DOT/FAA/AR-10/35

Air Traffic Organization
NextGen & Operations Planning
Office of Research and
Technology Development
Washington, DC 20591

Development of Criteria for Using the Superpave Gyratory Compactor to Design Airport Asphalt Pavement Mixtures

October 2011

Final Report

U.S. Department of Transportation
Federal Aviation Administration

U.S. Army Engineer Research
and Development Center

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-10/35		

4. Title and Subtitle	5. Report Date
DEVELOPMENT OF CRITERIA FOR USING THE SUPERPAVE GYRATORY COMPACTOR TO DESIGN AIRPORT ASPHALT PAVEMENT MIXTURES	October 2011
	6. Performing Organization Code
7. Author(s) John F. Rushing	8. Performing Organization Report No.
9. Performing Organization Name and Address U.S. Army Engineer Research and Development Center Geotechnical and Structures Laboratory 3090 Halls Ferry Road Vicksburg, MS 39180-6199	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Air Traffic Organization NextGen & Operations Planning Office of Research and Technology Development Washington, DC 20591	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code AAS-100

15. Supplementary Notes

The Federal Aviation Administration Airport and Aircraft Safety R&D Division COTR was Navneet Garg.

16. Abstract

Asphalt mix design for commercial airports in the United States is performed in accordance with guidelines set forth in the Federal Aviation Administration (FAA) Advisory Circular AC 150/5370-10D, "Standard for Specifying Construction of Airports, Item P-401—Plant Mix Bituminous Pavements." Currently, two methods are used to compact asphalt pavement mixtures used in transportation surfaces. The Marshall method, the standard method for commercial airports, uses an impact device that imparts a repetitive stress to the mixture. The Superpave design method provides a kneading action to compact the mixture under constant strain conditions. Design of asphalt mixtures for airfields has been successfully accomplished using the Marshall method since the 1940s. The Superpave design method was developed and adopted by state departments of transportation beginning in the mid-1990s. Currently, most transportation departments have adopted this concept. Since most of the paving work by the asphalt industry is funded by state departments of transportation and private work (which typically use department of transportation criteria), it is becoming more difficult to find laboratories and contractors that continue to use the Marshall method. Hence, it is important that the Superpave method be adopted for airfield pavements. Prior to adopting Superpave as the primary method, it was necessary to determine the number of gyrations required to provide an adequate compactive effort for airfield pavements.

This study evaluated the number of gyrations for a number of mixtures required to provide a density equal to 75 blows with the Marshall hammer. Since the 75-blow Marshall mixtures had performed well in the past, it was believed that providing a density with the gyratory compactor equal to that obtained with Marshall compaction would be a good way to adopt Superpave and still have confidence of good performance. This report describes the details of the study and provides a recommended number of gyrations with the Superpave gyratory compactor to provide a mixture that will perform similar to the 75-blow Marshall mixture. The study recommended that 70 gyrations are required to produce a mix similar to the 75-blow Marshall mixture. Additional research is also needed to correlate field performance of asphalt mixtures designed using Superpave methodologies.

17. Key Words	18. Distribution Statement
Hot mix asphalt, Asphalt, Superpave, Marshall mix design, Asphalt mixtures, Laboratory compaction	This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	247	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt cement
AR	Asphalt residue
ASTM	American Society of Testing and Materials
BBR	Bending Beam Rheometer
DSR	Dynamic Shear Rheometer
ESAL	Equivalent single-axle load
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
GTM	Gyratory testing machine
HMA	Hot Mix Asphalt
NCHRP	National Cooperative Highway Research Program
PAV	Pressure aging vessel
PG	Performance Grading
RTFO	Rolling thin-film oven
SGC	Superpave gyratory compactor
SHRP	Strategic Highway Research Program
VMA	Voids in mineral aggregate
WES	Waterways Experiment Station

EXECUTIVE SUMMARY

Asphalt mix design for commercial airports in the United States is performed in accordance with guidelines set forth in the Federal Aviation Administration (FAA) Advisory Circular 150/5370-10D, "Standards for Specifying Construction of Airports, Item P-401—Plant Mix Bituminous Pavements." A Marshall mix design procedure is used. Since the highway industry is rapidly converting to Superpave technology for the design of asphalt mix used in highway pavements, it is becoming more difficult to find contractors who are willing to design asphalt mix according to Marshall specifications and will become even more so in the future. The objective of this project was to establish specifications for designing asphalt mixes using the Superpave Gyratory Compactor that provides performance equivalent to the specifications for the Marshall mix designs.

In this study, the aggregate gradations and design binder content for each combination of test variables was selected based on criteria in Advisory Circular 150/5370-10D. Thirty-two aggregate combinations were tested. These combinations included variations in maximum aggregate size (1/2, 3/4, and 1 inch), aggregate type (limestone, granite, and chert gravel), gradation (upper and lower limits of Item P-401 specification band), and percentage of mortar sand (0% and 10%). The Marshall 75-blow manual compaction effort was used to identify the design binder content for each mixture. The design binder content in this study is the asphalt cement content that resulted in a compacted specimen having a density of 96.5% of the maximum theoretical density. This density corresponds to the air content of 3.5%. This air content was selected as the middle of the range of allowable air content (2.8% to 4.2%) in Item P-401. Superpave gyratory compacted specimens were prepared at this design binder content. The number of gyrations required to obtain 96.5% of the maximum theoretical density was determined. Data for all mixtures were then analyzed to identify the target gyration level for designing asphalt mixtures for airfield pavements.

The study recommended N_{design} for 70 gyrations. The N_{design} value should be further researched in laboratory and field studies prior to acceptance in future FAA criteria.

1. INTRODUCTION.

Asphalt mix design for commercial airports in the United States is performed in accordance with guidelines set forth in the Federal Aviation Administration (FAA) Advisory Circular AC 150/5370-10D [1]. A Marshall mix design procedure is used. Since the highway industry is rapidly converting to Superpave technology for the design of asphalt mix used in highway pavements, it is becoming more difficult to find contractors who are willing to design asphalt mix according to Marshall specifications and will become even more so in the future. The objective of this project was to establish specifications for designing asphalt mixes using the Superpave Gyratory Compactor that provides performance equivalent to the specifications for the Marshall mix designs.

1.1 BACKGROUND.

The first asphalt pavement constructed in the United States was in Newark, New Jersey, in 1870 [2]. In the years following, asphalt paving companies emerged and began developing methods for using asphalt binders and aggregate to construct roads. Although construction techniques were frequently revised according to individual experiences, a clear need for standardization of materials and methods was evident [3]. The penetration test was adopted for grading asphalt cements at the same time gradation controls were adopted for aggregate [3]. Subsequently, mixture design methods were developed to utilize paving materials more effectively and to produce quality mixtures. Mixture design methods were developed by the Warren Brothers, Skidmore, and Hubbard-Field. Over the years, other methods for designing asphalt paving mixtures were developed [4].

1.2 ASPHALT MIXTURE DESIGN METHODS.

1.2.1 Marshall Method.

The U.S. Army Corps of Engineers conducted an evaluation of mixture design methods in the 1940s because heavy aircraft loads and increased tire contact pressures were causing airfield pavement failures. The first research efforts were conducted at the U.S. Army Tulsa District [5] in the early 1940s. This study compared several design methods, including the Hubbard-Field, Hveem Stabilometer, Texas Punching Shear, and Skidmore Tests. The results from the study indicated the Hubbard-Field method was most successful at matching laboratory and field density. However, this method relied on a compactor that was suited only for laboratory use because of its large size and load requirements, which could only be imposed using a wheel and gear of large diameter.

Further tests were performed at the U.S. Army Engineer Waterways Experiment Station (WES) in Vicksburg, Mississippi, in 1943 to develop procedures for design and control of asphalt mixtures that could be used in the field [6]. The goal was to provide a simple apparatus for use with the California Bearing Ratio equipment available to Army engineers. Bruce Marshall developed the Marshall method in the late 1930s while employed by the Mississippi State Highway Department [5 and 7]. Originally, the laboratory compaction method consisted of 25 blows with a 10-lb, 18-in. drop hammer followed by application of a 5000-lb static load. The method was later adjusted to 50 drops of the same hammer, and the static load was eliminated.

The results from the laboratory tests showed that the combination of 25 drops of the hammer followed by the 5000-lb static load resulted in approximately 98% of the density obtained by using the 50-drop method. For this reason, field density was specified as meeting 98% of the laboratory density during construction [6]. The Marshall procedure, which employed an impact device to impart repetitive stress to the surface, showed promise and was adaptable for field use. As a result, the Marshall procedure was heavily researched during the mid-1940s at WES. The method was adopted by the U.S. Army Corps of Engineers during World War II with some modifications for designing asphalt paving mixtures for airfield pavements [2]. Modifications to the procedure were made to match laboratory densities with densities of field-compacted pavements.

Field tests performed at WES achieved verification of the design method and the modification of material specifications. Test sections were constructed and trafficked with 15,000-lb wheel loads at 50-psi tire pressure and 37,000- and 60,000-lb wheel loads at 110-psi tire pressure. Pavement distresses were monitored with increasing traffic to determine which mixtures performed satisfactorily. This research was critical to the development of the design and control specifications for airfield pavements. Products included the Marshall stability and flow criteria of a minimum of 500 lb and maximum of 0.2 inch, respectively. Stability requirements ensured the pavement material was stiff enough to withstand applied loads; flow requirements ensured plastic flow did not occur in the pavement.

In the 1950s, aircraft tire pressures increased to range from 200 to 240 psi [5]. These higher pressures, along with heavier aircraft gross weights, caused asphalt pavement failure. Additional research on the Marshall method was implemented to establish parameters to accommodate these aircraft. The results indicated 69 drops of the Marshall compaction hammer provided comparable density to field test sections for mixture design. The number of drops was adjusted to 75 for mixtures to be designed for high tire pressures and heavy gross aircraft loads. The 50- and 75-blow compaction effort continue to be used for both airfield and highway pavements.

Until recently, the Marshall method was widely used for hot mix asphalt (HMA) mixture design in the U.S. for roadways and for airport pavements [8]. The Marshall method is also widely used around the world. Wide-spread use of the Marshall method has been attributed to compaction closely representing field compaction and the ease of application and portability. The Marshall method is the predominant method currently accepted by the FAA and the Department of Defense for HMA mixture design of airport and military airfield pavements, respectively [1 and 9].

Current design procedures for airport pavements incorporate two levels of compaction: 50 blows and 75 blows [1 and 9]. These levels of compaction correspond to anticipated pavement traffic. Pavements with expected heavy wheel loads or high tire pressures are designed with the 75-blow method. The Marshall mixture design method also includes criteria for stability and for flow values for the 75-blow method. Tables 1 and 2 show the current 75-blow Marshall criteria used by the FAA.

Table 1. Item P-401 75-Blow Marshall Design Criteria [1]

Test Property	Pavements Designed for Aircraft Gross Weights of 60,000 lb or More or Tire Pressure of 100 psi or More
Number of blows	75
Stability, pounds (newtons)	≥2150 (9564)
Flow, 0.01 in. (0.25 mm)	10-14
Air voids (%)	2.8-4.2
Percent voids in mineral aggregate (minimum)	See table 2

Table 2. Item P-401 75-Blow Marshall Design Minimum Voids in Mineral Aggregate Requirements

Maximum Particle Size		Minimum Voids in Mineral Aggregate (%)
(in.)	(mm)	
1/2	12.5	16
3/4	19.0	15
1	25.0	14

1.2.2 Superpave Method.

The majority of HMA in the U.S. is used for highway pavements; the implementation of the Superpave design procedure by state departments of transportation has resulted in most asphalt testing laboratories dedicating training and equipment to the Superpave methods. The airport pavement community recognizes the need to adapt current construction specifications to include a Superpave method. The Superior Performing Asphalt Pavement (Superpave) mix design procedure was developed as a result of research funded under the Strategic Highway Research Program (SHRP), which was completed in the mid-1990s [10]. The concept included a new approach to binder grading, adoption of comprehensive aggregate requirements, new aggregate gradations, new laboratory compactor, volumetric requirements, and moisture sensitivity requirements [10]. A new mix design procedure was sought to provide a balance between competing problems of durability, cracking, and rutting associated with asphalt pavement performance. The laboratory compaction used to replicate field compaction was a major influence on designing durable, rut-resistant pavements because compaction is directly related to the binder content. Therefore, selection of the Superpave compactor was important.

1.2.3 Use of Superpave Method in Highway Pavements.

In studies of laboratory compaction devices, various types of compaction equipment were evaluated [11]. From these studies, benefits of gyratory compactors were recognized, and the Superpave gyratory compactor (SGC) was adopted. This compaction device was developed based on tests with the Texas gyratory compactor, French gyratory compactor, California Kneading Compactor, U.S. Army Corps of Engineers Gyratory Testing Machine (GTM), and the rolling wheel compactor. These studies concluded that gyratory or kneading compaction replicated volumetric properties of field cores taken from highway pavements. The SGC design adopted for Superpave used features of the above compactors.

The SGC procedure included a gyratory angle of 1°, ram pressure of 600 kPa (87 psi), and rotation speed of 30 rpm [10]. Each factor contributes to the densification of the asphalt mixture independently. This combination of variables with reasonable numbers of gyrations produced levels of compaction in the laboratory comparable to field compaction.

Studies were also performed to compare HMA densification in different SGC compactors adjusted to equivalent settings. Von Quintus conducted a study comparing an SGC built by the Rainhart Corporation, a U.S. Army Corps of Engineers GTM, and a modified Texas gyratory compactor [12]. One aggregate gradation was selected and prepared using a single asphalt cement source. The binder content was selected to include the design binder content (from the Marshall method) as well as 1% above and below this value. A plot was made of the percent of maximum theoretical density versus log gyrations for each mixture and for each compactor. The slope of the compaction curve and the densities at 10 and 230 gyrations were analyzed. These data indicated the compactors exhibited different rates of compaction and significantly different densities. Differences between the SGC and the modified Texas gyratory compactor were attributed to measured differences in the external angle of gyration during compaction. The modified Texas gyratory compactor external angle was 0.97°, while the SGC had an external gyration angle of 1.14°. Variations in the U.S. Army Corps of Engineers GTM were attributed to the variation in the number of fixed rotation points in the machine. The GTM was fixed at two points, while the modified Texas gyratory compactor and the SGC were fixed at three points. Data revealed that a difference in gyration angle of 0.02° would result in a change in the design binder content of 0.15%. This range was deemed acceptable, and the tolerance for the gyration angle was determined to be from 0.98° to 1.02°.

Another study was initiated to examine the effect of gyration angle at various levels of the number of design revolutions, N_{design} [13]. In the study, N_{design} was selected to produce a compacted target air void content. During the study, a mistake was discovered. Samples used for determining N_{design} were compacted using a gyration angle of 1.25° instead of the intended 1° angle. However, further experiments indicated the 1° angle of gyration did not provide sufficient compaction for some asphalt mixtures [10]. In addition, changing the external gyration angle to 1.25° produced comparable densities to field compaction. The requirement for the external gyration angle was subsequently changed to a range from 1.23° to 1.27° [10].

In 1994, the Federal Highway Administration (FHWA) approved two compactors, the Pine Instruments Company model AFGC125X and the Troxler Electronic Laboratories, Inc., model 4140 for use in the Superpave design procedure [14 and 15]. A comparison of these compactors by the Asphalt Institute, along with a prototype Rainhart compactor and the modified Texas gyratory compactor, was conducted using six asphalt mixtures. SGC compaction was achieved using 600-kPa ram pressure, 1.25° external gyration angle, and N_{design} of 100 gyrations [16]. Results from this study revealed that the Pine and Texas gyratory compactors produced comparable densities, and the Troxler and Rainhart gyratory compactors produced comparable densities. However, the Pine produced significantly higher densities than the Troxler compactor in five of the six mixtures.

In the above study, an external gyration angle of 1.25° was used. The external angle was measured by the compactor using its onboard measurement system. The internal angle of gyration is generally accepted to be lower than the external angle of gyration because of the response of the compactor to the reacting force produced by the asphalt mixture. The internal angle of gyration is the angle of the mold wall relative to the top and bottom platens. This angle produces the actual shearing characteristic of the Superpave gyratory compactor. The internal gyration angle can be measured using a device referred to as the Dynamic Angle Verification Kit [17]. Measurements of the internal gyration angle have been conducted to correlate this value to sample density. Dalton [18] found that changing the internal gyration angle by 0.1° would result in a 0.6% to 0.7% change in the air void content of the sample. Prowell [19] reported that a 0.1° change in the internal gyration angle could result in a 0.4% change in the air void content. These results reinforced the concern that the angle of gyration during compaction should be maintained at a consistent level to provide uniform results across testing laboratories.

The FHWA conducted a study to determine variability of the internal gyration angle in the Pine and Troxler SGCs [20]. Specimens of 1/2-inch (12.5-mm) Superpave mixtures using a performance grading (PG) 64-22 binder at 4.4% by weight of aggregate were compacted with an external gyration angle of 1.25°. The mean measured internal gyration angle was 1.140° and 1.176°, respectively using the Troxler 4140 SGC and Pine AFGC125X compactors. The study recommended that the target internal gyration angle should be 1.16° with a maximum variability of 0.02°. This value and tolerance was selected so that both machines shared a common range.

An original N_{design} table was developed by the Asphalt Institute through SHRP-A-408 Task F of SHRP contract A001 [10]. The goal of the task was to determine the number of gyrations producing equivalent densities of both as-constructed (92% of theoretical maximum density) and in-service (96% of theoretical maximum density) pavements. Sites were selected to include cold, moderate, and hot climates. Upper- and lower-pavement layers were cored to determine volumetric properties. These data, along with traffic data from each location, were used in the analyses. Aggregate was recovered from the samples through extraction of the binder. The aggregate was mixed with virgin asphalt binder and compacted in the SGC to produce a plot of percent of maximum theoretical density versus number of gyrations. Regression equations were developed to correlate N_{design} values with traffic levels for each of the climatic zones. The resulting N_{design} table is shown in table 3. This table has 28 levels of N_{design} based on both environmental and traffic influences. Environmental influences are categorized by the average expected maximum air temperature over 7 days. Traffic influences are categorized by the number of Equivalent Single-Axle Loads (ESAL). The table also includes specifications for $N_{initial}$ and $N_{maximum}$ values. $N_{initial}$ is a value that was included to prevent the use of “tender” mixtures. It was included to ensure that an asphalt mixture does not compact too readily during construction. $N_{maximum}$ is a value that was included to prevent the excessive densification of mixtures. It ensures that a minimum air content (2%) remains in the mixture when compacted to high gyration levels.

Table 3. Original Superpave Gyratory Compaction Efforts

Traffic (ESALs)	Design 7-Day Maximum Air Temperature (°C)											
	<39			39-41			41-43			43-45		
	N_i	N_d	N_m	N_i	N_d	N_m	N_i	N_d	N_m	N_i	N_d	N_m
$<3 \times 10^5$	7	68	104	7	74	114	7	78	121	7	82	127
$<1 \times 10^6$	7	76	117	7	83	129	7	88	138	8	93	146
$<3 \times 10^6$	7	86	134	8	95	150	8	100	158	8	105	167
$<1 \times 10^7$	8	96	152	8	106	169	8	113	181	9	119	192
$<3 \times 10^7$	8	109	174	9	121	195	9	128	208	9	135	220
$<1 \times 10^8$	9	126	204	9	139	228	9	146	240	10	153	253
$\geq 1 \times 10^8$	9	143	235	10	158	262	10	165	275	10	172	288

$N_i = N_{initial}$
N_d - N_{design}
$N_m = N_{maximum}$

The original table was developed from test results on single cores taken from 15 different sites [21]. The limited data set relied on many assumptions to develop the compaction requirements.

In 1999, a laboratory study (National Cooperative Highway Research Program (NCHRP)) was conducted on the effect of compaction levels and volumetric properties [22]. This study addressed several concerns. The compaction levels in the SGC resulted in lower voids in mineral aggregate (VMA) than typically achieved with 75-blow manual Marshall compaction. The lower VMA resulted in a lower binder content. Also, there were no significant differences in compacted density for several N_{design} levels in the original table. The study recommended the American Association of State Highway and Transportation Officials consolidate the table into fewer levels of compaction. An additional goal of the study was to validate the values of $N_{initial}$ and $N_{maximum}$ used in the table. As a result of this study, the compaction table was revised, as shown in table 4.

Table 4. The SGC Compaction Efforts Proposed in NCHRP 9-9 [22]

Design Traffic Level (million ESALs)	Gyration Levels			% G_{mm} at $N_{initial}$	% G_{mm} at $N_{maximum}$
	$N_{initial}$	N_{design}	$N_{maximum}$		
<0.1	6	50	74	<91.5	<98.0
0.1 to <1.0	7	70	107	<90.5	
1.0 to <30.0	8	100	158	<89.0	
>30.0	9	130	212	<89.0	

The NCHRP 9-9(1) study was conducted to verify the revised N_{design} levels in table 4 through monitoring of field sites [21]. Forty field sites were monitored during construction and at 3 months, 6 months, 1 year, and 2 years after construction. The selected pavements included multiple levels of traffic, binder performance grade, aggregate type and gradation, and climatic region. Three cores were extracted within and outside the wheel path at each site during each visit to determine densities over time and to compare to the original laboratory densities. As a result of this study, the compaction effort table was again revised, as shown in table 5.

Table 5. The N_{design} Table Proposed in NCHRP 9-9(1) [21]

20-Year Design Traffic (ESALs)	2-Year Design Traffic (ESALs)	N_{design} for Binders <PG 76-XX	N_{design} for Binders >PG 76-XX or Mixes Placed >4 in. (100 mm) From Surface
<300,000	<30,000	50	NA
300,000 to 3,000,000	30,000 to 230,000	65	50
3,000,000 to 10,000,000	230,000 to 925,000	80	65
10,000,000 to 30,000,000	925,000 to 2,500,000	80	65
>30,000,000	>2,500,000	100	80

In addition to the changes in the levels of N_{design}, it was concluded that $N_{initial}$ and $N_{maximum}$ values were not good indicators of field performance. As a result, it was recommended that $N_{initial}$ and $N_{maximum}$ criteria be dropped. It was also recommended to measure the internal gyration angle instead of the external gyration angle.

A review of state highway department specifications for pavement mixture design indicates that a range of values for N_{design} is currently used. These values have been adjusted by each state to provide better agreement with local experience. While N_{design} levels vary, gyratory compaction parameters are relatively uniform for state agencies. The SGC compaction parameters are summarized below.

- Compactor manufacturer — optional
- Mold size — 6-inch diameter
- Ram pressure — 600 kPa
- External gyration angle — 1.25° ±0.02°, if used
- Internal gyration angle — 1.16° ±0.02°, if used
- Rotational speed — 30 gyrations per minute
- Mixture compaction temperature — dependent on asphalt binder viscosity
- Mold temperature — same as compaction temperature
- Sample height — 4.5 ±0.15 in. (115 ±5 mm)
- N_{design} — Varies by state

1.2.4 Applicability of Superpave to Airport Pavements.

At the conclusion of the SHRP, Newman and Freeman produced a report for the FAA reviewing all SHRP products [23]. With respect to airport pavements, each of 128 SHRP products was analyzed and determined to be (1) not applicable, (2) applicable with major modifications, (3) applicable with minor modifications, or (4) directly applicable. Products involving the Superpave system included aggregate characteristics and gradations, mix design system, gyratory compactor and compaction levels, and binder specification, among others. The gyratory compactor and binder specification were determined to be applicable with minor revisions. Further research was recommended to provide data for determining changes to each product prior to implementation.

In 2004, the FAA developed the Airfield Asphalt Pavement Technology Program to address technology gaps and to provide improved construction guidance for airport asphalt pavements to enhance performance, durability, and cost effectiveness [24]. Portions of the program were dedicated to evaluating Superpave procedures and determining how they could be applied to the design of airport HMA pavement mixtures. For example, Cooley [25] discusses factors that should be addressed before implementing the Superpave methodology. He indicates that the Superpave mix design system can be divided into four distinct steps: (1) selection of materials, (2) selection of gradation, (3) determination of design binder content, and (4) tests for moisture sensitivity. Cooley also states that one of the most distinct differences in the Marshall and Superpave design methods is the compaction device [25]. He recommends that determining the correct compaction parameters of the SGC for designing airport asphalt pavement mixtures will require a thorough analysis of laboratory compaction data for both methods and that the approach to material selection and selection of design binder content in the Superpave system will most likely remain unchanged from current FAA Item P-401 specifications, except for the use of performance-graded asphalt binders. The final step, determining moisture sensitivity, should be investigated using the indirect tensile test to ensure acceptance values correlate well to airport HMA performance.

The FAA has recently produced criteria for using Superpave methodologies for designing airport pavements [26]. These criteria include recommendations for binder performance grade, aggregate gradations, and gyratory compaction levels. The FAA criteria for using the SGC to design asphalt pavement mixtures is shown in table 6.

Table 6. The FAA Superpave Design Criteria [26]

Pavements for Gross Aircraft Weights of 60,000 Pounds or More		
Test Property	Design Criteria for Nominal Maximum Aggregate Size	
	3/4″ (19 mm)	1/2″ (12.5 mm)
Initial number of gyrations ($N_{initial}$)	8	8
Design number of gyrations (N_{design})	85	85
Maximum number of gyrations ($N_{maximum}$)	130	130
Air voids at N_{design}	4.0	4.0
Voids in mineral aggregate at N_{design} %	13.0 min	14.0 min
Voids filled with asphalt at N_{design} %	65-78	65-78

Table 6. The FAA Superpave Design Criteria [26] (Continued)

Pavements for Gross Aircraft Weights of 60,000 Pounds or More		
Test Property	Design Criteria for Nominal Maximum Aggregate Size	
	3/4″ (19 mm)	1/2″ (12.5 mm)
Dust proportion	0.6-1.2	0.6-1.2
Dust proportion (coarser gradations*)	0.6-1.6	0.6-1.6
Fine aggregate angularity	45 min	45 min
$\%G_{mm}$ at $N_{initial}$	≤90.50	≤90.50
$\%G_{mm}$ at $N_{maximum}$	≤98.00	≤98.00

*A coarse gradation is defined as a gradation passing below the restricted zone. The restricted zone is defined in the Asphalt Institute's Manual Superpave, Series 2 (SP-2).

2. BINDER PROPERTIES.

2.1 BINDER SPECIFICATIONS.

Asphalt cement is a product of crude oil distillation. Because the crude sources vary, so do the properties of the asphalt cements. Asphalt binders are characterized according to their consistency to ensure that they will perform as desired at in-service temperatures. There have been several major approaches to characterizing asphalt binder consistency in recent history.

2.1.1 Penetration Grading.

ASTM adopted D 946 in 1947 [27]. The penetration grading procedure, ASTM D 5 [28], measures the depth of penetration of a standard needle loaded with 100-g total mass into an unaged binder at 77°F (25°C) for 5 seconds. Penetration depth is reported in tenths of a millimeter. The grading system specifies a lower limit and upper limit for the range of penetration values required. The desired penetration is selected by climatic region and design traffic. ASTM D 946 includes other consistency, chemical, and residue requirements for various penetration grades [27].

The penetration grading system provided an indication of binder stiffness. However, this indication of stiffness was only reported at one intermediate temperature. No indication of low- or high-temperature stiffness was reported in the ASTM criteria. Additionally, the method relied on empirical pavement performance data for determining which grade was appropriate for use in a given climatic region and for design traffic.

2.1.2 Viscosity Grading.

Viscosity grading was adopted for specifying asphalt paving grade binders in the 1970s [29]. Viscosity grading uses viscosity as the physical property by which binders are categorized. In this system, the kinematic viscosity [30] is measured at 275°F (135°C) and the absolute viscosity [31] is measured at 60°C (140°F). These values represent the approximate lay down temperature of HMA and the approximate maximum pavement surface temperature in service. ASTM D 3381 [32] identifies the viscosity grades and properties for grading asphalts. In this system, viscosity grades are designated as AC or AR. These designations refer to grades of unaged asphalt cement (AC) or aged asphalt residue (AR), respectively. In the AR system, the specification for viscosity is based on measurements from binder that has been aged in a rolling thin-film oven (RTFO) [33].

Viscosity grading provided an indication of viscoelastic properties at two temperatures. However, the method gave no indication of a binder property at low temperatures. The method continued to rely on empirical pavement performance data for selecting grades for the desired use.

The aging procedure used in the method was thought to provide an indication of the increase in stiffness observed during plant mixing, hauling, placement, and compaction. However, no prediction of long-term aging was included.

2.1.3 Performance Grading.

Asphalt PG is a product of the SHRP. The PG system includes physical property measurements at high, intermediate, and low temperatures. The particular properties are selected to correspond with pavement failure mechanisms at these temperatures. The system also includes an aging procedure to predict long-term oxidative degradation of binders.

High temperature measurements are intended to represent mixing through compaction conditions. Specifications ensure binders can be effectively mixed at typical plant temperatures. A rotational viscometer is used to measure the viscoelastic properties of the binder at 275°F (135°C). The rotational viscometer uses larger samples with greater sample thickness to reduce wall effects. The method provides better applicability for both modified and unmodified binders.

Intermediate temperature measurements are intended to represent average high pavement service temperatures. The grading criteria ensure PG binders provide adequate stiffness at these temperatures to resist flow and permanent deformation in the HMA. The Dynamic Shear Rheometer (DSR) is used to measure the viscoelastic properties of the binder to determine how it will react to loading with time and temperature. The DSR measures the complex shear modulus (G^*) and the phase angle (δ) of the material. The ratio of these components is used to determine the Performance Grade.

Low temperature measurements are intended to represent the coldest average daily temperature the pavement will experience. Criteria ensure binders provide adequate flexibility and tensile strength to resist cracking at these temperatures. Because binders are typically too stiff at these temperatures to accurately measure rheological properties, alternate methods were adopted. The Bending Beam Rheometer (BBR) tests how much a binder deflects or creeps under a constant load at a constant low temperature. The instrument uses a solid beam of binder in a three-point configuration for acquiring measurements. Both creep stiffness (S) and an m-value are reported. Creep stiffness is the resistance to creep loading, and the m-value is the change in stiffness with time during loading.

A Direct Tension Test measures the ability of the binder to elongate before fracturing. Desired binders are expected to exhibit ductile failure. Ductile failure occurs in materials that can undergo considerable elongation prior to fracture. They are expected to have greater resistance to thermal cracking. The Direct Tension Tester is used to determine the failure strain (ε_f) of the binder. The failure strain is the change in length divided by the original length and reported as a percentage.

The aging procedures included in the PG system were intended to represent short- and long-term aging. Short-term aging is considered to occur during mixing and compaction at the time traffic is applied; long-term aging represents years of binder aging. Short-term aging is imposed using the RTFO described in the previous section. For long-term aging, specimens from the RTFO are further aged in a Pressure Aging Vessel (PAV) at a temperature and pressure of 212°F (100°C) and 300 psi (2.1 MPa), respectively, for 20 hours.

The PAV uses high pressure and high temperature designed to rapidly oxidize the binder. Samples from the PAV are then tested using the DSR, BBR, and Direct Tension Tester. The test results are used to determine the binder PG.

The PG system was developed to grade binders for characteristics during production, construction, and long-term performance. The system also evaluates binder properties at extreme service temperatures to examine potential for typical pavement failure mechanisms. The PG system applies to both unmodified and modified binders.

2.2 AGGREGATE PROPERTIES.

Aggregates by both mass and volume represent the major component of HMA and have a significant effect on the properties of the compacted mixture. Aggregates are classified according to their properties. Aggregate properties such as shape, gradation, and type, along with binder type and grade affect HMA compactability and performance. The following aggregate properties are considered when selecting aggregates for use in HMA.

2.2.1 Gradation.

Aggregate gradation is the distribution of particle sizes expressed as a percent of the total weight. Aggregate sizes are fractioned by a set of standard sieves. The largest size particles used in a mixture are typically determined by the thickness of the layer of asphalt concrete. Gradations that give the densest particle packing typically provide increased stability through a greater number of contact points and reduced VMA. Aggregates for airport asphalt pavements typically have dense gradations.

Numerous research efforts have been devoted to correlating aggregate gradation to HMA performance. Studies have been made on the effects of gradation on Marshall stability [34 and 35], creep [34], split tensile strength [34], resilient modulus [34], fatigue [36], and permanent deformation [37]. Elliot, et al. [34], determined that poorly graded aggregates produce the lowest creep stiffness and Marshall stability values. Poorly graded aggregates were considered those crossing from the fine-to-coarse or the coarse-to-fine side of the maximum density line. They also determined that Marshall stability increased for fine-graded mixtures. Moore and

Welke [35] found that mixture gradations near the maximum density curve had higher Marshall stability values. Krutz and Sebaaly [37] determined that finer gradations were more resistant to permanent deformation. In general, aggregate gradations that were poorly graded had poorer mechanical properties than those that were well graded and approached the maximum density of the aggregates.

Current FAA criteria require the gradations listed in table 7. Figures 1 through 3 show each gradation plotted on a 0.45 power curve along with the maximum density gradation. Gradations above the maximum density gradation are typically considered fine gradations; gradations below the maximum density gradation are typically considered coarse gradations.

Table 7. Item P-401 Aggregate Gradation Specifications [1]

Sieve Size	Percentage by Weight Passing Sieves		
	1″ maximum	3/4″ maximum	1/2″ maximum
1 1/2 in. (37.5 mm)	--	--	--
1 in. (24.0 mm)	100	--	--
3/4 in. (19.0 mm)	76-98	100	--
1/2 in. (12.5 mm)	66-86	79-99	100
3/8 in. (9.5 mm)	57-77	68-88	79-99
No. 4 (4.75 mm)	40-60	48-68	58-78
No. 8 (2.36 mm)	26-46	33-53	39-59
No. 16 (1.18 mm)	17-37	20-40	26-46
No. 30 (0.600 mm)	11-27	14-30	19-35
No. 50 (0.300 mm)	7-19	9-21	12-24
No. 100 (0.150 mm)	6-16	6-16	7-17
No. 200 (0.075 mm)	3-6	3-6	3-6

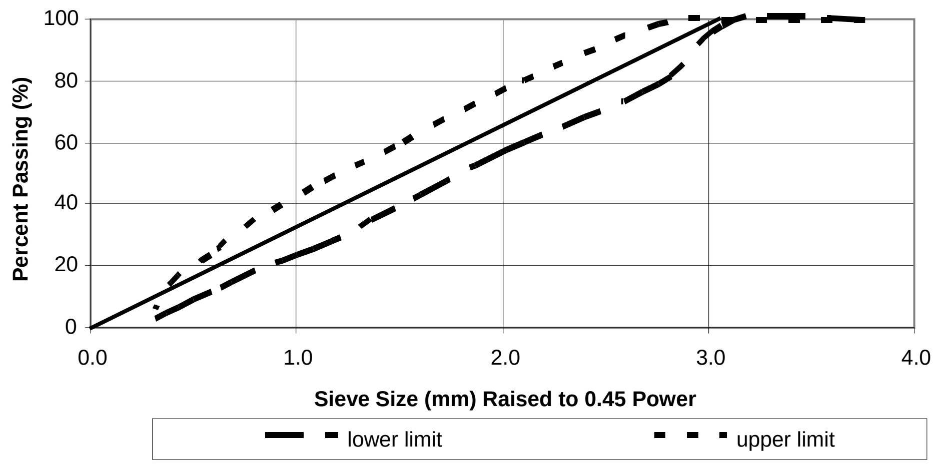


Figure 1. The FAA Gradation Band for 1/2-Inch Maximum Aggregate Size

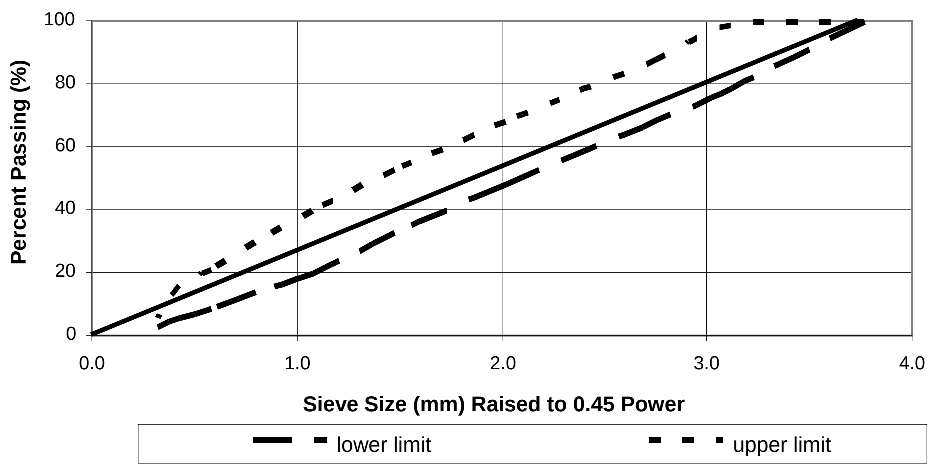


Figure 2. The FAA Gradation Band for 3/4-Inch Maximum Aggregate Size

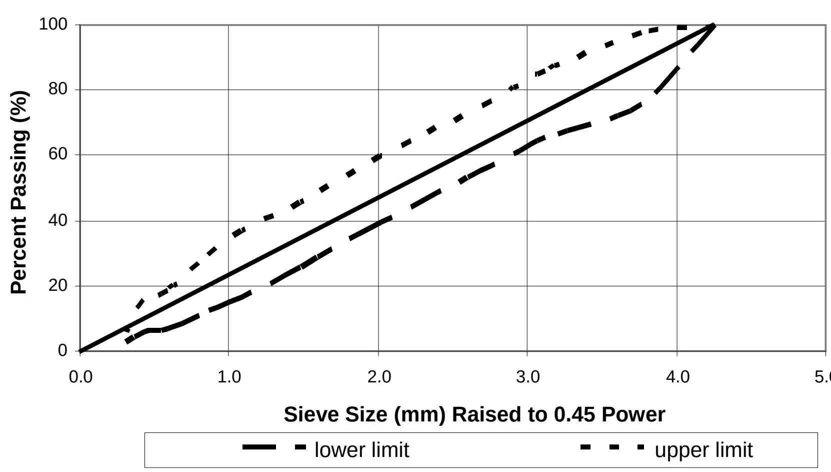


Figure 3. The FAA Gradation Band for 1-Inch Maximum Aggregate Size

2.2.2 Shape.

Aggregate particle shape refers to the form and contour of the individual aggregate particles [27]. The preferred aggregate shape is cubical with mechanically fractured faces. Flat and elongated aggregates should be limited in HMA mixtures. Angular particles provide greater particle interlock and mechanical stability.

Wedding and Gaynor [38] conducted a study to evaluate the effect of mechanically crushed particles in dense-graded asphalt concrete mixtures. Marshall properties of mixtures containing varying percentages of crushed and uncrushed aggregate were analyzed. They concluded that mixtures with crushed particles produced higher Marshall stability values than mixtures with uncrushed aggregates.

Field [39] determined that Marshall stability values were higher for compacted mixtures containing higher percentages of crushed versus uncrushed aggregates. He determined that the air void content and VMA increased when higher percentages of crushed versus uncrushed aggregates were used at a given binder content.

Gaudette and Welke [40] conducted a study to determine the effect of crushed faces on the stability of HMA mixtures. They concluded that the Marshall stability of compacted mixtures significantly increased when the percentage of crushed aggregate was increased from 0% to 50%.

The FAA controls HMA aggregate shape with tests measuring the percentage of fractured particles; the percentage of flat, elongated, or flat and elongated particles; and the fine aggregate angularity. For coarse aggregate, the percentage of crushed faces is determined by ASTM D 5821 [41]. The FAA requires that a minimum of 70% of the coarse aggregate have two or more fractured faces and that 85% of the coarse aggregate must have at least one fractured face. Additionally, ASTM D 4791 [42] provides an indication of geometric symmetry by measuring the percentage of flat, elongated, or flat and elongated aggregates. The FAA restricts the coarse aggregates to a maximum of 8% designated as flat, elongated, or flat and elongated using a 5:1 testing ratio. Fine aggregates are characterized by ASTM C 1252 [43]. This test is referred to as the fine aggregate angularity test. The FAA requires minimum fine aggregate angularity values of 45% for airport pavements.

2.2.3 Natural Sand Content.

Fine aggregates are typically described as being manufactured or natural. Manufactured aggregates are those obtained by crushing larger particles. Natural aggregates are from natural deposits and tend to be rounded in shape. Numerous research studies have been conducted to determine the impact of using natural sands on compacted HMA mixture properties.

Button, et al. [44], conducted a study to relate the effects of natural sand on plastic deformation of asphalt concrete pavements. Natural sand contents for this study included 0%, 5%, 10%, 20%, and 40% by total weight of aggregate. Laboratory tests, including Hveem stability, indirect tension, unconfined compression, static creep, and dynamic creep showed that deformation increased with increasing natural sand content for a given applied load. The study recommended that natural sand be limited to 10% to 15% to reduce rutting.

Ahlrich investigated the effect of natural sand on asphalt mixtures for airport pavements for the FAA [45]. In his study, Marshall stability and flow, indirect tensile, resilient modulus, and unconfined creep tests were used to analyze asphalt mixtures containing 0%, 10%, 20%, and 30% natural sand. The laboratory tests indicated that permanent deformation increased with increasing natural sand content. Recommendations of the study included a limit of 15% natural sand for asphalt mixtures for airport pavements.

In general, natural sand aids in compaction but reduces the strength of mixtures. The presence of excess natural sand is indicated by a "hump" in the gradation curve around the No. 30 sieve size [46]. Efforts to limit the amount of natural sand have included controlling the gradation at specific sieve size and numerical limits on the percentage of natural sand used in a mixture. Current FAA specifications limit the amount of natural sand in a mixture to 15% [1].

2.3 CURRENT FAA REQUIREMENTS FOR COMPACTED ASPHALT MIXTURES.

At the time of construction, HMA mixtures are designed so they have workability and resist permanent deformation, fatigue, low-temperature cracking, and moisture damage. Long-term durability is also important. Mixture criteria that produce these HMA properties have been developed from empirical data and correlations between in-service pavement performance and laboratory compacted specimens. Some of the HMA mixture design criteria ensuring desired HMA performance include VMA, air void content, and Marshall stability and flow.

2.3.1 Volumetric Properties.

Volumetric properties of HMA are determined according to ASTM D 2676 [47]. The weight of a specimen (in air, water, and the saturated surface dry weight) is used to determine the bulk specific gravity. The VMA is determined from the air void content and the aggregate and binder specific gravities. To determine these properties, the maximum theoretical specific gravity must be determined using ASTM D 2041 [48].

2.3.2 Air Void Content.

A traditional compacted HMA specimen consists of aggregate, binder, and air. The volumetric percentage of air in the mixture is dependent upon the aggregate gradation, binder content, and degree of compaction. Excess air in a mixture in the design phase tends to produce a lean mix. The absence of sufficient binder lowers durability by promoting oxidation of the binder and potential moisture damage. With excess air from low compaction during construction, a mixture tends to compact under traffic. On the other hand, insufficient air voids from high asphalt content lead to lateral shear failure and rutting.

In general, at a given compaction level, air void content increases with decreasing percentages of asphalt cement [6]. In the reference 6 study, correlations of laboratory mixture properties to field performance revealed that the design air void content should be approximately 4% for airport HMA pavements. The FAA requires selection of the design binder content so that the air void content is between the range of 2.8% to 4.2%. In many cases, mixtures for the FAA are designed using an air void content of 3.5%, the center of the allowable range. Designing the mixture at 3.5% air voids may lead to the selection of a binder content different from the original Marshall procedure that selected the binder content based on an average of optimum mixture characteristics, including air void content, percent of voids filled, stability, flow, and unit weight.

2.3.3 Voids in Mineral Aggregate.

A mixture's VMA is the volumetric space of the mixture that is not occupied by aggregate. This space includes both air and binder. Restrictions on the VMA have been developed because mixtures are often designed to a target air void content. Limitations on the minimum VMA values ensure that sufficient binder is added to the mix. Current FAA specifications have no maximum limitation on VMA. However, higher VMA typically correlates with higher binder contents and the potential for shear failure and rutting in HMA.

2.3.4 Marshall Stability.

Marshall stability is measured according to ASTM D 6927 [49]. Load is applied parallel to the compacted specimen face at a deformation rate of 2.0 ±0.15 in./min (50 ±5 mm/min). Marshall stability values have been shown to increase with increasing binder content until a peak is reached. At that point, the stability value decreases with further increase in binder content. Marshall stability is affected by aggregate type, gradation, shape, and maximum aggregate size [6]. Marshall stability typically increases with increasing binder content until a peak is reached. Further increases in binder content typically result in lower Marshall stability. The FAA requires a minimum Marshall stability value of 2,150 lb for gross aircraft weights of 60,000 lb or more or for tire pressures of 100 psi or greater.

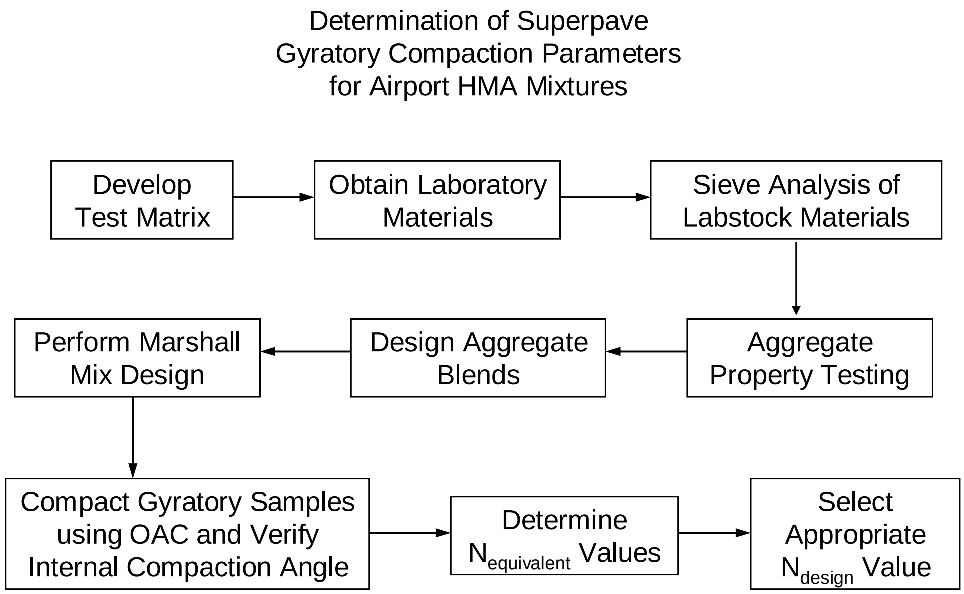
2.3.5 Marshall Flow.

Marshall flow is also measured according to ASTM D 6927 [49]. This property is determined during the same test used to determine the Marshall stability value. Marshall flow values have been shown to increase with increasing binder content [6]. A range of flow values from 10 to 14 is specified by the FAA for aircraft gross weights of 60,000 lb or greater, or for tire pressures of 100 psi or greater, to ensure plastic flow and flushing do not occur.

3. PLAN OF STUDY.

The purpose of this study was to identify Superpave gyratory compaction parameters with which to design HMA mixtures having volumetric properties comparable to those produced using the Marshall 75-blow manual compaction effort. The flow chart in figure 4 shows the research approach in this study.

The aggregate gradations and design binder content for each combination of test variables was selected based on criteria in Advisory Circular 150/5370-10D [1]. The results and discussion in this document include data from asphalt mixtures that meet specifications of the current version of Item P-401 (See tables 1 and 2).



OAC = Optimum Asphalt Content

Figure 4. Research Plan

For this study, 32 aggregate combinations were tested. These combinations included variations in maximum aggregate size (1/2, 3/4, and 1 inch), aggregate type (limestone, granite, and chert gravel), gradation (upper and lower limits of Item P-401 specification band), and percentage of mortar sand (0% and 10%). This experiment included the variables shown in figure 5.

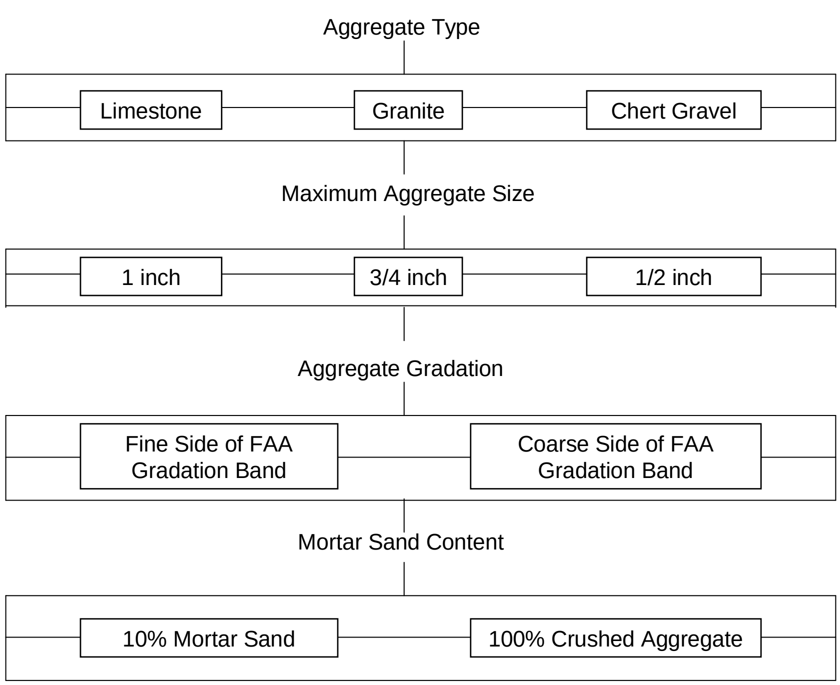


Figure 5. Test Factors

Because the chert gravel and limestone aggregate had a maximum particle size of 3/4 inch, blends meeting the requirements for a 1-inch maximum aggregate size were not evaluated. Additionally, only one gradation of chert gravel aggregate with a 1/2-inch maximum aggregate size was used because variations of the gradation did not meet Marshall stability criteria. The test matrix used in this study is given in table 8.

Table 8. Test Matrix

Aggregate Type	Maximum Aggregate Size (in.)	Gradation	Percentage of Mortar Sand	Binder Grade
Granite	1/2	Fine	0	PG 64-22
			10	PG 76-22
		Coarse	0	PG 64-22
			10	PG 76-22
	3/4	Fine	0	PG 64-22
			10	PG 76-22
		Coarse	0	PG 64-22
			10	PG 76-22
Granite	1	Fine	0	PG 64-22
			10	PG 76-22
		Coarse	0	PG 64-22
			10	PG 76-22
Limestone	1/2	Fine	0	PG 64-22
			10	PG 76-22
		Coarse	0	PG 64-22
			10	PG 76-22
	3/4	Fine	0	PG 64-22
			10	PG 76-22
		Coarse	0	PG 64-22
			10	PG 76-22
Chert gravel	1/2	Center	0	PG 64-22
			10	PG 76-22
	3/4	Fine	0	PG 64-22
			10	PG 76-22
		Coarse	0	PG 64-22
			10	PG 76-22

The Marshall 75-blow compaction effort was used to identify the design binder content for each mixture. The design binder content in this study is the AC content that resulted in a compacted specimen having a density of 96.5% of the maximum theoretical density. This density corresponds to an air content of 3.5%. This air content was selected as the middle of the range of allowable air contents (2.8% to 4.2%) in Item P-401 [1]. Superpave gyratory compacted specimens were prepared at this design binder content. The number of gyrations required to obtain 96.5% of the maximum theoretical density was determined. Data for all mixtures were then analyzed to identify the target gyration level for designing asphalt mixtures for airfield pavements.

4. MATERIALS.

4.1 ASPHALT BINDER.

Two asphalt binders were used in this study. Both were obtained from Ergon Asphalt and Emulsions, Inc. Tests by the distributor indicated the two asphalt binders were a PG 64-22 neat binder and a PG 76-22 polymer-modified binder. Distributor tests indicated both binders had a specific gravity of 1.038. Recommended mixing and compaction temperatures for the PG 64-22 binder were 310°F (154°C) and 290°F (145°C), respectively; and mixing and compaction temperatures for the PG 76-22 binder were 360°F (182°C) and 335°F (168°C), respectively. Mixing and compaction temperatures for the modified binder were higher than those typically used during construction. However, the temperatures used in this study provided equivalent Brookfield viscosities of the binders. Figure 6 shows Brookfield viscosity versus temperature relationships for the two binders.

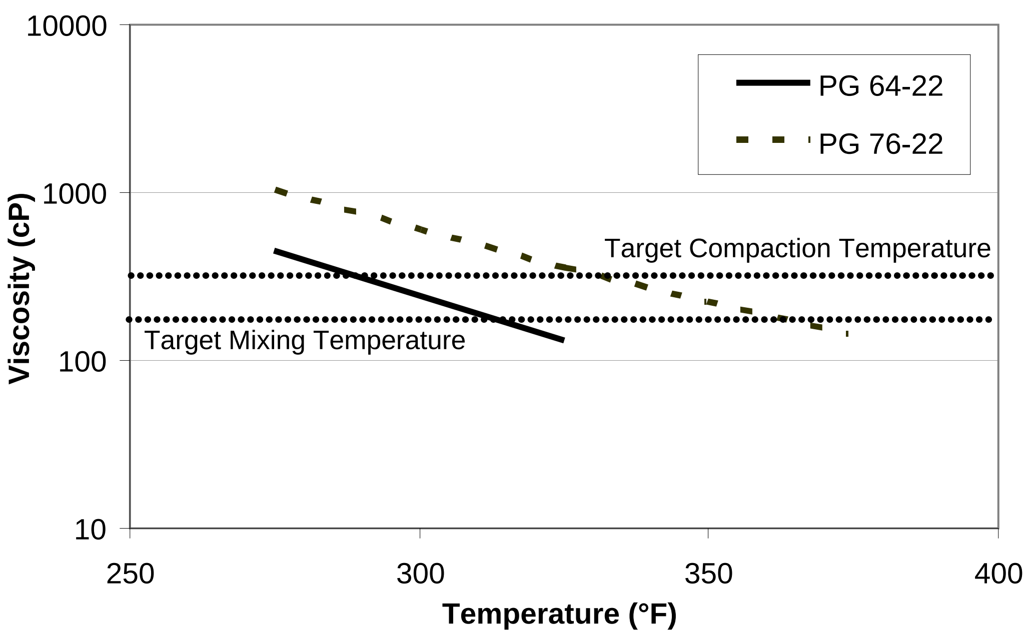


Figure 6. Brookfield Temperature vs Viscosity Curve for Asphalt Binders

4.2 AGGREGATE.

Aggregates used in this study consisted of materials stockpiled at the Engineer Research and Development Center. These included limestone, granite, and chert gravel aggregates. The limestone aggregate was from a Vulcan Materials quarry in Calera, Alabama. The granite aggregate was from a McGeorge Corp. quarry in Little Rock, Arkansas. The chert gravel aggregate was from Green Brothers Gravel Company in Copiah County, Mississippi. Additionally, some mixtures were blended with selected percentages of mortar sand which was locally purchased from Mississippi Materials Corporation. Aggregates were blended to meet the FAA gradations in table 7. Aggregate specific gravity, bulk specific gravity, and water absorption were determined by ASTM C 127 [50] and ASTM C 128 [51] and are listed in tables 9 through 11.

Table 9. Limestone Aggregate Properties

Aggregate Stockpile	Apparent Specific Gravity	Bulk Specific Gravity	Absorption (%)
ASTM #7 stone	2.80	2.75	0.6
ASTM #6 stone	2.79	2.75	0.5
821-1/4″ modified	2.80	2.75	0.5
892 stone sand	2.80	2.76	0.4

Table 10. Granite Aggregate Properties

Aggregate Stockpile (sieve)	Apparent Specific Gravity	Bulk Specific Gravity	Absorption (%)
3/4″	2.65	2.63	0.3
1/2″	2.64	2.61	0.4
3/8″	2.64	2.61	0.4
#4	2.65	2.61	0.5
#8	2.64	2.61	0.3
#16	2.63	2.61	0.4
#30	2.63	2.62	0.1
#50	2.62	2.61	0.3
#100	2.64	2.61	0.4

Table 11. Chert Gravel Aggregate Properties

Aggregate Stockpile (sieve)	Apparent Specific Gravity	Bulk Specific Gravity	Absorption (%)
1/2″	2.61	2.53	1.2
3/8″	2.62	2.50	1.8
#4	2.61	2.50	1.7
#8	2.62	2.49	1.9
#16	2.64	2.54	1.5
#30	2.61	2.53	1.2
#50	2.57	2.48	1.4
#100	2.62	2.50	1.3

Each aggregate type was represented by multiple stockpiles that were blended to meet the target gradations. The limestone aggregate was procured in four stockpiles and were used as received. Blends meeting FAA specifications could be obtained from these four stockpiles. Blends were adjusted to roughly follow the upper or lower limits of the Item P-401 gradation band. The granite aggregate was obtained as a single stockpile. This stockpile was sieved into the nine fractions of the gradation in Item P-401. Prior to sieving, the stockpile was oven-dried at 221°F (105°C) for 24 hours. The individual fractions were blended to meet designed gradations. The chert gravel aggregate was prepared using the same method as the granite aggregate. The individual gradation of aggregate stockpile gradations are shown in tables 12 through 14. Blended gradations and percent of each stockpile are shown in tables 15 through 24. A graphical depiction of the aggregate gradations and the specification limitation is given in appendix A along with other aggregate properties for each blend.

Table 12. Limestone and Mortar Sand Stockpile Gradations

Sieve Size	Percent Passing Limestone Stockpiles				
	ASTM #6 Stone	ASTM #7 Stone	892 Stone Sand	821 1/4″ Modified	Mortar Sand
1″	100	100	100	100	100
3/4″	90	100	100	100	100
1/2″	15	93	100	100	100
3/8″	2	57	100	100	100
#4	1	3	100	98	100
#8	0	1	95	72	100
#16	0	1	65	47	100
#30	0	1	41	31	94
#50	0	1	23	21	32
#100	0	1	10	13	1
#200	0.4	0.5	5.1	9.5	0.6

Table 13. Granite Stockpile Gradations

Sieve Size	Percent Passing Granite Stockpiles								
	3/4″	1/2″	3/8″	#4	#8	#16	#30	#50	#100
1″	100	100	100	100	100	100	100	100	100
3/4″	1	100	100	100	100	100	100	100	100
1/2″	1	8	99	100	100	100	100	100	100
3/8″	1	0	13	100	100	100	100	100	100
#4	1	0	0	6	99	100	100	100	100
#8	1	0	0	0	11	100	100	100	100
#16	1	0	0	0	0	14	100	100	100
#30	1	0	0	0	0	8	13	99	100
#50	1	0	0	0	0	2	2	16	100
#100	1	0	0	0	0	2	2	4	51
#200	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3

Table 14. Chert Gravel Stockpile Gradations

Sieve Size	Percent Passing Chert Gravel Stockpiles							
	1/2″	3/8″	#4	#8	#16	#30	#50	#100
1″	100	100	100	100	100	100	100	100
3/4″	100	100	100	100	100	100	100	100
1/2″	39	100	100	100	100	100	100	100
3/8″	0	14	100	100	100	100	100	100
#4	0	0	15	100	100	100	100	100
#8	0	0	2	19	100	100	100	100
#16	0	0	2	1	16	97	97	100
#30	0	0	2	1	1	25	75	100
#50	0	0	2	1	1	6	23	99
#100	0	0	1	0	1	4	5	44
#200	0.2	0.2	0.9	0.4	1.3	3.5	4.1	19.7

Table 15. Percent of Stockpiles for Limestone Aggregate Blends

Aggregate Blend	Weight Percentage of Limestone Stockpiles Used for Blend				
	ASTM #6 Stone	ASTM #7 Stone	821 1/4″ Modified	892 Stone Sand	Mortar Sand
1/2-inch fine mix	0	26	56	18	0
1/2-inch coarse mix	0	41	50	9	0
3/4-inch fine mix	0	33	51	16	0
3/4-inch coarse mix	17	33	43	7	0
1-inch fine mix	16	26	45	13	0
1-inch coarse mix	34	22	44	0	0
1/2-inch fine mix with mortar sand	0	30	60	0	10
1/2-inch coarse mix with mortar sand	0	38	52	0	10
3/4-inch fine mix with mortar sand	0	42	48	0	10
3/4-inch coarse mix with mortar sand	6	41	43	0	10

Table 16. Limestone Aggregate 1/2-Inch Blend Gradations

Sieve Size	Percent Passing				
	1/2-Inch Fine Mix	1/2-Inch Coarse Mix	1/2-Inch Fine Mix With Mortar Sand	1/2-Inch Coarse Mix With Mortar Sand	P-401 Specification Limits
1″	100	100	100	100	100
3/4″	100	100	100	100	100
1/2″	98	97	98	97	100
3/8″	89	82	87	84	79-99
#4	73	59	69	62	58-78
#8	58	45	53	48	39-59
#16	38	29	38	34	26-46
#30	25	20	28	26	19-35
#50	16	13	16	14	12-24
#100	9	8	8	7	7-17
#200	6.4	5.4	5.9	5.2	3-6

Table 17. Limestone Aggregate 3/4-Inch Blend Gradations

Sieve Size	Percent Passing				
	3/4-Inch Fine Mix	3/4-Inch Coarse Mix	3/4-Inch Fine Mix With Mortar Sand	3/4-Inch Coarse Mix With Mortar Sand	P-401 Specification Limits
1″	100	100	100	100	100
3/4″	100	98	100	99	100
1/2″	98	83	97	92	79-99
3/8″	86	69	82	76	68-88
#4	67	50	58	53	48-68
#8	52	38	45	41	33-53
#16	34	25	33	30	20-40
#30	23	17	28	23	14-30
#50	15	11	13	12	9-21
#100	9	7	7	6	6-16
#200	5.8	4.7	4.8	4.4	3-6

Table 18. Percent of Sieve Sizes for Granite Aggregate Blends

Aggregate Blend	Weight Percentage of Granite Stockpiles Used for Blend									
	3/4″	1/2″	3/8″	#4	#8	#16	#30	#50	#100	Mortar Sand
1/2-inch fine mix	0	0	7	21	19	13	9	13	18	0
1/2-inch coarse mix	0	0	22	19	19	10	8	9	13	0
3/4-inch fine mix	0	5	12	18	16	13	11	11	14	0
3/4-inch coarse mix	0	21	11	17	16	10	7	6	12	0
1-inch fine mix	5	13	11	15	14	8	11	8	15	0
1-inch coarse mix	21	10	12	15	15	7	5	3	12	0
1/2-inch fine mix with mortar sand	0	0	8	22	20	15	6	0	19	10
1/2-inch coarse mix with mortar sand	0	0	21	20	20	13	0	0	16	10
3/4-inch fine mix with mortar sand	0	6	12	18	17	17	4	0	16	10
3/4-inch coarse mix with mortar sand	0	20	11	18	16	10	0	0	15	10
1-inch fine mix with mortar sand	6	13	11	16	15	16	0	0	13	10
1-inch coarse mix with mortar sand	21	8	12	14	13	9	0	0	13	10

Table 19. Granite Aggregate 1/2-Inch Blend Gradations

Sieve Size	Percent Passing				
	1/2-Inch Fine Mix	1/2-Inch Coarse Mix	1/2-Inch Fine Mix With Mortar Sand	1/2-Inch Coarse Mix With Mortar Sand	P-401 Specification Limits
1″	100	100	100	100	100
3/4″	100	100	100	100	100
1/2″	100	100	100	100	100
3/8″	94	81	93	82	79-99
#4	73	60	71	60	58-78
#8	55	42	52	41	39-59
#16	42	32	37	28	26-46
#30	33	24	31	27	19-35
#50	21	15	23	20	12-24
#100	10	8	10	9	7-17
#200	5.6	4.1	5.4	4.6	3-6

Table 20. Granite Aggregate 3/4-Inch Blend Gradations

Sieve Size	Percent Passing				
	3/4-Inch Fine Mix	3/4-Inch Coarse Mix	3/4-Inch Fine Mix With Mortar Sand	3/4-Inch Coarse Mix With Mortar Sand	P-401 Specification Limits
1″	100	100	100	100	100
3/4″	100	100	100	100	100
1/2″	95	81	94	82	79-99
3/8″	85	70	84	71	68-88
#4	66	52	65	52	48-68
#8	51	37	49	37	33-53
#16	38	27	33	27	20-40
#30	28	20	27	25	14-30
#50	16	14	20	19	9-21
#100	8	7	9	8	6-16
#200	4.5	3.8	4.7	4.3	3-6

Table 21. Granite Aggregate 1-Inch Blend Gradations

Sieve Size	Percent Passing				
	1-Inch Fine Mix	1-Inch Coarse Mix	1-Inch Fine Mix With Mortar Sand	1-Inch Coarse Mix With Mortar Sand	P-401 Specification Limits
1″	100	100	100	100	100
3/4″	95	79	94	79	76-98
1/2″	83	70	82	72	66-86
3/8″	73	59	72	61	57-77
#4	57	43	55	46	40-60
#8	44	29	41	34	26-46
#16	35	21	25	25	17-37
#30	25	17	24	23	11-27
#50	17	13	17	17	7-19
#100	9	7	7	7	6-16
#200	4.6	3.7	3.9	3.8	3-6

Table 22. Percent of Sieve Sizes for Chert Gravel Aggregate Blends

Aggregate Blend	Weight Percentage of Chert Gravel Stockpiles Used for Blend								
	1/2″	3/8″	#4	#8	#16	#30	#50	#100	Mortar Sand
1/2-inch fine mix	0	7	21	19	13	9	13	18	0
1/2-inch coarse mix	0	22	19	15	10	11	11	12	0
3/4-inch fine mix	9	12	16	15	12	11	11	14	0
3/4-inch coarse mix	21	11	16	13	11	9	9	10	0
1/2-inch fine mix with mortar sand	0	7	21	21	15	8	0	18	10
1/2-inch coarse mix with mortar sand	0	22	21	18	11	0	0	18	10
3/4-inch fine mix with mortar sand	9	12	18	18	17	0	0	16	10
3/4-inch coarse mix with mortar sand	22	8	19	13	12	0	0	16	10

Table 23. Chert Gravel Aggregate 1/2-Inch Blend Gradations

Sieve Size	Percent Passing				
	1/2-Inch Fine Mix	1/2-Inch Coarse Mix	1/2-Inch Fine Mix With Mortar Sand	1/2-Inch Coarse Mix With Mortar Sand	P-401 Specification Limits
1″	100	100	100	100	100
3/4″	100	100	100	100	100
1/2″	100	100	100	100	100
3/8″	94	81	94	81	79-99
#4	75	62	75	60	58-78
#8	57	47	55	43	39-59
#16	42	36	39	30	26-46
#30	31	24	30	28	19-35
#50	22	16	22	22	12-24
#100	10	7	9	9	7-17
#200	4.8	3.6	4.4	4.1	3-6

Table 24. Chert Gravel Aggregate 3/4-Inch Blend Gradations

Sieve Size	Percent Passing Chert Gravel Aggregate 3/4-Inch Blends				
	3/4-Inch Fine Mix	3/4-Inch Coarse Mix	3/4-Inch Fine Mix With Mortar Sand	3/4-Inch Coarse Mix With Mortar Sand	P-401 Specification Limits
1″	100	100	100	100	100
3/4″	100	100	100	100	100
1/2″	95	87	95	87	79-99
3/8″	81	70	81	71	68-88
#4	65	54	64	54	48-68
#8	51	42	47	41	33-53
#16	38	30	29	28	20-40
#30	26	20	26	26	14-30
#50	18	13	20	20	9-21
#100	8	6	8	8	6-16
#200	4.0	3.1	3.7	3.7	3-6

The percentage of fractured faces [41] and percentage of flat and elongated particles [42] are included in appendix A. The percentages of aggregate with at least two fractured faces were 100%, 100%, and 97% for the limestone, granite, and chert gravel, respectively. The maximum percentages of flat, elongated, and flat and elongated aggregates were 0.2%, 0.4%, and 1.6%, respectively, for the limestone aggregate. Granite and chert gravel aggregates had no flat or elongated particles. The maximum percentages of flat and elongated particles were 1.0% and

0.3% for the granite and chert gravel, respectively. Each of the blends met the requirements (8% maximum) for aggregate properties required by the FAA for airport pavements.

The fine aggregate angularity [43] for the limestone, granite, chert gravel, and mortar sand aggregates was determined by Method A of ASTM C 1252 [43]. The limestone, granite, and chert gravel aggregates had a fine aggregate angularity of 47%, 47%, and 46%, respectively. These values were above the minimum value of 45% required by the FAA for airport pavement aggregates. The fine aggregate angularity of the mortar sand was 40%. This value is characteristic of rounded aggregate particles and is typical for natural sands [52].

For mixture designs, individual batches for each mixture were prepared by weighing the percentages of the target batch weight in tables 15, 18, and 22 for each stockpile or sieve size into a shallow mixing pan. Aggregate batches were placed in an oven overnight at the mixing temperature of the binder prior to performing mix designs.

5. LABORATORY COMPACTION.

5.1 MARSHALL COMPACTION.

The Marshall manual compaction effort produces compacted specimens that are 4 in. (102 mm) in diameter by nominal 2.5 in. (64 mm) high [53]. The procedure is acceptable for compacting bituminous paving mixtures with a maximum aggregate size of 1 in. (25.4 mm) according to ASTM D 6926 [53]. In this study, compaction was achieved with a hand-operated hammer with a flat, circular compaction foot. The hammer has a sliding mass of 10 lb (4.54 kg) and falls a distance of 18 in. (457.2 mm). Other characteristics of the compaction process, including specifications for the compaction pedestal, are given in ASTM D 6926 [53].

In preparation for compaction, the aggregate and binder were heated to the mixing temperature of the asphalt cement. The aggregate was weighed in a mixing bowl and binder was added to achieve the target binder content for the mixture. The sample was mixed using a Univex® commercial mixer until the aggregate was thoroughly coated with binder. The mixture was placed into a preheated compaction mold and stored in the oven at the compaction temperature for 1 hour. The molds were removed from the oven and placed on the compaction pedestal. Seventy-five blows with the compaction hammer were applied to each face of the specimen. The molds containing compacted specimen were placed in front of a fan for 1 hour to cool to room temperature. The compacted specimens were then extracted from the mold and allowed to stand on a flat surface overnight to cool. The bulk density of each specimen was determined according to ASTM D 2726 [47]. Stability and flow values were determined using methods described in ASTM D 6927 [49].

Additional asphalt mixtures were prepared at the design binder content to determine the maximum theoretical specific gravities. This test procedure was performed according to ASTM D 2041 [48]. The maximum theoretical specific gravity at additional AC contents was calculated using equation 1, where G_{mm} is the maximum theoretical specific gravity, P_b is the percentage of asphalt cement, G_b is the bulk specific gravity of the asphalt cement, and G_{se} is the effective specific gravity of the aggregate calculated using equation 2. The maximum theoretical specific gravity at each AC content is required to determine the volumetric properties at each binder content.

$$G_{mm} = \frac{1}{\left(\frac{1-P_b}{G_{se}}\right) + \frac{P_b}{G_b}} \tag{1}$$

$$G_{se} = \frac{1-P_b}{\left(\frac{1}{G_{mm}}\right) - \frac{P_b}{G_b}} \tag{2}$$

Marshall mix designs are conducted by preparing three replicates at increments of 0.5% binder content over a range bracketing the design binder content. The percentage of air voids versus AC content is plotted, and the design binder content is selected at 3.5% air voids. This AC content was the design binder content used in this study for compaction with the Superpave gyratory compactor. FAA Item P-401 criteria for designing asphalt mixtures using the Marshall method are shown in tables 1 and 2.

5.2 SUPERPAVE GYRATORY COMPACTION.

Superpave gyratory compaction of asphalt mixtures encompasses a range of factors that should be optimized to produce a compacted mixture that accurately represents field compaction. Most of these variables have been fixed through the development of the machine. This study was undertaken to provide a procedure for laboratory compaction and design of airport HMA mixtures using the Superpave gyratory compactor that could easily be adopted by design and test laboratories. Most of the above variables can be directly adopted for use in compacting airport HMA mixtures. These included mold size, ram pressure, internal gyration angle, rotational speed, mixture temperature, mold temperature, and sample height. This study used the same standard values, equipment, and procedures used by the highway pavement community. Although the internal gyration angle was not commonly used in practice at the time of this report, it was selected because research studies suggest the internal gyration angle may produce more consistent compaction than the external gyration angle for different compactor manufacturers. The remaining variable in the mixture design procedure that needed to be evaluated was N_{design} and is the focus of the following tests.

For this study, a Pine Instruments Company model AFGC125X gyratory compactor was used to produce cylindrical asphalt concrete specimens with a diameter of 6 in. (152 mm) at a target height of 4.5 in. (115 mm). Compaction was performed using a ram pressure of 87 psi (600 kPa) and a 1.16° ±0.02° internal angle of gyration. Asphalt mixtures were compacted to 125 gyrations at a rate of 30 revolutions per minute. Three replicate specimens were compacted for each mixture. Each asphalt concrete mixture was compacted at the design binder content determined from the Marshall mix design using the same aggregate blend proportions. Specimens were tested according to ASTM D 2726 to determine density.

The Pine gyratory compactor records specimen height after each gyration. The height can be translated to volume because the diameter of the compaction mold remains constant. Since the reduction in volume of the asphalt concrete is known, a compaction curve can be generated to show specimen density increase with number of gyrations. This calculation is based upon the measured bulk specific gravity after compaction. This value is divided by the maximum theoretical specific gravity to determine the air void content. The following variables are used in the subsequent equations:

- G_{mb} = Bulk specific gravity of the compacted asphalt mixture
- G_{mm} = Maximum theoretical specific gravity
- W_m = Weight of the compacted sample
- d = Mold diameter
- h = Sample height
- γ_w = Density of water
- C = Specific gravity correction factor
- $G_{measured}$ = Measured specific gravity of compacted asphalt mixture
- $G_{estimated}$ = Estimated specific gravity of compacted asphalt mixture

The air void content at each gyration level can be calculated using equation 3.

$$\%Air = \left[1 - \left(\frac{G_{mb}}{G_{mm}}\right)\right] \cdot 100 \tag{3}$$

where G_{mb} is the bulk specific gravity at the specified gyration number and is calculated using equation 4

$$G_{mb} = \frac{\left(\frac{4W_m}{\pi \cdot d^2 \cdot h_x}\right)}{\gamma_w} \cdot C \tag{4}$$

where

W_m = weight of compacted sample (g)
π = 3.14159
D = mold diameter (115 mm)
h_x = sample height (mm)
γ_m = density of water (1 g/cm^3)
C = correction factor (equation 5)

$$C = \frac{G_{measured}}{G_{estimated}} \tag{5}$$

$G_{measured}$ is the bulk specific gravity of the compacted sample and $G_{estimated}$ is the estimated specific gravity at N_{design}. $G_{estimated}$ is calculated according to equation 6.

$$G_{estimated} = \frac{\left(\dfrac{4W_m}{\pi \cdot d^2 \cdot h_x}\right)}{\gamma_w} \tag{6}$$

Some state transportation departments compact asphalt mixtures to a specified value of $N_{maximum}$ during the mix design process. The value of $N_{maximum}$ is higher than N_{design} and results in a compacted density that is approximately 98% of the maximum theoretical density. The air content at N_{design} is then calculated using this procedure. However, backcalculated values of air content can vary from measured values. The difference is caused by inaccurate predictions of the void spaces between the asphalt sample and the compaction mold [54]. Some of the volume between the mold and the specimens are external air voids that are not enclosed in the sample and are not measured as part of the volume when using ASTM D 2726. The correction factor in the equation attempts to reduce the error.

Specimens in this study were compacted to 125 gyrations. The maximum gyration level was determined by reviewing state specifications of N_{design}. After this study was initiated, the FAA produced criteria with 85 gyrations as N_{design} (table 6). The maximum gyration level used in this study was expected to produce air void contents lower than the target of 3.5% using the design binder content.

The calculated air content for each specimen was plotted against the number of gyrations to determine the number of gyrations required to compact the specimen to 96.5% of its maximum theoretical specific gravity. This value was determined to be $N_{equivalent}$ for each mixture. This approach is valid, assuming that the design binder content determined from the Marshall method is the appropriate binder content.

6. RESULTS AND DISCUSSION.

6.1 MARSHALL MIXTURE DESIGN RESULTS.

Representative plots of asphalt content, VMA, and Marshall stability and flow versus asphalt content are shown in figures 7 through 10. Summaries of Marshall test results of all mixtures included in the study are presented in tables 25 through 30. Additional information obtained from the Marshall mix designs is located in appendix A.

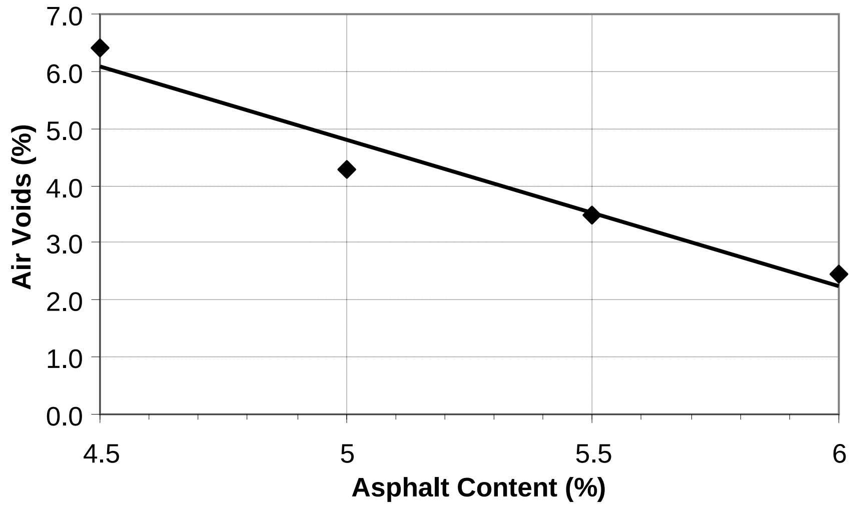


Figure 7. Representative Data for Air Void Content vs Asphalt Content

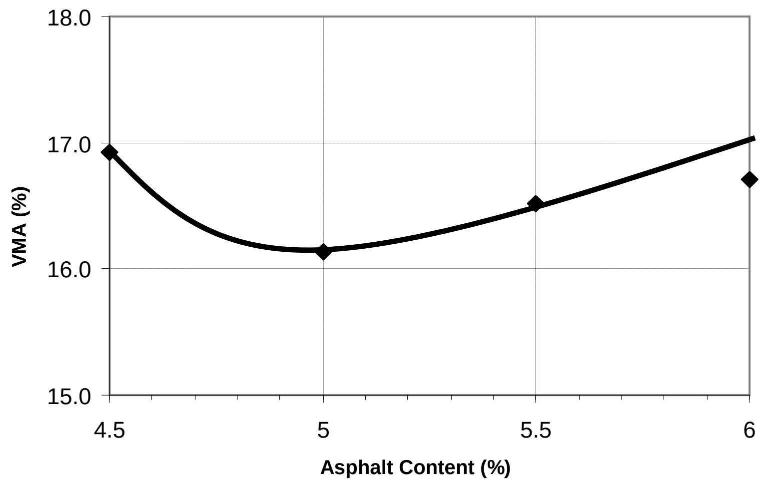


Figure 8. Representative Data for VMA vs Asphalt Content

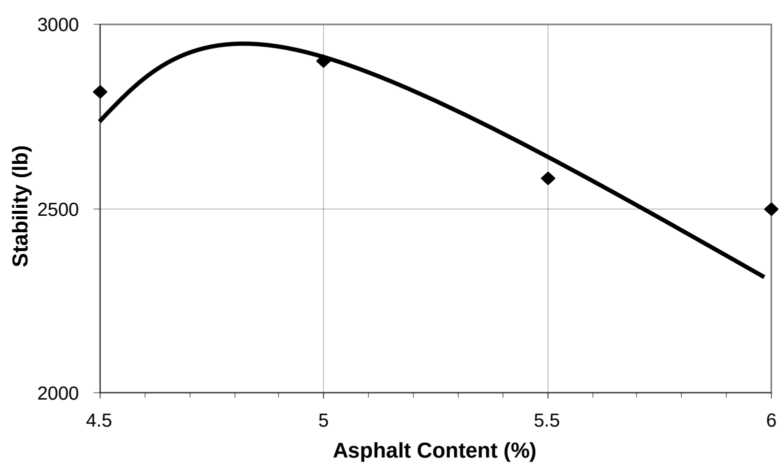


Figure 9. Representative Data for Marshall Stability vs Asphalt Content

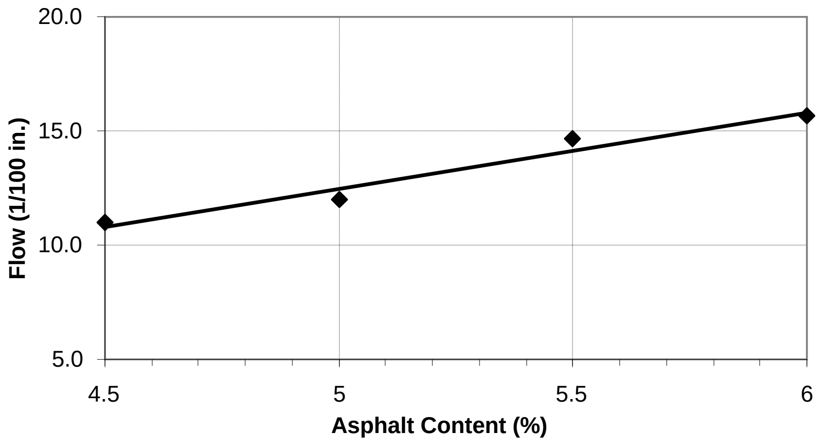


Figure 10. Representative Data for Marshall Flow vs Asphalt Content

Table 25. Marshall Mix Design Results for Limestone Aggregate With PG 64-22 Binder

	Limestone Aggregate					
	1-Inch Coarse Mix	1-Inch Fine Mix	3/4-Inch Coarse Mix	3/4-Inch Fine Mix	1/2-Inch Coarse Mix	1/2-Inch Fine Mix
Asphalt content (%)	--	--	4.8	5.4	5.3	5.5
Bulk specific gravity	--	--	2.50	2.48	2.46	2.46
VMA (%)	--	--	15.5	16.0	16.2	16.5
Stability (lb)	--	--	2710	2500	2480	2850
Flow (0.01 in.)	--	--	11	12	10	10
	Limestone Aggregate With 10% Mortar Sand					
	1-Inch Coarse Mix	1-Inch Fine Mix	3/4-Inch Coarse Mix	3/4-Inch Fine Mix	1/2-Inch Coarse Mix	1/2-Inch Fine Mix
Asphalt content (%)	--	--	5.0	5.1	5.4	5.7
Bulk specific gravity	--	--	2.46	2.46	2.46	2.44
VMA (%)	--	--	15.6	15.8	16.0	16.9
Stability (lb)	--	--	2410	2450	2460	2360
Flow (0.01 in.)	--	--	10	10	11	11

Table 26. Marshall Mix Design Results for Granite Aggregate With PG 64-22 Binder

	Granite Aggregate					
	1-Inch Coarse Mix	1-Inch Fine Mix	3/4-Inch Coarse Mix	3/4-Inch Fine Mix	1/2-Inch Coarse Mix	1/2-Inch Fine Mix
Asphalt content (%)	5.0	5.5	5.4	5.9	5.8	6.8
Bulk specific gravity	2.36	2.34	2.33	2.33	2.33	2.31
VMA (%)	14.8	15.9	15.8	16.8	16.5	18.2
Stability (lb)	2810	2880	2740	2810	2410	2160
Flow (0.01 in.)	10	10	10	10	10	12
	Granite Aggregate With 10% Mortar Sand					
	1-Inch Coarse Mix	1-Inch Fine Mix	3/4-Inch Coarse Mix	3/4-Inch Fine Mix	1/2-Inch Coarse Mix	1/2-Inch Fine Mix
Asphalt content (%)	4.6	5.2	5.1	5.5	5.7	6.3
Specific gravity	2.36	2.35	2.34	2.34	2.33	2.31
VMA (%)	14.1	15.3	15.1	15.8	16.4	17.6
Stability (lb)	2950	2940	2620	2660	2500	2400
Flow (0.01 in.)	12	12	10	11	12	12

Table 27. Marshall Mix Design Results for Chert Gravel Aggregate With PG 64-22 Binder

	Chert Gravel Aggregate				
	1-Inch Coarse Mix	1-Inch Fine Mix	3/4-Inch Coarse Mix	3/4-Inch Fine Mix	1/2-Inch Mix*
Asphalt content (%)	--	--	6.8	7.4	7.2
Bulk specific gravity	--	--	2.24	2.24	2.24
VMA (%)	--	--	18.4	19.1	19.1
Stability (lb)	--	--	2470	2170	2610
Flow (0.01 in.)	--	--	11	12	12
	Chert Gravel Aggregate With 10% Mortar Sand				
	1-Inch Coarse Mix	1-Inch Fine Mix	3/4-Inch Coarse Mix	3/4-Inch Fine Mix	1/2-Inch Mix*
Asphalt content (%)	--	--	5.9	6.2	6.4
Specific gravity	--	--	2.27	2.26	2.27
VMA (%)	--	--	16.3	16.9	17.5
Stability (lb)	--	--	2330	2340	2490
Flow (0.01 in.)	--	--	11	12	11

*Coarse and fine gradations did not meet minimum stability requirements, so only one gradation was used.

Table 28. Marshall Mix Design Results for Limestone Aggregate and PG 76-22 Binder

	Limestone Aggregate					
	1-Inch Coarse Mix	1-Inch Fine Mix	3/4-Inch Coarse Mix	3/4-Inch Fine Mix	1/2-Inch Coarse Mix	1/2-Inch Fine Mix
Asphalt content (%)	--	--	5.1	5.9	5.5	6.0
Bulk specific gravity	--	--	2.46	2.45	2.47	2.42
VMA (%)	--	--	15.8	17.2	16.6	17.8
Stability (lb)	--	--	3900	4300	4300	4000
Flow (0.01 in.)	--	--	15	16	19	20
	Limestone Aggregate with Mortar Sand					
	1-Inch Coarse Mix	1-Inch Fine Mix	3/4-Inch Coarse Mix	3/4-Inch Fine Mix	1/2-Inch Coarse Mix	1/2-Inch Fine Mix
Asphalt content (%)	--	--	4.8	5.1	5.2	5.5
Bulk specific gravity	--	--	2.48	2.46	2.47	2.45
VMA (%)	--	--	15.0	15.5	15.7	16.3
Stability (lb)	--	--	3000	3200	3300	3000
Flow (0.01 in.)	--	--	11	13	12	13

Table 29. Marshall Mix Design Results for Granite Aggregate With PG 76-22 Binder

	Granite Aggregate					
	1-Inch Coarse Mix	1-Inch Fine Mix	3/4-Inch Coarse Mix	3/4-Inch Fine Mix	1/2-Inch Coarse Mix	1/2-Inch Fine Mix
Asphalt content (%)	5.2	6.0	5.5	6.6	6.0	7.5
Bulk specific gravity	2.35	2.32	2.34	2.29	2.33	2.27
VMA (%)	15.2	17.0	15.8	18.4	17.0	20.0
Stability (lb)	3600	3400	3800	3100	4000	2950
Flow (0.01 in.)	14	13	12	12	13	13
	Granite Aggregate With Mortar Sand					
	1-Inch Coarse Mix	1-Inch Fine Mix	3/4-Inch Coarse Mix	3/4-Inch Fine Mix	1/2-Inch Coarse Mix	1/2-Inch Fine Mix
Asphalt content (%)	4.8	5.2	5.1	5.7	5.6	6.5
Specific gravity	2.35	2.36	2.35	2.33	2.33	2.30
VMA (%)	14.5	15.0	15.0	16.2	16.1	18.2
Stability (lb)	3700	4400	3600	3400	3500	3400
Flow (0.01 in.)	11	12	11	12	12	13

Table 30. Marshall Mix Design Results for Chert Gravel Aggregate With PG 76-22 Binder

	Chert Gravel Aggregate				
	1-Inch Coarse Mix	1-Inch Fine Mix	3/4-Inch Coarse Mix	3/4-Inch Fine Mix	1/2-Inch Mix*
Asphalt content (%)	--	--	6.9	7.4	7.1
Bulk specific gravity	--	--	2.25	2.23	2.26
VMA (%)	--	--	18.4	19.4	18.7
Stability (lb)	--	--	3600	3500	3900
Flow (0.01 in.)	--	--	16	17	16
	Chert Gravel Aggregate With Mortar Sand				
	1-Inch Coarse Mix	1-Inch Fine Mix	3/4-Inch Coarse Mix	3/4-Inch Fine Mix	1/2-Inch Mix*
Asphalt content (%)	--	--	5.5	5.9	6.4
Specific gravity	--	--	2.30	2.30	2.27
VMA (%)	--	--	15.1	15.9	17.5
Stability (lb)	--	--	4100	4200	4500
Flow (0.01 in.)	--	--	14	13	15

*Coarse and fine gradations did not meet minimum stability requirements, so only one gradation was used.

The above data indicate similar trends for the design binder content within each aggregate type for mixtures compacted with the Marshall method. Asphalt mixtures with larger maximum aggregate sizes had lower design binder contents than mixtures with smaller maximum aggregate sizes. The design binder content was from 0.3% to 0.6% lower for mixtures with a 1-inch maximum aggregate size than mixtures of the same aggregate type and relative gradation designation with a 3/4-inch maximum aggregate size. The average difference was 0.4% lower. The design binder content was from 0.1% to 0.9% lower for mixtures with a 3/4-inch maximum aggregate size than mixtures of the same aggregate type and relative gradation designation with a 1/2-inch maximum aggregate size. The average difference was 0.5% lower. Also, aggregate gradations on the coarse side of the specification band had lower design binder contents than gradations on the fine side of the specification band. Mixtures on the coarse side of the gradation band had a design binder content from 0.2% to 1.5% lower than mixtures on the fine side of the gradation band, and the average design binder content for mixtures on the coarse side of the gradation band were 0.6% lower than mixtures on the fine side of the gradation band. Each of these phenomena was caused by the relative packing ability of the aggregate in each of the mixtures and higher surface area of finer aggregates. VMA was the major influence on the design binder content for these mixtures. Mixtures with higher VMA required more binder to achieve the target air void content.

As expected, asphalt mixtures containing mortar sand generally had a lower design binder content than similar mixtures using 100% crushed aggregate. Mortar sand increases mixture compactibility leading to lower VMA and design binder content. Mortar sand in mixtures causes the design binder content to vary from an increase of 0.2% to a decrease of 1.5%, with an average decrease of 0.5%. These mixtures cannot be directly compared because of subtle differences in the aggregate gradations. Adding 10% mortar sand generally replaces aggregate fractions within the No. 30 to No. 50 sieve size range but also alters other sizes. The overall aggregate structure is affected and can alter the compacted VMA. Changes in the gradation, particularly in the range from the No. 30 to No. 50 sieve size, are presented in appendix A. However, the trend of the mixtures containing mortar sand to have a lower design binder content is due to the rounded sand particle realignment during compaction.

In general, asphalt mixtures with limestone aggregate had the lowest design binder content, while mixtures using the chert gravel aggregate had the highest design binder content among the three aggregate types. The average design binder content for the limestone, granite, and chert gravel aggregate blends was 5.4%, 5.8%, and 6.5%, respectively. These variations in design binder content were attributed to the differences in the VMA of the compacted mixtures. The average VMA for the limestone, granite, and chert gravel aggregate blends was 16.2%, 16.5%, and 17.5%, respectively. In particular, chert gravel mixtures had a higher VMA than limestone or granite mixtures. The chert gravel is mechanically fractured but also contains uncrushed faces. The particle shape is angular and does not pack as closely as limestone or granite aggregates that are produced by crushing quarried aggregates. The higher void content of the chert gravel aggregate structure required more asphalt to decrease the air content to the desired level for the compacted mixture. The higher VMA for mixtures using this gravel source has been previously noted by Ahlrich [45]. The crushed chert gravel has sharp angles that are resistant to degradation, unlike limestone aggregates that becomes more rounded during compaction.

Some of the asphalt mixtures containing mortar sand did not have initial stability values meeting the current Item P-401 criteria of 2150 lb. These included both the coarse and fine mixtures of chert gravel with a 1/2-inch maximum aggregate size. These mixtures were redesigned using a different aggregate gradation to produce a mixture that would meet P-401 specifications. This change led to elimination of the coarse and fine gradations of the 1/2-inch chert gravel mixture. The single, revised gradation lay along the median of the 1/2-inch gradation band. Mixtures not meeting stability requirements were not included in the data in this report.

The average stability of mixtures containing 100% crushed aggregate was 2580 lb, while the average stability of mixtures containing 10% mortar sand was 2530 lb. These differences are insignificant considering that the two results were within the allowable coefficient of variation (6%) of the testing procedure [49]. However, the presence of mortar sand appeared to impact the compaction behavior of the mixtures, as indicated by a lower VMA for mixtures containing mortar sand.

VMA minimum requirements (1 inch—14%, 3/4 inch—15%, 1/2 inch—16%) were met by all mixtures described in this document. On average, the VMA of mixtures containing mortar sand was approximately 1% lower than similar mixtures containing 100% crushed aggregate. The rounded sand particles enable the aggregates to pack more closely together and reduce the void spaces in the mixture. Some mixtures had VMA values higher than those typically submitted for a job mix formula for airport construction. It might be anticipated that contractors would redesign the aggregate gradation to approach the VMA minimum values to reduce the design binder content and the cost of the asphalt mixture.

6.2 SUPERPAVE GYRATORY COMPACTION RESULTS.

Compaction curves for each mixture are presented in appendix B. A representative set of compaction curves is shown in figure 11. The figure contains data from three specimens. The curves were generated using the previous correlation between specimen height and density for each gyration (equation 4). These curves were used to establish the number of gyrations in the SGC producing 3.5% air voids. This number of gyrations is termed $N_{equivalent}$ for each mixture. This term designates the number of gyrations required to achieve equivalent density to the 75-blow Marshall manual compaction effort at 3.5% air voids. The binder content at 3.5% air voids from the Marshall compacted mixtures was used as the design binder content for each mixture. Table 31 provides the $N_{equivalent}$ values for each mixture.

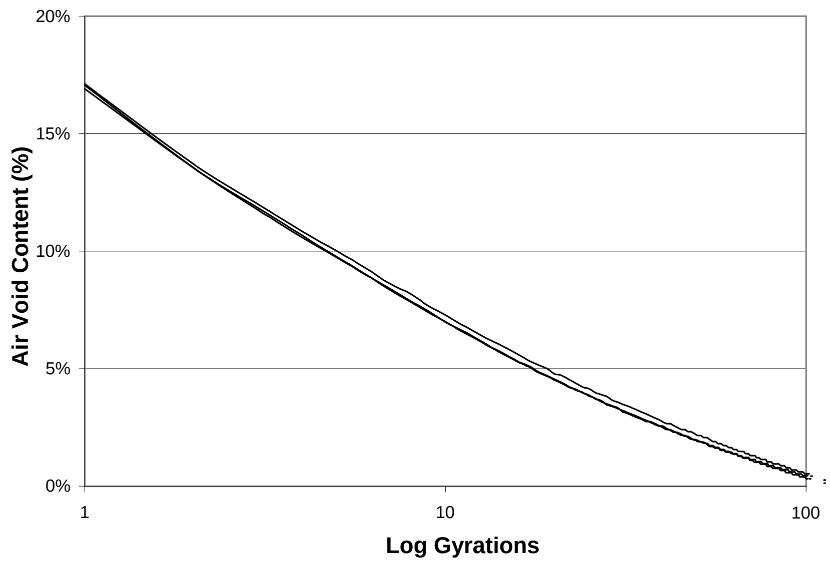


Figure 11. Representative Data for Superpave Gyratory Compaction Curves

Table 31. Summary of SGC $N_{equivalent}$ Values

Equivalent Gyrations Required to Compact Mixtures to 3.5% Air Voids*					
Aggregate Type	Maximum Aggregate Size (in.)	Gradation	Percentage of Mortar Sand	Asphalt Grade PG 64-22	Asphalt Grade PG 76-22
Granite	1/2	Fine	0	80	125
			10	50	99
		Coarse	0	85	125
			10	43	65
	3/4	Fine	0	30	125
			10	94	104
		Coarse	0	45	81
			10	40	76

Table 31. Summary of SGC $N_{equivalent}$ Values (Continued)

Equivalent Gyrations Required to Compact Mixtures to 3.5% Air Voids*					
Aggregate Type	Maximum Aggregate Size (in.)	Gradation	Percentage of Mortar Sand	Asphalt Grade	
Granite	1	Fine	0	65	106
			10	35	80
		Coarse	0	43	67
			10	68	79
Limestone	1/2	Fine	0	93	86
			10	35	52
		Coarse	0	61	60
			10	39	53
	3/4	Fine	0	76	55
			10	49	66
		Coarse	0	68	75
			10	42	61
Chert gravel	1/2	Center	0	62	61
			10	21	46
	3/4	Fine	0	54	44
			10	39	38
		Coarse	0	35	52
			10	25	49

*Compaction ceased at 125 gyrations.

From table 31, $N_{equivalent}$ values for the different mixtures range from 21 to 125 with an average of 64. However, the values given there are group averages composed of individual samples with their own variability. Nevertheless, the data indicates that a direct correlation between Marshall and SGC cannot be ascertained using these asphalt mixtures.

The SGC is fundamentally different from the Marshall compaction device in the way that asphalt mixtures are compacted. The Marshall hammer is an impact device that imparts a similar, repetitive stress to the mixture. The SGC provides a kneading action that compacts the mixture under constant strain conditions. The SGC mobilizes the aggregate particles to change their orientation. Apparently, the inherent differences in the compaction processes inhibit direct translation of compacted specimen volumetric properties between the two methods.

To obtain more accurate detail on the range of $N_{equivalent}$ values, the SGC data were compiled as individual samples to create a histogram of gyrations required to achieve air voids equivalent to air voids from the 75-blow Marshall manual compaction effort. In this procedure, each sample was analyzed to determine the number of equivalent gyrations that would result in a compacted specimen containing 3.5% air voids. The number of gyrations that resulted in this density was then entered into the data set. This procedure was repeated for each specimen compacted in the gyratory compactor. A histogram of the gyratory data is shown in figure 12.

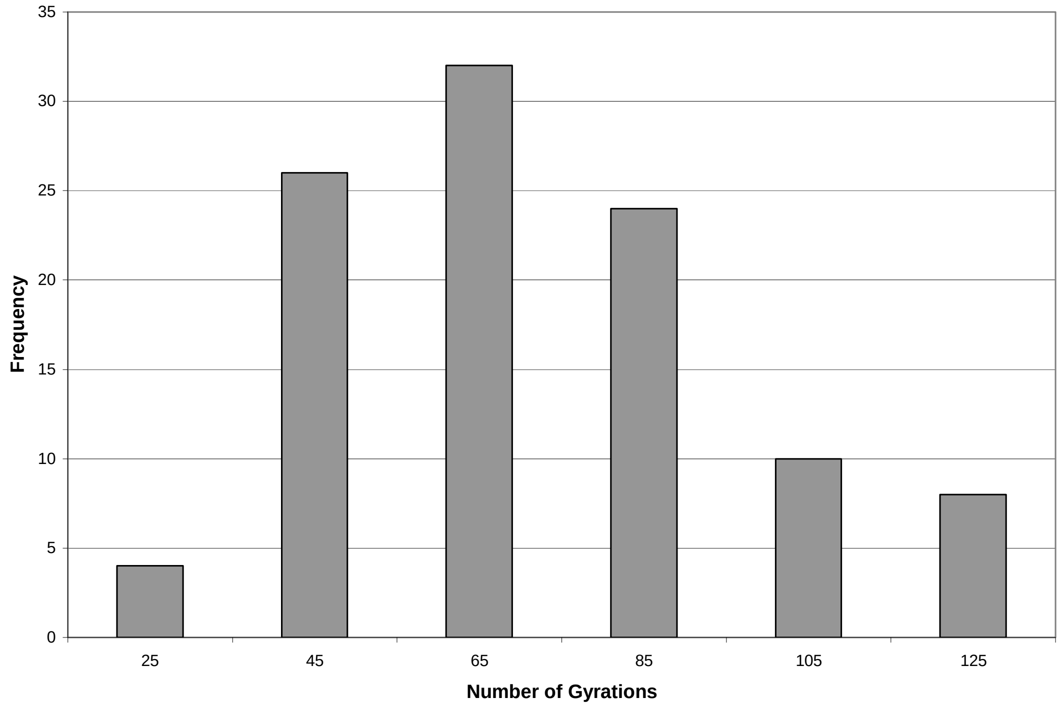


Figure 12. Histogram of $N_{equivalent}$ Values for 3.5% Air Voids

Figure 12 indicates that the data set is not normally distributed about the mean, but is positively skewed. Skewed populations have mean values that tend to lie to the same side of the mode as the longer tail [55]. A greater number of data points lies below the mean value than above the mean value. SigmaStat® software was used to analyze these data to provide limited statistical analyses. All analyses were performed using a 95% confidence level. Commonly used statistical analysis methods require two characteristics of the data sets being analyzed: (1) they are normally distributed about the mean, and (2) they contain equal variance. Skewed population distributions often do not meet these characteristics [55]. Therefore, statistical analyses of these data required the use of nonparametric tests.

6.2.1 Influence of Mortar Sand on Compaction.

Analyses were conducted using SigmaStat® software to define mixture variables significantly impacting compaction behavior. First, the data set was separated into two groups, aggregate containing 100% crushed particles and aggregate containing 10% mortar sand. These data sets were analyzed using a two-sample t-test to determine the influence of mortar sand on compaction. The two-sample t-test compares the two data sets to determine if they are derived from the same population. This test compares the means of two normally distributed data sets. The mean values for $N_{equivalent}$ for samples without and with mortar sand were 77 and 61, respectively. However, the test for normality failed and the test was aborted. Subsequently, a nonparametric test, the Mann-Whitney Rank Sum Test, was selected for analysis [55]. The Mann-Whitney test can be used to compare two data sets that are not normally distributed. The procedure uses a ranking system to sort the array of data for analysis. The results from this test (figure 13) indicate median values for $N_{equivalent}$ for samples without and with mortar sand to be 75 and 59, respectively. Additionally, the test concluded that the P value was <0.001, indicating that the two data sets are significantly different and that the mortar sand influences compaction by requiring fewer gyrations to achieve equivalent compaction. This effect results from the rounded sand particles facilitating coarse aggregate movement and reorientation in the SGC as compaction takes place.

t-test
Data source: No Sand vs Sand in Statistical Analysis.SNB

Normality Test: Failed (P < 0.050)

Test execution ended by user request, Rank Sum Test begun

Mann-Whitney Rank Sum Test

Data source: No Sand vs Sand in Statistical Analysis.SNB

Group	**N**	**Missing**	**Median**	**25%**	**75%**
Col 1	78	1	75.000	57.750	93.250
Col 2	79	1	59.000	43.000	77.000

Mann-Whitney U Statistic= 1881.500

T = 7127.500 n(small)= 77 n(big)= 78 (P = <0.001)

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

Figure 13. Statistical Analysis of Aggregate Without and With Mortar Sand

6.2.2 Influence of Aggregate Type on Compaction.

An analysis of variance procedure was conducted to determine the influence of aggregate type on HMA mixture compaction behavior. This procedure was selected since three data sets were included. This procedure is an efficient way to examine multiple data sets to determine if they are drawn from the same population. The test relies on assumptions that the data are normally distributed and that the groups have equal variance. In this case, the normality test for each data set passed, but the test for equal variance failed. The test was aborted, and the nonparametric, Kruskal-Wallis One Way Analysis of Variance on Ranks test was performed [55]. The Kruskal-Wallis One Way Analysis of Variance on Ranks is similar to the Mann-Whitney test in the fact that it assigns ranks to the data prior to performing the analysis. Assigning ranks creates a new data set that conforms to the desired characteristics. Results from the test (figure 14) indicate the median $N_{equivalent}$ values for data sets for gravel, granite, and limestone aggregate were 50, 84, and 69, respectively. The P value for the test was <0.001, indicating significant differences for the different aggregate types. The mean values for $N_{equivalent}$ for gravel, granite, and limestone were 50, 89, and 70, respectively. Dunn's method [55] was used to perform all pairwise comparisons, and each aggregate type was determined to be significantly different from the other two types. These results do not differentiate which aggregate property causes the mixture to compact differently. Angularity, gradation, and type all may contribute to the observed difference.

One Way Analysis of Variance

Data source: Aggregate Type in Statistical Analysis.SNB

Normality Test: Passed (P = 0.143)

Equal Variance Test: Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Aggregate Type in Statistical Analysis.SNB

Group	**N**	**Missing**	**Median**	**25%**	**75%**
Col 1	28	1	50.000	43.500	56.250
Col 2	55	1	84.500	73.000	104.000
Col 3	36	1	69.000	58.000	80.750

H = 55.321 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	**Diff of Ranks**	**Q**	**P<0.05**
Col 2 vs Col 1	58.574	7.389	Yes
Col 2 vs Col 3	25.028	3.430	Yes
Col 3 vs Col 1	33.546	3.894	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.

Figure 14. Statistical Analysis of Aggregate Type

6.2.3 Influence of Maximum Aggregate Size on Compaction.

Analysis of variance was also selected to compare $N_{equivalent}$ data for each maximum aggregate size because three maximum aggregate sizes were included in the study. The test for normality of the data failed, and the procedure was aborted. The Kruskal-Wallis One Way Analysis of Variance on Ranks test was used instead. The results from this procedure (figure 15) indicated that the median $N_{equivalent}$ value for 1/2-, 3/4-, and 1-inch maximum-sized mixtures were 72, 66, and 80, respectively. The mean values for $N_{equivalent}$ for gravel, granite, and limestone were 78, 69, and 82, respectively. Further, the P value from the test was 0.051, indicating that the data sets were not significantly different. However, this result suggests that the maximum aggregate size does have some influence on the compaction characteristics of HMA mixtures when using the gradations specified in P-401.

One Way Analysis of Variance

Data source: Aggregate Size in Statistical Analysis.SNB

Normality Test: Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Aggregate Size in Statistical Analysis.SNB

Group	N	Missing	Median	25%	75%
Col 1	46	1	72.000	58.750	95.250
Col 2	54	1	66.000	50.000	85.000
Col 3	19	1	80.000	67.000	86.000

H = 5.962 with 2 degrees of freedom. (P = 0.051)

The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.051)

Figure 15. Statistical Analysis of Maximum Aggregate Size

6.2.4 Influence of Aggregate Gradation on Compaction.

A two-sample t-test was performed to compare the $N_{equivalent}$ values for mixtures designated as fine and coarse. The objective was to compare the means of the data sets for both fine and coarse samples. The test for normality for these two data sets passed, but the test for equal variance failed. The test was aborted, and the Mann-Whitney Rank Sum Test was conducted. The Mann-Whitney test removes the unequal variance from the data set during ranking. The results (figure 16) indicate that the median $N_{equivalent}$ values for the fine and coarse mixtures were 80 and 69, respectively. The P value from the test was 0.047, indicating that the data sets were significantly different. The mean values for $N_{equivalent}$ for fine and coarse mixtures were 80 and 71, respectively. The finer-graded aggregate mixtures required a higher number of gyrations to compact to an equivalent density. This effect is related to the packing ability of the aggregate particles and the increased friction from the greater number of contact points between the finer aggregates.

t-test

Data source: Coarse/Fine in Statistical Analysis.SNB

Normality Test:	Passed	(P = 0.224)
Equal Variance Test:	Failed	(P < 0.050)

Test execution ended by user request, Rank Sum Test begun

Mann-Whitney Rank Sum Test

Data source: Coarse/Fine in Statistical Analysis.SNB

Group	**N**	**Missing**	**Median**	**25%**	**75%**
Col 1	56	2	68.500	57.000	81.000
Col 2	55	2	80.000	58.750	102.000

Mann-Whitney U Statistic= 1111.500

T = 3181.500 n(small)= 53 n(big)= 54 (P = 0.047)

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = 0.047)

Figure 16. Statistical Analysis of Aggregate Gradation

6.2.5 Influence of Binder Type on Compaction.

A two-sample t-test was performed to compare the $N_{equivalent}$ values for mixtures containing the unmodified and polymer-modified binder. The objective was to compare the means of the data sets for both unmodified and polymer-modified mixtures. The test for normality for these two data failed. The test was aborted, and the Mann-Whitney Rank Sum Test was conducted. The Mann-Whitney test ranks the values in the data set to create a new normally distributed data set. The results (figure 17) indicate that the median $N_{equivalent}$ values for the unmodified and polymer-modified mixtures were 62 and 66, respectively. The P value from the test was 0.027, indicating that the data sets are significantly different. The mean values for $N_{equivalent}$ for unmodified and modified mixtures were 63 and 75, respectively. The unmodified mixtures required a lower number of gyrations to compact to an equivalent density. This effect is related to the viscoelastic properties of the binder. The polymer-modified binder is stiffer than the unmodified binder. Even though the polymer-modified mixtures were compacted at higher temperatures, the properties of the binder caused these mixtures to resist compaction and require more effort to obtain equivalent density.

t-test

Data source: Unmodified/Modified in Statistical Analysis.SNB

Normality Test: Failed (P < 0.050)

Test execution ended by user request, Rank Sum Test begun

Mann-Whitney Rank Sum Test

Data source: Unmodified/Modified in Statistical Analysis.SNB

Group	**N**	**Missing**	**Median**	**25%**	**75%**
Col 1	79	1	62.000	46.000	83.000
Col 2	78	1	68.000	53.000	88.500

Mann-Whitney U Statistic= 2386.000

T = 6623.000 n(small)= 77 n(big)= 78 (P = 0.027)

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = 0.027)

Figure 17. Statistical Analysis of Binder Type

6.3 DISCUSSION.

The Marshall mixture design procedure has been used to design quality asphalt pavements for airports for many years. However, most contractors specializing in HMA pavement construction in the United States are producing mix designs using a Superpave gyratory compactor, as is used in highway construction. FAA specifications for construction of airport HMA pavements should include the option of using the Superpave gyratory compactor to design asphalt mixtures to ensure an adequate pool of contractors can bid on airport construction contracts. This implementation will require an initial pavement monitoring period to examine asphalt concrete mixtures designed with the proposed gyratory compaction parameters to ensure performance and durability.

This study was conducted to identify Superpave gyratory compaction parameters to produce the same binder content at 3.5% air voids obtained when using the Marshall 75-blow manual compaction effort. Equivalent performance of asphalt concrete mixtures could be expected if gyratory compaction parameters were found that would produce HMA mixtures having volumetric properties correlating strongly with asphalt mixtures designed using the Marshall 75-blow manual compaction effort.

The results from testing HMA mixtures designed using the Marshall 75-blow manual compaction effort showed expected trends for the design binder content at 3.5% air voids for each aggregate blend. The gradation of the aggregates was a factor that affected the design binder content. Aggregate blends with larger maximum sizes required lower percentages of asphalt. Introducing mortar sand to asphalt mixtures reduced the design binder content by reducing particle interaction and aiding compaction.

Determining the Superpave gyratory compaction parameters required to replicate the Marshall volumetric properties and mixture proportions provided less precise results. The ram pressure (600 kPa), mold diameter (152 mm), internal angle of gyration (1.16° ±0.02°), rotational speed (30 rpm), and target specimen height (115 mm) were all kept at values corresponding to those used for highway HMA mixture design. The remaining parameter to be defined was the number of design gyrations (N_{design}). This value was determined by compacting each asphalt mixture in the gyratory compactor using the design binder content at 3.5% air voids from the Marshall mix design. The number of gyrations required to compact the asphalt mixture to the target air content (3.5%) was determined to be the $N_{equivalent}$ for each particular mix. Analyzing all the $N_{equivalent}$ values identified the value that would result in volumetric mix proportions that were most similar to those produced using the Marshall 75-blow manual compaction effort.

The results from the statistical analysis suggest that mortar sand content, aggregate type and gradation, and binder type all influence the $N_{equivalent}$ for Superpave gyratory compaction. In the initial development of compaction requirements, there were 28 compaction levels [10]. The process was too cumbersome for practical implementation. Further modifications reduced the compaction requirements to four levels, dependent upon traffic. Currently, two compaction requirements, 50 and 75 blows with the Marshall hand hammer, exist for designing asphalt mixtures for airport pavements depending on the expected traffic [1]. This study only addresses the correlation for the Marshall 75-blow compaction effort at a design air void content of 3.5%.

The results from this study indicate that the average $N_{equivalent}$ value for compacting asphalt concrete mixtures to 3.5% air voids was 69 gyrations, but the standard deviation, 25, of these data was large. This type of variability in the data should be considered in the final selection of N_{design}.

Based upon a survey of state transportation department procedures for designing asphalt mixtures for high traffic roads, an N_{design} for airport mixtures is recommended to be no fewer than 60 and no more than 90 gyrations. These recommendations are made based on the fact that the same traffic levels for highways were previously designed by the Marshall 75-blow compaction effort. Selecting the best value requires an acknowledgement of the effect of N_{design} on the resulting mixture proportions. Two cases may exist if the number of gyrations specified for N_{design} is not in the appropriate range.

- If the N_{design} value is set too low, asphalt mixtures will be designed with too much AC. This result can lead to an asphalt mixture design that is susceptible to rutting. Rutting is more likely because the air void content will be too low and viscous flow can occur. Additionally, excess asphalt cement in the mixture will increase the mixture cost.

- If the N_{design} value is set too high, asphalt mixtures will be designed with too little AC. This result can lead to premature failure due to decreased durability of the pavement. Durability problems exist because the air void content is too high in the mixture. Mixtures with excessive air voids are prone to weathering, raveling, and stripping. Having a high N_{design} value may also result in mixtures that are difficult to compact in the field because of decreased lubrication from the binder. If the laboratory compaction effort is increased, the required field compaction effort will also increase. This result can lead to problems during pavement construction.

Data showed that the mixtures containing the polymer-modified binder required a higher number of gyrations to compact than the mixtures containing the unmodified binder. However, research has shown that polymer-modified asphalt concrete does not densify as much as its unmodified counterpart with traffic [21]. These results led to the recommendation of a lower N_{design} value when using polymer-modified asphalt on highway pavements. According to the data, specifying the same design gyration level for unmodified and polymer-modified mixtures would lead to an increase in the design binder content for polymer-modified mixtures.

Selection of a recommended N_{design} value is made by taking the mean value of all the $N_{equivalent}$ values determined in this study. Using the mean value acknowledges the balance in mixture properties that result from changes in N_{design}. Although the mean of all $N_{equivalent}$ values was 69, an N_{design} value of 70 is recommended for simplicity.

Further analysis was performed to evaluate the impact of N_{design} on the AC content of the mixture. Each mixture was evaluated to determine the air void content at 70 gyrations. Then, the air void content at other numbers of gyrations was identified. Each mixture was evaluated at 10 and 20 gyrations above and below 70 gyrations. Figure 18 shows the average change in air void content as the number of target gyrations changes. At 50 gyrations, mixtures had an average air content of 0.93% higher than the air content at 70 gyrations. At 60 gyrations, mixtures had an average air content of 0.42% higher than the air content at 70 gyrations. At 80 gyrations, mixtures had an average air content of 0.35% lower than the air content at 70 gyrations. At 90 gyrations, mixtures had an average air content of 0.65% lower than the air content at 70 gyrations.

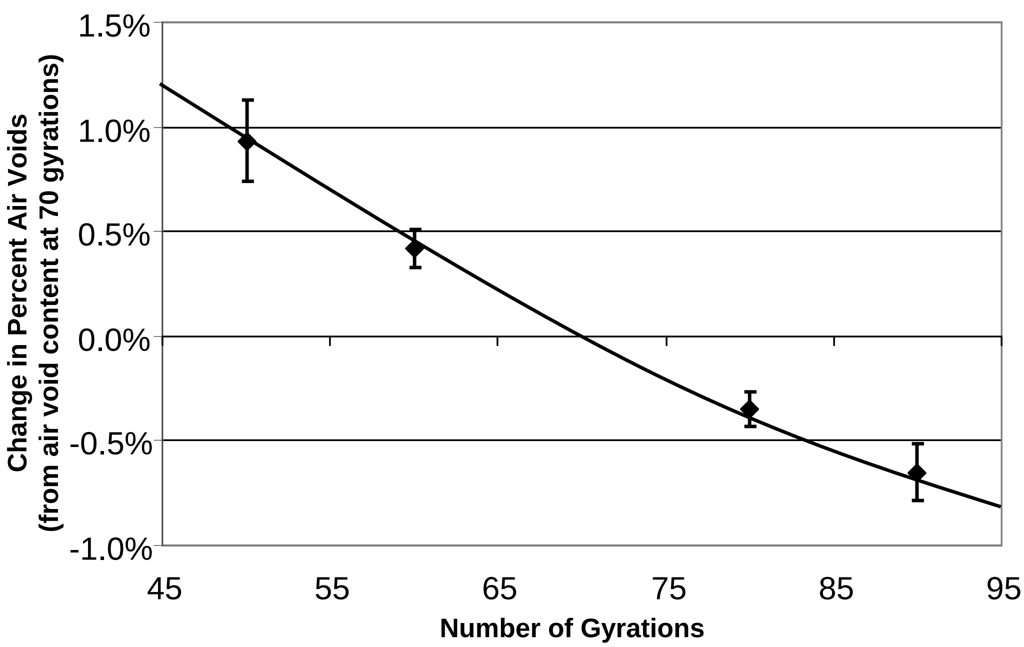


Figure 18. Influence of Number of Gyrations on Air Void Content

The data in figure 18 show the greater effect on the air void content that occurs by lowering the number of gyrations. This result is expected since the rate of compaction decreases with increasing gyrations. These data also show that small changes (10 gyrations) in N_{design} do not result in large changes (greater than 0.5%) in the air void content. Since the AC of the mixture is adjusted to achieve a target air content of 3.5%, the changes in N_{design} would result in a change in the selected AC content. The changes in selected AC content are expected to be lower than the observed changes in air void content since additional AC would aid compaction.

In the mixture design procedure, specifications provide tolerances on binder content that is accepted for use. These have been adjusted to ensure that quality asphalt mixtures are used for airport pavements. Adjustments to these tolerances have been made with empirical evidence. The current specifications are satisfactory in ensuring acceptable performance. Until an effective performance test for asphalt mixtures is included in design specifications, these property measurements will continue to provide a system of checks and balances for designing asphalt mixture proportions.

The Superpave asphalt mixture design system for highway pavements has used SGC compaction levels with which to evaluate additional asphalt mixtures. These additional criteria are the volumetric properties at $N_{initial}$ and $N_{maximum}$. Guidance in reference 26 for designing asphalt mixtures using the SGC for airports also includes specifications for these values. The criteria at $N_{initial}$ have been used to ensure that asphalt mixtures that compact too easily are eliminated in the design process. These mixtures include those that would be susceptible to rutting. The $N_{maximum}$ value used in this method ensures that mixtures do not continue to densify with increasing traffic.

Although these criteria were not used in this study, analysis of the gyratory compaction curves indicates that several of the asphalt mixtures used would not pass the criteria in reference 26 for volumetric properties at either $N_{initial}$ or $N_{maximum}$ at the binder contents used in the mixtures. In fact, only 46% passed both criteria. Fifty-five the of one hundred fifty-five (35%) specimens did not meet $N_{initial}$ criteria defined in reference 26. Additionally, 84 out of 155 (54%) specimens did not meet $N_{maximum}$ criteria defined in reference 26. Those that do not meet these criteria are generally mixtures containing the chert gravel aggregate or 10% mortar sand. This result indicates that the aggregate texture and angularity strongly influence compaction.

Additionally, $N_{initial}$ and $N_{maximum}$ impart additional limitations on the flexibility of the mixture design. They also have a tendency to limit the amount of AC in the mixture. Both criteria can be achieved more easily if the AC content is reduced. Reducing the AC content is undesirable for airport pavements since they typically fail from environmental-related distresses.

In NCHRP 9-9(1), Prowell found that a high percentage of highway pavements that were providing good performance in the field failed $N_{initial}$ and $N_{maximum}$ criteria [20]. Those that failed $N_{initial}$ and $N_{maximum}$ criteria were typically fine-graded mixtures. Prowell's results agree with the data presented above since airport mixtures are considered fine-graded by Superpave standards. Prowell determined that these values were not a good indication of rutting and should be eliminated from the design procedure.

7. CONCLUSIONS AND RECOMMENDATIONS.

The objective of this research was to recommend a value for the number of design gyrations, N_{design}, with which to design asphalt mixtures for airport pavements using the superpave gyratory compactor (SGC). Other SGC variables such as ram pressure (600 kPa), mold diameter (152 mm), internal angle of gyration (1.16°), rotational speed (30 revolutions per minute), and target specimen height (115 mm) were adopted from American Association of State Highway and Transportation Officials highway hot mix asphalt (HMA) mixture design protocol. The value for N_{design} was selected as the number of gyrations resulting in an air void content of 3.5%. This compaction was at the same binder content required to compact samples to 3.5% air voids using the Marshall 75-blow manual compaction effort.

7.1 CONCLUSIONS.

Based on the results of this research study, the following conclusions were made:

- The design binder content obtained from the Marshall 75-blow compaction effort (3.5% air voids) was used to compact mixtures in the SGC. The number of gyrations required to produce equivalent density had a mean value of 69 and one standard deviation of 25.

- Several analyses were performed to identify aggregate characteristics affecting SGC compaction. Mortar sand content, aggregate type and gradation, and binder type all contributed to significant differences in the number of gyrations required to compact mixtures to the target air void content of 3.5%.

- Even though mortar sand content, aggregate type and gradation, and binder type all contributed to significant differences in Nequivalent, one gyration level should be selected for simplicity. These individual variables should not produce a significant error in the selected asphalt cement content.

- The mean value of all Nequivalent values was selected for Ndesign. Further analysis was performed to determine the effect of Ndesign on the air void content of the mixtures. Changing the Ndesign value by 10 gyrations was determined to result in less than a 0.5% change in air void content.

- Mixtures were evaluated according to criteria for Ninitial in Engineering Brief 59A. Thirty-five percent of the mixtures failed the criteria at the binder content used for sample compaction. Using this criterion would result in eliminating 35% of mixtures that meet all criteria for the Marshall mixture design procedure.

- Mixtures were evaluated according to criteria for Nmaximum in Engineering Brief 59A. Fifty-four percent of the mixtures failed the criteria at the binder content used for sample compaction. Using this criterion would result in eliminating 54% of mixtures that meet all criteria for the Marshall mixture design procedure. No determination has been made if these mixtures would be susceptible to rutting in the field or in service.

- Only 36% of mixtures pass both Ninitial and Nmaximum criteria in Engineering Brief 59A. However, these mixtures were designed at 3.5% air voids; mixtures in the criteria are designed at a lower binder content producing 4.0% air voids.

7.2 RECOMMENDATIONS.

Based on research conducted in this study, the following recommendations were made.

- The specification for designing asphalt mixtures for aircraft greater than 60,000-lb gross weight can use an N_{design} of 70 gyrations. This N_{design} value should be further researched in laboratory and field studies prior to acceptance in future Federal Aviation Administration criteria.

- Additional research is recommended to determine the applicability of $N_{initial}$ and $N_{maximum}$ criteria when designing asphalt mixtures for airports. Currently, the recommendation is that these values should be eliminated from the mixture design procedure since they will reject a high percentage of mixtures that are deemed satisfactory by the Marshall mixture design criteria. Mixtures should be compacted to the N_{design} value in the laboratory for analysis.

- Additional research is also needed to correlate field performance of asphalt mixtures designed using Superpave methodologies.

- A performance test should be adopted to evaluate mixtures in the laboratory.

- In-service pavements should be monitored to compare densities to those obtained in the laboratory design procedure to provide an indication of the prediction capability.

- In-service airport pavements should be monitored to determine if the ultimate density of the HMA with polymer-modified asphalt is similar to HMA with unmodified asphalt.

8. REFERENCES.

1. Advisory Circular 150/5370-10D, "Standards for Specifying Construction of Airports," U.S. Department of Transportation, Federal Aviation Administration, 2008.

2. Leahy, R.B. and McGennis, R.B., "Asphalt Mixes: Materials, Design, and Characterization," *Journal of the Association of Asphalt Paving Technologists*, Vol. 68A, Chicago, Illinois, 1999, pp. 70-127.

3. Halstead, W.J. and Welborn, J.Y., "History of the Development of Asphalt Testing Apparatus and Asphalt Specifications," *Proceedings of the Association of Asphalt Paving Technologists Historical Session*, Vol. 43A, Williamsburg, Virginia, 1974, pp. 89-120.

4. Prowell, B.D., "Verification of the Superpave Gyratory N_{design} Compaction Levels," Doctoral Dissertation, Auburn University, Auburn, Alabama, 2006.

5. White, T.D., “Marshall Procedures for Design and Quality Control of Asphalt Mixtures,” *Journal of the Association of Asphalt Paving Technologists*, Vol. 54, Minneapolis, Minnesota, 1985.

6. War Department, Corps of Engineers, U.S. Army, Mississippi River Commission, “Investigation of the Design and Control of Asphalt Paving Mixtures,” Technical Memorandum No. 3-254, Vol. 1, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi, May 1948.

7. Roberts, F.L., Kandhal, P.S., Brown, E.R., Lee, D-Y, and Kennedy, T.W., *Hot Mix Asphalt Materials, Mixture Design and Construction*, 2nd ed., NAPA Education Foundation, Lanham, Maryland, 1996.

8. Kandhal, P.S. and Koehler, W.S., “Marshall Mix Design Method: Current Practices,” *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 54, San Antonio, Texas, 1985, pp. 284-303.

9. Unified Facilities Guide Specification 32 12 15, “Hot Mix Asphalt (HMA) for Airfields,” United States Department of Defense, Washington, DC, 2006.

10. Cominsky, R., Leahy, R.B., and Harrigan, E.T., “Level One Mix Design: Materials Selection, Compaction, and Conditioning,” SHRP-A-408, Strategic Highway Research Program, National Research Council, Washington, DC, 1994.

11. Consuega, A., Little, D.N., Von Quintus, H., and Burati, J., “Comparative Evaluation of Laboratory Compaction Devices Based on Their Ability to Produce Mixtures With Engineering Properties Similar to Those Produced in the Field,” *Transportation Research Record 1228*, Transportation Research Board, National Research Council, Washington, DC, 1989, pp. 80-87.

12. Von Quintus, H.L., Scherocman, J.A., Hughes, C.S., and Kennedy, T.W., “Asphalt-Aggregate Mixture Analysis System AAMAS,” *NCHRP Report No. 338*, Transportation Research Board, National Research Council, Washington, DC, 1991.

13. Blankenship, P.B., “Gyratory Compaction Characteristics: Relation to Service Densities of Asphalt Mixtures,” Master’s Thesis, University of Kentucky, Lexington, Kentucky, 1993.

14. American Association of State Highway and Transportation Officials, AASHTO Provisional Standards, Washington, DC, 2001.

15. Yildirim, Y., Solaimanian, M., McGennis, R.B., and Kennedy, T.W., “Comparative Analysis of Volumetric Properties for Superpave Gyratory Compactors,” *Transportation Research Record 1712*, Transportation Research Board, National Research Council, Washington, DC, 2000.

16. McGennis, R.B., Anderson, R.M., Perdomo, D., and Turner, P., "Issues Pertaining to Use of Superpave Gyratory Compactor," *Transportation Research Record 1543*, Transportation Research Board, National Research Council, Washington, DC, 1996, pp. 139-144.

17. Test Quip Corporation, "Operating Instructions for the Dynamic Angle Validation Kit (DAVK) for Superpave Gyratory Compactors," New Brighton, Minnesota, 2001.

18. Dalton, F., "Application of Internal Angle Verification to Obtain Equivalent Results From Various SGC Models," Report 2001-01 Revision A, Pine Instrument Company, Grove City, Pennsylvania, 2001.

19. Prowell, B.D., Brown, E.R., and Huner, M., "Evaluation of the Internal Angle of Gyration of Superpave Gyratory Compactors in Alabama," NCAT 03-04, National Center for Asphalt Technology, 2003.

20. Al-Khaateeb, G., Paugh, C., Stuart, K., Harman, T., and D'Angelo, J., "Target and Tolerance for the Angle of Gyration Used in the Superpave Gyratory Compactor (SGC)," *Transportation Research Record 1789*, Transportation Research Board, National Research Council, Washington, DC, 2002, pp. 208-215.

21. Prowell, B.D. and Brown, E.R., "Superpave Mix Design: Verifying Compaction Levels in the N_{design} Table," *NCHRP Report 573*, Transportation Research Board, National Research Council, Washington, DC, 2007.

22. Brown, E.R. and Buchanan, M.S., "Superpave Gyratory Compaction Guidelines," *NCHRP Research Results Digest 237*, Transportation Research Board, National Research Council, Washington, DC, 1999.

23. Newman, J.K. and Freeman, R.B., "Evaluation of Strategic Highway Research Program (SHRP) Products for Application to Airport Pavements, Report 1: Review of SHRP Products," FAA report DOT/FAA/CT-96/118, 1998.

24. "Airfield Asphalt Pavement Technology Program (AAPTP) Procedures Manual," U.S. Department of Transportation, Federal Aviation Administration, Airport Technology Research, 2005.

25. Cooley, L.A., Jr., Ahlrich, R.C., James, R.S., Prowell, B.D., and Brown, E.R., "Implementation of Superpave Mix Design for Airfield Pavements," *Proceedings of the 2007 FAA Worldwide Airport Technology Transfer Conference*, Atlantic City, New Jersey, 2007.

26. Engineering Brief No. 59A, "Item P-401 Plant Mix Bituminous Pavements (Superpave)," U.S. Department of Transportation, Federal Aviation Administration, 2006.

27. American Society of Testing and Materials, “Standard Specification for Penetration-Graded Asphalt Cement for Use in Pavement Construction,” Designation: D 946-82, West Conshohocken, Pennsylvania, 2005.

28. American Society of Testing and Materials, “Standard Test Method for Penetration of Bituminous Material,” Designation: D 5-05a, West Conshohocken, Pennsylvania, 2005.

29. *The Asphalt Handbook*, Manual Series No. 4 (MS-4), 7th ed., The Asphalt Institute, Lexington, Kentucky, 2007.

30. American Society of Testing and Materials, “Standard Test Method for Kinematic Viscosity of Asphalts (Bitumens),” Designation: D 2170-01a, West Conshohocken, Pennsylvania, 2001.

31. American Society of Testing and Materials, “Standard Test Method for Viscosity of Asphalts by Vacuum Capillary Viscometer,” Designation: D 2171-01, West Conshohocken, Pennsylvania, 2001.

32. American Society of Testing and Materials, “Standard Specification for Viscosity-Graded Asphalt Cement for Use in Pavement Construction,” Designation: D 3381-92, West Conshohocken, Pennsylvania, 1999.

33. American Society of Testing and Materials, “Standard Test Method for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test),” Designation: D 2872-04, West Conshohocken, Pennsylvania, 2004.

34. Elliot, R.P., Ford, M.C., Jr., Ghanim, M., and Tu, Y.F., “Effect of Aggregate Gradation Variation on Asphalt Concrete Mix Properties,” *Transportation Research Record 1317*, Transportation Research Board, National Research Council, Washington, DC, 1991.

35. Moore, R.B. and Welke, R.A., “Effects of Fine Aggregate on Stability of Bituminous Mixes,” Michigan Department of State Highways and Transportation, Research Report Number 78 TB-34-79F, 1979.

36. Kim, Y.R., Yim, N., and Khosla, N.P., “Effects of Aggregate Type and Gradation on Fatigue and Permanent Deformation of Asphalt Concrete,” American Society of Testing and Materials STP 1147, Philadelphia, Pennsylvania, 1992.

37. Krutz, N.C. and Sebaaly, P.E., “The Effects of Aggregate Gradation on Permanent Deformation of Asphalt Concrete,” *Proceedings of Association of Asphalt Paving Technologists*, Volume 62, 1993.

38. Wedding, P.A. and Gaynor, R.D., “The Effects of Using Gravel as the Coarse and Fine Aggregate in Dense Graded Bituminous Mixtures,” *Proceedings of Association of Asphalt Paving Technologists*, Volume 30, 1961.

39. Field, F., "The Effect of Percent Crushed Variation in Coarse Aggregate for Bituminous Mixes," *Proceedings of Association of Asphalt Paving Technologists*, Volume 27, 1957.

40. Gaudette, B.E. and Welke, R.A., "Investigation of Crushed Aggregates for Bituminous Mixes," Michigan Department of State Highways and Transportation, Research Report Number TB-58, 1977.

41. American Society of Testing and Materials, "Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate," Designation: D 5821-01, West Conshohocken, Pennsylvania, 2006.

42. American Society of Testing and Materials, "Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate," Designation: D 4791-05, West Conshohocken, Pennsylvania, 2005.

43. American Society of Testing and Materials, "Standard Test Methods for Uncompacted Void Content of Fine Aggregate (as Influenced by Particle Shape, Surface Texture, and Grading)," Designation: C 1252-06, West Conshohocken, Pennsylvania, 2006.

44. Button, J.W., Perdomo, D., and Lytton, R.L., "Influence of Aggregate on Rutting in Asphalt Concrete Pavements," *Transportation Research Record 1259*, Transportation Research Board, National Research Council, Washington, DC, 1990.

45. Ahlrich, R.C., "Influence of Aggregate Gradation and Particle Shape/Texture on Permanent Deformation of Hot Mix Asphalt Pavements," Technical Report GL-96-1, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi, 1996.

46. Bureau of Public Roads, "Aggregate Gradation for Highways," United States Government Printing Office, Washington, DC, May 1962.

47. American Society of Testing and Materials, "Standard Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixes," Designation: D 2676-00, West Conshohocken, Pennsylvania, 2000.

48. American Society of Testing and Materials, "Standard Test Method for Maximum Theoretical Specific Gravity and Density of Bituminous Paving Mixtures," Designation: D 2041-03a, West Conshohocken, Pennsylvania, 2003.

49. American Society of Testing and Materials, "Standard Test Method for Marshall Stability and Flow of Bituminous Mixtures," Designation: D 6927-06, West Conshohocken, Pennsylvania, 2006.

50. American Society of Testing and Materials, "Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate," Designation: C 127-04, West Conshohocken, Pennsylvania, 2004.

51. American Society of Testing and Materials, "Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate," Designation: C 128-04a, West Conshohocken, Pennsylvania, 2004.

52. Kandhal, P., Motter, J., and Khatri, M., "Evaluation of Particle Shape and Texture: Manufactured Versus Natural Sands," NCAT 91-03, National Center for Asphalt Technology, Auburn University, Alabama, 1991.

53. American Society of Testing and Materials, "Standard Practice for Preparation of Bituminous Specimens Using Marshall Apparatus," Designation: D 6926-04, West Conshohocken, Pennsylvania, 2004.

54. Mallick, R., Buchanan, S., Brown, E.R., and Huner, M., "An Evaluation of Superpave Gyratory Compaction of Hot Mix Asphalt," NCAT 98-05, National Center for Asphalt Technology, Auburn University, Alabama, 1998.

55. Spiegel, M.S. and Stephens, L.J., *Schaum's Outline of Theory and Problems of Statistics,* 3rd ed., McGraw-Hill, 1999.

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Fine Limestone

		Individual Stockpiles				
Percent Passing	**Total Combined Gradation**	**#6**	**#7**	**821-1/4 mod**	**692 Stone Sand**	**Mortar Sand**
1″	100	100	100	100	100	100
3/4″	100	90	100	100	100	100
1/2″	98	15	93	100	100	100
3/8″	89	2	57	100	100	100
#4	73	1	3	100	98	100
#8	58	0	1	95	72	100
#16	38	0	1	65	47	100
#30	25	0	1	41	31	94
#50	16	0	1	23	21	32
#100	9	0	1	10	13	1
#200	6.4	0.4	0.5	5.1	9.5	0.6
Percent Used:	100%	0%	26%	56%	18%	0%

Percent of Asphalt Cement	5.5%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160°C (320°F)
Compaction Temperature	145°C (290°F)

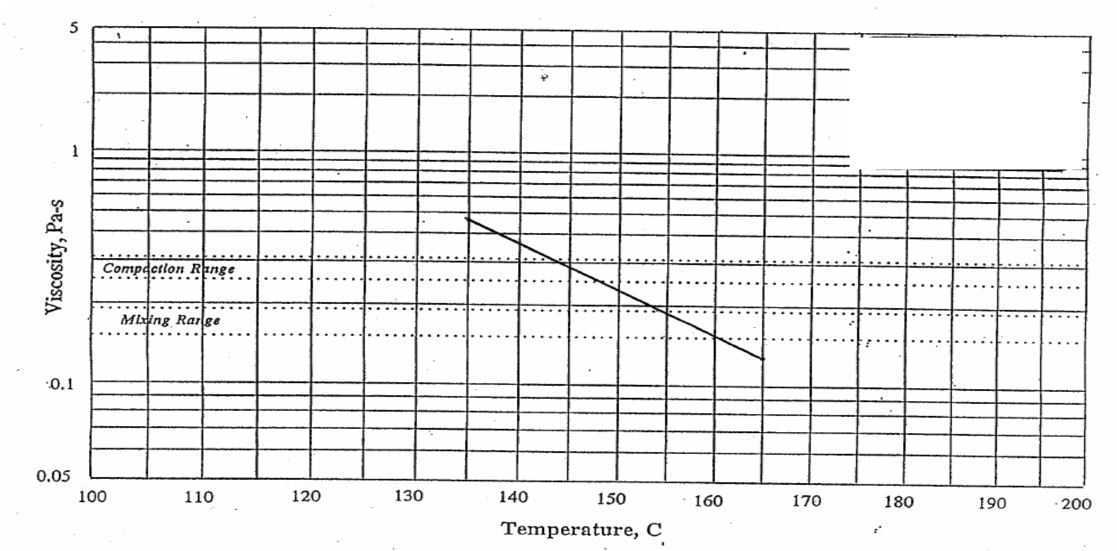


Figure A-1. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Fine Limestone

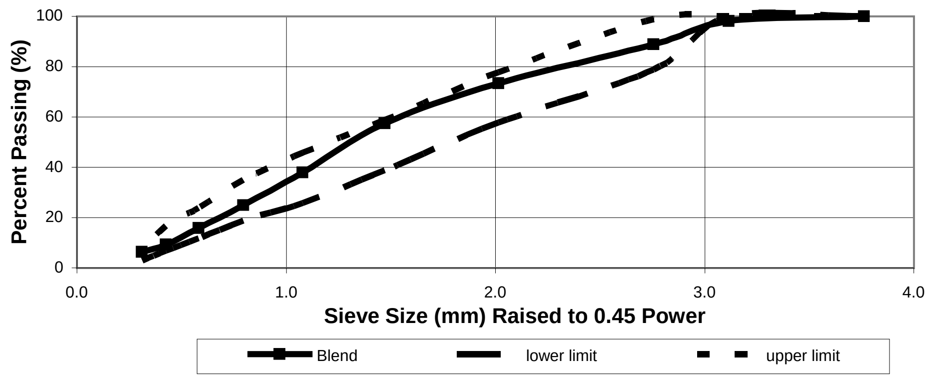
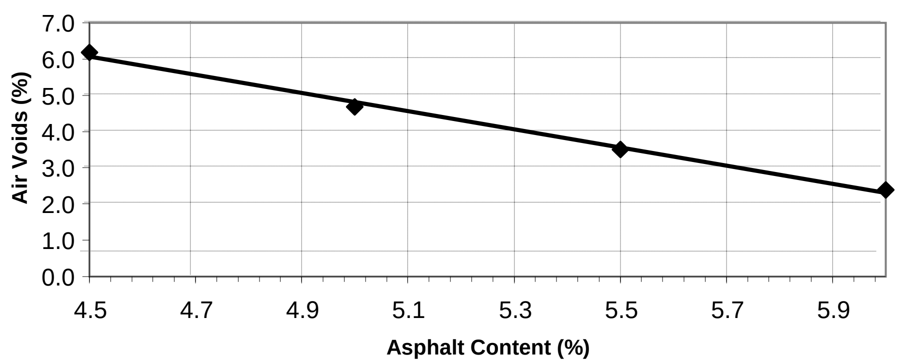


Figure A-2. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Fine Mix Limestone



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.2%
Percent by Weight Elongated Particles (5:1)	0.4%
Percent by Weight Flat Particles (5:1)	1.6%

Figure A-3. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Fine Mix Limestone

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

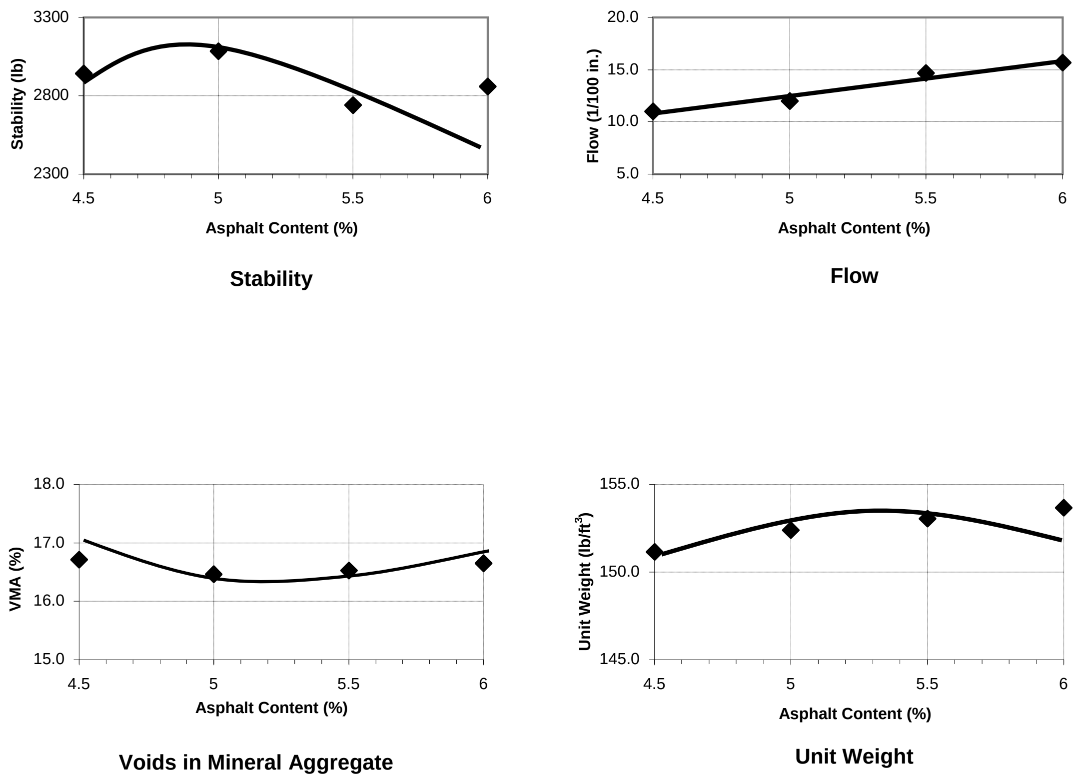


Figure A-4. Marshall Mix Design Results, 1/2-Inch Fine Limestone, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Coarse Limestone

		Individual Stockpiles				
Percent Passing	**Total Combined Gradation**	**#6**	**#7**	**821-1/4 mod**	**692 Stone Sand**	**Mortar Sand**
1"	100	100	100	100	100	100
3/4"	100	90	100	100	100	100
1/2"	97	15	93	100	100	100
3/8"	82	2	57	100	100	100
#4	59	1	3	100	98	100
#8	45	0	1	95	72	100
#16	29	0	1	65	47	100
#30	20	0	1	41	31	94
#50	13	0	1	23	21	32
#100	8	0	1	10	13	1
#200	5.4	0.4	0.5	5.1	9.5	0.6
Percent Used:	100%	0%	41%	50%	9%	0%

Percent of Asphalt Cement	5.3%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160°C (320°F)
Compaction Temperature	145°C (290°F)

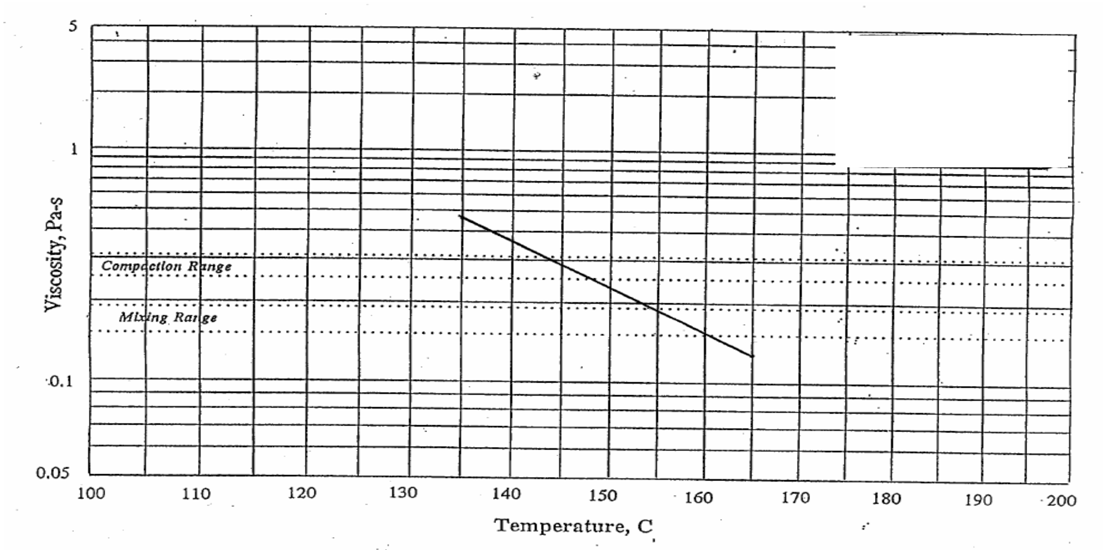


Figure A-5. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Coarse Limestone

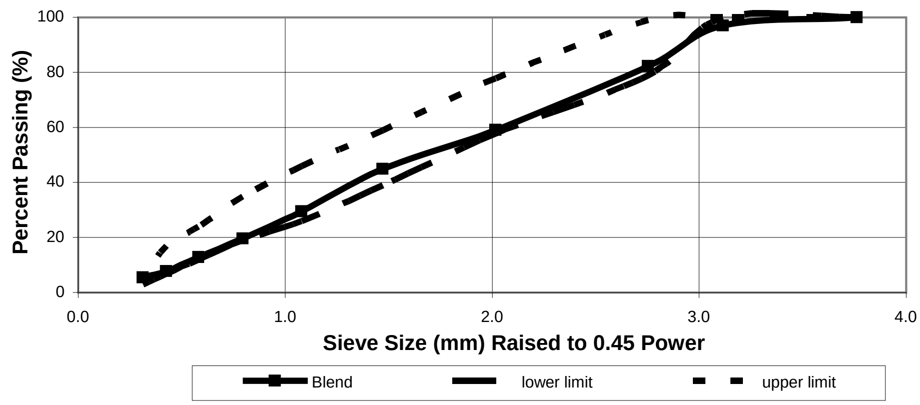
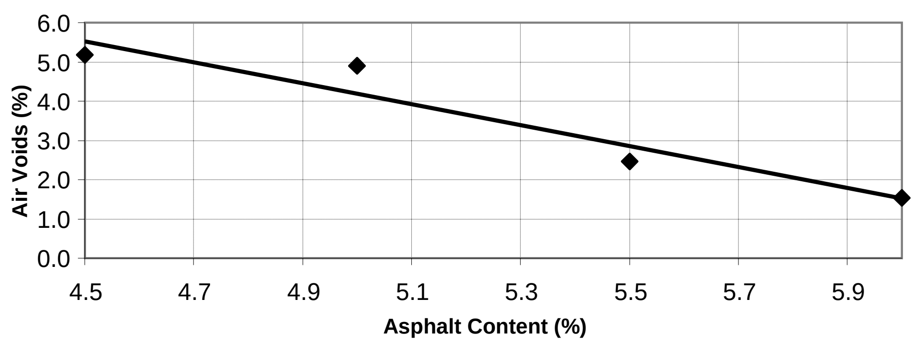


Figure A-6. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Coarse Mix Limestone



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.2%
Percent by Weight Elongated Particles (5:1)	0.4%
Percent by Weight Flat Particles (5:1)	1.5%

Figure A-7. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Fine Mix Limestone

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

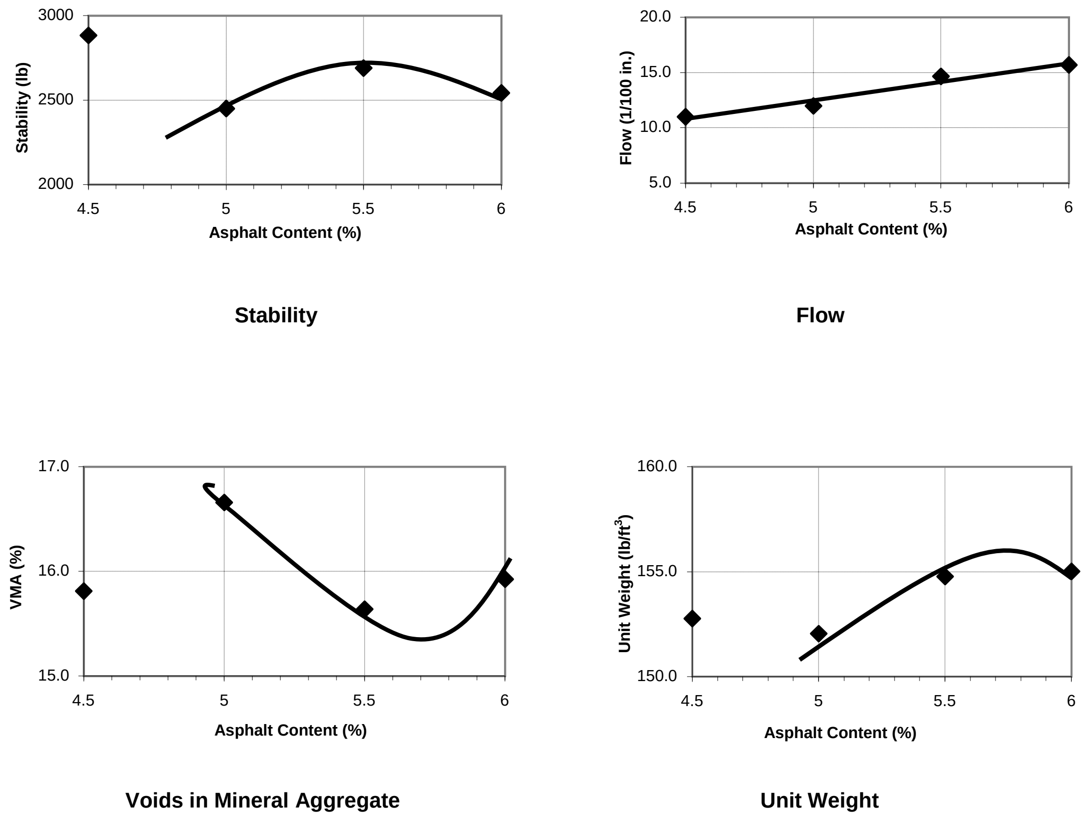


Figure A-8. Marshall Mix Design Results, 1/2-Inch Coarse Limestone, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Fine Limestone

		Individual Stockpiles				
Percent Passing	**Total Combined Gradation**	**#6**	**#7**	**821-1/4 mod**	**692 Stone Sand**	**Mortar Sand**
1"	100	100	100	100	100	100
3/4"	100	90	100	100	100	100
1/2"	98	15	93	100	100	100
3/8"	86	2	57	100	100	100
#4	67	1	3	100	98	100
#8	52	0	1	95	72	100
#16	34	0	1	65	47	100
#30	23	0	1	41	31	94
#50	15	0	1	23	21	32
#100	9	0	1	10	13	1
#200	5.8	0.4	0.5	5.1	9.5	0.6
Percent Used:	100	0%	33%	51%	16%	0%

Percent of Asphalt Cement	5.4%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160°C (320°F)
Compaction Temperature	145°C (290°F)

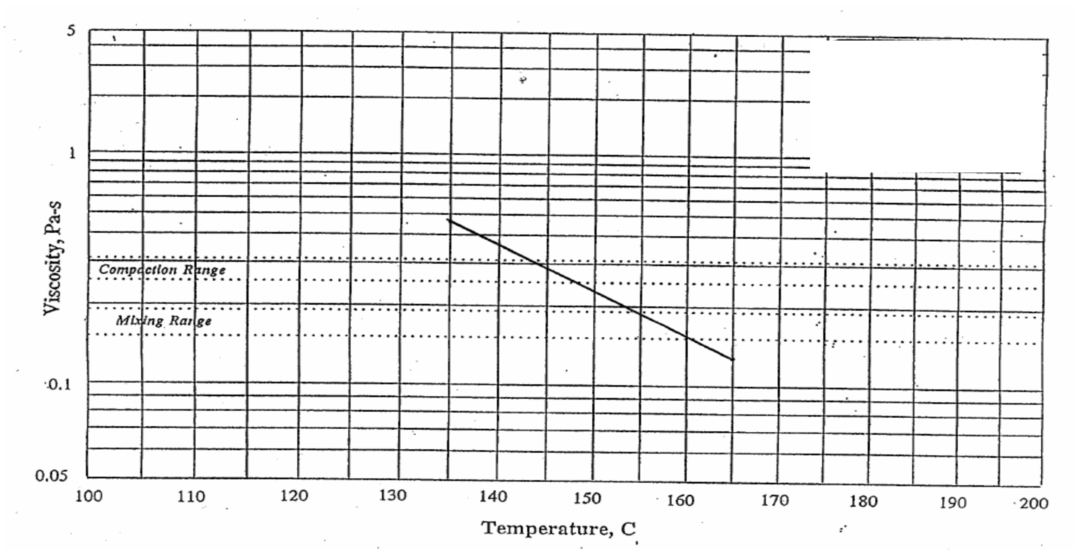


Figure A-9. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Fine Limestone

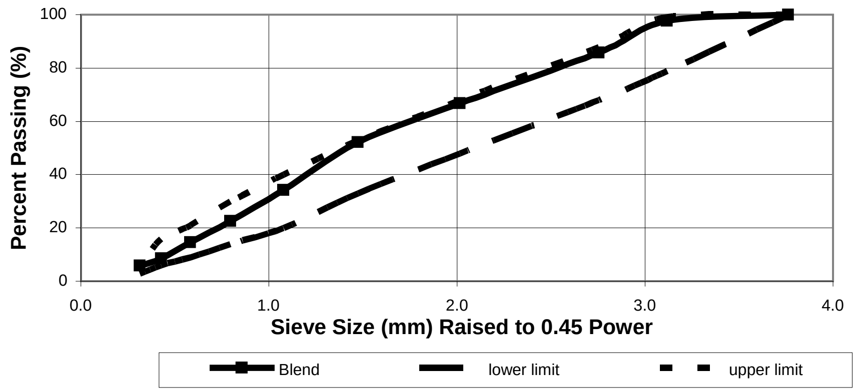
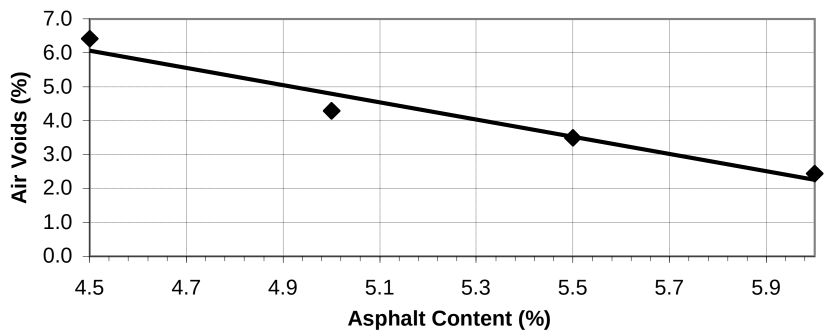


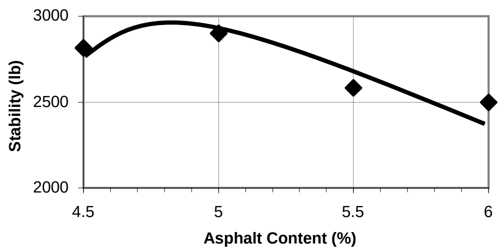
Figure A-10. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Fine Mix Limestone



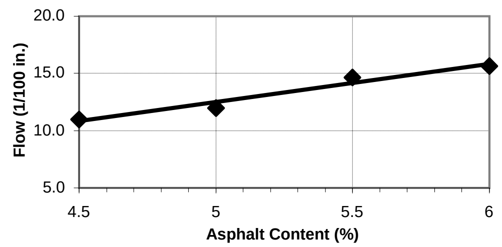
Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.2%
Percent by Weight Elongated Particles (5:1)	0.4%
Percent by Weight Flat Particles (5:1)	1.5%

Figure A-11. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Fine Mix Limestone

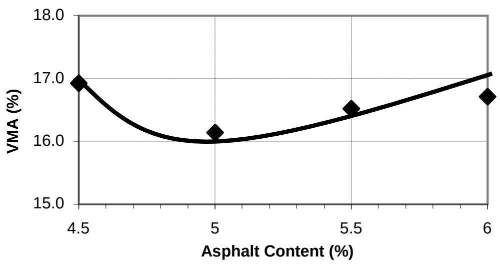
Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content



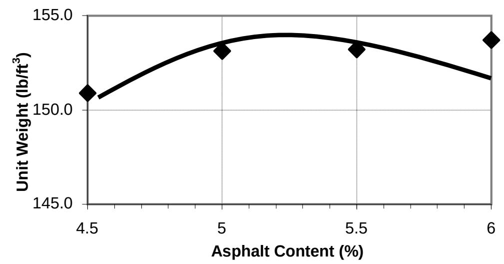
Stability



Flow



Voids in Mineral Aggregate



Unit Weight

Figure A-12. Marshall Mix Design Results, 3/4-Inch Fine Limestone, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Coarse Limestone

		Individual Stockpiles				
	Total Combined				692 Stone	
Percent Passing	**Gradation**	**#6**	**#7**	**821-1/4 mod**	**Sand**	**Mortar Sand**
1"	100	100	100	100	100	100
3/4"	98	90	100	100	100	100
1/2"	83	15	93	100	100	100
3/8"	69	2	57	100	100	100
#4	50	1	3	100	98	100
#8	38	0	1	95	72	100
#16	25	0	1	65	47	100
#30	17	0	1	41	31	94
#50	11	0	1	23	21	32
#100	7	0	1	10	13	1
#200	4.7	0.4	0.5	5.1	9.5	0.6
Percent Used:	100	17%	33%	43%	7%	0%

Percent of Asphalt Cement	4.8%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160°C (320°F)
Compaction Temperature	145°C (290°F)

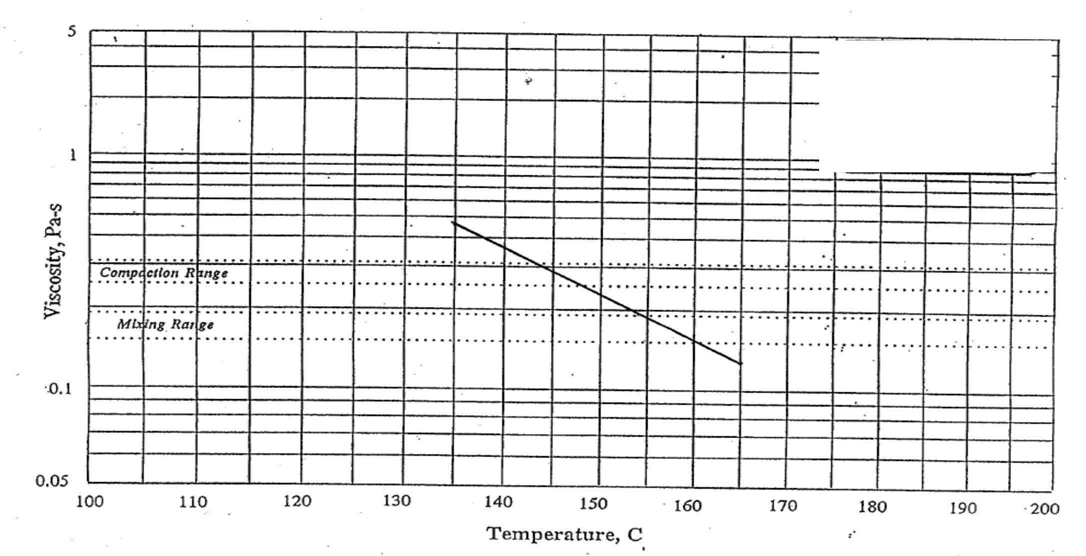


Figure A-13. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Limestone

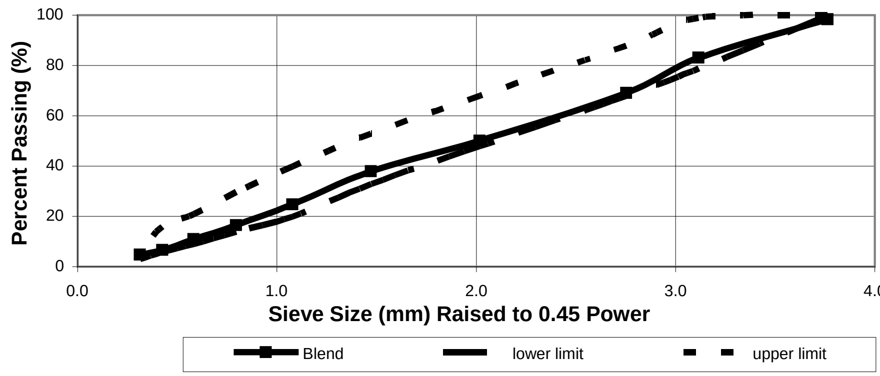
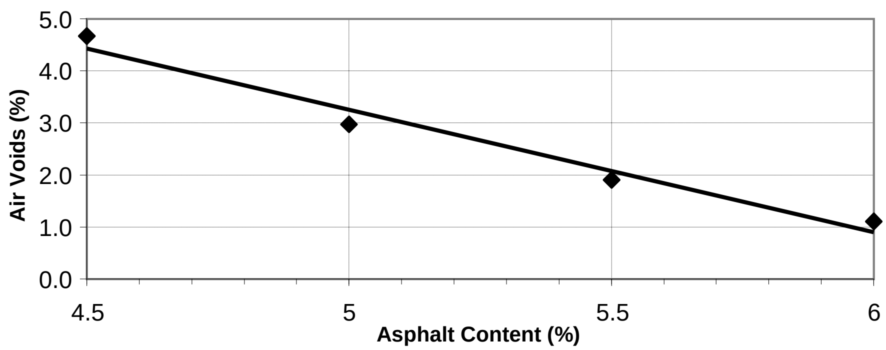


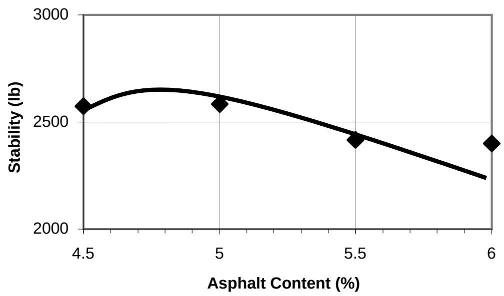
Figure A-14. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Coarse Mix Limestone



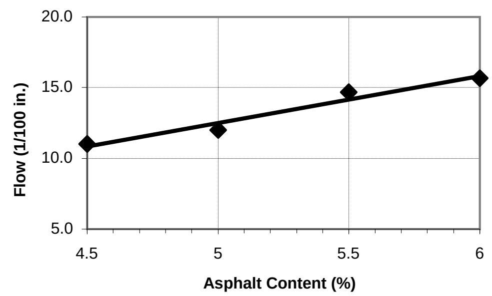
Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.1%
Percent by Weight Elongated Particles (5:1)	0.3%
Percent by Weight Flat Particles (5:1)	1.2%

Figure A-15. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Coarse Mix Limestone

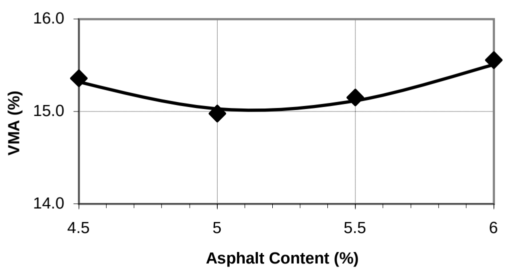
Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content



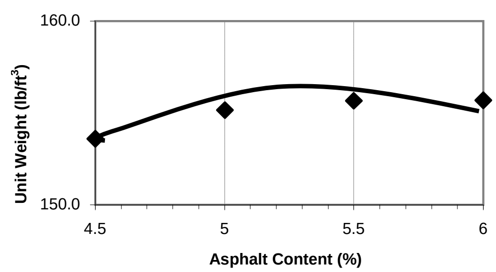
Stability



Flow



Voids in Mineral Aggregate



Unit Weight

Figure A-16. Marshall Mix Design Results, 3/4-Inch Coarse Limestone, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Fine Limestone With Mortar Sand

		Individual Stockpiles				
Percent Passing	**Total Combined Gradation**	**#6**	**#7**	**821-1/4 mod**	**692 Stone Sand**	**Mortar Sand**
1"	100	100	100	100	100	100
3/4"	100	90	100	100	100	100
1/2"	98	15	93	100	100	100
3/8"	87	2	57	100	100	100
#4	69	1	3	100	98	100
#8	53	0	1	95	72	100
#16	38	0	1	65	47	100
#30	28	0	1	41	31	94
#50	16	0	1	23	21	32
#100	8	0	1	10	13	1
#200	5.9	0.4	0.5	5.1	9.5	0.6
Percent Used:	100	0%	30%	60%	0%	10%

Percent of Asphalt Cement	5.7%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160°C (320°F)
Compaction Temperature	145°C (290°F)

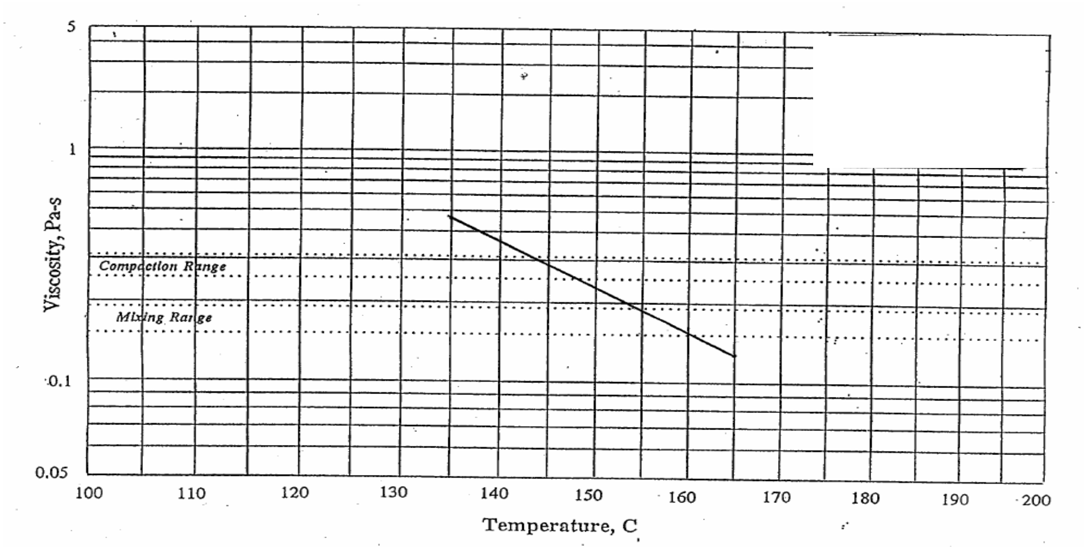


Figure A-17. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Fine Limestone With Mortar Sand

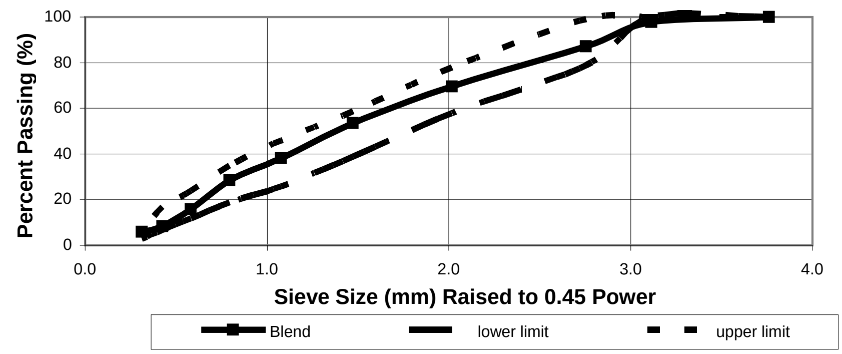
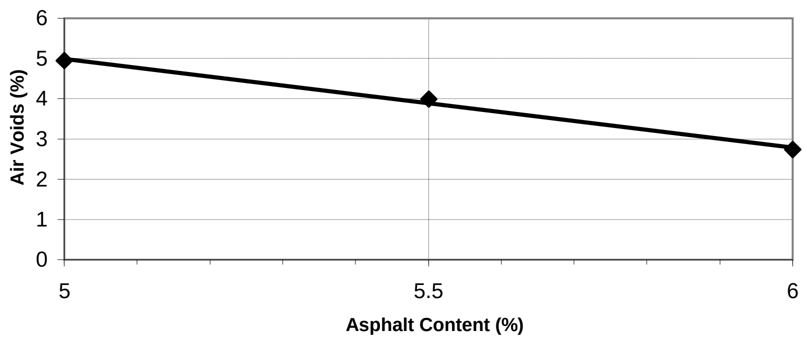


Figure A-18. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Fine Mix Limestone With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.2%
Percent by Weight Elongated Particles (5:1)	0.4%
Percent by Weight Flat Particles (5:1)	1.5%

Figure A-19. Plot of Air Content vs Asphalt Content for 1/2-Inch Fine Mix Limestone With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

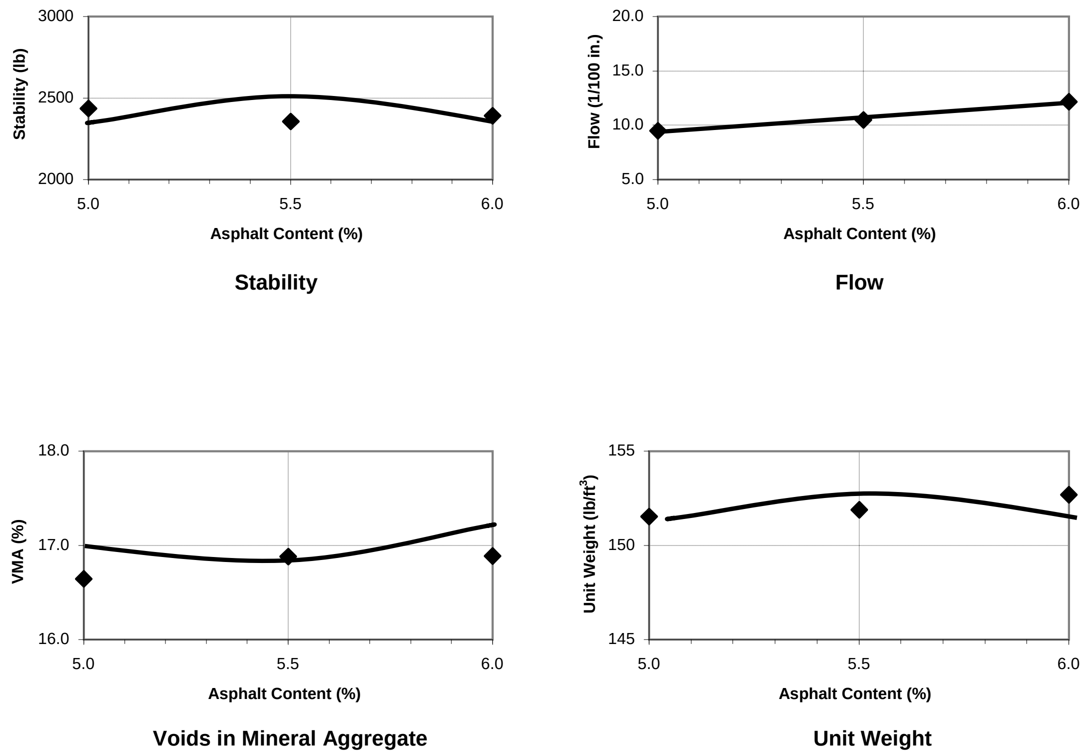


Figure A-20. Marshall Mix Design Results, 1/2-Inch Fine Limestone With Mortar Sand, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Coarse Limestone With Mortar Sand

Percent Passing	Total Combined Gradation	#6	#7	821-1/4 mod	692 Stone Sand	Mortar Sand
			Individual Stockpiles			
1"	100	100	100	100	100	100
3/4"	100	90	100	100	100	100
1/2"	97	15	93	100	100	100
3/8"	84	2	57	100	100	100
#4	62	1	3	100	98	100
#8	48	0	1	95	72	100
#16	34	0	1	65	47	100
#30	26	0	1	41	31	94
#50	14	0	1	23	21	32
#100	7	0	1	10	13	1
#200	5.2	0.4	0.5	5.1	9.5	0.6
Percent Used:	100	0%	38%	52%	0%	10%

Percent of Asphalt Cement	5.4%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160 °C (320°F)
Compaction Temperature	145 °C (290°F)

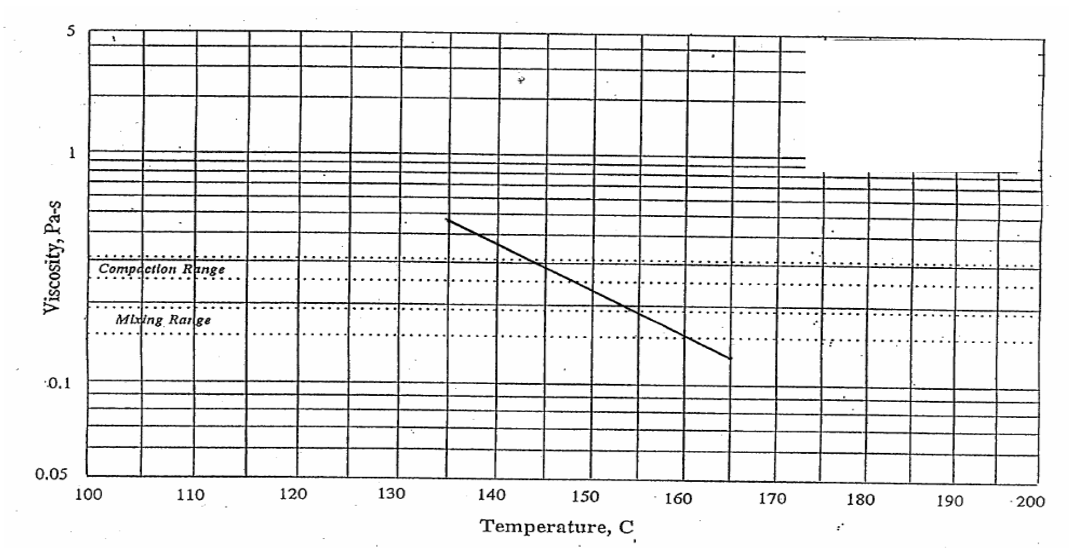


Figure A-21. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Coarse Limestone With Mortar Sand

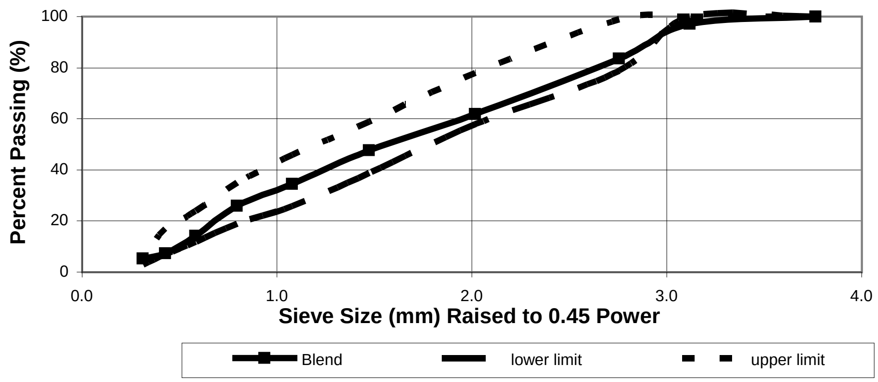
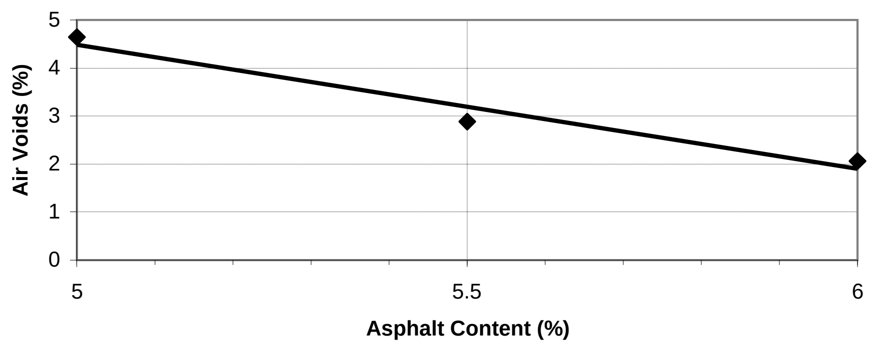


Figure A-22. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Coarse Mix Limestone With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.2%
Percent by Weight Elongated Particles (5:1)	0.4%
Percent by Weight Flat Particles (5:1)	1.5%

Figure A-23. Plot of Air Content vs Asphalt Content for 1/2-Inch Coarse Mix Limestone With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

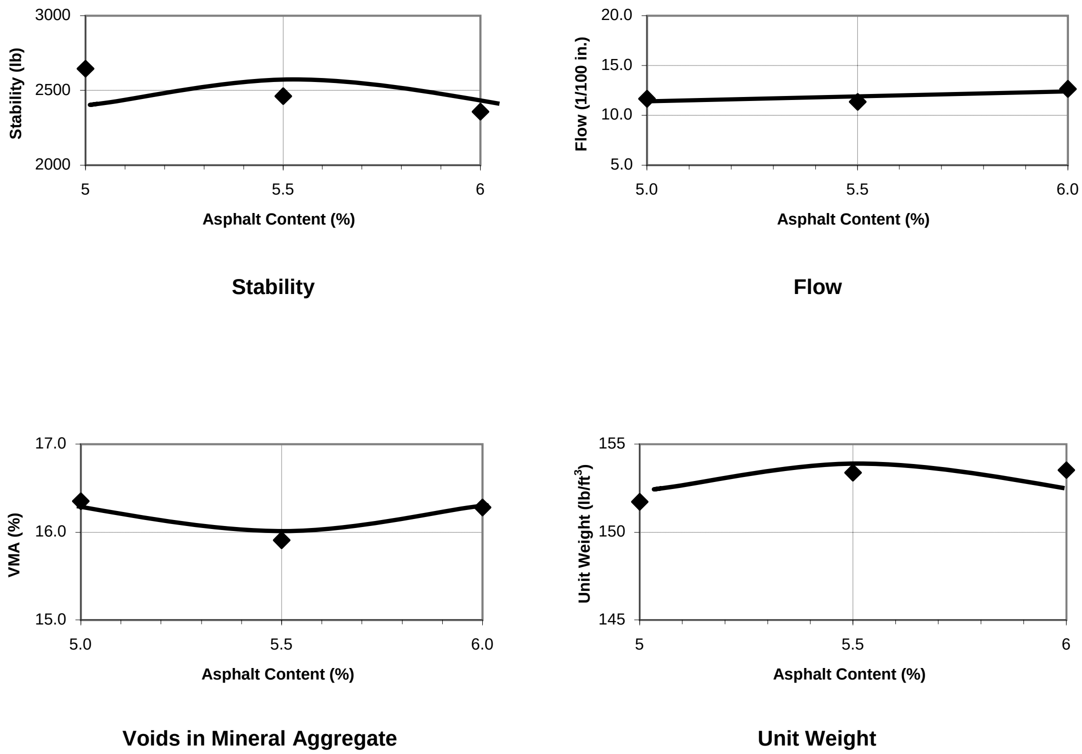


Figure A-24. Marshall Mix Design Results, 1/2-Inch Coarse Limestone With Mortar Sand, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Fine Limestone With Mortar Sand

		Individual Stockpiles				
	Total Combined				692 Stone	
Percent Passing	**Gradation**	**#6**	**#7**	**821-1/4 mod**	**Sand**	**Mortar Sand**
1"	100	100	100	100	100	100
3/4"	100	90	100	100	100	100
1/2"	97	15	93	100	100	100
3/8"	82	2	57	100	100	100
#4	58	1	3	100	98	100
#8	45	0	1	95	72	100
#16	33	0	1	65	47	100
#30	28	0	1	41	31	94
#50	13	0	1	23	21	32
#100	7	0	1	10	13	1
#200	4.8	0.4	0.5	5.1	9.5	0.6
Percent Used:	100	0%	42%	48%	0%	10%

Percent of Asphalt Cement	5.1%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160°C (320°F)
Compaction Temperature	145°C (290°F)

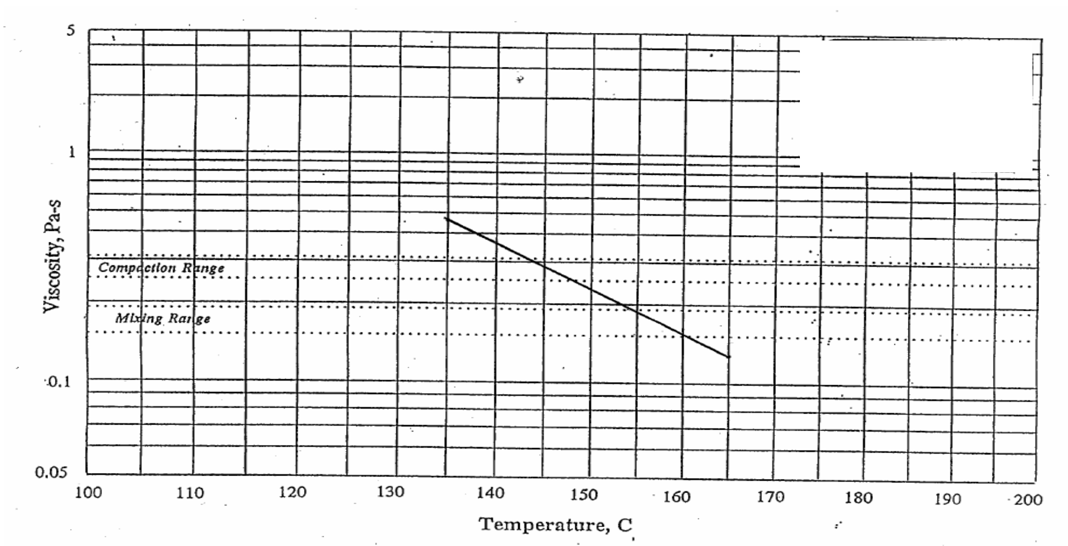


Figure A-25. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Fine Mix Limestone With Mortar Sand

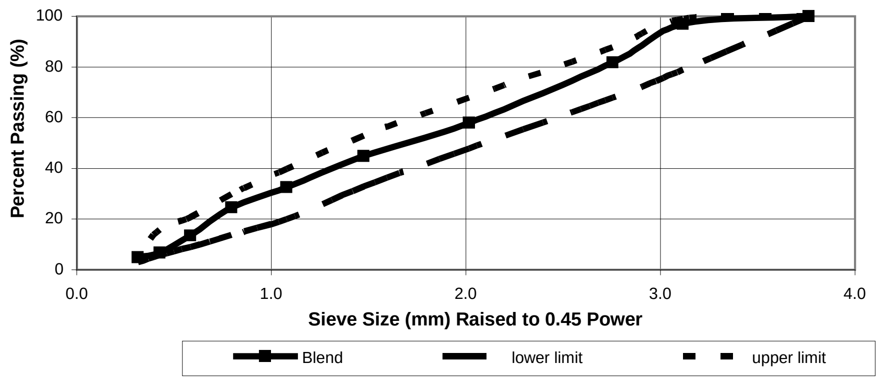
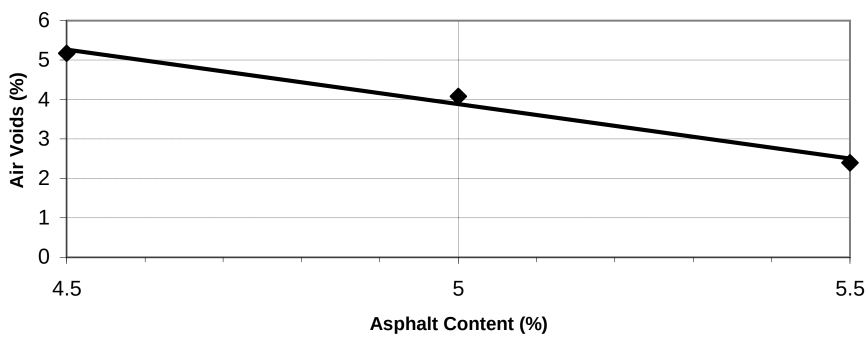


Figure A-26. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Fine Mix Limestone With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.2%
Percent by Weight Elongated Particles (5:1)	0.4%
Percent by Weight Flat Particles (5:1)	1.5%

Figure A-27. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Fine Mix Limestone With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

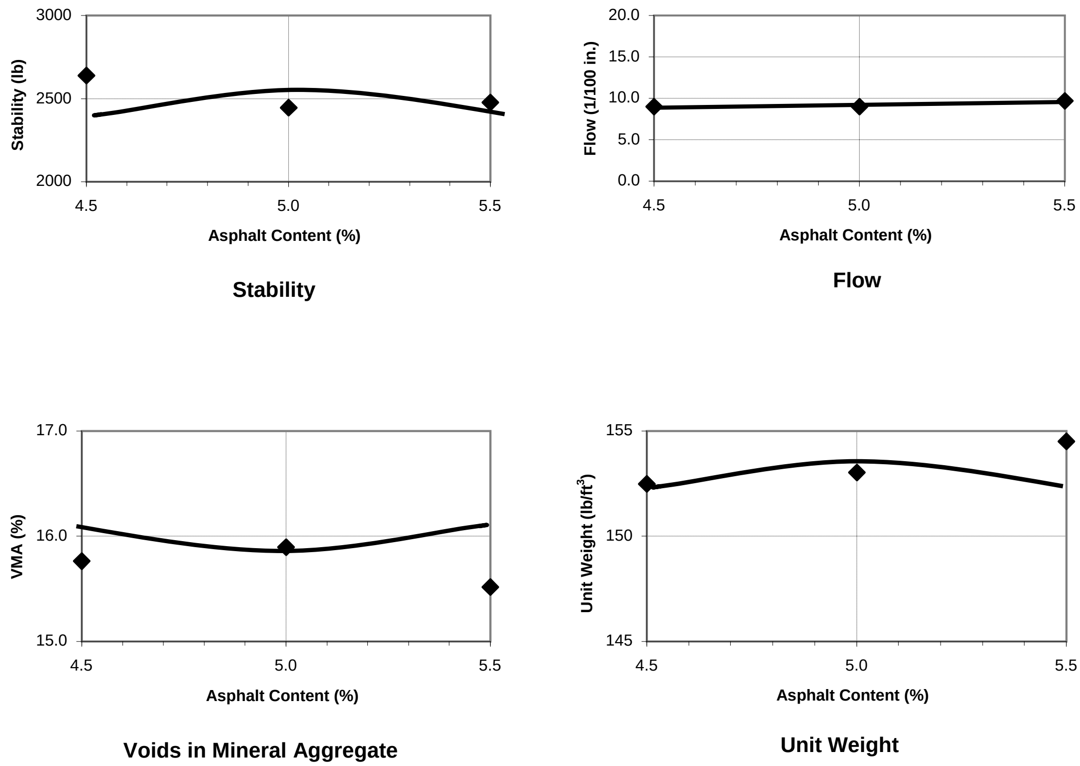


Figure A-28. Marshall Mix Design Results, 3/4-Inch Fine Mix Limestone With Sand, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Coarse Limestone With Mortar Sand

		Individual Stockpiles				
	Total Combined				692 Stone	
Percent Passing	**Gradation**	**#6**	**#7**	**821-1/4 mod**	**Sand**	**Mortar Sand**
1"	100	100	100	100	100	100
3/4"	99	90	100	100	100	100
1/2"	92	15	93	100	100	100
3/8"	76	2	57	100	100	100
#4	53	1	3	100	98	100
#8	41	0	1	95	72	100
#16	30	0	1	65	47	100
#30	23	0	1	41	31	94
#50	12	0	1	23	21	32
#100	6	0	1	10	13	1
#200	4.4	0.4	0.5	5.1	9.5	0.6
Percent Used:	100	5%	40%	45%	0%	10%

Percent of Asphalt Cement	5.0%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160°C (320°F)
Compaction Temperature	145°C (290°F)

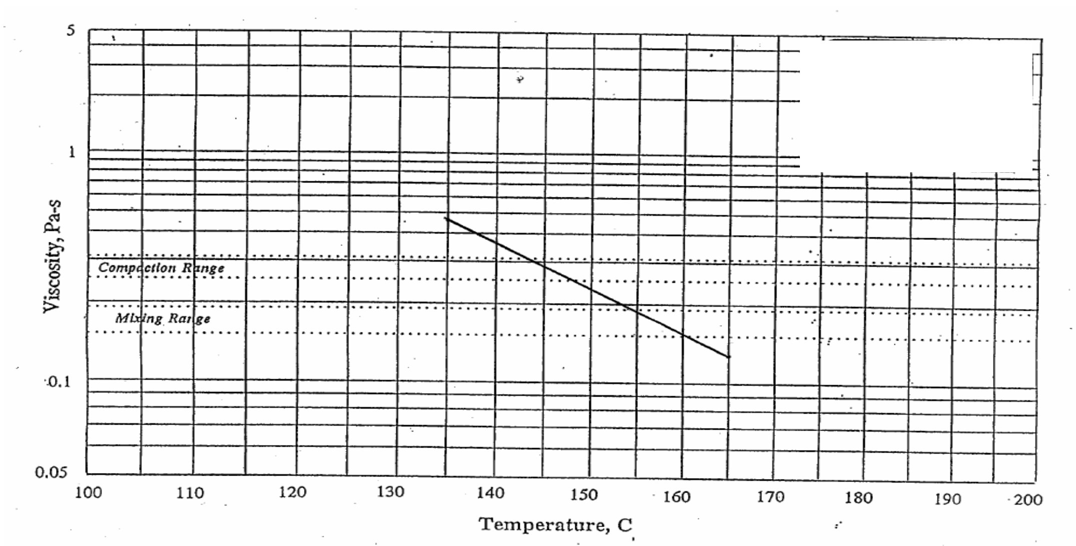


Figure A-29. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Coarse Limestone With Mortar Sand

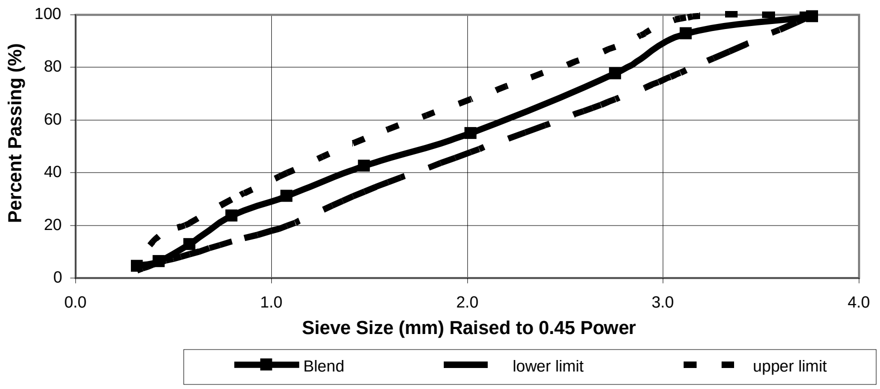
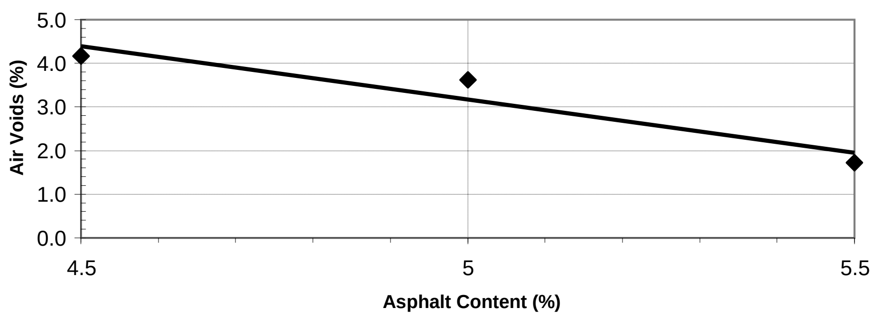


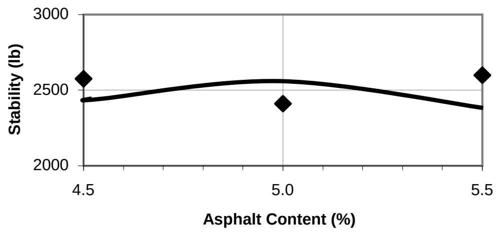
Figure A-30. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Coarse Mix Limestone With 10% Mortar Sand



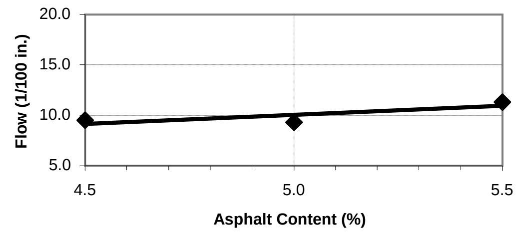
Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.1%
Percent by Weight Elongated Particles (5:1)	0.3%
Percent by Weight Flat Particles (5:1)	1.4%

Figure A-31. Plot of Air Content vs Asphalt Content for 3/4-Inch Coarse Mix Limestone With Mortar Sand

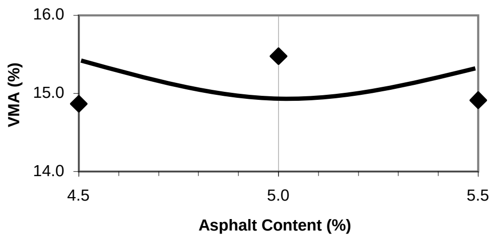
Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content



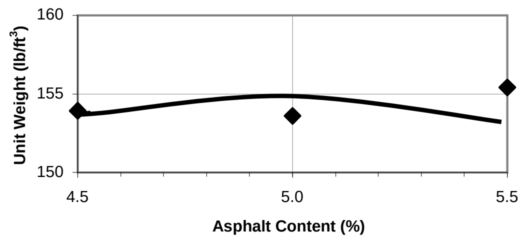
Stability



Flow



Voids in Mineral Aggregate



Unit Weight

Figure A-32. Marshall Mix Design Results, 3/4-Inch Coarse Mix Limestone With Sand, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Fine Granite

Percent Passing	Combined Gradation	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	Mortar Sand
		Individual Stockpiles									
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	100	1	8	99	100	100	100	100	100	100	100
3/8"	94	1	0	13	100	100	100	100	100	100	100
#4	73	1	0	0	6	99	100	100	100	100	100
#8	55	1	0	0	0	11	100	100	100	100	100
#16	42	1	0	0	0	0	14	100	100	100	100
#30	33	1	0	0	0	0	8	13	99	100	94
#50	21	1	0	0	0	0	2	2	16	100	32
#100	10	1	0	0	0	0	2	2	4	51	1
#200	5.6	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100%	0%	0%	7%	21%	19%	13%	9%	13%	18%	0%

Percent of Asphalt Cement	6.8%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160^{o}C (320^{o}F)
Compaction Temperature	145^{o}C (290^{o}F)

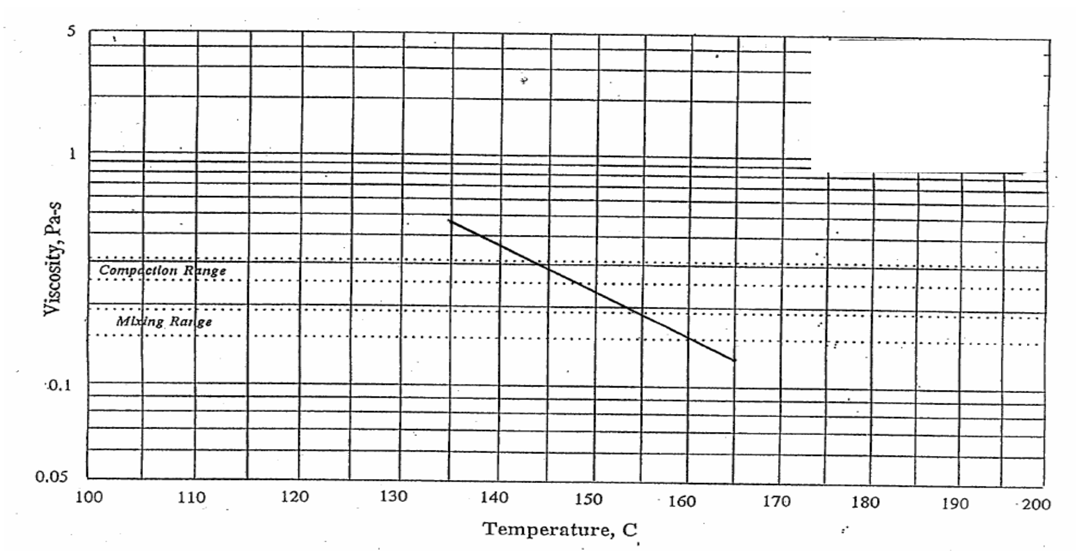


Figure A-33. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Fine Granite

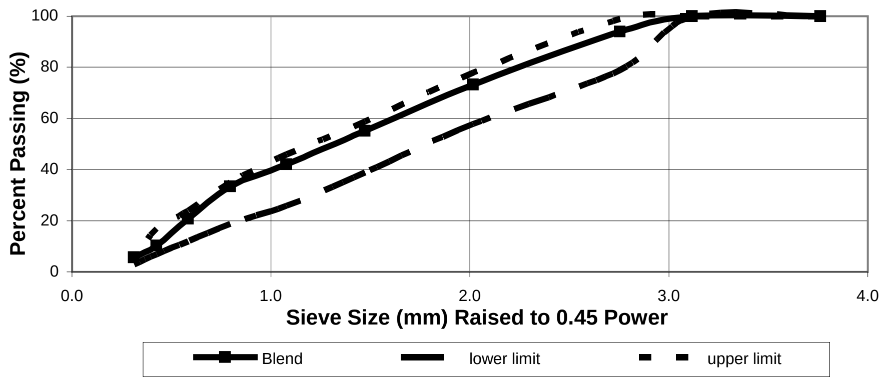
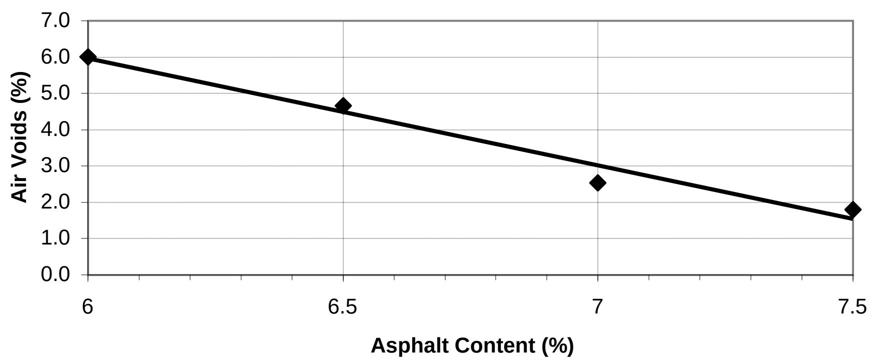


Figure A-34. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Fine Mix Granite



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	1.1%

Figure A-35. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Fine Mix Granite

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

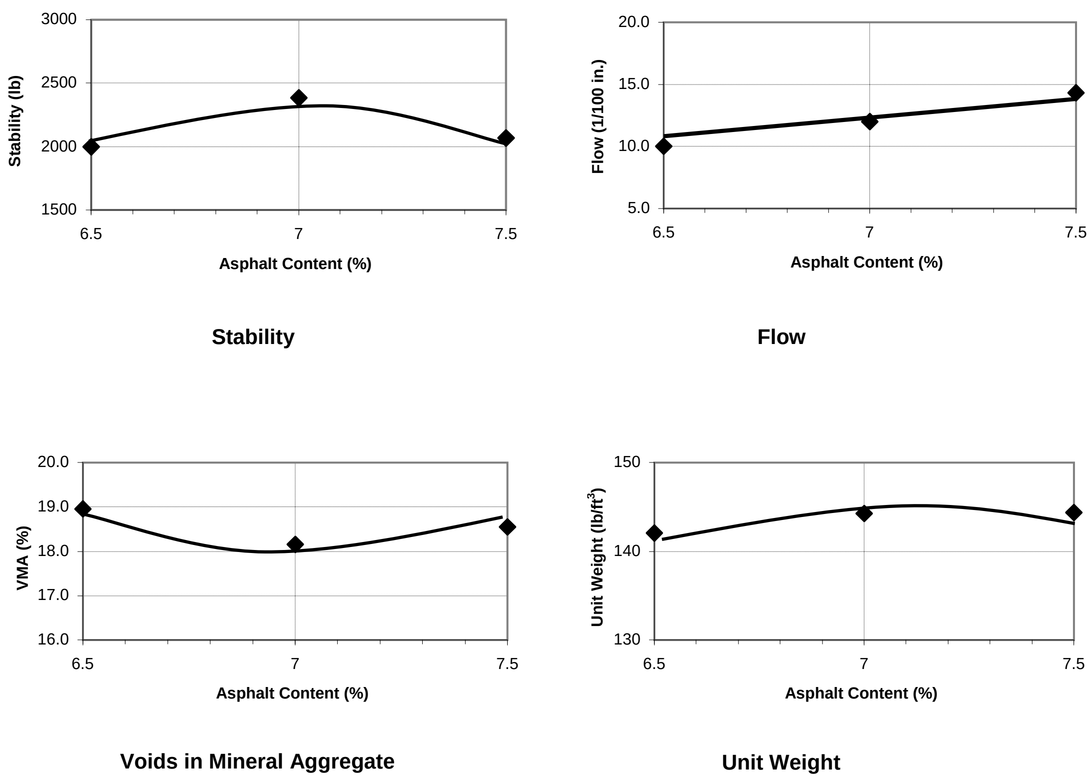


Figure A-36. Marshall Mix Design Results, 1/2-Inch Fine Mix Granite, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Coarse Granite

		Individual Stockpiles									
Percent Passing	**Combined Gradation**	**3/4"**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	100	1	8	99	100	100	100	100	100	100	100
3/8"	81	1	0	13	100	100	100	100	100	100	100
#4	60	1	0	0	6	99	100	100	100	100	100
#8	42	1	0	0	0	11	100	100	100	100	100
#16	32	1	0	0	0	0	14	100	100	100	100
#30	24	1	0	0	0	0	8	13	99	100	94
#50	15	1	0	0	0	0	2	2	16	100	32
#100	8	1	0	0	0	0	2	2	4	51	1
#200	4.1	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100%	0%	0%	22%	19%	19%	10%	8%	9%	13%	0%

Percent of Asphalt Cement	5.8%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160 °C (320°F)
Compaction Temperature	145 °C (290°F)

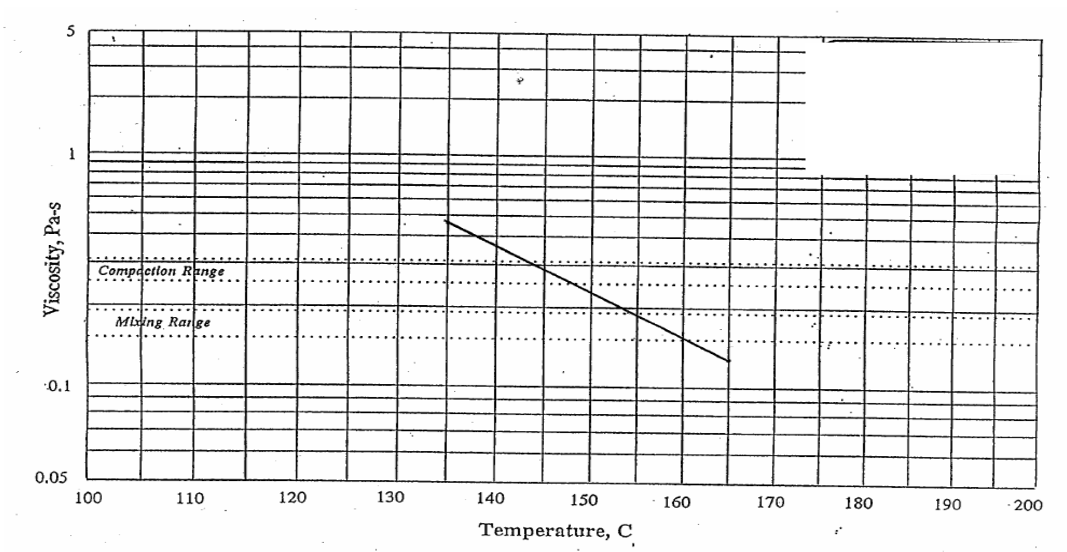


Figure A-37. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Coarse Granite

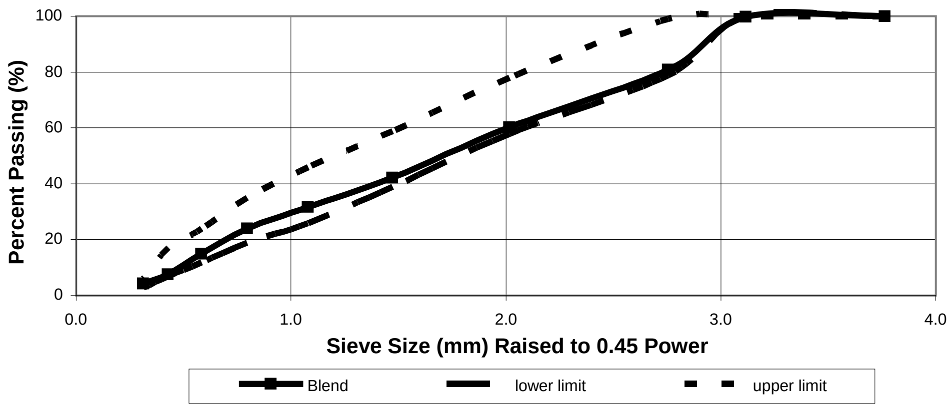
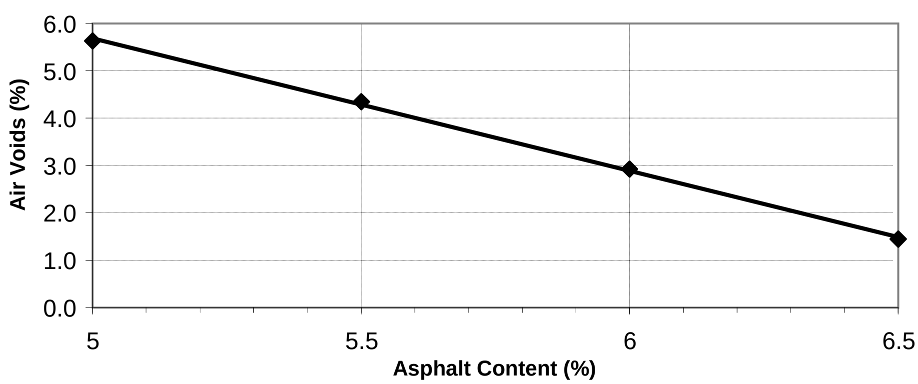


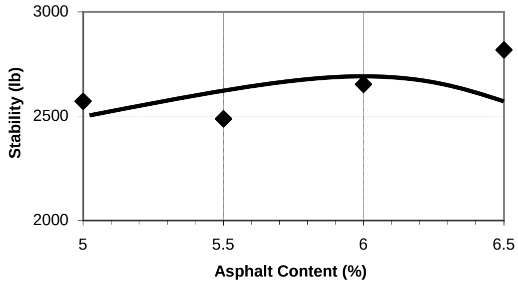
Figure A-38. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Coarse Mix Granite



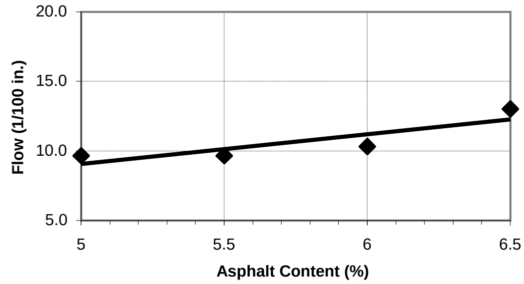
Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.9%

Figure A-39. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Coarse Mix Granite

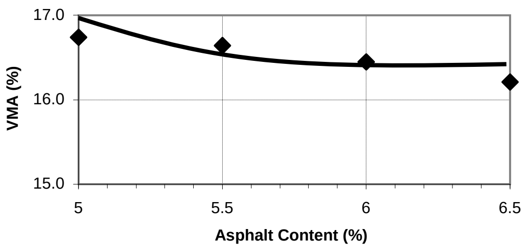
Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content



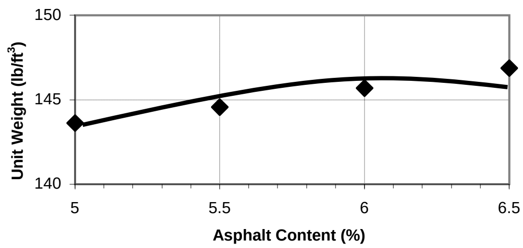
Stability



Flow



Voids in Mineral Aggregate



Unit Weight

Figure A-40. Marshall Mix Design Results, 1/2-Inch Coarse Granite, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Fine Granite

		Individual Stockpiles									
Percent Passing	**Combined Gradation**	**3/4"**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	95	1	8	99	100	100	100	100	100	100	100
3/8"	85	1	0	13	100	100	100	100	100	100	100
#4	66	1	0	0	6	99	100	100	100	100	100
#8	51	1	0	0	0	11	100	100	100	100	100
#16	38	1	0	0	0	0	14	100	100	100	100
#30	28	1	0	0	0	0	8	13	99	100	94
#50	16	1	0	0	0	0	2	2	16	100	32
#100	8	1	0	0	0	0	2	2	4	51	1
#200	4.5	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	0%	5%	12%	18%	16%	13%	11%	11%	14%	0%

Percent of Asphalt Cement	5.9%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160 °C (320°F)
Compaction Temperature	145 °C (290°F)

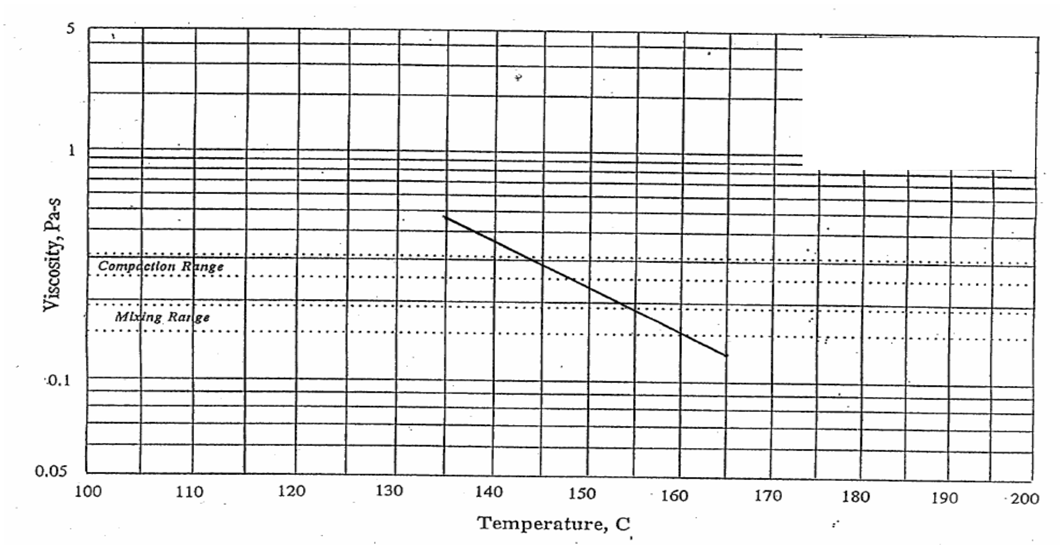


Figure A-41. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Fine Granite

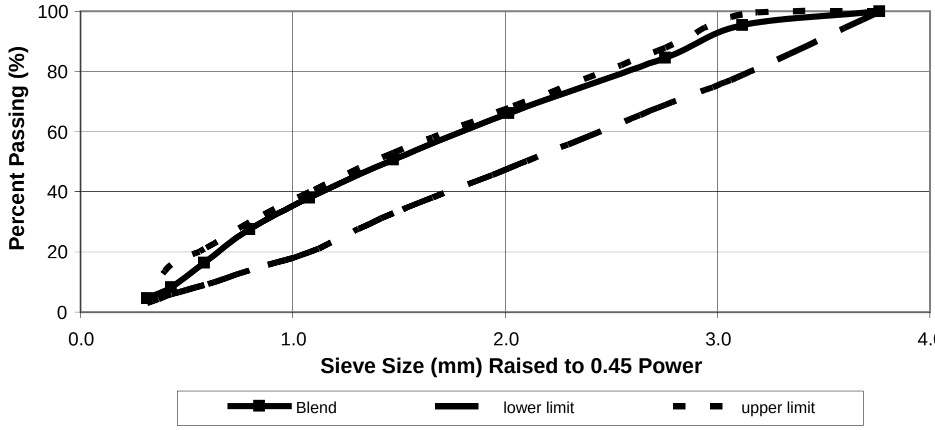
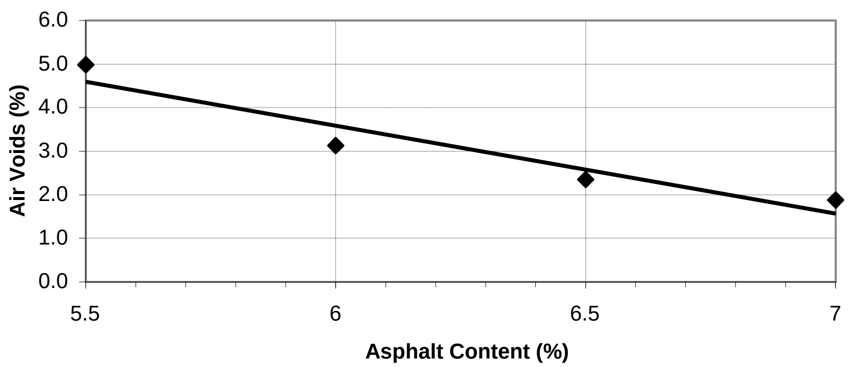


Figure A-42. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Fine Mix Granite



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.9%

Figure A-43. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Fine Mix Granite

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

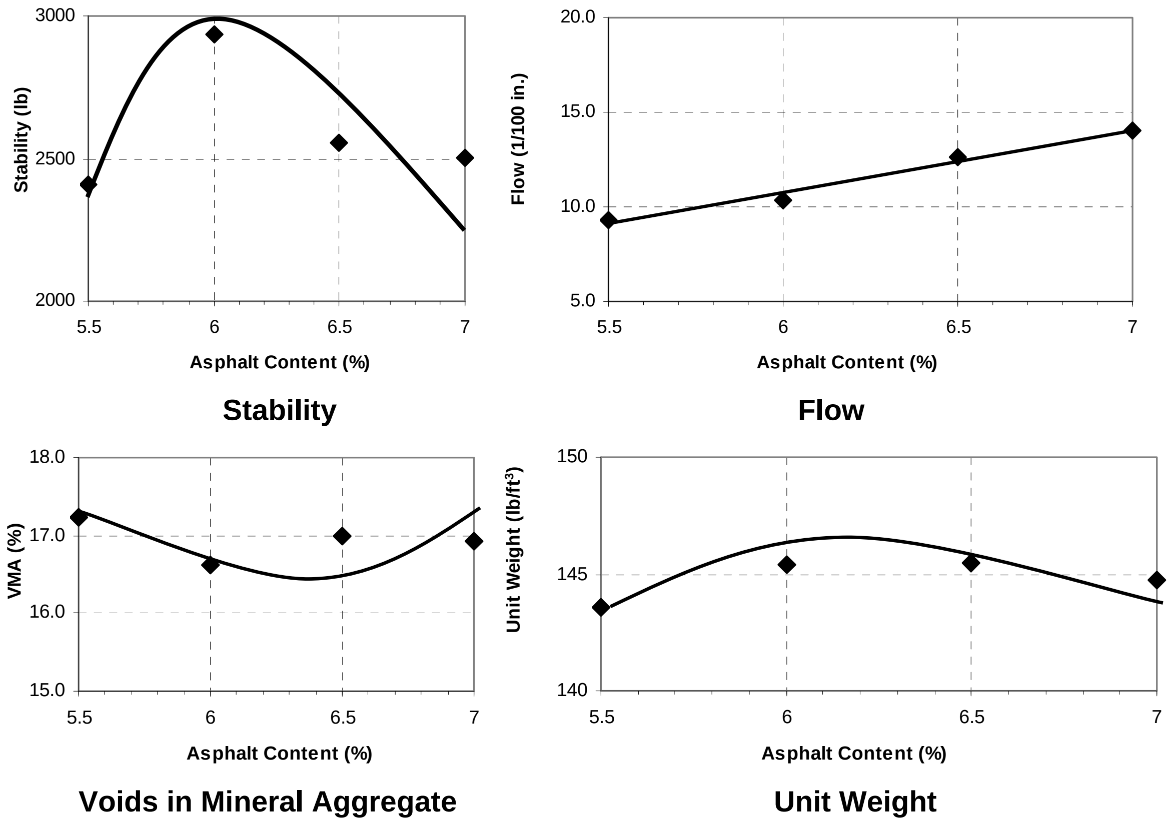


Figure A-44. Marshall Mix Design Results, 3/4-Inch Fine Granite, PG 64-22

Marshall Mix Design Results

Aggregate Blend : 3/4-Inch Coarse Granite

		Individual Stockpiles									
Percent Passing	**Combined Gradation**	**3/4"**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	81	1	8	99	100	100	100	100	100	100	100
3/8"	70	1	0	13	100	100	100	100	100	100	100
#4	52	1	0	0	6	99	100	100	100	100	100
#8	37	1	0	0	0	11	100	100	100	100	100
#16	27	1	0	0	0	0	14	100	100	100	100
#30	20	1	0	0	0	0	8	13	99	100	94
#50	14	1	0	0	0	0	2	2	16	100	32
#100	7	1	0	0	0	0	2	2	4	51	1
#200	3.8	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	0%	21%	11%	17%	16%	10%	7%	6%	12%	0%

Percent of Asphalt Cement	5.4%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160°C (320°F)
Compaction Temperature	145°C (290°F)

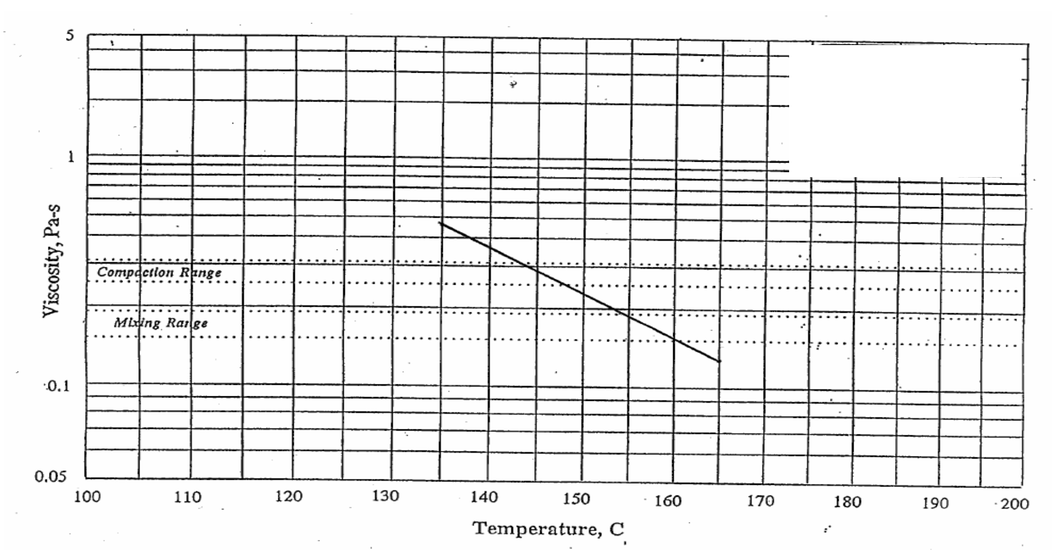


Figure A-45. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Coarse Granite

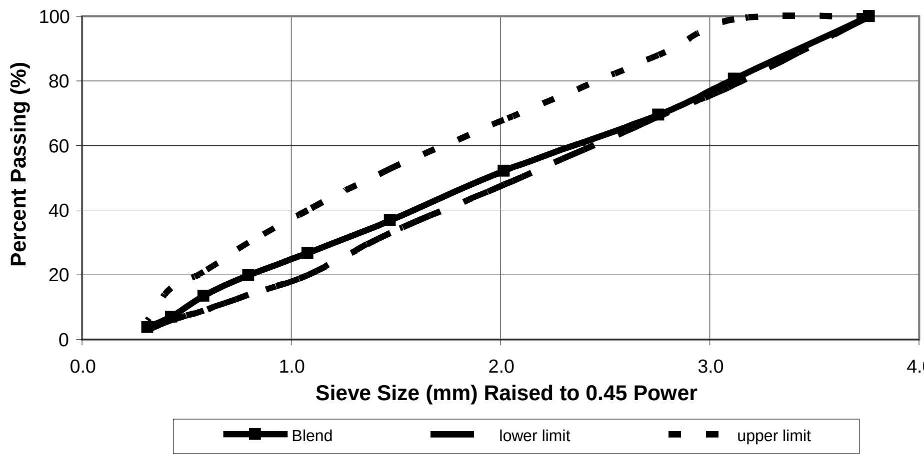
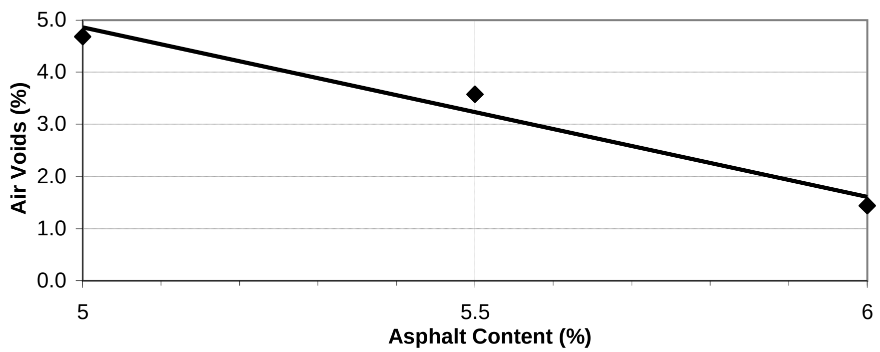


Figure A-46. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Coarse Mix Granite



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.8%

Figure A-47. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Coarse Mix Granite

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

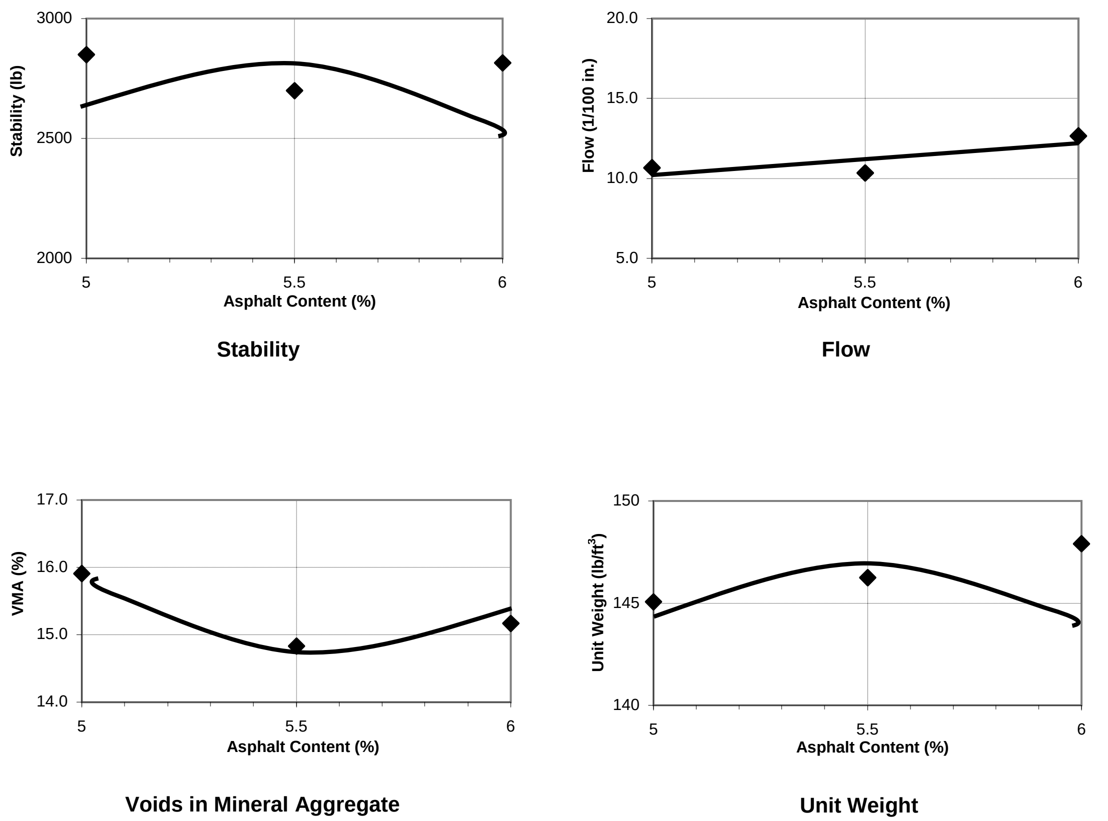


Figure A-48. Marshall Mix Design Results, 3/4-Inch Coarse Granite, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 1-Inch Fine Granite

		Individual Stockpiles									
Percent Passing	**Combined Gradation**	**3/4"**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	95	1	100	100	100	100	100	100	100	100	100
1/2"	83	1	8	99	100	100	100	100	100	100	100
3/8"	73	1	0	13	100	100	100	100	100	100	100
#4	57	1	0	0	6	99	100	100	100	100	100
#8	44	1	0	0	0	11	100	100	100	100	100
#16	35	1	0	0	0	0	14	100	100	100	100
#30	25	1	0	0	0	0	8	13	99	100	94
#50	17	1	0	0	0	0	2	2	16	100	32
#100	9	1	0	0	0	0	2	2	4	51	1
#200	4.6	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	5%	13%	11%	15%	14%	8%	11%	8%	15%	0%

Percent of Asphalt Cement	5.5%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160^{o}C (320^{o}F)
Compaction Temperature	145^{o}C (290^{o}F)

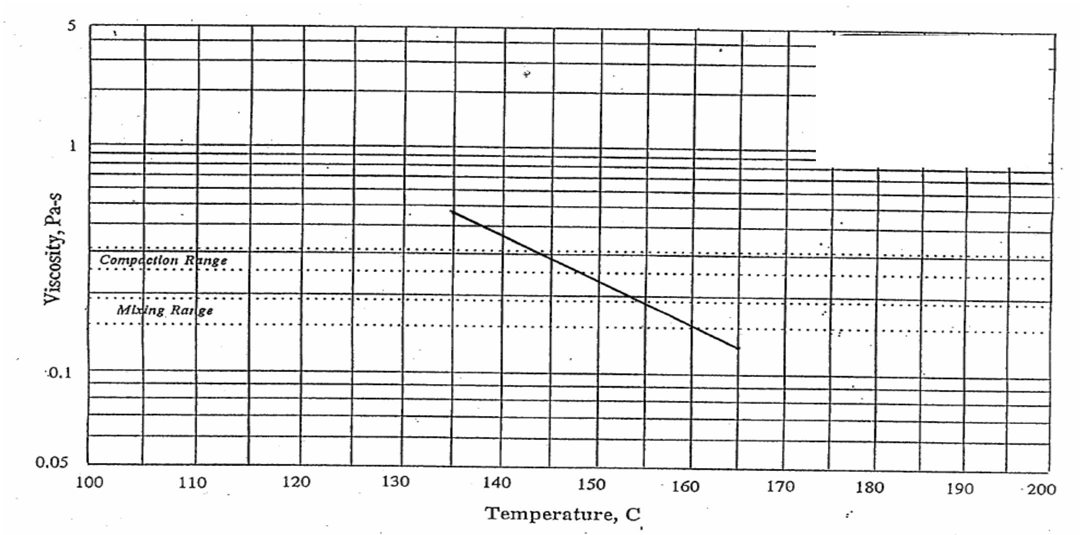


Figure A-49. Temperature Viscosity Relationship of Asphalt Cement for 1-Inch Fine Granite

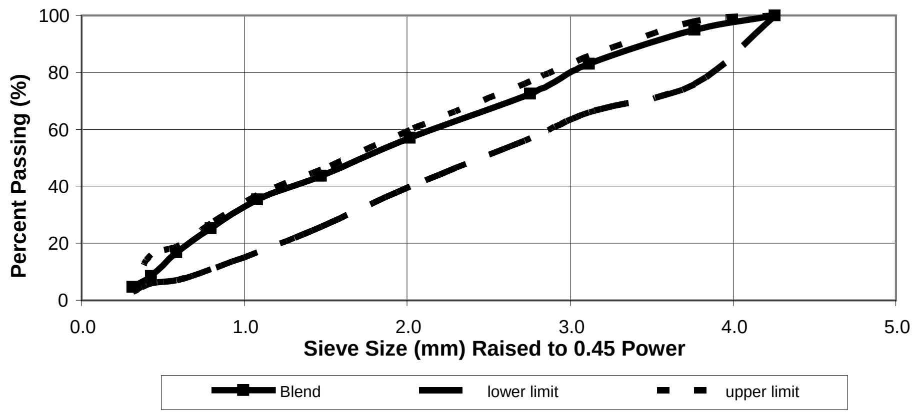
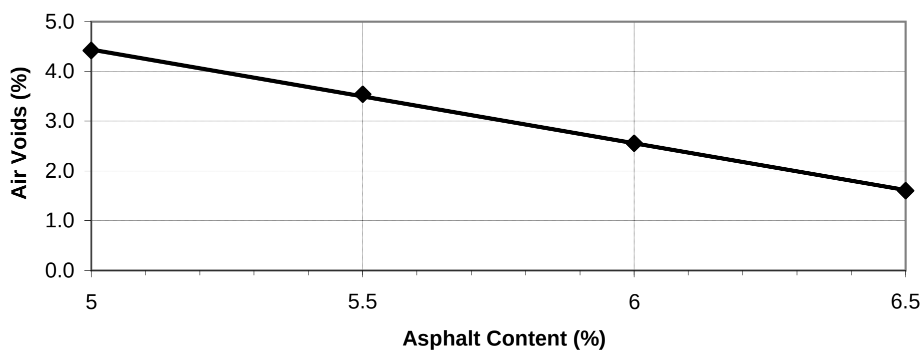


Figure A-50. Combined Gradation Plotted on 0.45 Power Curve for 1-Inch Mix Granite



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.9%

Figure A-51. Plot of Air Void Content vs Asphalt Content for 1-Inch Mix Granite

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

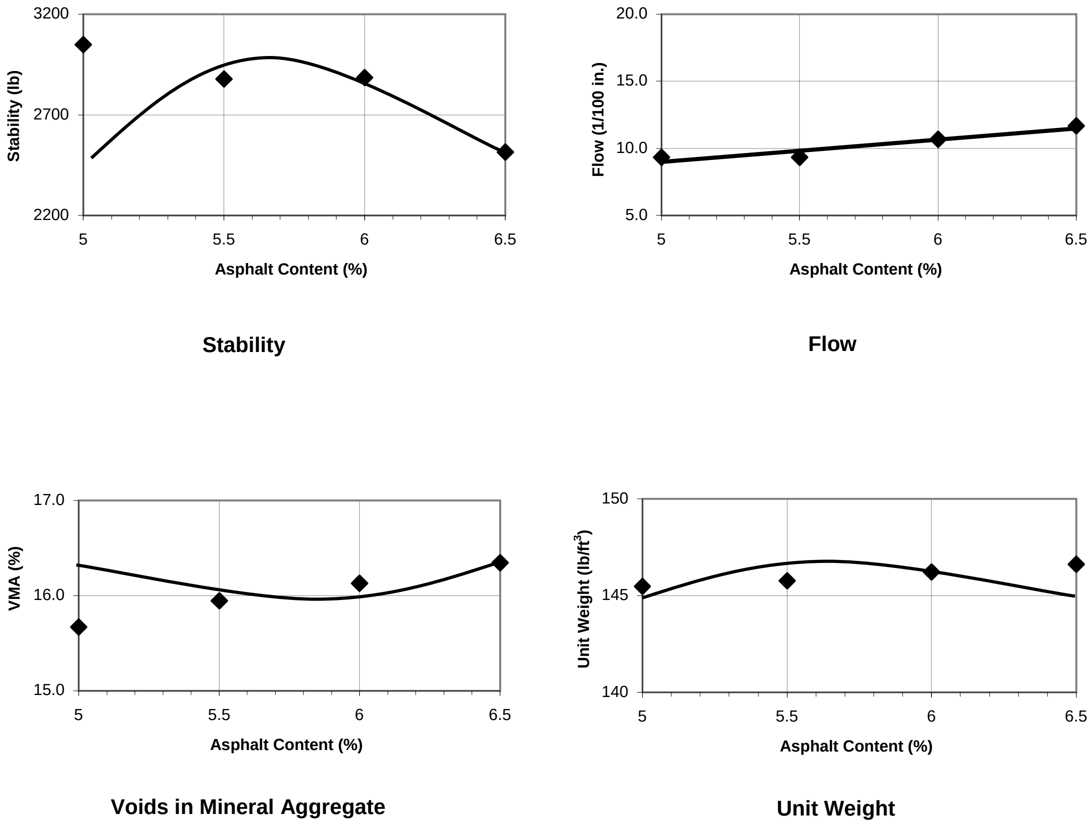


Figure A-52. Marshall Mix Design Results, 1-Inch Fine Granite, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 1-Inch Coarse Granite

Percent Passing	Combined Gradation	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	Mortar Sand
		Individual Stockpiles									
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	79	1	100	100	100	100	100	100	100	100	100
1/2"	70	1	8	99	100	100	100	100	100	100	100
3/8"	59	1	0	13	100	100	100	100	100	100	100
#4	43	1	0	0	6	99	100	100	100	100	100
#8	29	1	0	0	0	11	100	100	100	100	100
#16	21	1	0	0	0	0	14	100	100	100	100
#30	17	1	0	0	0	0	8	13	99	100	94
#50	13	1	0	0	0	0	2	2	16	100	32
#100	7	1	0	0	0	0	2	2	4	51	1
#200	3.7	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	21%	10%	12%	15%	15%	7%	5%	3%	12%	0%

Percent of Asphalt Cement	5.0%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160 °C (320°F)
Compaction Temperature	145 °C (290°F)

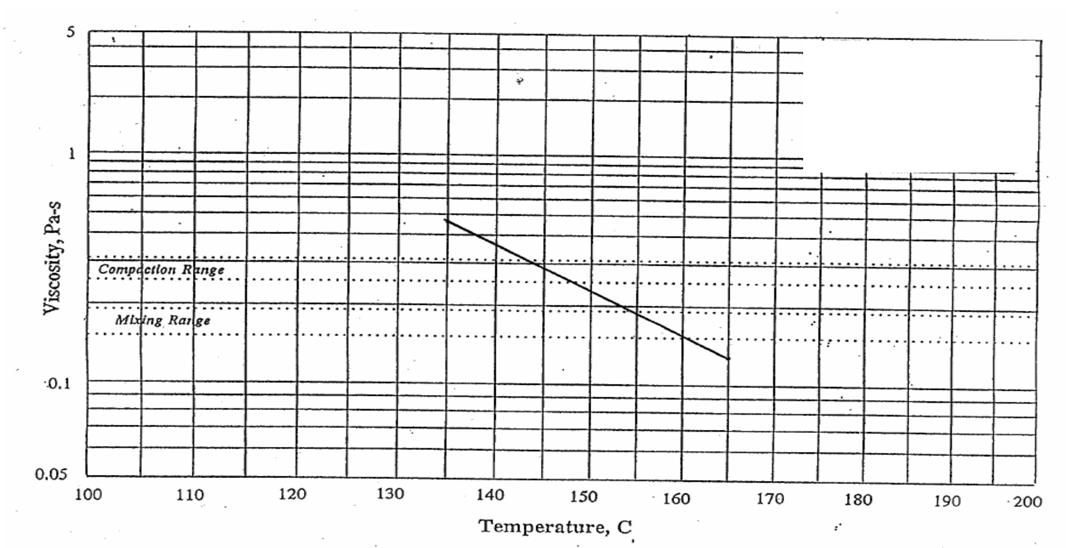


Figure A-53. Temperature Viscosity Relationship of Asphalt Cement for 1-Inch Coarse Granite

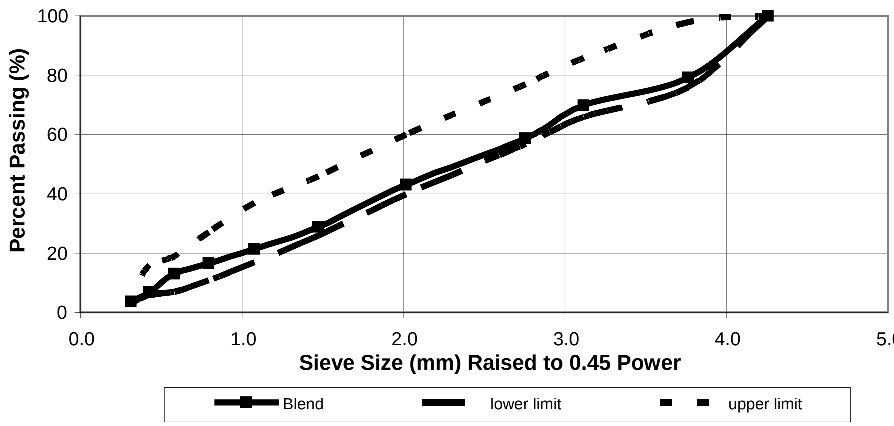
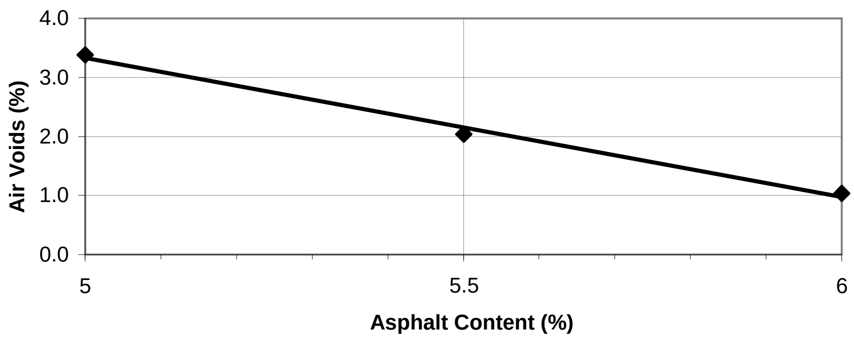


Figure A-54. Combined Gradation Plotted on 0.45 Power Curve for 1-Inch Coarse Mix Granite



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	1.0%

Figure A-55. Plot of Air Void Content vs Asphalt Content for 1-Inch Coarse Mix Granite

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

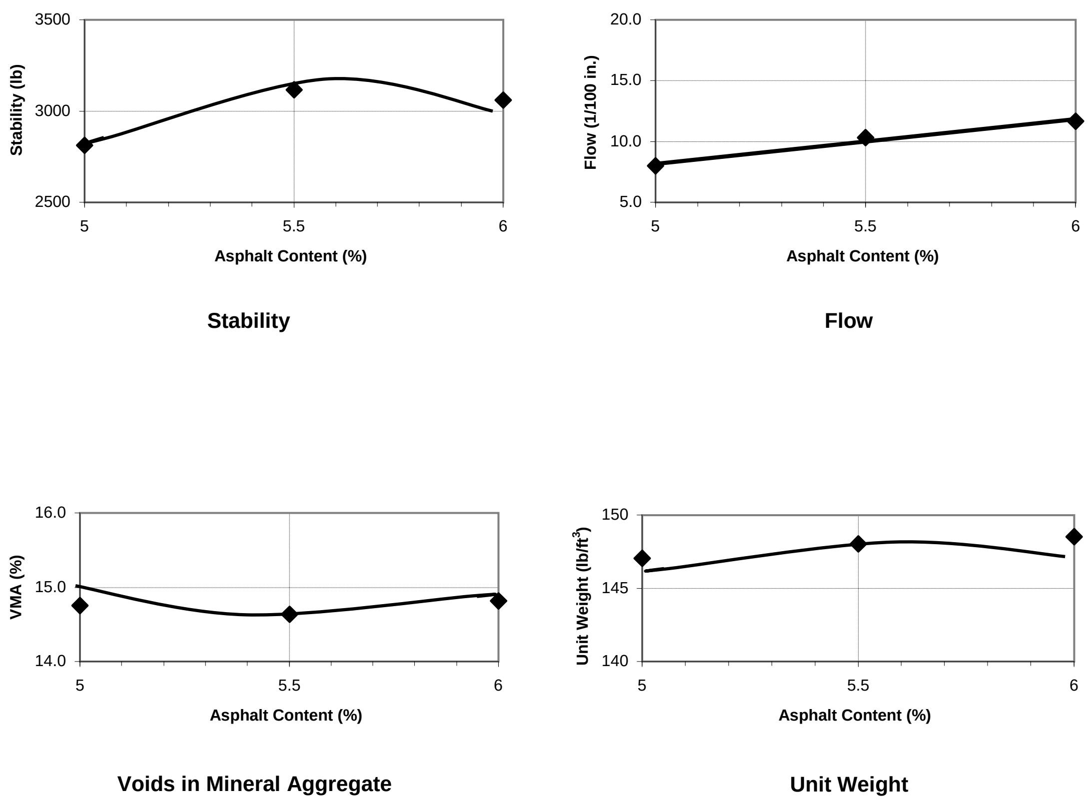


Figure A-56. Marshall Mix Design Results, 1-Inch Coarse Granite, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Fine Granite With Mortar Sand

		Individual Stockpiles									
Percent Passing	**Combined Gradation**	**3/4"**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	100	1	8	99	100	100	100	100	100	100	100
3/8"	93	1	0	13	100	100	100	100	100	100	100
#4	71	1	0	0	6	99	100	100	100	100	100
#8	52	1	0	0	0	11	100	100	100	100	100
#16	37	1	0	0	0	0	14	100	100	100	100
#30	31	1	0	0	0	0	8	13	99	100	94
#50	23	1	0	0	0	0	2	2	16	100	32
#100	10	1	0	0	0	0	2	2	4	51	1
#200	5.4	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	0%	0%	8%	22%	20%	15%	6%	0%	19%	10%

Percent of Asphalt Cement	6.3%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160 °C (320°F)
Compaction Temperature	145 °C (290°F)

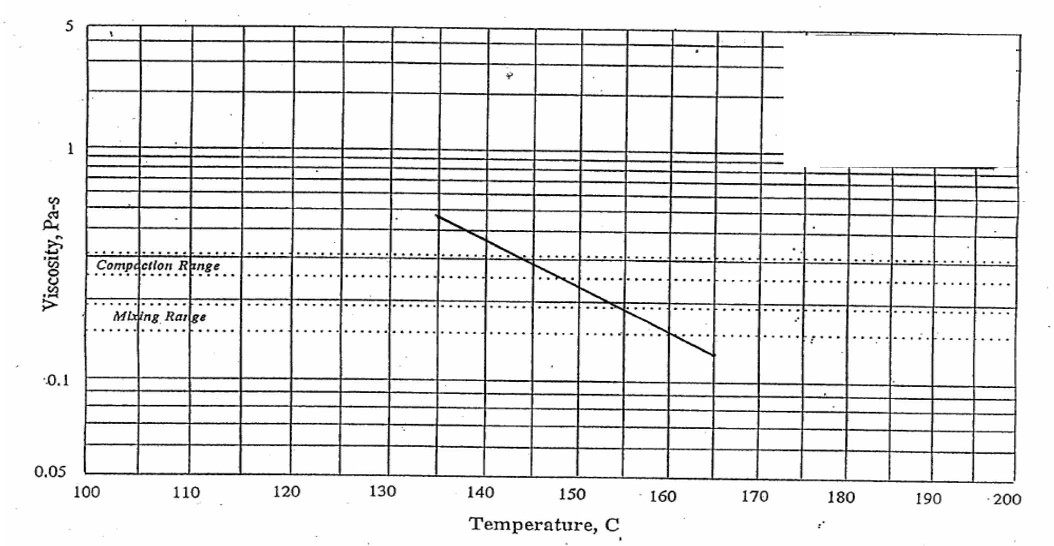


Figure A-57. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Fine Granite With Mortar Sand

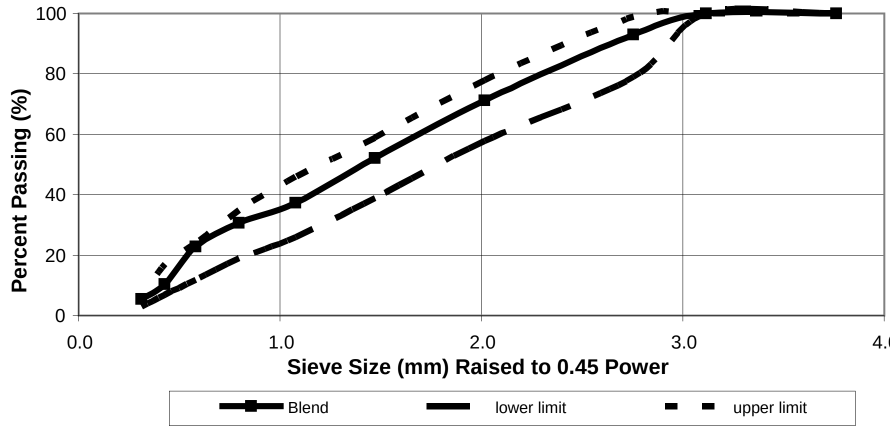
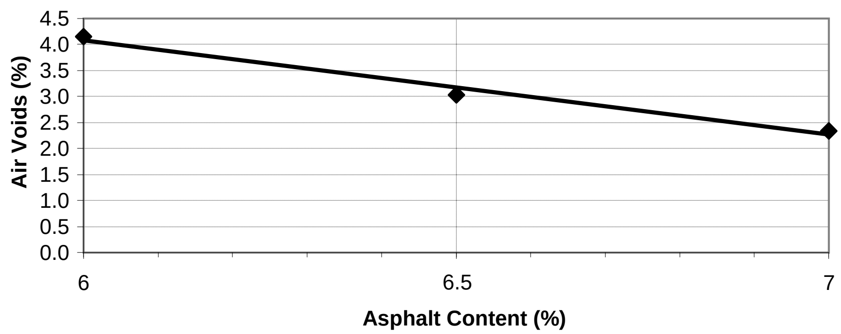


Figure A-58. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Fine Mix With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	1.1%

Figure A-59. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Fine Mix Granite With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

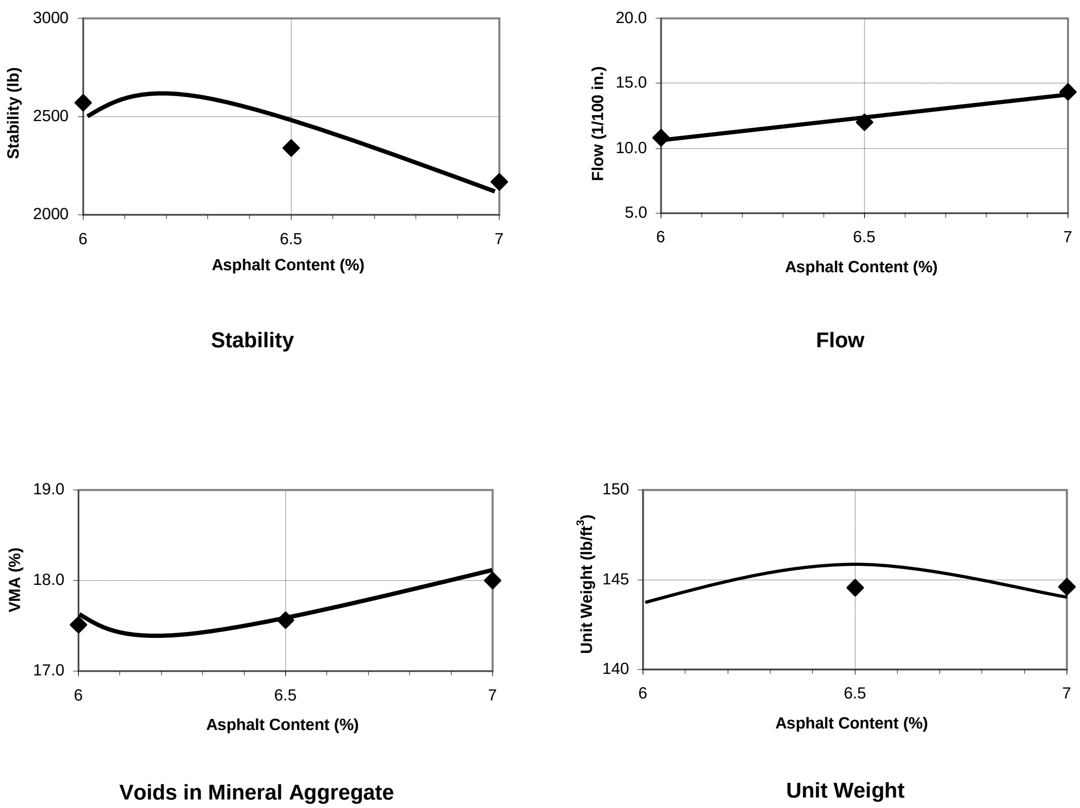


Figure A-60. Marshall Mix Design Results, 1/2-Inch Fine Granite With Mortar Sand, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Coarse Granite With Mortar Sand

Percent Passing	Combined Gradation	Individual Stockpiles 3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	Mortar Sand
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	100	1	8	99	100	100	100	100	100	100	100
3/8"	82	1	0	13	100	100	100	100	100	100	100
#4	60	1	0	0	6	99	100	100	100	100	100
#8	41	1	0	0	0	11	100	100	100	100	100
#16	28	1	0	0	0	0	14	100	100	100	100
#30	27	1	0	0	0	0	8	13	99	100	94
#50	20	1	0	0	0	0	2	2	16	100	32
#100	9	1	0	0	0	0	2	2	4	51	1
#200	4.6	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	0%	0%	21%	20%	20%	13%	0%	0%	16%	10%

Percent of Asphalt Cement	5.7%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160 °C (320°F)
Compaction Temperature	145 °C (290°F)

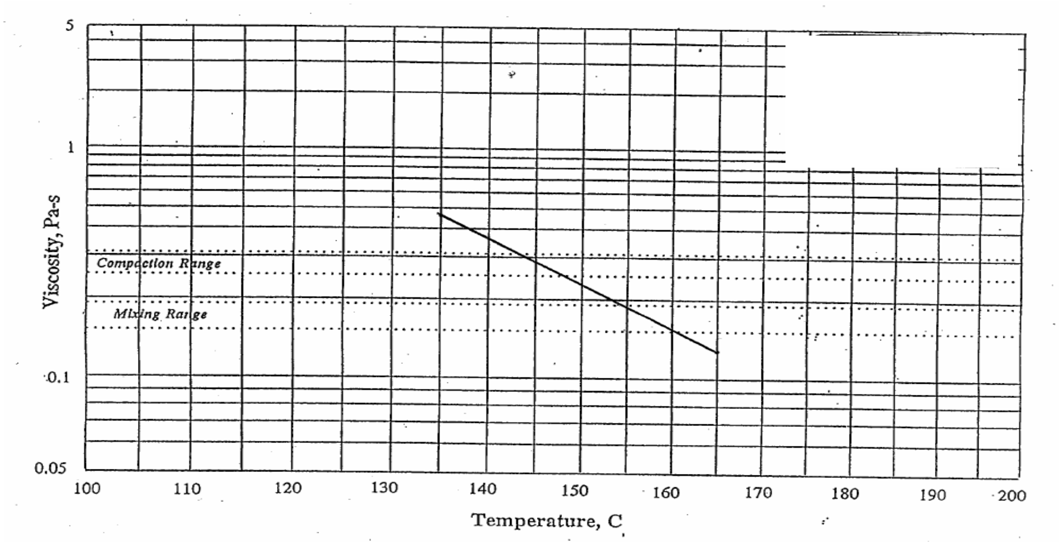


Figure A-61. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Coarse Granite With Mortar Sand

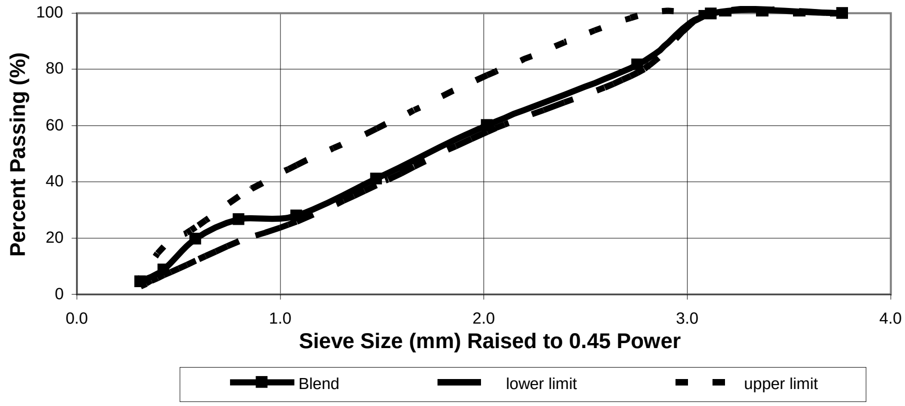
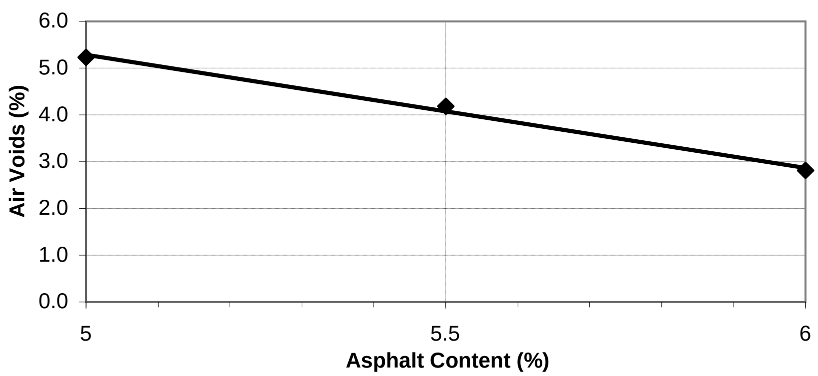


Figure A-62. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Coarse Mix Granite With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.9%

Figure A-63. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Coarse Mix Granite With Mortar Sand

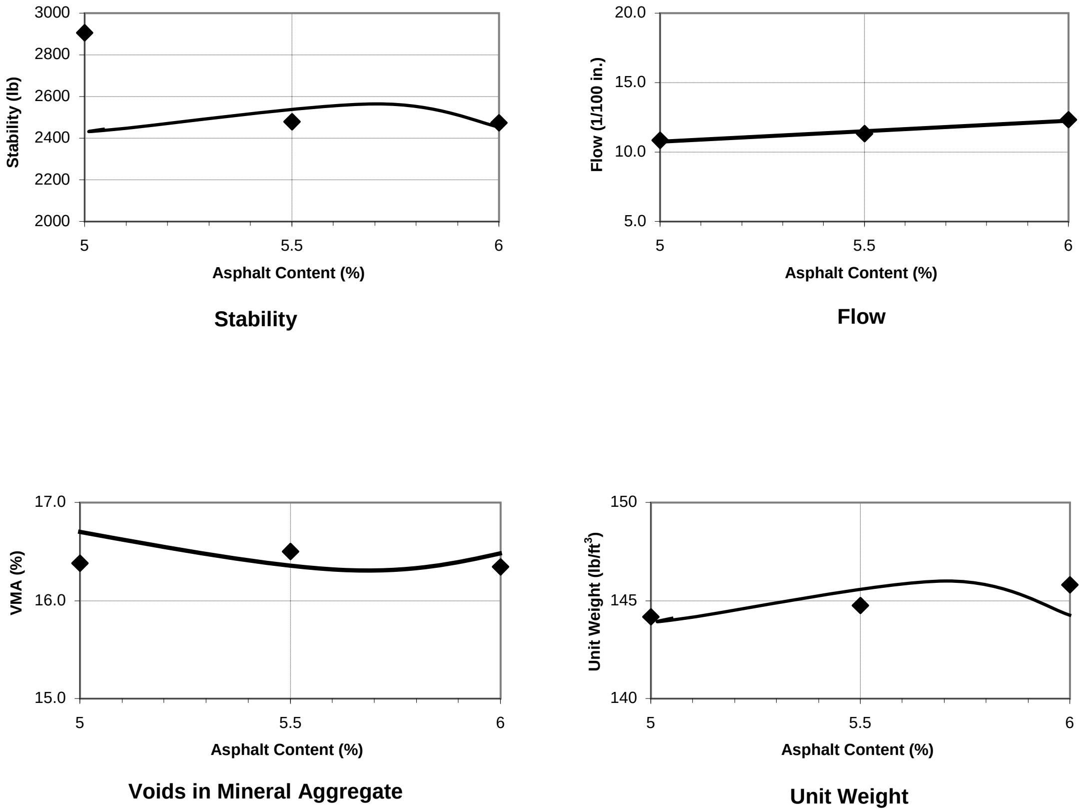


Figure A-64. Marshall Mix Design Results, 1/2-Inch Coarse Granite With Mortar Sand, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Fine Granite With Mortar Sand

Percent Passing	Combined Gradation	Individual Stockpiles 3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	Mortar Sand
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	94	1	8	99	100	100	100	100	100	100	100
3/8"	84	1	0	13	100	100	100	100	100	100	100
#4	65	1	0	0	6	99	100	100	100	100	100
#8	49	1	0	0	0	11	100	100	100	100	100
#16	33	1	0	0	0	0	14	100	100	100	100
#30	27	1	0	0	0	0	8	13	99	100	94
#50	20	1	0	0	0	0	2	2	16	100	32
#100	9	1	0	0	0	0	2	2	4	51	1
#200	4.7	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	0%	6%	12%	18%	17%	17%	4%	0%	16%	10%

Percent of Asphalt Cement	5.5%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160 °C (320°F)
Compaction Temperature	145 °C (290°F)

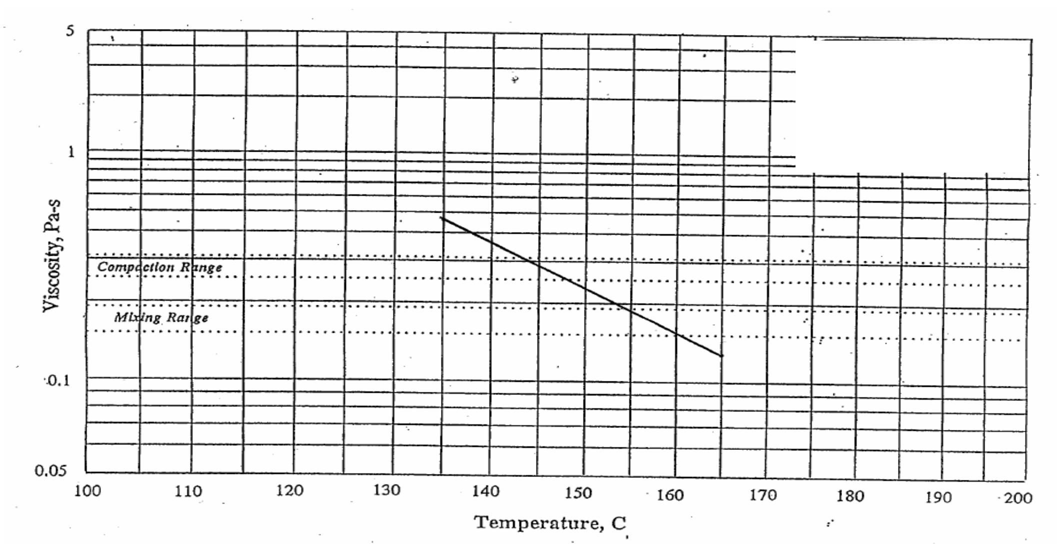


Figure A-65. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Fine Granite With Mortar Sand

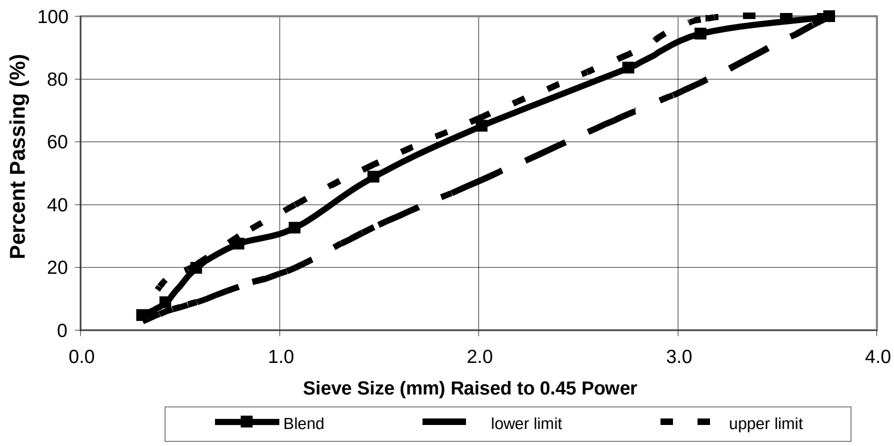
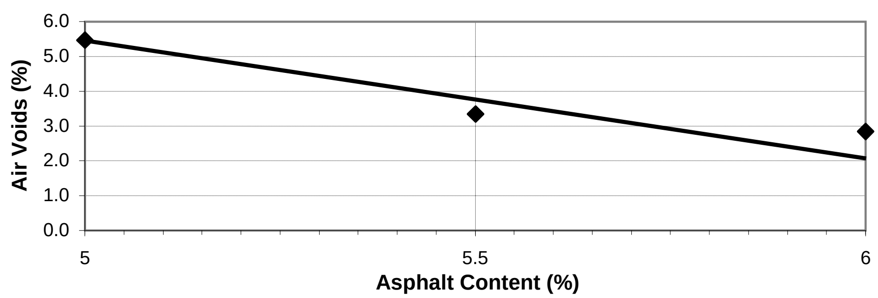


Figure A-66. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Fine Mix Granite With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.9%

Figure A-67. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Fine Mix Granite With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

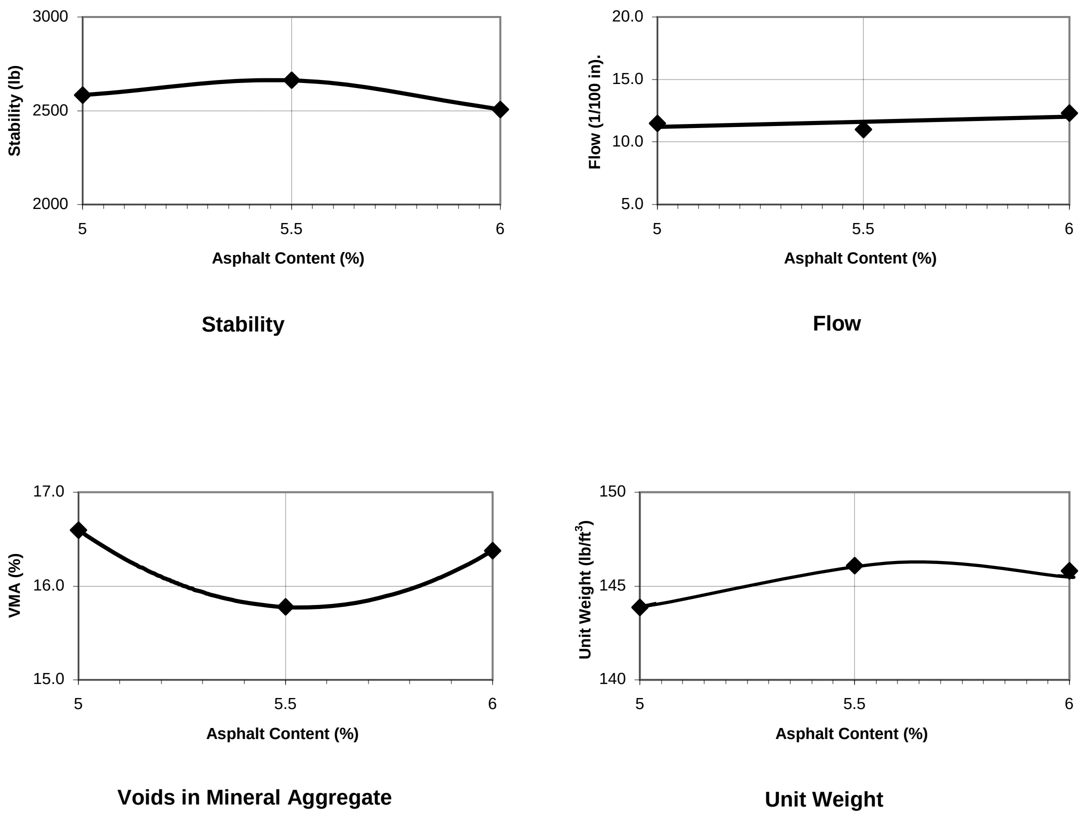


Figure A-68. Marshall Mix Design Results, 3/4-Inch Fine Granite With Mortar Sand, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Coarse Granite With Mortar Sand

Percent Passing	Combined Gradation	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	Mortar Sand
		Individual Stockpiles									
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	82	1	8	99	100	100	100	100	100	100	100
3/8"	71	1	0	13	100	100	100	100	100	100	100
#4	52	1	0	0	6	99	100	100	100	100	100
#8	37	1	0	0	0	11	100	100	100	100	100
#16	27	1	0	0	0	0	14	100	100	100	100
#30	25	1	0	0	0	0	8	13	99	100	94
#50	19	1	0	0	0	0	2	2	16	100	32
#100	8	1	0	0	0	0	2	2	4	51	1
#200	4.3	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	0%	21%	11%	19%	17%	10%	0%	0%	12%	10%

Percent of Asphalt Cement	5.1%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160 °C (320°F)
Compaction Temperature	145 °C (290°F)

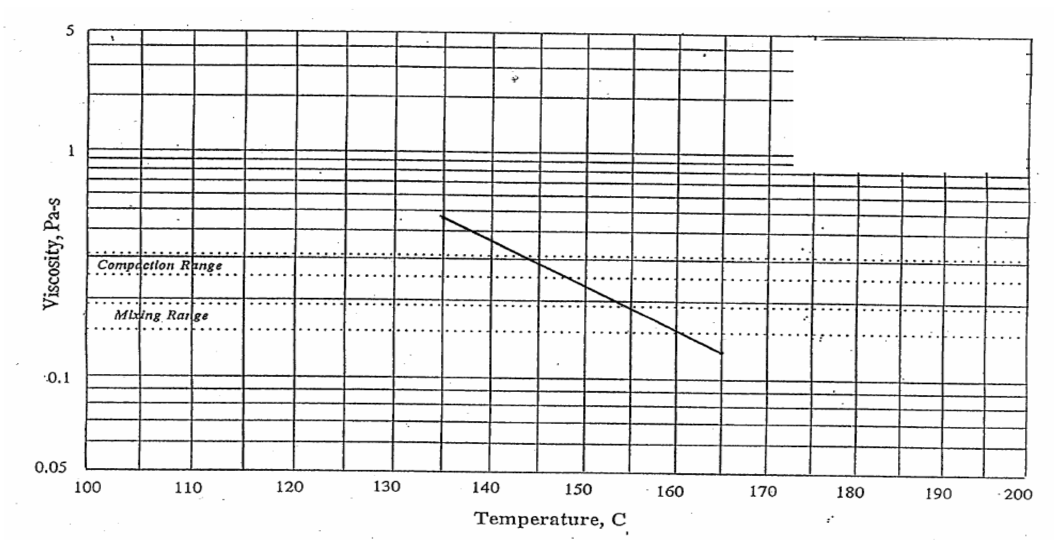


Figure A-69. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Coarse Granite With Mortar Sand

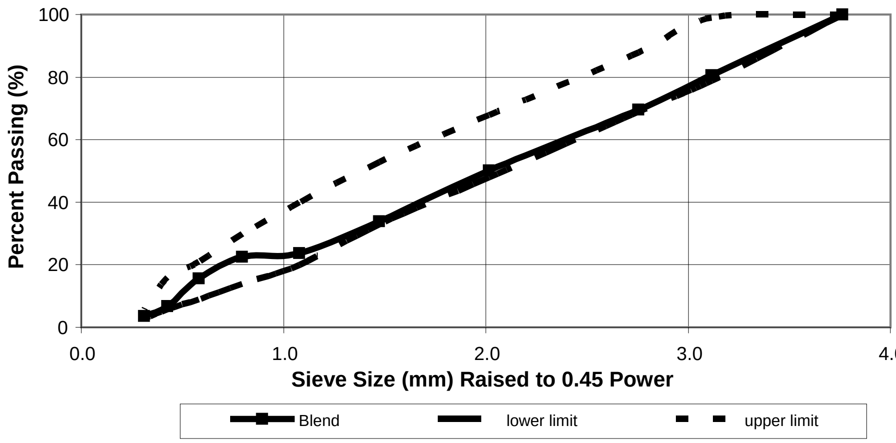
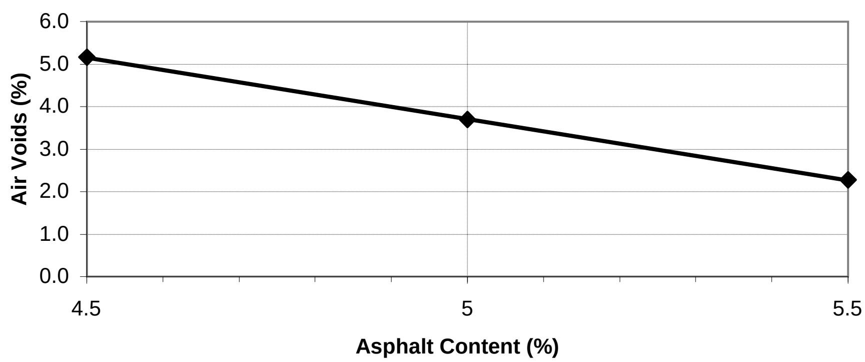


Figure A-70. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Coarse Mix Granite With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.8%

Figure A-71. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Coarse Mix Granite With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

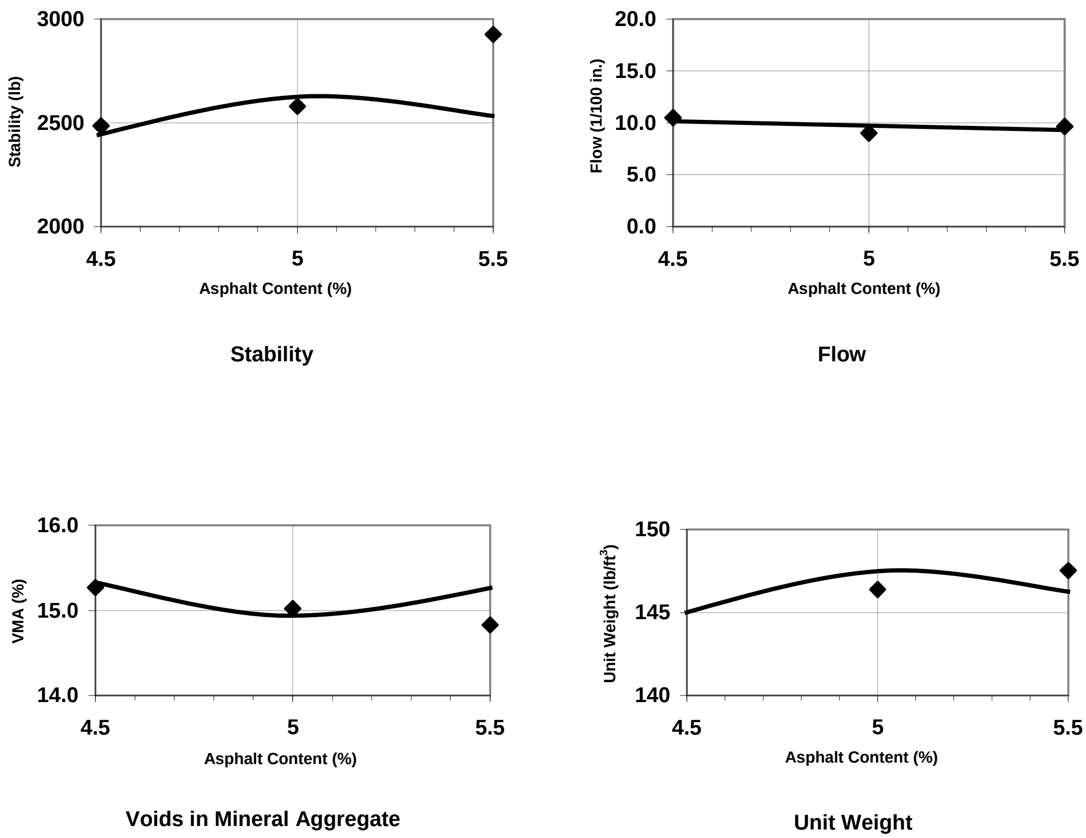


Figure A-72. Marshall Mix Design Results, 3/4-Inch Coarse Granite With Mortar Sand, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 1-Inch Fine Granite With Mortar Sand

Percent Passing	Total Combined Gradation	Individual Stockpiles 3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	Mortar Sand
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	94	1	100	100	100	100	100	100	100	100	100
1/2"	82	1	8	99	100	100	100	100	100	100	100
3/8"	72	1	0	13	100	100	100	100	100	100	100
#4	55	1	0	0	6	99	100	100	100	100	100
#8	41	1	0	0	0	11	100	100	100	100	100
#16	25	1	0	0	0	0	14	100	100	100	100
#30	24	1	0	0	0	0	8	13	99	100	94
#50	17	1	0	0	0	0	2	2	16	100	32
#100	7	1	0	0	0	0	2	2	4	51	1
#200	3.9	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	6%	13%	11%	16%	15%	16%	0%	0%	13%	10%

Percent of Asphalt Cement	5.2%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160 °C (320°F)
Compaction Temperature	145 °C (290°F)

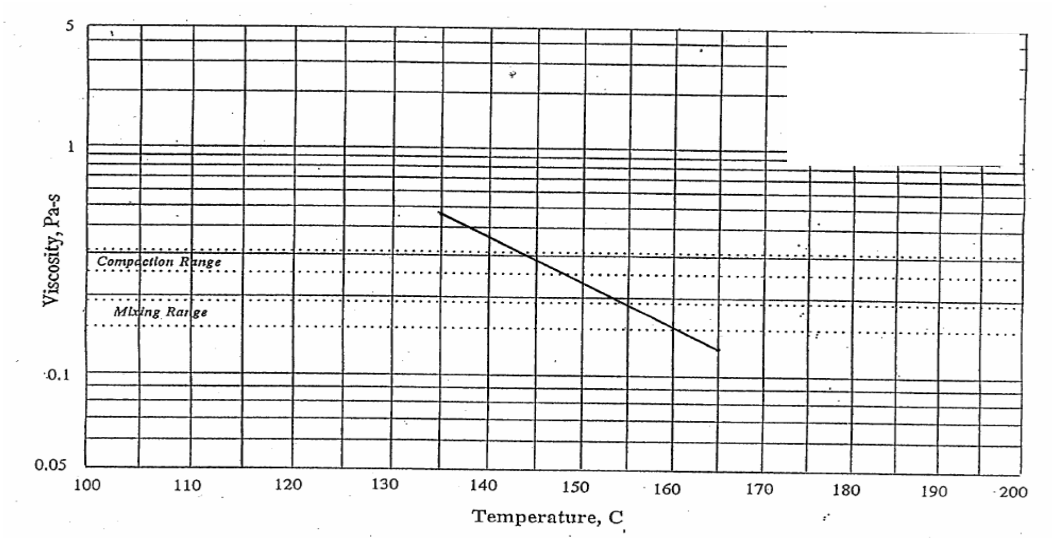


Figure A-73. Temperature Viscosity Relationship of Asphalt Cement for 1-Inch Fine Granite With Mortar Sand

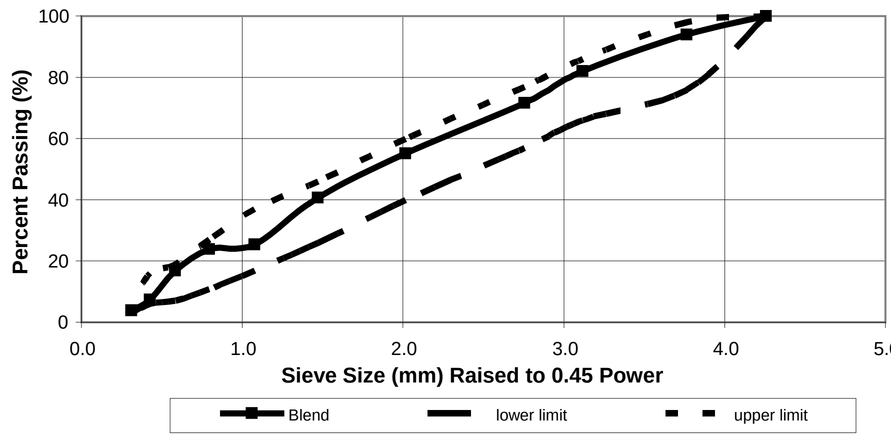
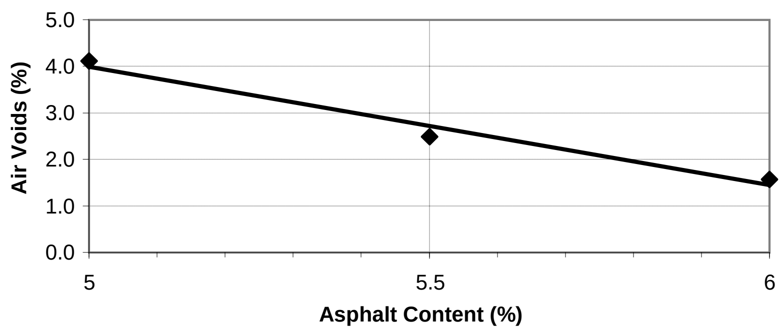


Figure A-74. Combined Gradation Plotted on 0.45 Power Curve for 1-Inch Fine Mix Granite With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.9%

Figure A-75. Plot of Air Void Content vs Asphalt Content for 1-Inch Fine Mix Granite With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

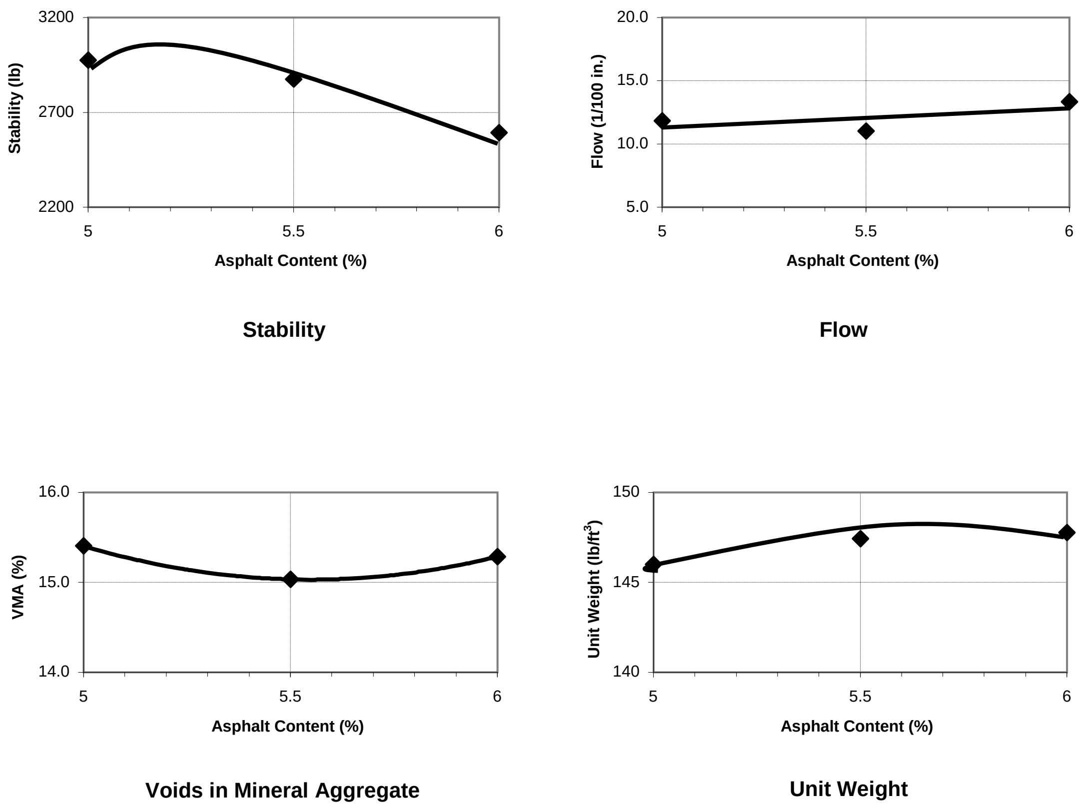


Figure A-76. Marshall Mix Design Results, 1-Inch Fine Granite With Mortar Sand, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 1-Inch Coarse Granite With Mortar Sand

		Individual Stockpiles									
Percent Passing	**Total Combined Gradation**	**3/4"**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	79	1	100	100	100	100	100	100	100	100	100
1/2"	72	1	8	99	100	100	100	100	100	100	100
3/8"	61	1	0	13	100	100	100	100	100	100	100
#4	46	1	0	0	6	99	100	100	100	100	100
#8	34	1	0	0	0	11	100	100	100	100	100
#16	25	1	0	0	0	0	14	100	100	100	100
#30	23	1	0	0	0	0	8	13	99	100	94
#50	17	1	0	0	0	0	2	2	16	100	32
#100	7	1	0	0	0	0	2	2	4	51	1
#200	3.8	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	21%	8%	12%	14%	13%	9%	0%	0%	13%	10%

Percent of Asphalt Cement	4.6%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160 °C (320°F)
Compaction Temperature	145 °C (290°F)

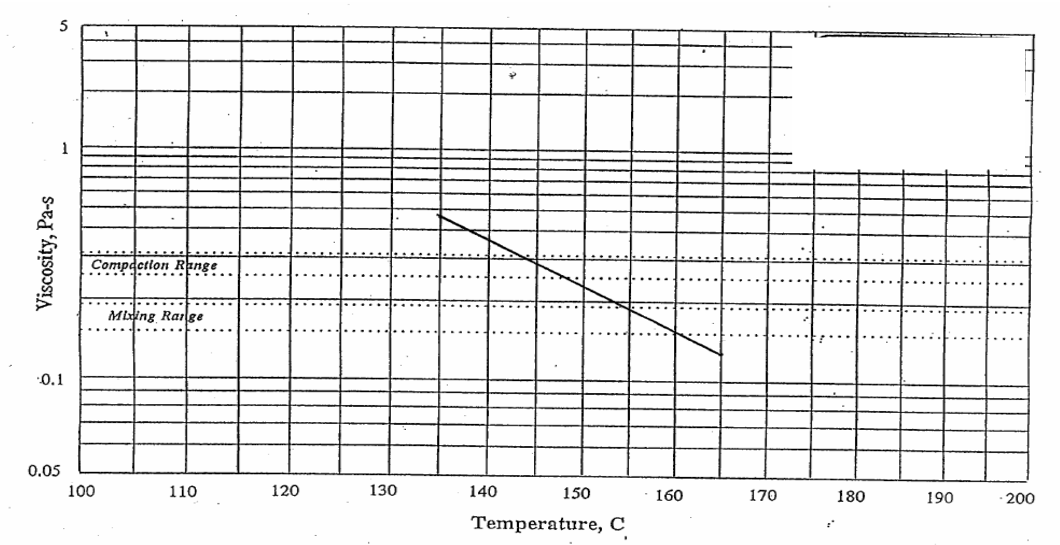


Figure A-77. Temperature Viscosity Relationship of Asphalt Cement for 1-Inch Coarse Granite With Mortar Sand

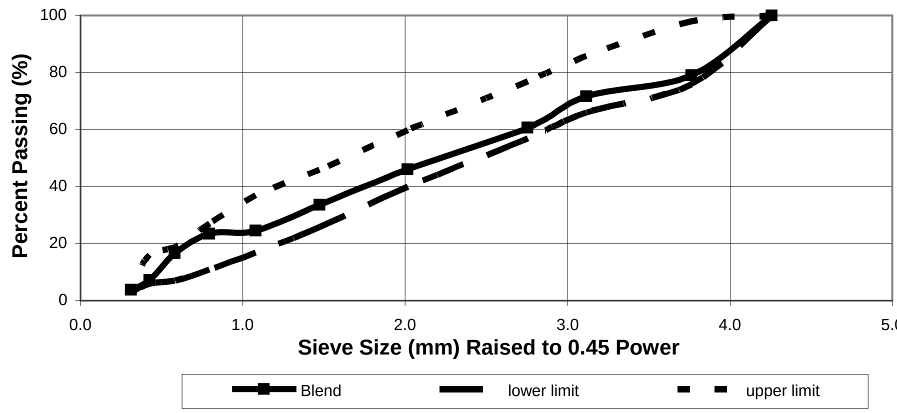
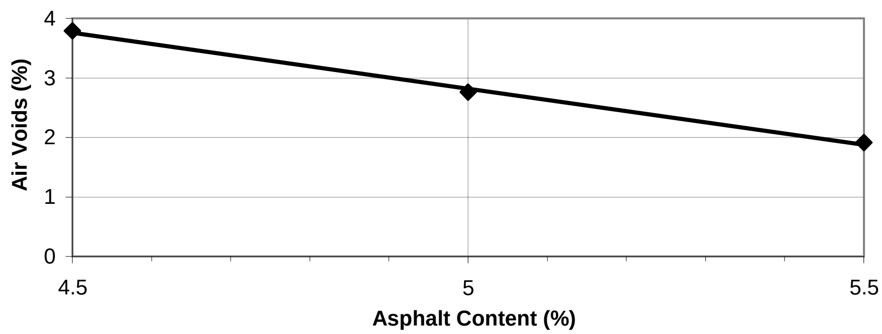


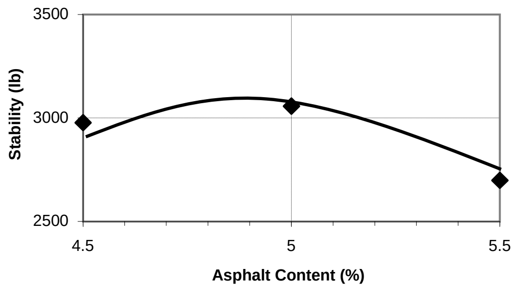
Figure A-78. Combined Gradation Plotted on 0.45 Power Curve for 1-Inch Coarse Mix Granite With 10% Mortar Sand



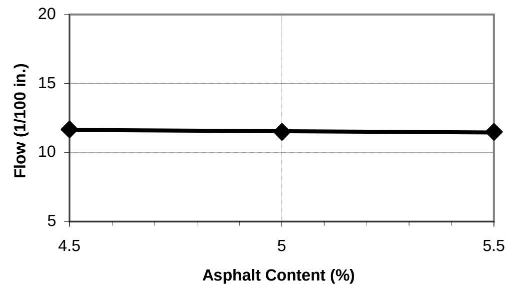
Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	1.0%

Figure A-79. Plot of Air Void Content vs Asphalt Content for 1-Inch Coarse Mix Granite With Mortar Sand

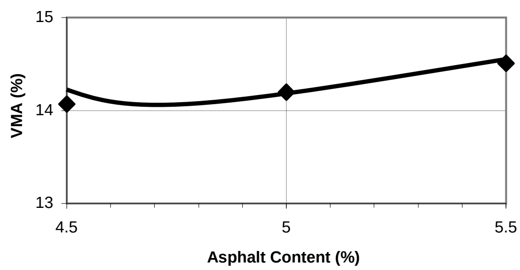
Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content



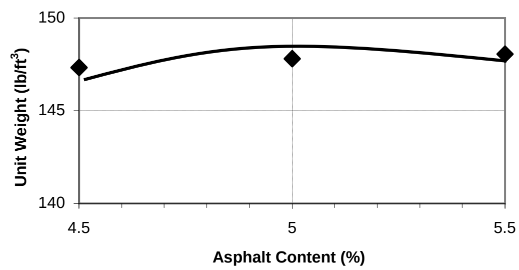
Stability



Flow



Voids in Mineral Aggregate



Unit Weight

Figure A-80. Marshall Mix Design Results, 1-Inch Coarse Granite With Sand, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Chert Gravel

		Individual Stockpiles								
Percent Passing	**Total Combined**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100
3/4"	100	100	100	100	100	100	100	100	100	100
1/2"	100	39	100	100	100	100	100	100	100	100
3/8"	87.9	0	14	100	100	100	100	100	100	100
#4	69	0	0	15	100	100	100	100	100	100
#8	53.4	0	0	2	19	100	100	100	100	100
#16	39	0	0	2	1	16	97	97	100	100
#30	27.6	0	0	2	1	1	25	75	100	94
#50	20.3	0	0	2	1	1	6	23	99	32
#100	9	0	0	1	0	1	4	5	44	1
#200	4.6	0.2	0.2	0.9	0.4	1.3	3.5	4.1	19.7	0.6
Percent Used:	1	0%	14%	20%	16%	13%	10%	10%	17%	0%

Percent of Asphalt Cement	7.2%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160° C (320°F)
Compaction Temperature	145°C (290°F)

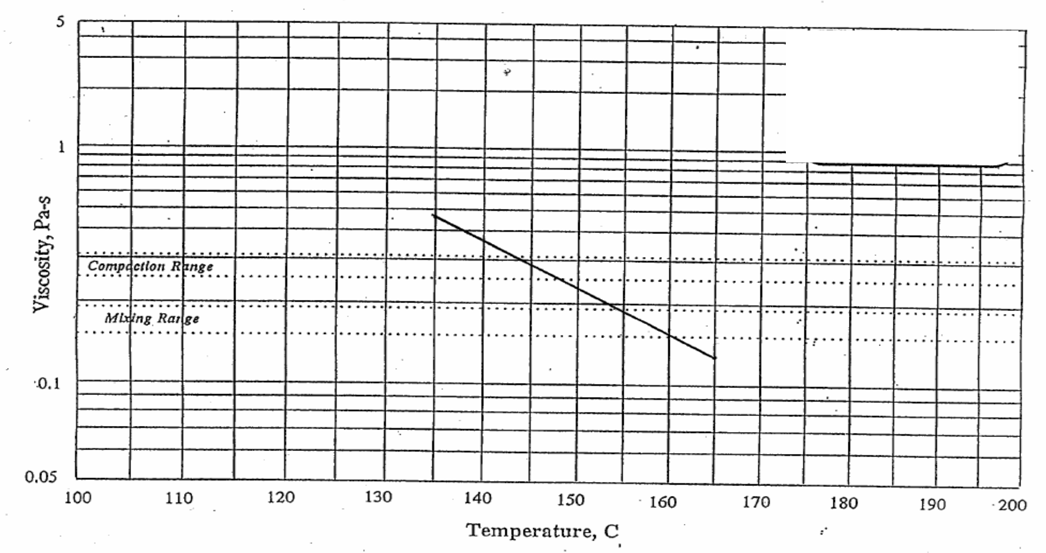


Figure A-81. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Chert Gravel

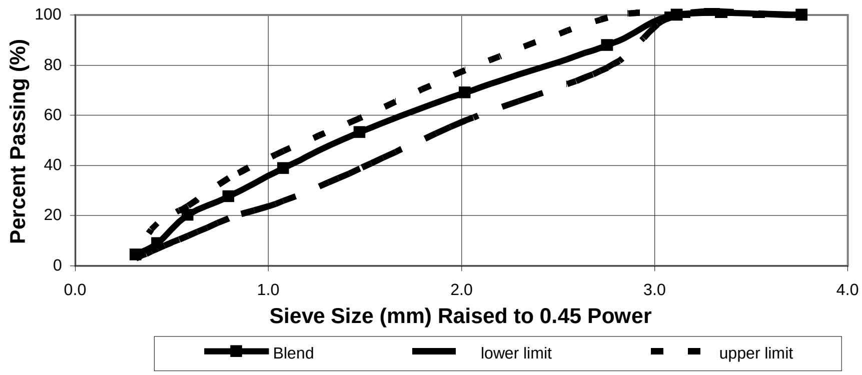
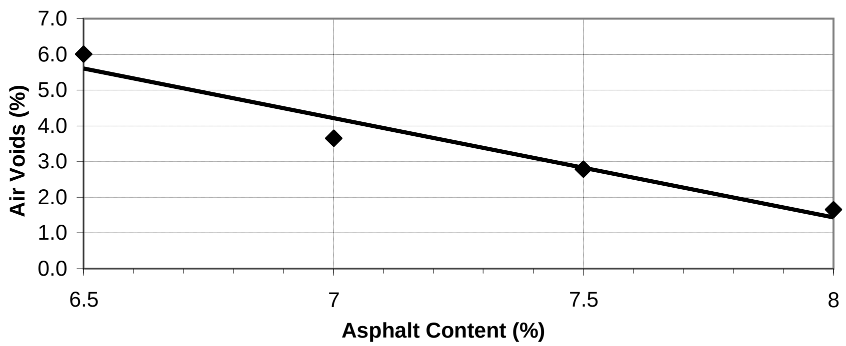


Figure A-82. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Fine Mix Chert Gravel



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.3%

Figure A-83. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Chert Gravel

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

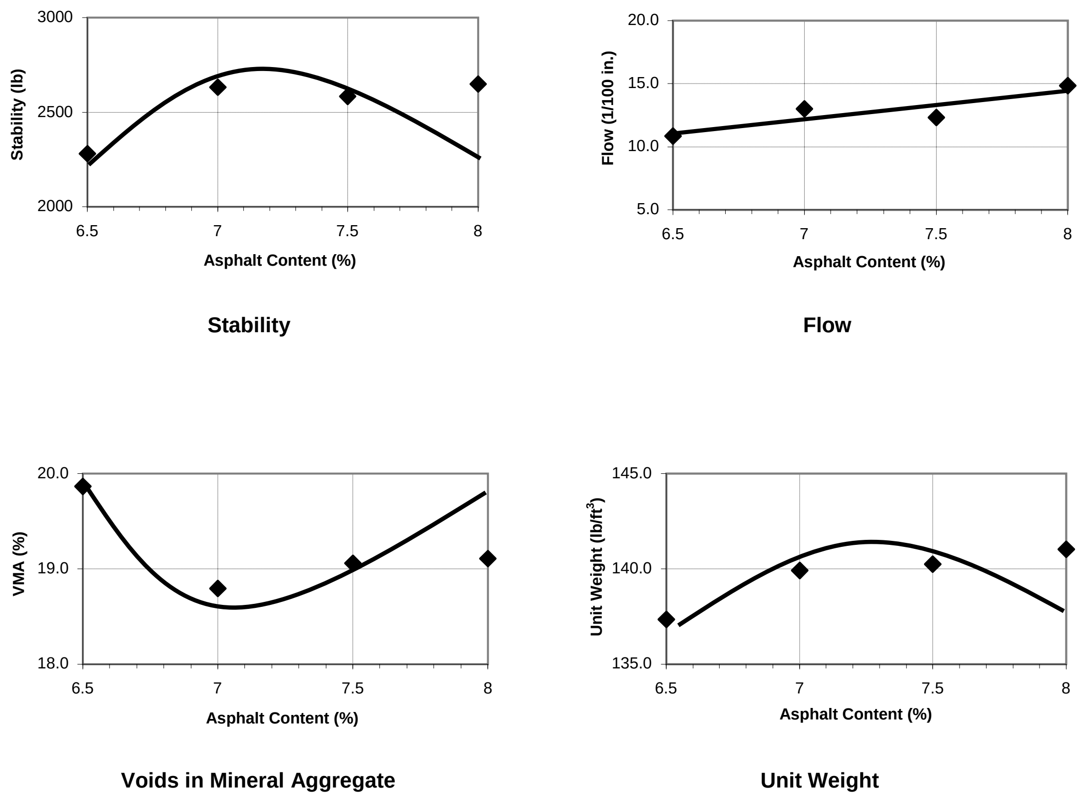


Figure A-84. Marshall Mix Design Results, 1/2-Inch Chert Gravel, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Fine Chert Gravel

		Individual Stockpiles								
Percent Passing	**Total Combined Gradation**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100
3/4"	100	100	100	100	100	100	100	100	100	100
1/2"	95	39	100	100	100	100	100	100	100	100
3/8"	81	0	14	100	100	100	100	100	100	100
#4	65	0	0	15	100	100	100	100	100	100
#8	51	0	0	2	19	100	100	100	100	100
#16	38	0	0	2	1	16	97	97	100	100
#30	26	0	0	2	1	1	25	75	100	94
#50	18	0	0	2	1	1	6	23	99	32
#100	8	0	0	1	0	1	4	5	44	1
#200	4	0.2	0.2	0.9	0.4	1.3	3.5	4.1	19.7	0.6
Percent Used:	100	9%	12%	16%	15%	12%	11%	11%	14%	0%

Percent of Asphalt Cement	7.4%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160°C (320°F)
Compaction Temperature	145°C (290°F)

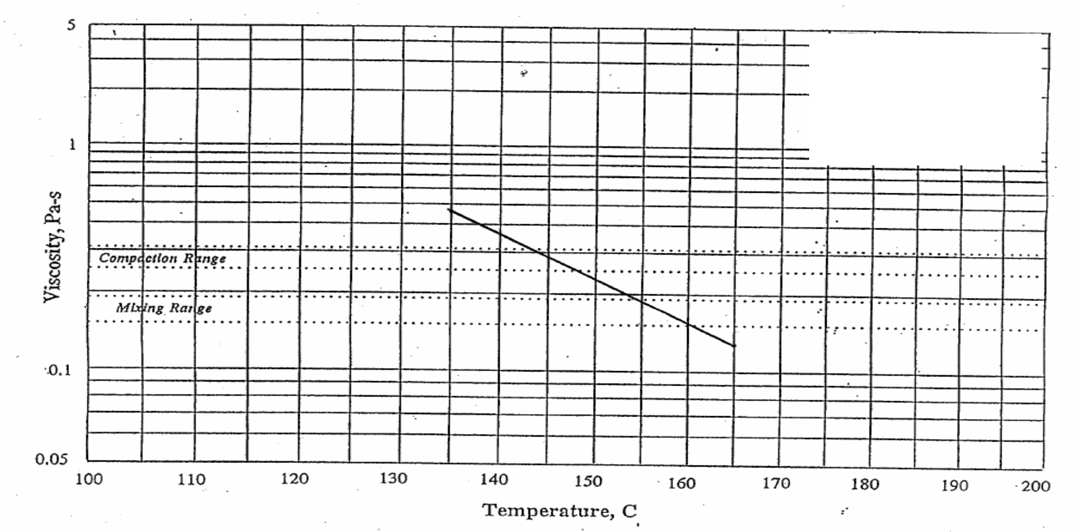


Figure A-85. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Fine Mix Chert Gravel

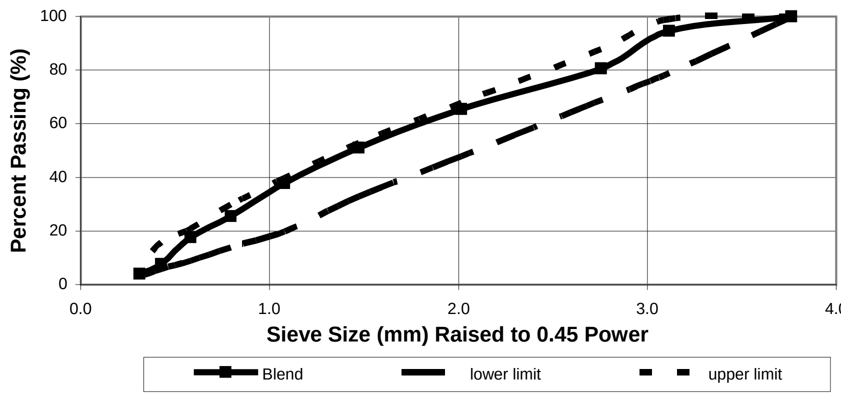
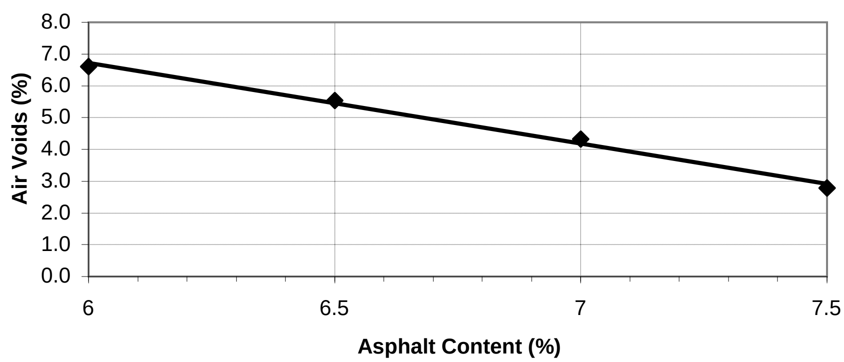


Figure 86. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Fine Mix Chert Gravel



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.2%

Figure A-87. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Fine Mix Chert Gravel

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

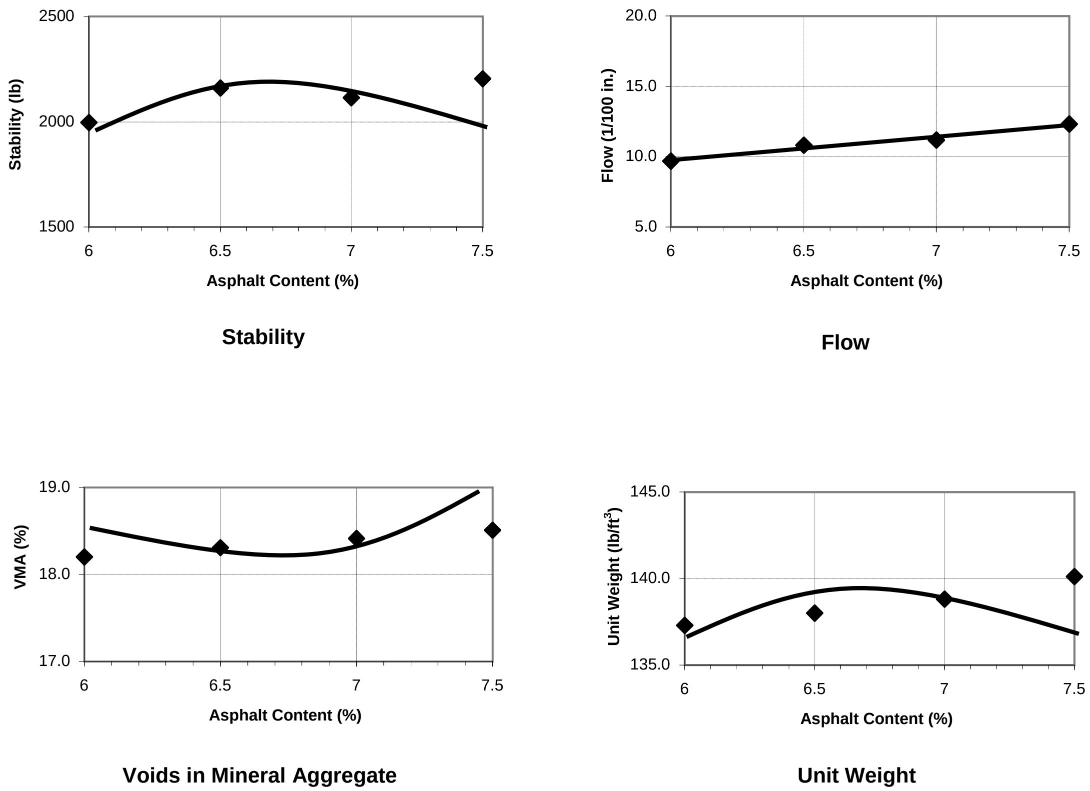


Figure A-88. Marshall Mix Design Results, 3/4-Inch Fine Mix Chert Gravel, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Coarse Chert Gravel

		Individual Stockpiles								
Percent Passing	**Total Combined Gradation**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100
3/4"	100	100	100	100	100	100	100	100	100	100
1/2"	87	39	100	100	100	100	100	100	100	100
3/8"	70	0	14	100	100	100	100	100	100	100
#4	54	0	0	15	100	100	100	100	100	100
#8	42	0	0	2	19	100	100	100	100	100
#16	30	0	0	2	1	16	97	97	100	100
#30	20	0	0	2	1	1	25	75	100	94
#50	13	0	0	2	1	1	6	23	99	32
#100	6	0	0	1	0	1	4	5	44	1
#200	3.1	0.2	0.2	0.9	0.4	1.3	3.5	4.1	19.7	0.6
Percent Used:	100	21%	11%	16%	13%	11%	9%	9%	10%	0%

Percent of Asphalt Cement	6.8%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160°C (320°F)
Compaction Temperature	145°C (290°F)

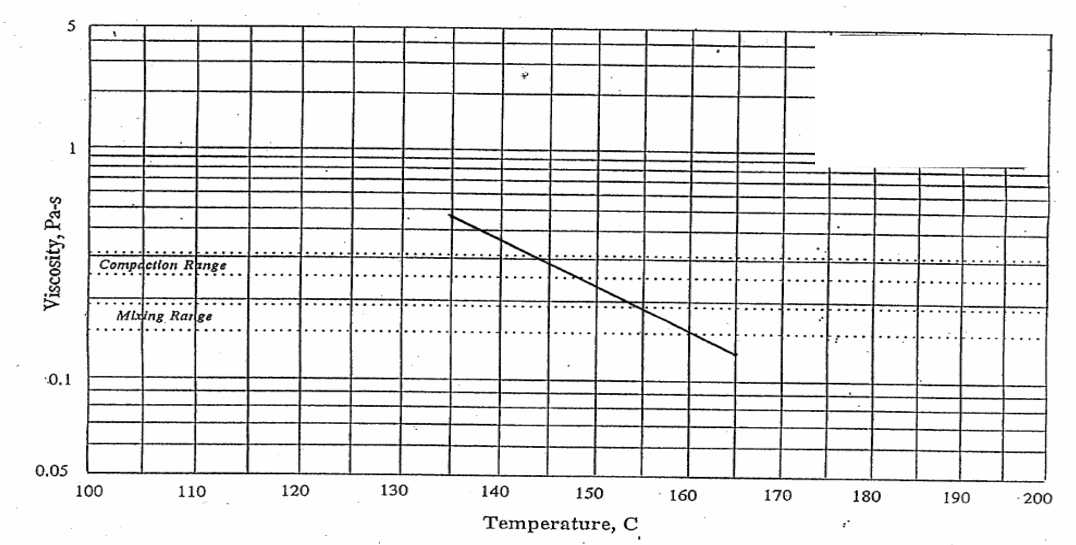


Figure A-89. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Coarse Chert Gravel

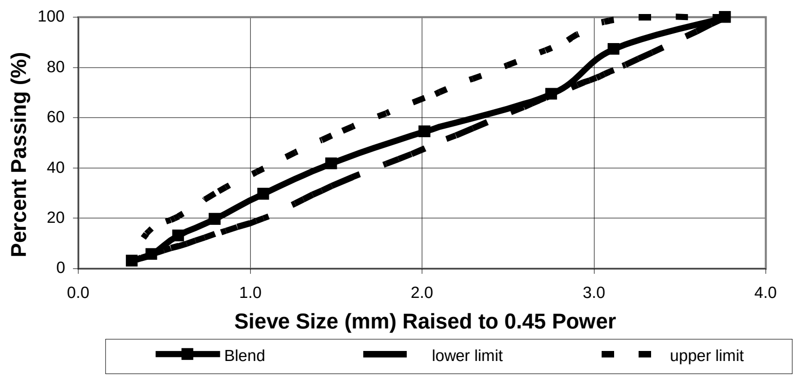
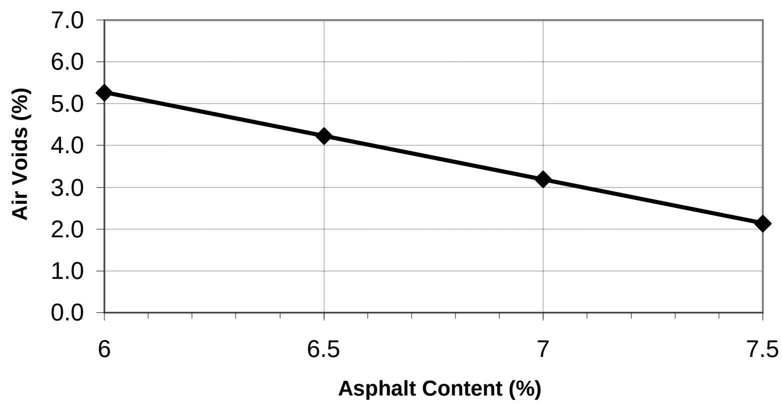


Figure A-90. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Coarse Mix Chert Gravel



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.1%

Figure A-91. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Coarse Mix Chert Gravel

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

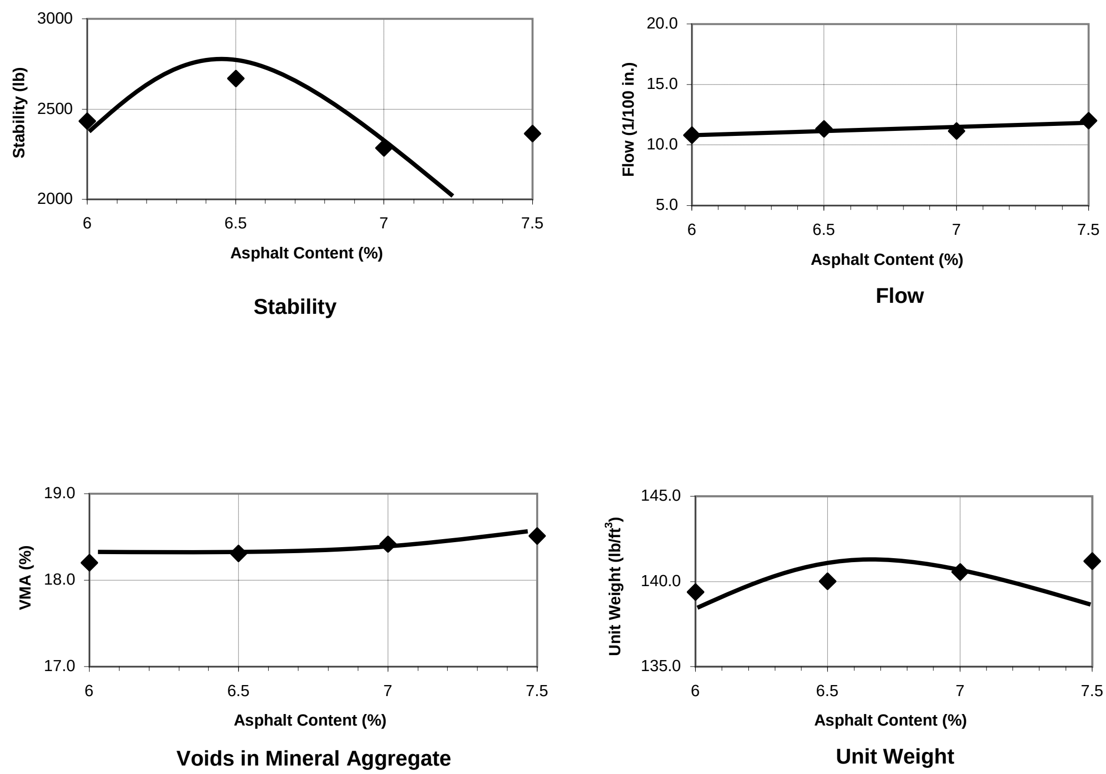


Figure A-92. Marshall Mix Design Results, 3/4-Inch Coarse Mix Chert Gravel, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Chert Gravel With Mortar Sand

		Individual Stockpiles								
Percent Passing	Total Combined Gradation	1/2"	3/8"	#4	#8	#16	#30	#50	#100	Mortar Sand
1"	100	100	100	100	100	100	100	100	100	100
3/4"	100	100	100	100	100	100	100	100	100	100
1/2"	100	39	100	100	100	100	100	100	100	100
3/8"	87	0	14	100	100	100	100	100	100	100
#4	67	0	0	15	100	100	100	100	100	100
#8	47	0	0	2	19	100	100	100	100	100
#16	32	0	0	2	1	16	97	97	100	100
#30	29	0	0	2	1	1	25	75	100	94
#50	23	0	0	2	1	1	6	23	99	32
#100	9	0	0	1	0	1	4	5	44	1
#200	4.3	0.2	0.2	0.9	0.4	1.3	3.5	4.1	19.7	0.6
Percent Used:	100	0%	15%	21%	21%	14%	0%	0%	19%	10%

Percent of Asphalt Cement	6.4%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160°C (320°F)
Compaction Temperature	145°C (290°F)

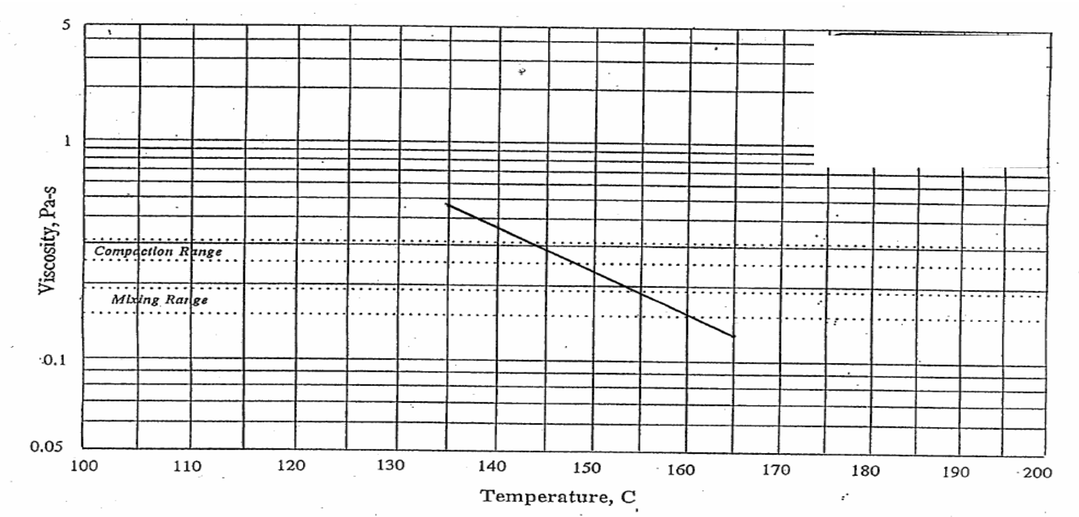


Figure A-93. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Chert Gravel With Mortar Sand

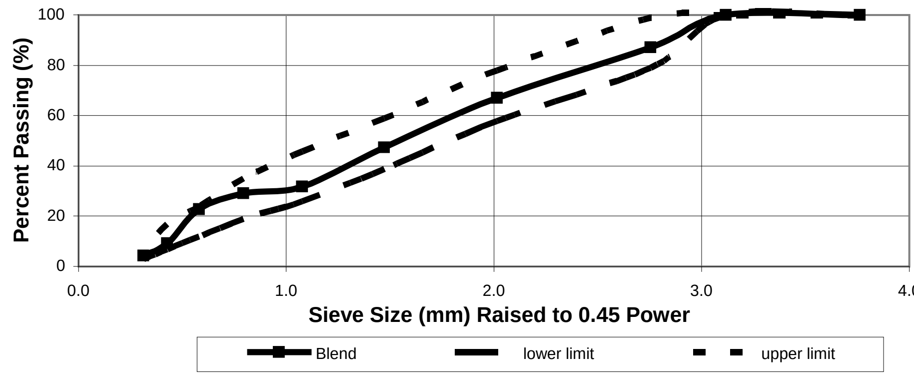
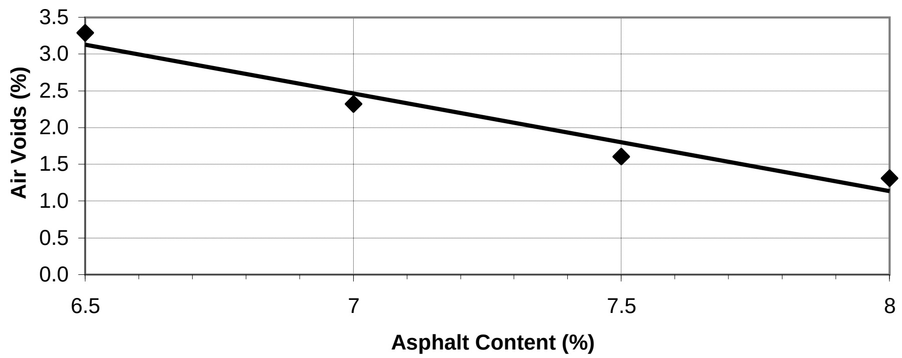


Figure A-94. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Fine Mix Chert Gravel With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.3%

Figure A-95. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Chert Gravel With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

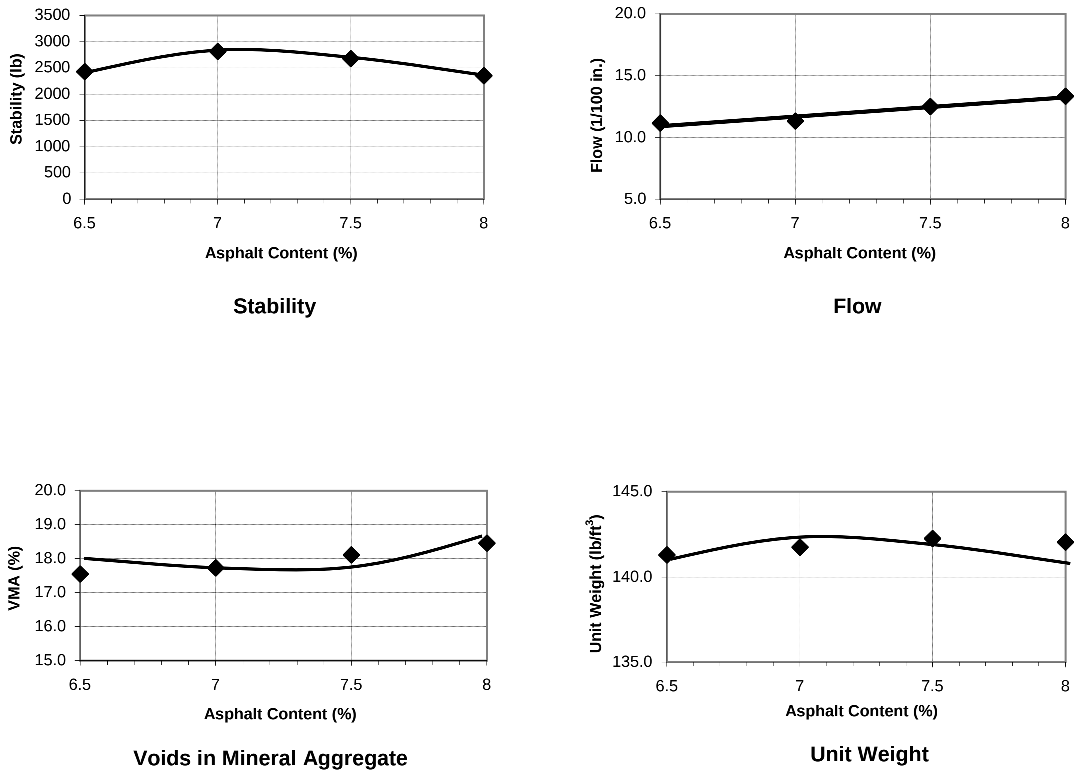


Figure A-96. Marshall Mix Design Results, 1/2-Inch Chert Gravel With Sand, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Fine Chert Gravel With Mortar Sand

Percent Passing	Combined Gradation	Individual Stockpiles 1/2"	3/8"	#4	#8	#16	#30	#50	#100	Mortar Sand
1"	100	100	100	100	100	100	100	100	100	100
3/4"	100	100	100	100	100	100	100	100	100	100
1/2"	95	39	100	100	100	100	100	100	100	100
3/8"	81	0	14	100	100	100	100	100	100	100
#4	64	0	0	15	100	100	100	100	100	100
#8	47	0	0	2	19	100	100	100	100	100
#16	29	0	0	2	1	16	97	97	100	100
#30	26	0	0	2	1	1	25	75	100	94
#50	20	0	0	2	1	1	6	23	99	32
#100	8	0	0	1	0	1	4	5	44	1
#200	3.7	0.2	0.2	0.9	0.4	1.3	3.5	4.1	19.7	0.6
Percent Used:	100	9%	12%	18%	18%	17%	0%	0%	16%	10%

Percent of Asphalt Cement	6.2%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160°C (320°F)
Compaction Temperature	145°C (290°F)

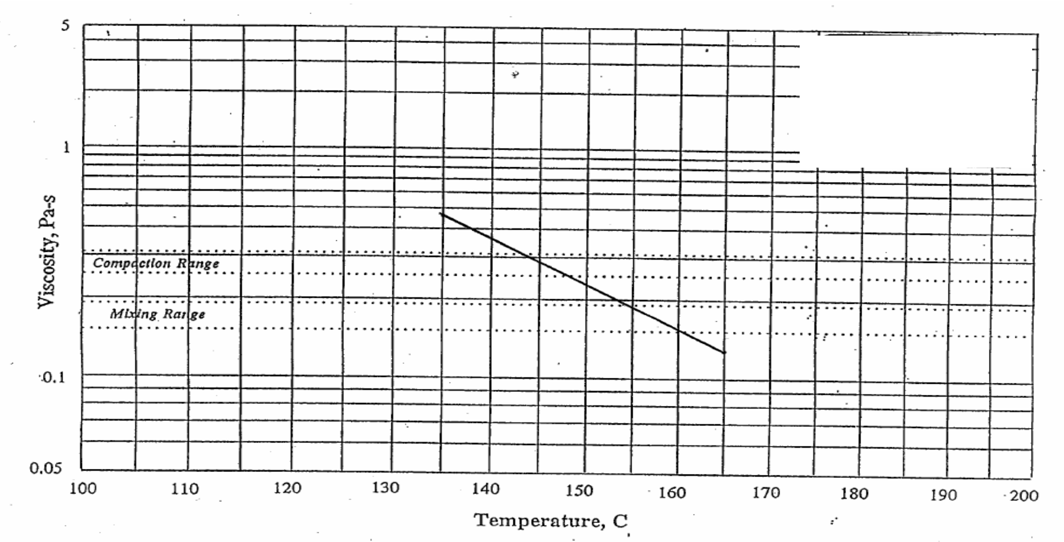


Figure A-97. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Fine Chert Gravel With Mortar Sand

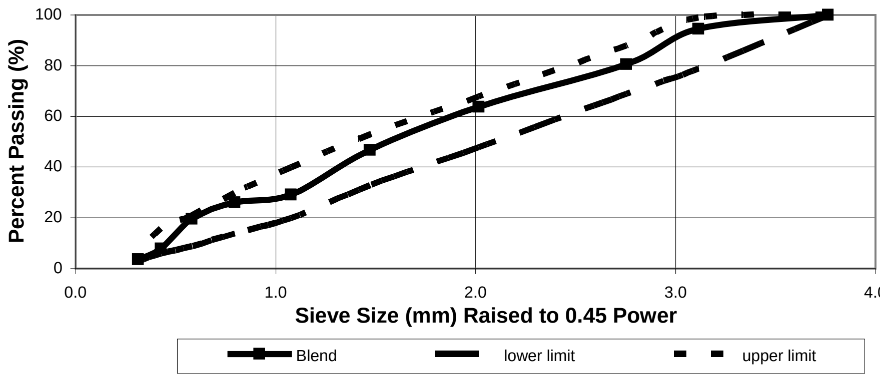
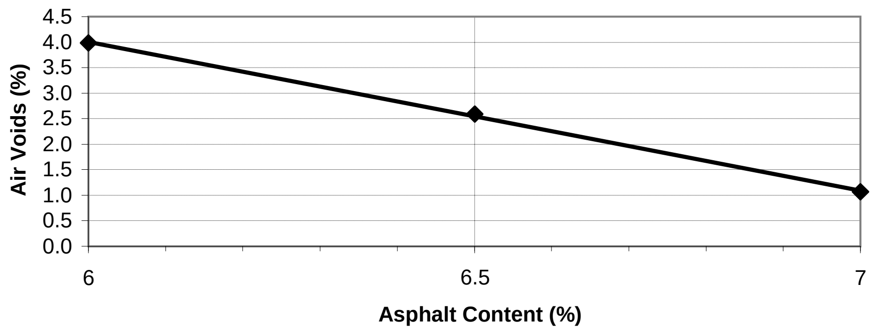


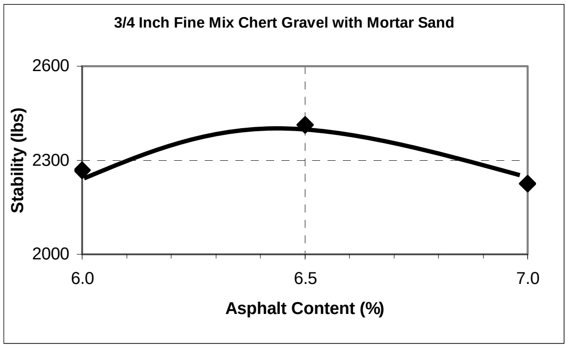
Figure A-98. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Fine Mix Chert Gravel With 10% Mortar Sand



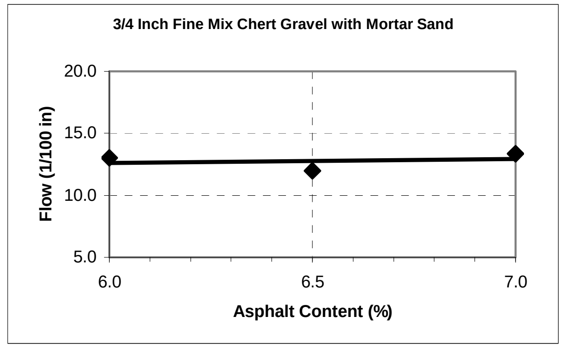
Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.2%

Figure A-99. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Fine Mix Chert Gravel With Mortar Sand

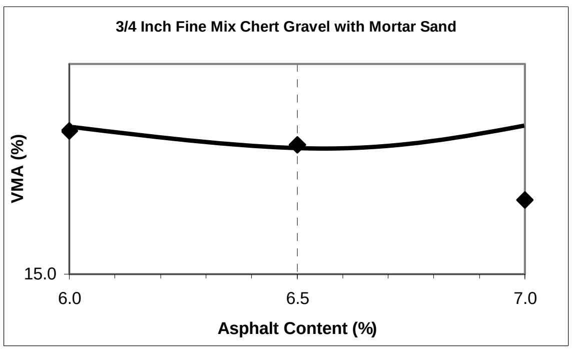
Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content



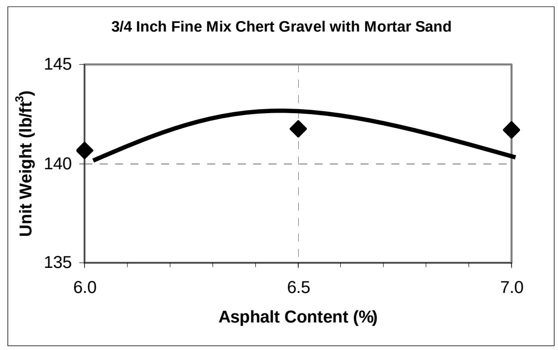
Stability



Flow



Voids in Mineral Aggregate



Unit Weight

Figure A-100. Marshall Mix Design Results, 3/4-Inch Fine Chert Gravel With Sand, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Coarse Chert Gravel With Mortar Sand

		Individual Stockpiles								
Percent Passing	**Combined Gradation**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100
3/4"	100	100	100	100	100	100	100	100	100	100
1/2"	87	39	100	100	100	100	100	100	100	100
3/8"	71	0	14	100	100	100	100	100	100	100
#4	54	0	0	15	100	100	100	100	100	100
#8	41	0	0	2	19	100	100	100	100	100
#16	28	0	0	2	1	16	97	97	100	100
#30	26	0	0	2	1	1	25	75	100	94
#50	20	0	0	2	1	1	6	23	99	32
#100	8	0	0	1	0	1	4	5	44	1
#200	3.7	0.2	0.2	0.9	0.4	1.3	3.5	4.1	19.7	0.6
Percent Used:	100	22%	8%	19%	13%	12%	0%	0%	16%	10%

Percent of Asphalt Cement	5.9%
Asphalt Performance Grade	PG 64-22
Number of Hammer Blows per Side	75
Mixing Temperature	160°C (320°F)
Compaction Temperature	145°C (290°F)

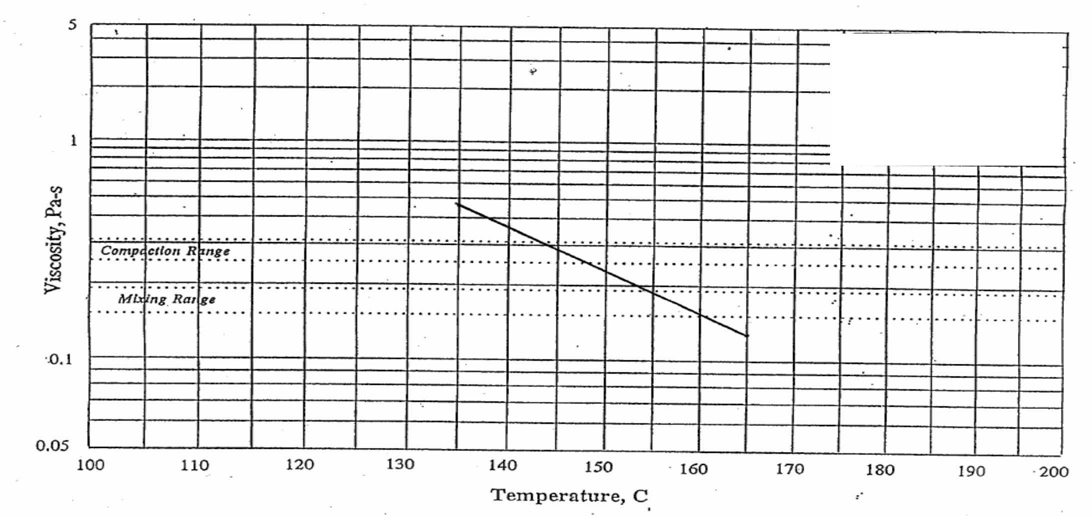


Figure A-101. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Coarse Chert Gravel With Mortar Sand

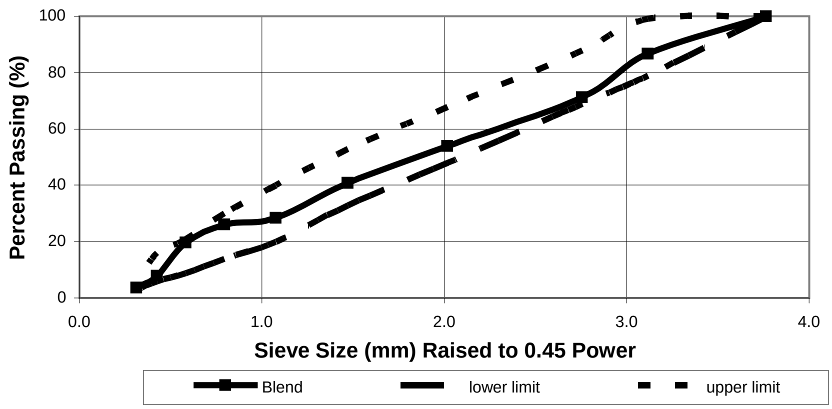
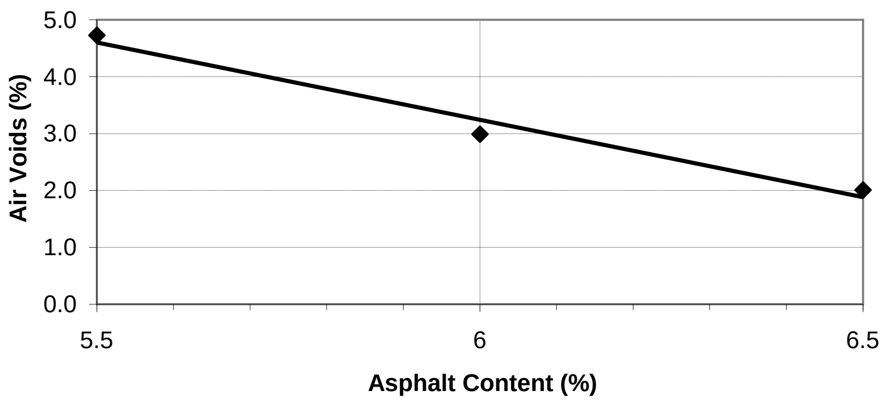


Figure A-102. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Coarse Mix Chert Gravel With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.1%

Figure A-103. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Coarse Mix Chert Gravel With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

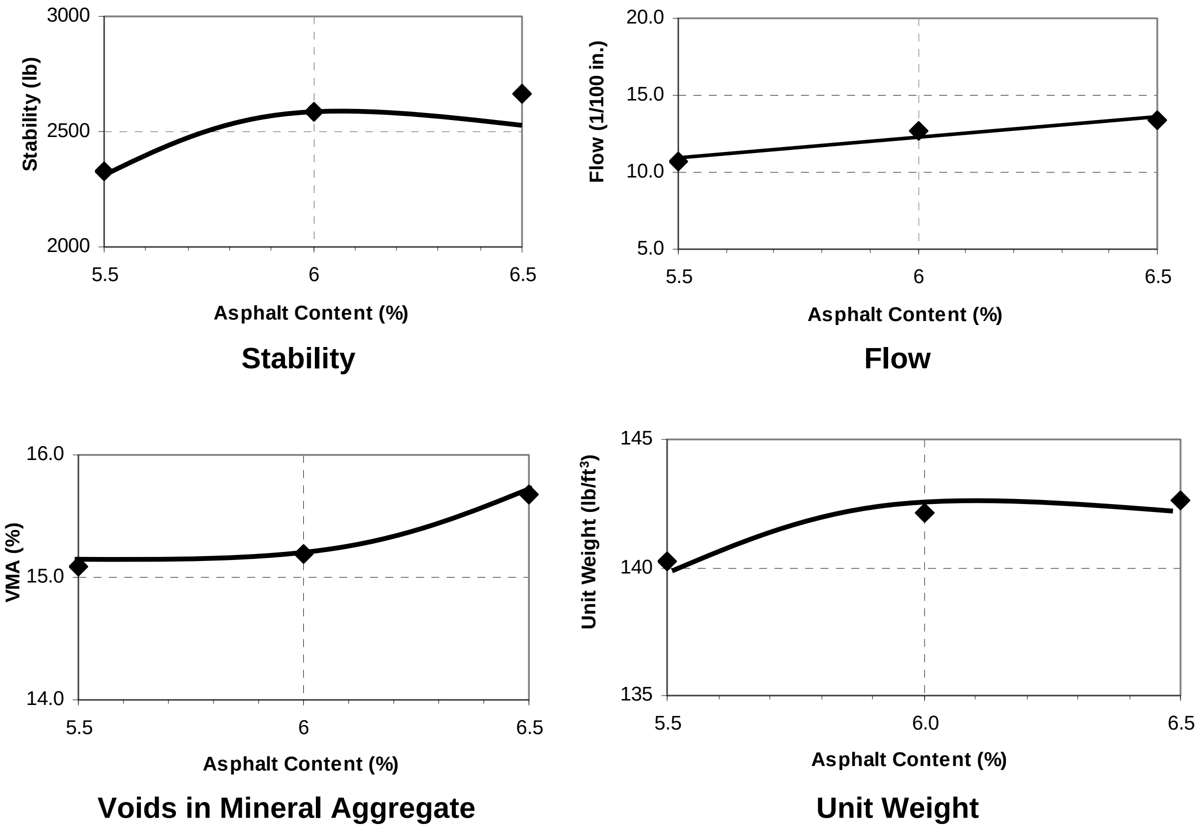


Figure A-104. Marshall Mix Design Results, 3/4-Inch Coarse Chert Gravel With Sand, PG 64-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Fine Limestone

		Individual Stockpiles				
Percent Passing	Total Combined Gradation	#6	#7	821-1/4 mod	692 Stone Sand	Mortar Sand
1"	100	100	100	100	100	100
3/4"	100	90	100	100	100	100
1/2"	98	15	93	100	100	100
3/8"	89	2	57	100	100	100
#4	73	1	3	100	98	100
#8	58	0	1	95	72	100
#16	38	0	1	65	47	100
#30	25	0	1	41	31	94
#50	16	0	1	23	21	32
#100	9	0	1	10	13	1
#200	6.4	0.4	0.5	5.1	9.5	0.6
Percent Used:	100%	0%	26%	56%	18%	0%

Percent of Asphalt Cement	6.0%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185 °C (365°F)
Compaction Temperature	168 °C (335°F)

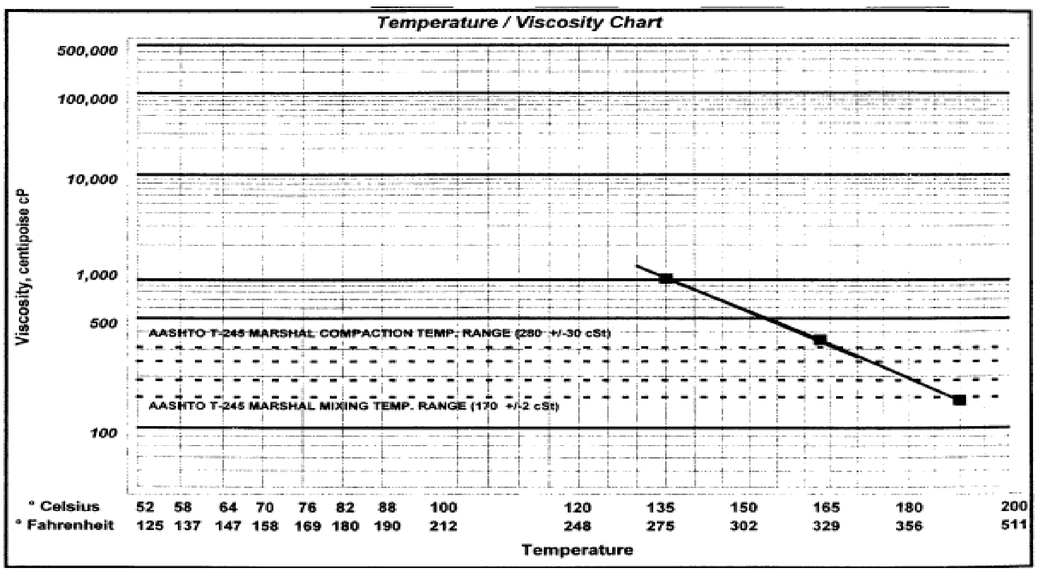


Figure A-105. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Fine Limestone

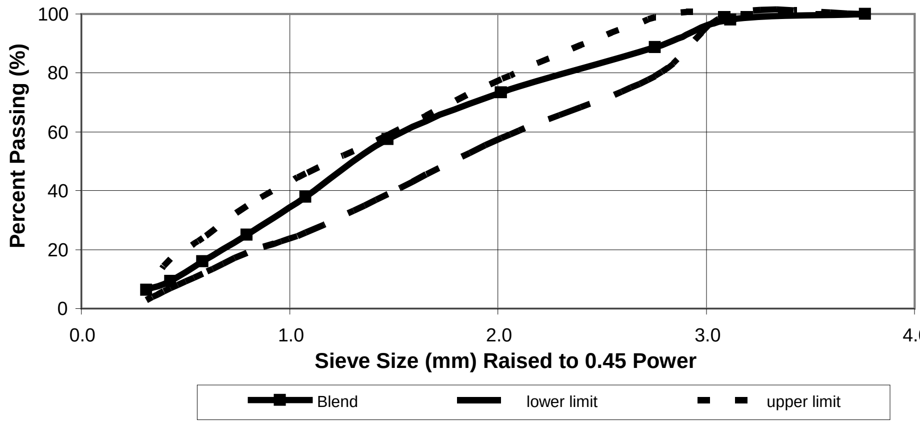
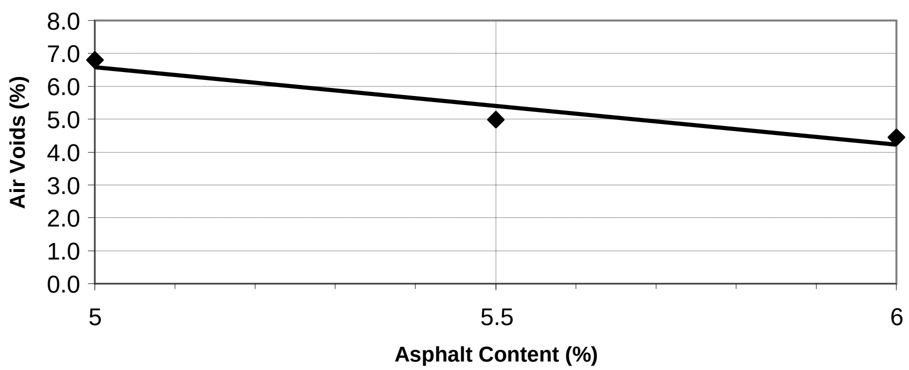


Figure A-106. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Fine Mix Limestone



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.2%
Percent by Weight Elongated Particles (5:1)	0.4%
Percent by Weight Flat Particles (5:1)	1.6%

Figure A-107. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Fine Mix Limestone

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

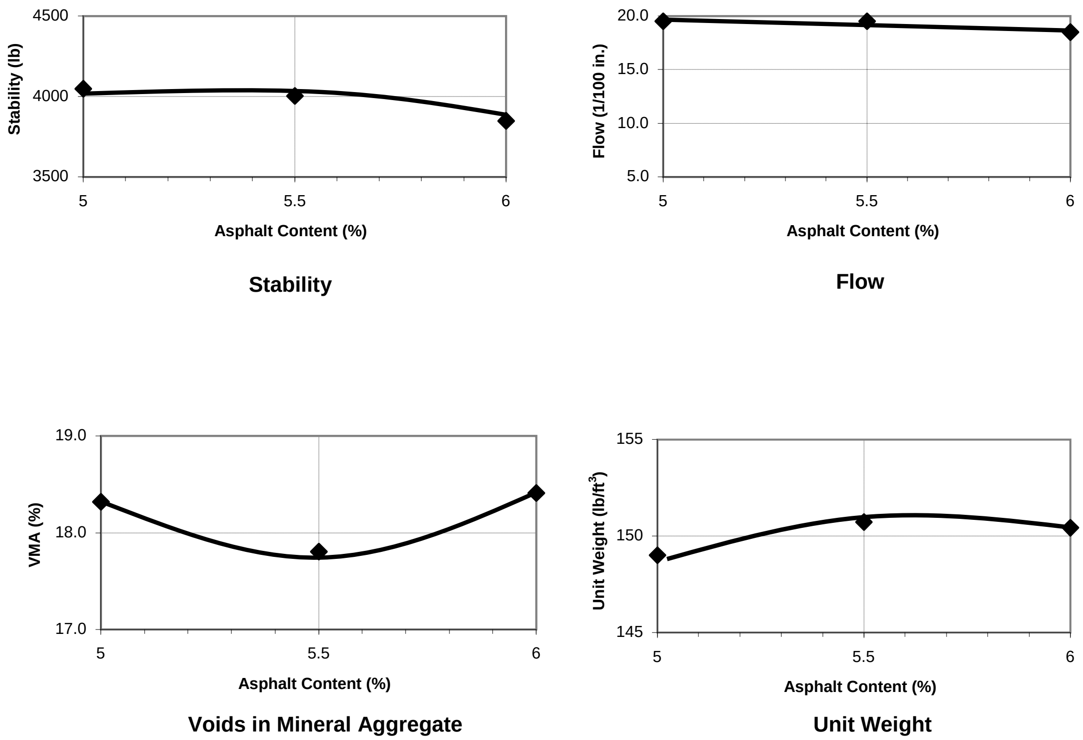


Figure A-108. Marshall Mix Design Results, 1/2-Inch Fine Limestone, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Coarse Limestone

		Individual Stockpiles				
Percent Passing	**Total Combined Gradation**	**#6**	**#7**	**821-1/4 mod**	**692 Stone Sand**	**Mortar Sand**
1"	100	100	100	100	100	100
3/4"	100	90	100	100	100	100
1/2"	97	15	93	100	100	100
3/8"	82	2	57	100	100	100
#4	59	1	3	100	98	100
#8	45	0	1	95	72	100
#16	29	0	1	65	47	100
#30	20	0	1	41	31	94
#50	13	0	1	23	21	32
#100	8	0	1	10	13	1
#200	5.4	0.4	0.5	5.1	9.5	0.6
Percent Used:	100%	0%	41%	50%	9%	0%

Percent of Asphalt Cement	5.5%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

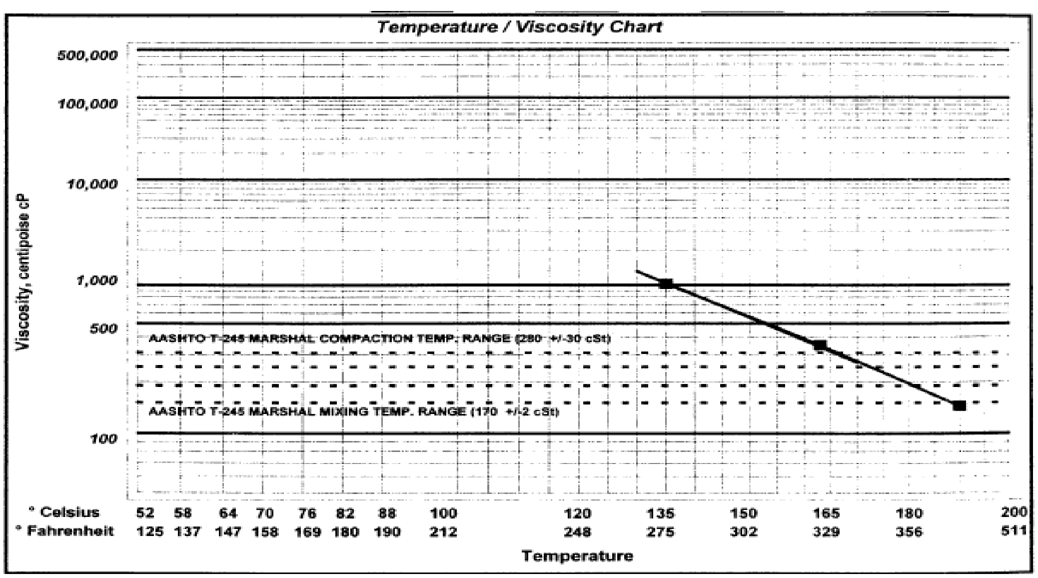


Figure A-109. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Coarse Limestone

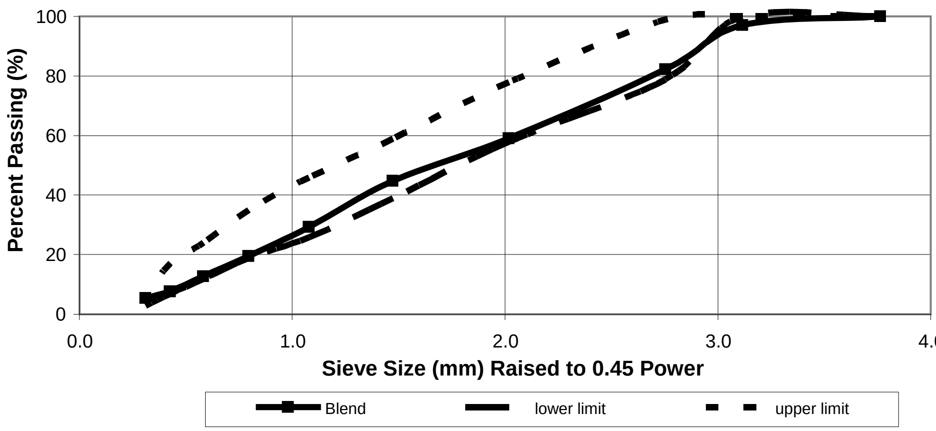
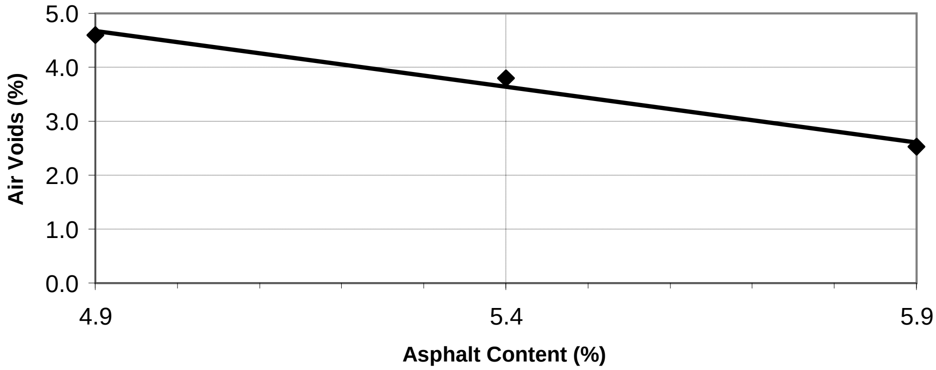


Figure A-110. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Coarse Mix Limestone



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.2%
Percent by Weight Elongated Particles (5:1)	0.4%
Percent by Weight Flat Particles (5:1)	1.5%

Figure A-111. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Coarse Mix Limestone

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

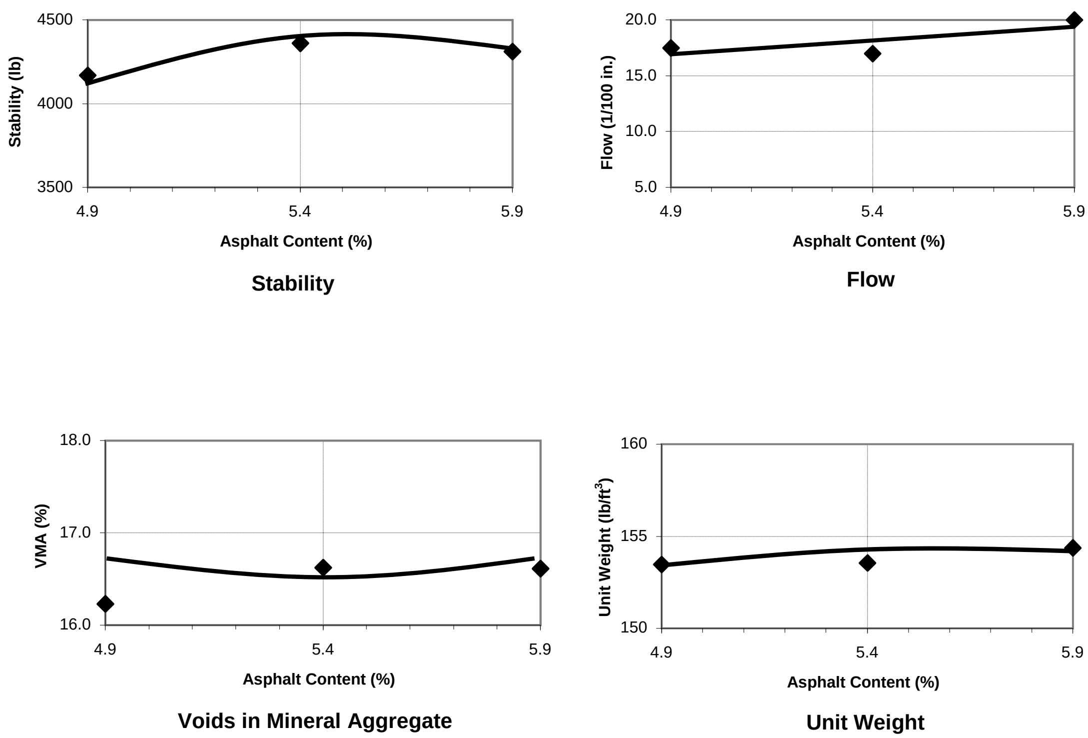


Figure A-112. Marshall Mix Design Results, 1/2-Inch Coarse Mix Limestone, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Fine Limestone

Percent Passing	Total Combined Gradation	#6	#7	821-1/4 mod	692 Stone Sand	Mortar Sand
		Individual Stockpiles				
1"	100	100	100	100	100	100
3/4"	100	90	100	100	100	100
1/2"	98	15	93	100	100	100
3/8"	86	2	57	100	100	100
#4	67	1	3	100	98	100
#8	52	0	1	95	72	100
#16	34	0	1	65	47	100
#30	23	0	1	41	31	94
#50	15	0	1	23	21	32
#100	9	0	1	10	13	1
#200	5.8	0.4	0.5	5.1	9.5	0.6
Percent Used:	100	0%	33%	51%	16%	0%

Percent of Asphalt Cement	5.9%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185 °C (365°F)
Compaction Temperature	168 °C (335°F)

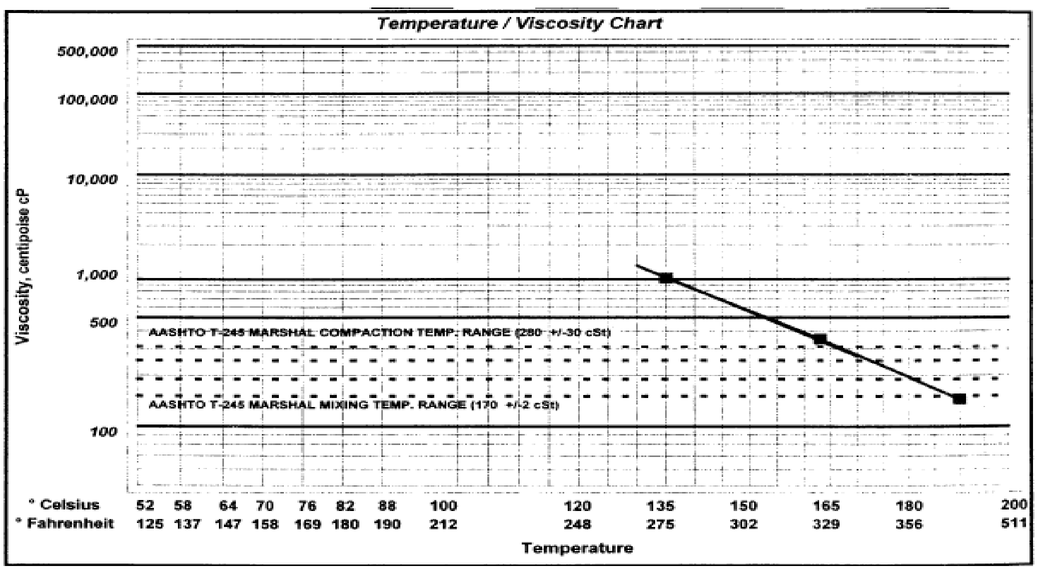
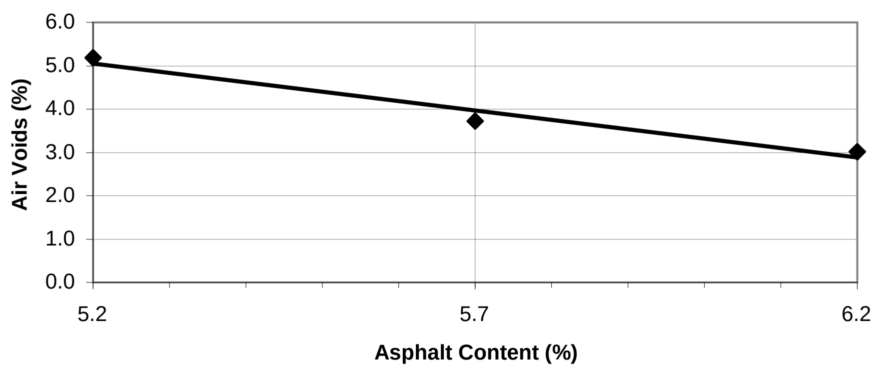


Figure A-113. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Fine Limestone

Figure A-114. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Fine Mix Limestone



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.2%
Percent by Weight Elongated Particles (5:1)	0.4%
Percent by Weight Flat Particles (5:1)	1.5%

Figure A-115. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Fine Mix Limestone

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

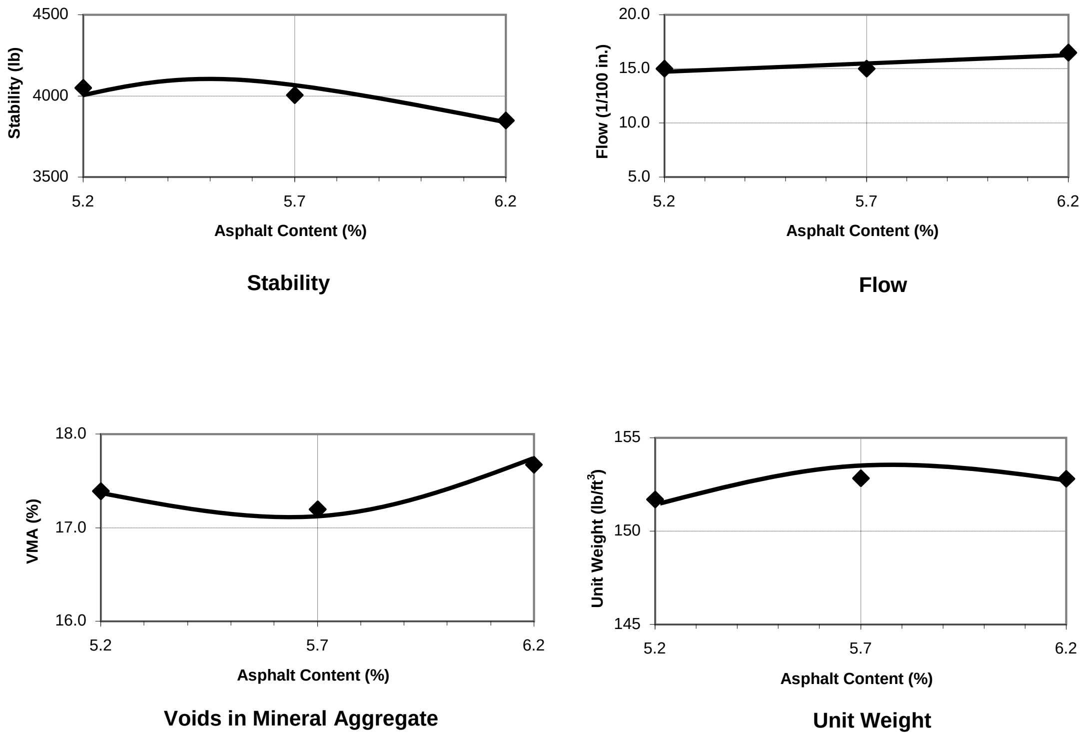


Figure A-116. Marshall Mix Design Results, 3/4-Inch Fine Mix Limestone, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Coarse Limestone

Percent Passing	Total Combined Gradation	Individual Stockpiles #6	#7	821-1/4 mod	692 Stone Sand	Mortar Sand
1"	100	100	100	100	100	100
3/4"	98	90	100	100	100	100
1/2"	83	15	93	100	100	100
3/8"	69	2	57	100	100	100
#4	50	1	3	100	98	100
#8	38	0	1	95	72	100
#16	25	0	1	65	47	100
#30	17	0	1	41	31	94
#50	11	0	1	23	21	32
#100	7	0	1	10	13	1
#200	4.7	0.4	0.5	5.1	9.5	0.6
Percent Used:	100	17%	33%	43%	7%	0%

Percent of Asphalt Cement	5.1%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185 °C (365°F)
Compaction Temperature	168 °C (335°F)

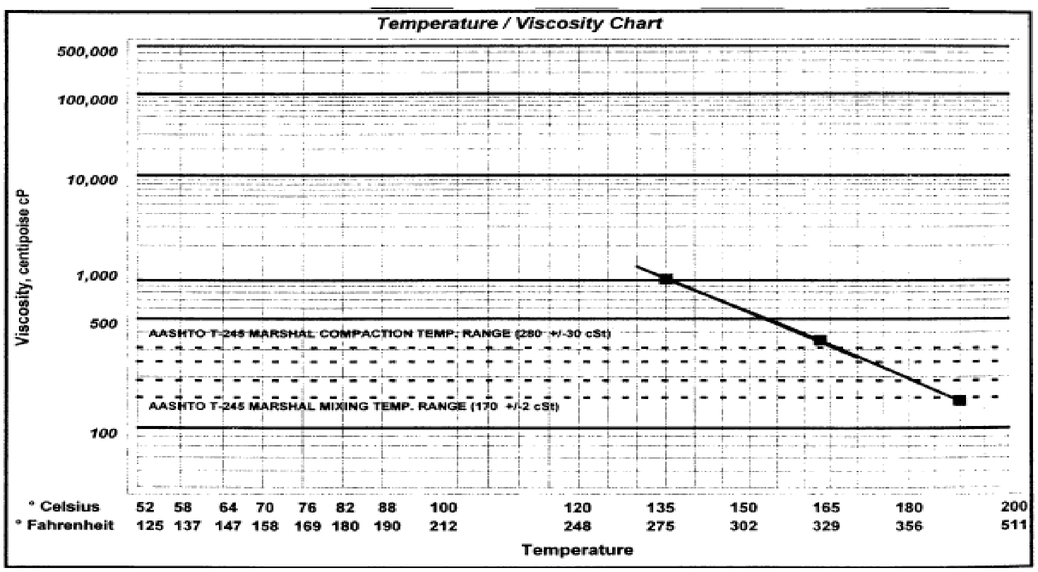


Figure A-117. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Coarse Limestone

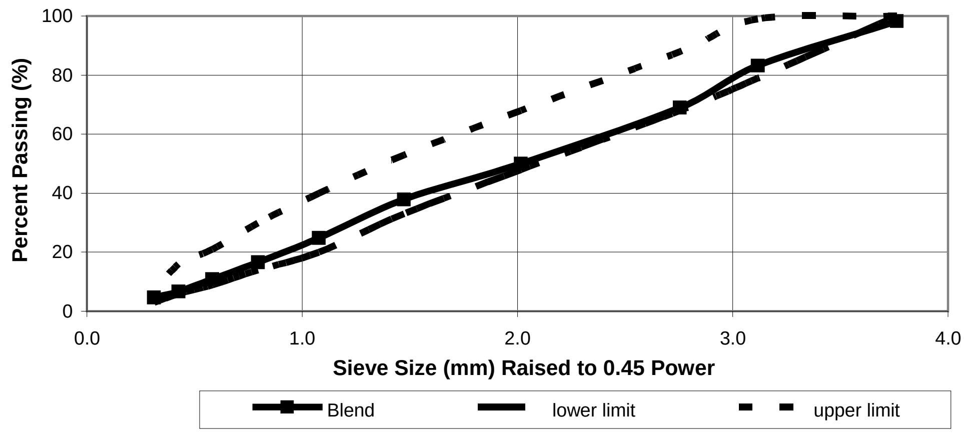
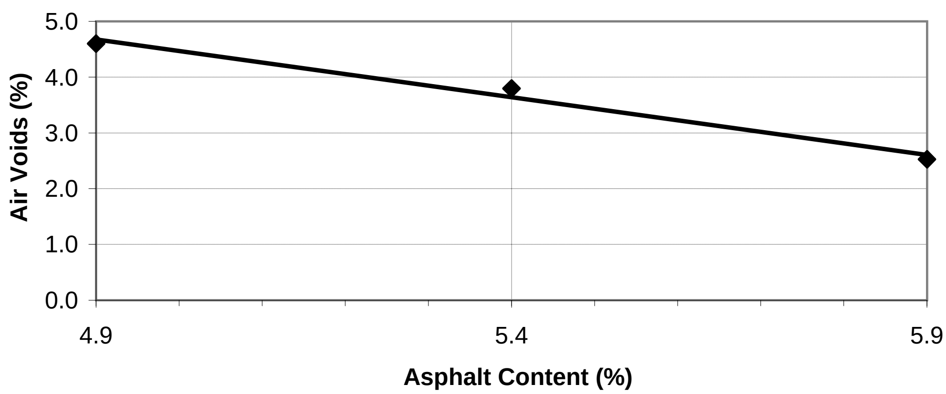


Figure A-118. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Coarse Mix Limestone



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.1%
Percent by Weight Elongated Particles (5:1)	0.3%
Percent by Weight Flat Particles (5:1)	1.2%

Figure A-119. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Coarse Mix Limestone

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

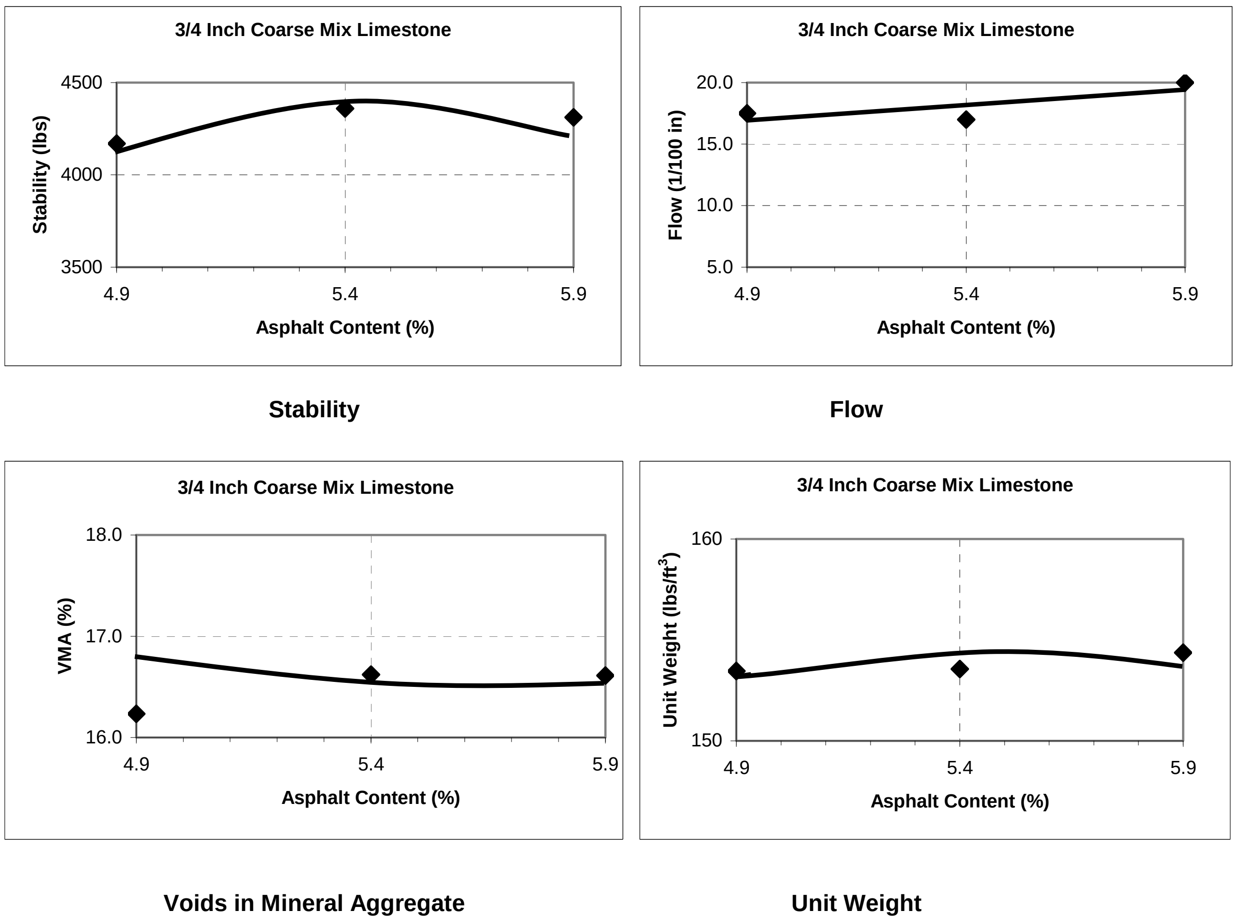


Figure A-120. Marshall Mix Design Results, 3/4-Inch Coarse Limestone, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Fine Limestone With Mortar Sand

		Individual Stockpiles				
	Total Combined				692 Stone	
Percent Passing	**Gradation**	**#6**	**#7**	**821-1/4 mod**	**Sand**	**Mortar Sand**
1"	100	100	100	100	100	100
3/4"	100	90	100	100	100	100
1/2"	98	15	93	100	100	100
3/8"	87	2	57	100	100	100
#4	69	1	3	100	98	100
#8	53	0	1	95	72	100
#16	38	0	1	65	47	100
#30	28	0	1	41	31	94
#50	16	0	1	23	21	32
#100	8	0	1	10	13	1
#200	5.9	0.4	0.5	5.1	9.5	0.6
Percent Used:	100	0%	30%	60%	0%	10%

Percent of Asphalt Cement	5.5%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185 °C (365°F)
Compaction Temperature	168 °C (335°F)

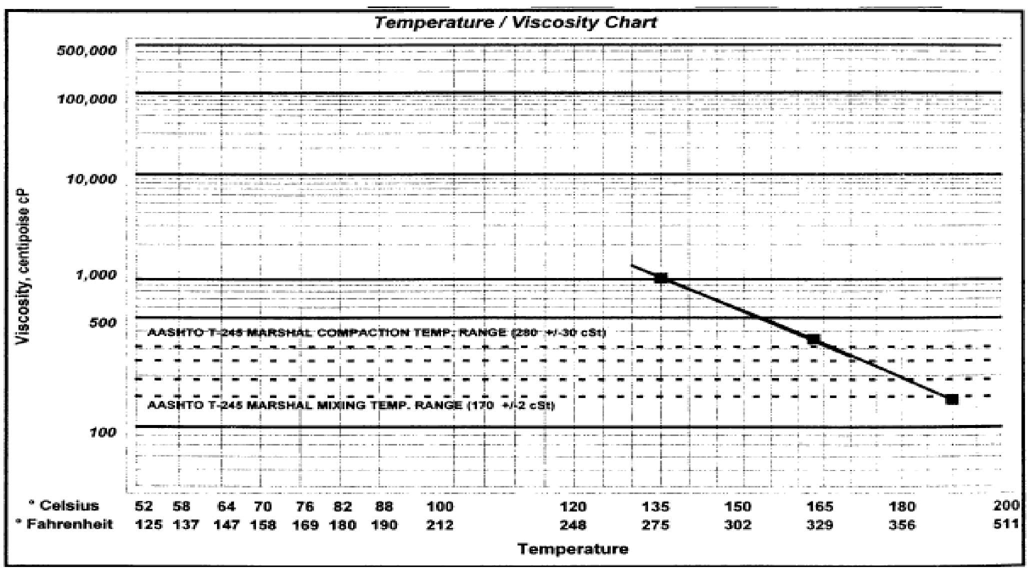


Figure A-121. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Fine Limestone With Mortar Sand

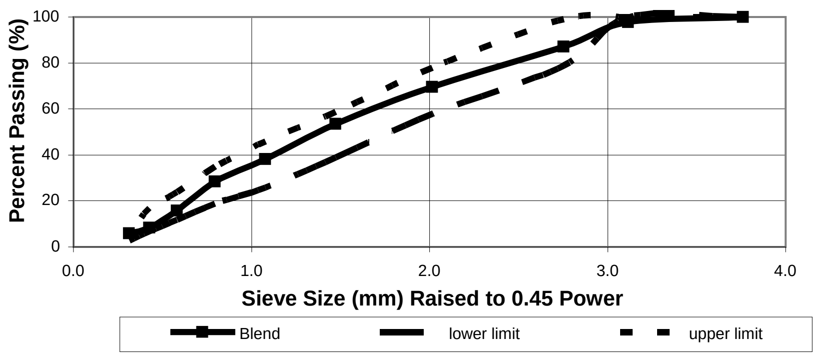
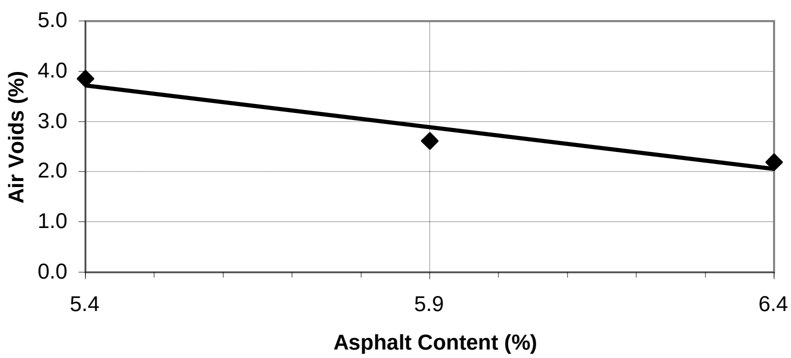


Figure A-122. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Fine Mix Limestone With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.2%
Percent by Weight Elongated Particles (5:1)	0.4%
Percent by Weight Flat Particles (5:1)	1.5%

Figure A-123. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Fine Mix Limestone With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

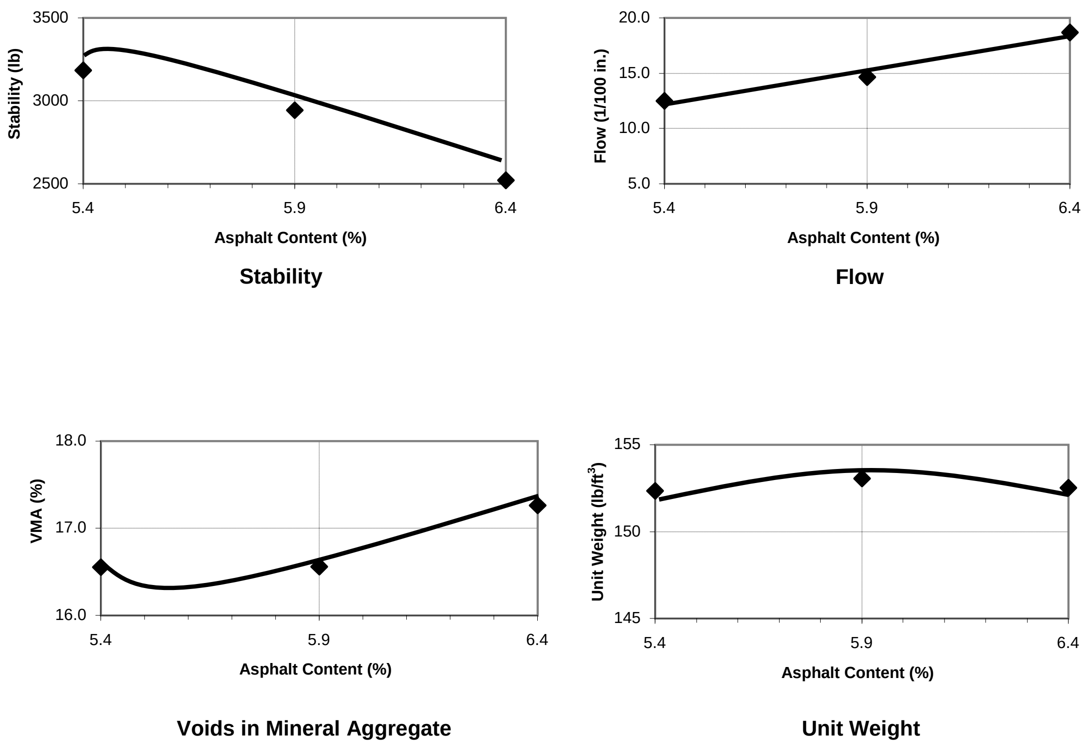


Figure A-124. Marshall Mix Design Results, 1/2-Inch Fine Limestone With Mortar Sand, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Coarse Limestone With Mortar Sand

		Individual Stockpiles				
Percent Passing	**Total Combined Gradation**	**#6**	**#7**	**821-1/4 mod**	**692 Stone Sand**	**Mortar Sand**
1"	100	100	100	100	100	100
3/4"	100	90	100	100	100	100
1/2"	97	15	93	100	100	100
3/8"	84	2	57	100	100	100
#4	62	1	3	100	98	100
#8	48	0	1	95	72	100
#16	34	0	1	65	47	100
#30	26	0	1	41	31	94
#50	14	0	1	23	21	32
#100	7	0	1	10	13	1
#200	5.2	0.4	0.5	5.1	9.5	0.6
Percent Used:	100	0%	38%	52%	0%	10%

Percent of Asphalt Cement	5.2%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185^{o}C (365^{o}F)
Compaction Temperature	168^{o}C (335^{o}F)

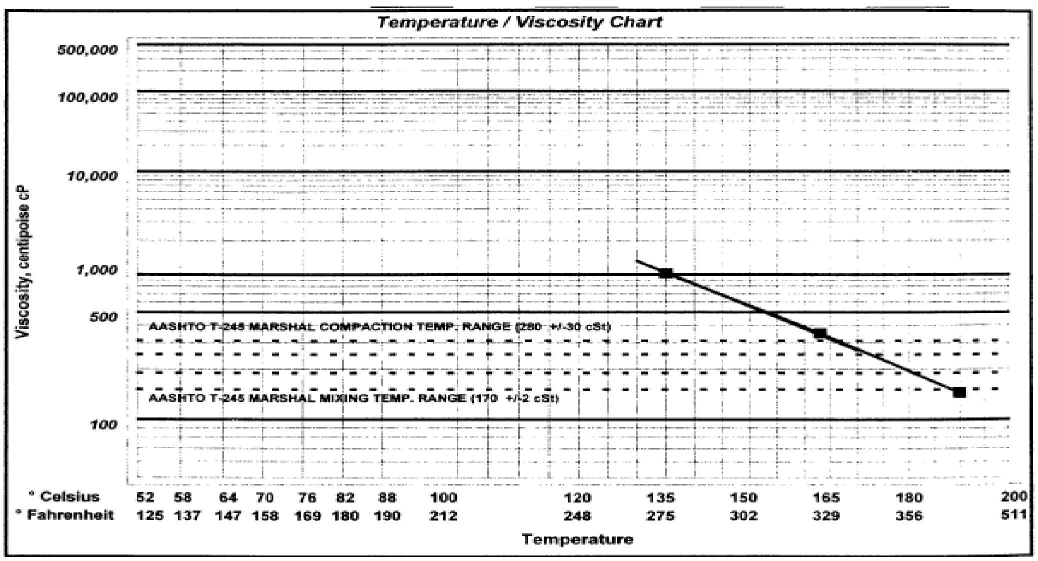


Figure A-125. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Coarse Limestone With Mortar Sand

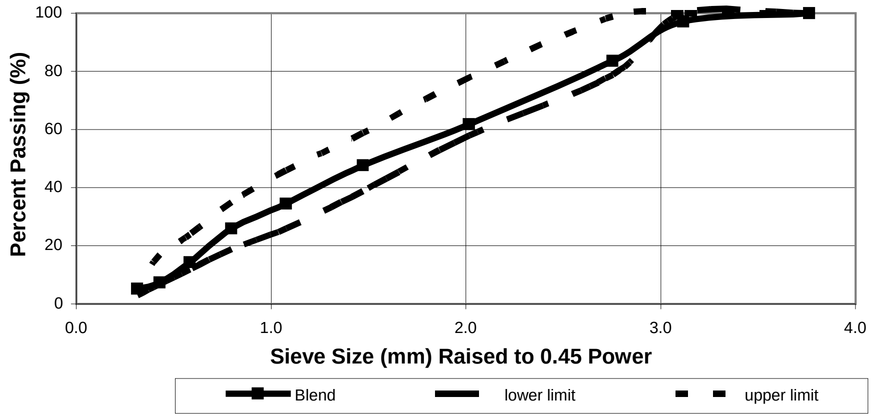
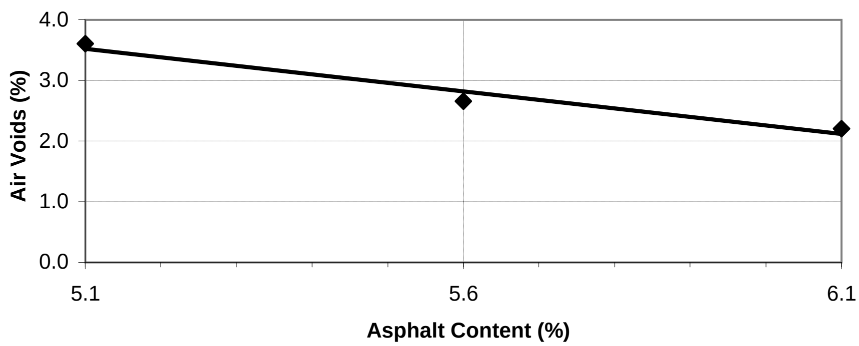


Figure A-126. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Coarse Mix Limestone With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.2%
Percent by Weight Elongated Particles (5:1)	0.4%
Percent by Weight Flat Particles (5:1)	1.5%

Figure A-127. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Coarse Mix Limestone With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

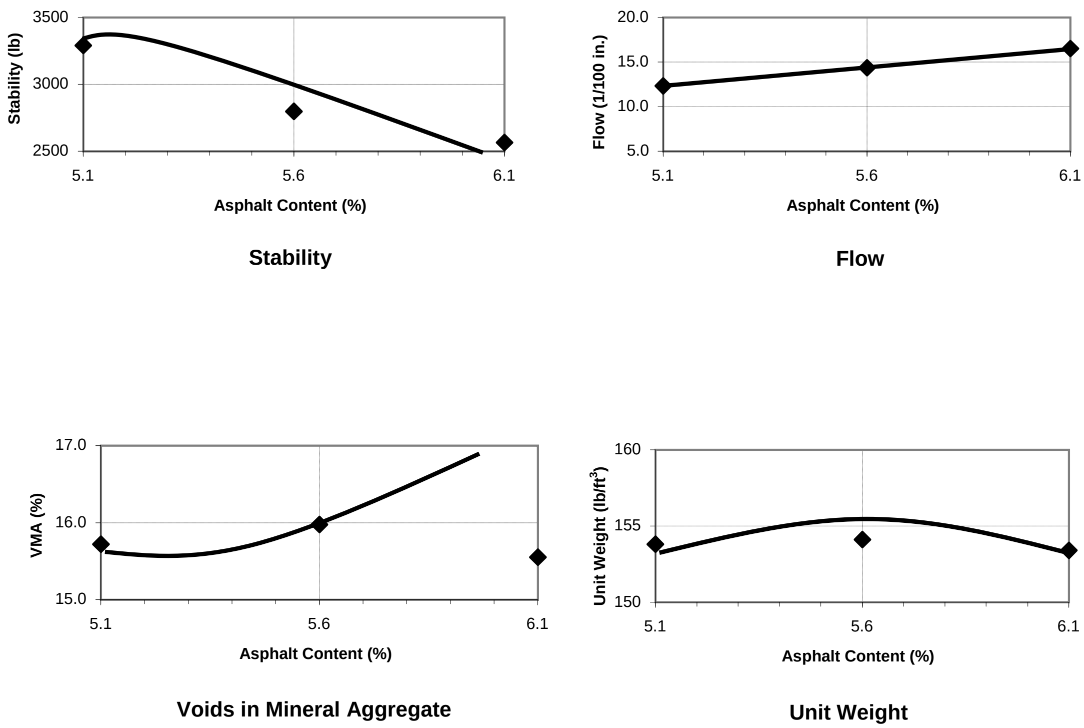


Figure A-128. Marshall Mix Design Results, 1/2-Inch Coarse Limestone With Mortar Sand, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Fine Limestone With Mortar Sand

		Individual Stockpiles				
Percent Passing	**Total Combined Gradation**	**#6**	**#7**	**821-1/4 mod**	**692 Stone Sand**	**Mortar Sand**
1"	100	100	100	100	100	100
3/4"	100	90	100	100	100	100
1/2"	97	15	93	100	100	100
3/8"	82	2	57	100	100	100
#4	58	1	3	100	98	100
#8	45	0	1	95	72	100
#16	33	0	1	65	47	100
#30	28	0	1	41	31	94
#50	13	0	1	23	21	32
#100	7	0	1	10	13	1
#200	4.8	0.4	0.5	5.1	9.5	0.6
Percent Used:	100	0%	42%	48%	0%	10%

Percent of Asphalt Cement	5.1%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185 °C (365°F)
Compaction Temperature	168 °C (335°F)

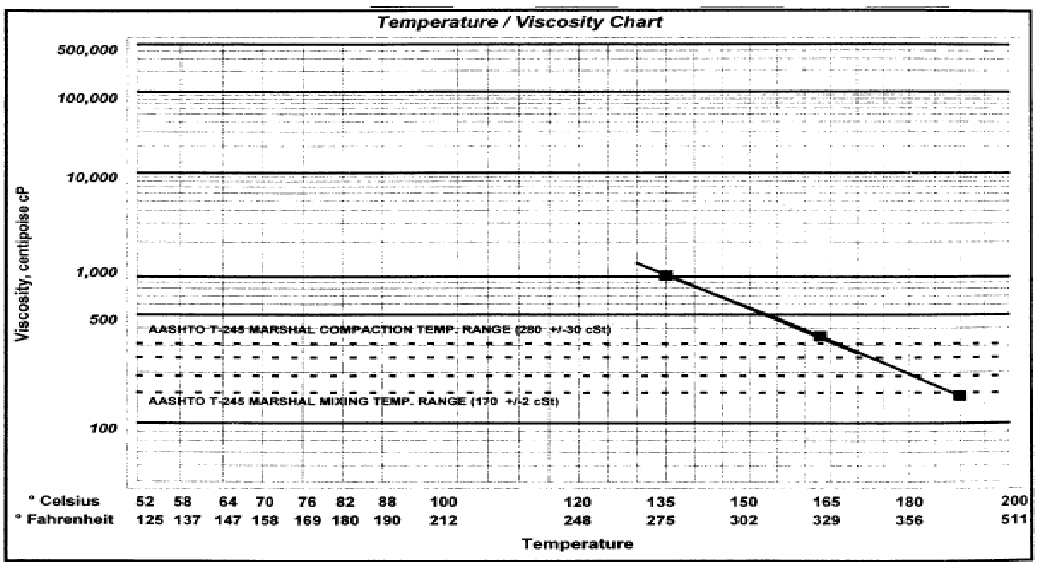


Figure A-129. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Fine Limestone With Mortar Sand

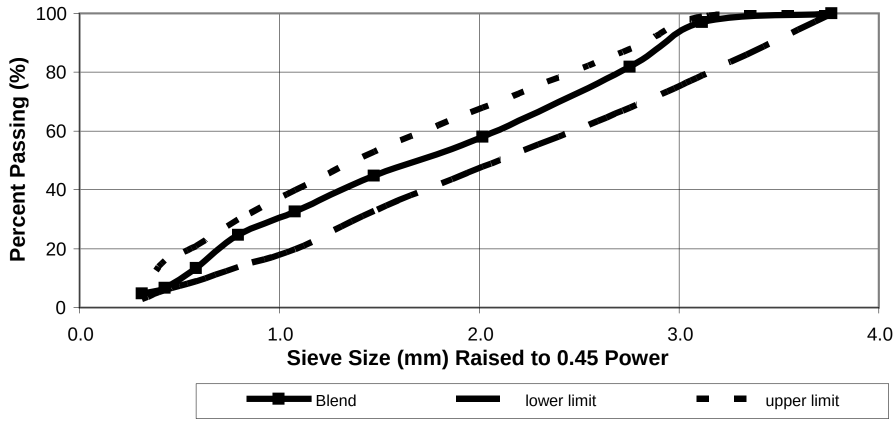
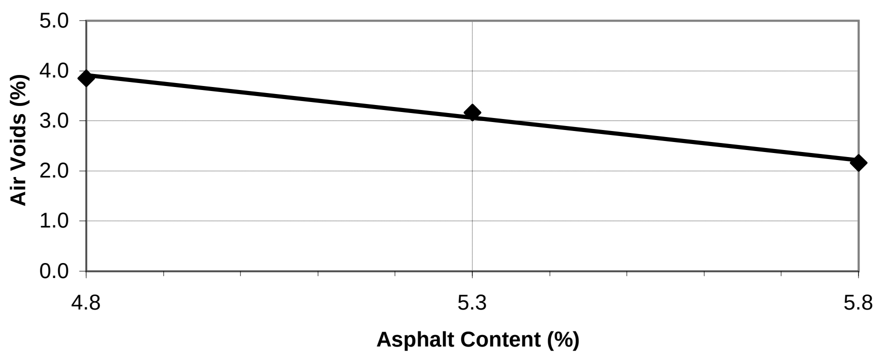


Figure A-130. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Fine Mix Limestone With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.2%
Percent by Weight Elongated Particles (5:1)	0.4%
Percent by Weight Flat Particles (5:1)	1.5%

Figure A-131. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Fine Mix Limestone With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

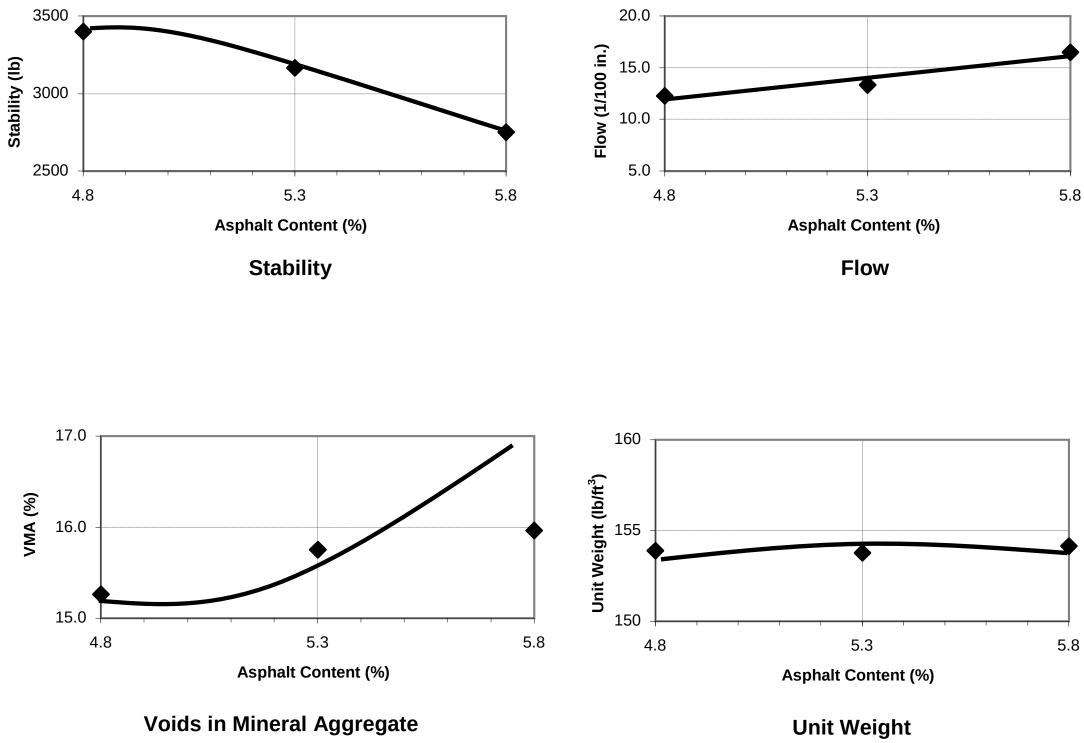


Figure A-132. Marshall Mix Design Results, 3/4-Inch Fine Limestone With Mortar Sand, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Coarse Limestone With Mortar Sand

Percent Passing	Total Combined Gradation	Individual Stockpiles #6	#7	821-1/4 mod	692 Stone Sand	Mortar Sand
1"	100	100	100	100	100	100
3/4"	99	90	100	100	100	100
1/2"	92	15	93	100	100	100
3/8"	76	2	57	100	100	100
#4	53	1	3	100	98	100
#8	41	0	1	95	72	100
#16	30	0	1	65	47	100
#30	23	0	1	41	31	94
#50	12	0	1	23	21	32
#100	6	0	1	10	13	1
#200	4.4	0.4	0.5	5.1	9.5	0.6
Percent Used:	100	5%	40%	45%	0%	10%

Percent of Asphalt Cement	4.8%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

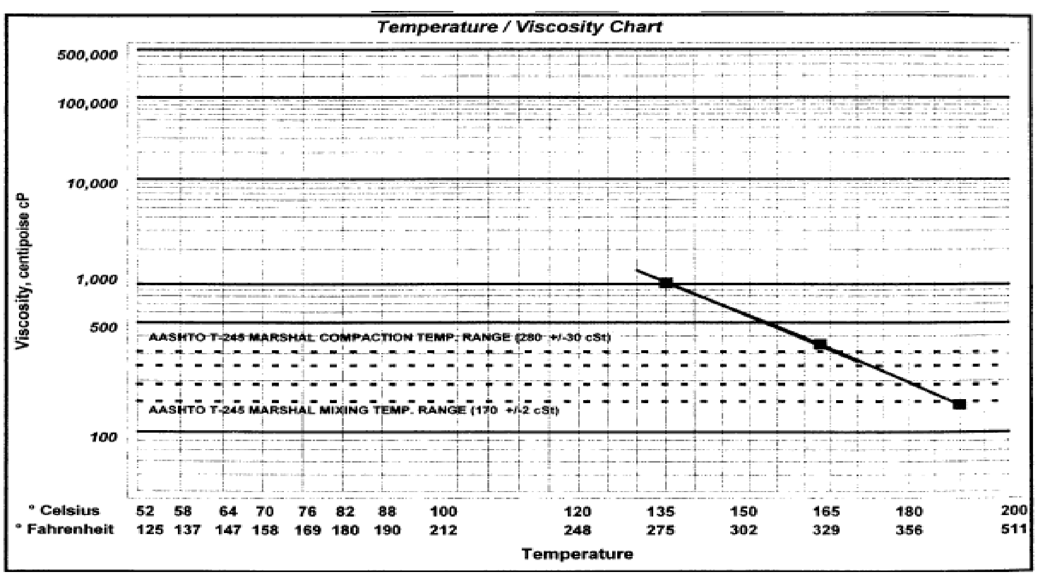


Figure A-133. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Coarse Limestone With Mortar Sand

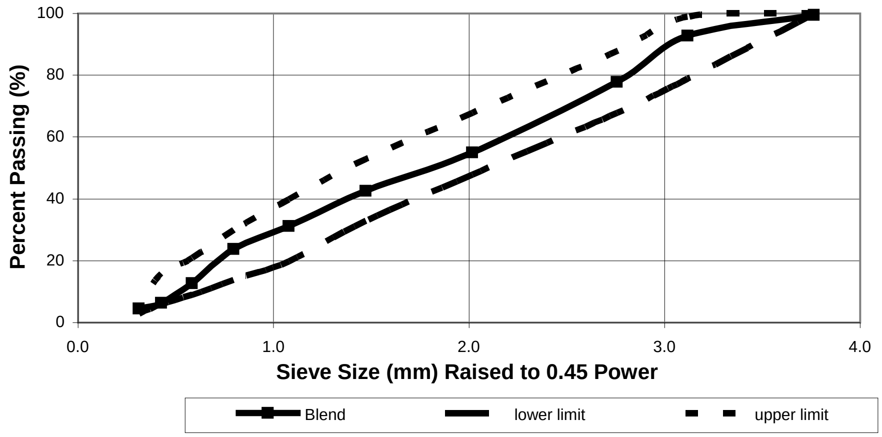
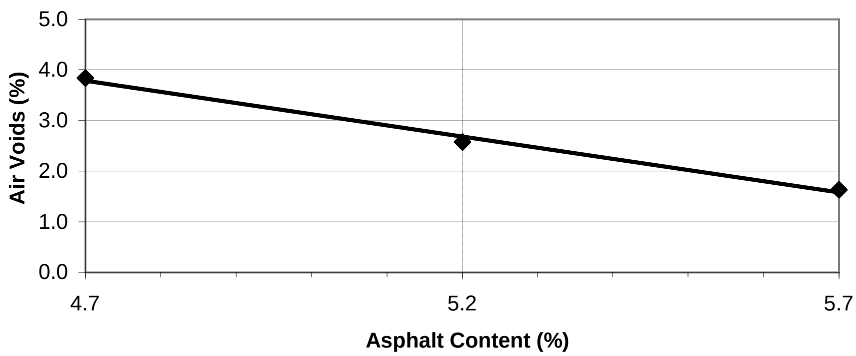


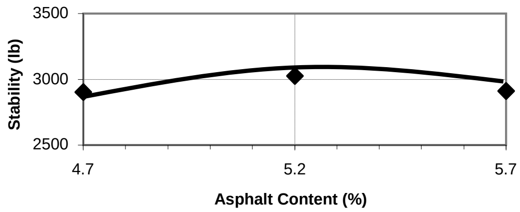
Figure A-134. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Coarse Mix Limestone With 10% Mortar Sand



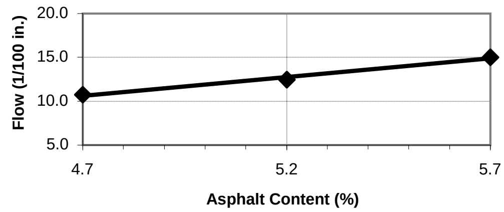
Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent By Weight Flat Particles (5:1)	0.1%
Percent By Weight Elongated Particles (5:1)	0.3%
Percent By Weight Flat Particles (5:1)	1.4%

Figure A-135. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Coarse Mix Limestone With Mortar Sand

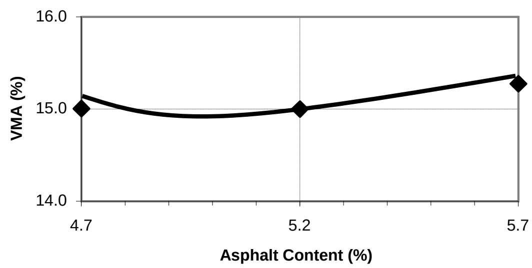
Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content



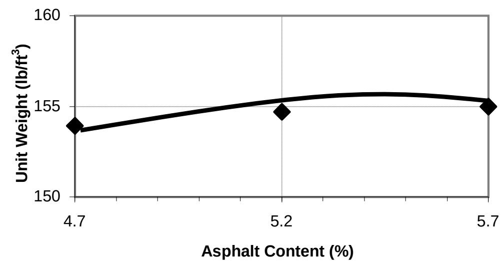
Stability



Flow



Voids in Mineral Aggregate



Unit Weight

Figure A-136. Marshall Mix Design Results, 3/4-Inch Coarse Limestone With Mortar Sand, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Fine Granite

		Individual Stockpiles									
Percent Passing	**Total Combined Gradation**	**3/4"**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	100	1	8	99	100	100	100	100	100	100	100
3/8"	94	1	0	13	100	100	100	100	100	100	100
#4	73	1	0	0	6	99	100	100	100	100	100
#8	55	1	0	0	0	11	100	100	100	100	100
#16	42	1	0	0	0	0	14	100	100	100	100
#30	33	1	0	0	0	0	8	13	99	100	94
#50	21	1	0	0	0	0	2	2	16	100	32
#100	10	1	0	0	0	0	2	2	4	51	1
#200	5.6	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100%	0%	0%	7%	21%	19%	13%	9%	13%	18%	0%

Percent of Asphalt Cement	7.5%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

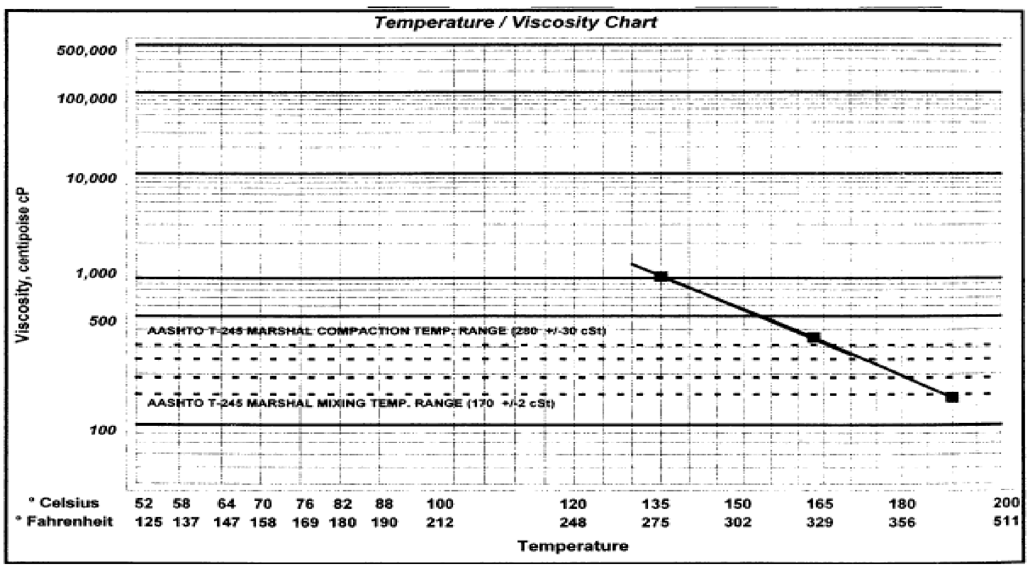


Figure A-137. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Fine Granite

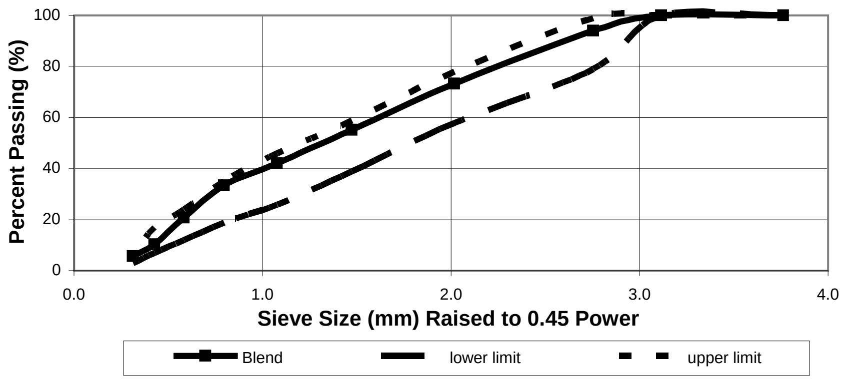
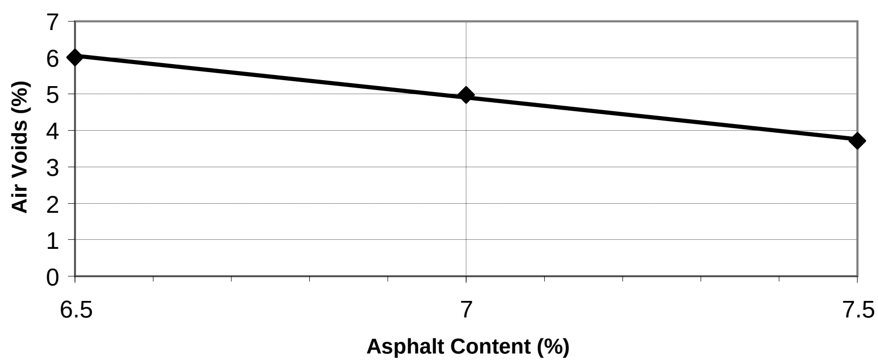


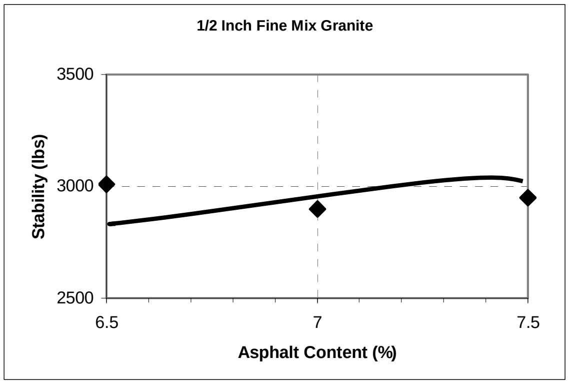
Figure A-138. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Fine Mix Granite



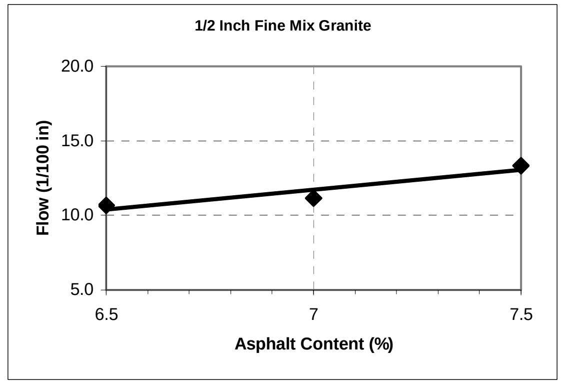
Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	1.1%

Figure A-139. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Fine Mix Granite

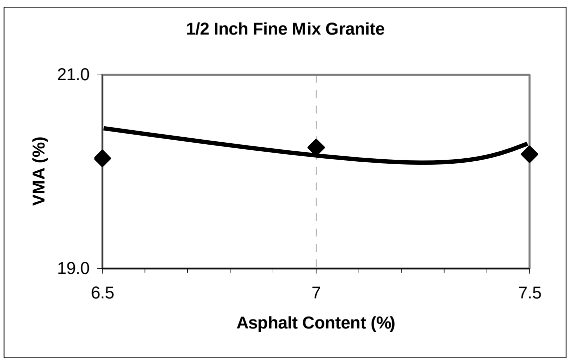
Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content



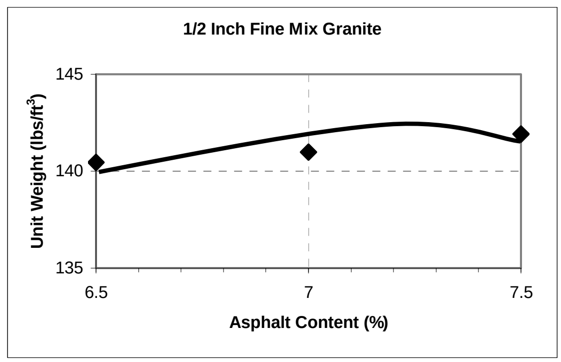
Stability



Flow



Voids in Mineral Aggregate



Unit Weight

Figure A-140. Marshall Mix Design Results, 1/2-Inch Fine Granite, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Coarse Granite

		Individual Stockpiles									
Percent Passing	**Total Combined Gradation**	**3/4"**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	100	1	8	99	100	100	100	100	100	100	100
3/8"	81	1	0	13	100	100	100	100	100	100	100
#4	60	1	0	0	6	99	100	100	100	100	100
#8	42	1	0	0	0	11	100	100	100	100	100
#16	32	1	0	0	0	0	14	100	100	100	100
#30	24	1	0	0	0	0	8	13	99	100	94
#50	15	1	0	0	0	0	2	2	16	100	32
#100	8	1	0	0	0	0	2	2	4	51	1
#200	4.1	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100%	0%	0%	22%	19%	19%	10%	8%	9%	13%	0%

Percent of Asphalt Cement	6.0%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

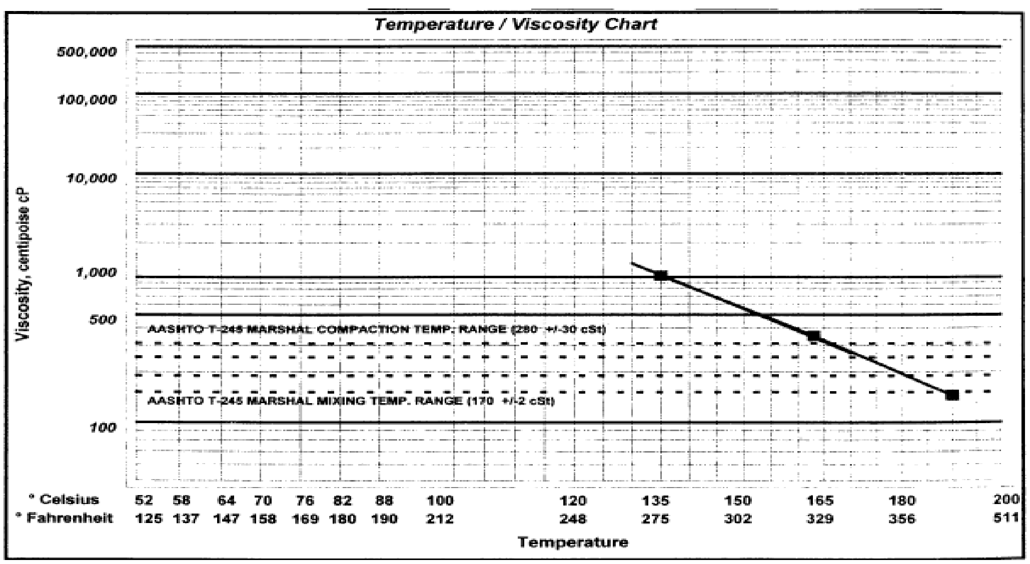


Figure A-141. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Coarse Granite

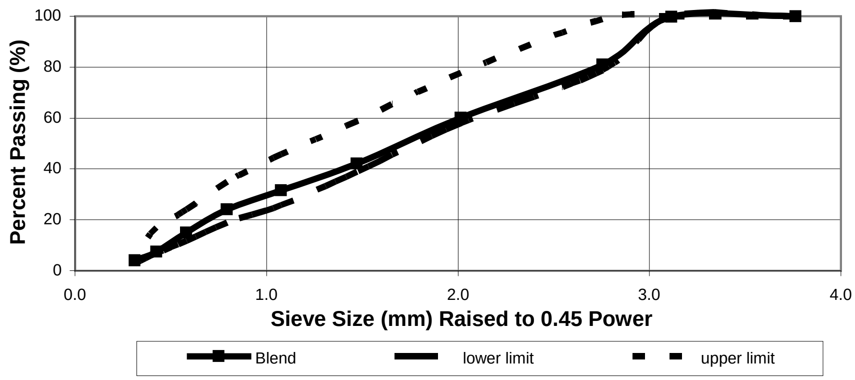
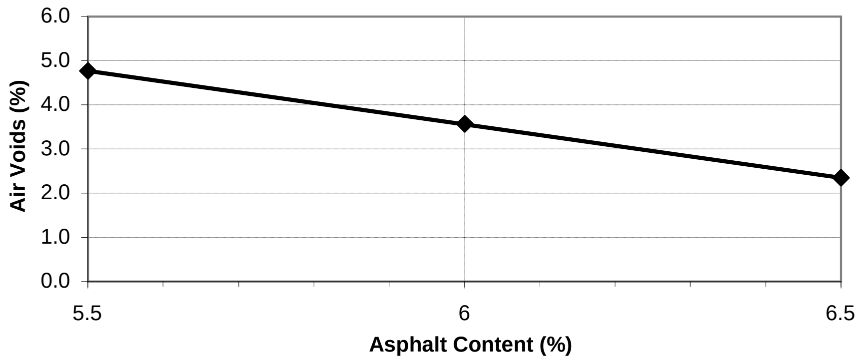


Figure A-142. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Coarse Mix Granite



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.9%

Figure A-143. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Coarse Mix Granite

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

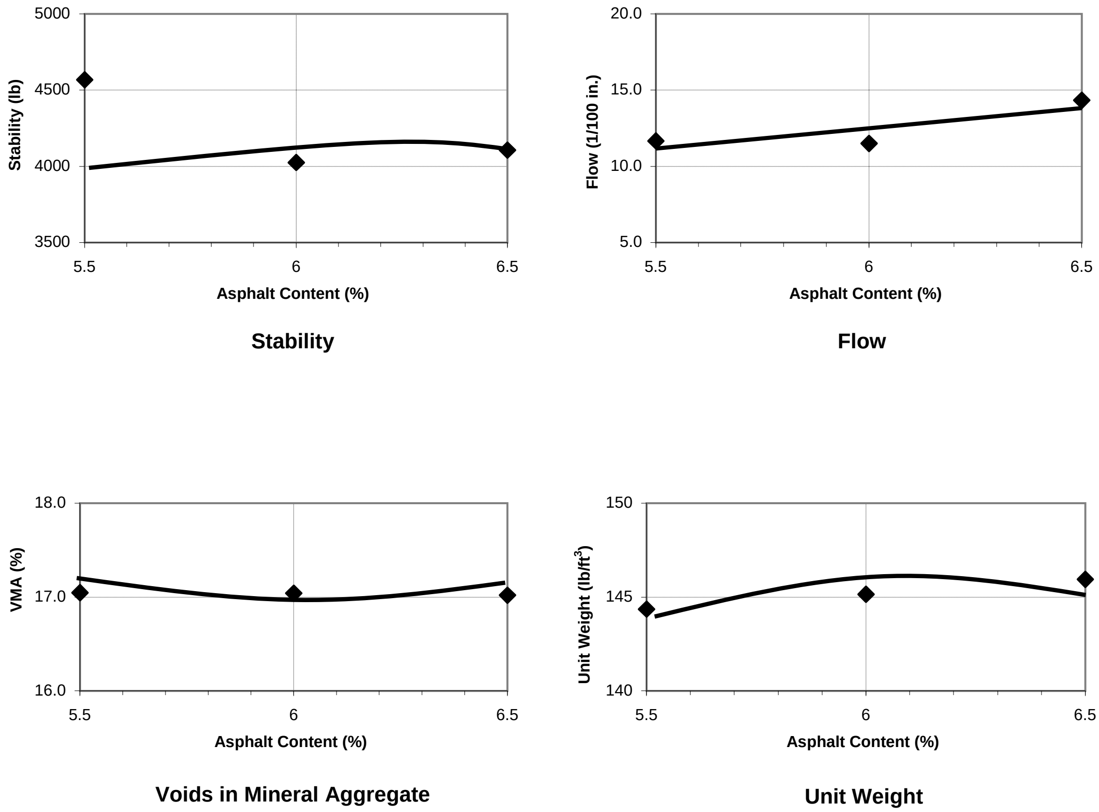


Figure A-144. Marshall Mix Design Results, 1/2-Inch Coarse Granite, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Fine Granite

Percent Passing	Total Combined Gradation	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	Mortar Sand
		Individual Stockpiles									
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	95	1	8	99	100	100	100	100	100	100	100
3/8"	85	1	0	13	100	100	100	100	100	100	100
#4	66	1	0	0	6	99	100	100	100	100	100
#8	51	1	0	0	0	11	100	100	100	100	100
#16	38	1	0	0	0	0	14	100	100	100	100
#30	28	1	0	0	0	0	8	13	99	100	94
#50	16	1	0	0	0	0	2	2	16	100	32
#100	8	1	0	0	0	0	2	2	4	51	1
#200	4.5	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	0%	5%	12%	18%	16%	13%	11%	11%	14%	0%

Percent of Asphalt Cement	6.6%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185 °C (365°F)
Compaction Temperature	168 °C (335°F)

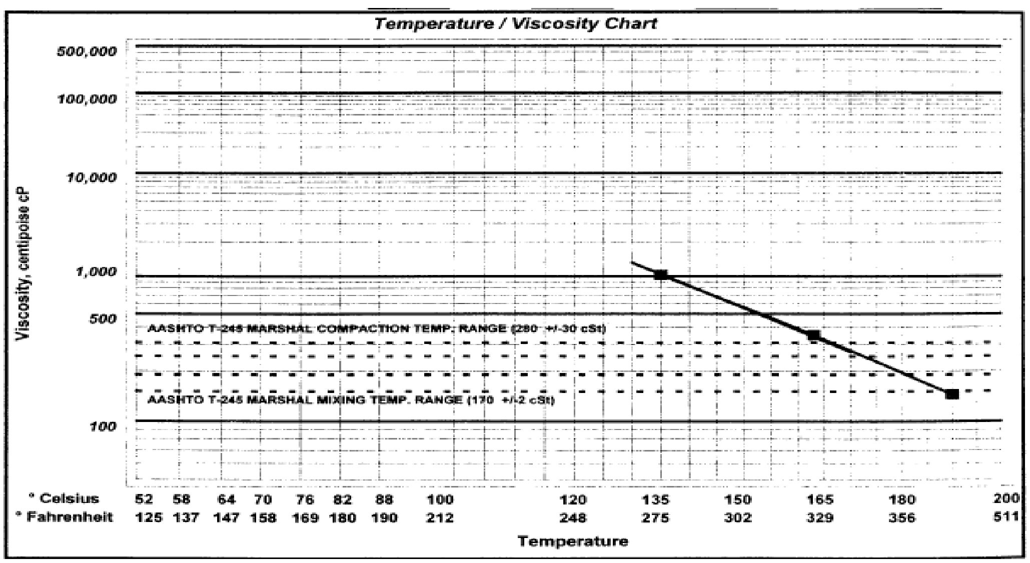


Figure A-145. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Fine Granite

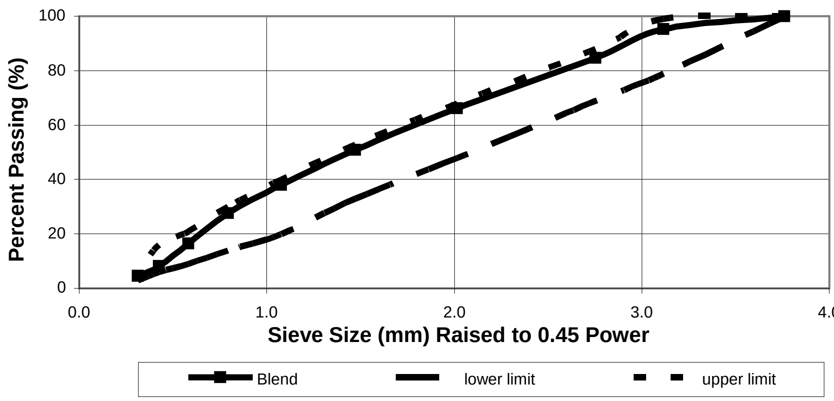
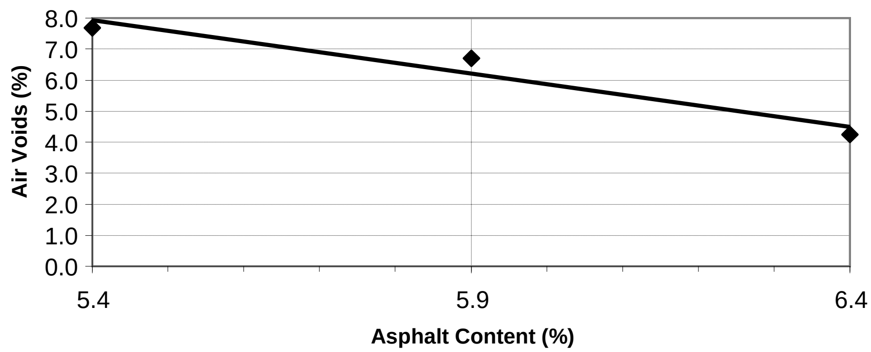


Figure A-146. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Fine Mix Granite



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.9%

Figure A-147. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Fine Mix Granite

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

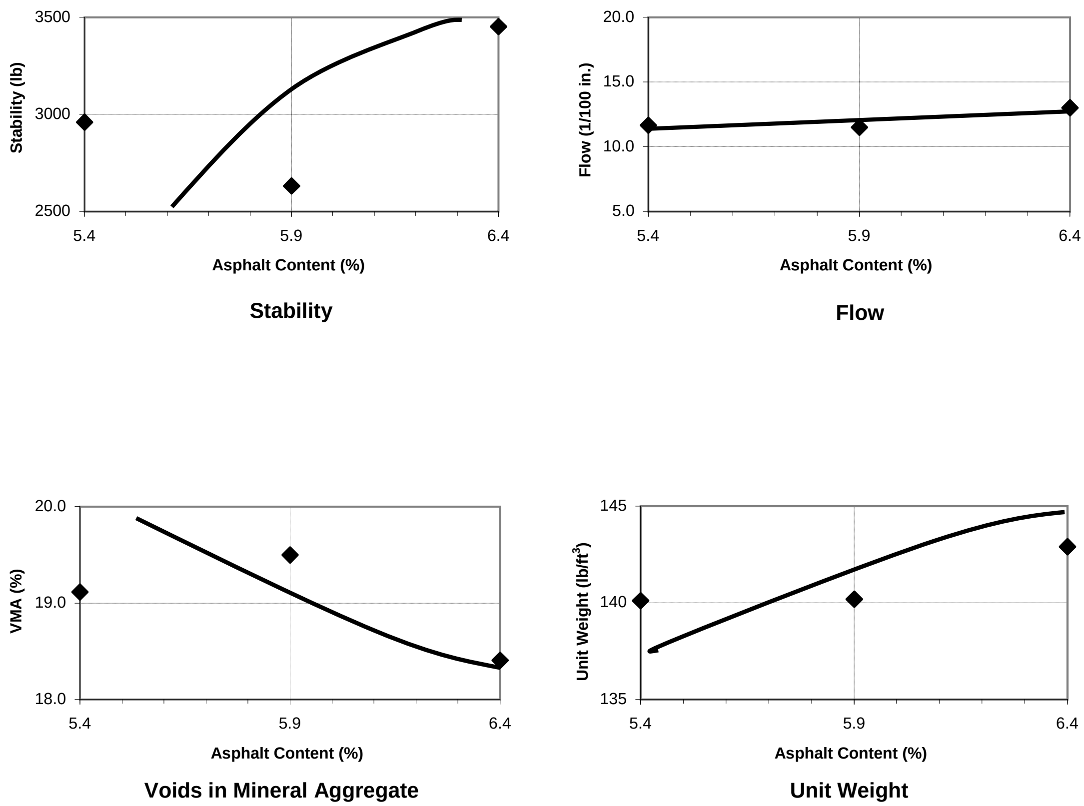


Figure A-148. Marshall Mix Design Results, 3/4-Inch Fine Granite, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Coarse Granite

Percent Passing	Total Combined Gradation	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	Mortar Sand
		Individual Stockpiles									
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	81	1	8	99	100	100	100	100	100	100	100
3/8"	70	1	0	13	100	100	100	100	100	100	100
#4	52	1	0	0	6	99	100	100	100	100	100
#8	37	1	0	0	0	11	100	100	100	100	100
#16	27	1	0	0	0	0	14	100	100	100	100
#30	20	1	0	0	0	0	8	13	99	100	94
#50	14	1	0	0	0	0	2	2	16	100	32
#100	7	1	0	0	0	0	2	2	4	51	1
#200	3.8	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	0%	21%	11%	17%	16%	10%	7%	6%	12%	0%

Percent of Asphalt Cement	5.5%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

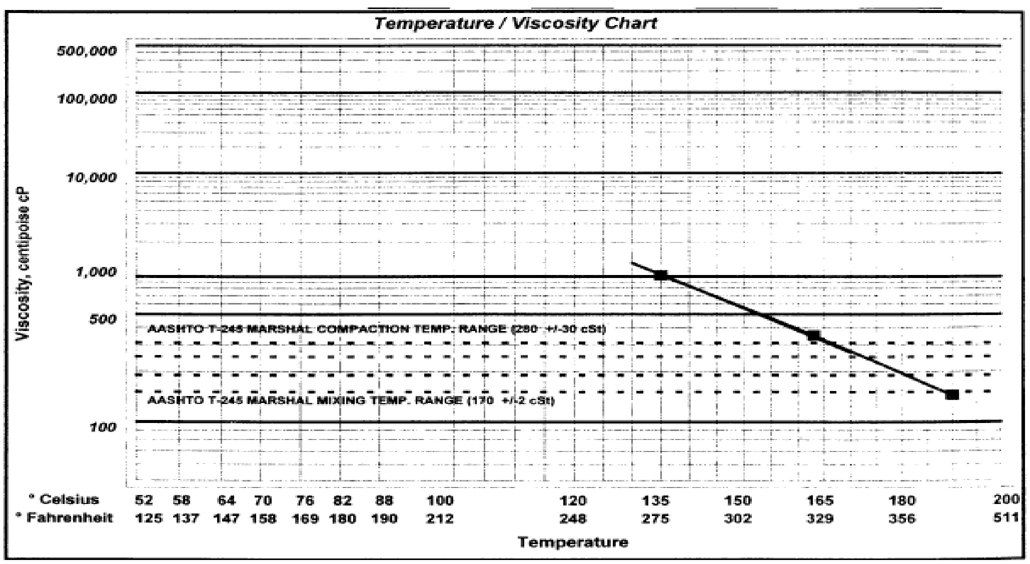


Figure A-149. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Coarse Granite

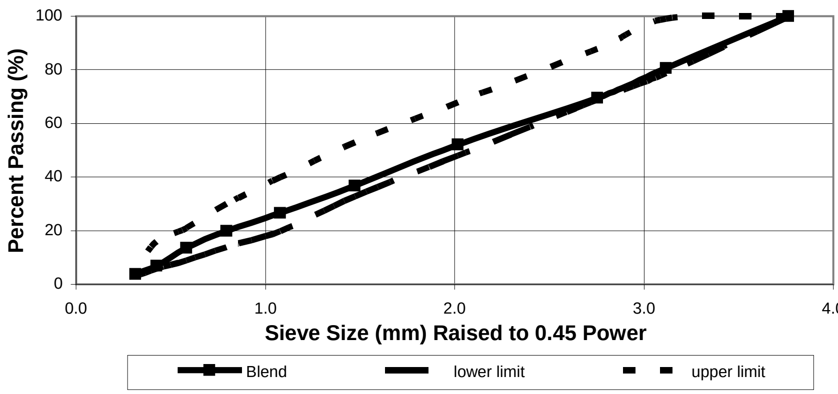
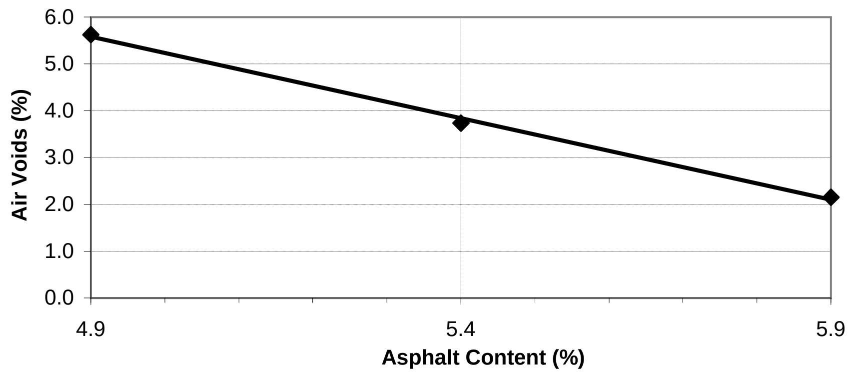


Figure A-150. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Coarse Mix Granite



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.8%

Figure A-151. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Coarse Mix Granite

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

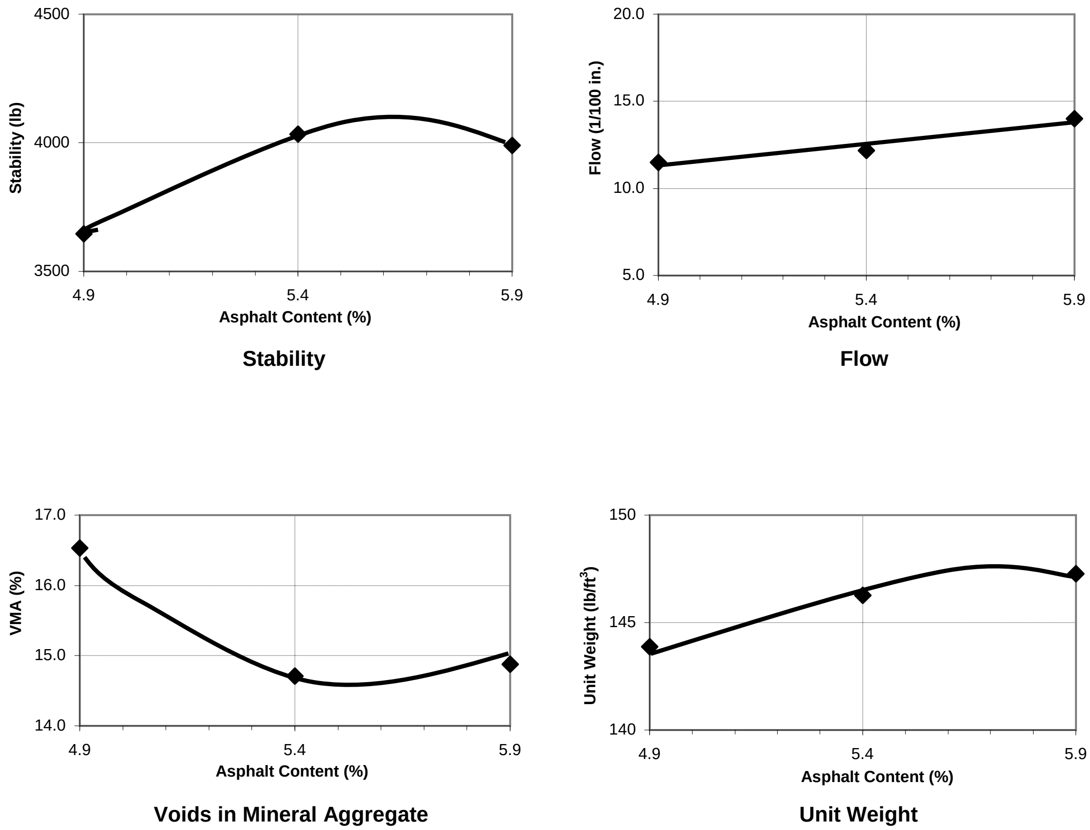


Figure A-152. Marshall Mix Design Results, 3/4-Inch Coarse Granite, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 1-Inch Fine Granite

Percent Passing	Total Combined Gradation	Individual Stockpiles 3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	Mortar Sand
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	95	1	100	100	100	100	100	100	100	100	100
1/2"	83	1	8	99	100	100	100	100	100	100	100
3/8"	73	1	0	13	100	100	100	100	100	100	100
#4	57	1	0	0	6	99	100	100	100	100	100
#8	44	1	0	0	0	11	100	100	100	100	100
#16	35	1	0	0	0	0	14	100	100	100	100
#30	25	1	0	0	0	0	8	13	99	100	94
#50	17	1	0	0	0	0	2	2	16	100	32
#100	9	1	0	0	0	0	2	2	4	51	1
#200	4.6	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	5%	13%	11%	15%	14%	8%	11%	8%	15%	0%

Percent of Asphalt Cement	6.0%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185 °C (365 °F)
Compaction Temperature	168 °C (335 °F)

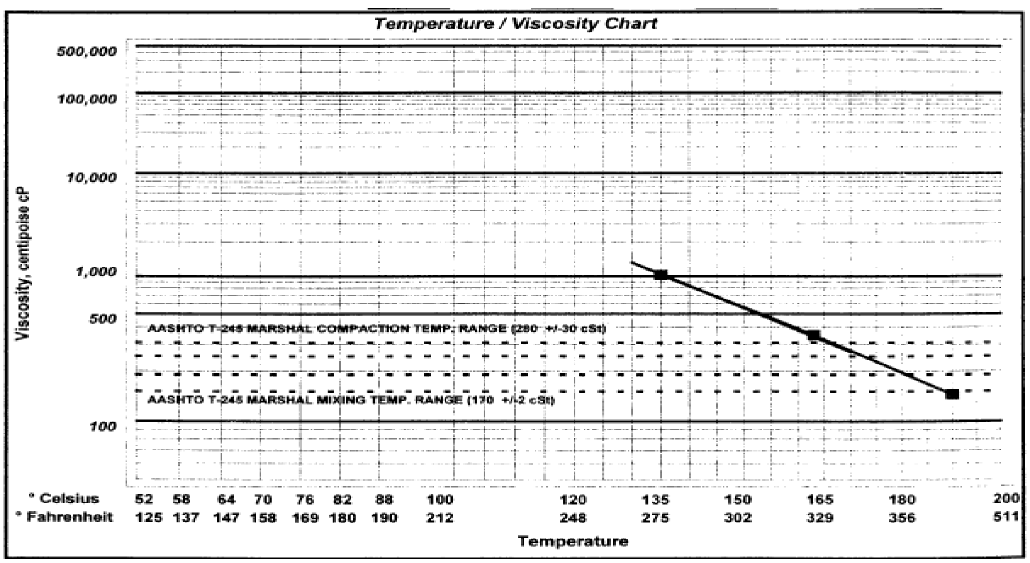


Figure A-153. Temperature Viscosity Relationship of Asphalt Cement for 1-Inch Fine Granite

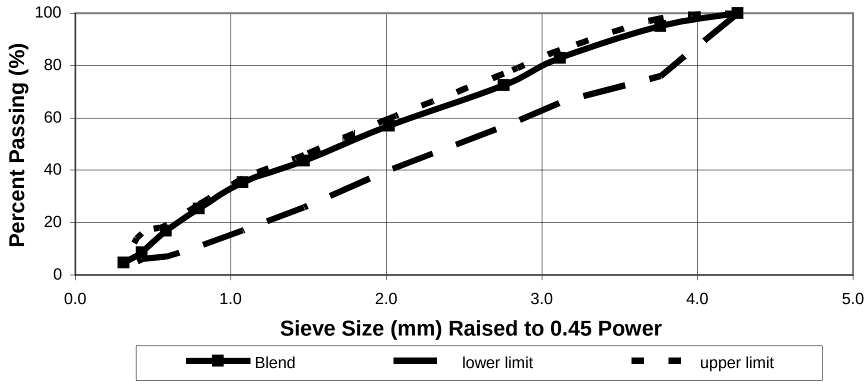
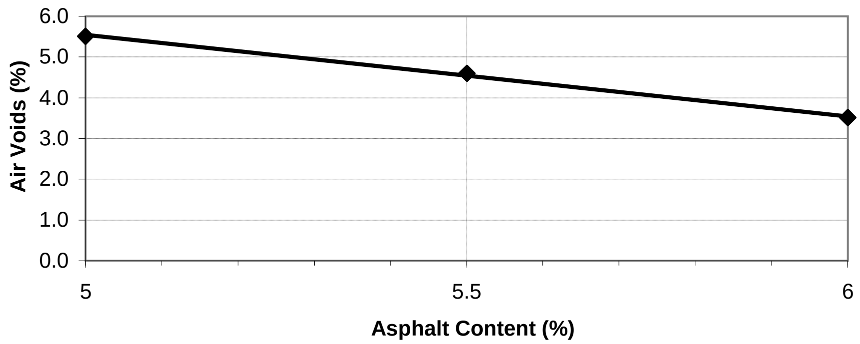


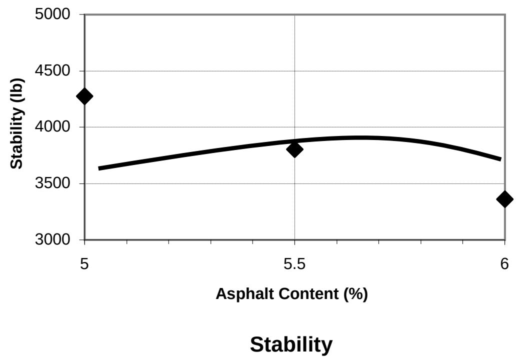
Figure A-154. Combined Gradation Plotted on 0.45 Power Curve for 1-Inch Fine Mix Granite

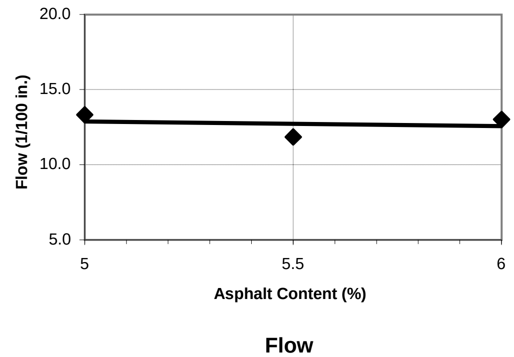


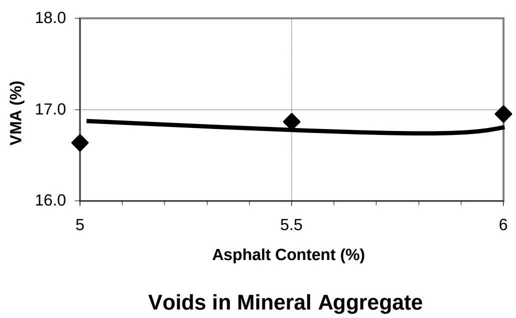
Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.9%

Figure A-155. Plot of Air Void Content vs Asphalt Content for 1-Inch Fine Mix Granite

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content







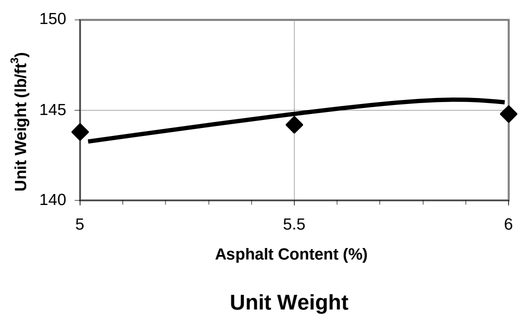


Figure A-156. Marshall Mix Design Results, 1-Inch Fine Granite, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 1-Inch Coarse Granite

		Individual Stockpiles									
Percent Passing	**Total Combined Gradation**	**3/4"**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	79	1	100	100	100	100	100	100	100	100	100
1/2"	70	1	8	99	100	100	100	100	100	100	100
3/8"	59	1	0	13	100	100	100	100	100	100	100
#4	43	1	0	0	6	99	100	100	100	100	100
#8	29	1	0	0	0	11	100	100	100	100	100
#16	21	1	0	0	0	0	14	100	100	100	100
#30	17	1	0	0	0	0	8	13	99	100	94
#50	13	1	0	0	0	0	2	2	16	100	32
#100	7	1	0	0	0	0	2	2	4	51	1
#200	3.7	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	21%	10%	12%	15%	15%	7%	5%	3%	12%	0%

Percent of Asphalt Cement	5.2%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

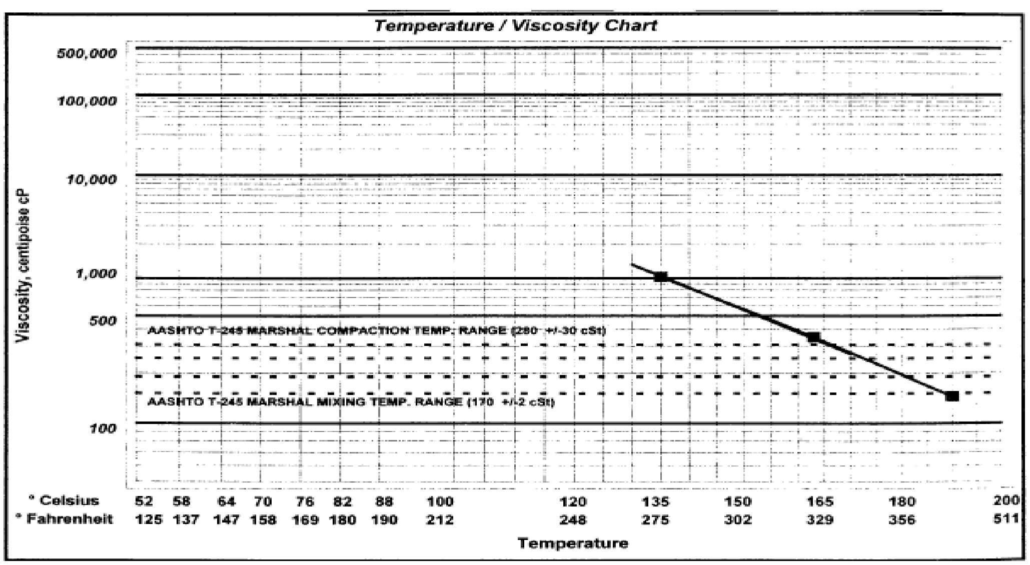


Figure A-157. Temperature Viscosity Relationship of Asphalt Cement for 1-Inch Coarse Granite

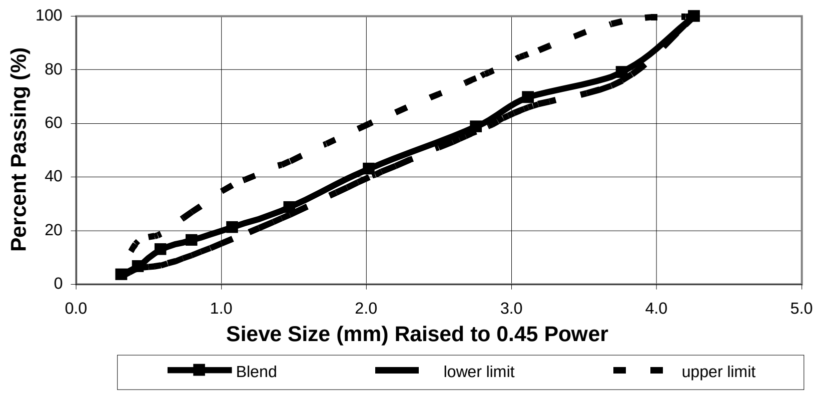
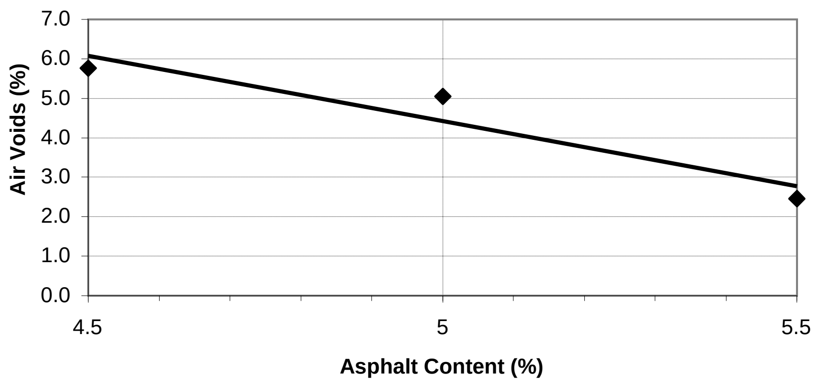


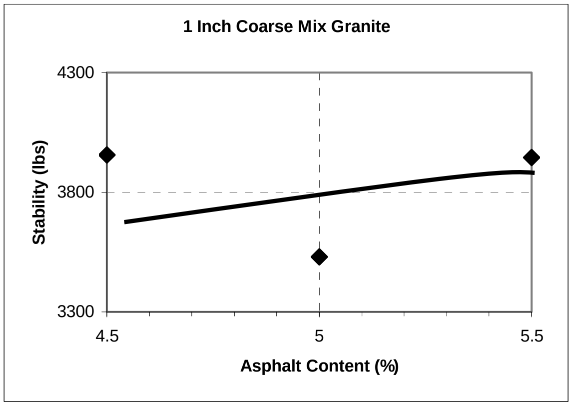
Figure A-158. Combined Gradation Plotted on 0.45 Power Curve for 1-Inch Coarse Mix Granite



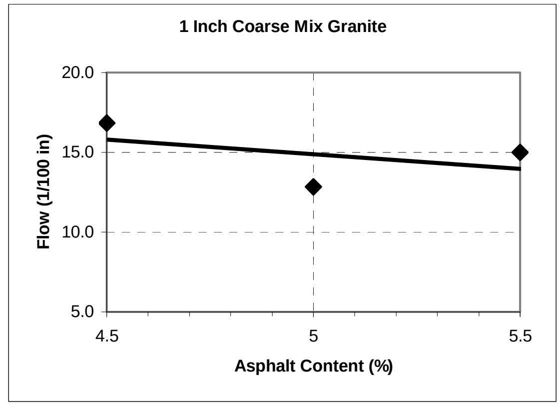
Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	1.0%

Figure A-159. Plot of Air Void Content vs Asphalt Content for 1-Inch Coarse Mix Granite

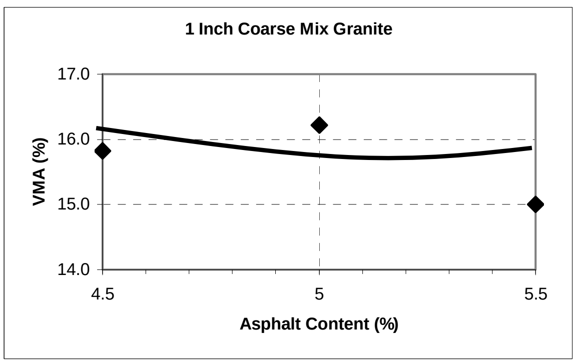
Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content



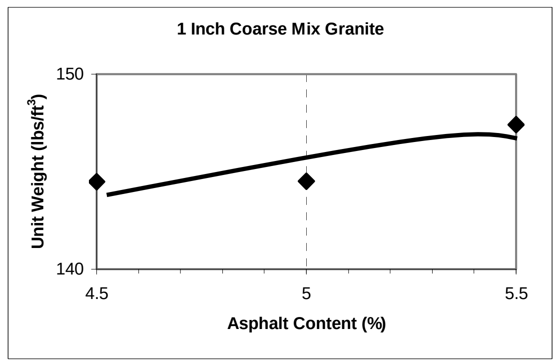
Stability



Flow



Voids in Mineral Aggregate



Unit Weight

Figure A-160. Marshall Mix Design Results, 1-Inch Coarse Granite, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Fine Granite With Mortar Sand

		Individual Stockpiles									
Percent Passing	**Total Combined Gradation**	**3/4"**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	100	1	8	99	100	100	100	100	100	100	100
3/8"	93	1	0	13	100	100	100	100	100	100	100
#4	71	1	0	0	6	99	100	100	100	100	100
#8	52	1	0	0	0	11	100	100	100	100	100
#16	37	1	0	0	0	0	14	100	100	100	100
#30	31	1	0	0	0	0	8	13	99	100	94
#50	23	1	0	0	0	0	2	2	16	100	32
#100	10	1	0	0	0	0	2	2	4	51	1
#200	5.4	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	0%	0%	8%	22%	20%	15%	6%	0%	19%	10%

Percent of Asphalt Cement	6.5%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

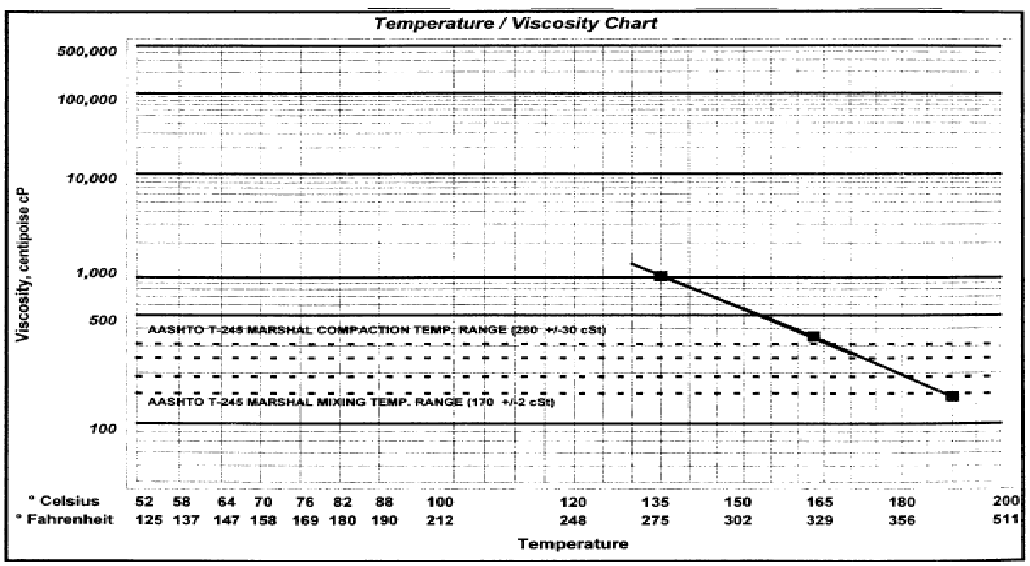


Figure A-161. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Fine Granite With Mortar Sand

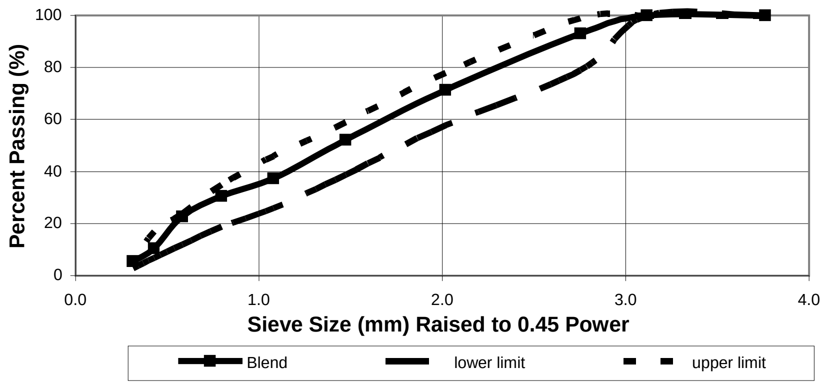
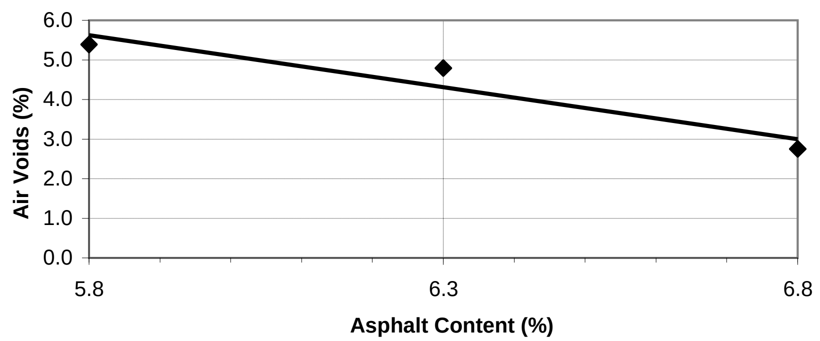


Figure A-162. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Fine Mix Granite With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	1.1%

Figure A-163. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Fine Mix Granite With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

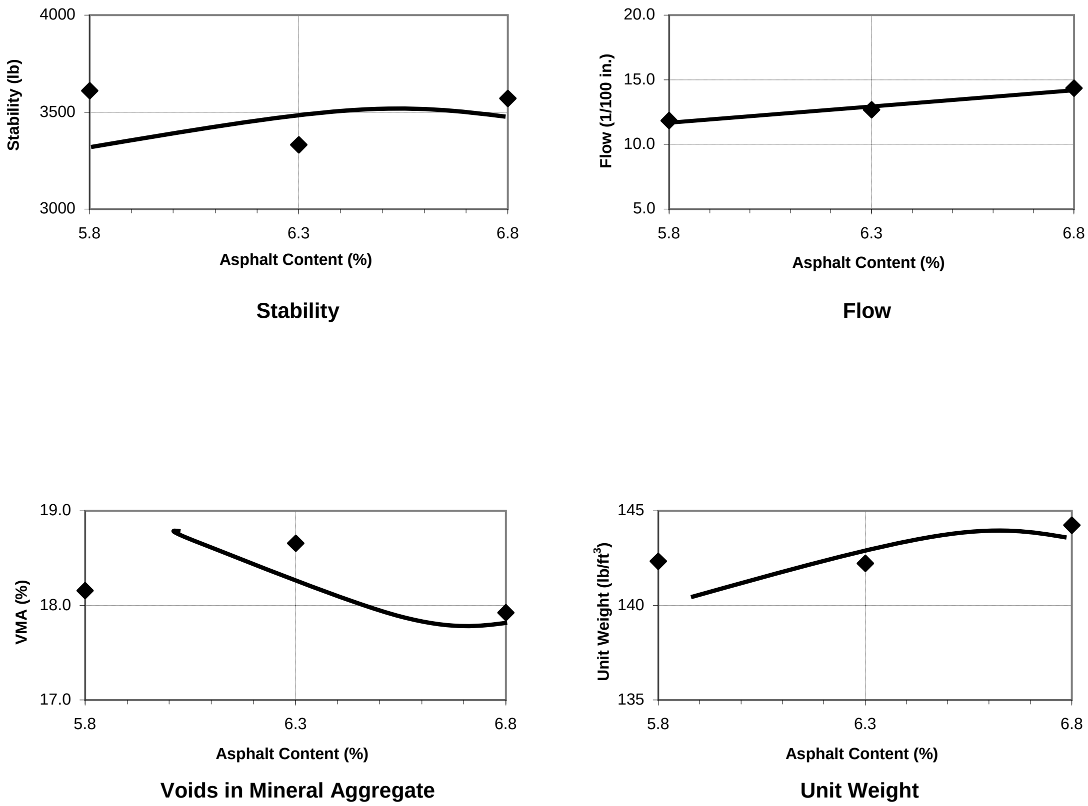


Figure A-164. Marshall Mix Design Results, 1/2-Inch Fine Granite With Mortar Sand, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Coarse Granite With Mortar Sand

		Individual Stockpiles									
Percent Passing	**Total Combined Gradation**	**3/4"**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	100	1	8	99	100	100	100	100	100	100	100
3/8"	82	1	0	13	100	100	100	100	100	100	100
#4	60	1	0	0	6	99	100	100	100	100	100
#8	41	1	0	0	0	11	100	100	100	100	100
#16	28	1	0	0	0	0	14	100	100	100	100
#30	27	1	0	0	0	0	8	13	99	100	94
#50	20	1	0	0	0	0	2	2	16	100	32
#100	9	1	0	0	0	0	2	2	4	51	1
#200	4.6	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100										10%

Percent of Asphalt Cement	5.6%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

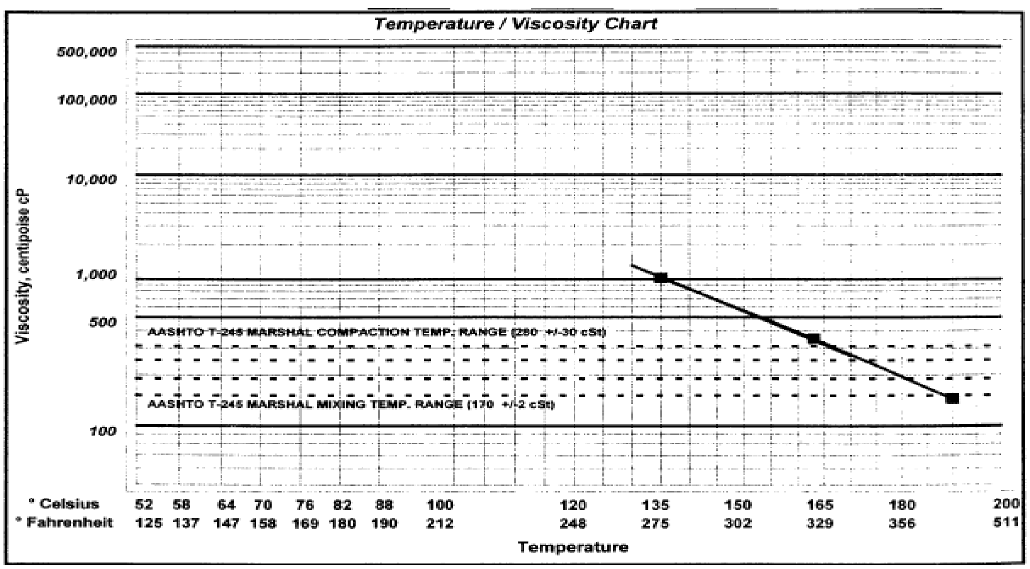


Figure A-165. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Coarse Granite With Mortar Sand

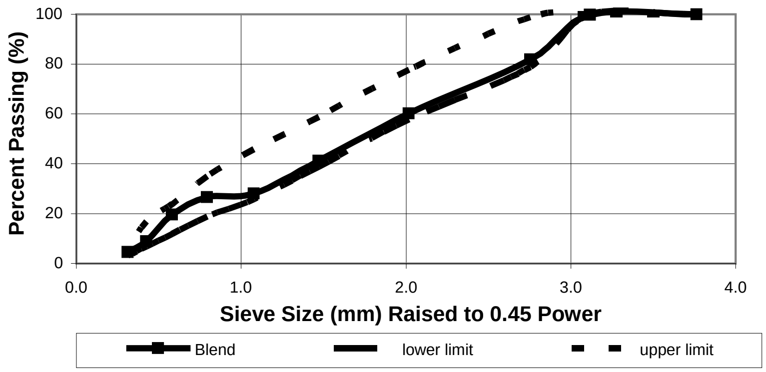
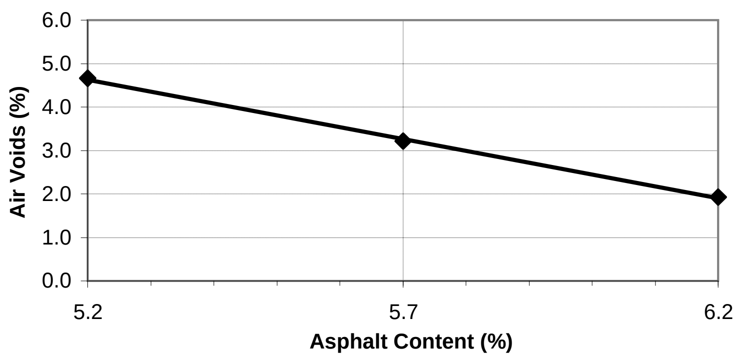


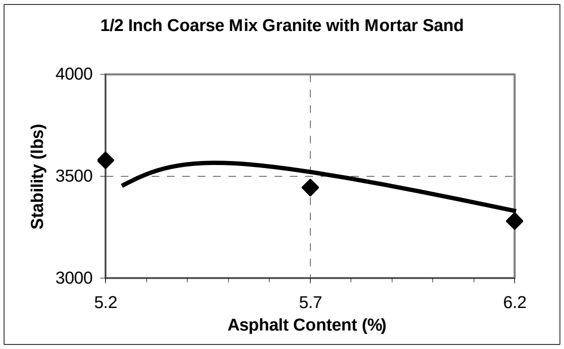
Figure A-166. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Coarse Mix Granite With 10% Mortar Sand

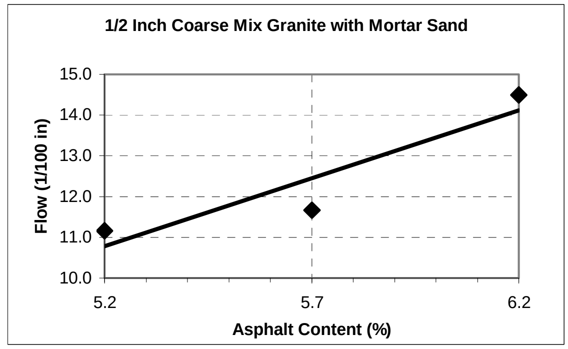


Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.9%

Figure A-167. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Coarse Mix Granite With Mortar Sand

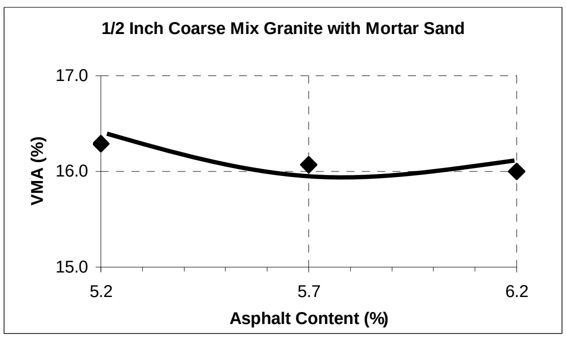
Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

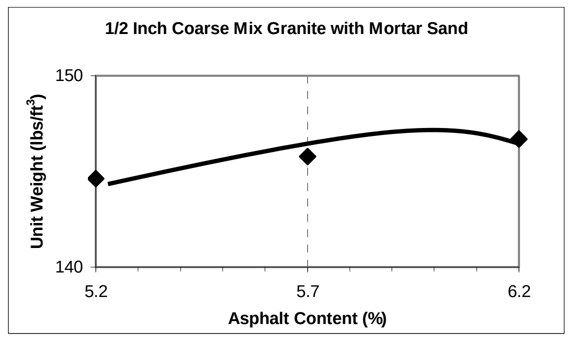




Stability

Flow





Voids in Mineral Aggregate

Unit Weight

Figure A-168. Marshall Mix Design Results, 1/2-Inch Coarse Granite With Sand, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Fine Granite With Mortar Sand

		Individual Stockpiles									
Percent Passing	**Total Combined Gradation**	**3/4"**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	94	1	8	99	100	100	100	100	100	100	100
3/8"	84	1	0	13	100	100	100	100	100	100	100
#4	65	1	0	0	6	99	100	100	100	100	100
#8	49	1	0	0	0	11	100	100	100	100	100
#16	33	1	0	0	0	0	14	100	100	100	100
#30	27	1	0	0	0	0	8	13	99	100	94
#50	20	1	0	0	0	0	2	2	16	100	32
#100	9	1	0	0	0	0	2	2	4	51	1
#200	4.7	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	0%	6%	12%	18%	17%	17%	4%	0%	16%	10%

Percent of Asphalt Cement	5.7%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

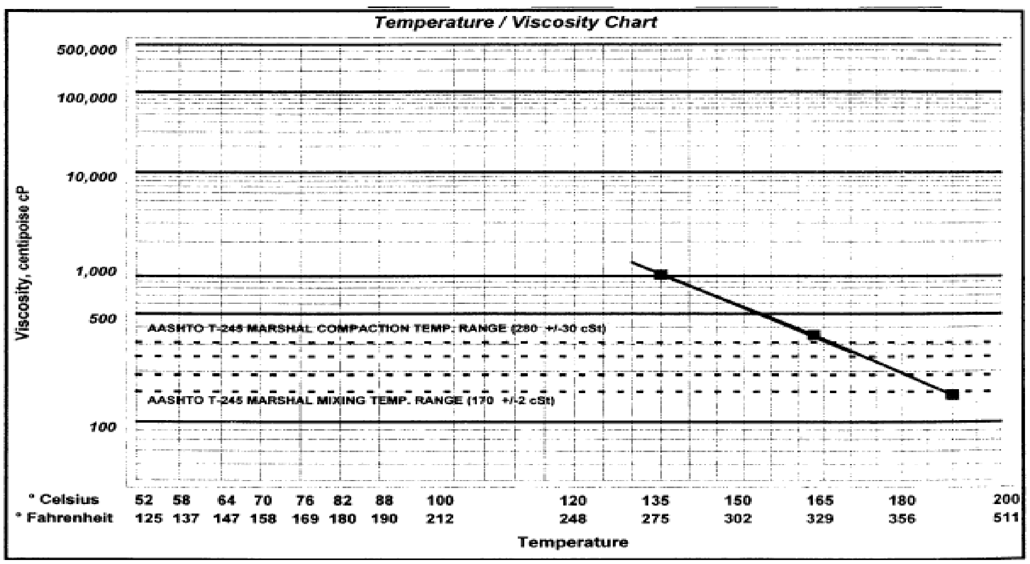


Figure A-169. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Fine Granite With Mortar Sand

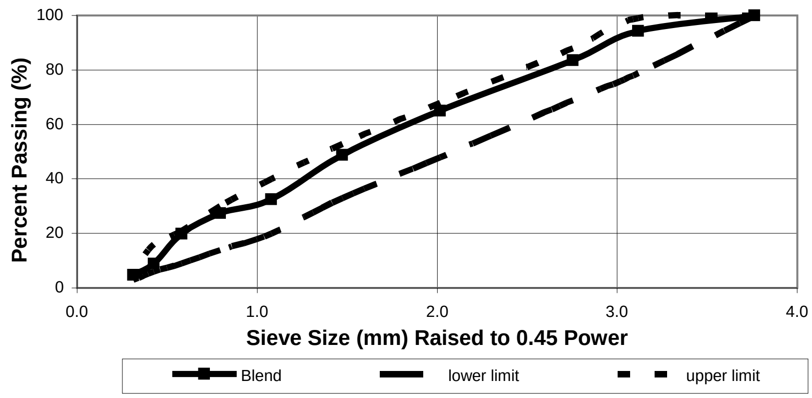
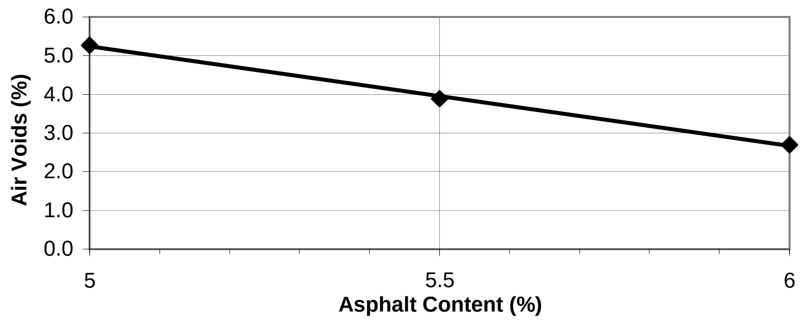


Figure A-170. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Fine Mix Granite With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.9%

Figure A-171. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Fine Mix Granite With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

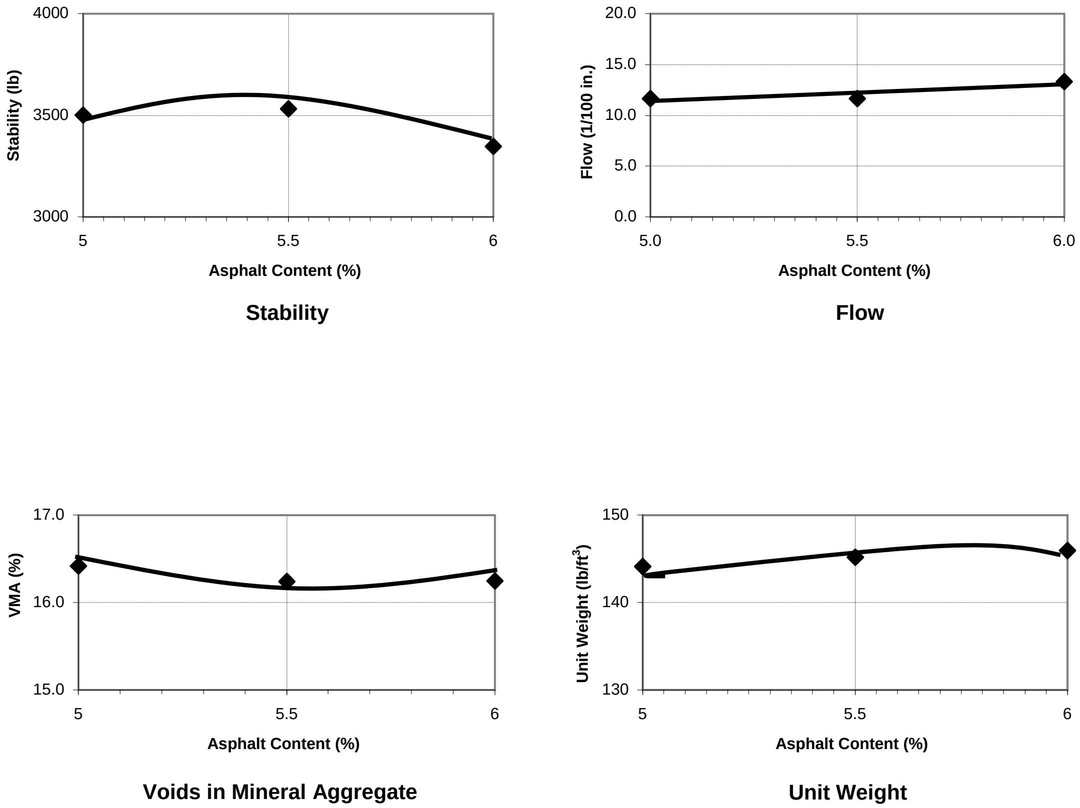


Figure A-172. Marshall Mix Design Results, 3/4-Inch Fine Granite With Mortar Sand, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Coarse Granite With Mortar Sand

Percent Passing	Total Combined Gradation	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	Mortar Sand
		Individual Stockpiles									
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	100	1	100	100	100	100	100	100	100	100	100
1/2"	82	1	8	99	100	100	100	100	100	100	100
3/8"	71	1	0	13	100	100	100	100	100	100	100
#4	52	1	0	0	6	99	100	100	100	100	100
#8	37	1	0	0	0	11	100	100	100	100	100
#16	27	1	0	0	0	0	14	100	100	100	100
#30	25	1	0	0	0	0	8	13	99	100	94
#50	19	1	0	0	0	0	2	2	16	100	32
#100	8	1	0	0	0	0	2	2	4	51	1
#200	4.3	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100										10%

Percent of Asphalt Cement	5.1%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

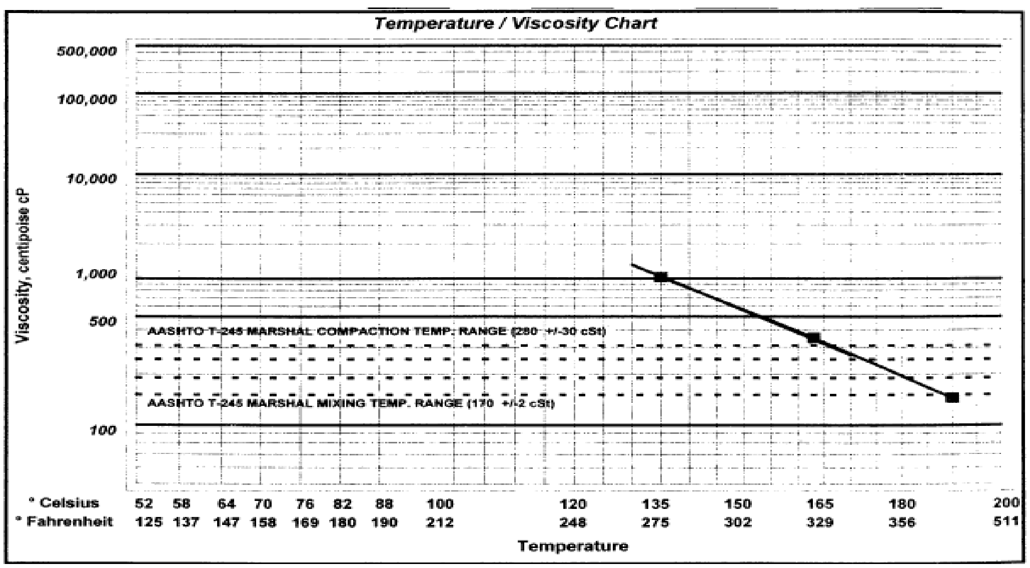


Figure A-173. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Coarse Granite With Mortar Sand

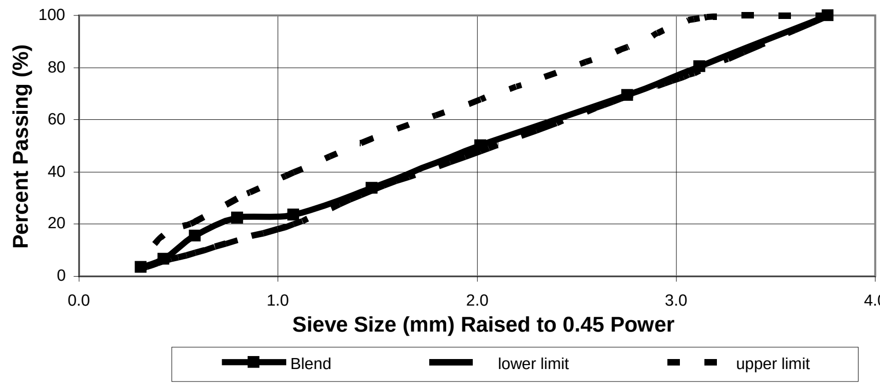
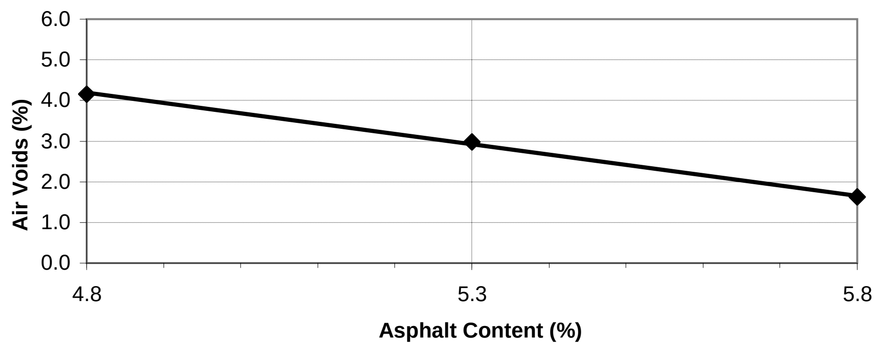


Figure A-174. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Coarse Mix Granite With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.8%

Figure A-175. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Coarse Mix Granite With 10% Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

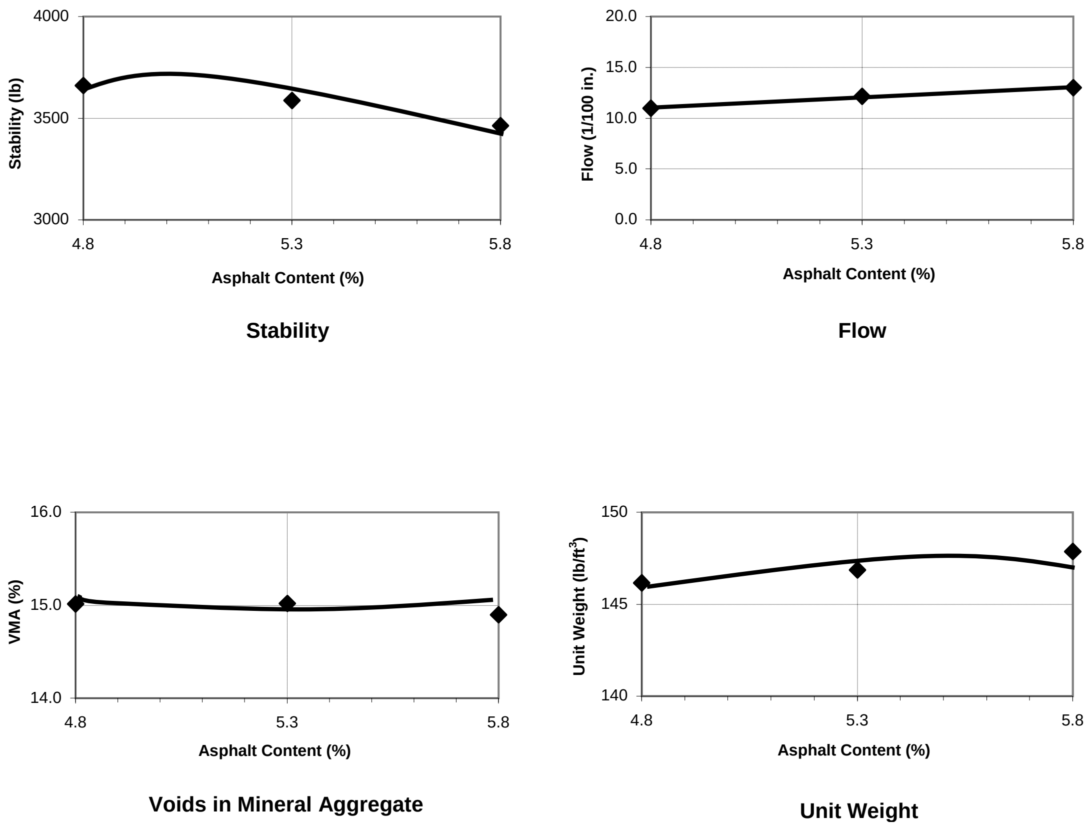


Figure A-176. Marshall Mix Design Results, 3/4-Inch Coarse Granite With Mortar Sand, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 1-Inch Fine Granite With Mortar Sand

Percent Passing	Total Combined Gradation	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	Mortar Sand
		Individual Stockpiles									
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	94	1	100	100	100	100	100	100	100	100	100
1/2"	82	1	8	99	100	100	100	100	100	100	100
3/8"	72	1	0	13	100	100	100	100	100	100	100
#4	55	1	0	0	6	99	100	100	100	100	100
#8	41	1	0	0	0	11	100	100	100	100	100
#16	25	1	0	0	0	0	14	100	100	100	100
#30	24	1	0	0	0	0	8	13	99	100	94
#50	17	1	0	0	0	0	2	2	16	100	32
#100	7	1	0	0	0	0	2	2	4	51	1
#200	3.9	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100	6%	13%	11%	16%	15%	16%	0%	0%	13%	10%

Percent of Asphalt Cement	5.2%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

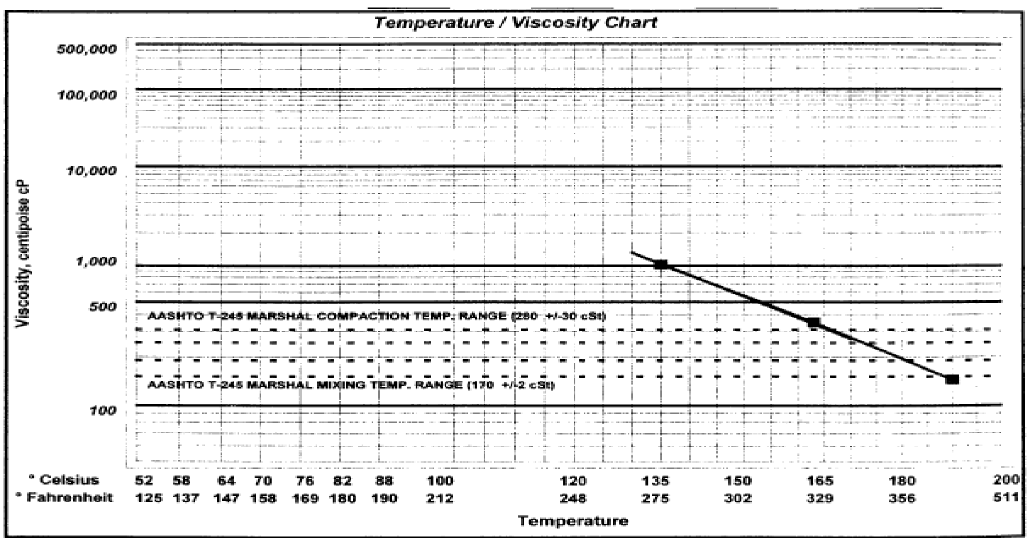


Figure A-177. Temperature Viscosity Relationship of Asphalt Cement for 1-Inch Fine Granite With Mortar Sand

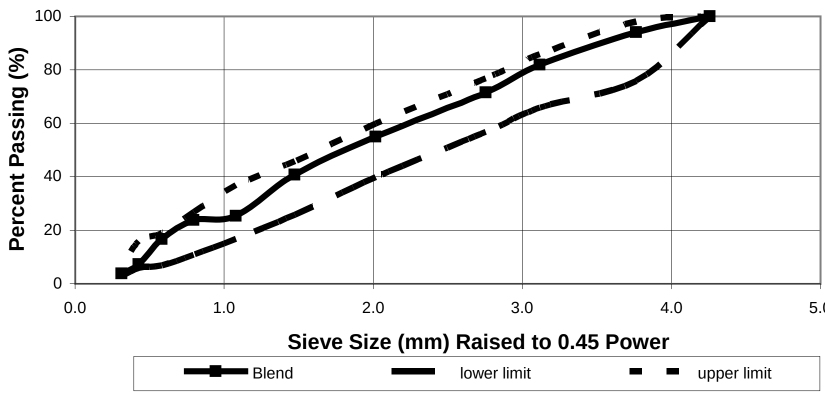
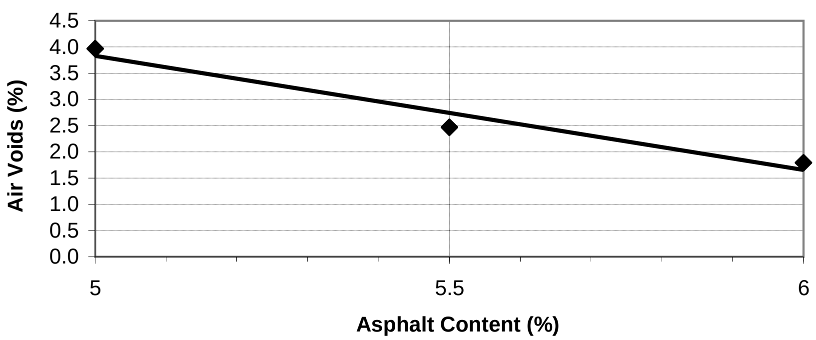


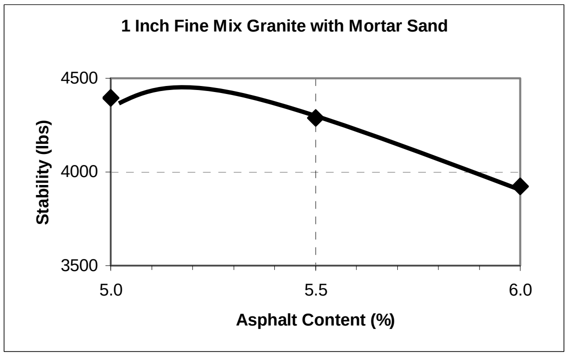
Figure A-178. Combined Gradation Plotted on 0.45 Power Curve for 1-Inch Fine Mix Granite With 10% Mortar Sand



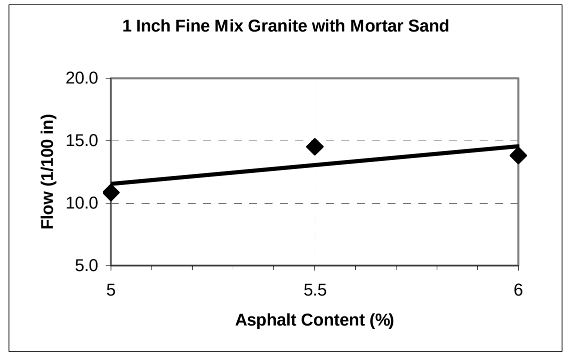
Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.9%

Figure A-179. Plot of Air Void Content vs Asphalt Content for 1-Inch Fine Mix Granite With 10% Mortar Sand

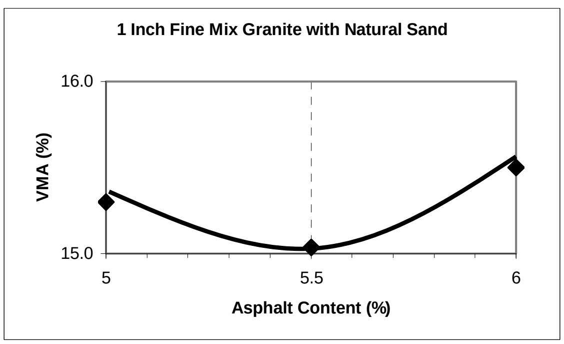
Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content



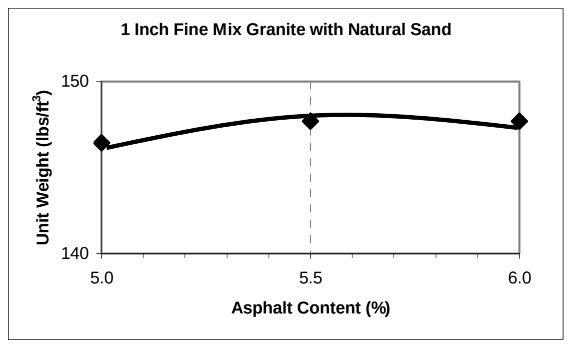
Stability



Flow



Voids in Mineral Aggregate



Unit Weight

Figure A-180. Marshall Mix Design Results, 1-Inch Fine Granite With Mortar Sand, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 1-Inch Coarse Granite With Mortar Sand

		Individual Stockpiles									
Percent Passing	**Total Combined Gradation**	**3/4"**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100	100
3/4"	79	1	100	100	100	100	100	100	100	100	100
1/2"	72	1	8	99	100	100	100	100	100	100	100
3/8"	61	1	0	13	100	100	100	100	100	100	100
#4	46	1	0	0	6	99	100	100	100	100	100
#8	34	1	0	0	0	11	100	100	100	100	100
#16	25	1	0	0	0	0	14	100	100	100	100
#30	23	1	0	0	0	0	8	13	99	100	94
#50	17	1	0	0	0	0	2	2	16	100	32
#100	7	1	0	0	0	0	2	2	4	51	1
#200	3.8	0.5	0.4	0.3	0.4	0.5	1.8	1.6	3.5	25.3	0.6
Percent Used:	100										10%

Percent of Asphalt Cement	4.8%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

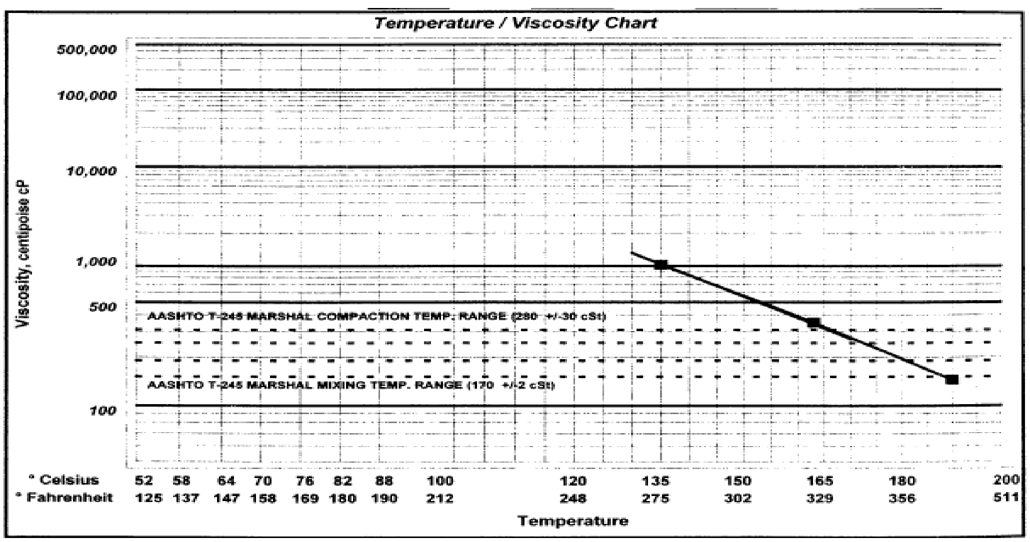


Figure A-181. Temperature Viscosity Relationship of Asphalt Cement for 1-Inch Coarse Granite With Mortar Sand

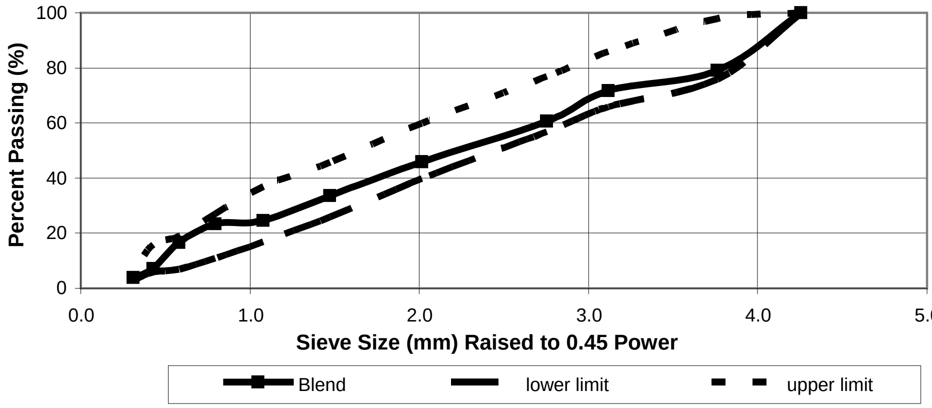
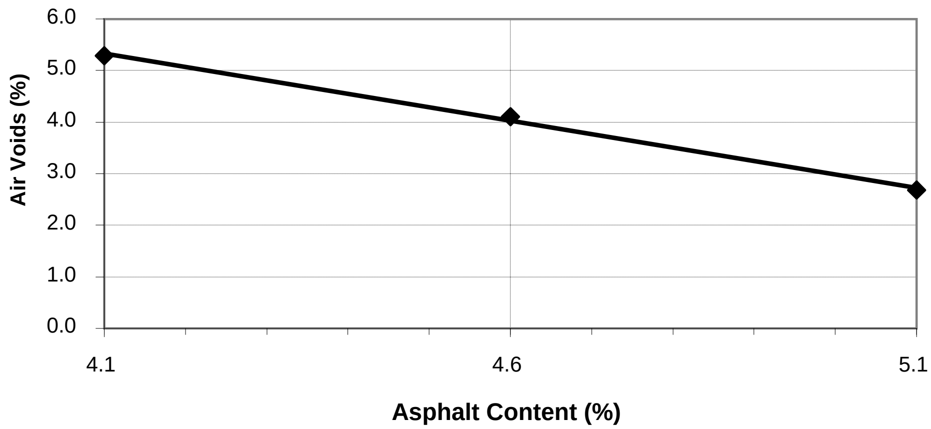


Figure A-182. Combined Gradation Plotted on 0.45 Power Curve for 1-Inch Coarse Mix Granite With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	1.0%

Figure A-183. Plot of Air Void Content vs Asphalt Content for 1-Inch Coarse Mix Granite With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

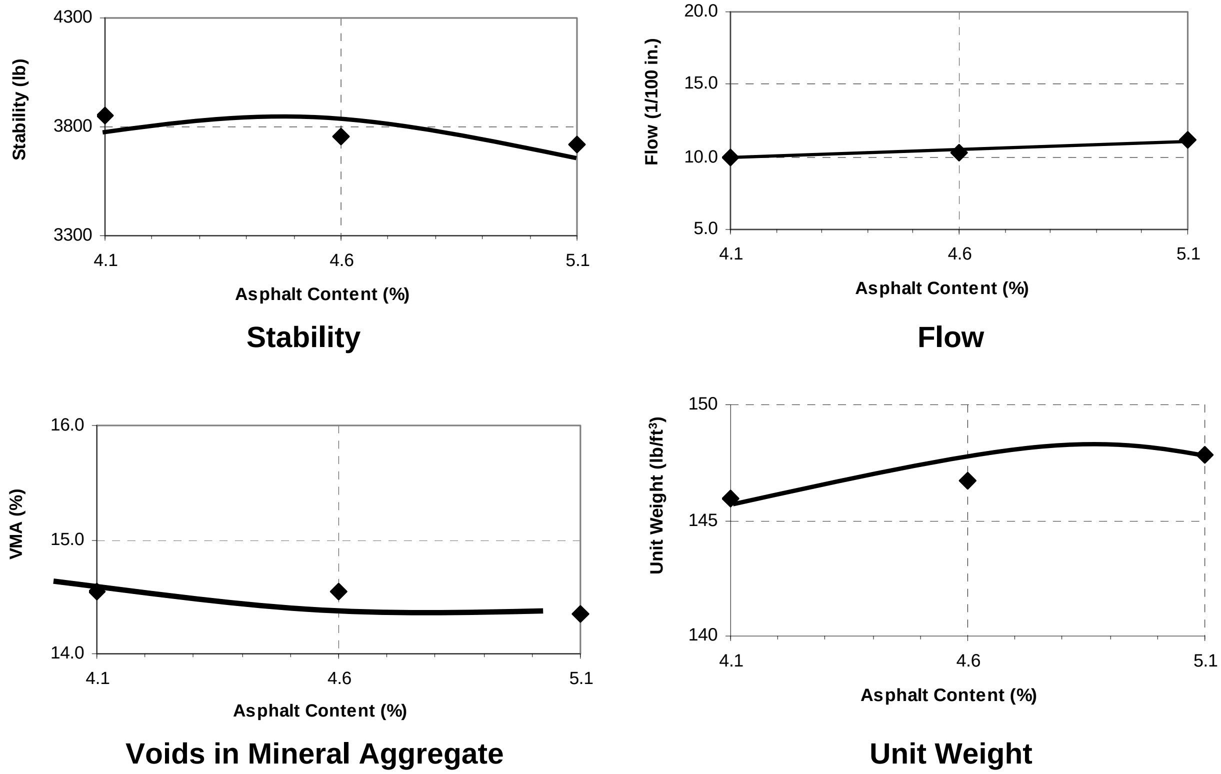


Figure A-184. Marshall Mix Design Results, 1-Inch Coarse Granite With Mortar Sand, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Chert Gravel

		Individual Stockpiles								
Percent Passing	Total Combined Gradation	1/2"	3/8"	#4	#8	#16	#30	#50	#100	Mortar Sand
1"	100	100	100	100	100	100	100	100	100	100
3/4"	100	100	100	100	100	100	100	100	100	100
1/2"	100	39	100	100	100	100	100	100	100	100
3/8"	88	0	14	100	100	100	100	100	100	100
#4	69	0	0	15	100	100	100	100	100	100
#8	53	0	0	2	19	100	100	100	100	100
#16	39	0	0	2	1	16	97	97	100	100
#30	28	0	0	2	1	1	25	75	100	94
#50	20	0	0	2	1	1	6	23	99	32
#100	9	0	0	1	0	1	4	5	44	1
#200	4.6	0.2	0.2	0.9	0.4	1.3	3.5	4.1	19.7	0.6
Percent Used:	100%	0%	14%	20%	16%	13%	10%	10%	17%	0%

Percent of Asphalt Cement	
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

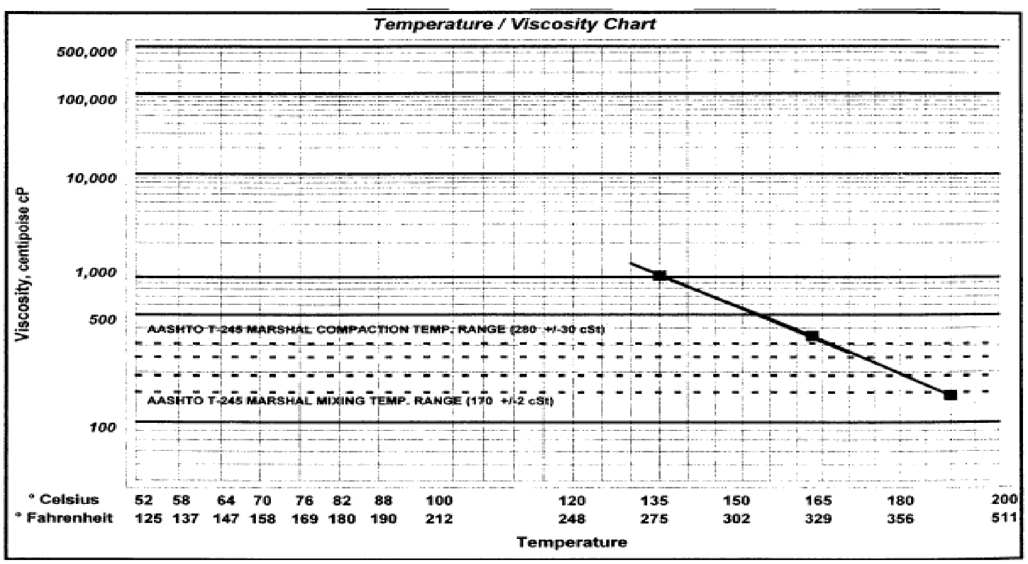


Figure A-185. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Chert Gravel

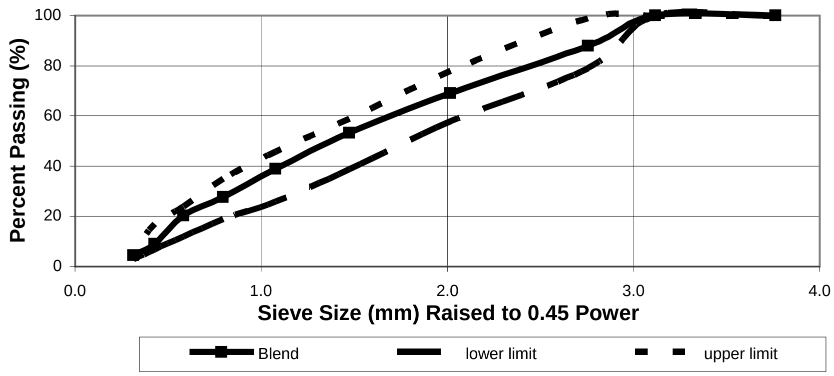
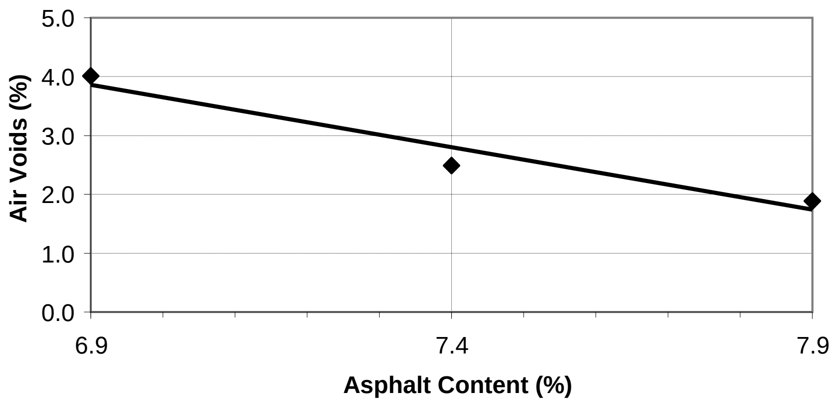


Figure A-186. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Chert Gravel



Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.3%

Figure A-187. Plot of Air Void Content vs Asphalt Content for 1/2-Inch Chert Gravel

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

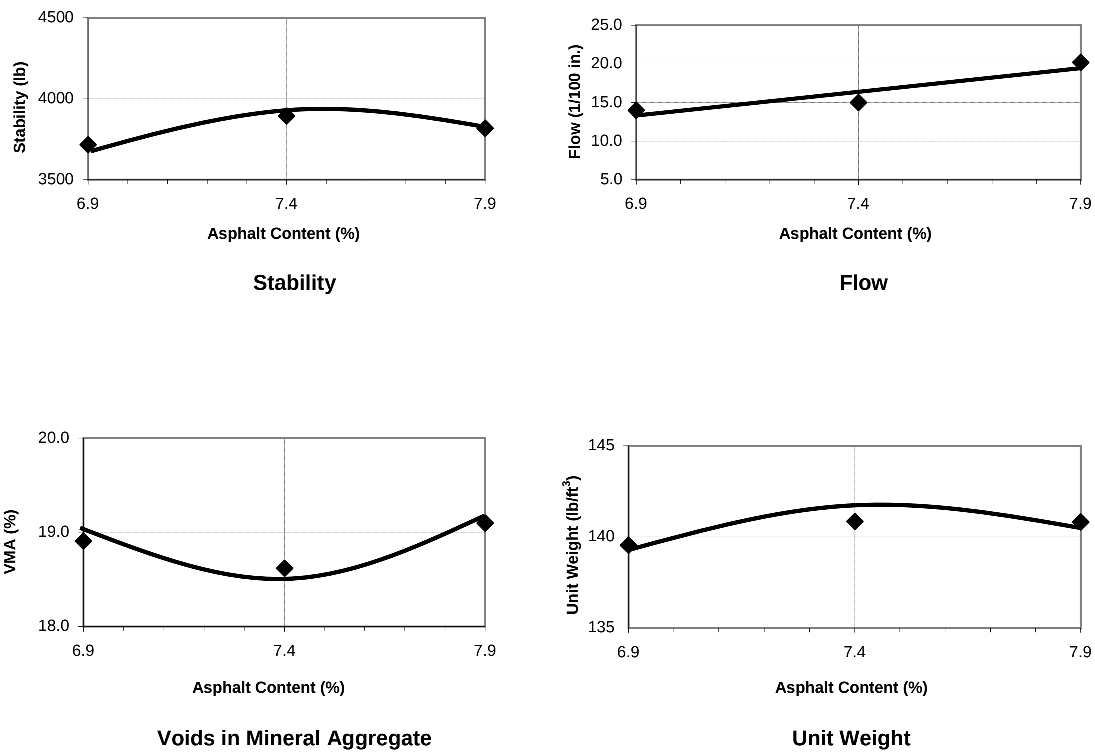


Figure A-188. Marshall Mix Design Results, 1/2-Inch Chert Gravel, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Fine Chert Gravel

		Individual Stockpiles								
Percent Passing	**Total Combined Gradation**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100
3/4"	100	100	100	100	100	100	100	100	100	100
1/2"	95	39	100	100	100	100	100	100	100	100
3/8"	81	0	14	100	100	100	100	100	100	100
#4	65	0	0	15	100	100	100	100	100	100
#8	51	0	0	2	19	100	100	100	100	100
#16	38	0	0	2	1	16	97	97	100	100
#30	26	0	0	2	1	1	25	75	100	94
#50	18	0	0	2	1	1	6	23	99	32
#100	8	0	0	1	0	1	4	5	44	1
#200	4	0.2	0.2	0.9	0.4	1.3	3.5	4.1	19.7	0.6
Percent Used:	100	9%	12%	16%	15%	12%	11%	11%	14%	0%

Percent of Asphalt Cement	7.4%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

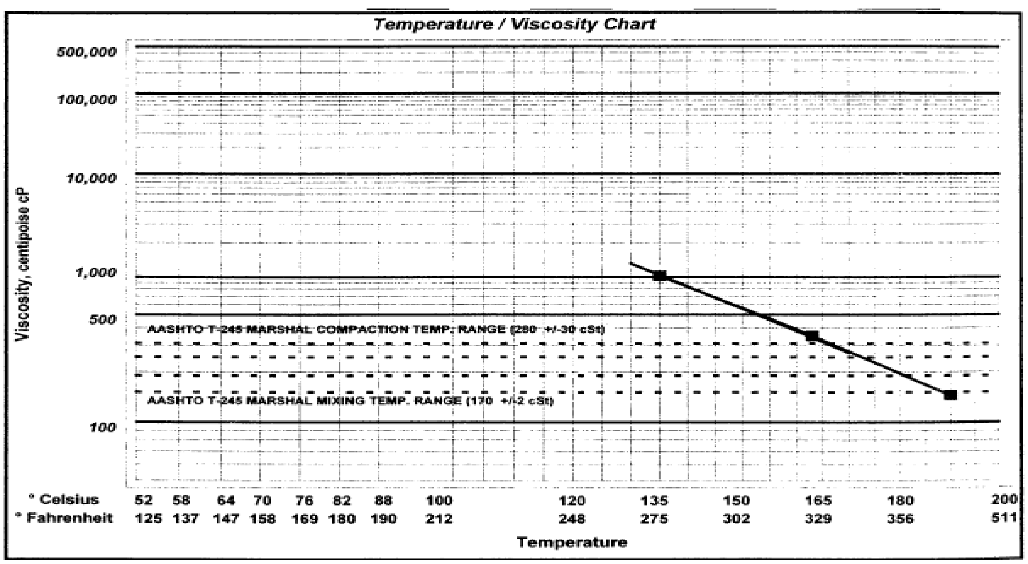


Figure A-189. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Fine Chert Gravel

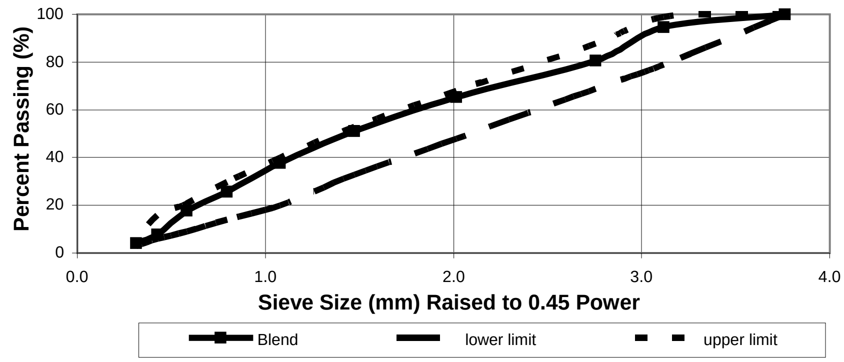
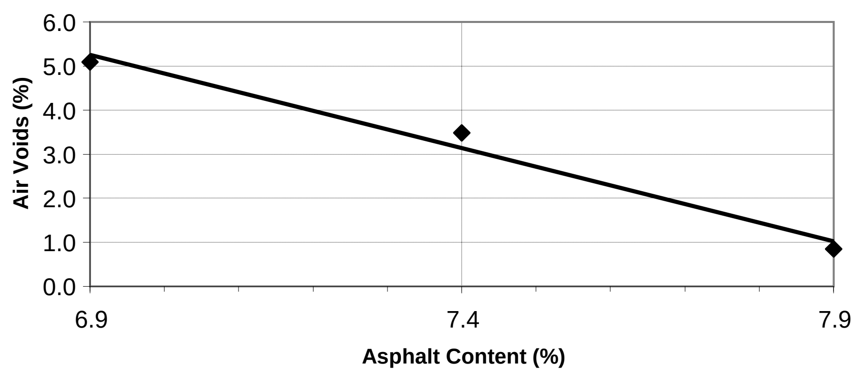


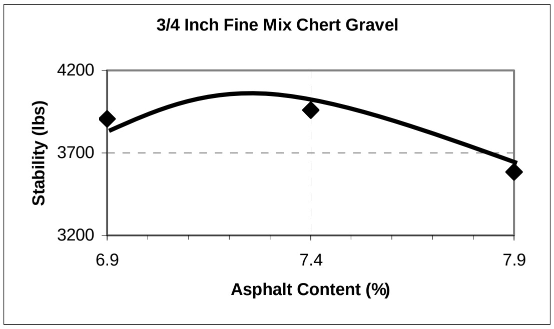
Figure A-190. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Fine Mix Chert Gravel



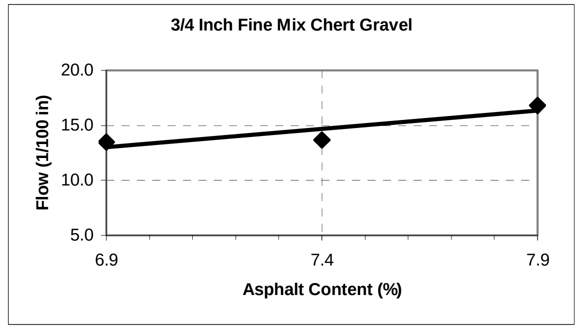
Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.2%

Figure A-191. Plot of Air Content vs Asphalt Content for 3/4-Inch Fine Mix Chert Gravel

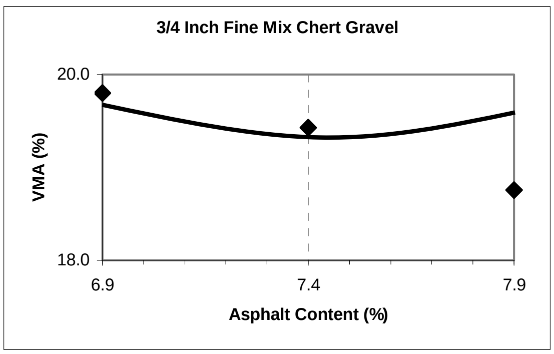
Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content



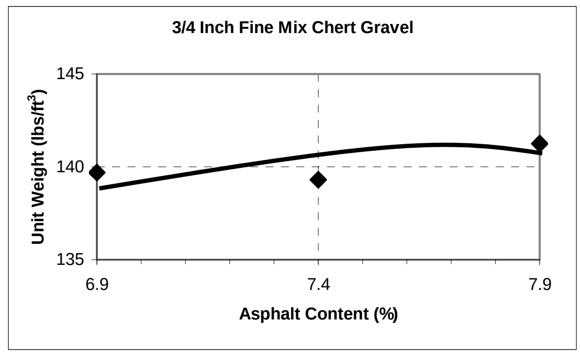
Stability



Flow



Voids in Mineral Aggregate



Unit Weight

Figure A-192. Marshall Mix Design Results, 3/4-Inch Fine Mix Chert Gravel, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Coarse Chert Gravel

		Individual Stockpiles								
Percent Passing	**Total Combined Gradation**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100
3/4"	100	100	100	100	100	100	100	100	100	100
1/2"	87	39	100	100	100	100	100	100	100	100
3/8"	70	0	14	100	100	100	100	100	100	100
#4	54	0	0	15	100	100	100	100	100	100
#8	42	0	0	2	19	100	100	100	100	100
#16	30	0	0	2	1	16	97	97	100	100
#30	20	0	0	2	1	1	25	75	100	94
#50	13	0	0	2	1	1	6	23	99	32
#100	6	0	0	1	0	1	4	5	44	1
#200	3.1	0.2	0.2	0.9	0.4	1.3	3.5	4.1	19.7	0.6
Percent Used:	100	21%	11%	16%	13%	11%	9%	9%	10%	0%

Percent of Asphalt Cement	6.9%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

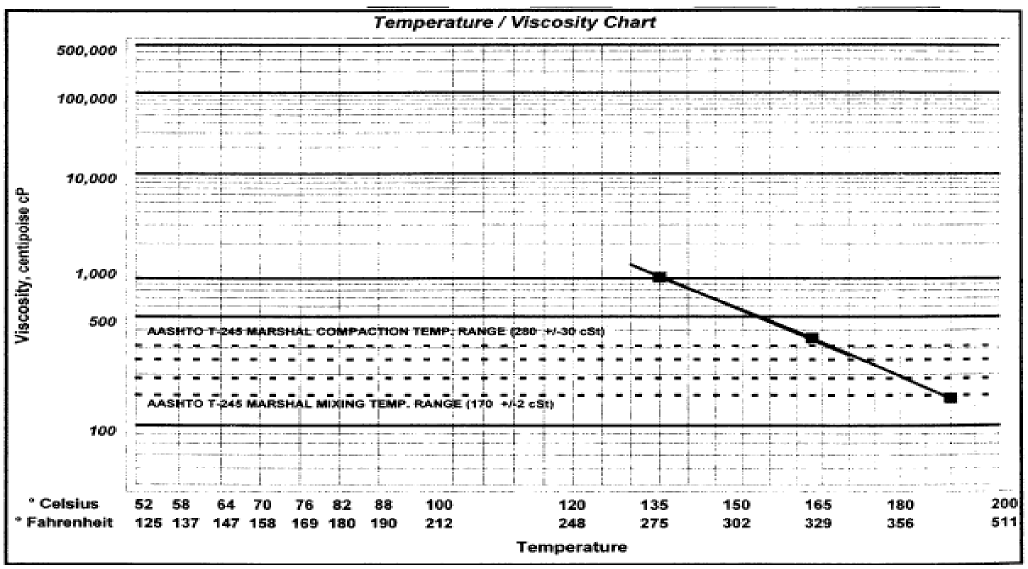


Figure A-193. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Coarse Chert Gravel

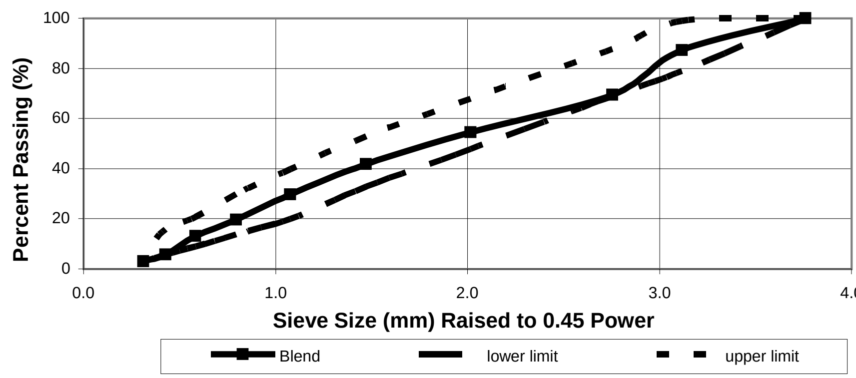
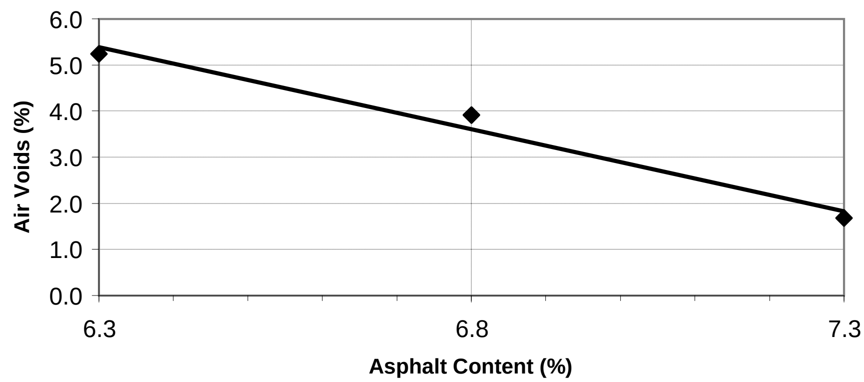


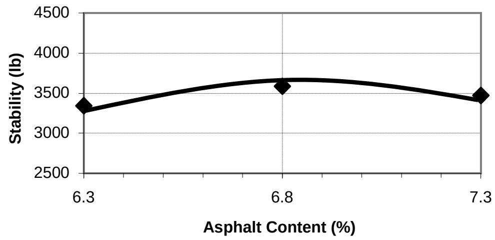
Figure A-194. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Coarse Mix Chert Gravel



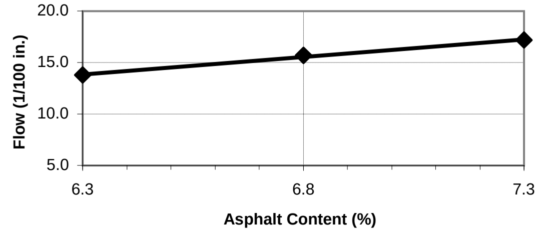
Percent Mortar Sand	0%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.1%

Figure A-195. Plot of Void Content vs Asphalt Content for 3/4-Inch Coarse Mix Chert Gravel

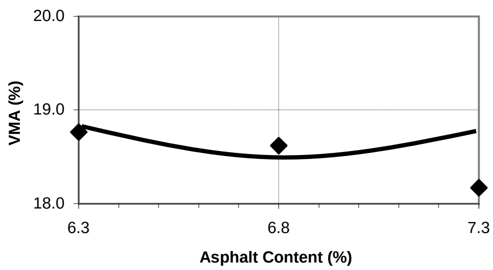
Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content



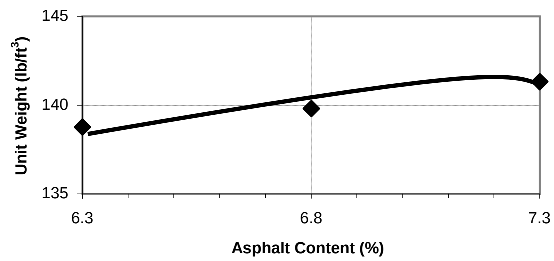
Stability



Flow



Voids in Mineral Aggregate



Unit Weight

Figure A-196. Marshall Mix Design Results, 3/4-Inch Coarse Mix Chert Gravel, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 1/2-Inch Chert Gravel With Mortar Sand

		Individual Stockpiles								
Percent Passing	**Total Combined Gradation**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100
3/4"	100	100	100	100	100	100	100	100	100	100
1/2"	100	39	100	100	100	100	100	100	100	100
3/8"	87	0	14	100	100	100	100	100	100	100
#4	67	0	0	15	100	100	100	100	100	100
#8	47	0	0	2	19	100	100	100	100	100
#16	32	0	0	2	1	16	97	97	100	100
#30	29	0	0	2	1	1	25	75	100	94
#50	23	0	0	2	1	1	6	23	99	32
#100	9	0	0	1	0	1	4	5	44	1
#200	4.3	0.2	0.2	0.9	0.4	1.3	3.5	4.1	19.7	0.6
Percent Used:	100	0%	15%	21%	21%	14%	0%	0%	19%	10%

Percent of Asphalt Cement	7.1%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

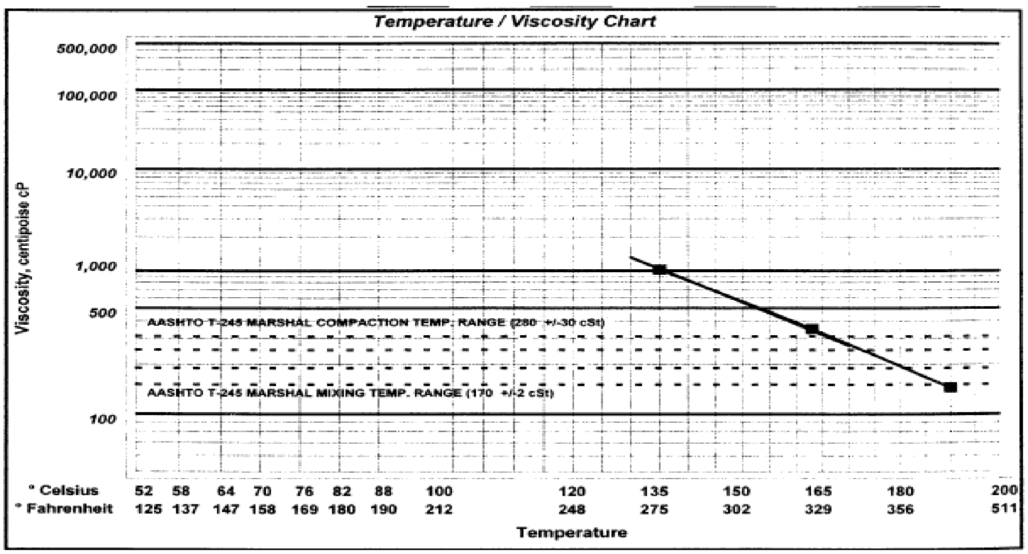


Figure A-197. Temperature Viscosity Relationship of Asphalt Cement for 1/2-Inch Chert Gravel With Mortar Sand

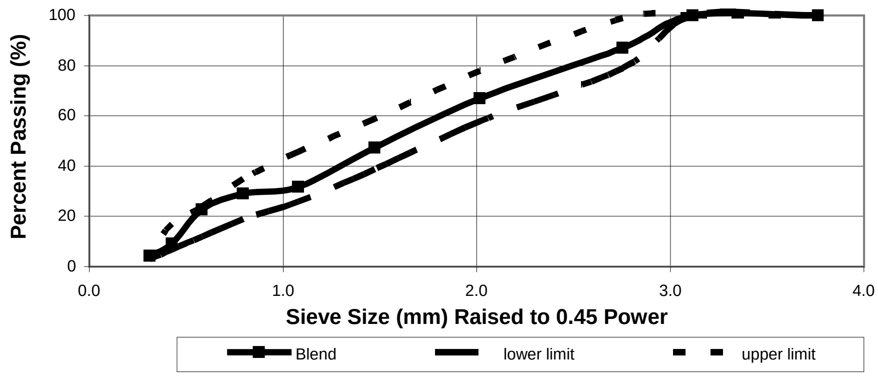
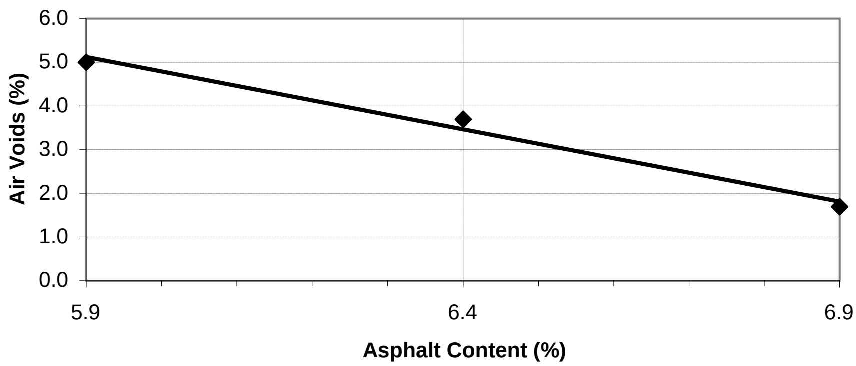


Figure A-198. Combined Gradation Plotted on 0.45 Power Curve for 1/2-Inch Chert Gravel With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.3%

Figure A-199. Plot of Air Content vs Asphalt Content for 1/2-Inch Chert Gravel With Mortar Sand

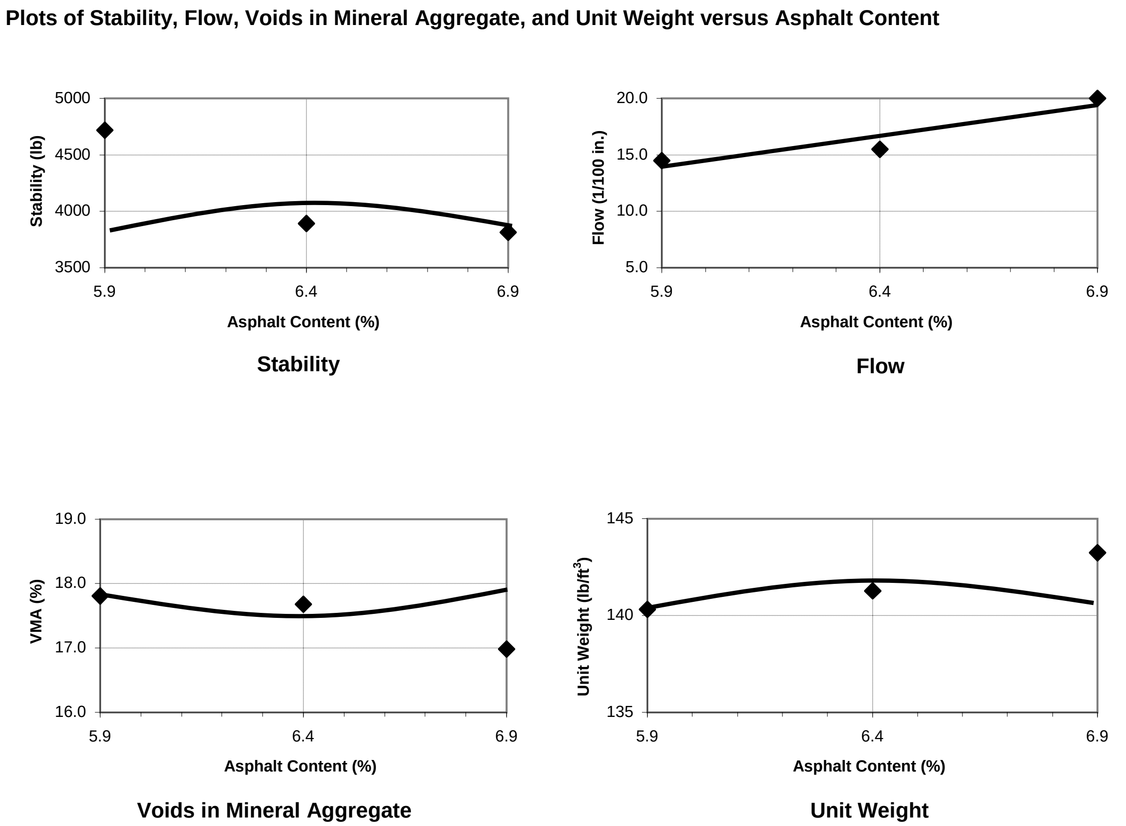


Figure A-200. Marshall Mix Design Results, 1/2-Inch Chert Gravel With Mortar Sand, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Fine Chert Gravel With Mortar Sand

Percent Passing	Total Combined Gradation	Individual Stockpiles 1/2"	3/8"	#4	#8	#16	#30	#50	#100	Mortar Sand
1"	100	100	100	100	100	100	100	100	100	100
3/4"	100	100	100	100	100	100	100	100	100	100
1/2"	95	39	100	100	100	100	100	100	100	100
3/8"	81	0	14	100	100	100	100	100	100	100
#4	64	0	0	15	100	100	100	100	100	100
#8	47	0	0	2	19	100	100	100	100	100
#16	29	0	0	2	1	16	97	97	100	100
#30	26	0	0	2	1	1	25	75	100	94
#50	20	0	0	2	1	1	6	23	99	32
#100	8	0	0	1	0	1	4	5	44	1
#200	3.7	0.2	0.2	0.9	0.4	1.3	3.5	4.1	19.7	0.6
Percent Used:	100	9%	12%	18%	18%	17%	0%	0%	16%	10%

Percent of Asphalt Cement	5.9%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

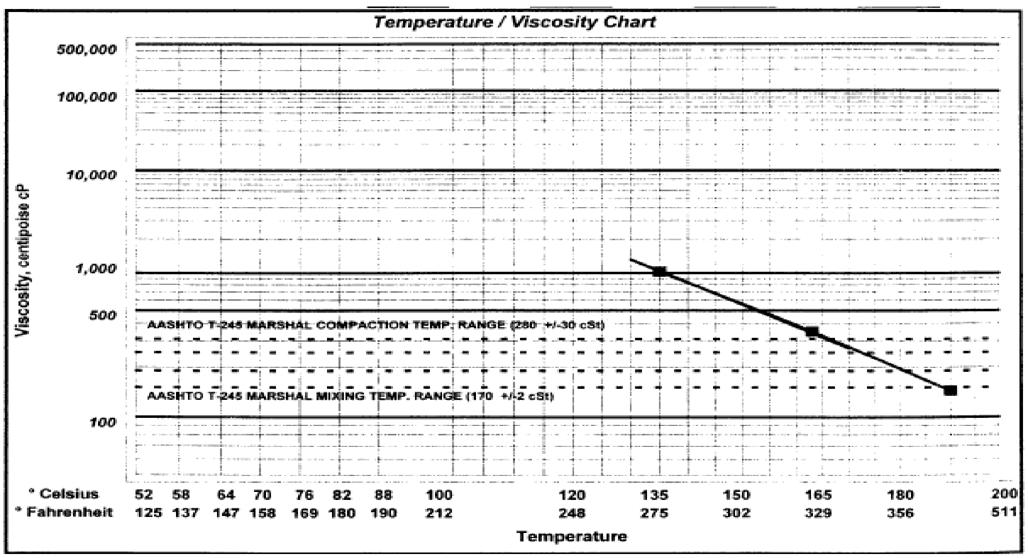


Figure A-201. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Fine Chert Gravel With Mortar Sand

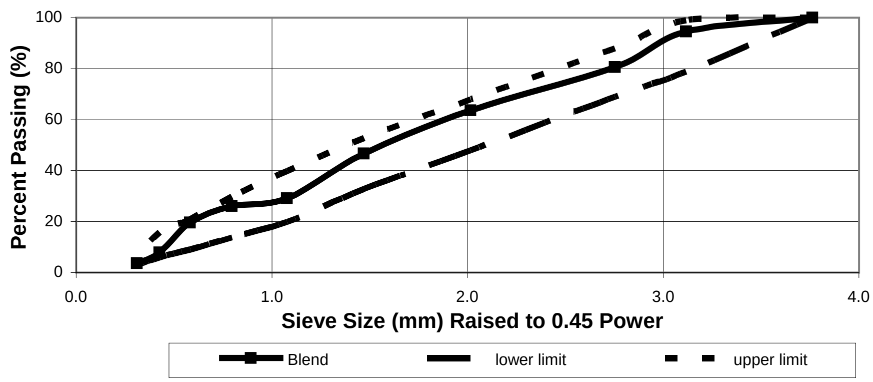
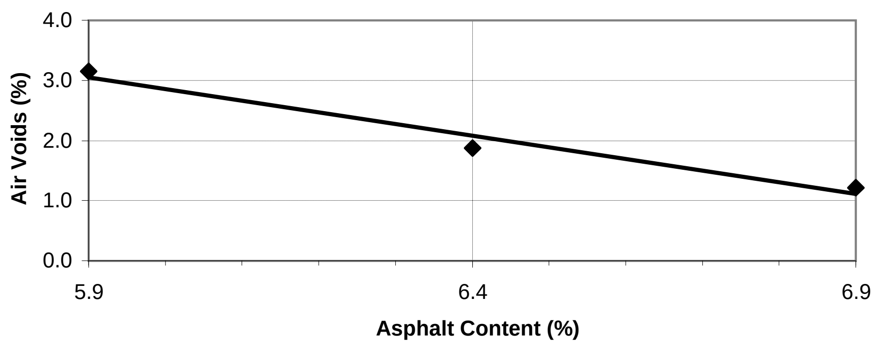


Figure A-202. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Fine Mix Chert Gravel With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.2%

Figure A-203. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Fine Mix Chert Gravel With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

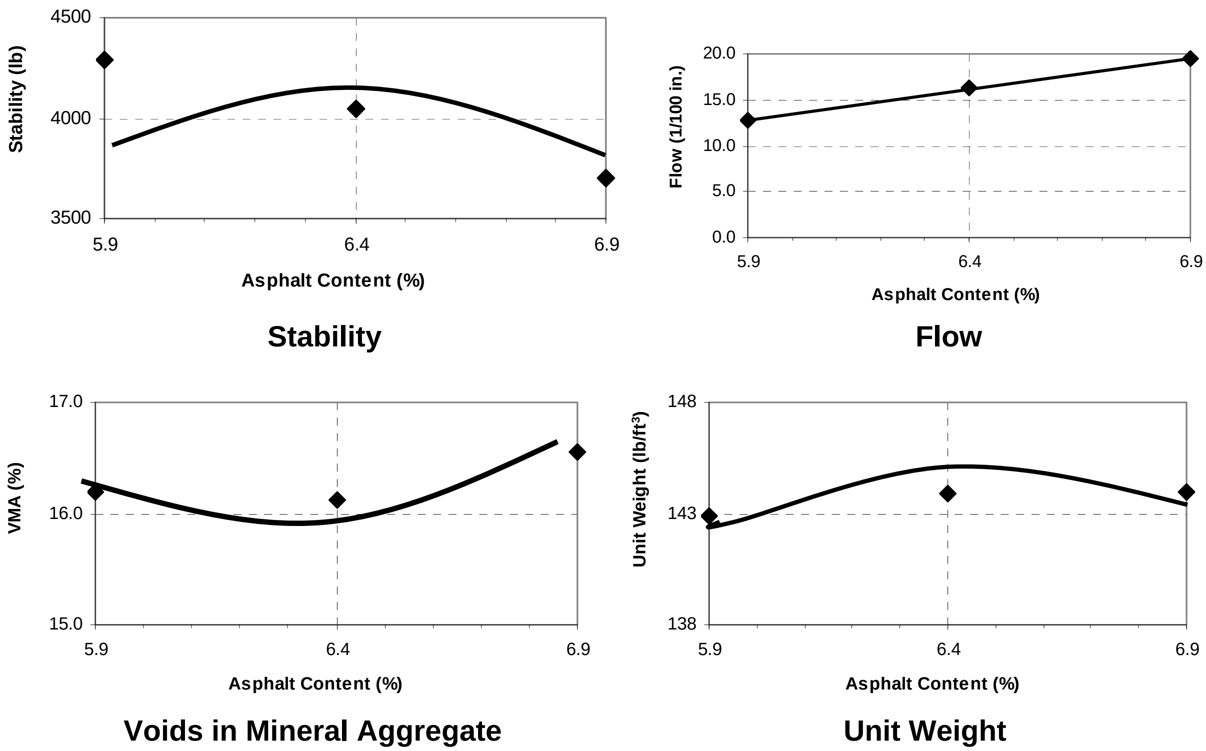


Figure A-204. Marshall Mix Design Results, 3/4-Inch Fine Mix Chert Gravel With Sand, PG 76-22

Marshall Mix Design Results

Aggregate Blend: 3/4-Inch Coarse Chert Gravel With Mortar Sand

		Individual Stockpiles								
Percent Passing	**Total Combined Gradation**	**1/2"**	**3/8"**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**Mortar Sand**
1"	100	100	100	100	100	100	100	100	100	100
3/4"	100	100	100	100	100	100	100	100	100	100
1/2"	87	39	100	100	100	100	100	100	100	100
3/8"	71	0	14	100	100	100	100	100	100	100
#4	54	0	0	15	100	100	100	100	100	100
#8	41	0	0	2	19	100	100	100	100	100
#16	28	0	0	2	1	16	97	97	100	100
#30	26	0	0	2	1	1	25	75	100	94
#50	20	0	0	2	1	1	6	23	99	32
#100	8	0	0	1	0	1	4	5	44	1
#200	3.7	0.2	0.2	0.9	0.4	1.3	3.5	4.1	19.7	0.6
Percent Used:	100	22%	8%	19%	13%	12%	0%	0%	16%	10%

Percent of Asphalt Cement	5.5%
Asphalt Performance Grade	PG 76-22
Number of Hammer Blows per Side	75
Mixing Temperature	185°C (365°F)
Compaction Temperature	168°C (335°F)

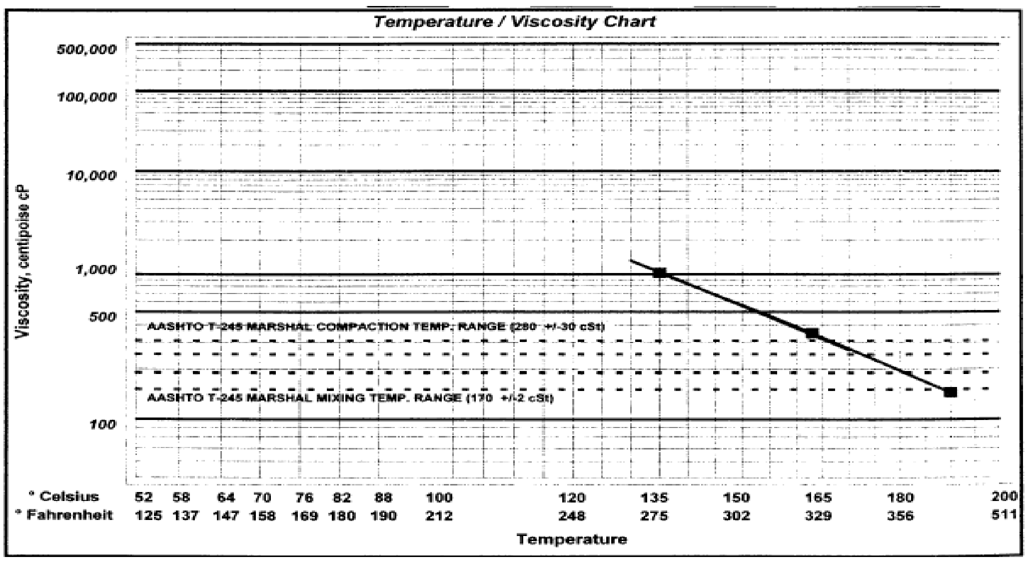


Figure A-205. Temperature Viscosity Relationship of Asphalt Cement for 3/4-Inch Coarse Chert Gravel With Mortar Sand

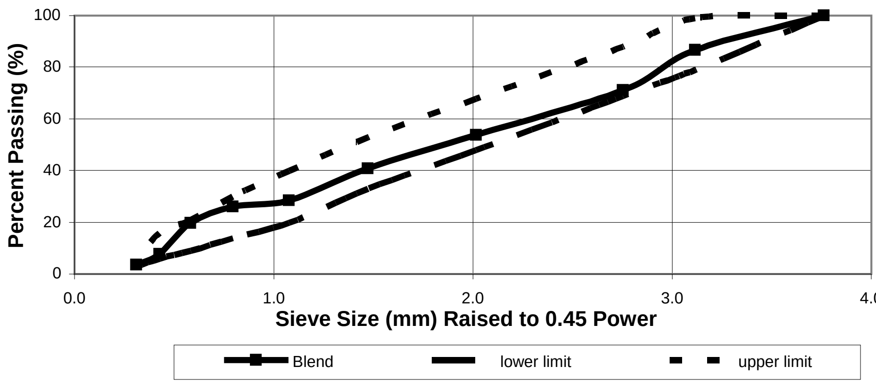
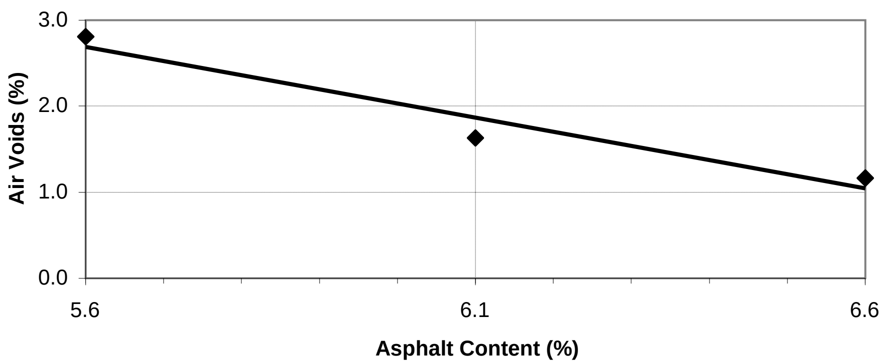


Figure A-206. Combined Gradation Plotted on 0.45 Power Curve for 3/4-Inch Coarse Mix Chert Gravel With 10% Mortar Sand



Percent Mortar Sand	10%
Percent Fractured Faces	100%
Percent by Weight Flat Particles (5:1)	0.0%
Percent by Weight Elongated Particles (5:1)	0.0%
Percent by Weight Flat Particles (5:1)	0.1%

Figure A-207. Plot of Air Void Content vs Asphalt Content for 3/4-Inch Coarse Mix Chert Gravel With Mortar Sand

Plots of Stability, Flow, Voids in Mineral Aggregate, and Unit Weight versus Asphalt Content

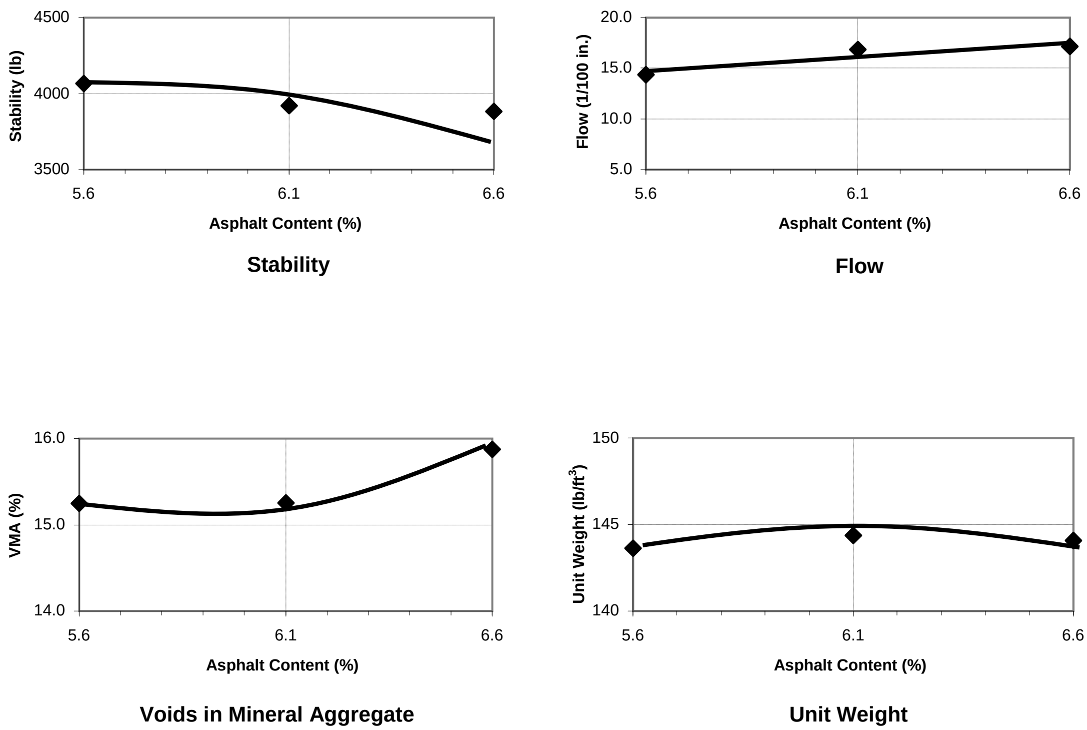


Figure A-208. Marshall Mix Design Results, 3/4-Inch Coarse Chert Gravel With Mortar Sand, PG 76-22

APPENDIX B—GYRATORY COMPACTION CURVES

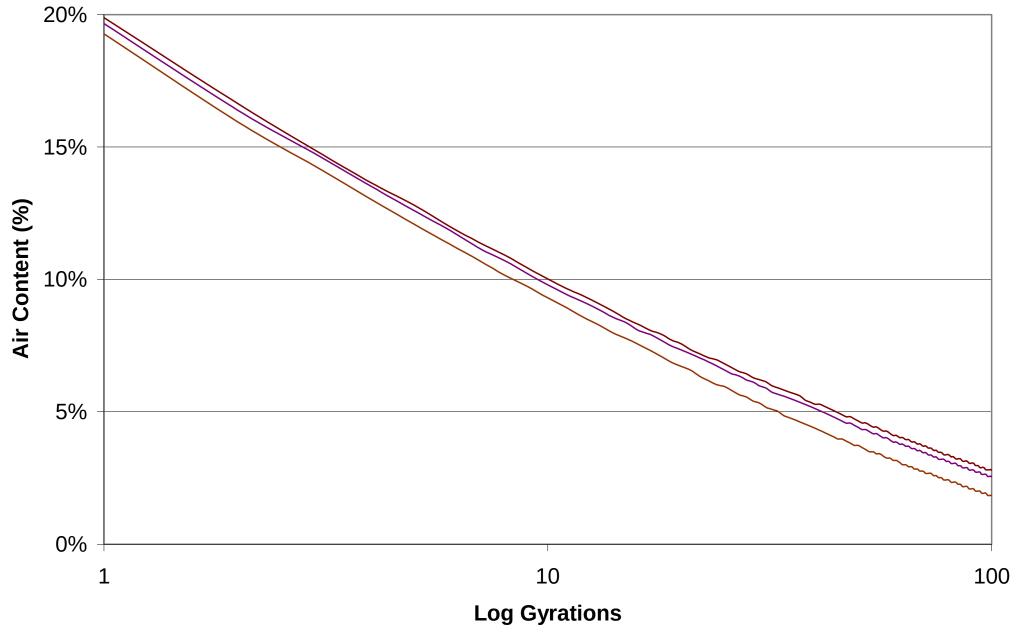


Figure B-1. Gyratory Compaction Curve for 1/2-Inch Gravel, PG 64-22 Binder

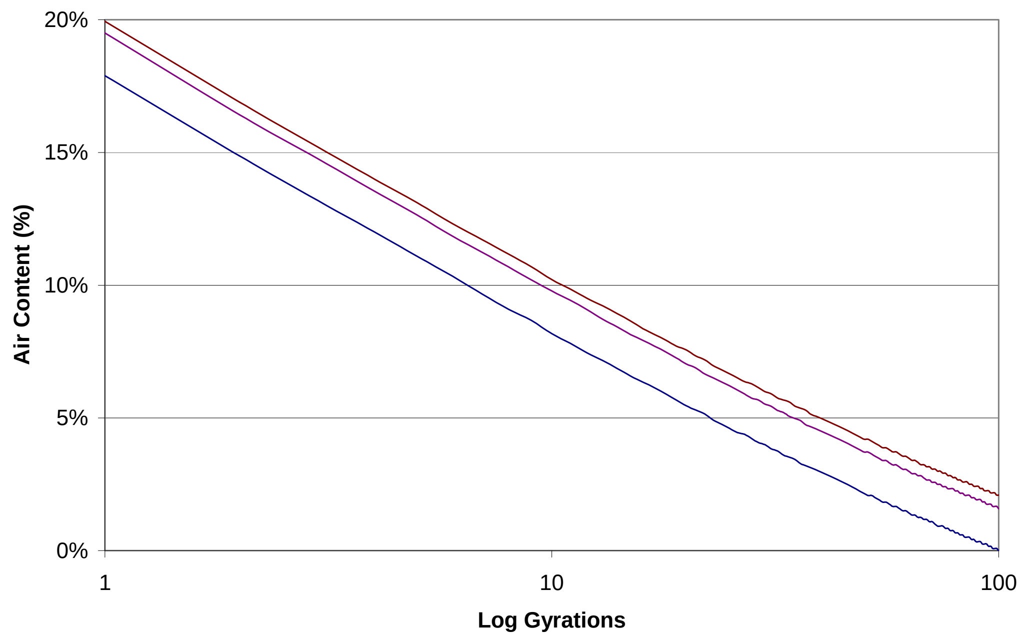


Figure B-2. Gyratory Compaction Curve for 3/4-Inch Fine Mix Gravel, PG 64-22 Binder

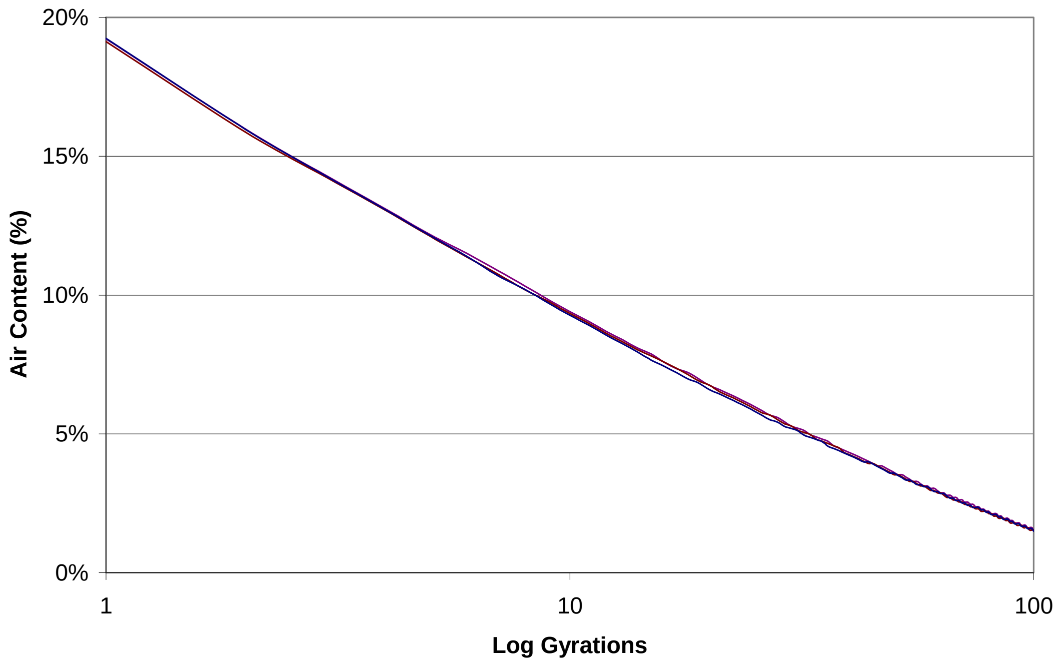


Figure B-3. Gyratory Compaction Curve for 3/4-Inch Coarse Mix Gravel, PG 64-22 Binder

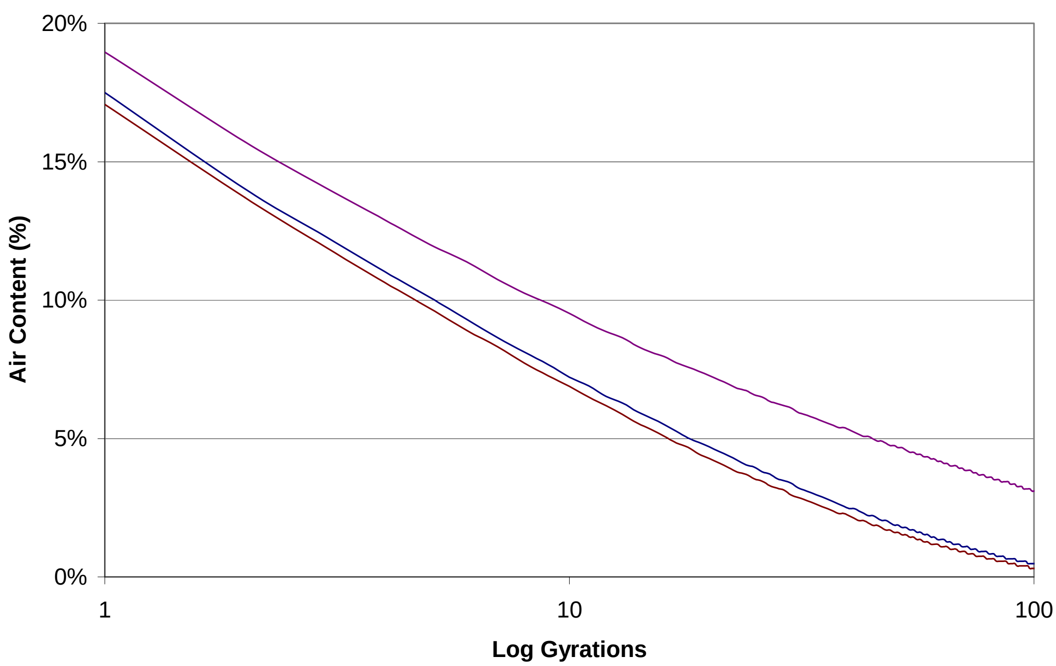


Figure B-4. Gyratory Compaction Curve for 1/2-Inch Gravel With Mortar Sand, PG 64-22 Binder

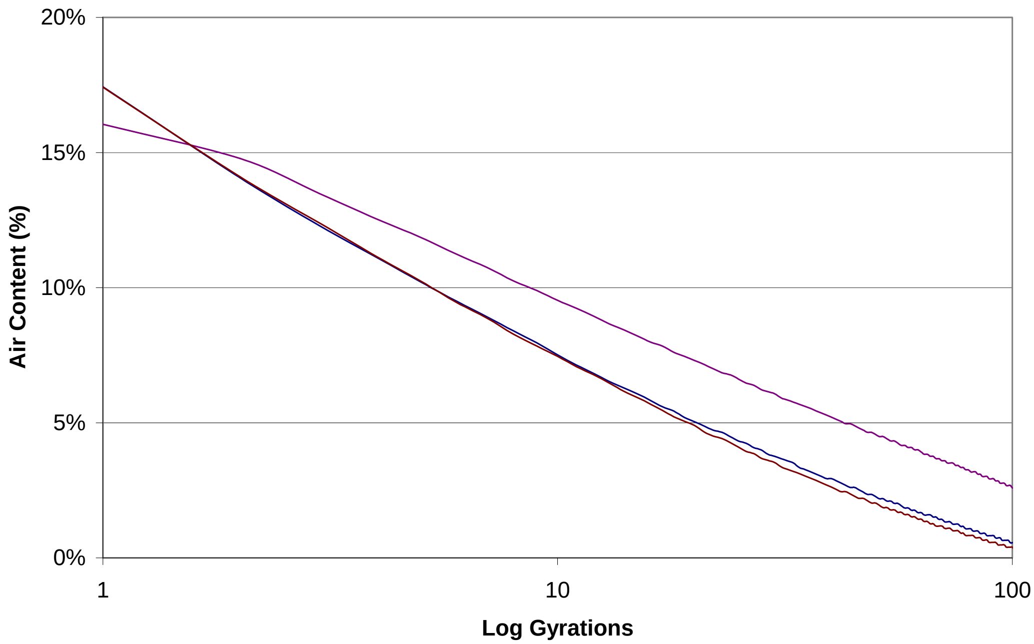


Figure B-5. Gyratory Compaction Curve for 3/4-Inch Fine Mix Gravel With Mortar Sand, PG 64-22 Binder

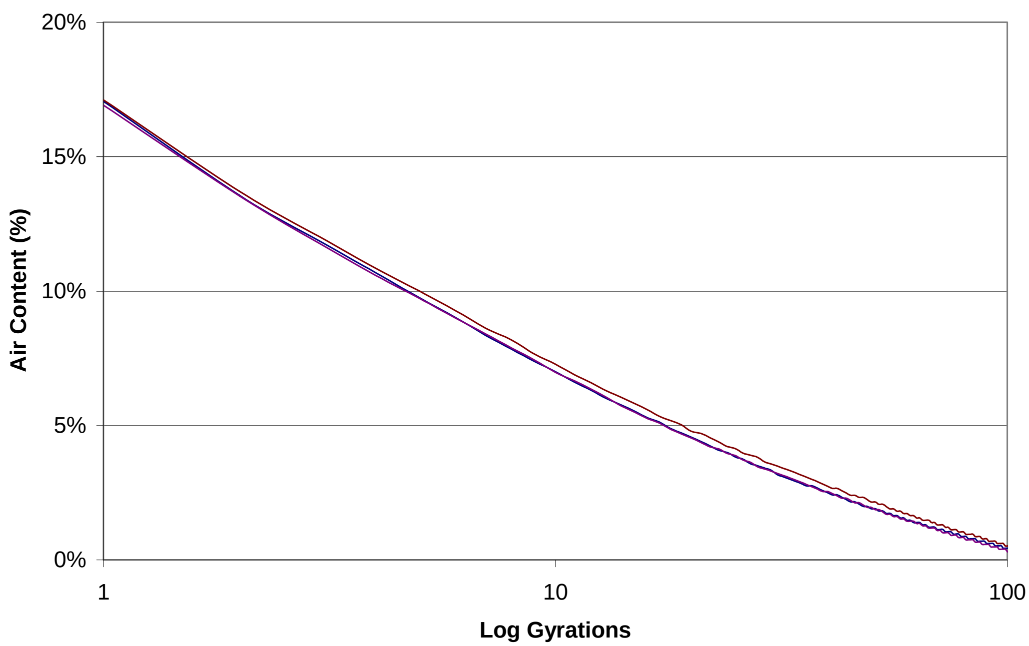


Figure B-6. Gyratory Compaction Curve for 3/4-Inch Coarse Mix Gravel With Mortar Sand, PG 64-22 Binder

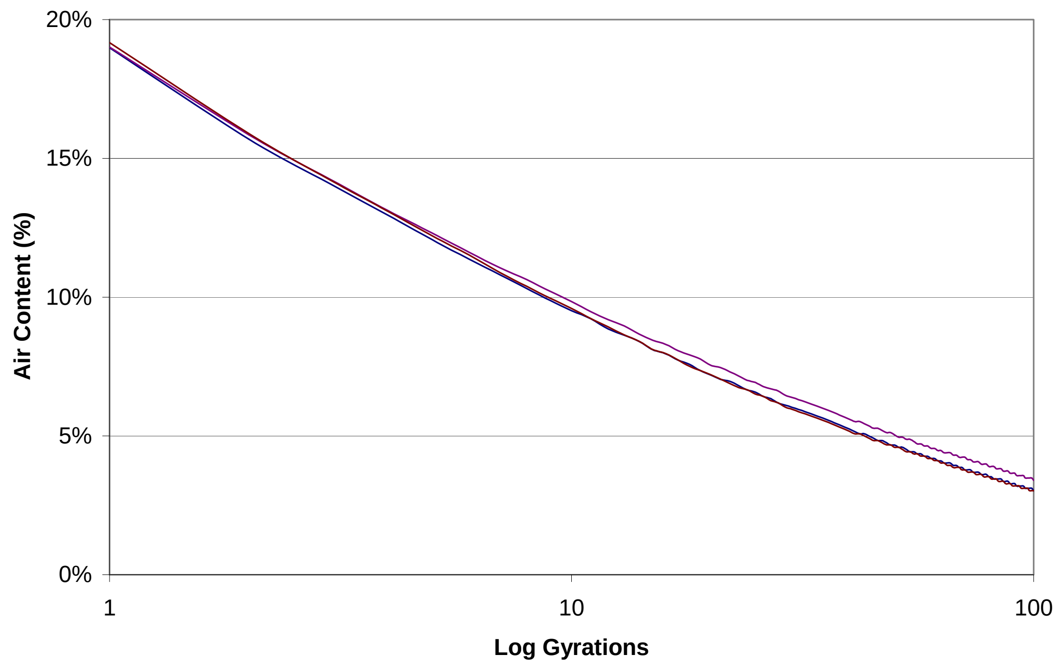


Figure B-7. Gyratory Compaction Curve for 1/2-Inch Fine Mix Granite, PG 64-22 Binder

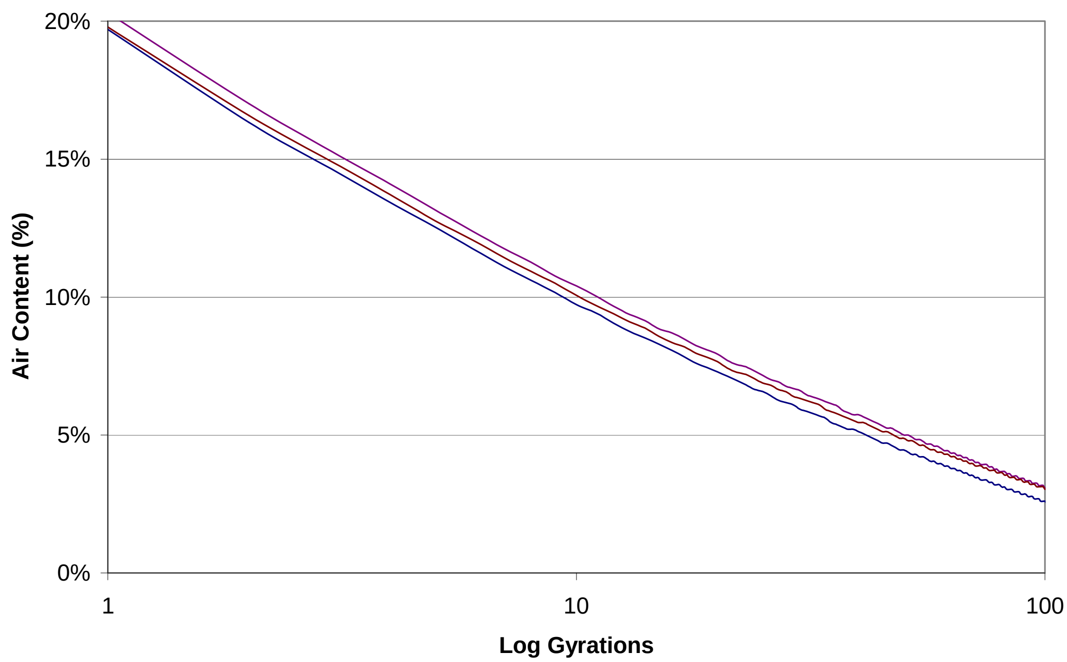


Figure B-8. Gyratory Compaction Curve for 1/2-Inch Coarse Mix Granite, PG 64-22 Binder

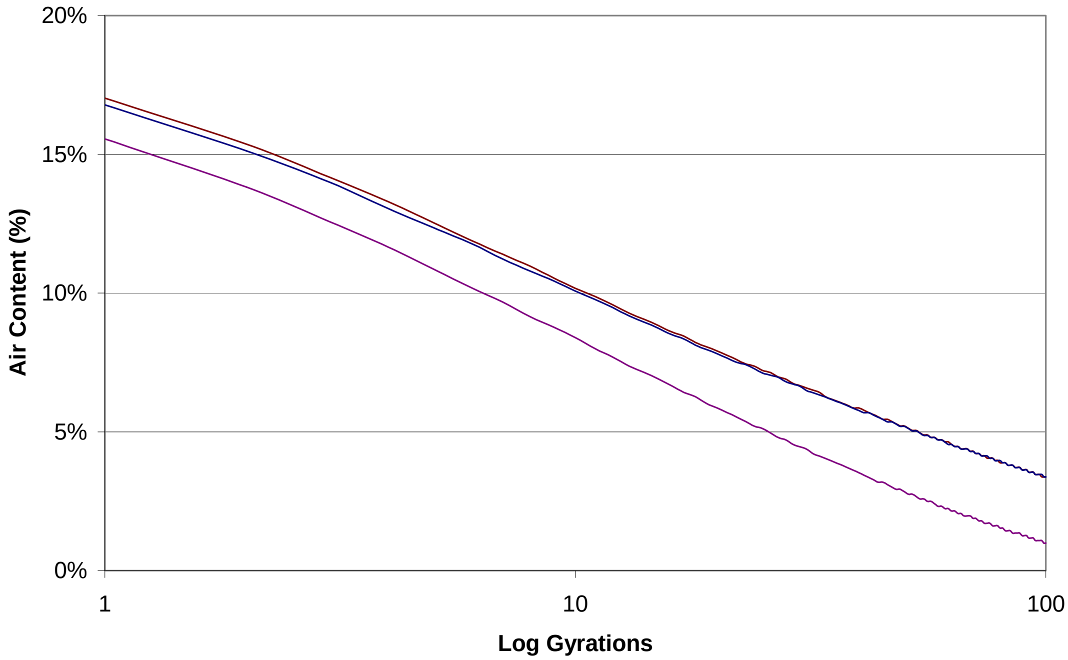


Figure B-9. Gyratory Compaction Curve for 3/4-Inch Fine Mix Granite, PG 64-22 Binder

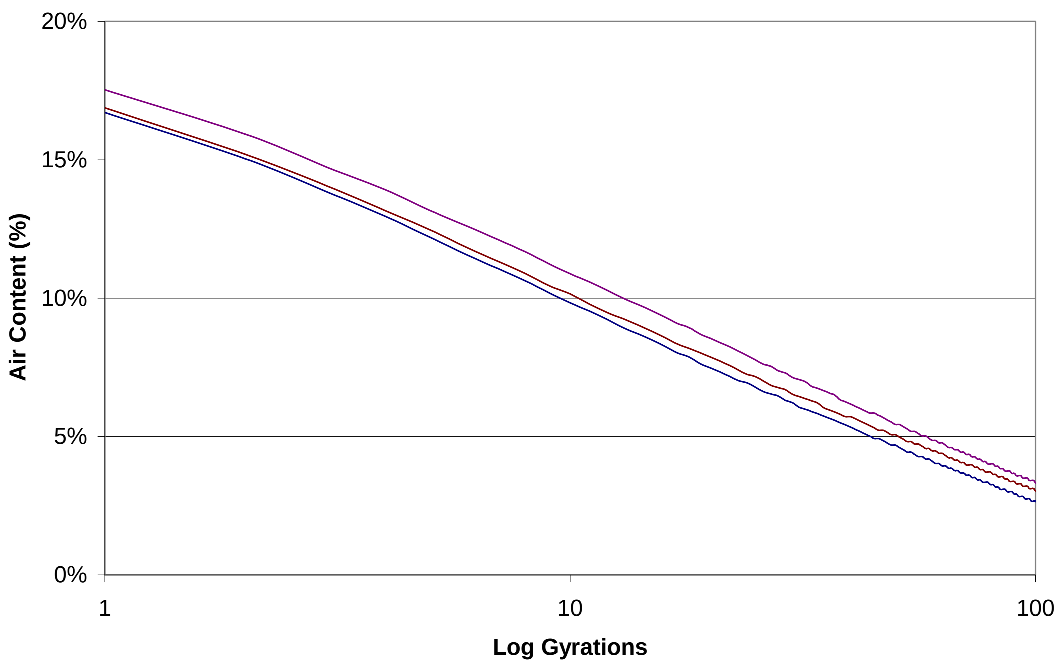


Figure B-10. Gyratory Compaction Curve for 3/4-Inch Coarse Mix Granite, PG 64-22 Binder

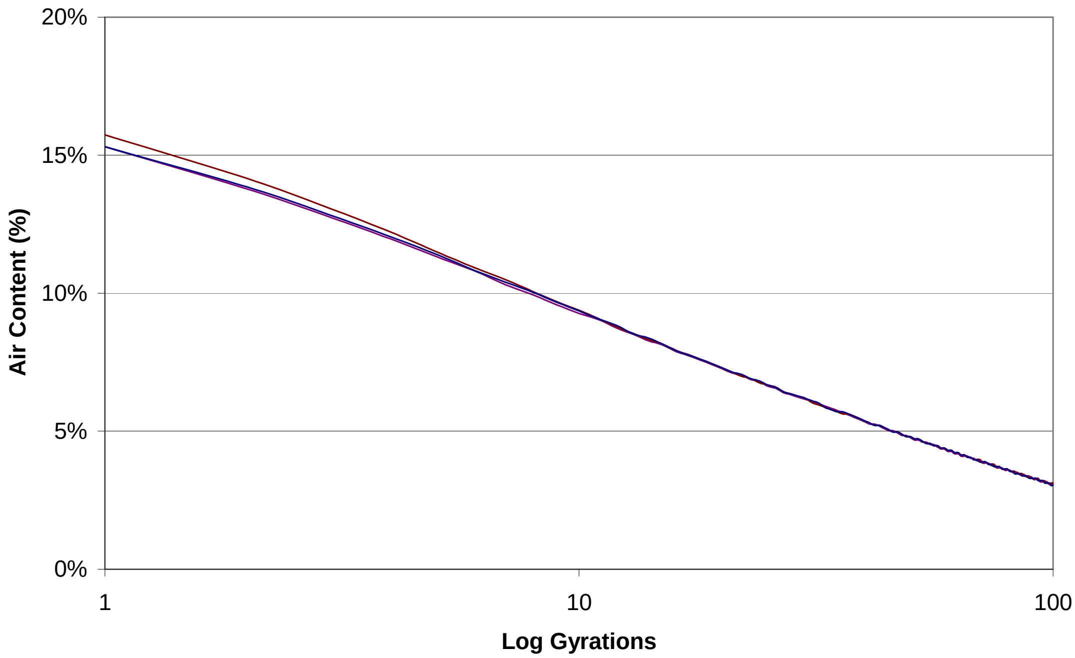


Figure B-11. Gyratory Compaction Curve for 1-Inch Fine Mix Granite, PG 64-22 Binder

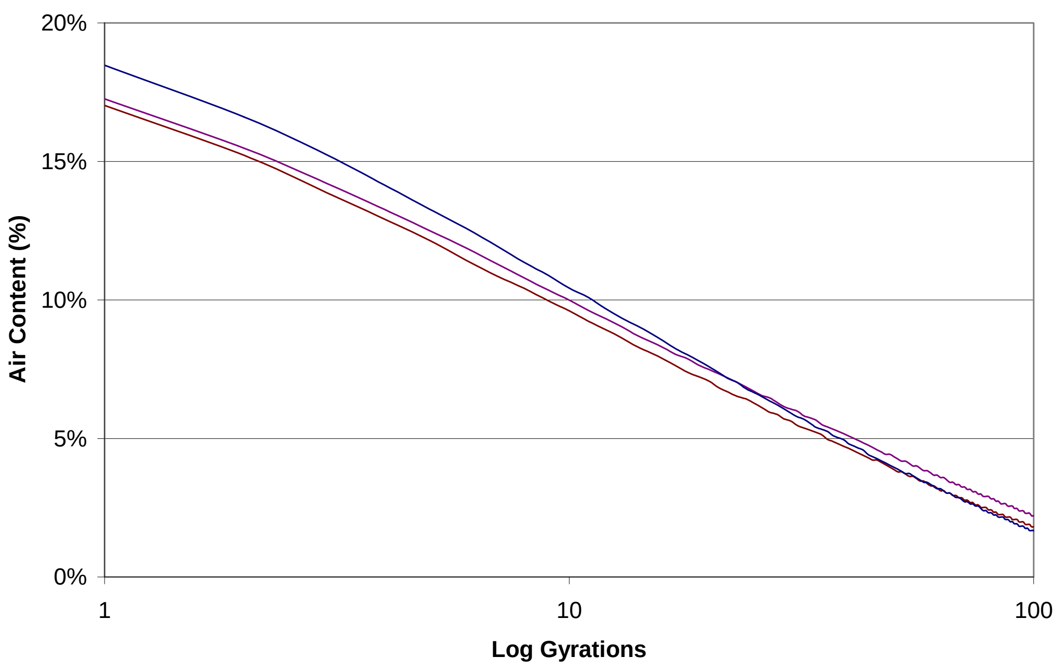


Figure B-12. Gyratory Compaction Curve for 1-Inch Coarse Mix Granite, PG 64-22 Binder

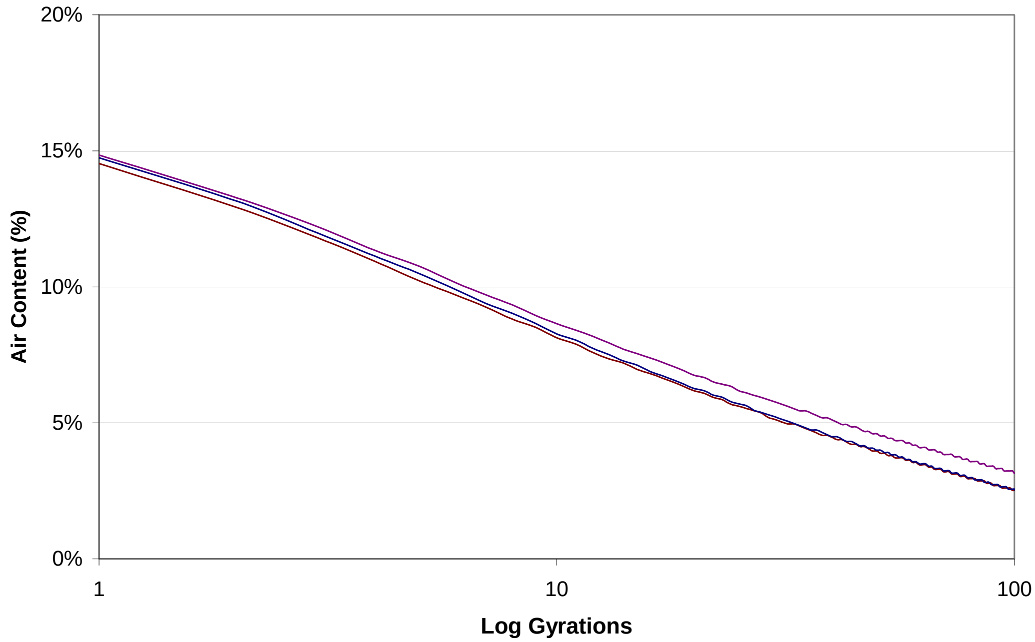


Figure B-13. Gyratory Compaction Curve for 1/2-Inch Fine Mix Granite With Mortar Sand, PG 64-22 Binder

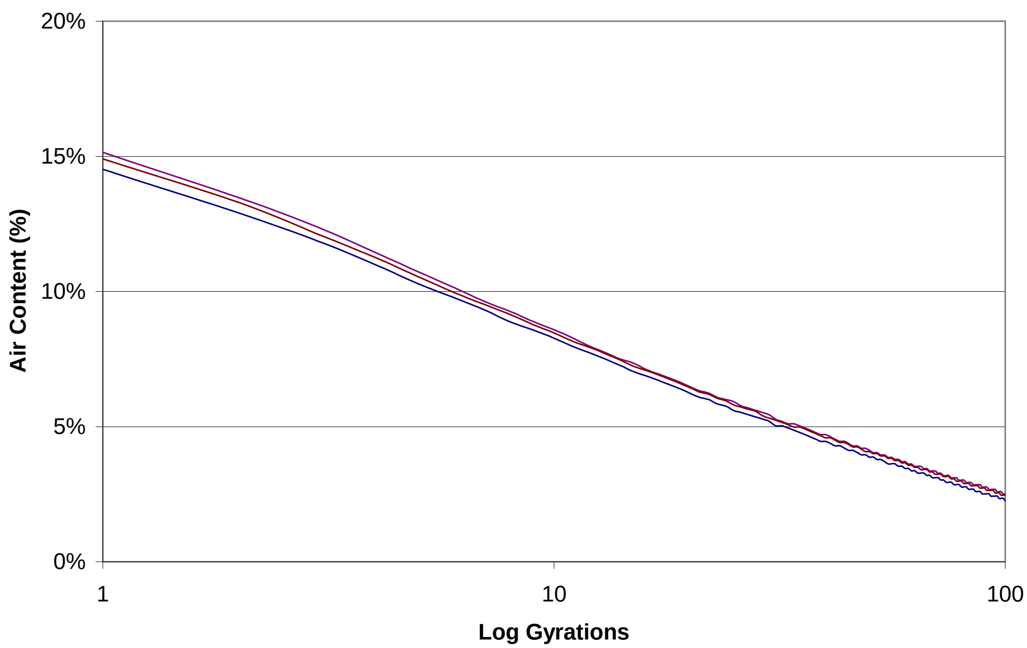


Figure B-14. Gyratory Compaction Curve for 1/2-Inch Coarse Mix Granite With Mortar Sand, PG 64-22 Binder

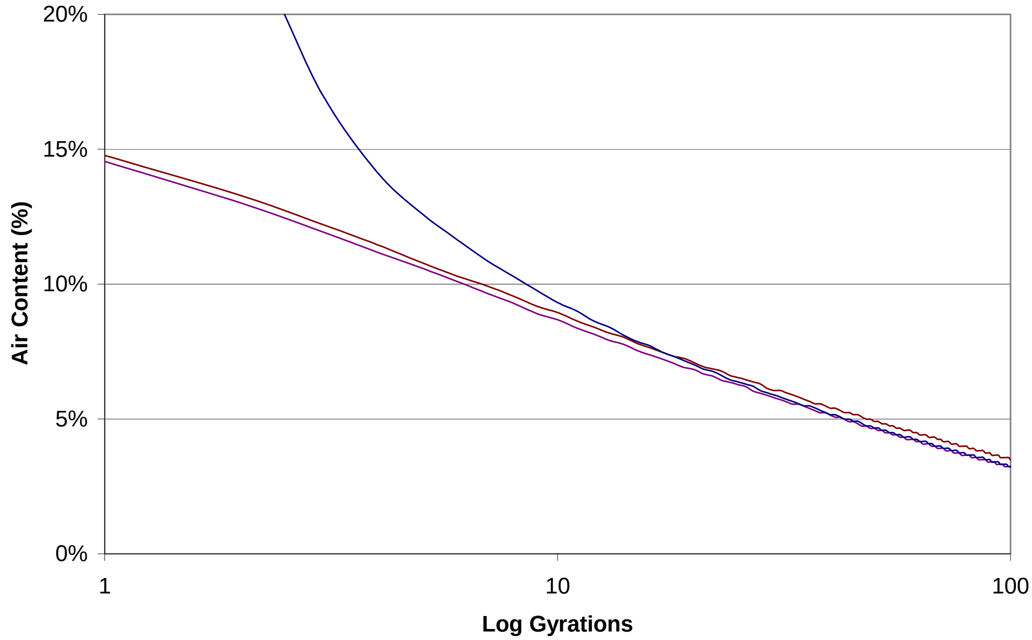


Figure B-15. Gyratory Compaction Curve for 3/4-Inch Fine Mix Granite With Mortar Sand, PG 64-22 Binder

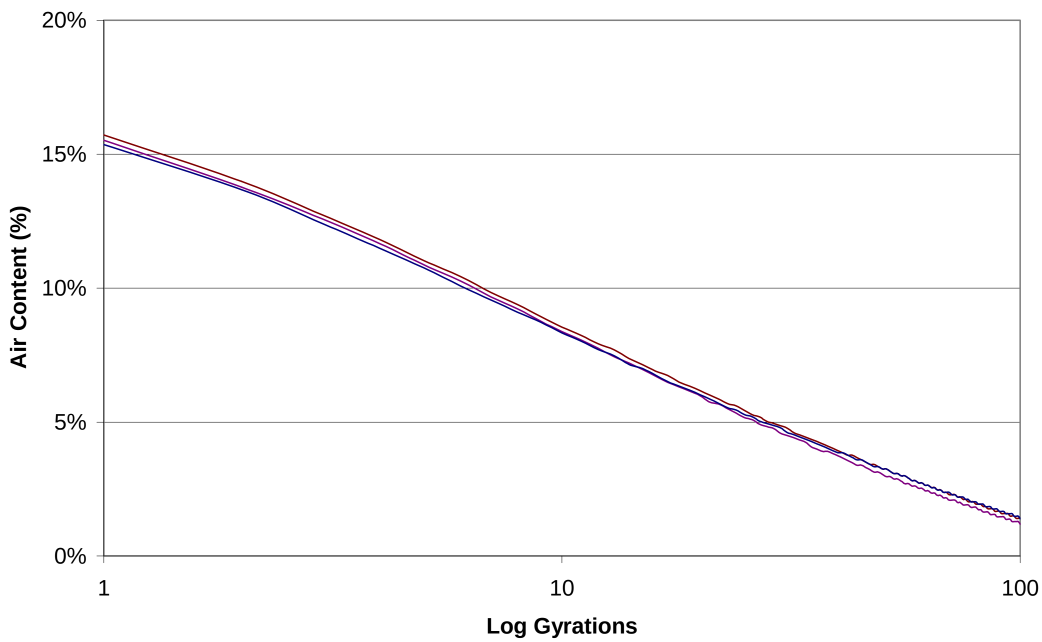


Figure B-16. Gyratory Compaction Curve for 3/4-Inch Coarse Mix Granite With Mortar Sand, PG 64-22 Binder

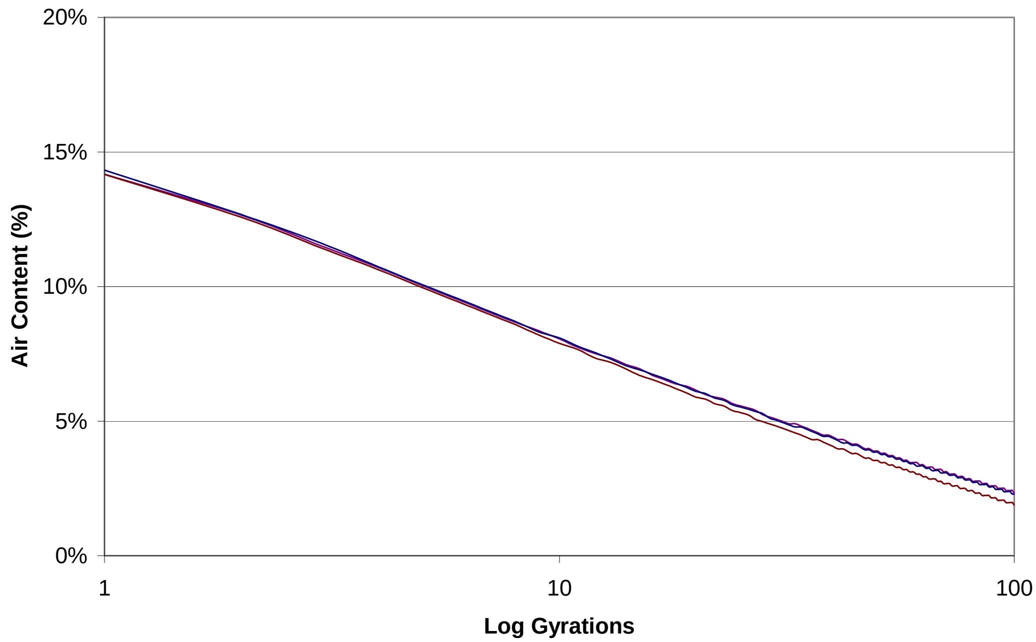


Figure B-17. Gyratory Compaction Curve for 1-Inch Fine Mix Granite With Mortar Sand, PG 64-22 Binder

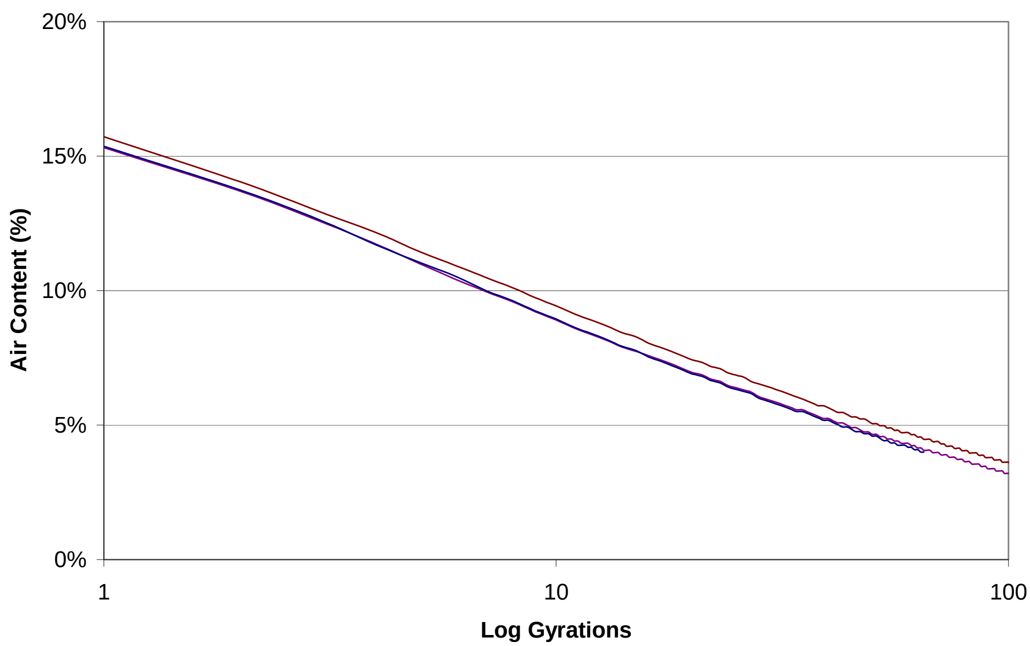


Figure B-18. Gyratory Compaction Curve for 1-Inch Coarse Mix Granite With Mortar Sand, PG 64-22 Binder

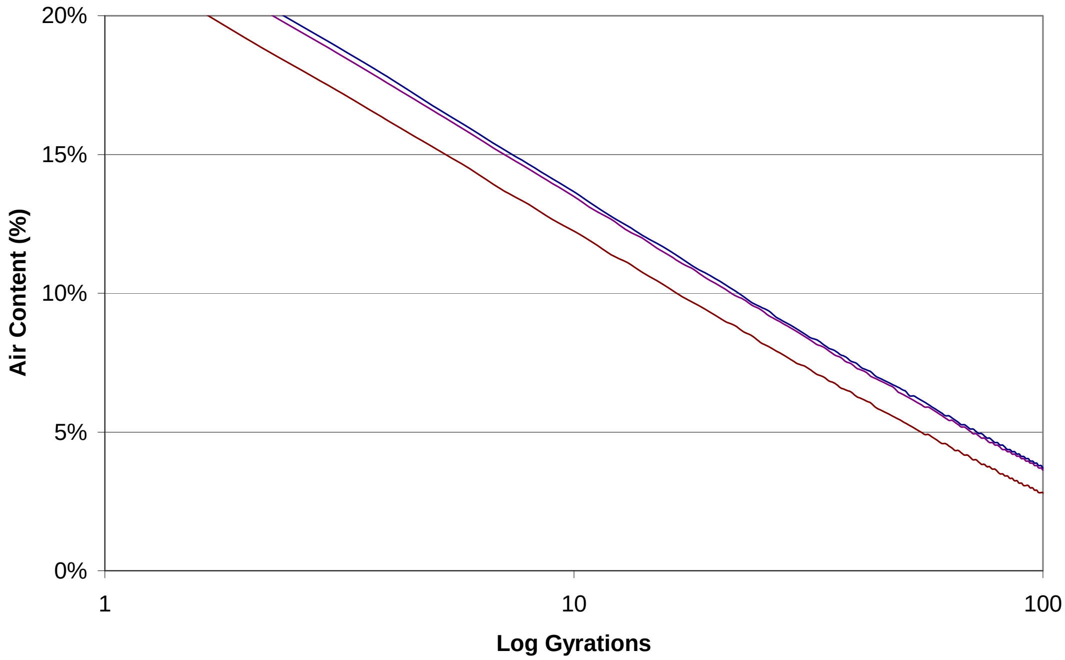


Figure B-19. Gyratory Compaction Curve for 1/2-Inch Fine Mix Limestone, PG 64-22 Binder

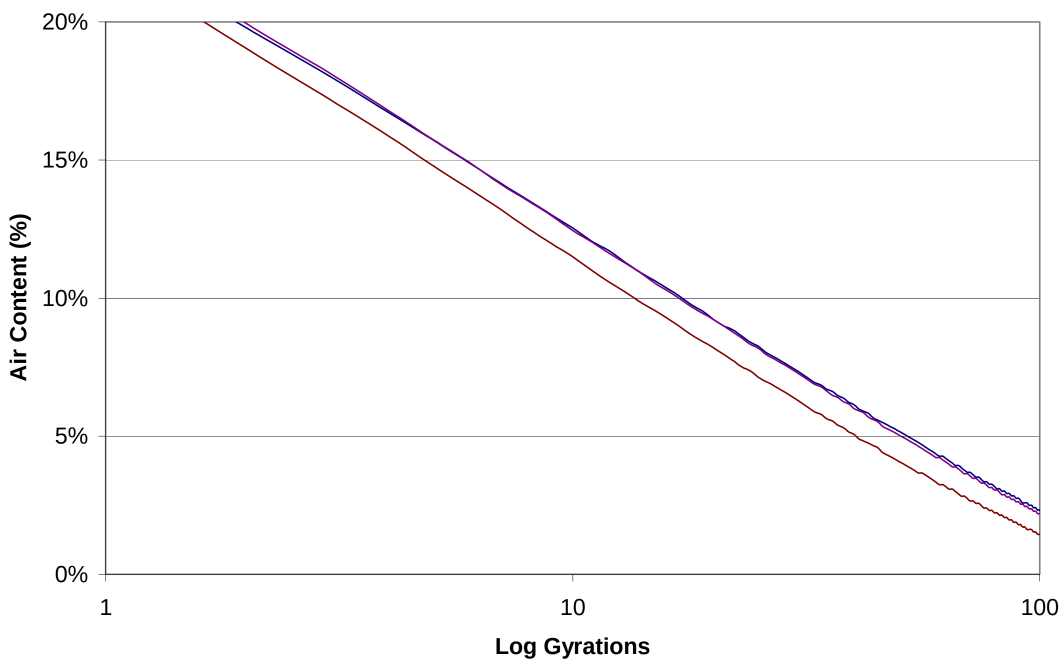


Figure B-20. Gyratory Compaction Curve for 1/2-Inch Coarse Mix Limestone, PG 64-22 Binder

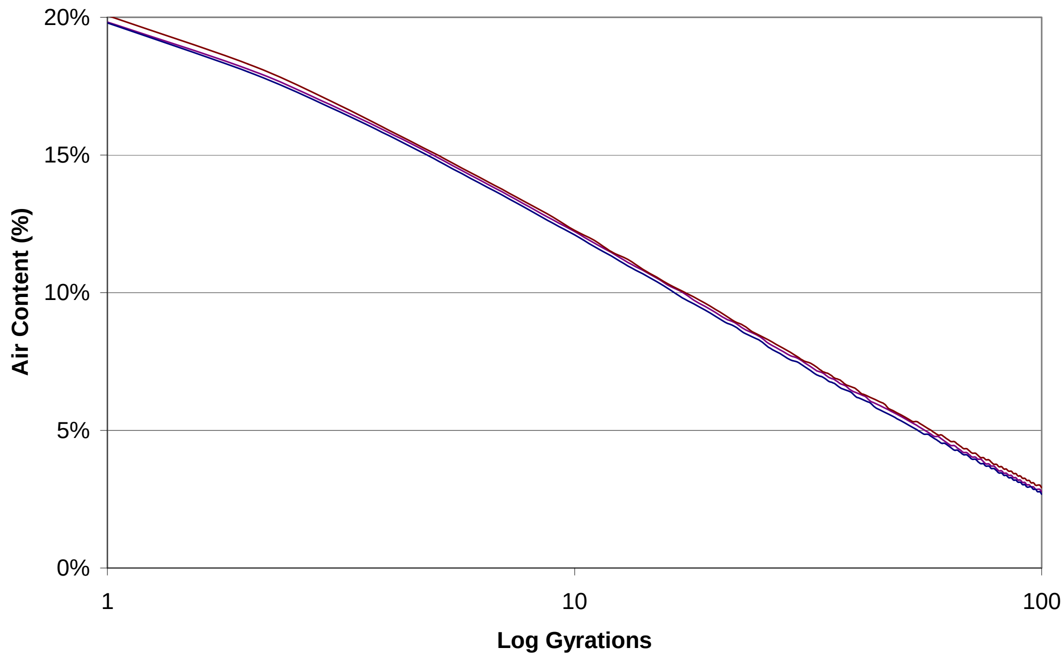


Figure B-21. Gyratory Compaction Curve for 3/4-Inch Fine Mix Limestone, PG 64-22 Binder

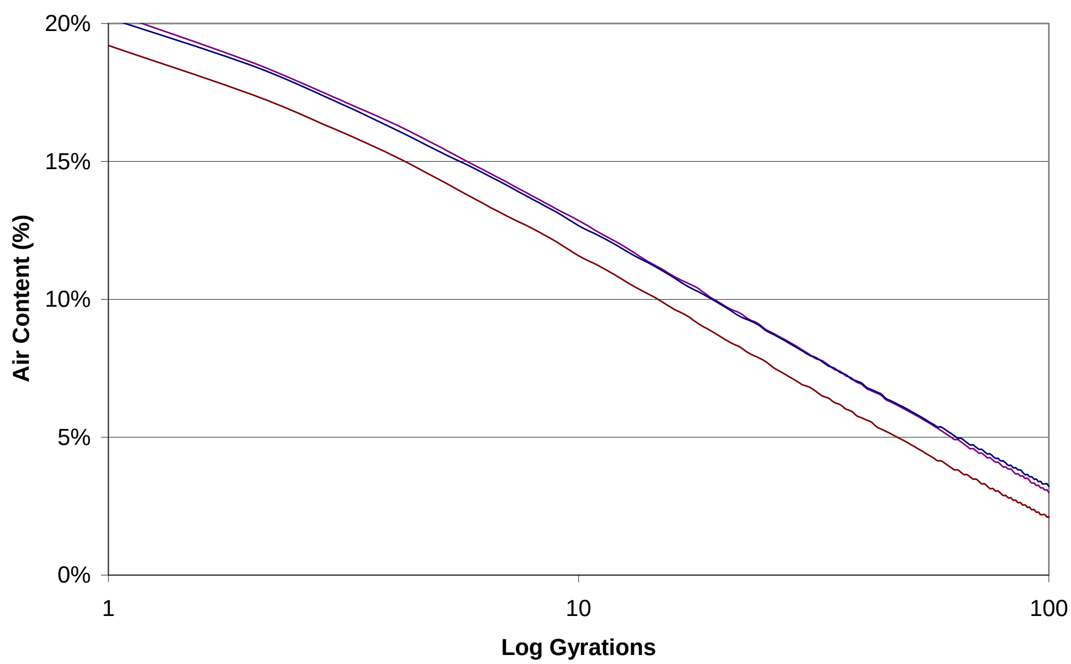


Figure B-22. Gyratory Compaction Curve for 3/4-Inch Coarse Mix Limestone, PG 64-22 Binder

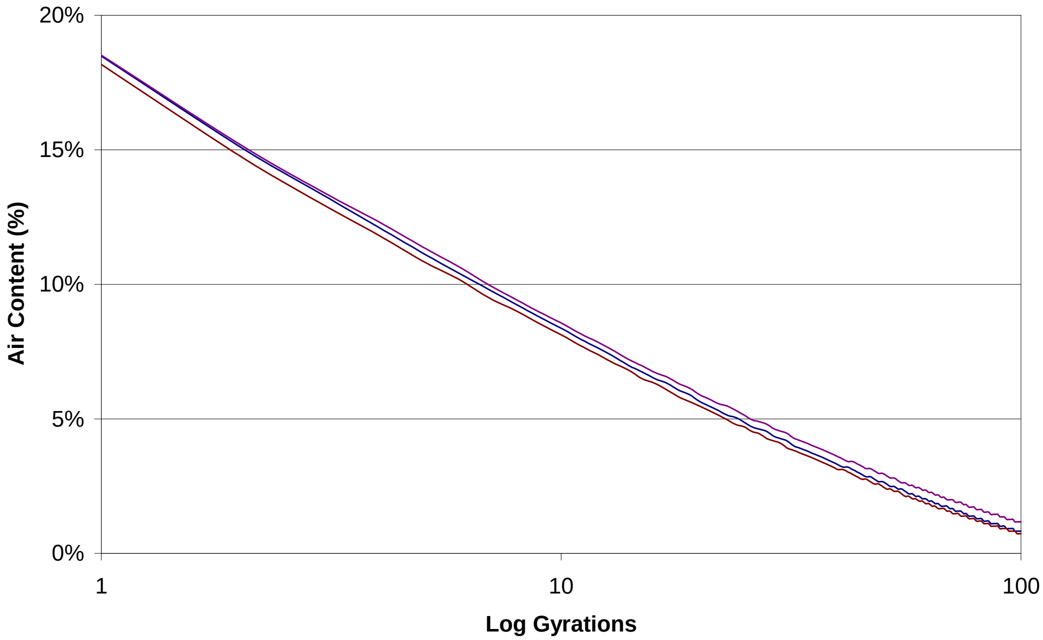


Figure B-23. Gyratory Compaction Curve for 1/2-Inch Fine Mix Limestone With Mortar Sand, PG 64-22 Binder

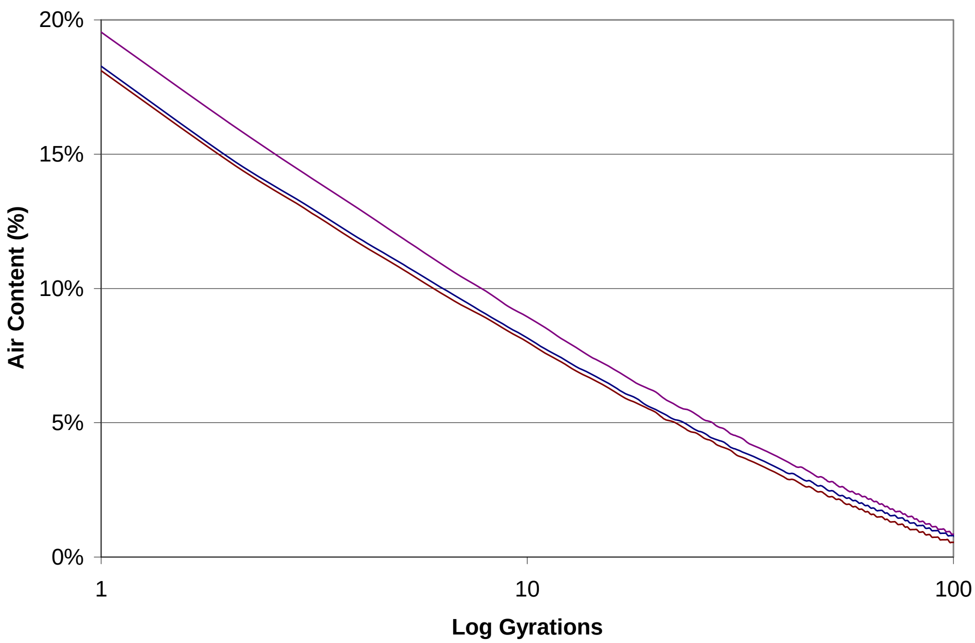


Figure B-24. Gyratory Compaction Curve for 1/2-Inch Coarse Mix Limestone With Mortar Sand, PG 64-22 Binder

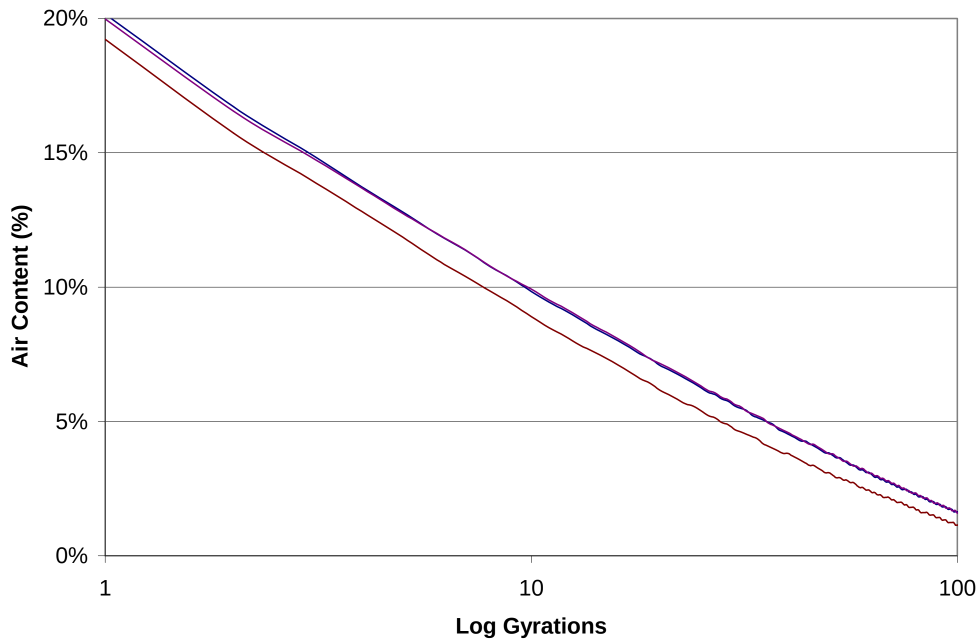


Figure B-25. Gyratory Compaction Curve for 3/4-Inch Fine Mix Limestone With Mortar Sand, PG 64-22 Binder

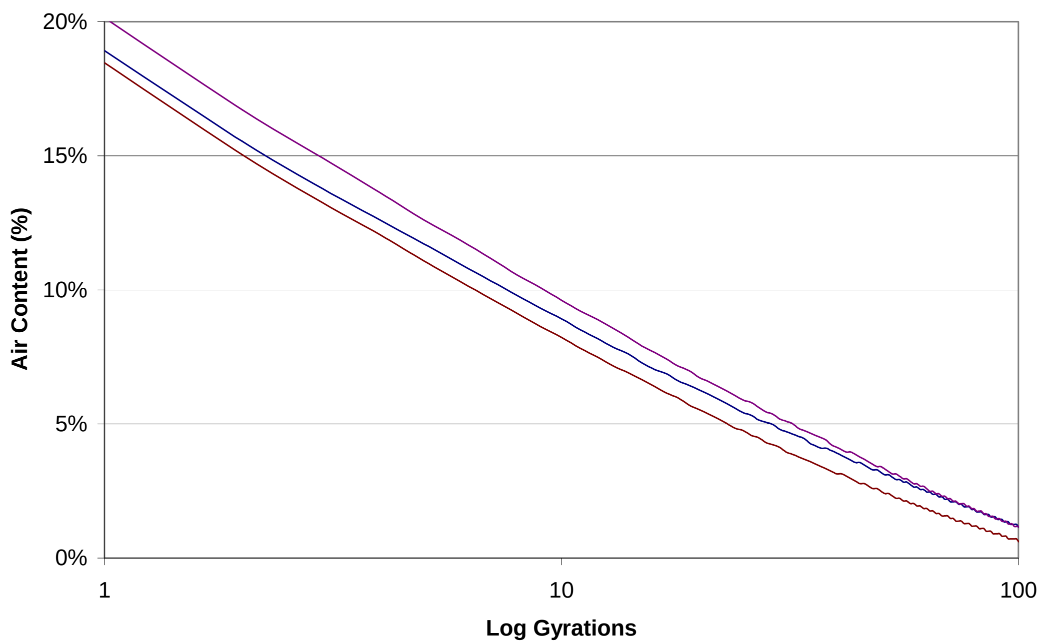


Figure B-26. Gyratory Compaction Curve for 3/4-Inch Coarse Mix Limestone With Mortar Sand, PG 64-22 Binder

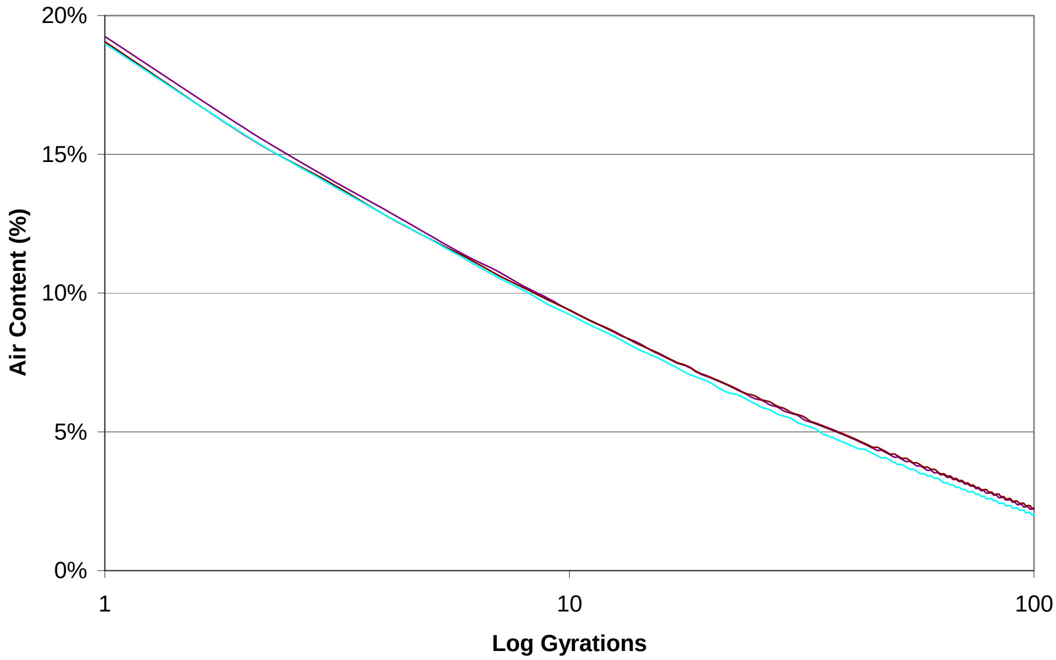


Figure B-27. Gyratory Compaction Curve for 1/2-Inch Gravel, PG 76-22 Binder

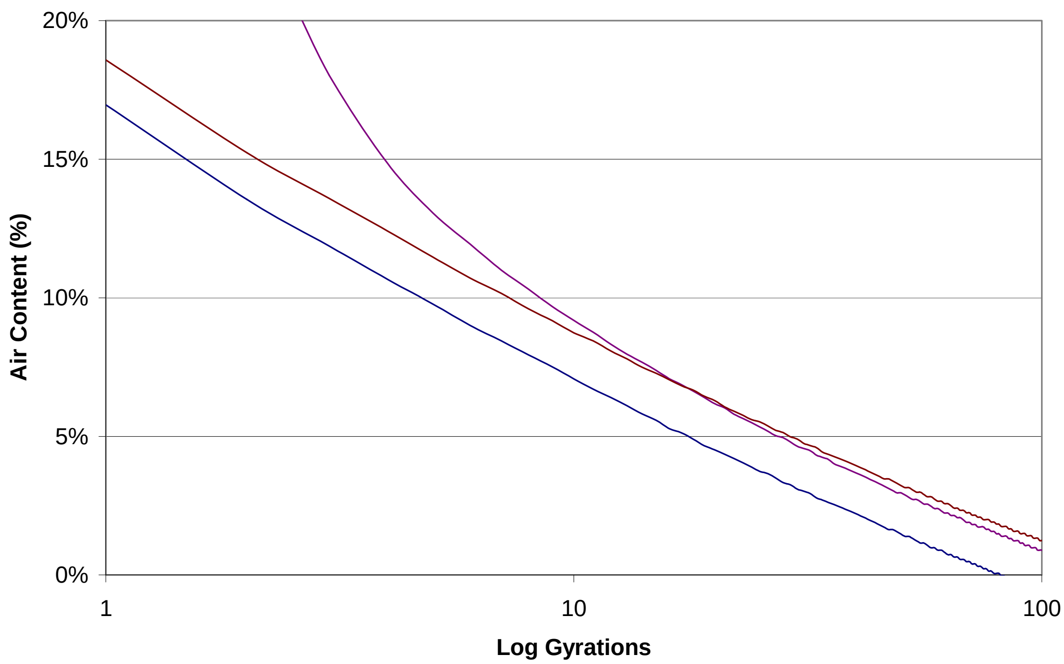


Figure B-28. Gyratory Compaction Curve for 3/4-Inch Fine Mix Gravel, PG 76-22 Binder

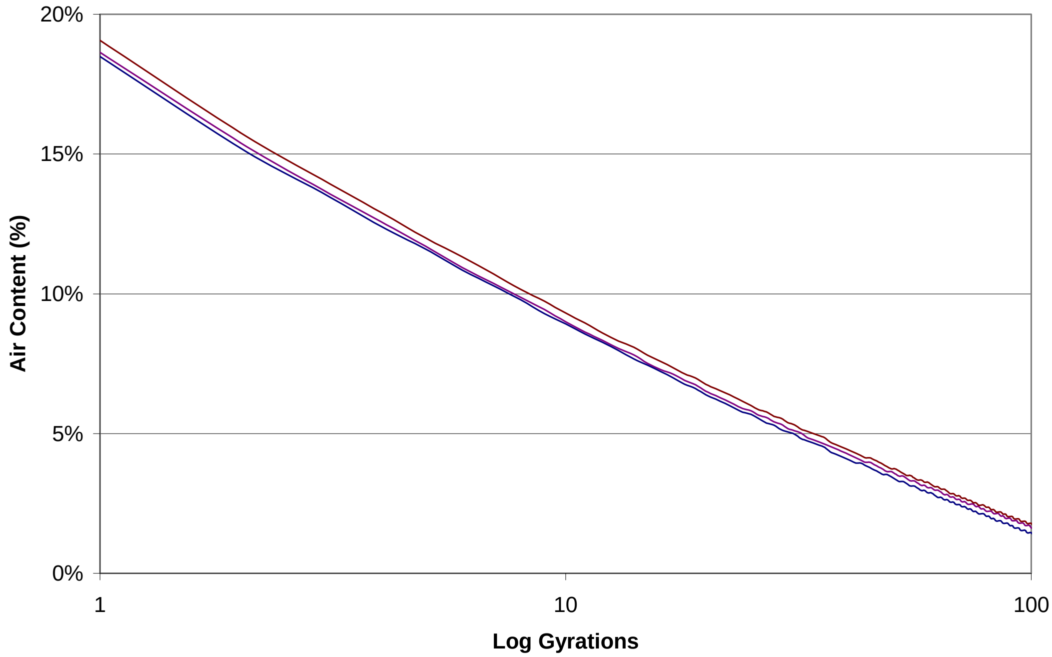


Figure B-29. Gyratory Compaction Curve for 3/4-Inch Coarse Mix Gravel, PG 76-22 Binder

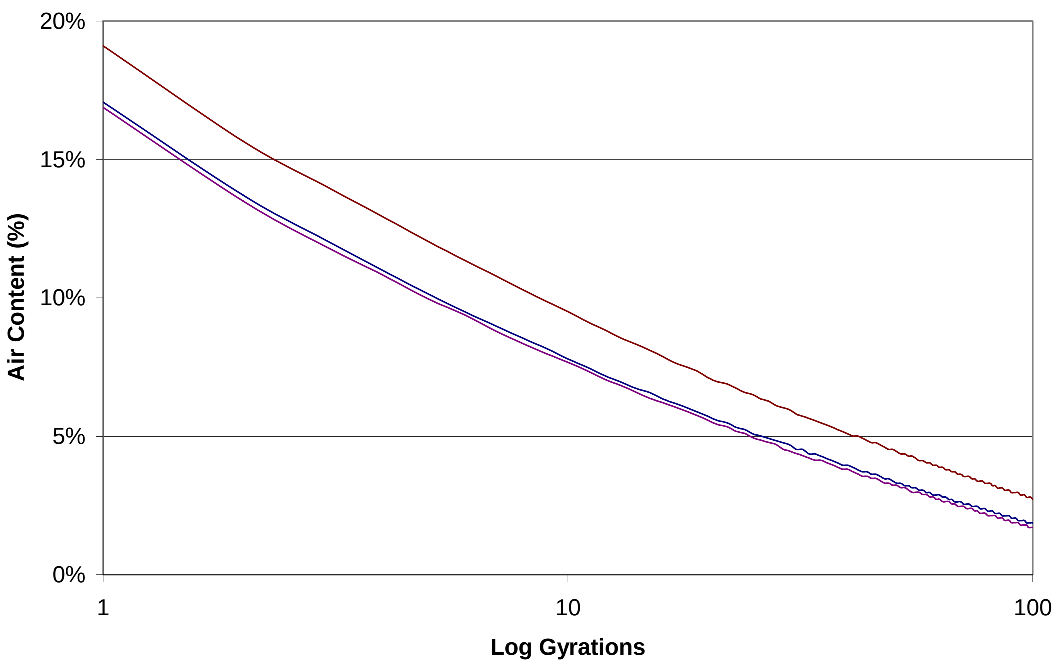


Figure B-30. Gyratory Compaction Curve for 1/2-Inch Gravel With Mortar Sand, PG 76-22 Binder

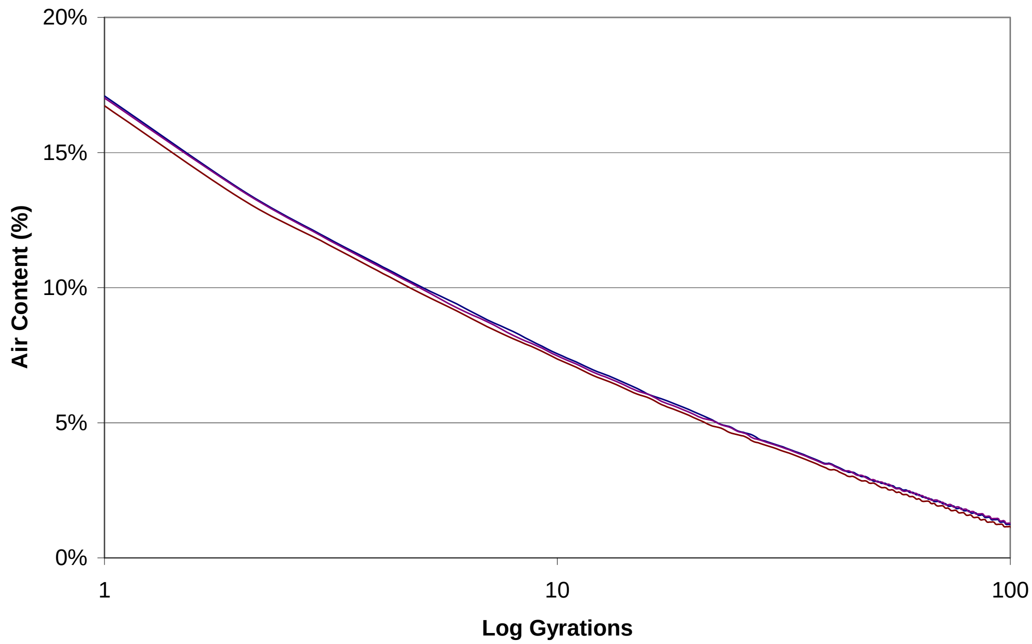


Figure B-31. Gyratory Compaction Curve for 3/4-Inch Fine Mix Gravel With Mortar Sand, PG 76-22 Binder

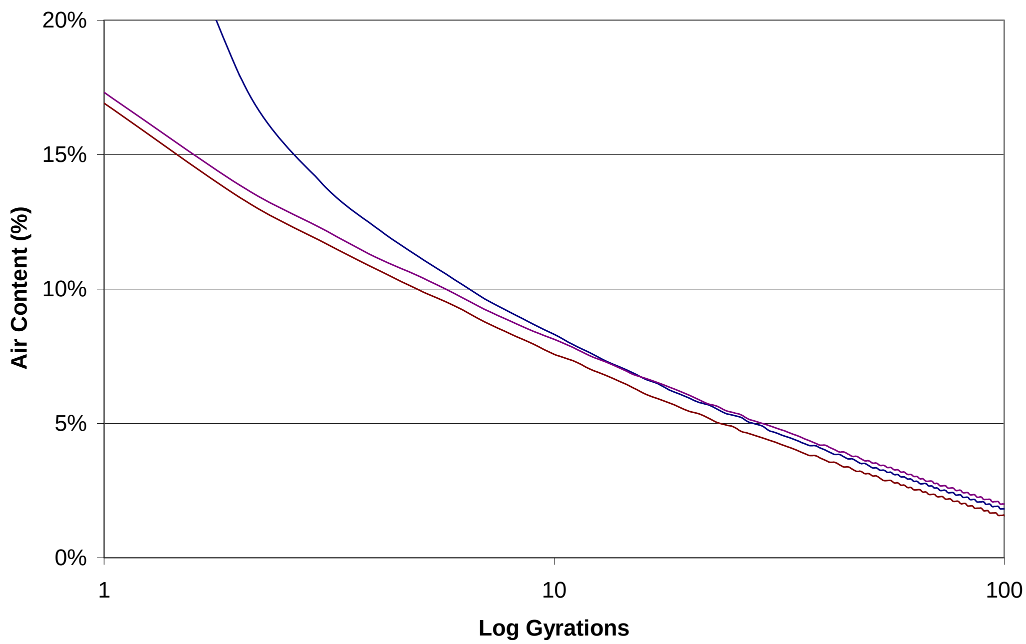


Figure B-32. Gyratory Compaction Curve for 3/4-Inch Coarse Mix Gravel With Mortar Sand, PG 76-22 Binder

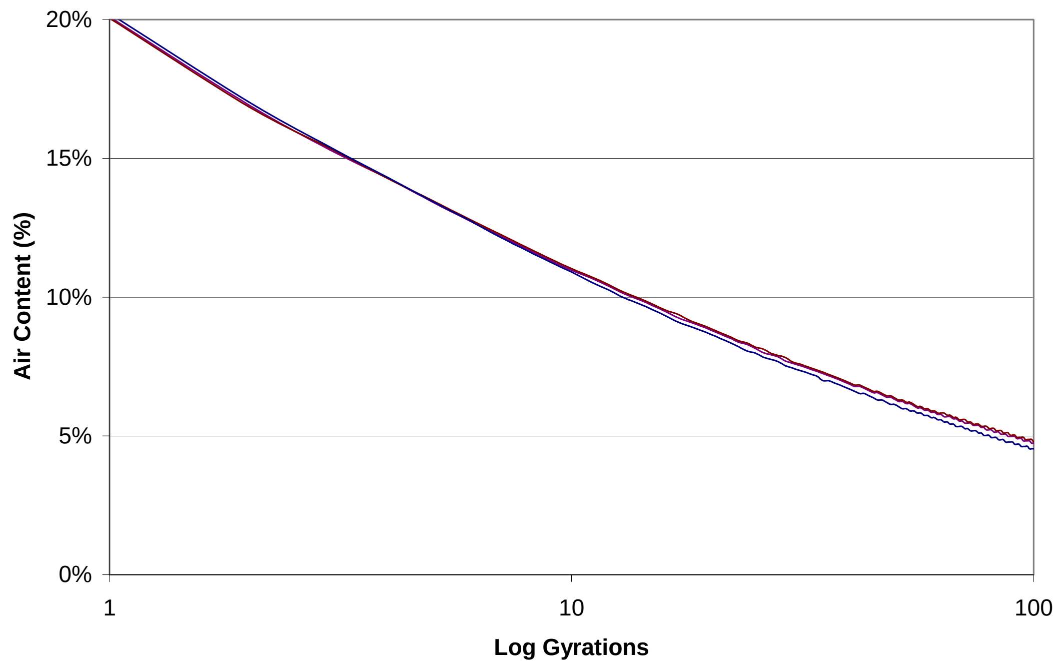


Figure B-33. Gyratory Compaction Curve for 1/2-Inch Fine Mix Granite, PG 76-22 Binder

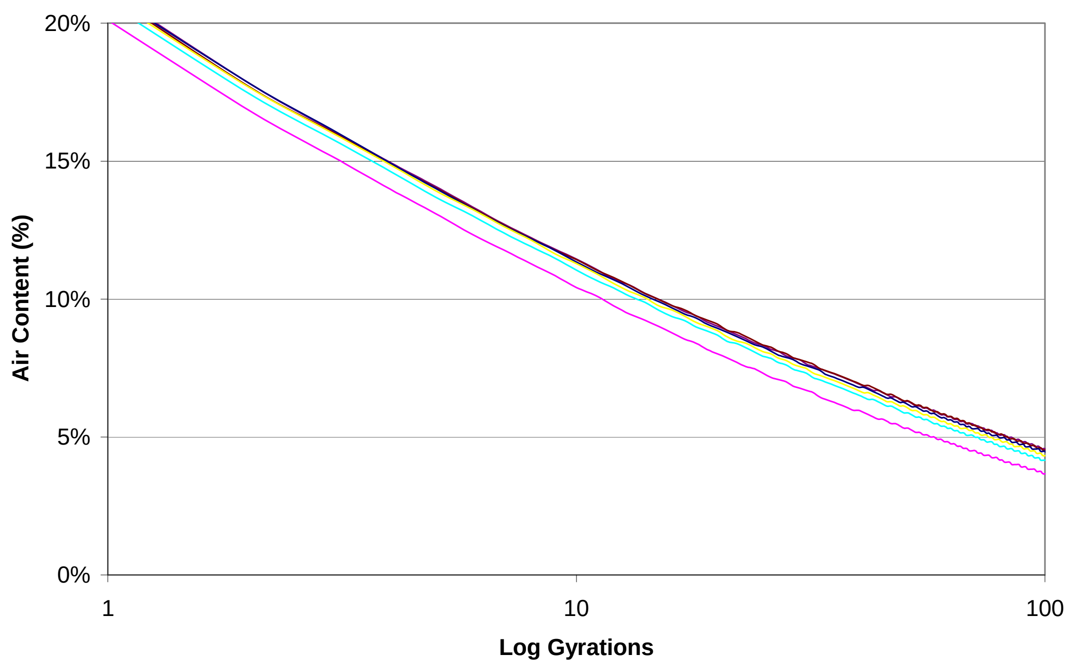


Figure B-34. Gyratory Compaction Curve for 1/2-Inch Coarse Mix Granite, PG 76-22 Binder

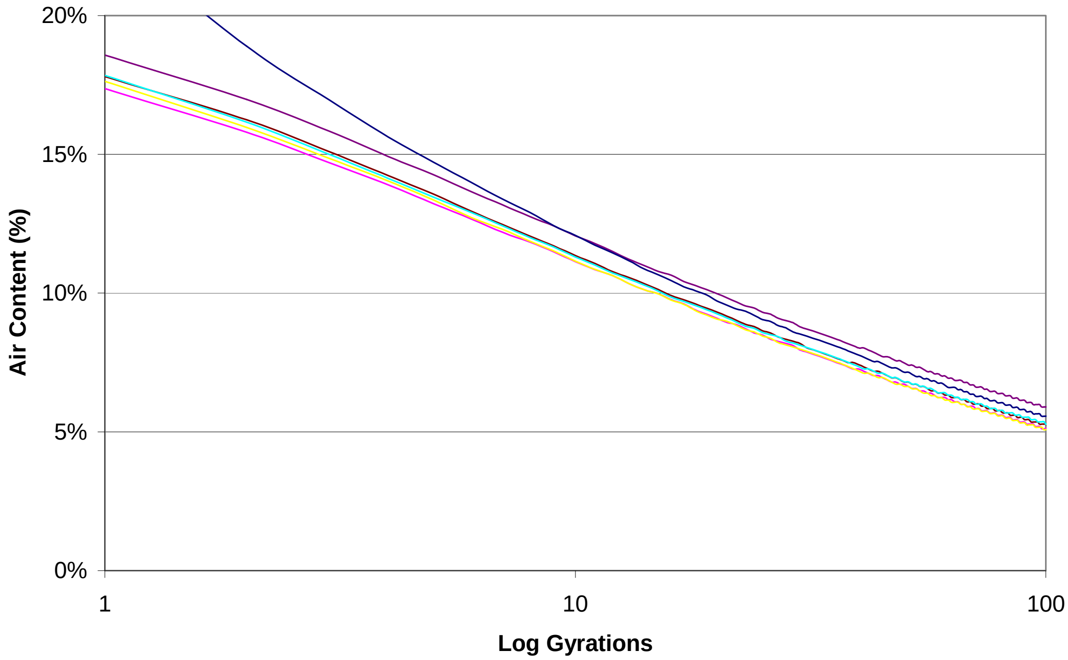


Figure B-35. Gyratory Compaction Curve for 3/4-Inch Fine Mix Granite, PG 76-22 Binder

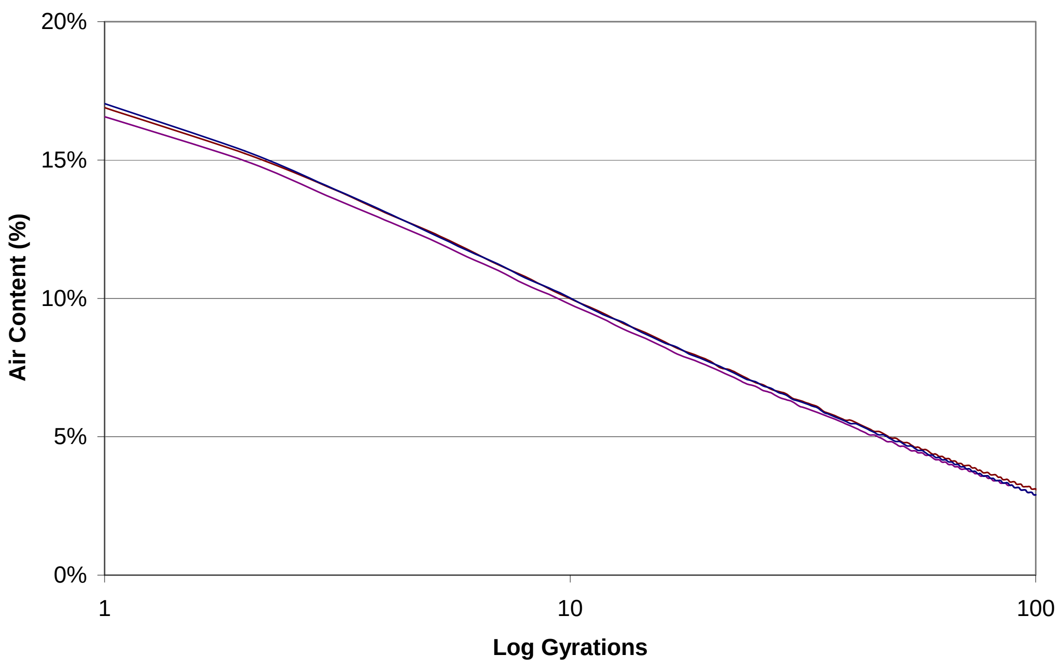


Figure B-36. Gyratory Compaction Curve for 3/4-Inch Coarse Mix Granite, PG 76-22 Binder

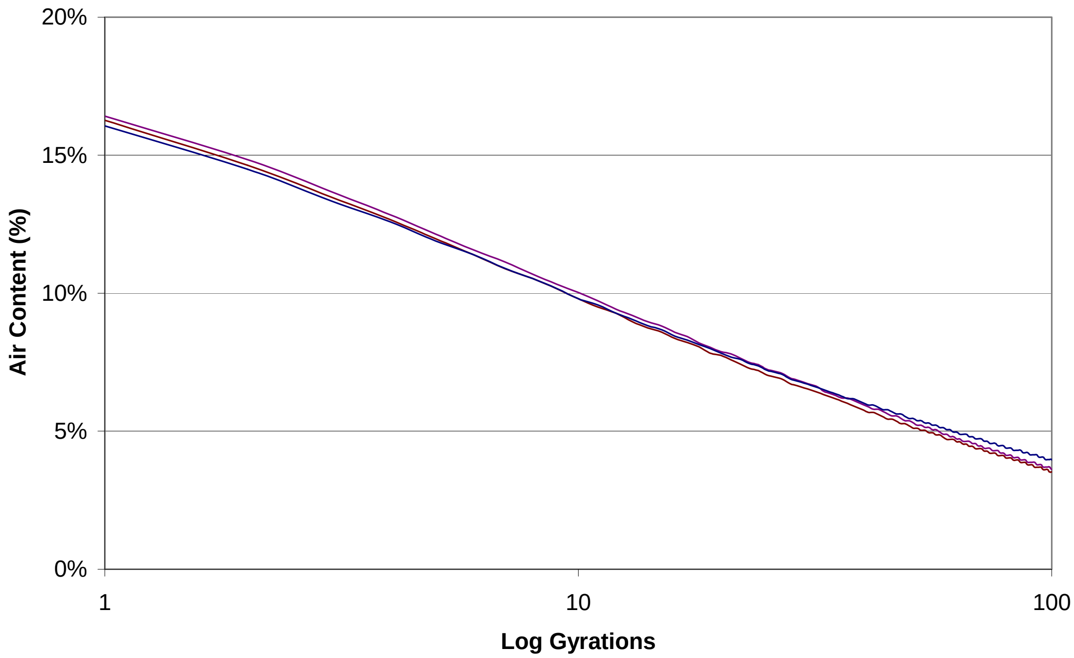


Figure B-37. Gyratory Compaction Curve for 1-Inch Fine Mix Granite, PG 76-22 Binder

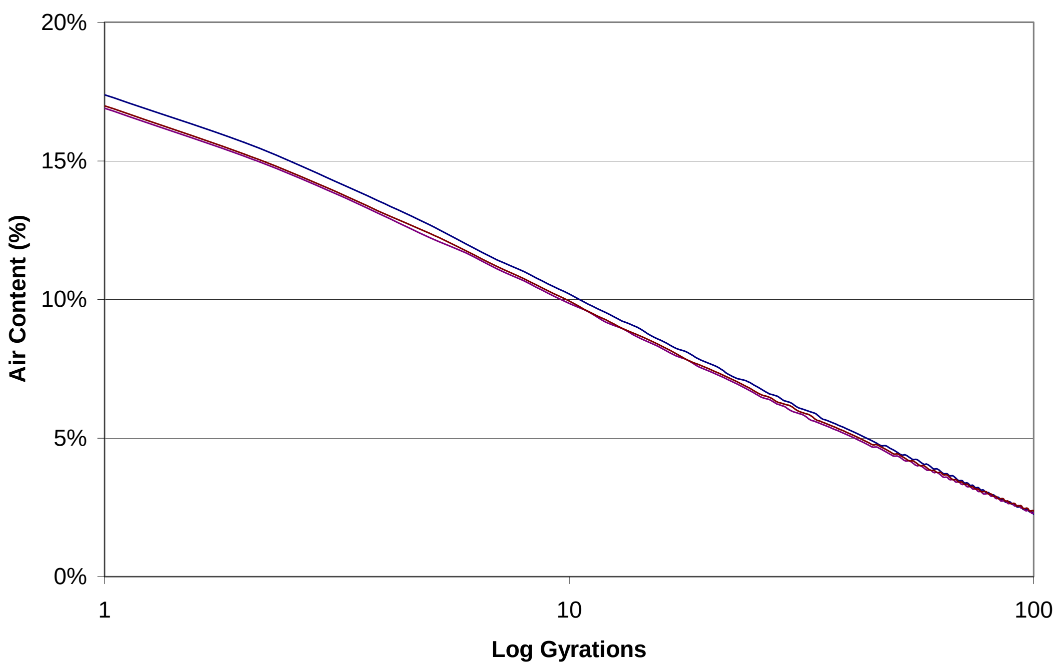


Figure B-38. Gyratory Compaction Curve for 1-Inch Fine Mix Granite, PG 76-22 Binder

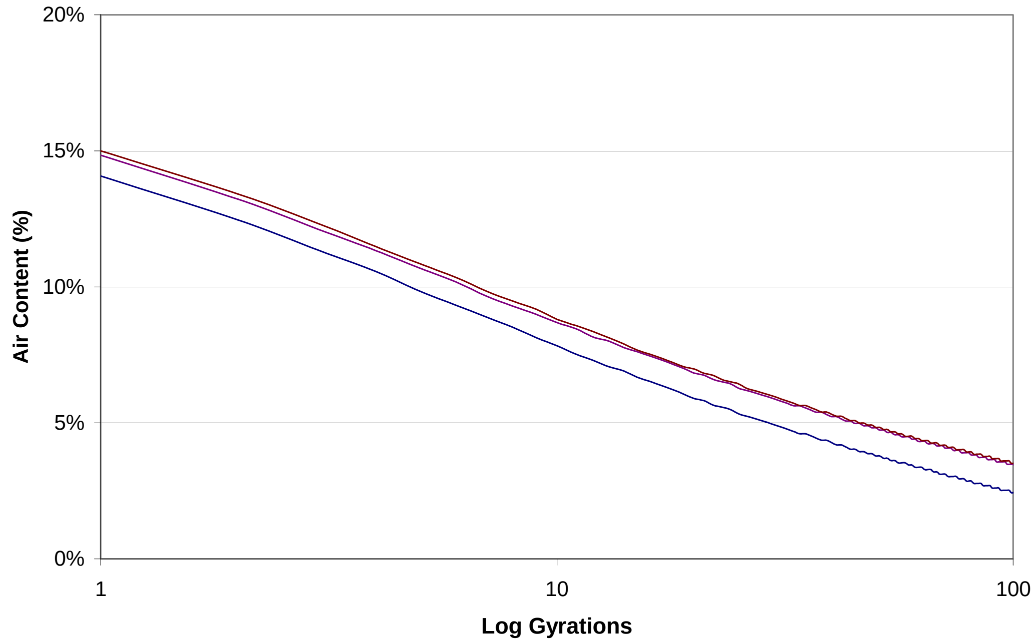


Figure B-39. Gyratory Compaction Curve for 1/2-Inch Fine Mix Granite With Mortar Sand, PG 76-22 Binder

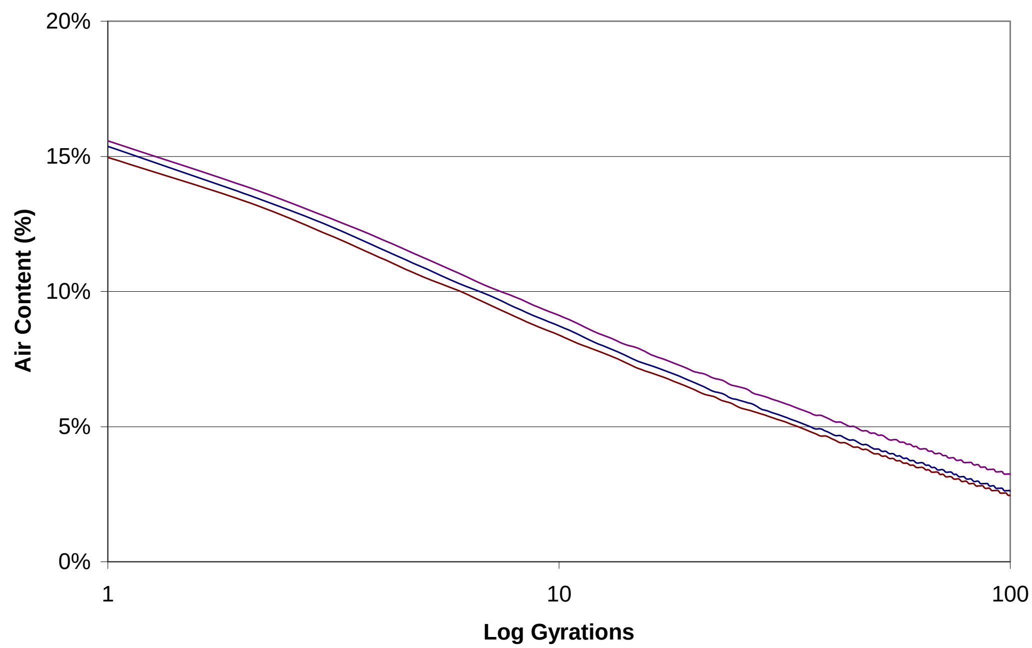


Figure B-40. Gyratory Compaction Curve for 1/2-Inch Coarse Mix Granite With Mortar Sand, PG 76-22 Binder

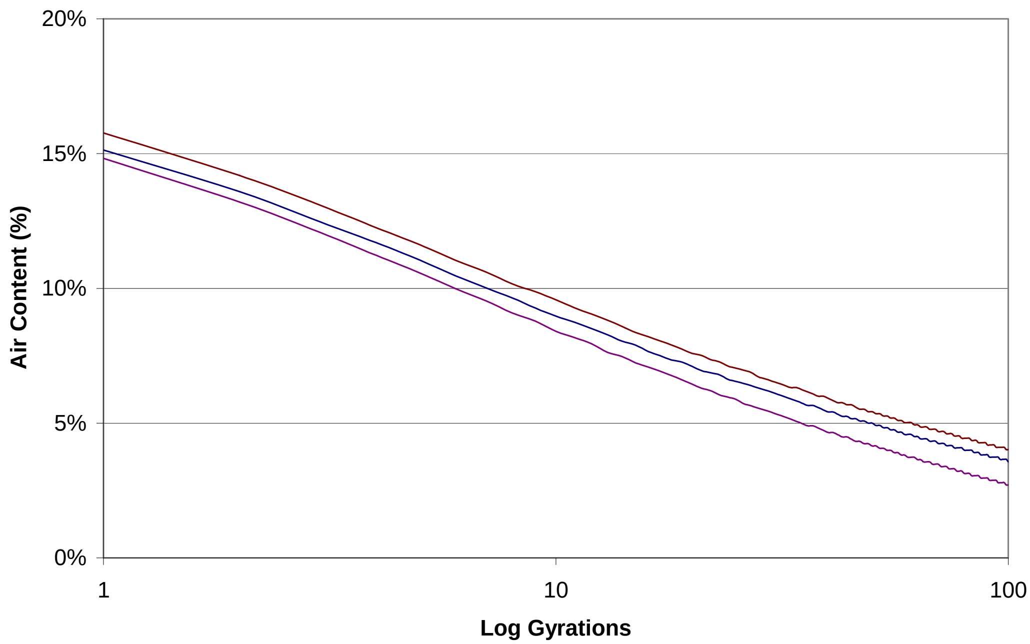


Figure B-41. Gyratory Compaction Curve for 3/4-Inch Fine Mix Granite With Mortar Sand, PG 76-22 Binder

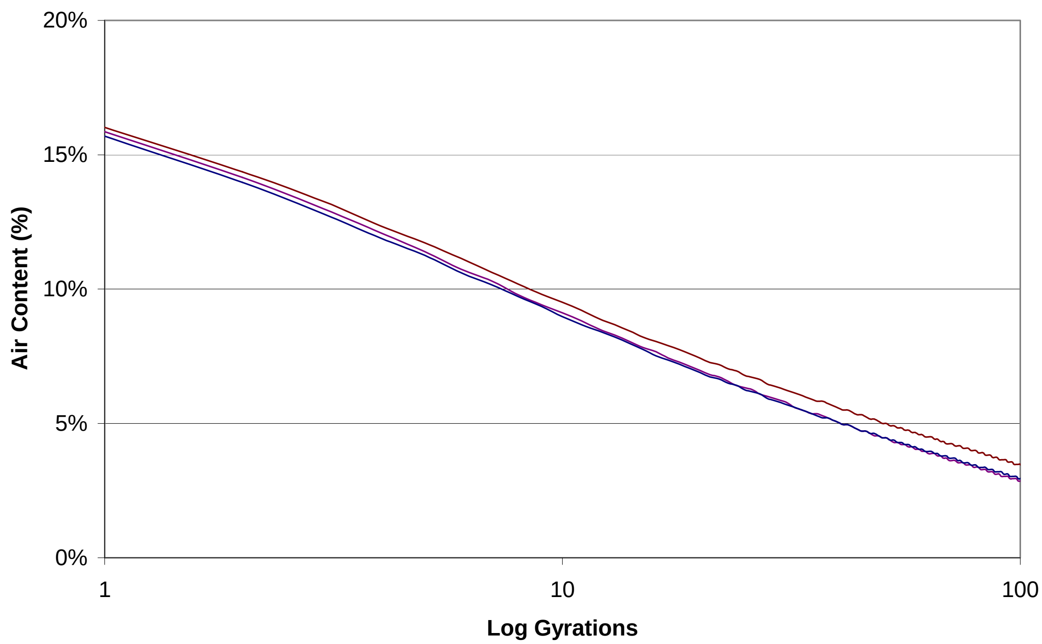


Figure B-42. Gyratory Compaction Curve for 3/4-Inch Coarse Mix Granite With Mortar Sand, PG 76-22 Binder

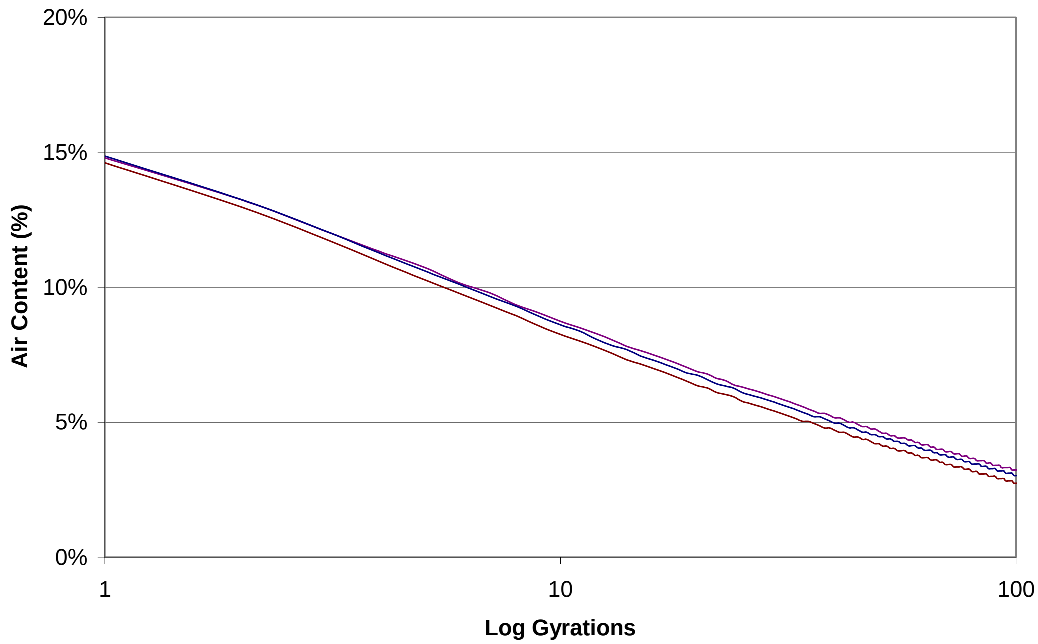


Figure B-43. Gyratory Compaction Curve for 1-Inch Fine Mix Granite With Mortar Sand, PG 76-22 Binder

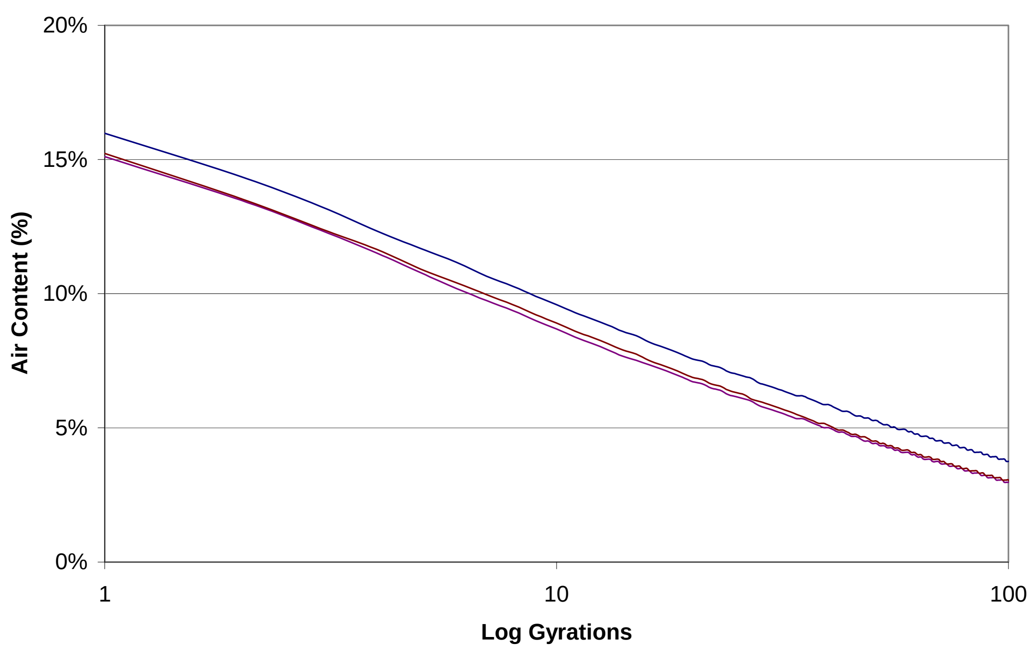


Figure B-44. Gyratory Compaction Curve for 1-Inch Coarse Mix Granite With Mortar Sand, PG 76-22 Binder

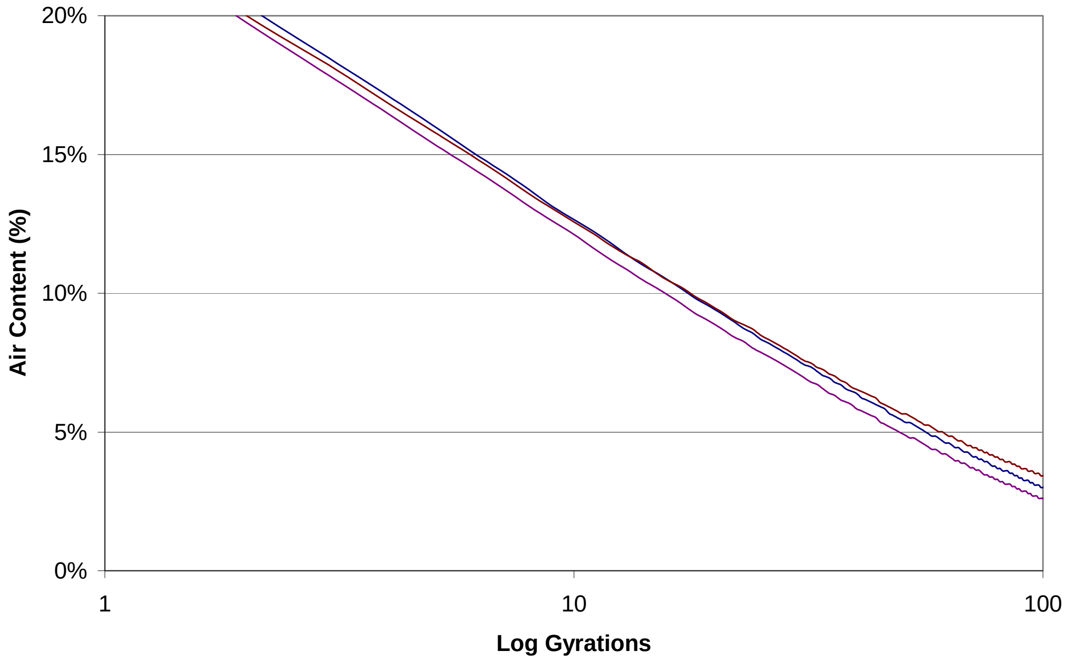


Figure B-45. Gyratory Compaction Curve for 1/2-Inch Fine Mix Limestone, PG 76-22 Binder

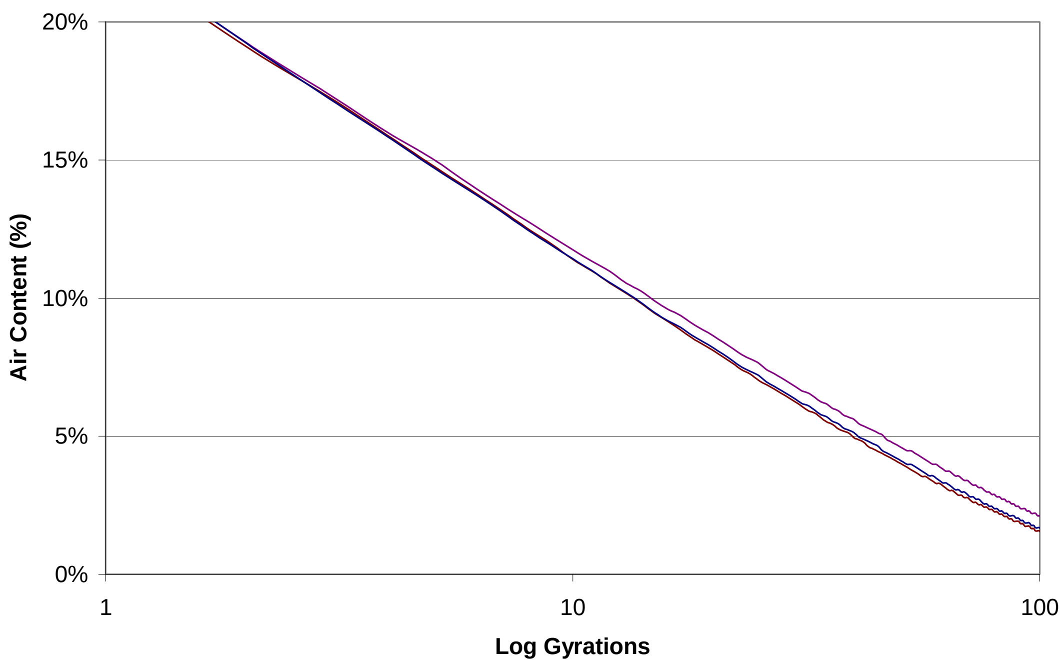


Figure B-46. Gyratory Compaction Curve for 1/2-Inch Coarse Mix Limestone, PG 76-22 Binder

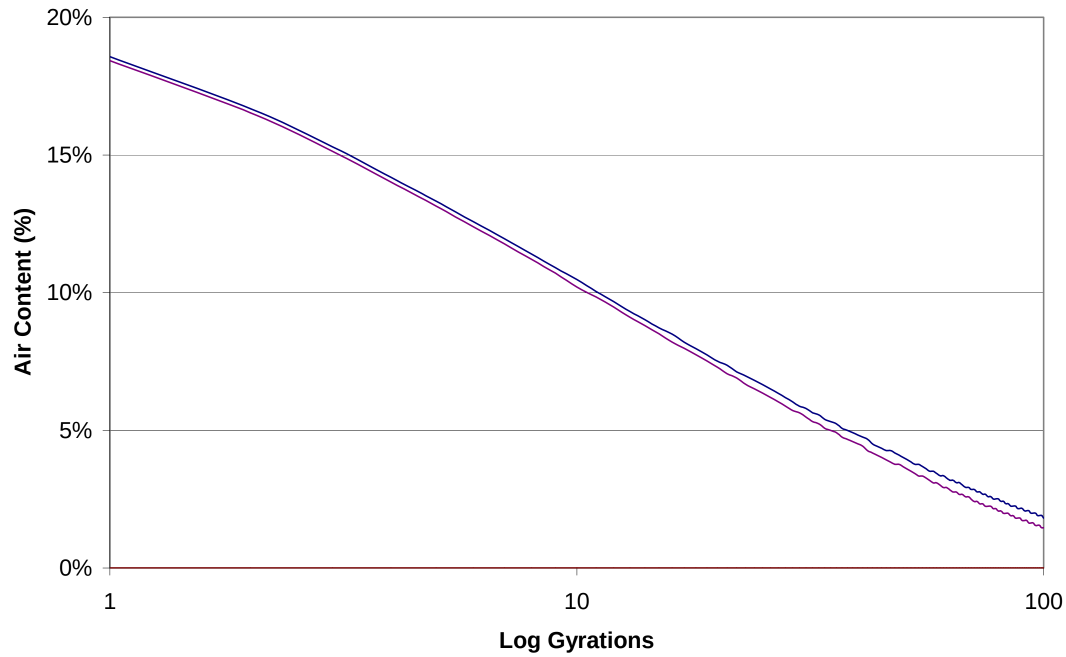


Figure B-47. Gyratory Compaction Curve for 3/4-Inch Fine Mix Limestone, PG 76-22 Binder

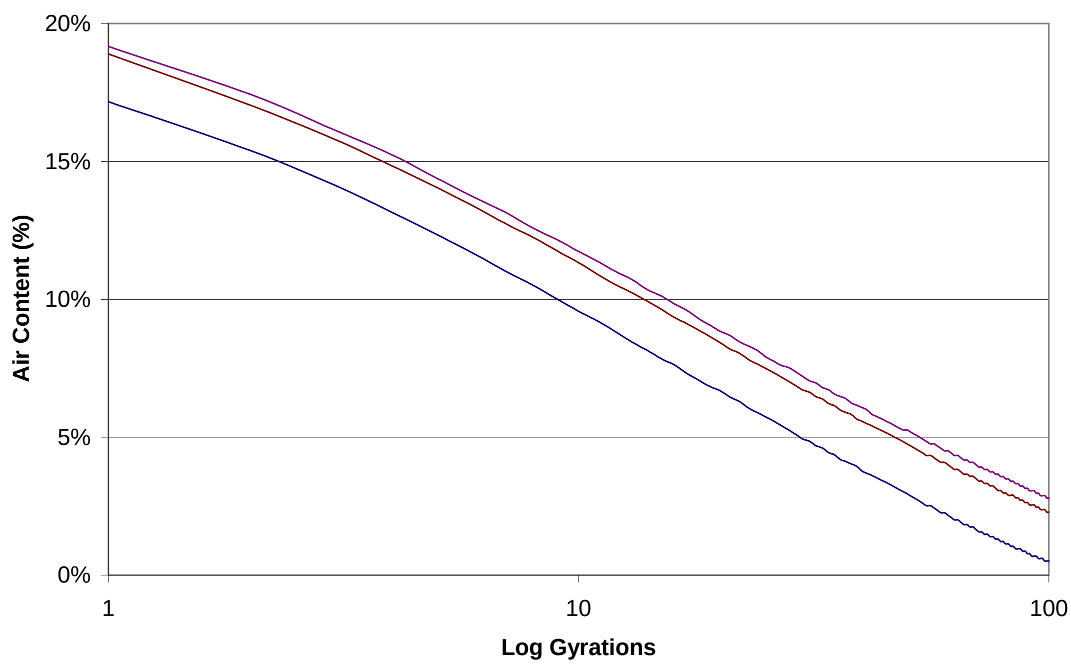


Figure B-48. Gyratory Compaction Curve for 3/4-Inch Coarse Mix Limestone, PG 76-22 Binder

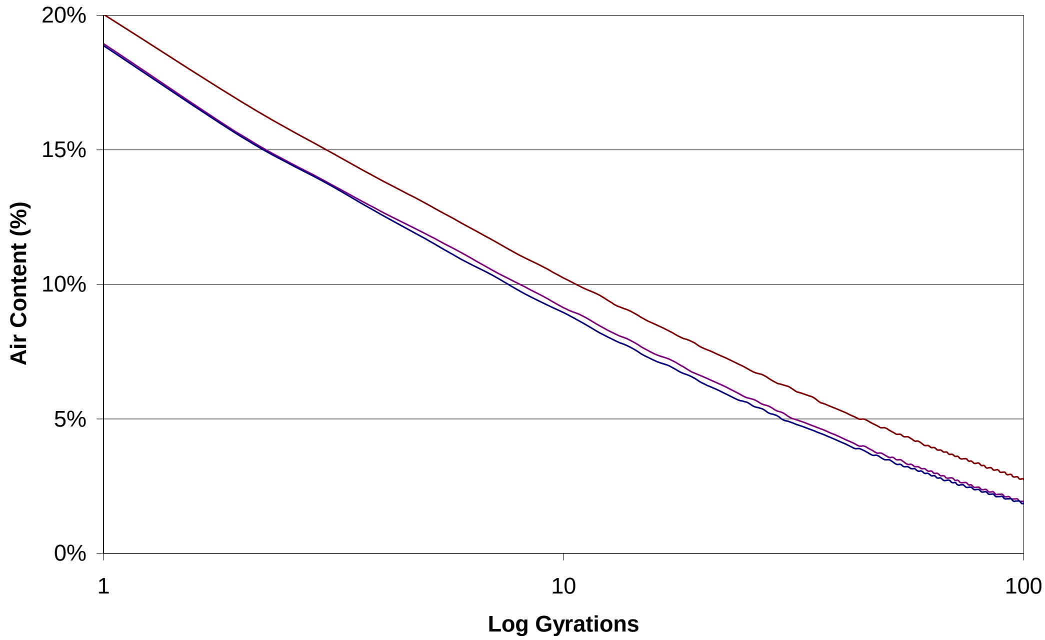


Figure B-49. Gyratory Compaction Curve for 1/2-Inch Fine Mix Limestone With Mortar Sand, PG 76-22 Binder

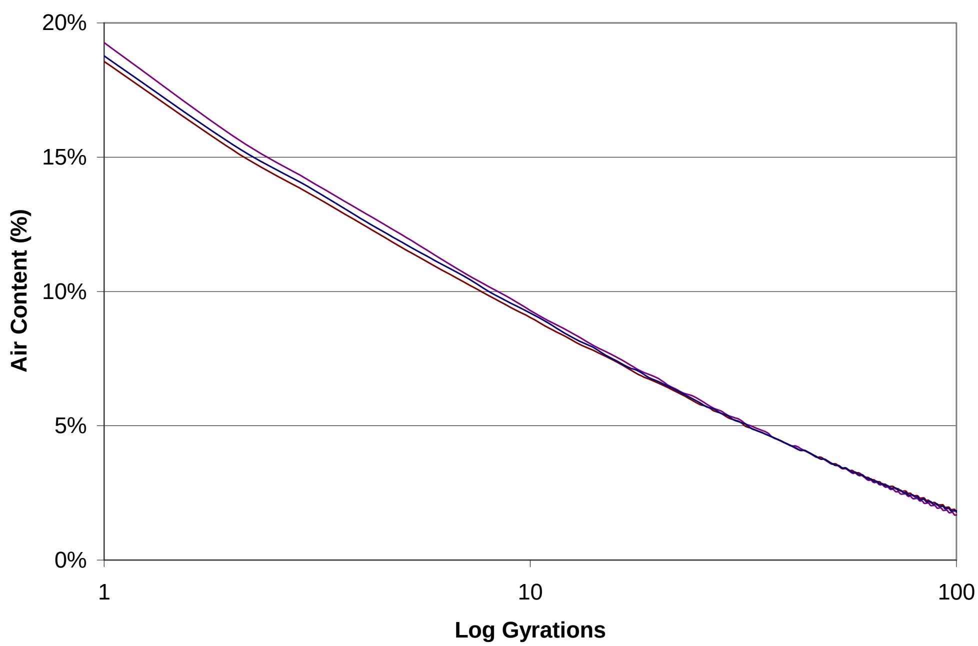


Figure B-50. Gyratory Compaction Curve for 1/2-Inch Coarse Mix Limestone With Mortar Sand, PG 76-22 Binder

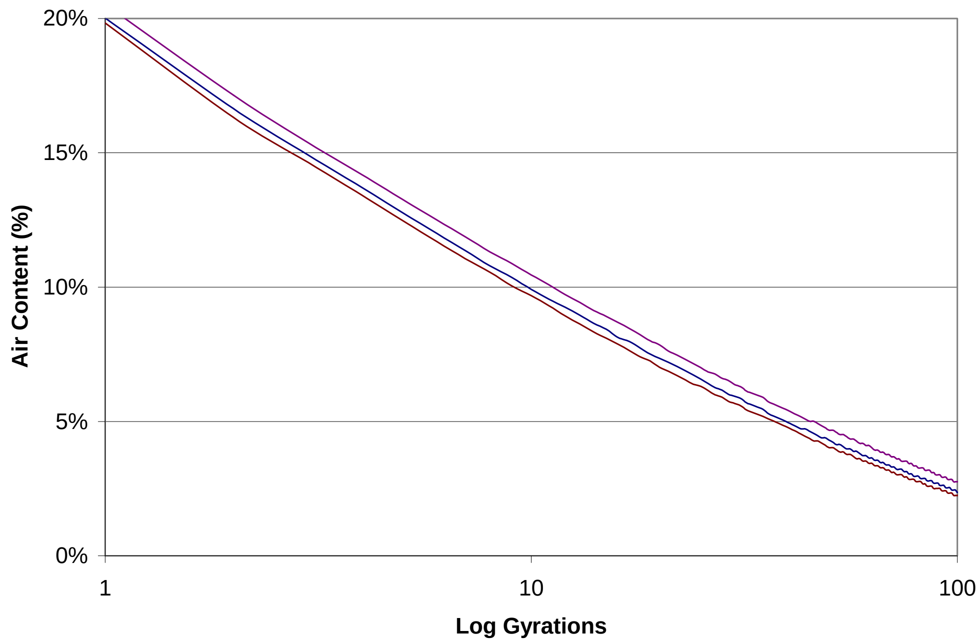


Figure B-51. Gyratory Compaction Curve for 3/4-Inch Fine Mix Limestone With Mortar Sand, PG 76-22 Binder

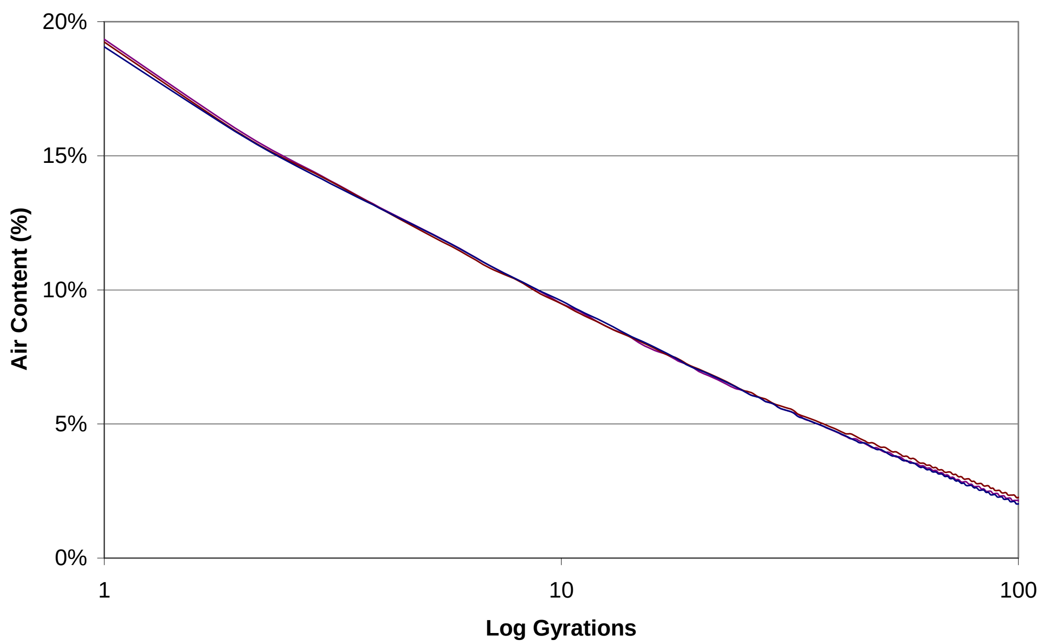


Figure B-52. Gyratory Compaction Curve for 3/4-Inch Coarse Mix Limestone With Mortar Sand, PG 76-22 Binder