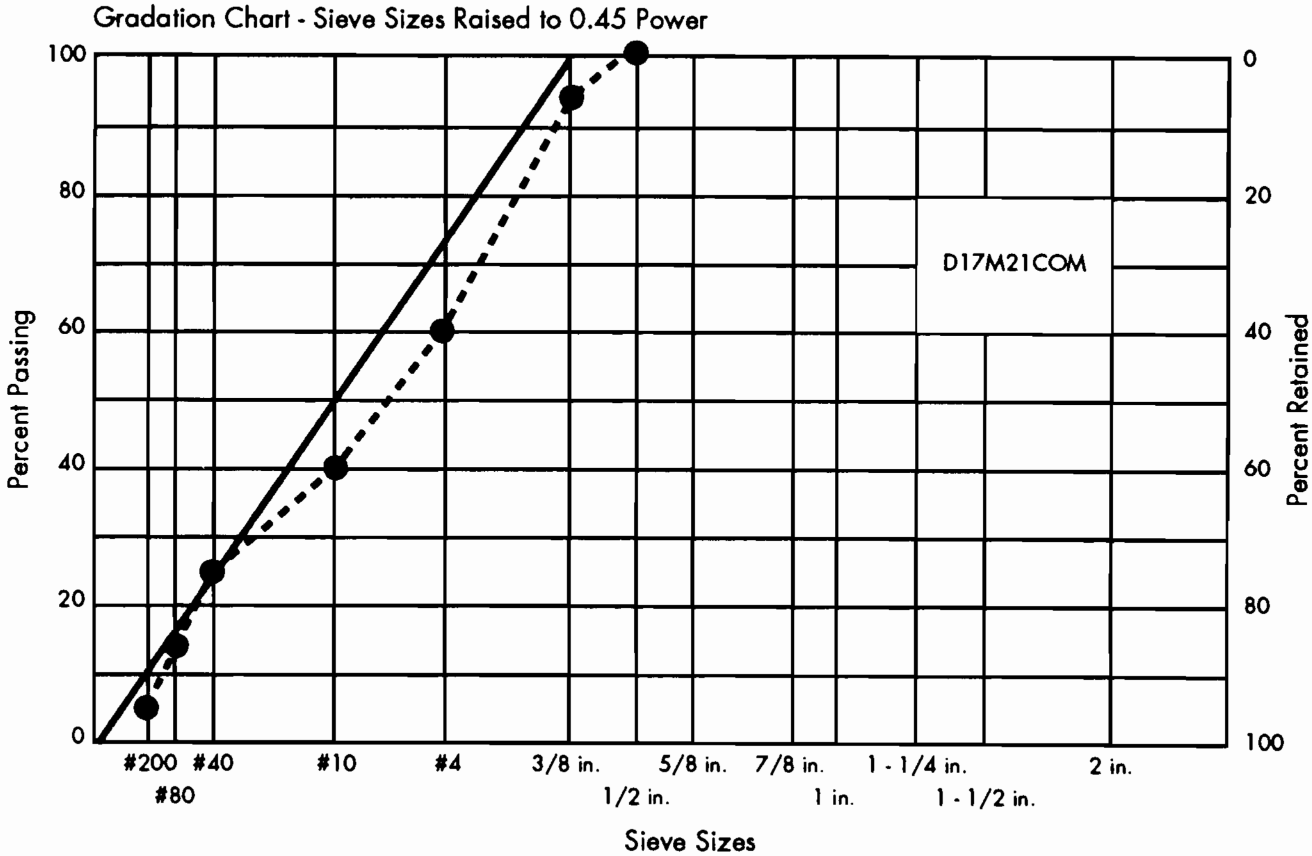


Figure 4.8 Typical gradation for a Type D mix on FHWA 0.45 power gradation chart

this way, normalized R coefficients (called R_n) were obtained. For these projects, R_n varies between 1 and 2, larger values implying larger differences between the R coefficient of gradation line and that of the 0.45 line. Plots of VMA versus R_n for all data, Type C and Type D, are given in Figure 4.10. For lower values of R_n, VMA values tend to be concentrated at larger magnitudes. For higher R_n values, most VMA's are concentrated in the lower range.

Another index used to indicate the relative position of the gradation line with respect to the 0.45 power line is called the position index (PI). This index indicates, in the range of two consecutive sieve sizes, whether the gradation line lies below the 0.45 line, lies above the 0.45 line, or crosses it. This index is defined as:

$$PI = \frac{(P_{.45} - P) + (P'_{.45} - P')}{ABS\,(P_{.45} - P) + ABS\,(P'_{.45} - P')}$$

where P and P′ are percent material passing two consecutive sieves, given by the gradation line, $P_{.45}$ and $P'_{.45}$ are percent material passing two consecutive sieves, given by the 0.45 power line, and ABS implies 'absolute value.' Three positions are recognized for a gradation line in the range of interest. The PI value and the implications are given below:

PI = 1 : the gradation line lies totally below the 0.45 line in that range;

PI = -1 : the gradation line lies totally above the 0.45 line in that range; and

-1<PI<1 : the gradation line crosses the 0.45 line in that range.

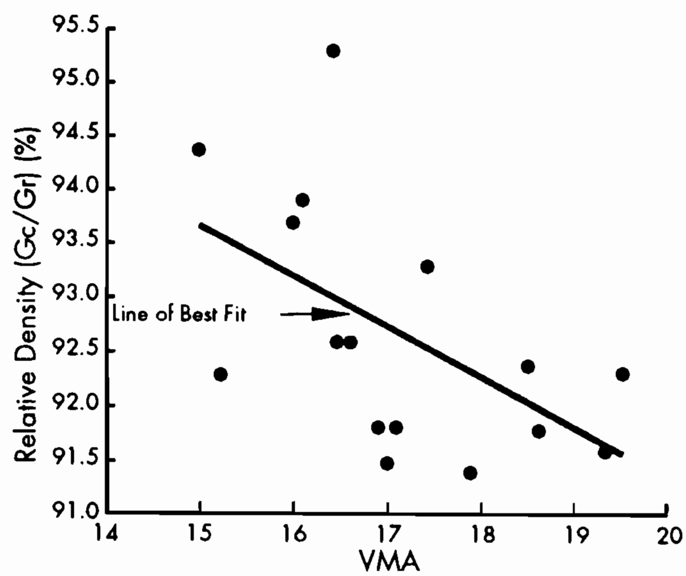


Figure 4.9 Relative density as a function of VMA

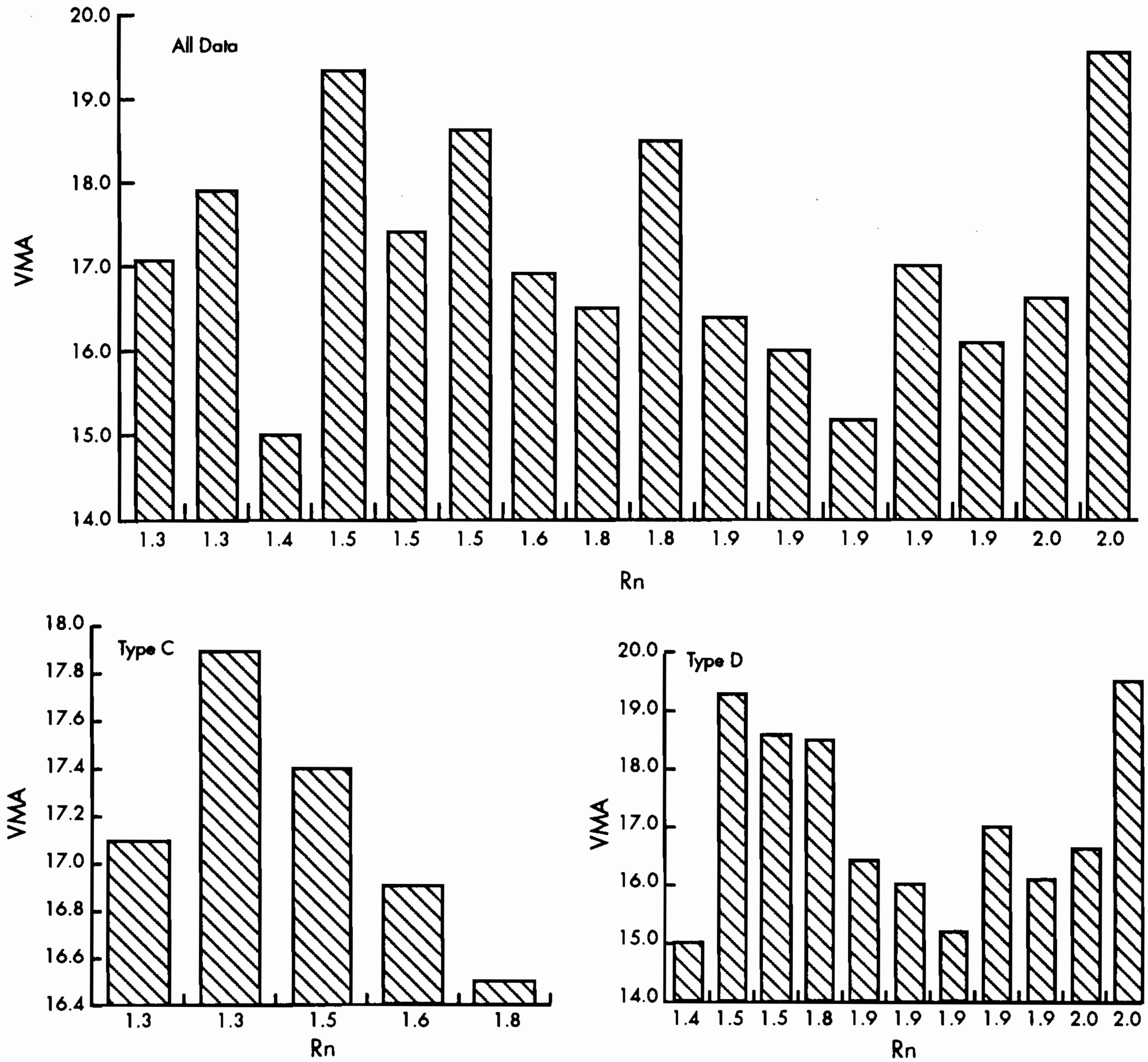


Figure 4.10 VMA versus normalized R coefficient R_n : a) for all mix types; b) for Type C mixes; and c) for Type D mixes

Depending on the range of interest, the position index can be used for any part of the gradation line. Because it is believed that percent fine sand (material passing the No. 40 sieve and retained on the No. 200 sieve) has a significant effect on VMA, density, and compaction (Ref 10), PI values were calculated for the projects within this range. These values are given in Table B-9. As shown, almost all gradation lines for Type B mixtures of the projects investigated in this study intersect the 0.45 line given by the FHWA chart in the range of the fine sand material. For Type C mixes, two gradation lines almost lie below the 0.45 line in this range while others intersect with this line. For Type D mixes, there are a considerable number of gradation lines lying below the 0.45 line in this range. However, there are some mixes whose lines intersect the 0.45 line, with a major part of their lines lying below the 0.45 line. The VMA values were plotted against the position index (Figure 4.11, page 22). For PI values less than 0.5, VMA's do not exceed 17 except in one case. For larger PI values, VMA's vary within a wider range. Five out of the 9 projects with PI's larger than 0.5 have VMA values greater than 17.5.

Another type of index developed to show deviations from the 0.45 line is the sum of differences (SOD) index. This index is defined as the algebraic sum of differences in percent passing between the gradation line and the 0.45 line. SOD roughly quantifies the magnitude of departure from the maximum-

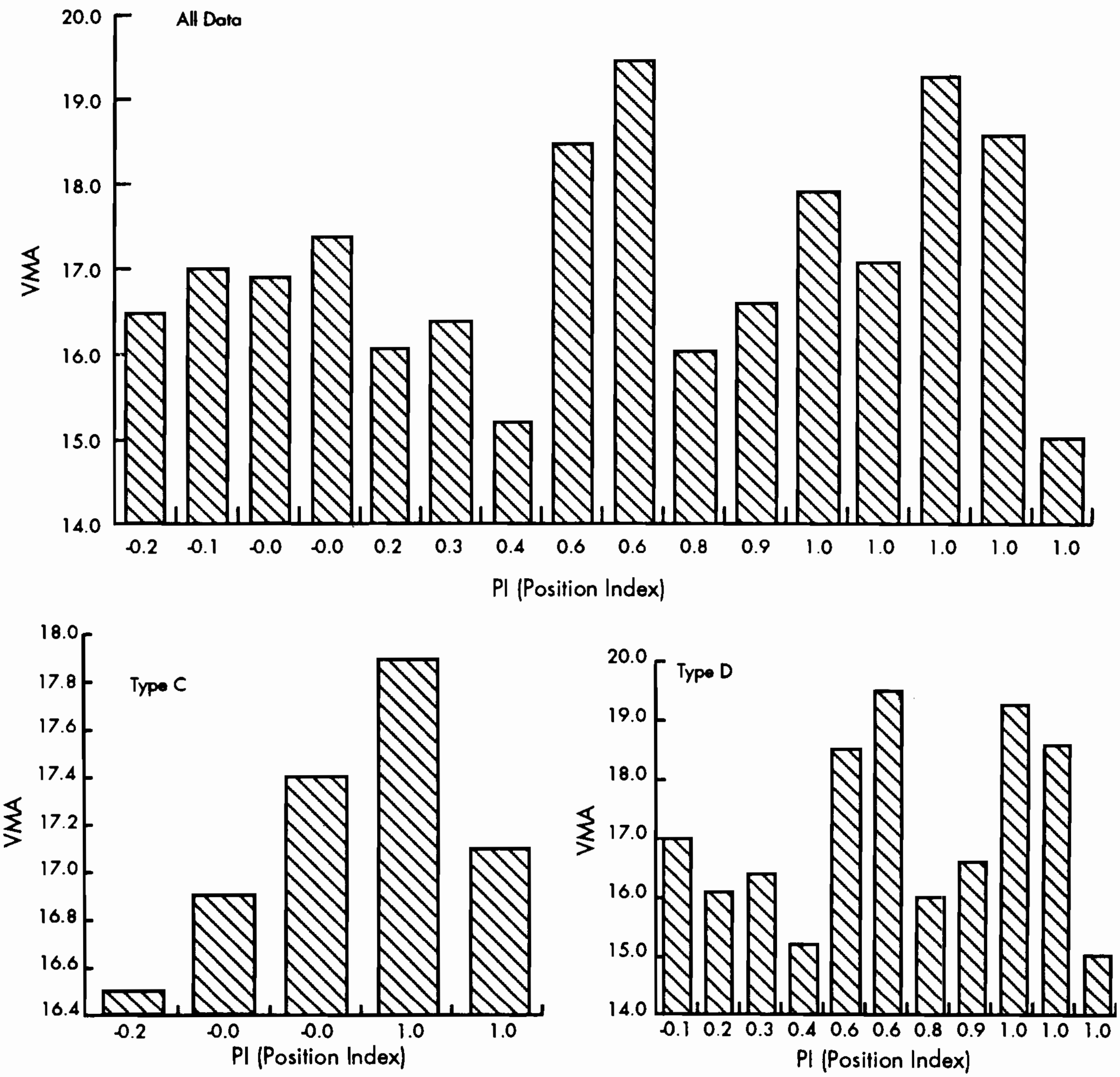
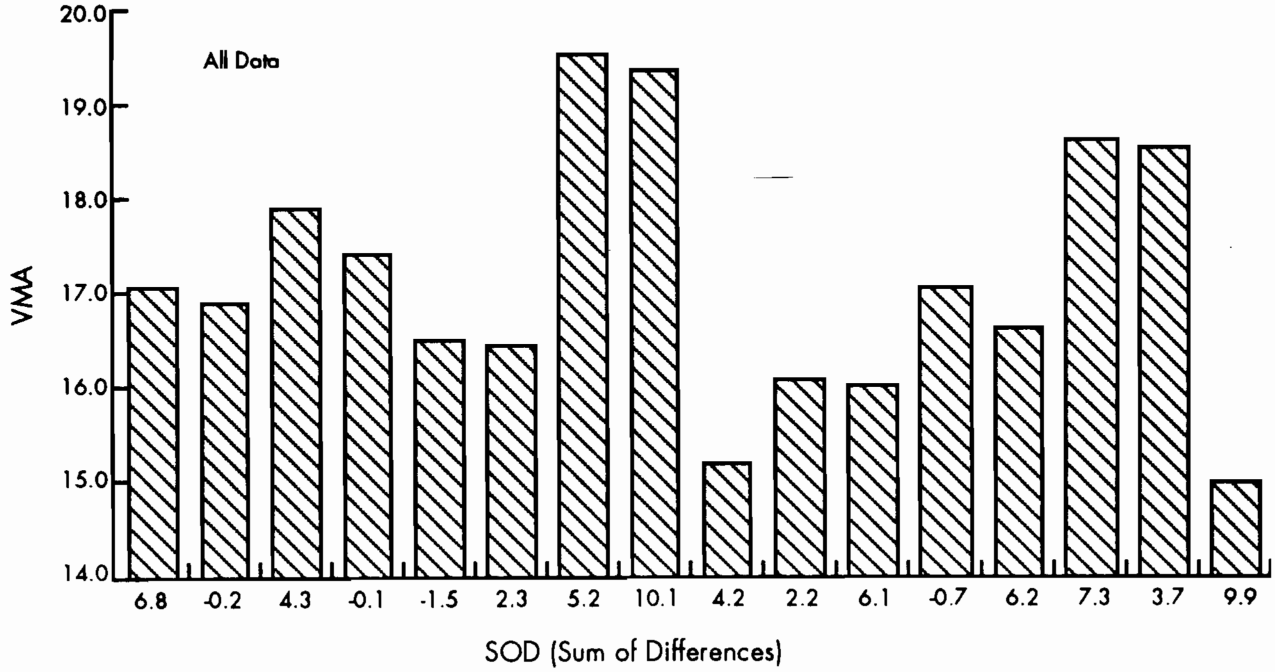
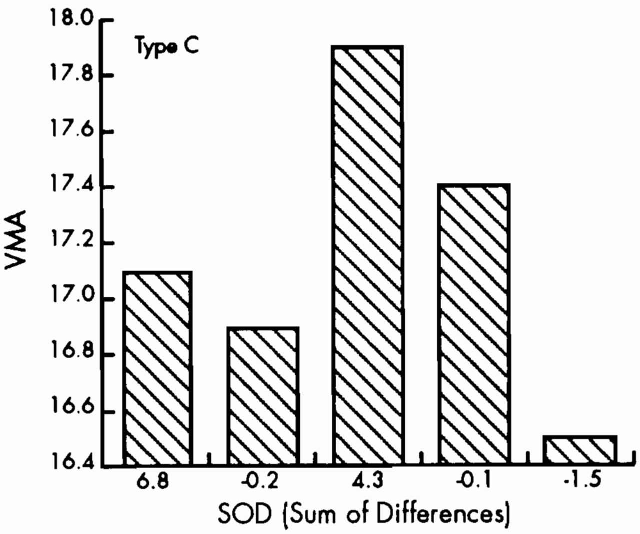


Figure 4.11 VMA versus position index PI: a) for all mix types; b) for Type C mixes; and c) for Type D mixes

density line. This index is obtained simply by first finding the differences between the percent aggregate passing some specified sieves (given by the gradation curve) and the percent aggregate passing the same sieves (given by the 0.45 line) and then determining the sum of these differences. For example, percent aggregate passing the 3/8-inch, No. 4, No. 10, No. 40, No. 80, and No. 200 sieves could be determined, and their differences, with percents given by the 0.45 line, could be obtained. The sum of these differences would be the SOD index. This index is a very crude indication of departure from the 0.45 line, because it does not take into account any humps in the gradation curve and does not represent variations that exist in deviations from the 0.45 line. Deviations above the 0.45 line are considered negative and those below this line are considered positive.

The SOD indices based on percent material passing sieves No. 40 and No. 200 were determined for all projects and are given in Table B-11. Each index roughly presents the difference between the amount of fine sand given by the project gradation line and the 0.45 line. Plots of VMA versus SOD are given in Figure 4.12.





A summary of numerical values of the different gradation indices discussed here is presented in Table B-10. A clear trend could not be observed in any of these plots, probably because of the complexity of the problem and the influence of a large number of variations. Clear relationships between the indices discussed in this report (R_n, PI, and SOD) and relative densities could not be found. However, these indices, probably with some modifications, may prove indicative of meaningful relationships with VMA's and relative densities if a sensitivity analysis is conducted under controlled laboratory or field conditions. In this way, the effect of gradation on density and VMA can be investigated while the influences of all the interacting factors are controlled.

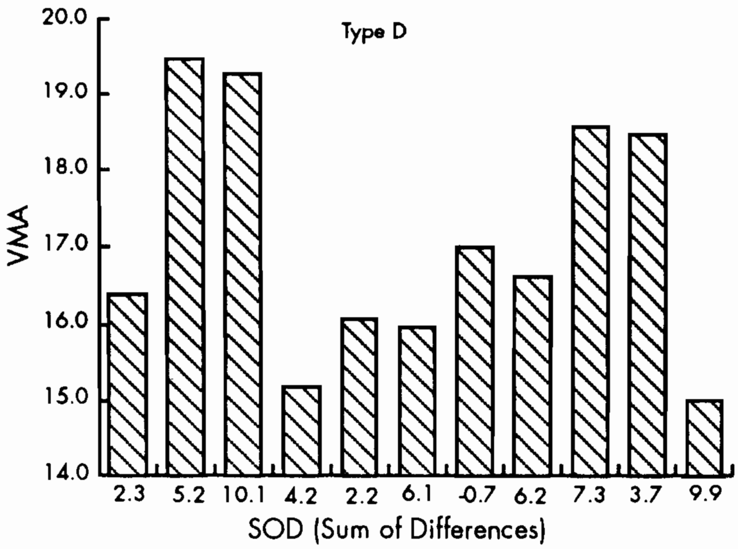


Figure 4.12 VMA versus SOD: a) for all mix types (top of page); b) for Type C mixes (above, left); and c) for Type D mixes (right)

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Most of the projects reported in the 1987 HMAC field construction reports and discussed in Chapters 3 and 4 presented only one value for each project for such variables as temperature, type, and condition of rollers. This made it impossible to properly evaluate individual core test results.

Based on the data presented and analyzed in Chapters 3 and 4, the following conclusions can be made regarding density levels achieved in Texas and the factors contributing to density variations.

1. Mixtures properly designed and compacted at thicknesses over 1.5 inches are capable of achieving the minimum required density level of 92 percent.
2. Most projects cited in this report did not have a problem achieving the minimum target density of 92 percent based on Rice specific gravity.
3. Average relative densities follow a normal distribution with an average value of 93 percent and a standard deviation of 1.3 percent.
4. Mixtures exhibiting tender behavior or mixes with segregation problems generally did not achieve densities as high as those of mixtures without these problems.
5. Density levels were generally lower for projects having thin layers of asphalt concrete compared with those having thick layers.
6. A drop in mix temperature during compaction is significantly larger for thin mats than for thick mats, and this large drop is a contributing cause of lower densities in thinner mats.
7. As expected, mixes with higher VMA values had lower relative densities.
8. In general, projects with higher mix temperatures during first breakdown rolling reported higher relative densities than those with lower temperatures during breakdown rolling.
9. Differences between extracted and design asphalt contents for different projects did not exceed allowable tolerances required by specifications. The average difference was zero with a standard deviation of 0.1 percent.
10. Indices R_n (normalized R index), PI (position index), and SOD (sum of differences) did not correlate well with the relative density in this study, but a controlled study may show that they have some value in defining the position and the departure of the gradation line from the maximum-density line.
11. Comparison of this study with the previous study conducted in 1983 indicates little to no improvement has occurred in obtaining density with the change in specifications.

Recommendations

The literature suggests that the VMA, PVF, and dust-to-AC ratios are among the important parameters contributing to pavement performance. Therefore, the design procedures of the Texas State Department of Highways and Public Transportation for hot-mix asphalt concrete should be revised to require satisfying limits on these parameters.

A collection of a comprehensive data set, including all aspects of mix characteristics and compaction processes that influence density of hot mix asphalt concrete mixtures, can be very beneficial in developing new specifications concerning compaction and density levels. It is recommended that data of this type be continuously gathered from different real field projects covering a vast range of different mixes and compaction processes. The present data set should be continuously enhanced and expanded. More reliable conclusions could be made through a more comprehensive statistical analysis of a larger data set. One major problem with the present data set is that almost all projects reported only one overall field construction data set; i.e., there is only one value reported for each of several variables—temperature, type, condition of rollers, etc.—for the whole construction period. Although some factors are independent of time and remain constant throughout the entire construction period, others vary from day to day and from time to time. Some variables of the latter type are mix temperature during hauling, laydown, and various stages of compaction and ambient air temperature A day-by-day record of these variables makes the analysis more meaningful.

The relationship between gradation indices discussed in this report (R_n, PI, and SOD) or other types of indices and VMA and relative densities should be further analyzed through controlled field or laboratory conditions. Such indices may prove to be good indications of deviations of gradation lines from maximum-density lines.

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APPENDIX A

FIGURES AND TABLES CORRESPONDING TO PROJECTS DIRECTLY INVESTIGATED BY THE UNIVERSITY OF TEXAS AT AUSTIN

TABLE A-1. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 1: DISTRICT 10, HIGHWAY US 287, TYPE D

SPEC.	RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	DENSITY BASED ON Gr1 %	DENSITY BASED ON Gr2 %	EXT. AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
1	2.473	2.462	95.9	96.4	5.5	16	77	0.9
2	2.473	2.462	91.0	91.4	5.5	20	58	0.9
3	2.473	2.462	92.0	92.4	5.5	20	61	0.9
4	2.473	2.462	95.4	95.8	5.5	17	75	0.9
5	2.473	2.462	94.4	94.8	5.5	17	70	0.9
6	2.473	2.462	93.3	93.7	5.5	18	66	0.9
7	2.473	2.462	93.7	94.1	5.4	18	67	0.9
8	2.473	2.462	92.6	93.0	5.4	19	63	0.9
9	2.473	2.462	94.4	94.8	5.4	17	70	0.9
10	2.473	2.462	93.8	94.2	5.4	18	67	0.9
11	2.473	2.462	93.8	94.3	5.4	18	68	0.9
12	2.473	2.462	94.7	95.2	5.4	17	72	0.9
13	2.473	2.462	94.2	94.6	5.4	18	69	0.9
14	2.473	2.462	92.6	93.0	5.4	19	63	0.9
15	2.473	2.462	93.7	94.2	5.4	18	67	0.9
16	2.473	2.462	95.4	95.8	5.4	16	75	0.9
17	2.473	2.462	92.6	93.0	5.4	19	63	0.9
18	2.449	2.444	93.2	93.4	5.4	19	65	0.8
19	2.449	2.444	93.9	94.1	5.4	19	68	0.8
20	2.449	2.444	93.0	93.2	5.4	19	65	0.8
21	2.449	2.444	94.9	95.1	5.4	18	72	0.8
22	2.449	2.444	92.8	93.0	5.4	19	64	0.8
23	2.449	2.444	93.2	93.4	5.4	19	65	0.8
24	2.449	2.444	92.0	92.2	5.4	20	61	0.8
25	2.449	2.444	94.4	94.6	5.1	18	70	0.9
26	2.449	2.444	94.0	94.2	5.1	18	68	0.9
27	2.449	2.444	93.4	93.6	5.1	19	66	0.9
28	2.449	2.444	92.2	92.4	5.1	20	62	0.9
29	2.449	2.444	94.1	94.3	5.1	18	69	0.9
30	2.449	2.444	93.4	93.6	5.1	19	66	0.9
31	2.449	2.444	93.8	94.0	5.1	18	68	0.9
32	2.449	2.444	94.6	94.8	5.1	18	70	0.9
33	2.449	2.444	93.2	93.4	5.1	19	65	0.9
34	2.449	2.444	93.3	93.5	5.1	19	65	0.9
35	2.463	2.458	93.6	93.8	5.1	18	66	0.9
36	2.463	2.458	93.3	93.5	5.1	18	65	0.8
37	2.463	2.458	92.0	92.2	5.1	19	60	0.8
38	2.463	2.458	93.0	93.2	5.1	19	64	0.8
39	2.463	2.458	94.9	95.1	5.1	17	71	0.8
40	2.463	2.458	92.7	92.9	5.1	19	62	0.8
41	2.463	2.458	95.1	95.3	5.1	17	72	0.8
42	2.463	2.458	94.5	94.7	5.1	17	69	0.8
43	2.463	2.458	93.9	94.1	5.1	18	67	0.8
44	2.463	2.458	95.5	95.7	5.1	16	74	0.8
45	2.463	2.458	94.3	94.4	5.1	18	68	0.8

TABLE A-1. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 1: DISTRICT 10, HIGHWAY US 287, TYPE D (CONT'D)

SPEC.	RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	DENSITY BASED ON Gr1 %	DENSITY BASED ON Gr2 %	AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
46	2.463	2.458	94.3	94.5	5.1	17	69	0.8
47	2.463	2.458	92.9	93.1	5.1	19	63	0.8
48	2.463	2.458	93.7	93.9	5.1	18	66	0.8
49	2.463	2.458	95.6	95.8	5.1	16	74	0.8
50	2.463	2.458	92.9	93.0	5.1	19	63	0.8
COUNT	50	50	50	50	50	50	50	50
AVG.	2.462	2.455	93.7	94.0	5.3	18	67	0.9
STD.	6.440	6.440	17.1	17.1	6.1	5	12	6.7
MAX.	2.473	2.462	95.9	96.4	5.5	20	77	0.9
MIN.	2.[illegible]9	2.444	91.0	91.4	5.1	16	58	0.8

TABLE A-2. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 2: DISTRICT 12, HIGHWAY SH 287, TYPE D

SPEC.	RICE RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	RELATIVE DENSITY BASED ON Gr1 %	RELATIVE DENSITY BASED ON Gr2 %	EXTRACTED AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
S4	2.408	2.389	91.7	92.5	4.9	19	61	1.1
S5	2.408	2.389	91.3	92.0	4.9	20	60	1.1
S6	2.408	2.389	95.1	95.9	4.9	16	75	1.1
S7	2.408	2.389	96.5	97.2	4.9	15	82	1.1
S8	2.408	2.389	95.5	96.2	4.9	16	76	1.1
S9	2.408	2.389	95.8	96.6	4.9	16	78	1.1
S10	2.408	2.389	94.0	94.8	4.9	17	70	1.1
S11	2.408	2.389	93.1	93.8	4.9	18	66	1.1
S12	2.408	2.389	91.2	92.0	4.9	20	59	1.1
S13	2.408	2.389	94.2	95.0	4.9	17	71	1.1
S14	2.408	2.389	93.6	94.4	4.9	18	68	1.1
S15	2.438	2.421	92.4	93.0	4.9	18	61	1.1
S17	2.438	2.421	91.9	92.6	4.9	18	59	1.1
S18	2.438	2.421	91.5	92.2	4.9	19	58	1.1
S19	2.438	2.421	92.7	93.3	4.9	17	62	1.1
S20	2.438	2.421	92.2	92.9	4.9	18	60	1.1
S21	2.438	2.421	92.5	93.1	4.9	18	61	1.1
S22	2.438	2.421	91.6	92.2	4.9	18	58	1.1
S23	2.438	2.421	91.2	91.9	4.9	19	57	1.1
S24	2.438	2.421	92.5	93.1	4.9	18	61	1.1
S27	2.438	2.421	92.9	93.6	4.9	17	63	1.1
S28	2.438	2.421	90.9	91.6	4.9	19	56	1.1
S29	2.438	2.421	93.8	94.5	4.9	16	66	1.1
S30	2.438	2.421	94.3	95.0	4.9	16	69	1.1
S31	2.438	2.421	92.2	92.8	4.9	18	60	1.1
S33	2.438	2.421	93.5	94.2	4.9	17	65	1.1
S34	2.438	2.421	88.5	89.1	4.9	21	49	1.1
S35	2.438	2.421	89.0	89.6	4.9	21	50	1.1
S36	2.438	2.421	89.2	89.8	4.9	21	51	1.1
S37	2.438	2.421	90.0	90.6	4.9	20	53	1.1
S38	2.438	2.421	90.6	91.2	4.9	19	55	1.1
S39	2.438	2.421	91.6	92.2	4.9	18	58	1.1
S40	2.438	2.421	94.2	94.8	4.9	16	68	1.1
S41	2.438	2.421	89.0	89.6	4.9	21	50	1.1
S42	2.438	2.421	91.6	92.3	4.9	18	58	1.1
S43	2.423	2.403	93.2	94.0	4.9	18	66	1.1
S44	2.423	2.403	93.5	94.3	4.9	17	67	1.1
S45	2.423	2.403	91.8	92.6	4.9	19	60	1.1
S46	2.423	2.403	91.9	92.7	4.9	19	61	1.1
S47	2.423	2.403	93.2	94.0	4.9	17	66	1.1
S48	2.423	2.403	91.1	91.9	4.9	19	58	1.1
S50	2.435	2.416	90.5	91.2	4.9	19	55	1.1
S51	2.435	2.416	93.0	93.8	4.9	17	64	1.1
S52	2.435	2.416	93.1	93.8	4.9	17	64	1.1

TABLE A-2. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 2:
DISTRICT 12, HIGHWAY SH 287, TYPE D (CONT'D)

SPEC.	RICE RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	RELATIVE DENSITY BASED ON Gr1 %	RELATIVE DENSITY BASED ON Gr2 %	EXTRACTED AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
S53	2.435	2.416	92.5	93.2	4.9	18	62	1.1
S54	2.435	2.416	92.4	93.1	4.9	18	61	1.1
S55	2.435	2.416	94.9	95.7	4.9	16	72	1.1
S56	2.435	2.416	91.7	92.4	4.9	18	59	1.1
S57	2.435	2.416	89.7	90.4	4.9	20	52	1.1
S58	2.435	2.416	93.2	93.9	4.9	17	64	1.1
S59	2.435	2.416	92.4	93.1	4.9	18	61	1.1
S60	2.435	2.416	93.3	94.0	5.3	17	66	1.0
S61	2.435	2.416	89.4	90.1	5.3	21	52	1.0
S62	2.435	2.416	90.5	91.2	5.3	20	56	1.0
S64	2.435	2.416	92.7	93.4	5.3	18	63	1.0
S65	2.435	2.416	91.7	92.4	5.3	19	60	1.0
S66	2.435	2.416	94.0	94.8	5.3	17	69	1.0
S67	2.435	2.416	92.1	92.8	5.3	18	61	1.0
S68	2.435	2.416	88.7	89.4	5.3	21	51	1.0
S69	2.435	2.416	91.0	91.7	5.3	19	57	1.0
S75	2.440	2.426	93.8	94.4	5.3	17	66	3.0
S76	2.440	2.426	92.2	92.7	5.3	18	60	3.0
S77	2.440	2.426	92.7	93.2	4.7	17	61	3.3
S78	2.440	2.426	92.7	93.3	4.7	17	61	0.9
S79	2.440	2.426	32.3	92.8	4.7	18	59	0.9
S80	2.440	2.426	91.9	92.4	4.7	18	58	0.9
S81	2.440	2.426	94.4	95.0	4.7	16	68	0.9
S82	2.440	2.426	90.7	91.3	4.7	19	54	0.9
S83	2.440	2.426	91.3	91.8	4.7	19	56	0.9
S84	2.440	2.426	92.2	92.7	4.7	18	59	0.9
S85	2.440	2.426	91.4	91.9	4.7	18	56	0.9
S86	2.440	2.426	93.4	93.9	4.9	17	64	1.2
S87	2.440	2.426	91.6	92.1	4.9	18	57	1.2
S88	2.440	2.426	92.7	93.2	4.9	17	61	1.2
S89	2.440	2.426	92.1	92.7	4.9	18	59	1.2
S90	2.440	2.426	88.7	89.2	4.9	21	49	1.2
S91	2.440	2.426	93.4	94.0	4.9	17	64	1.2
S92	2.440	2.426	90.6	91.1	4.9	19	54	1.2
S94	2.440	2.426	90.5	91.0	4.9	19	54	1.2
S95	2.440	2.426	90.6	91.1	4.9	19	54	1.2
S96	2.440	2.426	90.6	91.1	4.9	19	54	1.2
S97	2.440	2.426	93.9	94.4	4.9	16	66	1.2
S98	2.440	2.426	91.5	92.0	4.9	18	57	1.2
S99	2.406	2.390	92.3	92.9	5.3	19	63	1.0
S100	2.406	2.390	91.2	91.8	5.3	20	59	1.0
S101	2.406	2.390	93.9	94.6	5.3	18	69	1.0
S102	2.406	2.390	93.5	94.1	5.3	18	68	1.0
S103	2.406	2.390	94.4	95.0	5.3	17	71	1.0

TABLE A-2. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 2: DISTRICT 12, HIGHWAY SH 287, TYPE D (CONT'D)

SPEC.	RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	RELATIVE DENSITY BASED ON Gr1 %	RELATIVE DENSITY BASED ON Gr2 %	EXTRACTED AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
S104	2.406	2.390	93.9	94.6	5.3	18	69	1.1
S105	2.406	2.390	93.9	94.6	5.3	18	69	1.1
S106	2.406	2.390	94.5	95.1	5.3	17	72	1.1
S107	2.406	2.390	94.1	94.8	5.3	18	70	1.1
S108	2.406	2.390	92.1	92.7	5.3	19	62	1.1
S109	2.406	2.390	93.8	94.5	5.3	18	69	1.0
S110	2.406	2.390	94.5	95.1	5.3	17	72	1.0
S111	2.406	2.390	94.7	95.4	5.3	17	73	1.0
S112	2.406	2.390	94.5	95.1	5.3	17	72	1.0
S113	2.428	2.403	91.2	92.1	5.3	20	60	1.0
S115	2.428	2.403	94.9	95.9	5.3	16	75	1.0
S116	2.428	2.403	95.8	96.8	5.3	15	79	1.0
S117	2.428	2.403	95.5	96.5	5.4	16	78	1.2
S118	2.428	2.403	94.9	95.9	5.4	16	75	1.2
S119	2.428	2.403	93.9	94.8	5.4	17	70	1.2
S120	2.428	2.403	94.6	95.6	5.4	17	73	1.2
S121	2.428	2.403	92.1	93.1	5.4	19	63	1.2
S122	2.428	2.403	94.5	95.5	5.3	17	73	1.2
S123	2.428	2.403	93.9	94.8	5.3	17	70	1.2
S124	2.428	2.403	94.1	95.1	5.3	17	71	1.2
S125	2.428	2.403	94.8	95.8	5.3	16	74	1.2
COUNT	109	109	109	109	109	109	109	109
AVG.	2.429	2.411	92.6	93.3	5.0	18	63	1.1
STD.	0.013	0.014	1.7	1.8	0.2	1	7	0.3
MAX.	2.440	2.426	96.5	97.2	5.4	21	82	3.3
MIN.	2.406	2.389	88.5	89.1	4.7	15	49	0.9

TABLE A-3. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 3: DISTRICT 14, HIGHWAY IH 35, TYPE B

SPEC.	RICE RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	RELATIVE DENSITY BASED ON Gr1 %	RELATIVE DENSITY BASED ON Gr2 %	AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
1	2.557	2.537	91.8	92.6	5.0	13	42	1.1
2	2.557	2.537	91.9	92.6	5.0	13	42	1.1
21A	2.410	2.395	93.6	94.1	5.1	16	64	1.1
21B	2.410	2.395	91.5	92.1	5.1	18	57	1.1
21C	2.410	2.395	93.9	94.5	5.1	16	66	1.1
32A	2.422	2.405	95.1	95.8	5.2	15	71	1.1
32B	2.422	2.405	96.5	97.2	5.2	13	79	1.1
32C	2.422	2.405	93.6	94.2	5.2	16	64	0.9
35A	2.412	2.399	93.6	94.1	5.4	17	64	0.9
35B	2.412	2.399	90.9	91.4	5.4	19	55	0.9
35C	2.412	2.399	94.3	94.8	5.4	16	67	0.9
38A	2.434	2.409	93.6	94.6	5.4	16	66	0.9
38B	2.434	2.409	93.9	94.8	5.4	16	67	0.9
38C	2.434	2.409	93.1	94.1	5.4	16	63	0.9
39A	2.414	2.386	93.8	94.9	5.4	16	59	0.9
39B	2.414	2.386	95.2	96.3	5.4	15	75	0.9
39C	2.414	2.386	90.5	91.6	5.4	19	56	1.2
41A	2.409	2.398	92.9	93.4	5.4	17	62	1.2
41B	2.409	2.398	92.8	93.3	5.4	17	61	1.2
41C	2.409	2.398	94.2	94.6	5.4	16	67	1.2
354	2.405	2.392	95.2	95.7	5.6	16	72	1.1
492	2.405	2.392	91.9	92.4	5.6	18	59	1.1
COUNT	22	22	22	22	22	22	22	22
AVG.	2.429	2.411	93.4	94.0	5.3	16	63	1.0
STD.	0.042	0.041	1.5	1.5	0.2	2	9	0.1
MAX.	2.557	2.537	96.5	97.2	5.6	19	79	1.2
MIN.	2.405	2.386	90.5	91.4	5.0	13	42	0.9

TABLE A-4. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 4: DISTRICT 14, HIGHWAY IH 35, TYPE C

SPEC.	RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	RELATIVE DENSITY BASED ON Gr1 %	RELATIVE DENSITY BASED ON Gr2 %	EXT. AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
1A	2.397	2.384	89.4	89.8	4.8	20	48	1.1
1B	2.397	2.384	91.0	91.5	4.8	18	53	1.1
1C	2.397	2.384	92.5	93.0	4.8	17	58	1.1
2A	2.417	2.412	89.6	89.7	5.1	19	46	1.1
2B	2.417	2.412	90.5	90.7	5.1	18	49	1.1
2C	2.417	2.412	93.4	93.6	5.1	16	59	1.1
3A	2.412	2.406	89.3	89.5	5.3	20	46	1.0
3B	2.412	2.406	90.1	90.3	5.3	19	49	1.0
3C	2.412	2.406	92.1	92.4	5.3	17	55	1.0
4A	2.423	2.402	87.5	88.2	5.3	21	44	0.9
4B	2.423	2.402	89.2	90.0	5.3	19	48	0.9
4C	2.423	2.402	92.0	92.8	5.3	17	57	0.9
5A	2.399	2.382	92.5	93.1	5.2	17	60	1.0
5B	2.399	2.382	91.2	91.8	5.2	18	55	1.0
5C	2.399	2.382	93.9	94.6	5.2	16	66	1.0
6A	2.426	2.414	89.9	90.4	5.1	18	48	1.0
6B	2.426	2.414	89.6	90.1	5.1	19	47	1.0
6C	2.426	2.414	91.4	91.9	5.1	17	52	1.0
7A	2.415	2.406	89.3	89.6	5.2	19	47	1.2
7B	2.415	2.406	89.9	90.3	5.2	19	48	1.2
7C	2.415	2.406	90.7	91.0	5.2	18	51	1.2
COUNT	21	21	21	21	21	21	21	21
AVG.	2.413	2.401	90.7	91.2	5.1	18	52	1.0
STD.	0.010	0.012	1.6	1.6	0.1	1	6	0.1
MAX.	2.426	2.414	93.9	94.6	5.3	21	66	1.2
MIN.	2.397	2.382	87.5	88.2	4.8	16	44	0.9

TABLE A-5. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 5: DISTRICT 14, LOOP 1, TYPE C

SPEC.	RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	RELATIVE DENSITY BASED ON Gr1 %	RELATIVE DENSITY BASED ON Gr2 %	EXT. AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
4/17-1	2.390	2.368	91.8	92.7	5.3	18	59.3	1.1
4/17-2	2.390	2.368	93.6	94.5	5.3	16	66.4	1.1
4/17-3	2.390	2.368	90.6	91.5	5.3	19	55.3	1.1
4/18-1	2.421	2.400	91.8	92.6	4.8	17	55.2	1.2
4/18-2	2.421	2.400	90.1	90.9	4.8	18	49.5	1.2
4/18-3	2.421	2.400	92.2	93.1	4.8	16	56.9	1.2
4/20-1	2.402	2.370	94.0	95.3	4.9	15	69.2	1.6
4/20-2	2.402	2.370	92.6	93.8	4.9	17	62.7	1.6
4/20-3	2.402	2.370	93.6	94.9	4.9	16	67.3	1.6
4/21-1	2.429	2.399	90.9	92.1	5.4	18	54.9	1.1
4/21-2	2.429	2.399	92.1	93.2	5.4	17	59.0	1.1
4/21-3	2.429	2.399	92.9	94.1	5.4	16	62.6	1.1
4/22-3	2.415	2.398	93.5	94.1	5.0	15	62.0	1.3
4/22-282	2.415	2.398	91.8	92.4	5.0	17	55.3	1.3
4/24-6	2.381	2.364	94.5	95.2	5.3	16	69.9	1.1
4/24-409	2.381	2.364	95.1	95.8	5.3	15	72.8	1.1
4/24-882	2.381	2.364	93.5	94.2	5.3	17	65.6	1.1
4/25-7	2.401	2.386	94.4	95.0	4.8	15	66.6	1.2
4/25-8	2.401	2.386	93.9	94.5	4.8	15	64.2	1.2
4/25-9	2.401	2.386	91.5	92.1	4.8	18	54.8	1.2
4/26-390	2.412	2.39	90.4	91.3	5.0	18	52.3	1.8
4/26-410	2.412	2.39	91.3	92.1	5.0	18	55.0	1.8
4/26-450	2.412	2.39	91.6	92.5	5.0	17	56.2	1.8
4-28-1	2.414	2.396	88.6	89.3	5.0	20	46.0	1.4
4-28-2	2.414	2.396	90.6	91.3	5.0	18	51.9	1.4
4-28-3	2.414	2.396	93.0	93.7	5.0	16	60.4	1.4
5-1-445	2.403	2.384	92.1	92.8	5.3	17	58.6	1.3
5-1-540	2.403	2.384	91.9	92.6	5.3	18	57.7	1.3
5-1-550	2.403	2.384	91.3	92.0	5.3	18	55.8	1.3
5-2-525	2.414	2.405	90.0	90.3	4.7	18	47.3	1.0
5-2-540	2.414	2.405	90.2	90.5	4.7	18	47.9	1.0
5-3-1	2.422	2.403	90.5	91.2	4.4	17	49.6	0.7
5-3-2	2.422	2.403	91.7	92.4	4.4	16	53.6	0.7
5-3-3	2.422	2.403	89.9	90.6	4.4	18	47.6	0.7
5-4-515	2.411	2.393	91.3	92.0	4.9	17	54.2	0.9
5-4-560	2.411	2.393	91.2	91.9	4.9	18	53.9	0.9
5-4-470	2.411	2.393	91.3	92.0	4.9	17	54.1	0.9
COUNT	37	37	37	37	37	37	37	37
AVG.	2.409	2.388	91.9	92.7	5.0	17	57.6	1.2
STD.	0.013	0.013	1.48	1.6	0.3	1	6.7	0.3
MAX.	2.429	2.405	95.1	95.8	5.4	20	72.8	1.8
MIN.	2.381	2.364	88.6	89.3	4.4	15	46.0	0.7

TABLE A-6. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 6: DISTRICT 14, LOOP 1, TYPE D

SPEC.	RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	RELATIVE DENSITY BASED ON Gr1 %	RELATIVE DENSITY BASED ON Gr2 %	EXT. AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
A4	2.429	2.419	91.3	91.7	5.1	17	51	0.5
A5	2.429	2.419	90.6	91.0	5.1	18	49	0.5
A6	2.429	2.419	91.6	92.0	5.1	17	52	0.5
B4	2.428	2.415	91.0	91.4	5.2	18	51	0.8
B5	2.428	2.415	88.9	89.3	5.2	19	45	0.8
B6	2.428	2.415	85.8	86.3	5.2	22	38	0.8
C1	2.418	2.404	88.6	89.2	5.5	20	46	0.8
C2	2.418	2.404	90.6	91.1	5.5	18	52	0.8
C3	2.418	2.404	90.0	90.5	5.5	19	50	0.8
D7	2.423	2.407	92.4	93.1	5.5	17	58	0.8
D8	2.423	2.407	88.6	89.2	5.5	20	46	0.8
D9	2.423	2.407	89.3	89.9	5.5	19	48	0.8
E1	2.432	2.413	88.0	88.7	5.3	20	44	0.6
E2	2.432	2.413	83.4	84.0	5.3	24	34	0.6
F2	2.425	2.416	86.0	86.3	5.3	22	38	0.5
F3	2.425	2.416	87.8	88.1	5.3	21	42	0.5
AVII	2.425	2.425	92.5	92.5	5.5	16	55	0.8
AVIII	2.425	2.425	91.4	91.4	5.5	18	51	0.8
AIX	2.425	2.425	87.9	87.9	5.5	21	42	0.8
B-4	2.408	2.391	87.6	88.2	5.2	21	44	0.6
B-5	2.408	2.391	89.9	90.6	5.2	19	51	0.6
B-6	2.408	2.391	88.9	89.6	5.2	20	48	0.6
C-1	2.407	2.39	86.2	86.8	5.2	22	41	0.8
C-2	2.407	2.39	89.9	90.6	5.2	19	51	0.8
C-3	2.407	2.39	88.9	89.5	5.2	20	48	0.8
D-1	2.415	2.400	92.1	92.6	5.1	17	56	0.9
D-2	2.415	2.400	86.9	87.5	5.1	21	42	0.9
D-3	2.415	2.400	88.9	89.4	5.1	20	46	0.9
EIV	2.407	2.389	88.4	89.0	5.3	21	47	0.9
EV	2.407	2.389	90.6	91.2	5.3	19	53	0.9
EVI	2.407	2.389	85.2	85.9	5.3	23	40	0.9
F-7	2.418	2.399	90.5	91.2	5.3	18	52	0.5
F-8	2.418	2.399	88.9	89.6	5.2	20	47	0.5
F-9	2.418	2.399	88.7	89.4	5.2	20	47	0.5
G-I	2.410	2.400	87.9	88.2	5.5	21	44	0.6
G-II	2.410	2.400	86.8	87.2	5.5	22	42	0.6
G-III	2.410	2.400	88.4	88.8	5.5	21	46	0.6
H-IV	2.408	2.392	91.5	92.1	5.4	18	56	0.7
H-V	2.408	2.392	88.3	88.9	5.4	21	46	0.7
H-VI	2.408	2.392	91.1	91.7	5.4	18	54	0.7

TABLE A-6. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 6: DISTRICT 14, LOOP 1, TYPE C (CONT'D)

COUNT	40	40	40	40	40	40	40	40
AVG.	2.418	2.404	89.0	89.5	5.3	20	47	0.7
STD.	0.009	0.011	2.1	2.0	0.2	2	5	0.1
MAX.	2.432	2.425	92.5	93.1	5.5	24	58	0.9
MIN.	2.407	2.389	83.4	84.0	5.1	16	34	0.5

TABLE A-7. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 7: DISTRICT 14, HIGHWAY RR2244, TYPE C

SPEC.	RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	RELATIVE DENSITY BASED ON Gr1 %	RELATIVE DENSITY BASED ON Gr2 %	EXT. AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
4/4-1	2.433	2.414	92.3	93.1	4.2	15	54	0.9
4/4-2	2.433	2.414	92.2	92.9	4.2	15	53	0.9
4/4-3	2.433	2.414	92.2	93.0	4.2	15	54	0.9
4/5-1	2.418	2.394	92.8	93.7	4.4	15	59	0.8
4/5-2	2.418	2.394	91.7	92.7	4.4	16	55	0.8
4/5-3	2.418	2.394	92.9	93.9	4.4	15	60	0.8
4/6-1	2.425	2.408	91.4	92.1	4.7	17	53	0.8
4/6-2	2.425	2.408	90.8	91.4	4.7	17	50	0.8
4/6-3	2.425	2.408	91.4	92.0	4.7	17	52	0.8
4/7-1	2.428	2.403	90.9	91.8	4.6	17	52	0.8
4/7-2	2.428	2.403	91.1	92.1	4.6	17	53	0.8
4/7-3	2.428	2.403	92.5	93.5	4.6	15	58	0.8
4/8-1	2.417	2.402	89.1	89.7	4.6	19	46	0.8
4/8-2	2.417	2.402	91.1	91.6	4.6	17	51	0.8
4/8-3	2.417	2.402	92.8	93.4	4.6	16	58	0.8
4/13-4	2.426	2.408	92.6	93.3	4.8	16	57	1.8
4/13-5	2.426	2.408	92.9	93.6	4.8	15	59	1.8
4/13-6	2.426	2.408	89.6	90.3	4.8	18	47	1.8
COUNT	18	18	18	18	18	18	18	18
AVG.	2.425	2.405	91.7	92.4	4.6	16	54	1.0
STD.	0.006	0.006	1.1	1.1	0.2	1	4	0.3
MAX.	2.433	2.414	92.9	93.9	4.8	19	60	1.8
MIN.	2.417	2.394	89.1	89.7	4.2	15	46	0.8

TABLE A-8. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 8: DISTRICT 14, HIGHWAY LOOP 360, TYPE C

SPEC.	RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	RELATIVE DENSITY BASED ON Gr1 %	RELATIVE DENSITY BASED ON Gr2 %	EXT. AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
1A	2.417	2.399	92.2	92.9	4.6	16.2	56	0.9
2A	2.417	2.399	92.6	93.3	4.6	15.8	58	0.9
3A	2.417	2.399	91.7	92.4	4.6	16.7	54	0.9
1B	2.437	2.415	91.1	92.0	4.6	16.4	51	1.0
2B	2.437	2.415	89.8	90.6	4.6	17.6	47	1.0
3B	2.437	2.415	91.8	92.6	4.6	15.8	53	1.0
1C	2.430	2.412	92.7	93.4	4.7	15.4	57	0.9
2C	2.430	2.412	92.6	93.3	4.7	15.4	56	0.9
3C	2.430	2.412	92.1	92.8	4.7	15.8	55	0.9
1D	2.421	2.405	93.5	94.1	5.0	15.2	61	0.8
2D	2.421	2.405	93.8	94.4	5.0	14.9	63	0.8
3D	2.421	2.405	91.3	91.9	5.0	17.2	53	0.8
1E	2.417	2.408	91.0	91.3	4.6	17.3	50	1.0
2E	2.417	2.408	93.2	93.6	4.6	15.2	58	1.0
3E	2.417	2.408	94.0	94.3	4.6	14.6	61	1.0
A1	2.420	2.410	91.9	92.2	4.7	16.4	53	0.9
A2	2.420	2.410	93.5	93.9	4.7	14.9	59	0.9
A3	2.420	2.410	92.2	92.6	4.7	16.1	54	0.9
B1	2.434	2.412	90.0	90.8	4.9	17.8	48	0.8
B3	2.434	2.412	88.3	89.1	4.9	19.4	44	0.8
C1	2.427	2.416	91.2	91.6	4.5	16.7	50	0.8
C2	2.427	2.416	90.4	90.8	4.5	17.4	47	0.8
C3	2.427	2.416	91.5	92.0	4.5	16.4	51	0.8
D1	2.428	2.415	90.7	91.2	4.8	17.3	49	0.7
D2	2.428	2.415	93.3	93.8	4.8	14.9	59	0.7
E1	2.480	2.468	88.9	89.3	5.4	17.8	40	0.9
E2	2.480	2.468	89.3	89.7	5.4	17.4	41	0.9
E3	2.480	2.468	88.2	88.6	5.4	18.4	38	0.9
F2	2.453	2.428	90.5	91.5	4.7	16.5	48	0.9
F3	2.453	2.428	89.9	90.8	4.7	17.2	46	0.9
G1	2.431	2.420	92.1	92.5	5.2	16.3	54	0.8
G2	2.431	2.420	92.9	93.3	5.2	15.6	57	0.8
G3	2.431	2.420	90.6	91.0	5.2	17.6	49	0.8
H2	2.469	2.440	90.7	91.7	4.9	16.1	49	0.9
H3	2.469	2.440	88.2	89.2	4.9	18.4	41	0.9
K1	2.440	2.417	93.0	93.9	5.3	15.3	60	0.8
K2	2.440	2.417	93.0	93.9	5.3	15.2	60	0.8
K3	2.440	2.417	92.2	93.1	5.3	16.0	57	0.8
COUNT	38	38	38	38	38	38	38	38
AVG.	2.435	2.418	91.5	92.1	4.8	16.4	52	0.9
STD.	0.000	0.000	1.6	1.6	0.3	1.1	6	0.1
MAX.	2.480	2.468	94.0	94.4	5.4	19.4	63	1.0
MIN.	2.417	2.399	88.2	88.6	4.5	14.6	38	0.7

TABLE A-9. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 9: DISTRICT 18, HIGHWAY IH 635, TYPE C, LEVEL UP

SPEC.	RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	RELATIVE DENSITY BASED ON Gr1 %	RELATIVE DENSITY BASED ON Gr2 %	EXT. AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
1	2.483	2.470	94.6	95.1	3.5			0.9
2	2.483	2.470	95.4	96.0	3.5			0.9
3	2.483	2.470	95.7	96.2	3.5			0.9
4	2.483	2.470	94.4	94.9	3.5			0.9
5	2.483	2.470	95.6	96.1	3.5			0.9
6	2.483	2.470	95.3	95.8	3.5			0.9
7	2.483	2.470	94.3	94.8	3.5			0.9
8	2.483	2.470	95.2	95.7	3.5			0.9
9	2.483	2.470	94.4	94.9	3.5			0.9
10	2.483	2.470	95.5	96.0	3.9			0.4
11	2.483	2.470	94.6	95.1	3.9			0.4
12	2.483	2.470	93.9	94.4	3.9			0.4
13	2.483	2.470	95.0	95.5	3.9			0.4
14	2.483	2.470	96.4	96.9	3.9			0.4
15	2.483	2.470	96.6	97.1	3.9			0.4
16	2.483	2.470	96.5	97.0	3.9			0.4
17	2.483	2.470	96.5	97.0	3.9			0.4
18	2.483	2.470	96.0	96.5	3.9			0.4
19	2.483	2.470	96.5	97.0	3.8			0.4
20	2.483	2.470	95.4	95.9	3.8			0.4
21	2.483	2.470	95.9	96.4	3.8			0.4
22	2.483	2.470	95.0	95.5	3.8			0.4
23	2.483	2.470	95.3	95.8	3.8			0.4
24	2.483	2.470	95.9	96.4	3.8			0.4
25	2.483	2.470	95.7	96.2	3.8			0.4
26	2.483	2.470	95.3	95.8	3.8			0.4
27	2.483	2.470	95.3	95.8	3.8			0.4
COUNT	27	27	27	27	27			27
AVG.	2.483	2.470	95.4	95.9	3.8			0.6
STD.	0.000	0.000	0.7	0.7	0.2			0.3
MAX.	2.483	2.470	96.6	97.1	3.9			0.9
MIN.	2.483	2.470	93.9	94.4	3.5			0.4

TABLE A-10. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 10: DISTRICT 18, HIGHWAY IH 635, TYPE C, SURFACE

SPEC.	RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	DENSITY BASED ON Gr1 %	DENSITY BASED ON Gr2 %	EXT. AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
1	2.411	2.406	92.2	92.4	4.1	18	57	0.2
2	2.411	2.406	92.8	93.0	4.1	17	59	0.2
3	2.411	2.406	93.7	93.8	4.1	16	62	0.2
4	2.411	2.406	92.7	92.9	4.1	17	59	0.2
5	2.411	2.406	92.5	92.7	4.1	17	58	0.2
6	2.411	2.406	91.9	92.1	4.1	18	56	0.2
7	2.411	2.406	92.3	92.5	4.1	18	57	0.2
8	2.411	2.406	93.2	93.4	4.1	17	61	0.4
9	2.411	2.406	93.9	94.1	4.1	16	63	0.4
10	2.411	2.406	93.9	94.1	4.1	16	64	0.4
11	2.411	2.406	94.1	94.3	4.1	16	64	0.4
12	2.411	2.406	93.6	93.8	4.1	16	62	0.4
13	2.411	2.406	92.5	92.7	4.1	17	58	0.4
14	2.411	2.406	92.7	92.9	4.1	17	59	0.4
15	2.411	2.406	93.7	93.9	3.7	16	62	0.1
16	2.411	2.406	93.7	93.9	3.7	16	62	0.1
17	2.411	2.406	93.1	93.3	3.7	17	59	0.1
18	2.411	2.406	92.8	93.0	3.7	17	58	0.1
19	2.411	2.406	94.3	94.5	3.7	15	64	0.1
20	2.411	2.406	93.2	93.4	3.7	16	60	0.1
21	2.411	2.406	93.4	93.6	3.7	16	61	0.1
22	2.411	2.406	94.0	94.2	3.7	16	63	0.1
COUNT	22	22	22	22	22	22	22	22
AVG.	2.411	2.406	93.2	93.4	4.0	17	60	0.2
STD.	0.000	0.000	0.7	0.7	0.2	1	2	0.1
MAX.	2.411	2.406	94.3	94.5	4.1	18	64	0.4
MIN.	2.411	2.406	91.9	92.1	3.7	15	56	0.1

TABLE A-11. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 11: DISTRICT 19, HIGHWAY SH 67 (MT. PLEASANT), TYPE D

SPEC.	RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	RELATIVE DENSITY BASED ON Gr1 %	RELATIVE DENSITY BASED ON Gr2 %	EXT. AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
1	2.401	2.391	98.4	98.8	5.6			0.8
2	2.401	2.391	98.6	99.0	5.6			0.8
3	2.401	2.391	97.9	98.3	5.6			0.8
4	2.401	2.391	97.9	98.3	5.6			0.8
5	2.401	2.391	98.6	99.0	5.6			0.8
6	2.401	2.391	97.9	98.4	5.6			0.8
7	2.401	2.391	98.3	98.7	5.6			0.8
8	2.416	2.415	97.2	97.2	5.6			0.8
9	2.415	2.406	97.8	98.2	5.6			0.8
10	2.415	2.406	93.5	93.9	5.0			0.9
11	2.415	2.406	97.8	98.2	5.0			0.9
12	2.416	2.415	94.3	94.4	5.0			0.9
13	2.416	2.415	94.6	94.6	5.0			0.9
14	2.416	2.415	95.8	95.8	5.0			0.9
15	2.415	2.406	94.1	94.4	5.0			0.9
16	2.415	2.406	95.6	96.0	5.0			0.9
17	2.415	2.406	96.2	96.5	5.0			0.3
18	2.415	2.406	98.0	98.3	5.0			0.9
19	2.399	2.390	96.7	97.1	5.0			0.9
20	2.399	2.390	96.2	96.5	5.2			0.9
21	2.399	2.390	93.4	93.7	5.2			0.9
22	2.399	2.390	97.2	97.6	5.2			0.9
23	2.399	2.390	95.5	95.8	5.2			0.9
24	2.399	2.390	96.1	96.5	5.2			0.9
25	2.399	2.390	95.3	95.6	5.2			0.9
26	2.399	2.390	97.9	98.3	5.2			0.9
27	2.399	2.390	98.2	98.6	5.2			0.9
COUNT	27	27	27	27	27			27.0
AVG.	2.406	2.398	96.6	97.0	5.3			0.9
STD.	0.008	0.010	1.6	1.7	0.2			0.01
MAX.	2.416	2.415	98.6	99.0	5.6			0.9
MIN.	2.399	2.390	93.4	93.7	5.0			0.8

TABLE A-12. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 12: DISTRICT 19, HIGHWAY SH 67(TEXARKANA), TYPE D

SPEC.	RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	RELATIVE DENSITY BASED ON Gr1 %	RELATIVE DENSITY BASED ON Gr2 %	EXT. AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
1	2.432	2.417	97.7	98.3	5.4			1.1
2	2.432	2.417	98.1	98.7	5.4			1.1
3	2.432	2.417	94.0	94.6	5.4			1.1
4	2.432	2.417	98.3	98.9	5.4			1.1
5	2.432	2.417	97.6	98.2	5.4			1.1
6	2.432	2.417	98.1	98.7	5.4			1.1
7	2.426	2.416	97.7	98.1	5.4			1.1
8	2.426	2.416	97.3	97.7	5.4			1.1
9	2.426	2.416	97.5	97.9	5.4			1.1
10	2.426	2.416	96.1	96.5	5.2			1.0
11	2.426	2.416	96.8	97.2	5.2			1.0
12	2.426	2.416	95.7	96.0	5.2			1.0
13	2.426	2.416	95.6	96.0	5.2			1.0
14	2.426	2.416	97.7	98.1	5.2			1.0
15	2.426	2.416	97.2	97.6	5.2			1.0
16	2.434	2.420	97.6	98.2	5.2			1.0
17	2.434	2.420	97.3	97.9	5.2			1.0
18	2.434	2.420	96.1	96.7	5.2			1.0
19	2.434	2.420	94.8	95.4	5.2			1.0
20	2.434	2.420	97.2	97.7	5.1			1.1
21	2.434	2.420	96.1	96.6	5.1			1.1
22	2.434	2.420	97.1	97.7	5.1			1.1
23	2.434	2.420	96.5	97.1	5.1			1.1
24	2.434	2.420	97.9	98.4	5.1			1.1
25	2.434	2.420	96.9	97.5	5.1			1.1
COUNT	25	25	25	25	25			25
AVG.	2.431	2.418	96.9	97.4	5.3			1.1
STD.	0.004	0.002	1.0	1.1	0.1			0.0
MAX.	2.434	2.420	98.3	98.9	5.4			1.1
MIN.	2.426	2.416	94.0	94.6	5.1			1.0

TABLE A-13. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 13: DISTRICT 21, HIGHWAY US 77, TYPE B, BASE

SPEC.	RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	RELATIVE DENSITY BASED ON Gr1 %	RELATIVE DENSITY BASED ON Gr2 %	EXT. AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
395	2.418	2.401	91.4	92.1	5.3	18	57	0.5
435+00	2.410	2.391	91.4	92.2	5.1	18	58	0.6
435+00	2.410	2.391	93.1	93.9	5.1	17	64	0.6
600+00	2.401	2.382	94.5	95.2	6.0	17	72	0.5
680+00 1	2.401	2.382	91.1	91.9	6.0	20	59	0.5
680+00 2	2.401	2.382	96.3	97.1	6.0	15	81	0.5
752	2.397	2.387	93.9	94.3	5.2	17	66	0.5
752 1	2.397	2.387	93.3	93.7	5.2	17	63	0.5
752 2	2.397	2.387	94.0	94.4	5.2	17	67	0.5
830+00 1	2.432	2.411	92.6	93.4	5.4	17	61	1.1
830+00 2	2.432	2.411	91.3	92.1	5.4	18	56	1.1
830+00 3	2.432	2.411	92.9	93.7	5.4	17	62	1.1
COUNT	12	12	12	12	12	12	12	12
AVG.	2.411	2.394	93.0	93.7	5.5	17	64	0.7
STD.	0.014	0.011	1.5	1.5	0.4	1	6.70	0.26
MAX.	2.432	2.411	96.3	97.1	6.0	20	81	1.1
MIN.	2.397	2.382	91.1	91.9	5.1	15	56	0.5

TABLE A-14. RELATIVE DENSITIES AND SOME MIX PARAMETERS FOR PROJECT 14: DISTRICT 10, HIGHWAY US 77, TYPE D, SURFACE

SPEC.	RICE S.G. UNCOR. Gr1	RICE S.G. COR. Gr2	RELATIVE DENSITY BASED ON Gr1 %	RELATIVE DENSITY BASED ON Gr2 %	EXT. AC %	VMA, %	VOIDS FILLED %	DUST-AC RATIO
1	2.393	2.371	94.4	95.3	5.8	18	73	0.4
2	2.376	2.359	91.6	92.3	5.3	20	62	0.3
3	2.376	2.359	90.6	91.3	5.3	21	58	0.3
4	2.393	2.371	92.9	93.8	5.8	19	67	0.4
5	2.376	2.359	92.2	92.9	5.3	20	64	0.3
6	2.393	2.371	93.2	94.1	5.8	19	68	0.4
7	2.376	2.359	93.4	94.1	5.3	19	68	0.3
8	2.393	2.371	94.7	95.6	5.8	17	74	0.4
9	2.376	2.359	93.4	94.0	5.3	19	68	0.3
10	2.393	2.371	94.5	95.4	5.8	17	74	0.4
11	2.376	2.359	91.4	92.1	5.6	21	62	0.4
12	2.393	2.371	92.6	93.4	5.8	19	66	0.4
13	2.416	2.395	88.4	89.2	5.7	22	51	0.5
14	2.398	2.385	93.2	93.7	5.7	18	66	0.4
15	2.416	2.395	88.3	89.1	5.7	22	51	0.5
16	2.401	2.385	94.1	94.8	5.7	17	70	0.4
17	2.416	2.395	89.0	89.7	5.2	21	51	0.5
18	2.401	2.385	91.8	92.4	5.7	19	61	0.4
19	2.401	2.385	90.1	90.7	5.7	21	56	0.4
20	2.401	2.385	90.4	91.0	5.7	21	57	0.4
COUNT	20	20	20	20	20	20	20	20
AVG.	2.393	2.375	92.0	92.7	5.6	19	63	0.4
STD.	0.013	0.013	1.96	1.98	0.2	1	7	0.1
MAX.	2.416	2.395	94.7	95.6	5.8	22	74	0.5
MIN.	2.376	2.359	88.3	89.1	5.2	17	51	0.3

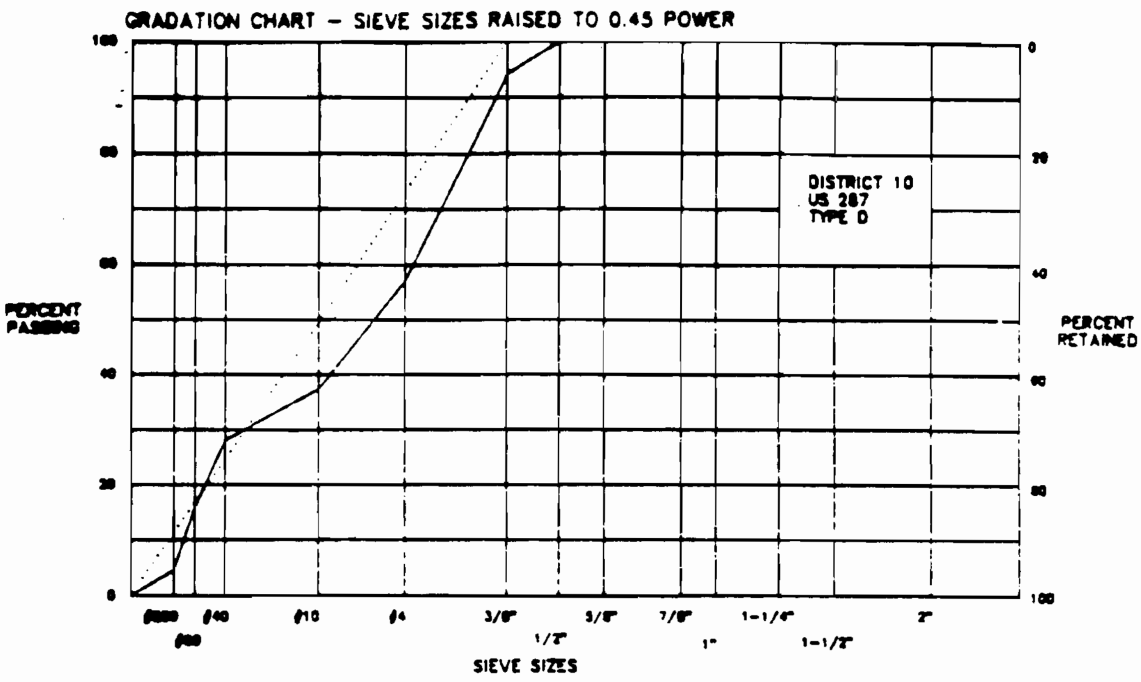

Figure A-1. Gradation Chart for Project 1.

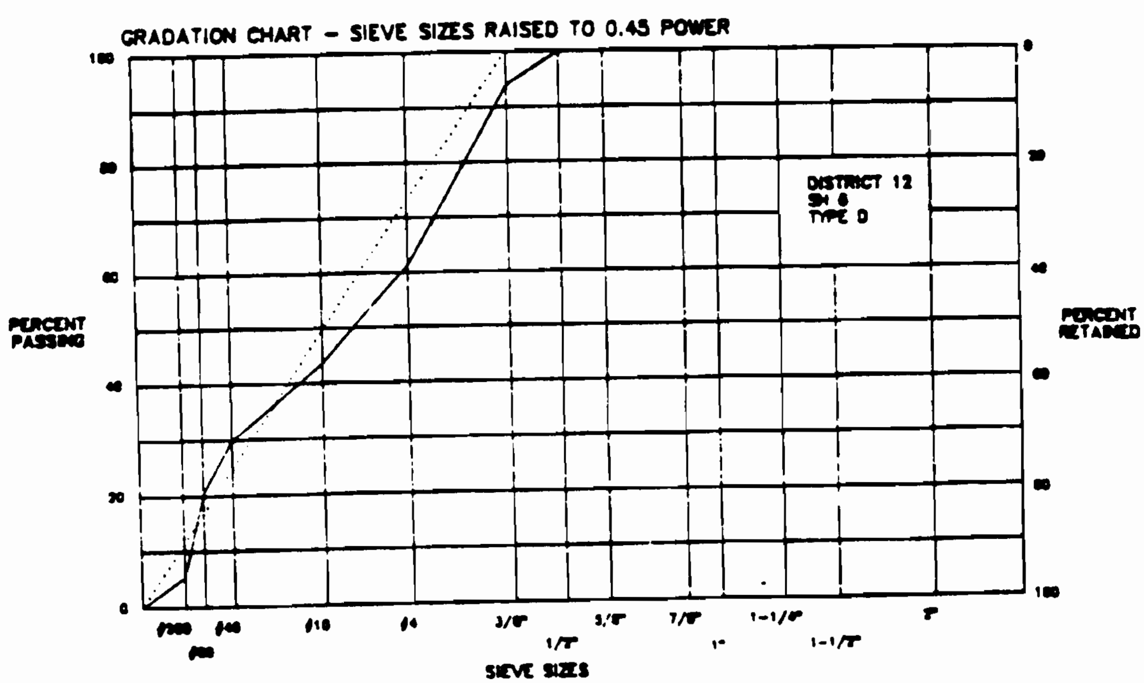

Figure A-2. Gradation Chart for Project 2.

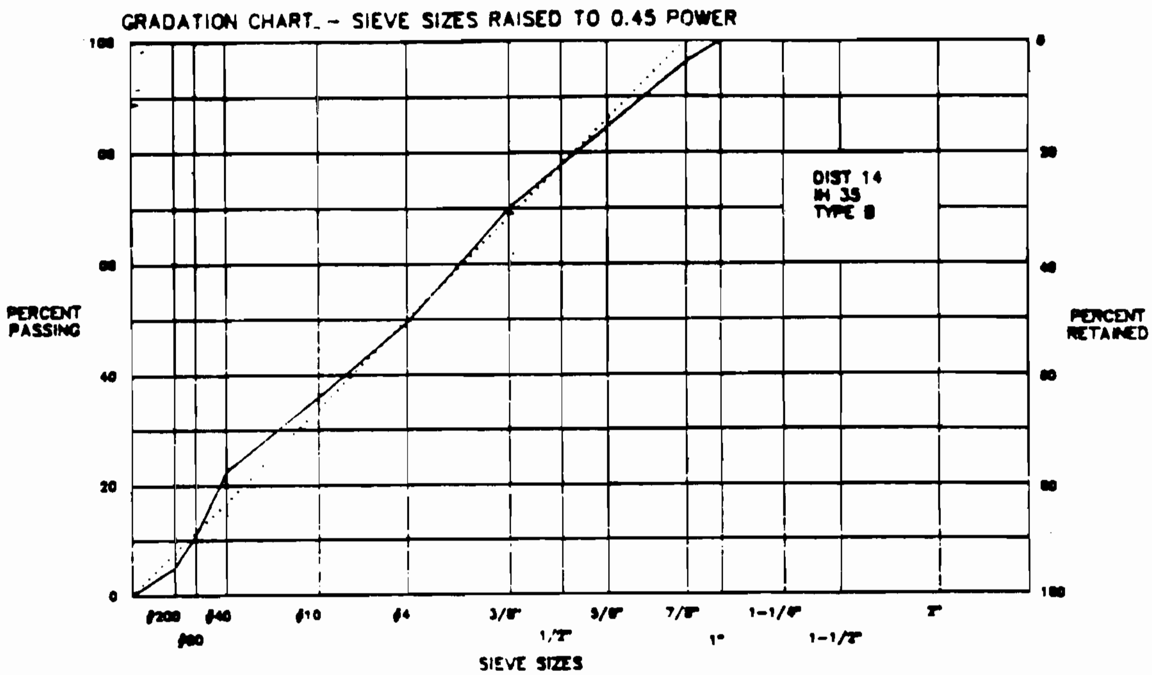

Figure A-3. Gradation Chart for Project 3.

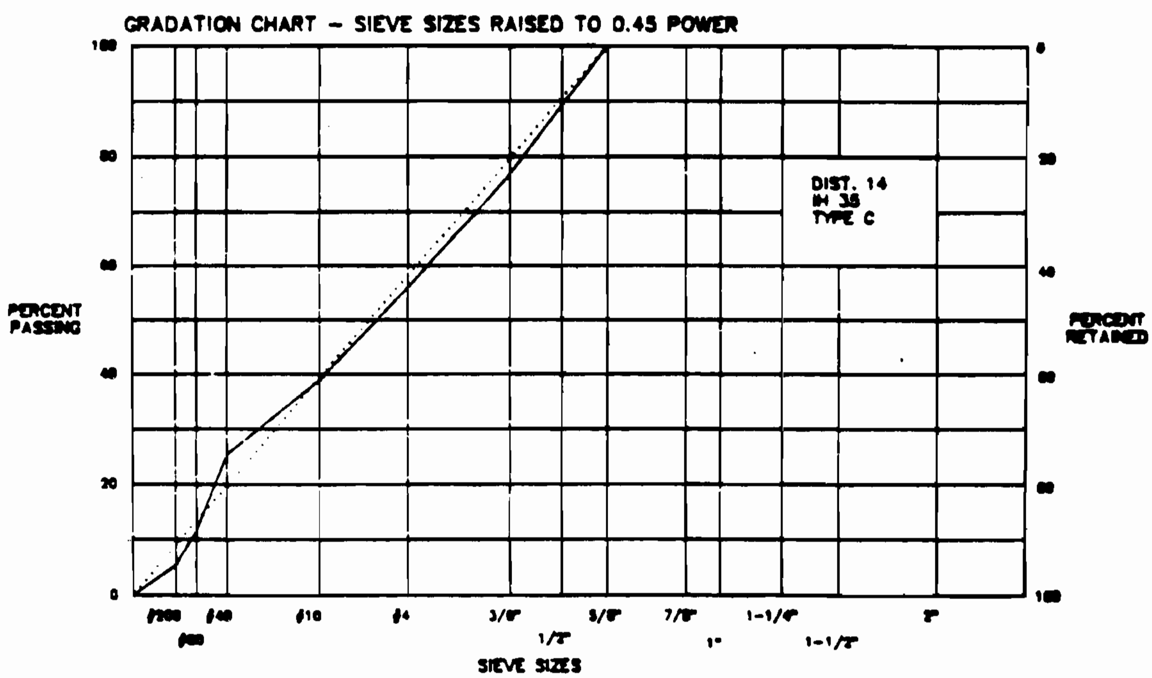

Figure A-4. Gradation Chart for Project 4.

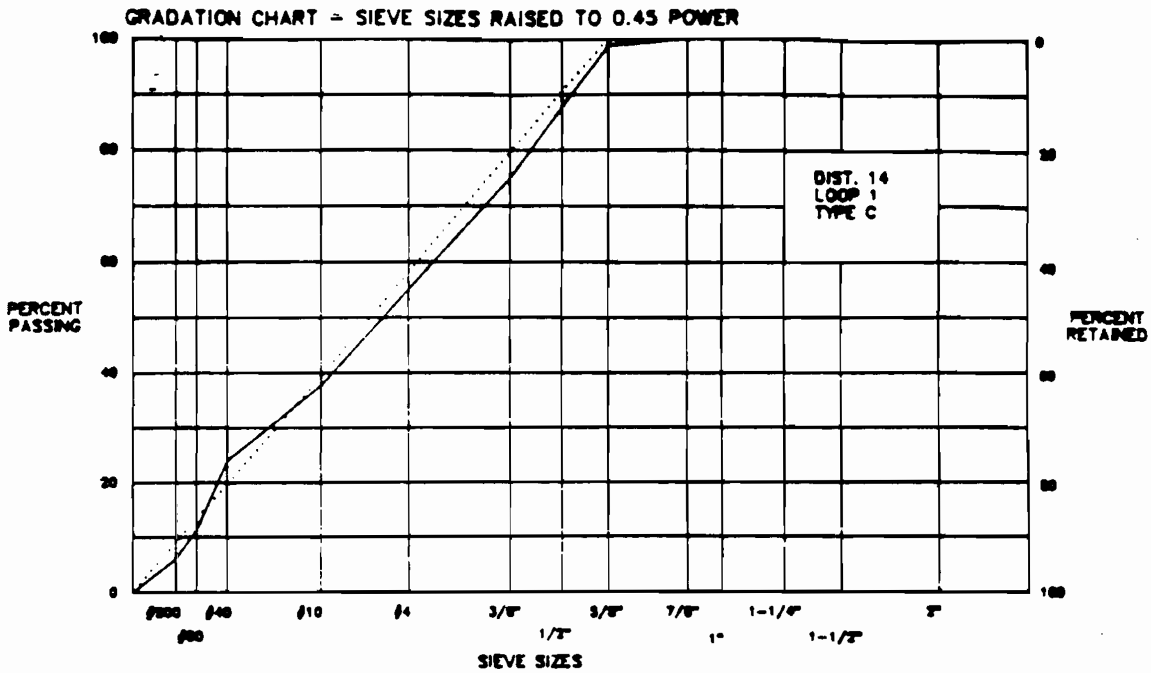

Figure A-5. Gradation Chart for Project 5.

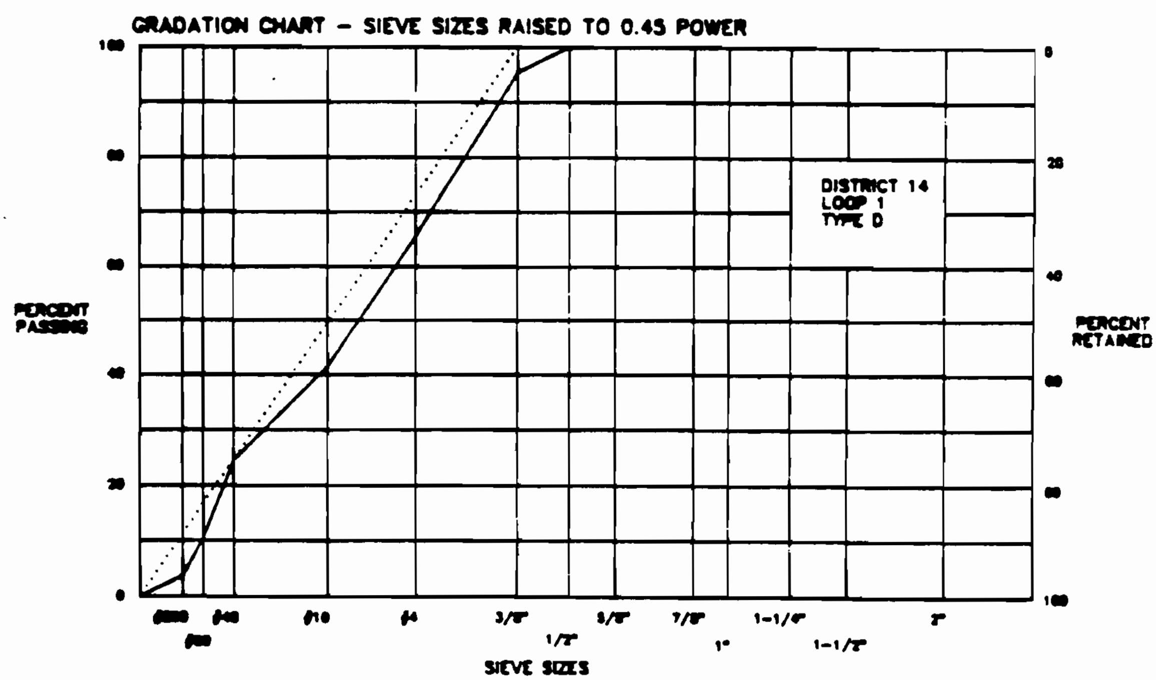

Figure A-6. Gradation Chart for Project 6.

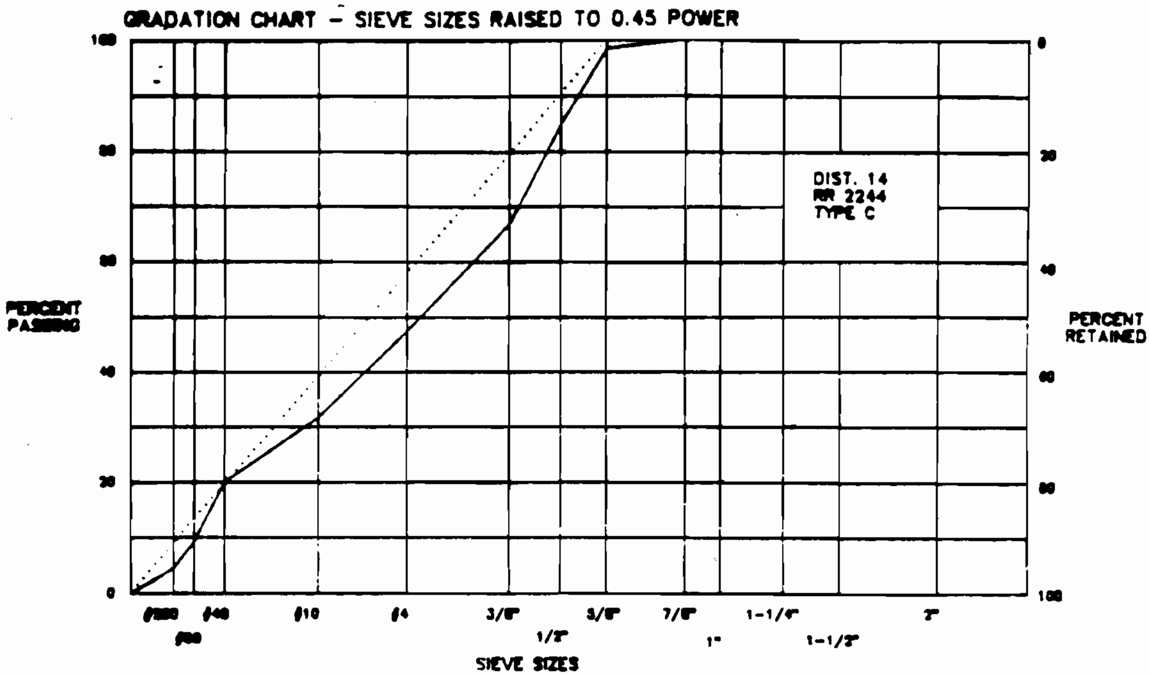

Figure A-7. Gradation Chart for Project 7.

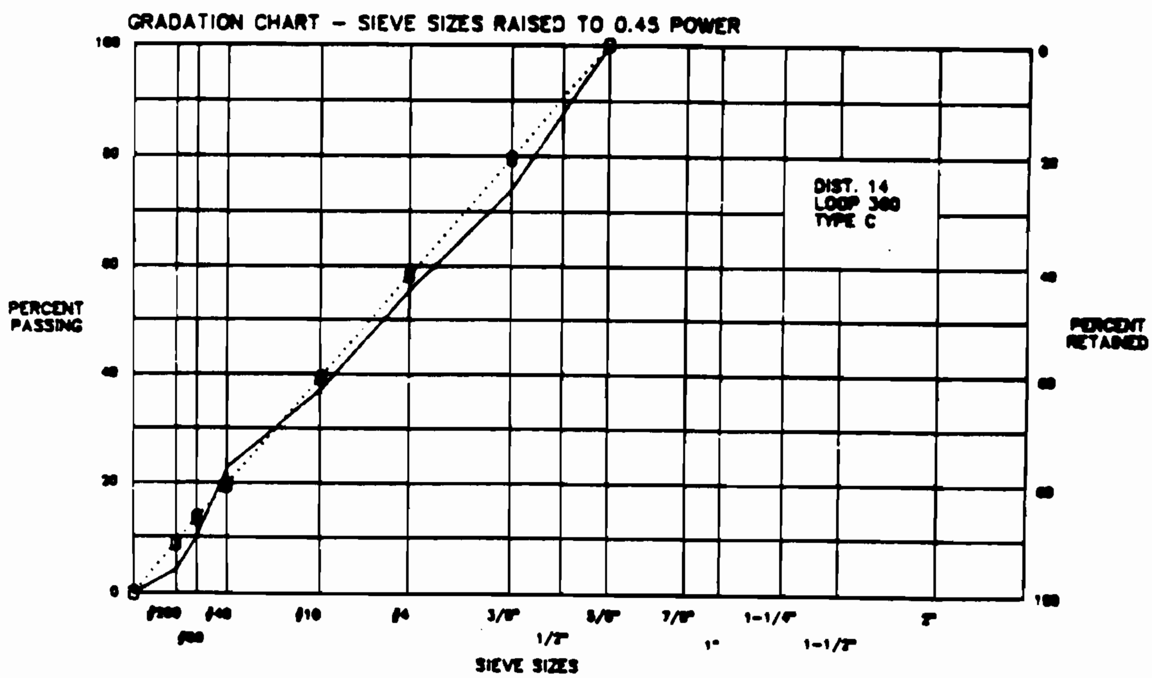

Figure A-8. Gradation Chart for Project 8.

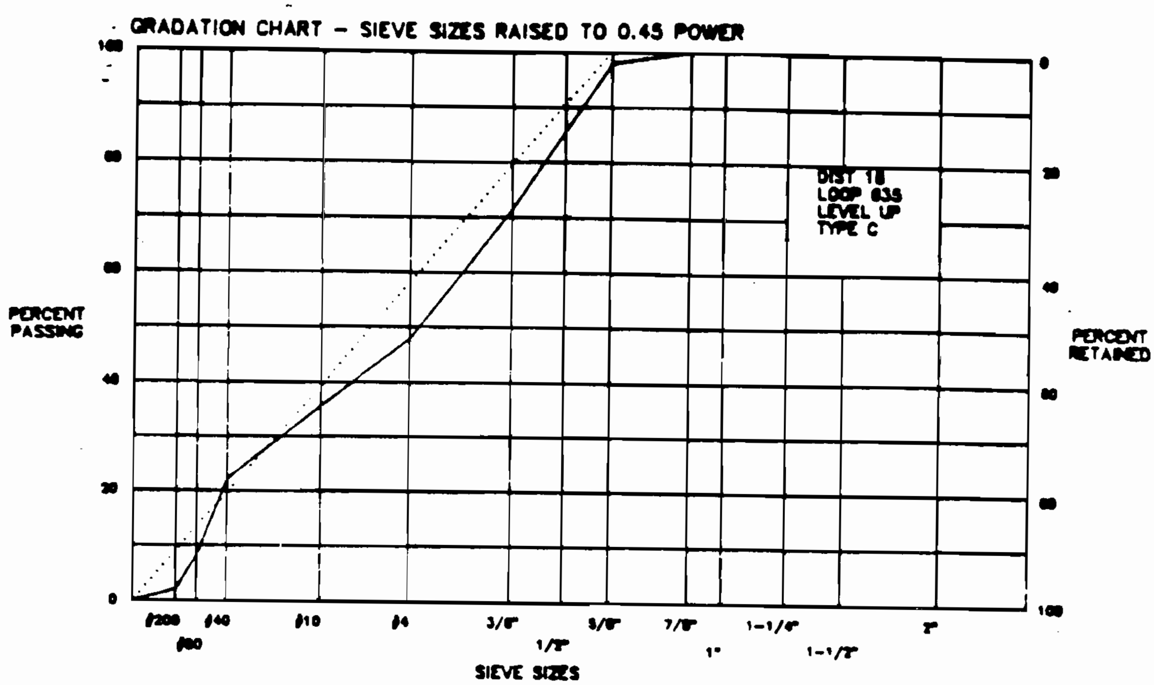

Figure A-9. Gradation Chart for Project 9.

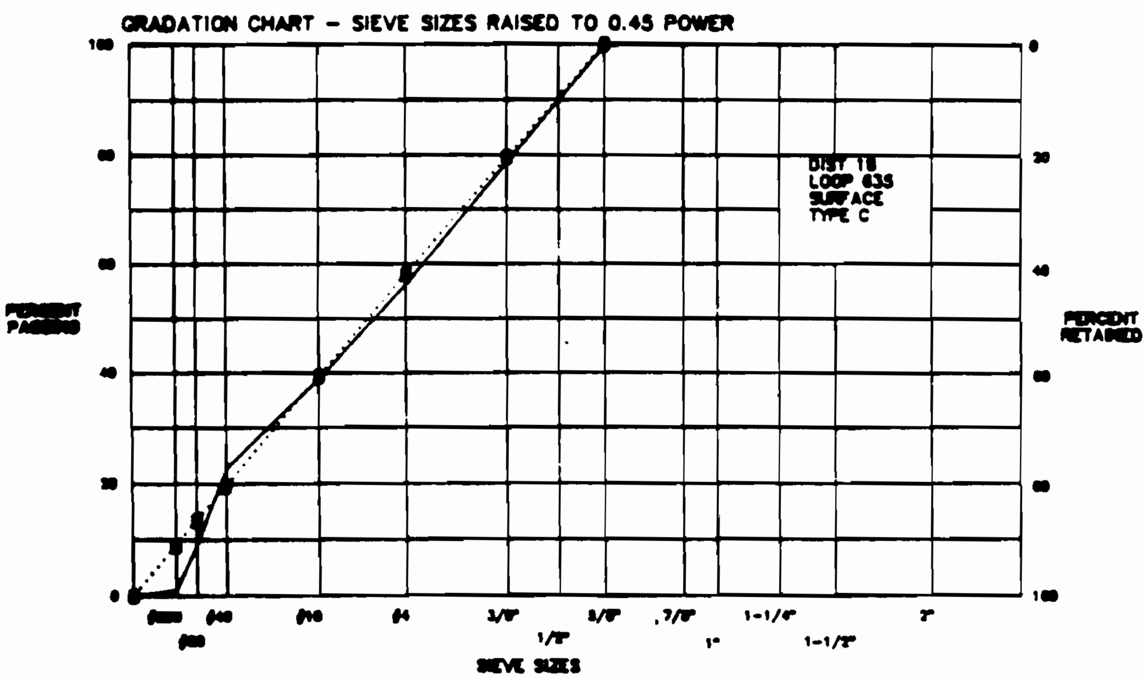

Figure A-10. Gradation Chart for Project 10.

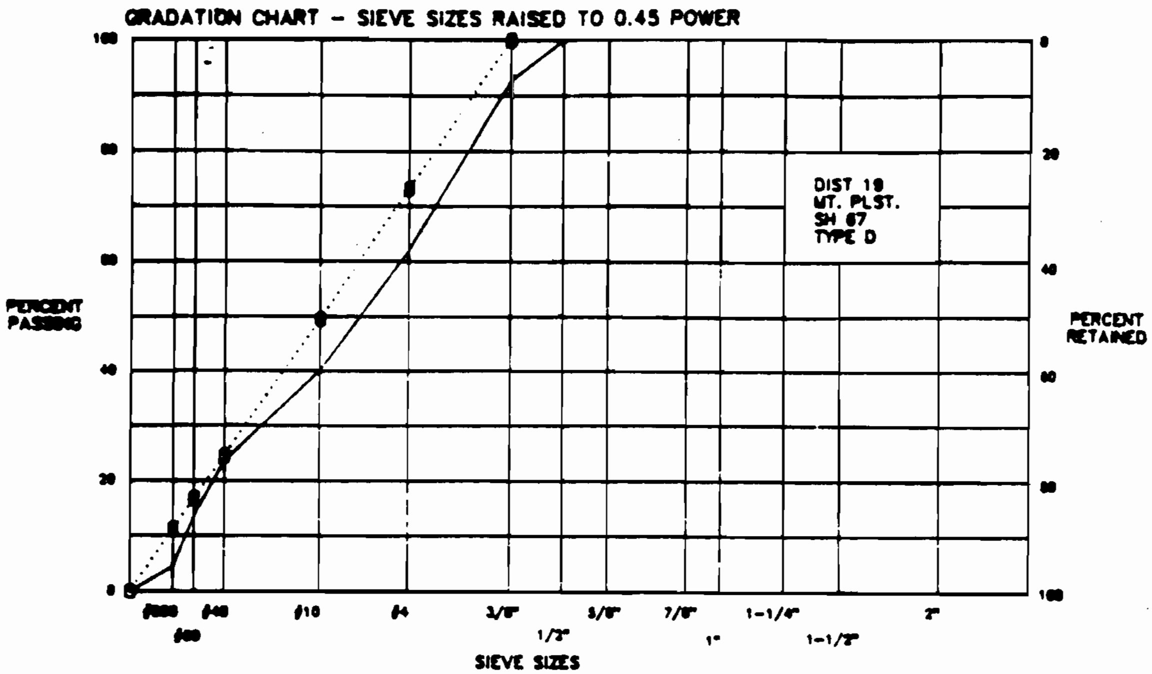

Figure A-11. Gradation Chart for Project 11.

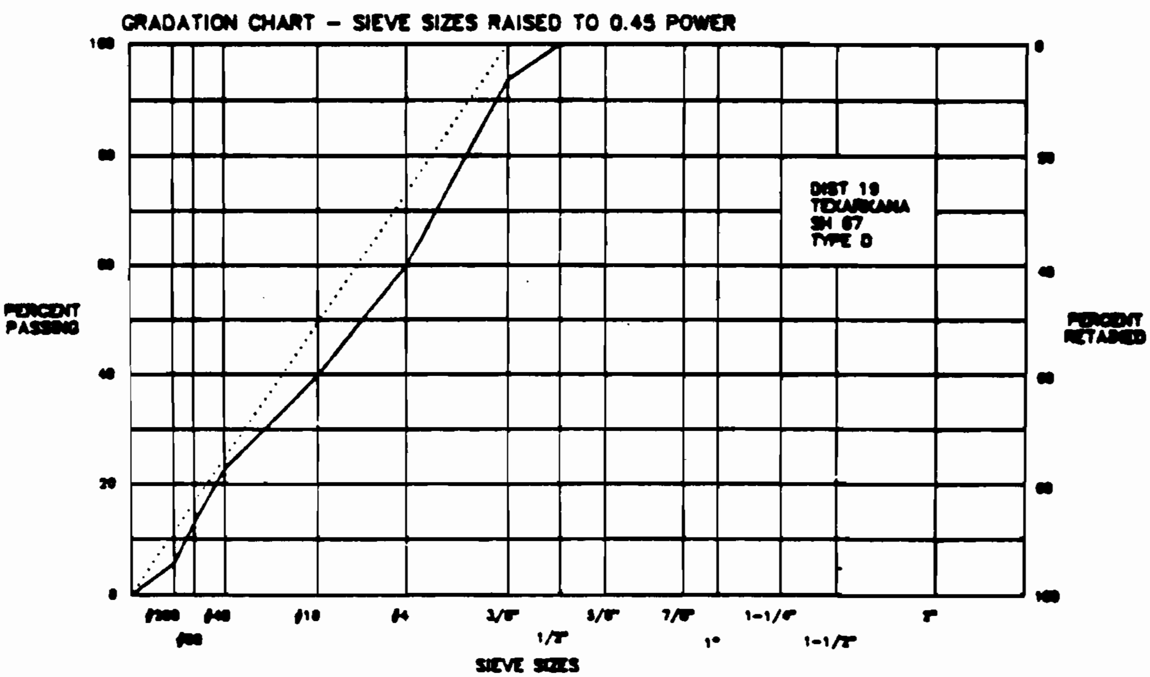

Figure A-12. Gradation Chart for Project 12.

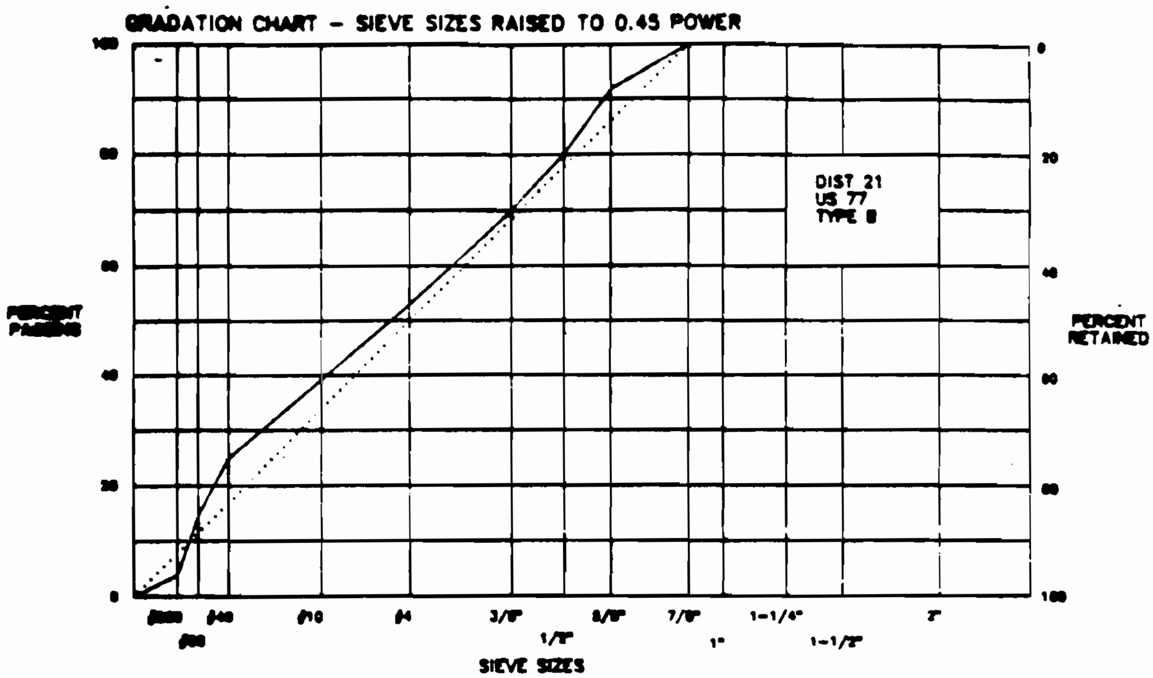

Figure A-13. Gradation Chart for Project 13.

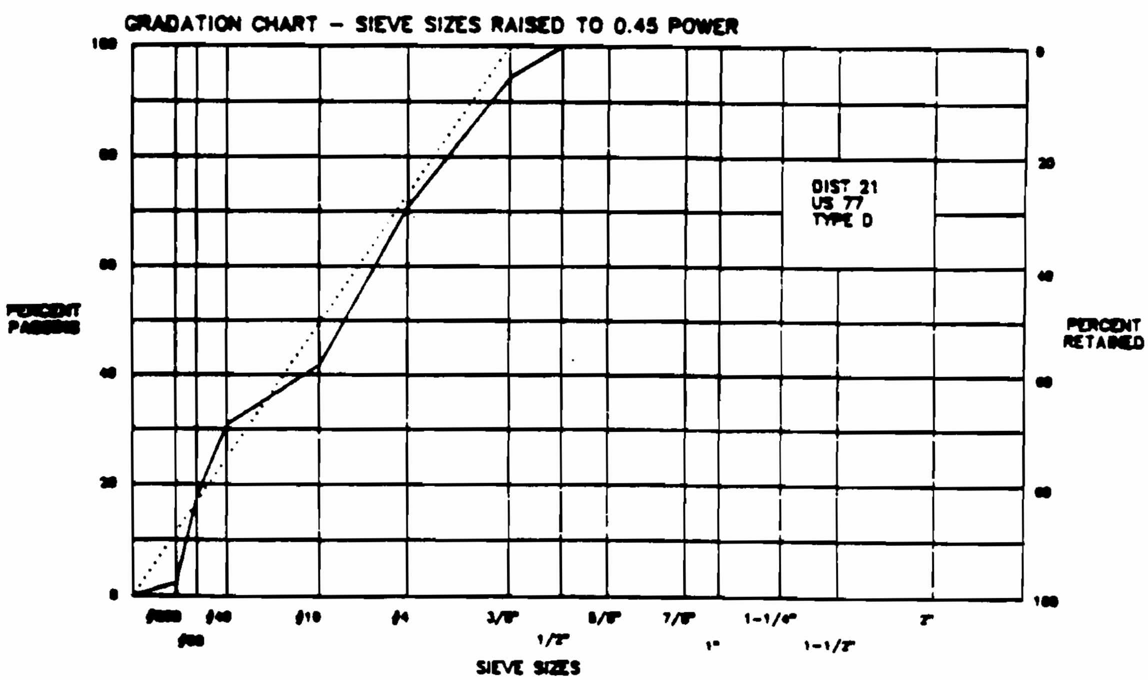

Figure A-14. Gradation Chart for Project 14.

APPENDIX B

FIGURES AND TABLES CORRESPONDING TO PROJECTS REPORTED IN 1987 HMAC FIELD CONSTRUCTION DATA

TABLE B-1. CORE RELATIVE DENSITY BASED ON RICE MAXIMUM SPECIFIC GRAVITY FOR DIFFERENT PROJECTS (Gc/Gr)

DIST	COUNTY	PROJECT	TYPE	DESIGN #	N	AVG. %	STD. %	MIN. %	MAX. %
1	FANNIN	US 82	D LEVEL UP	DS3	14	95.3	1.77	90.1	97.3
1	HUNT	SH 50	D SURFACE	DS3	9	92.4	1.80	89.1	94.8
1	LAMAR	SH 19	C SURFACE	DS3	7	93.3	1.15	92.3	95.3
3	WHICHITA	US 82	D SURFACE	4	7	93.9	1.51	92.7	97.2
5	GARZA	FM 651	D LEVEL UP	3	12	92.2	0.38	91.7	93.1
5	LUBBOCK	SPUR 326	D SURFACE	1	5	93.1	1.17	92.3	95.1
5	LUBBOCK	US 84	D SURFACE	1	12	92.7	1.03	91.3	94.7
5	LUBBOCK	US 84	C SURFACE	1	6	93.5	1.09	91.8	94.6
5	LUBBOCK	US 84	D LEVEL UP	3	6	93.3	1.74	91.4	95.1
5	GARZA	US 84	D SURFACE	1	7	91.6	3.37	86.0	94.6
10	ANDERSON	US 287	D SURFACE	DS3	21	92.3	1.70	88.1	94.8
12	GALVESTON	FM 1764	D LEVEL UP	D1	16	93.7	1.17	91.6	96.0
12	MONTGOMERY	FM 1314	D SURFACE	DS1	13	91.5	0.65	90.3	92.5
12	MONTGOMERY	IH 45	D SURFACE	DS1	5	92.3	2.04	89.5	94.9
12	TOM GREEN	US 67	D SURFACE		18	93.9	1.25	92.0	96.9
13	FAYETTE	US 77	D SURFACE	DW4	11	92.7	1.09	91.1	94.6
13	FAYETTE	US 77	D SURFACE	DW5	32	92.1	1.33	89.4	94.1
13	FAYETTE	US 77	D SURFACE	DW6	16	94.0	1.10	92.0	95.6
13	GONZALES	SH 80	D SURFACE	DS3	22	90.7	1.66	88.0	95.3
13	GONZALES	US 87	D SURFACE	DS3	11	90.1	1.84	87.5	93.1
13	JACKSON	SH 111	D SURFACE	86-184	21	90.6	1.89	87.0	93.8
13	LAVACA	SH 95	D SURFACE	DW5	37	93.1	1.82	88.3	96.7
14	BASTROP	SH 21	C SURFACE	1	5	91.8	0.76	90.5	92.5
14	BASTROP	SH 21	C SURFACE	2	10	91.4	0.89	90.1	93.2
14	BASTROP	SH 71	D SURFACE	2	12	91.8	0.77	90.6	93.2
14	BLANCO	US 281	C SURFACE	DS3	9	92.6	1.70	88.8	94.7
14	LEE	US 290	C SURFACE	1	6	92.6	0.79	91.1	93.3
14	TRAVIS	IH35-MAIN	C SURFACE	DS3	15	92.2	1.07	90.6	94.9
14	TRAVIS	IH35-FRONTAGE	C SURFACE	DS3	15	91.8	1.00	90.0	93.1
16	JIM WELL	US 281	C SURFACE	4	14	94.2	0.90	92.6	95.7
16	JIM WELL	US 281	C SURFACE	6	7	92.4	0.38	92.0	93.1
16	NUECES	SH 44	D SURFACE	DS1	10	93.7	1.40	91.2	95.6
16	REFUGIO	US 77	B BASE	1	14	94.3	0.98	92.9	96.7
16	REFUGIO	US 77	B BASE	3D	10	93.9	0.54	93.0	94.9
16	REFUGIO	US 77	D SURFACE	1A	8	93.1	0.48	92.6	93.9
16	SAN PATRICIO	US 181	B BASE		16	95.1	1.51	90.3	96.6
16	SAN PATRICIO	US 181	D SURFACE	5D	8	94.1	0.17	93.9	94.3
17	BURLESON	SH 21	B SURFACE		49	93.2	1.49	89.0	95.5
17	BURLESON	SH 36	B SURFACE		20	95.5	1.95	90.8	98.0
17	BURLESON	SH 36	D SURFACE		9	93.3	0.94	92.3	94.8
17	GRIMES	SH 105	D SURFACE		8	94.1	1.15	92.7	96.0
17	GRIMES	SH 6	D SURFACE	7	17	91.2	1.34	88.5	93.3
17	WASHINGTON	US 290	D SURFACE	1	9	94.9	0.84	93.8	96.2
17	WASHINGTON	US 290	B BASE	7	25	94.4	1.49	92.0	97.6
17	WASHINGTON	US 290	B BASE	8	12	93.5	0.76	92.2	94.5

TABLE B-1. CORE RELATIVE DENSITY BASED ON RICE MAXIMUM SPECIFIC GRAVITY FOR DIFFERENT PROJECTS (Gc/Gr), (CONTINUED)

DIST	COUNTY	PROJECT	TYPE	DESIGN #	N	AVG. %	STD. %	MIN. %	MAX. %
17	WASHINGTON	US 290	B BASE	10	7	93.9	0.93	92.4	94.9
17	BRAZOS	SH30/OSR	D SURFACE		5	91.6	1.72	89.0	93.4
17	BRAZOS	SH30/21	D SURFACE		5	90.4	1.85	88.0	92.2
17	ROBERTSON	US 79	D SURFACE		6	90.8	1.61	88.3	93.1
17	MADISON	SH 21	D SURFACE		5	93.6	1.05	92.2	95.1
19	CASS	SH 59	D 4 COURSES	1	39	94.4	1.21	92.0	96.6
19	MARION	US 59	D 3 COURSES	2	6	95.8	1.38	93.5	97.5
19	PANOLA	US 59	C BASE	2C	30	93.5	1.05	91.5	96.0
21	CAMERON	FM 1419	D SURFACE	1D	7	92.3	0.77	91.2	93.6
21	HIDALGO	US 83	D SURFACE	1D	8	93.0	0.63	92.1	94.2
23	LAMPASAS	US 190	D SURFACE	1D	21	92.6	1.60	88.9	95.2
23	McCULLOCH	US 87	G SURFACE	1D	5	95.0	0.73	94.0	95.9
			COUNT		57	57	57	57	57
			AVG.		13	93.0	1.23	90.8	94.9
			STD.		9	1.3	0.54	1.9	1.4
			MAX.		49	95.8	3.37	94.0	98.0
			MIN.		5	90.1	0.17	86.0	92.2

TABLE B-2. LOWER AND UPPER LIMITS OF THE TRUE MEAN OF Gc/Gr AT 95% CONFIDENCE LEVEL

DIST	COUNTY	PROJECT	TYPE	DESIGN #	N	AVG. %	STD. %	SSE	T	LOWER LIMIT	UPPER LIMIT
1	FANNIN	US 82	D	LEVEL DS3	14	95.3	1.77	0.47	2.160	94.3	96.3
1	HUNT	SH 50	D	SURFACDS3	9	92.4	1.80	0.60	2.306	91.0	93.8
1	LAMAR	SH 19	C	SURFACDS3	7	93.3	1.15	0.43	2.447	92.2	94.4
3	WHICHITA	US 82	D	SURFAC4	7	93.9	1.51	0.57	2.447	92.5	95.3
5	GARZA	FM 651	D	LEVEL 3	12	92.2	0.38	0.11	2.201	92.0	92.4
5	LUBBOCK	SPUR 326	D	SURFAC1	5	93.1	1.17	0.52	2.776	91.6	94.6
5	LUBBOCK	US 84	D	SURFAC1	12	92.7	1.03	0.30	2.201	92.0	93.4
5	LUBBOCK	US 84	C	SURFAC1	6	93.5	1.09	0.44	2.571	92.4	94.6
5	LUBBOCK	US 84	D	LEVEL 3	6	93.3	1.74	0.71	2.571	91.5	95.1
5	GARZA	US 84	D	SURFAC1	7	91.6	3.37	1.27	2.447	88.5	94.7
10	ANDERSON	US 287	D	SURFACDS3	21	92.3	1.70	0.37	2.086	91.5	93.1
12	GALVESTON	FM 1764	D	LEVEL D1	16	93.7	1.17	0.29	2.131	93.1	94.3
12	MONTGOMERY	FM 1314	D	SURFACDS1	13	91.5	0.65	0.18	2.179	91.1	91.9
12	MONTGOMERY	IH 45	D	SURFACDS1	5	92.3	2.04	0.91	2.776	89.8	94.8
12	TOM GREEN	US 67	D	SURFACE	18	93.9	1.25	0.29	2.110	93.3	94.5
13	FAYETTE	US 77	D	SURFACDW4	11	92.7	1.09	0.33	2.228	92.0	93.4
13	FAYETTE	US 77	D	SURFACDW5	32	92.1	1.33	0.24	2.038	91.6	92.6
13	FAYETTE	US 77	D	SURFACDW6	16	94.0	1.10	0.28	2.131	93.4	94.6
13	GONZALES	SH 80	D	SURFACDS3	22	90.7	1.66	0.35	2.080	90.0	91.4
13	GONZALES	US 87	D	SURFACDS3	11	90.1	1.84	0.55	2.228	88.9	91.3
13	JACKSON	SH 111	D	SURFAC86-	21	90.6	1.89	0.41	2.086	89.7	91.5
13	LAVACA	SH 95	D	SURFACDW5	37	93.1	1.82	0.30	2.030	92.5	93.7
14	BASTROP	SH 21	C	SURFAC1	5	91.8	0.76	0.34	2.776	90.9	92.7
14	BASTROP	SH 21	C	SURFAC2	10	91.4	0.89	0.28	2.262	90.8	92.0
14	BASTROP	SH 71	D	SURFAC2	12	91.8	0.77	0.22	2.201	91.3	92.3
14	BLANCO	US 281	C	SURFACDS3	9	92.6	1.70	0.57	2.306	91.3	93.9
14	LEE	US 290	C	SURFAC1	6	92.6	0.79	0.32	2.571	91.8	93.4
14	TRAVIS	IH35-MAIN	C	SURFACDS3	15	92.2	1.07	0.28	2.145	91.6	92.8
14	TRAVIS	IH35-FRNTGE	C	SURFACDS3	15	91.8	1.00	0.26	2.145	91.2	92.4
16	JIM WELL	US 281	C	SURFAC4	14	94.2	0.90	0.24	2.160	93.7	94.7
16	JIM WELL	US 281	C	SURFAC6	7	92.4	0.38	0.14	2.447	92.0	92.8
16	NUECES	SH 44	D	SURFACDS1	10	93.7	1.40	0.44	2.262	92.7	94.7
16	REFUGIO	US 77	B	BASE 1	14	94.3	0.98	0.26	2.160	93.7	94.9
16	REFUGIO	US 77	B	BASE 3D	10	93.9	0.54	0.17	2.262	93.5	94.3
16	REFUGIO	US 77	D	SURFAC1A	8	93.1	0.48	0.17	2.365	92.7	93.5
16	SAN PATRICIUS	181	B	BASE	16	95.1	1.51	0.38	2.131	94.3	95.9
16	SAN PATRICIUS	181	D	SURFAC5D	8	94.1	0.17	0.06	2.365	94.0	94.2
17	BURLESON	SH 21	B	SURFACE	49	93.2	1.49	0.21	2.010	92.8	93.6
17	BURLESON	SH 36	B	SURFACE	20	95.5	1.95	0.44	2.093	94.6	96.4
17	BURLESON	SH 36	D	SURFACE	9	93.3	0.94	0.31	2.306	92.6	94.0
17	GRIMES	SH 105	D	SURFACE	8	94.1	1.15	0.41	2.365	93.1	95.1
17	GRIMES	SH 6	D	SURFAC7	17	91.2	1.34	0.32	2.120	90.5	91.9
17	WASHINGTON	US 290	D	SURFAC1	9	94.9	0.84	0.28	2.306	94.3	95.5
17	WASHINGTON	US 290	B	BASE 7	25	94.4	1.49	0.30	2.060	93.8	95.0
17	WASHINGTON	US 290	B	BASE 8	12	93.5	0.76	0.22	2.201	93.0	94.0

TABLE B-2. LOWER AND UPPER LIMITS OF THE TRUE MEAN OF Gc/Gr AT 95% CONFIDENCE LEVEL (CONTINUED

DIST	COUNTY	PROJECT	DESIGN TYPE	N	AVG. %	STD. %	SSE	T	LOWER LIMIT	UPPER LIMIT
17	WASHINGTON	US 290	B BASE 10	7	93.9	0.93	0.35	2.447	93.0	94.8
17	BRAZOS	SH30/OSR	D SURFACE	5	91.6	1.72	0.77	2.776	89.5	93.7
17	BRAZOS	SH30/21	D SURFACE	5	90.4	1.85	0.83	2.776	88.1	92.7
17	ROBERTSON	US 79	D SURFACE	6	90.8	1.61	0.66	2.571	89.1	92.5
17	MADISON	SH 21	D SURFACE	5	93.6	1.05	0.47	2.776	92.3	94.9
19	CASS	SH 59	D 4 COUR1	39	94.4	1.21	0.19	2.024	94.0	94.8
19	MARION	US 59	D 3 COUR2	6	95.8	1.38	0.56	2.571	94.4	97.2
19	PANOLA	US 59	C BASE 2C	30	93.5	1.05	0.19	2.042	93.1	93.9
21	CAMERON	FM 1419	D SURFAC1D	7	92.3	0.77	0.29	2.447	91.6	93.0
21	HIDALGO	US 83	D SURFAC1D	8	93.0	0.63	0.22	2.365	92.5	93.5
23	LAMPASAS	US 190	D SURFAC1D	21	92.6	1.60	0.35	2.086	91.9	93.3
23	McCULLOCH	US 87	G SURFAC1D	5	95.0	0.73	0.33	2.776	94.1	95.9
			COUNT	57	57	57	57	57	57	57
			AVG.	13	93.0	1.23	0.38	2.31	92.1	93.9
			STD.	9	1.3	0.54	0.21	0.23	1.58	1.33
			MAX.	49	95.8	3.37	1.27	2.78	94.6	97.2
			MIN.	5	90.1	0.17	0.06	2.01	88.1	91.3

TABLE B-3. CONFIDENCE TOLERENCES AT 95% CONFIDENCE LEVEL THAT A RANDOM DENSITY MEASUREMENT LIES BETWEEN THE GIVEN LIMITS, (CONTINUED)

DIST	COUNTY	PROJECT	TYPE	DESIGN #	N	AVG. %	STD. %	T	LOWER LIMIT	UPPER LIMIT
1	FANNIN	US 82	D LEVEL UP	DS3	14	95.3	1.77	2.160	91.3	99.3
1	HUNT	SH 50	D SURFACE	DS3	9	92.4	1.80	2.306	88.0	96.8
1	LAMAR	SH 19	C SURFACE	DS3	7	93.3	1.15	2.447	90.3	96.3
3	WHICHITA	US 82	D SURFACE	4	7	93.9	1.51	2.447	89.9	97.9
5	GARZA	FM 651	D LEVEL UP	3	12	92.2	0.38	2.201	91.3	93.1
5	LUBBOCK	SPUR 326	D SURFACE	1	5	93.1	1.17	2.776	89.5	96.7
5	LUBBOCK	US 84	D SURFACE	1	12	92.7	1.03	2.201	90.3	95.1
5	LUBBOCK	US 84	C SURFACE	1	6	93.5	1.09	2.571	90.5	96.5
5	LUBBOCK	US 84	D LEVEL UP	3	6	93.3	1.74	2.571	86.5	98.1
5	GARZA	US 84	D SURFACE	1	7	91.6	3.37	2.447	82.8	100.0
10	ANDERSON	US 287	D SURFACE	DS3	21	92.3	1.70	2.086	88.7	95.9
12	GALVESTON	FM 1764	D LEVEL UP	D1	16	93.7	1.17	2.131	91.1	96.3
12	MONTGOMERY	FM 1314	D SURFACE	DS1	13	91.5	0.65	2.179	90.0	93.0
12	MONTGOMERY	IH 45	D SURFACE	DS1	5	92.3	2.04	2.776	86.1	98.5
12	TOM GREEN	US 67	D SURFACE		18	93.9	1.25	2.110	91.2	96.6
13	FAYETTE	US 77	D SURFACE	DW4	11	92.7	1.09	2.228	90.2	95.2
13	FAYETTE	US 77	D SURFACE	DW5	32	92.1	1.33	2.038	89.3	94.9
13	FAYETTE	US 77	D SURFACE	DW6	16	94.0	1.10	2.131	91.6	96.4
13	GONZALES	SH 80	D SURFACE	DS3	22	90.7	1.66	2.080	87.2	94.2
13	GONZALES	US 87	D SURFACE	DS3	11	90.1	1.84	2.228	85.8	94.4
13	JACKSON	SH 111	D SURFACE	86-184	21	90.6	1.89	2.086	86.6	94.6
13	LAVACA	SH 95	D SURFACE	DW5	37	93.1	1.82	2.030	89.4	96.8
14	BASTROP	SH 21	C SURFACE	1	5	91.8	0.76	2.776	89.5	94.1
14	BASTROP	SH 21	C SURFACE	2	10	91.4	0.89	2.262	89.3	93.5
14	BASTROP	SH 71	D SURFACE	2	12	91.8	0.77	2.201	90.0	93.6
14	BLANCO	US 281	C SURFACE	DS3	9	92.6	1.70	2.306	88.5	96.7
14	LEE	US 290	C SURFACE	1	6	92.6	0.79	2.571	90.4	94.8
14	TRAVIS	IH35-MAIN	C SURFACE	DS3	15	92.2	1.07	2.145	89.8	94.6
14	TRAVIS	IH35-FRNTGE	C SURFACE	DS3	15	91.8	1.00	2.145	89.6	94.0
16	JIM WELL	US 281	C SURFACE	4	14	94.2	0.90	2.160	92.2	96.2
16	JIM WELL	US 281	C SURFACE	6	7	92.4	0.38	2.447	91.4	93.4
16	NUECES	SH 44	D SURFACE	DS1	10	93.7	1.40	2.262	90.4	97.0
16	REFUGIO	US 77	B BASE	1	14	94.3	0.98	2.160	92.1	96.5
16	REFUGIO	US 77	B BASE	3D	10	93.9	0.54	2.262	92.6	95.2
16	REFUGIO	US 77	D SURFACE	1A	8	93.1	0.48	2.365	91.9	94.3
16	SAN PATRICIO	US 181	B BASE		16	95.1	1.51	2.131	91.8	98.4
16	SAN PATRICIO	US 181	D SURFACE	5D	8	94.1	0.17	2.365	93.7	94.5
17	BURLESON	SH 21	B SURFACE		49	93.2	1.49	2.010	90.2	96.2
17	BURLESON	SH 36	B SURFACE		20	95.5	1.95	2.093	91.3	99.7
17	BURLESON	SH 36	D SURFACE		9	93.3	0.94	2.306	91.0	95.6
17	GRIMES	SH 105	D SURFACE		8	94.1	1.15	2.365	91.2	97.0
17	GRIMES	SH 6	D SURFACE	7	17	91.2	1.34	2.120	88.3	94.1
17	WASHINGTON	US 290	D SURFACE	1	9	94.9	0.84	2.306	92.9	96.9
17	WASHINGTON	US 290	B BASE	7	25	94.4	1.49	2.060	91.3	97.5
17	WASHINGTON	US 290	B BASE	8	12	93.5	0.76	2.201	91.8	95.2

TABLE B-3. CONFIDENCE TOLERENCES AT 95% CONFIDENCE LEVEL THAT A RANDOM DENSITY MEASUREMENT LIES BETWEEN THE GIVEN LIMITS

DIST	COUNTY	PROJECT	TYPE	DESIGN #	N	AVG. %	STD. %	T	LOWER LIMIT	UPPER LIMIT
17	WASHINGTON	US 290	B BASE	10	7	93.9	0.93	2.447	91.5	96.3
17	BRAZOS	SH30/OSR	D SURFACE		5	91.6	1.72	2.776	86.4	96.8
17	BRAZOS	SH30/21	D SURFACE		5	90.4	1.85	2.776	84.8	96.0
17	ROBERTSON	US 79	D SURFACE		6	90.8	1.61	2.571	86.3	95.3
17	MADISON	SH 21	D SURFACE		5	93.6	1.05	2.776	90.4	96.8
19	CASS	SH 59	D 4 COURSES	1	39	94.4	1.21	2.024	91.9	96.9
19	MARION	US 59	D 3 COURSES	2	6	95.8	1.38	2.571	92.0	99.6
19	PANOLA	US 59	C BASE	2C	30	93.5	1.05	2.042	91.3	95.7
21	CAMERON	FM 1419	D SURFACE	1D	7	92.3	0.77	2.447	90.3	94.3
21	HIDALGO	US 83	D SURFACE	1D	8	93.0	0.63	2.365	91.4	94.6
23	LAMPASAS	US 190	D SURFACE	1D	21	92.6	1.60	2.086	89.2	96.0
23	McCULLOCH	US 87	G SURFACE	1D	5	95.0	0.73	2.776	92.8	97.2
				COUNT	57	57	57	57	57	57
				AVG.	13	93.0	1.23	2.31	90.0	96.0
				STD.	9	1.3	0.54	0.23	2.16	1.69
				MAX.	49	95.8	3.37	2.78	93.7	100.0
				MIN.	5	90.1	0.17	2.01	82.8	93.0

TABLE B.4. PROBABILITIES THAT A RANDOM DENSITY MEASUREMENT LIES BETWEEN 92 AND 97 PERCENTS

DIST.	COUNTY	PROJECT	TYPE	N	AVG.(%)	T	PROB.(%)
1	FANNIN	US 82	D	14	95.3	1.77	78.1
1	HUNT	SH 50	D	9	92.4	1.80	56.9
1	LAMAR	SH 19	C	7	93.3	1.15	84.3
3	WHICHITA	US 82	D	7	93.9	1.51	83.3
5	GARZA	FM 651	D	12	92.2	0.38	69.5
5	LUBBOCK	SPUR 326	D	5	93.1	1.17	79.2
5	LUBBOCK	US 84	D	12	92.7	1.03	74.5
5	LUBBOCK	US 84	C	6	93.5	1.09	87.9
5	LUBBOCK	US 84	D	6	93.3	1.74	71.6
5	GARZA	US 84	D	7	91.6	3.37	37.6
10	ANDERSON	US287	D	21	91.6	1.70	40.6
12	GALVESTON	FM 1764	D	16	93.7	1.17	91.1
12	MONTGOMERY	FM 1314	D	13	91.5	0.65	22.7
12	MONTGOMERY	IH 45	D	5	92.3	2.04	51.8
12	TOM GREEN	US 67	D	18	93.9	1.25	91.6
13	FAYETTE	US 77	D	11	92.7	1.09	73.2
13	FAYETTE	US 77	D	32	92.1	1.33	53.0
13	FAYETTE	US 77	D	16	94.0	1.10	94.9
13	GONZALES	SH 80	D	22	90.7	1.66	22.0
13	GONZALES	US 87	D	11	90.1	1.84	16.1
13	JACKSON	SH 111	D	21	90.6	1.89	23.2
13	LAVACA	SH 95	D	37	93.1	1.82	70.7
14	BASTROP	SH 21	C	5	91.8	0.76	40.4
14	BASTROP	SH 21	C	10	91.4	0.89	25.8
14	BASTROP	SH 71	D	12	91.8	0.77	40.0
14	BLANCO	US 281	C	9	92.6	1.70	61.9
14	LEE	US 290	C	6	92.6	0.79	76.1
14	TRAVIS	IH 35MAN	C	15	92.2	1.07	57.3
14	TRAVIS	IH 35FRN	C	15	91.8	1.00	42.2
14	JIM WELL	US 281	C	14	94.2	0.90	98.2
14	JIM WELL	US 281	C	7	92.4	0.38	83.5
16	NUECES	SH 44	D	10	93.7	1.40	85.2
16	REFUGIO	US 77	B	14	94.3	0.98	97.5
16	REFUGIO	US 77	B	10	93.9	0.54	99.7
16	REFUGIO	US 77	D	8	93.1	0.48	97.4
16	SAN PATRIO	US 181	B	16	95.1	1.51	85.8
16	SAN PATRIO	US 181	D	8	94.1	0.17	99.8
17	BURLESON	SH 21	B	49	93.2	1.49	78.2
17	BURLESON	SH 35	B	20	95.5	1.95	73.1
17	BURLESON	SH 35	D	9	93.3	0.94	89.7
17	GRIMES	SH 105	D	8	94.1	1.15	92.7
17	GRIMES	SH 6	D	17	91.2	1.34	27.9
17	WASHINGTON	US 290	D	9	94.9	0.84	97.9
17	WASHINGTON	US 290	B	25	94.4	1.49	89.4
17	WASHINGTON	US 290	B	12	93.5	0.76	96.4
17	WASHINGTON	US 290	B	7	93.9	0.93	95.2
17	BRAZOS	SH 30/OSR	D	5	91.6	1.72	40.0
17	BRAZOS	SH 30/21	D	5	90.4	1.85	20.8
17	ROBERTSON	US 79	D	6	90.8	1.61	24.0

TABLE B.4. PROBABILITIES THAT A RANDOM DENSITY MEASUREMENT LIES BETWEEN 92 AND 97 PERCENTS

DIST.	COUNTY	PROJECT	TYPE	N	AVG.(%)	T	PROB.(%)
17	MADISON	SH 21	D	5	93.6	1.05	89.0
19	CASS	SH 59	D	39	94.4	1.21	95.5
19	MARION	US 59	D	6	95.8	1.38	77.2
19	PANOLA	US 59	C	30	93.5	1.05	91.8
21	CAMERON	FM 1419	D	7	92.3	0.77	64.6
21	HIDALGO	US 83	D	8	93.0	0.63	92.3
23	LAMPASAS	US 190	D	21	92.6	1.60	63.9
23	McCULLOGH	US 87	G	5	95.0	0.73	97.5

TABLE B-5. DESIGN AND EXTRACTED ASPHALT CONTENTS AND DIFFERENCES BETWEEN THEM FOR DIFFERENT PROJECTS

DIST	COUNTY	PROJECT	TYPE	DESIGN #	N	DESIGN % AC	EXT AC AVG	EXT AC STD	DES-EXT AVG	DES-EXT STD
1	FANNIN	US 82	D LEVEL UP	DS3	57	5.6	5.5	0.34	0.1	0.31
1	HUNT	SH 50	D SURFACE	DS3	29	5.6	5.3	0.27	0.3	0.26
1	LAMAR	SH 19	C SURFACE	DS3	26	5.3	5.3	0.08	0.0	0.08
1	LAMAR	US 82	D SURFACE	1	5	5.8	5.6	0.15	0.2	0.15
2	TARRANT	FM 1886	G SURFACE	631	10	7.6	7.5	0.34	0.1	0.34
2	TARRANT	IH 20	G SURFACE	662	11	5.4	5.2	0.21	0.2	0.21
3	CLAY	US 287	D LEVEL UP	1	15	4.8	4.8	0.22	0.0	0.15
3	WHICHITA	US 82	D SURFACE	4	18	5.1	4.9	0.16	0.2	0.16
4	CARSON	US 60	D SURFACE	1	8	4.8	4.8	0.09	0.0	0.09
4	CARSON	US 60	D LEVEL UP	9	6	5.2	5.3	0.31	0.0	0.28
5	GARZA	FM 651	D LEVEL UP	3	48	4.2	4.3	0.22	0.0	0.26
5	HOCKLEY	FM 300	D SURFACE	2	15	4.8	5.1	0.16	-0.3	0.10
5	LUBBOCK	SPUR 326	D SURFACE	1	14	6.7	6.6	0.17	0.1	0.13
5	LUBBOCK	US 84	D SURFACE	1	19	4.7	4.6	0.17	0.1	0.17
5	LUBBOCK	US 84	C SURFACE	1	9	4.5	4.4	0.25	0.1	0.25
5	LUBBOCK	US 84	D LEVEL UP	3	12	5.0	4.8	0.10	0.2	0.10
5	GARZA	US 84	D SURFACE	1	7	5.1	5.2	0.46	-0.1	0.16
8	NOLAN	IH 20	D SURFACE	1	6	5.5	5.6	0.22	-0.2	0.23
8	NOLAN	IH 20	D LEVEL UP		20	5.5	5.6	0.25	-0.1	0.24
8	TAYLOR	IH 20	D SURFACE	1	12	5.8	5.9	0.23	-0.1	0.23
8	TAYLOR	US 83	D SURFACE	DS3	24	4.7	4.8	0.22	-0.1	0.22
10	ANDERSON	US 287	D SURFACE	DS3	25	5.4	5.4	0.17	0.1	0.17
12	GALVESTON	FM 1764	D LEVEL UP	D1	19	5.2	4.9	0.35	0.3	0.35
12	GALVESTON	FM 1764	D LEVEL UP	D2-3	11	4.9	5.0	0.35	-0.1	0.36
12	MONTGOMERY	FM 1314	D SURFACE	DS1	28	5.3	5.3	0.27	0.1	0.27
12	MONTGOMERY	IH 45	D SURFACE	DS1	14	5.6	5.2	0.45	0.4	0.45
12	TOM GREEN	FM 388	D SURFACE		5	5.4	5.4	0.25	0.0	0.26
12	TOM GREEN	US 67	D SURFACE		18	5.4	5.6	0.27	-0.2	0.27
13	FAYETTE	US 77	D SURFACE	DW4	8	6.0	6.1	0.18	-0.1	0.18
13	FAYETTE	US 77	D SURFACE	DW5	19	5.5	5.9	0.27	-0.4	0.34
13	FAYETTE	US 77	D SURFACE	DW6	11	6.0	6.0	0.27	0.0	0.27
13	GONZALES	SH 80	D SURFACE	DS3	27	4.7	4.6	0.19	0.1	0.13
13	GONZALES	US 87	D SURFACE	DS3	19	4.7	4.6	0.16	0.1	0.13
13	JACKSON	SH 111	D SURFACE	86-184	35	4.5	4.6	0.17	-0.1	0.17
13	LAVACA	SH 95	D SURFACE	DW5	28	5.7	6.1	0.24	-0.4	0.24
14	BASTROP	SH 21	C SURFACE	1	8	4.5	4.5	0.07	0.0	0.07
14	BASTROP	SH 21	C SURFACE	2	22	4.5	4.5	0.15	0.0	0.15
14	BASTROP	SH 71	D SURFACE	2	27	5.0	5.0	0.25	0.0	0.19
14	BLANCO	US 281	C SURFACE	DS3	23	4.8	4.6	0.30	0.2	0.30
14	LEE	US 290	C SURFACE	1	10	4.9	5.0	0.12	-0.1	0.12
14	TRAVIS	IH 35	A LEVEL UP	2	37	4.3	4.3	0.26	0.0	0.26
14	TRAVIS	IH35-MAIN	C SURFACE	DS3	38	4.8	4.7	0.21	0.1	0.21
14	TRAVIS	IH35-FRONTAGE	C SURFACE	DS3	22	4.7	4.7	0.24	0.1	0.24
16	JIM WELL	US 281	C SURFACE	4	31	4.9	4.9	0.09	0.1	0.09
16	JIM WELL	US 281	C SURFACE	6	14	4.9	4.9	0.08	0.0	0.08
16	NUECES	SH 44	D SURFACE	DS1	17	4.8	4.8	0.11	0.0	0.11
16	REFUGIO	FM 2678	D LEVEL UP		6	5.4	5.3	0.13	0.1	0.12
16	REFUGIO	US 77	B BASE	1	41	4.9	4.8	0.12	0.1	0.10

TABLE B-5. DESIGN AND EXTRACTED ASPHALT CONTENTS AND DIFFERENCES BETWEEN THEM FOR DIFFERENT PROJECTS (CONT'D)

DIST	COUNTY	PROJECT	TYPE	DESIGN #	N	DESIGN % AC	EXT AC AVG	EXT AC STD	DES-EXT AVG	DES-EXT STD
16	REFUGIO	US 77	B BASE	3D	19	4.8	4.7	0.07	0.1	0.07
16	REFUGIO	US 77	D LEVEL UP	1	7	5.4	5.3	0.06	0.1	0.06
16	REFUGIO	US 77	D SURFACE	1A	14	5.5	5.5	0.15	0.0	0.11
16	SAN PATRICIO	US 181	B BASE		25	4.5	4.5	0.14	0.0	0.12
16	SAN PATRICIO	US 181	D SURFACE	5D	11	5.0	5.0	0.03	0.0	0.03
17	BRAZOS	FM 2818	D SURFACE		10	5.8	5.8	0.34	0.0	0.34
17	BRAZOS	SH 21	D SURFACE	1	13	5.8	5.7	0.27	0.1	0.26
17	BURLESON	SH 21	B SURFACE		26	5.6	5.5	0.21	0.1	0.27
17	BURLESON	SH 36	B SURFACE		6	5.6	5.5	0.26	0.1	0.26
17	BURLESON	SH 36	D SURFACE		7	5.8	5.5	0.17	0.3	0.17
17	GRIMES	SH 105	D SURFACE		5	5.1	4.9	0.55	0.2	0.40
17	GRIMES	SH 6	D SURFACE	5	12	5.8	5.7	0.25	0.1	0.25
17	GRIMES	SH 6	D SURFACE	7	9	5.8	5.5	0.12	0.3	0.12
17	WASHINGTON	US 290	D SURFACE	1	10	4.2	4.2	0.08	0.0	0.10
17	WASHINGTON	US 290	B BASE	7	33	3.7	3.7	0.12	0.1	0.12
17	WASHINGTON	US 290	B BASE	8	16	3.7	3.6	0.25	0.1	0.25
17	WASHINGTON	US 290	B BASE	10	17	3.7	3.8	0.30	-0.1	0.28
17	WASHINGTON	US 290	D SURFACE		5	6.2	5.9	0.35	0.3	0.35
17	BRAZOS	SH30/OSR	D SURFACE		6	5.4	5.6	0.79	-0.1	0.60
17	BRAZOS	SH30/21	D SURFACE		10	5.3	5.0	0.71	0.3	0.33
17	ROBERTSON	US 79	D SURFACE		5	6.1	5.8	0.59	0.3	0.56
17	MADISON	SH 21	D SURFACE		5	6.0	6.0	0.24	0.0	0.24
18	DALLAS	IH 635	C LEVEL UP	2449-B	37	4.5	4.4	0.19	0.1	0.19
18	NAVARRO	FM 1603	G BASE/SURF	G3	19	4.6	4.6	0.16	0.0	0.16
19	CASS	SH 59	D 4 COURSES	1	44	4.8	4.7	0.23	0.1	0.23
19	MARION	US 59	D 3 COURSES	2	13	5.7	5.6	0.33	0.1	0.33
19	PANOLA	US 59	C BASE	2C	57	4.6	4.7	0.31	-0.1	0.31
20	TYLER	US 69	G SURFACE	1	37	4.7	4.6	0.15	0.1	0.14
21	CAMERON	FM 1419	D SURFACE	1D	14	5.0	5.1	0.05	-0.1	0.35
21	HIDALGO	US 83	D SURFACE	1D	13	4.0	4.0	0.07	0.1	0.07
21	STARR	FM 755	D SURFACE	1D	20	4.8	4.7	0.46	0.1	0.09
23	BROWN	FM 45	D SURFACE		6	4.0	4.0	0.12	0.0	0.08
23	BROWN	US 67	D SURFACE		7	3.9	3.9	0.10	0.0	0.10
23	EASTLAND	IH 20	D SURFACE	1	18	4.1	4.1	0.12	0.0	0.10
23	EASTLAND	IH 20	D SURFACE	4	6	4.0	4.1	0.12	-0.1	0.12
23	LAMPASAS	US 190	D SURFACE	1D	25	5.1	5.2	0.17	-0.1	0.11
23	McCULLOCH	US 87	G SURFACE	1D	7	3.9	3.9	0.22	0.0	0.22
24	CULBERSON	US62/180	D SURF/LEVEL		50	5.0	4.9	0.28	0.0	0.24
				COUNT	86	86	86	86	86	86
				AVG.	18	5.1	5.0	0.23	0.0	0.21
				STD.	12	0.7	0.7	0.14	0.1	0.11
				MAX.	57	7.6	7.5	0.79	0.4	0.60
				MIN.	5	3.7	3.6	0.03	-0.4	0.03

TABLE B-6. DUST TO AC RATIO FOR DIFFERENT PROJECTS

PROJECT	MIX TYPE	DUST/AC	Gc/Gr	PROJECT	MIX TYPE	DUST/AC	Gc/Gr
D1FNUS82	D	1.00	95.3	D14TIH35F	C	1.43	91.8
D1HUSH50	D	1.17	92.4	D16JUS28	C	0.84	94.2
D1LMSH19	C	0.87	93.3	D16JUS28B	C	0.78	92.4
D3WUS82	D	0.84	93.9	D16NSH44	D	0.65	93.7
D5GAFM65	D	0.30	92.2	D16RUS77B	B	0.60	94.3
D5LSP326	D	0.42	93.1	D16RUS77B	B	0.60	93.9
D5LUUS84	D	0.50	92.7	D16RUS77S	D	0.98	93.1
D5LUUS84	C	0.50	93.5	D16SPU18B	B	0.76	95.1
D5LUUS84	D	0.52	93.3	D16SPU18S	B	0.80	94.1
D5GAUS84	D	0.71	91.6	D17BUS21	B	1.11	93.2
D8NI20L	D	1.00	93.9	D17BSH36T	B	1.35	95.5
D10AMU28	D	0.80	92.3	D17BSH36T	D	0.95	93.3
D12GFM17	D	0.88	93.7	D17GS105	D	1.12	94.1
D12MFM13	D	1.26	91.5	D17GSH6B	D	0.64	91.2
D12MIH45	D	0.69	92.3	D17WUS29D	D	1.43	94.9
D12TGU67	D	1.00	93.9	D17WUS29B	B	0.89	94.4
D13FAU77	D	0.62	92.7	D17WUS29B	B	0.86	93.5
D13FAU77	D	1.12	92.1	D17WUS29B	B	1.29	93.9
D13FAU77	D	0.72	94.0	D17BSORCO	D	0.57	91.6
D13GOSH8	D	0.76	90.7	D17B21COM	D	0.62	90.4
D13GOU87	D	0.74	90.1	D17R79COM	D	0.67	90.8
D13JAS11	D	1.48	90.6	D17MS21CO	D	0.78	93.6
D13LAS95	D	1.21	93.1	D19CUS59	D	0.77	94.4
D14BSH21	C	0.82	91.8	D19MUS59	C	0.41	95.8
D14BSH21	C	1.00	91.4	D19PUS59	C	1.21	93.5
D14BSH71	D	1.30	91.8	D21CFM14	D	0.35	92.3
D14BUS28	C	0.98	92.6	D21HUS83	D	0.52	93.0
D14LUS29	C	0.48	92.6	D23LU190	D	0.88	92.6
D14TIH35	C	1.00	92.2	D23MUS87	GR4	1.69	95.0

TABLE B-7. PROJECTS WITH DUST TO AC RATIO LESS THAT 0.6

PROJECT	MIX TYPE	DUST/AC	Gc/Gr
D5GAFM65	D	0.30	92.2
D5LSP326	D	0.42	93.1
D5LUUS84D	D	0.50	92.7
D5LUUS84C	C	0.50	93.5
D5LUUS84L1	D	0.52	93.3
D14LUS29	C	0.48	92.6
D16RUS77B1	B	0.60	94.3
D16RUS77B2	B	0.60	93.9
D17BSORCOM	D	0.57	91.6
D19MUS59	C	0.41	95.8
D21CFM14	D	0.35	92.3
D21HUS83	D	0.52	93.0

TABLE B-8. PROJECTS WITH DUST TO AC RATIO GREATER THAN 1.2

PROJECT	MIX TYPE	DUST/AC	Gc/Gr
D12MFM13	D	1.26	91.5
D13JAS11	D	1.48	90.6
D13LAS95	D	1.21	93.1
D14BSH71	D	1.30	91.8
D14TIH35F	C	1.43	91.8
D17BSH36T	B	1.35	95.5
D17WUS29D	D	1.43	94.9
D17WUS29B	B	1.29	93.9
D19PUS59	C	1.21	93.5
D23MUS87	GR4	1.69	95.0

TABLE B-9. DUST TO AC RATIO FOR PROJECTS WITH RELATIVE DESNITY (Gc/Gr) LESS THAN 92 PERCENT

PROJECT	MIX TYPE	DUST/AC	Gc/Gr
D5GAUS84	D	0.71	91.6
D12MFM13	D	1.26	91.5
D13GOSH8	D	0.76	90.7
D13GOU87	D	0.74	90.1
D13JAS11	D	1.48	90.6
D14BSH21	C	0.82	91.8
D14BSH21	C	1.00	91.4
D14BSH71	D	1.30	91.8
D14TIH35	C	1.43	91.8
D17GSH6B	D	0.64	91.2
D17BSORC	D	0.57	91.6
D17B21CO	D	0.62	90.4
D17R79CO	D	0.67	90.8

TABLE B-10. DATA ON VMA VALUES AND PERCENT VOIDS FILLED WITH ASPHALT FOR DIFFERENT PROJECTS

DIST	COUNTY	PROJECT	TYPE	DESIGN #	N	VMA DATA AVG.	VMA DATA STD.	VMA DATA MIN.	VMA DATA MAX.	% VOIDS FILLED AVG.	% VOIDS FILLED STD.	% VOIDS FILLED MIN.	% VOIDS FILLED MAX.
1	FANNIN	US 82	D LEVEL UP	DS3	14	16.4	1.65	14.4	20.9	71.8	7.26	52.6	82.5
1	HUNT	SH 50	D SURFACE	DS3	8	18.5	1.73	16.5	21.9	59.6	6.52	50.3	68.6
1	LAMAR	SH 19	C SURFACE	DS3	7	17.4	0.94	15.8	18.4	62.0	4.78	58.2	70.2
3	WHICHITA	US 82	D SURFACE	4	7	16.1	1.45	13.0	17.4	62.8	7.13	57.1	78.5
5	GARZA	US 84	D SURFACE	1	7	19.3	2.68	16.6	23.5	57.7	10.76	40.5	70.3
10	ANDERSON	US 287	D SURFACE	DS3	21	19.5	1.49	17.4	22.7				
12	GALVESTON	FM 1764	D LEVEL UP	D1	15	16.0	1.48	13.5	18.7	61.2	5.03	50.6	70.3
12	MONTGOMERY	FM 1314	D SURFACE	DS1	13	17.0	0.75	16.0	18.3	50.3	2.42	45.0	53.3
12	MONTGOMERY	IH 45	D SURFACE	DS1	5	15.2	1.81	13.4	17.8	49.7	8.37	41.1	61.8
14	BASTROP	SH 21	C SURFACE	1	5	17.1	0.33	16.6	17.4	52.0	3.83	45.3	54.9
14	BASTROP	SH 21	C SURFACE	2	10	17.9	1.82	15.5	22.6	51.9	2.81	48.0	56.2
14	BASTROP	SH 71	D SURFACE	2	12	18.6	0.70	17.2	19.4	55.9	2.84	51.6	61.2
14	BLANCO	US 281	C SURFACE	DS3	9	16.5	1.15	15.1	18.7	55.5	7.04	40.1	65.2
14	TRAVIS	IH35-FRONT	C SURFACE	DS3	15	16.9	1.01	15.3	18.8	51.6	3.15	46.3	55.2
19	CASS	SH 59	D 4 COURSES	1	39	15.0	1.27	12.3	18.1	62.8	5.29	53.4	72.6
23	LAMPASAS	US 190	D SURFACE	1D	21	16.6	1.40	14.1	20.3	55.5	5.30	45.4	66.9
				COUNT	16	16	16	16	16	15	15	15	15
				AVG.	13	17.1	1.35	15.2	19.7	57.4	5.50	48.4	65.8
				STD.	9	1.3	0.56	1.6	2.0	6.1	2.36	5.7	8.8
				MAX.	39	19.5	2.68	17.4	23.5	71.8	10.76	58.2	82.5
				MIN.	5	15.0	0.33	12.3	17.4	49.7	2.42	40.1	53.3

TABLE B-11. DIFFERENT GRADATION INDICES FOR PROJECTS FOR WHICH Gc/Gr IS AVAILABLE

PROJECT	MIX TYPE	Gc/Gr	R-EDGE	RN	PI	AI
D17BSH36TB	B	95.5	0.63	1.79	-0.95	-11.90
D17BUS21	B	93.2	0.66	1.87	-0.72	-8.40
D17WUS29B3	B	93.9	0.60	1.71	-0.49	-5.40
D16SPU18B	B	95.1	0.63	1.81	-0.25	-2.90
D17WUS29B1	B	94.4	0.62	1.78	-0.27	-3.20
D17WUS29B2	B	93.5	0.62	1.76	-0.12	-1.30
D16RUS77B1	B	94.3	0.56	1.59	0.30	2.20
D16RUS77B2	B	93.9	0.57	1.62	0.23	1.80
D14TIH35FR	C	91.8	0.54	1.55	-0.04	-0.20
D16JUS28	C	94.2	0.57	1.62	0.07	0.60
D14BSH21	C	91.8	0.45	1.28	1.00	6.80
D14TIH35ML	C	92.2	0.64	1.82	-0.21	-2.30
D19MUS59	C	95.8	0.62	1.78	0.08	1.00
D14LUS29	C	92.6	0.50	1.44	0.91	6.20
D5LUUS84C	C	93.5	0.54	1.54	0.84	6.10
D14BUS28	C	92.6	0.62	1.78	-0.15	-1.50
D19PUS59	C	93.5	0.59	1.70	-0.33	-3.10
D16JUS28B	C	92.4	0.55	1.57	0.09	0.80
D1LMSH19	C	93.3	0.53	1.50	-0.01	-0.10
D14BSH21B	C	91.4	0.46	1.31	0.96	4.30
D5LUUS84L1	D	93.3	0.52	1.49	1.00	11.30
D5GAFM65	D	92.2	0.47	1.35	1.00	16.60
D17BSH36TD	D	93.3	0.68	1.93	0.11	1.20
D13LAS95	D	93.1	0.61	1.75	0.03	0.20
D17GS105	D	94.1	0.61	1.73	1.00	6.00
D13GOSH8	D	90.7	0.65	1.84	0.66	6.10
D17GSH6B	D	91.2	0.51	1.44	1.00	10.70
D13FAU77C	D	94.0	0.61	1.73	0.66	5.50
D17WUS29D	D	94.9	0.61	1.73	0.49	3.40
D13FAU77	D	92.7	0.57	1.63	1.00	8.20
D3WUS82	D	93.9	0.67	1.93	0.18	2.20
D12TGU67	D	93.9	0.52	1.50	1.00	6.90
D12GFM17	D	93.7	0.65	1.87	0.79	6.10
D16NSH44	D	93.7	0.43	1.22	1.00	13.30
D1HUSH50	D	92.4	0.64	1.82	0.59	3.70
D12MFM13	D	91.5	0.67	1.90	-0.07	-0.70
D17BSORCOM	D	91.6	0.65	1.86	0.51	5.40
D5LUUS84D	D	92.7	0.52	1.50	1.00	12.20
D17B21COM	D	90.4	0.61	1.76	0.86	7.50
D5LSP326	D	93.1	0.56	1.60	1.00	9.90
D17R79COM	D	90.8	0.64	1.82	0.46	4.60
D13GOU87	D	90.1	0.64	1.84	1.00	9.10
D17MS21COM	D	93.6	0.59	1.69	0.78	5.70
D13FAU77B	D	92.1	0.61	1.74	0.35	2.40
D19CUS59	D	94.4	0.49	1.40	1.00	9.90

TABLE B-11. DIFFERENT GRADATION INDICES FOR PROJECTS FOR WHICH Gc/Gr IS AVAILABLE (CONT'D)

PROJECT	MIX TYPE	Gc/Gr	R-EDGE	RN	PI	AI
D12MIH45	D	92.3	0.67	1.90	0.38	4.20
D10ANU28	D	92.3	0.69	1.98	0.60	5.20
D16RUS77S	D	93.1	0.64	1.82	0.41	3.40
D8NI20L	D	93.9	0.64	1.84	0.56	4.00
D13JAS11	D	90.6	0.60	1.71	0.22	1.60
D21CFM14	D	92.3	0.62	1.77	1.00	10.60
D1FNUS82	D	95.3	0.65	1.85	0.25	2.30
D21HUS83	D	93.0	0.65	1.85	0.75	7.80
D16SPU18S	D	94.1	0.44	1.25	1.00	11.10
D5GAUS84	D	91.6	0.51	1.46	1.00	10.10
D14BSH71	D	91.8	0.53	1.50	1.00	7.30
D23LU190	D	92.6	0.69	1.97	0.89	6.20
D23MUS87	GR4	95.0	0.39	1.11	1.00	7.30

R : R COEFFICIENT SUGGESTED BY EDGE (REF. 13)

Rn : NORMALIZED R COEFFICIENT (R OF GRADATION LINE DIVIDED BY R OF 0.45 LINE)

PI : POSITION INDEX

SOD : SUM OF DIFFERENCES BETWEEN PERCENTS PASSING GRADATION LINE AND 0.45 LINE

TABLE B-12. DIFFERENT GRADATION INDICES FOR PROJECTS FOR WHICH VMA VALUES ARE AVAILABLE

PROJECT	MIX TYP	VMA	R COEF. (EDGE)	Rn	PI	SOD
D14BSH21	C	17.1	0.45	1.28	1.00	6.80
D14TIH35FR	C	16.9	0.54	1.55	-0.04	-0.20
D14BSH21B	C	17.9	0.46	1.31	0.96	4.30
D18DIH63	C	12.7	0.62	1.77	0.09	1.00
D1LMSH19	C	17.4	0.53	1.50	-0.01	-0.10
D14BUS28	C	16.5	0.62	1.78	-0.15	-1.50
D1FNUS82	D	16.4	0.65	1.85	0.25	2.30
D10ANU28	D	19.5	0.69	1.98	0.60	5.20
D5GAUS84	D	19.3	0.51	1.46	1.00	10.10
D12MTH45	D	15.2	0.67	1.90	0.38	4.20
D3WUS82	D	16.1	0.67	1.93	0.18	2.20
D12GFM17	D	16.0	0.65	1.87	0.79	6.10
D12MFM13	D	17.0	0.67	1.90	-0.07	-0.70
D23LU190	D	16.6	0.69	1.97	0.89	6.20
D14BSH71	D	18.6	0.53	1.50	1.00	7.30
D1HUSH50	D	18.5	0.64	1.82	0.59	3.70
D19CUS59	D	15.0	0.49	1.40	1.00	9.90
D18NFM16	G	13.0	0.60	1.71	0.06	0.80

R : R COEFFICIENT SUGGESTED BY EDGE (REF. 13)

Rn : NORMALIZED R COEFFICIENT (R OF GRADATION LINE DIVIDED BY R OF 0.45 LINE)

PI : POSITION INDEX

SOD : SUM OF DIFFERENCES BETWEEN PERCENTS PASSING GRADATION LINE AND 0.45 LINE