Evaluation of SUPERPAVE Gyratory Compactor in the Field Management of Asphalt Mixes: Four Simulation Studies

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The SHRP-SUPERPAVE Design System utilizes the SUPERPAVE Gyratory Compactor (SGC) for asphalt-mixture specimen compaction. As part of the Demonstration Project Program, the Federal Highway Administration Office of Technology Applications (FHWA–OTA) has incorporated the SGC into FHWA–OTA mobile asphalt laboratories. Simulation studies are conducted for states to demonstrate aspects of the SUPERPAVE Design System, along with the application of certain innovative concepts in field management of asphalt mixes. The use of the SGC for field management is investigated. Four production mixes are evaluated. Based on production results, tolerance limits are established for SGC acceptance parameters. FHWA–OTA-recommended SGC volumetric acceptance parameters are asphalt binder content, voids in total mix, and voids in mineral aggregate. During the studies, companion samples were taken using the standard Marshall compactor. Results indicate that the Marshall compactor cannot be used as a surrogate for the SGC. The two compaction methods do not produce equivalent specimens.

DEMONSTRATION PROJECT BACKGROUND

Each year, millions of tons of asphalt mix are produced and placed on U.S. highways. Some of these asphalt mixes, which meet the respective state highway agencies' design requirements, are displaying premature pavement distress in the form of stripping, bleeding, rutting, cracking, and raveling. These distresses lead to a poor ride, skid problems, an increased cost for maintenance, and an accelerated need for rehabilitation. To address these problem mixes, engineers and contractors are placing additional emphasis on improved field management of asphalt mixes.

To ensure that asphalt mixes will perform as required, various quality control systems are used. Historically, monitoring of asphalt and aggregate proportions has been used to measure and control the quality of a mix. However, mixes produced with the required asphalt binder content and aggregate gradation have not always performed as intended. A change in the fundamental composition of mixes occurs from design to construction. This is because the design mixing bowl cannot duplicate what happens in the contractor's plant. Incorporating volumetric mix design properties into field quality control and quality assurance systems can help identify mix-related problems before thousands of tons of material are placed on the roadway. These properties include voids in total mix (VTM or V_a) and voids in mineral aggregate (VMA). When these properties are determined and monitored in the field, on plant-produced mix, engineers have the information necessary to identify problems and make effective changes to the mix.

To demonstrate the concept of volumetric properties in field quality management of asphalt mixes, FHWA–OTA developed Demonstration Project No. 90 (DP 90), *"SUPERPAVE Asphalt Mix Design and Field Management."* The project centers on two fully equipped mobile asphalt laboratories. For a simulation study, one of the laboratories is brought onto an active paving project site of a requesting state highway agency. Once set up, the laboratory personnel demonstrate aspects of the SUPERPAVE Design System, along with the application of certain innovative concepts in field management of asphalt mixes.

The Strategic Highway Research Program developed the SGC based on technical, operational, and financial factors (1–6). It is not the intent of this report to judge or justify the use of the SGC in the SUPERPAVE Design System.

INTRODUCTION

Four active paving projects are used to evaluate the use of the SGC in the field management process. On these projects, the mix was sampled directly from the haul vehicles, brought back into the FHWA–OTA mobile laboratory, and compacted in a prototype SGC. Companion samples were also compacted using a standard Marshall compactor. A statistical quality level analysis of SGC and standard Marshall results is performed based on the field management system developed by FHWA–OTA demonstration projects (*7*). Additionally, an analysis is conducted comparing the volumetric properties of the SGC specimens to those of the Marshall specimens.

FIELD MANAGEMENT OF ASPHALT MIXES

Production Mix Verification of Design Volumetric Properties and Quality Control

Principles

Generally, state highway agencies establish or approve a job mix formula (JMF) based on gradation bands and volumetric criteria. The JMF includes single-point gradation and asphalt binder content

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target values that, if adhered to, *should* produce a mix with certain desirable volumetric properties. This process is completed before construction. Many times the JMF is based on preliminary stockpile samples mixed with nonproject asphalt binder in a laboratory mixing bowl.

Mix verification consists of validating the JMF and design properties on the first full day of production. Mix verification is performed using the actual plant facilities and the actual project materials. Mix verification includes

1. Prepaving meeting between organizations,
2. Review of contract specifications,
3. Review of source approval documents,
4. Inspection of contractor's plant and paving equipment,
5. Inspection of coarse and fine aggregate feeds and dust control techniques,
6. Inspection of all testing equipment, and
7. Testing and analysis of mix produced at the plant facility.

The testing performed under mix verification can be separated into two areas: process control and quality control. Process control verifies the consistency of the mix proportions: aggregate gradation and asphalt binder content. Quality control verifies the volumetric properties of the production mix. The mix verification process is best illustrated by a decision tree (Figure 1).

Statistics

The Mix Verification Decision Tree is governed by statistical analysis of production test results. Quality level analysis (QLA) is performed on control acceptance parameters to determine if a sample passes or fails. QLA is a process based on the noncentral *t*-analysis for small samples to determine the percentage of production within tolerance limits (*8*). The keys to an effective system based on this process are the selection of pertinent acceptance parameters and the determination of their associated tolerance limits. Arbitrary limits set too restrictively will potentially fail quality production. Limits that are not restrictive enough will potentially pass poor production.

Limits must be established based on actual production data. Under Demonstration Project No. 74, *"Field Management of Asphalt Mixes,"* FHWA–OTA has established tolerance limits for JMF gradation and Marshall volumetric properties (*7*). FHWA–OTA limits are based on production data from more than 40 simulation studies conducted in over 35 different states across the United States. Individual states must establish their own limits based on local production to account for regional differences.

QLA limits are set based on the average standard deviation (Ave. σ) of the production. Typically, two standard deviations ($2 \times$ Ave. σ) define the plus/minus range of the upper and lower specification limits. For example, the average standard deviation for production asphalt binder content is 0.2 percent. Two standard deviations define a plus/minus range of ± 0.4 percent. If a project target asphalt binder content is 5.0 percent, the upper and lower specification limits would be 5.4 percent and 4.6 percent, respectively. QLA for this project would be determined based on the percentage of production within these limits (*7*). (See Table 1.)

Quality levels (QL) are determined for each individual parameter based on the percentage within the tolerance limits of the original JMF. The gradation QL is equal to the lowest individual sieve QL. The volumetric QL is equal to the lowest individual volumet-

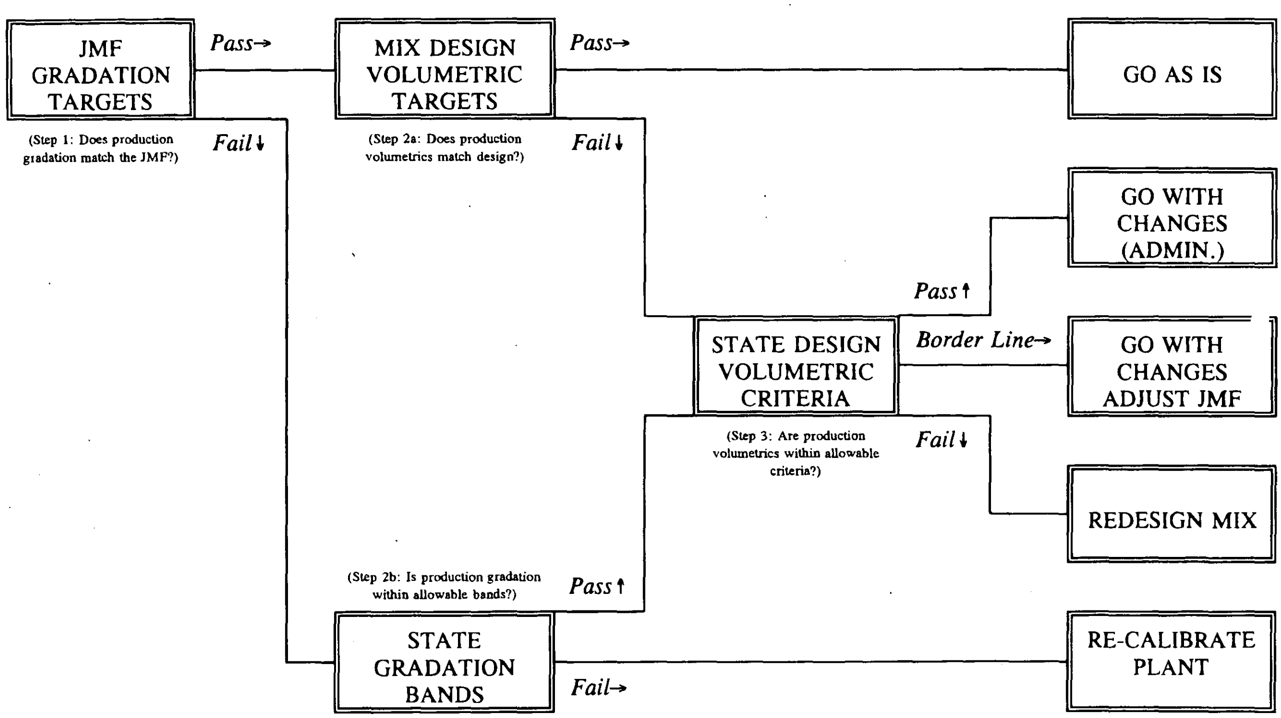

FIGURE 1 Mix verification—decision tree.

TABLE 1 FHWA–OTA Tolerance Limits

JMF GRADATION	
Acceptance Parameter	Tolerance Limits from JMF Targets
50.0 mm to 2.36 mm	± 6 %
1.18 mm, 0.60 mm	± 4 %
0.30 mm, 0.15 mm	± 3 %
0.075 mm	± 2 %
MARSHALL VOLUMETRICS	
Asphalt Binder Content	± 0.4 %
Voids in Total Mix (V_a)	± 1.5 %
Voids in Mineral Aggregate (VMA)	± 1.5 %
Marshall Flow (1/100")	± 1.8 (1/100")
Marshall Stability	minimum required

ric QL. FHWA–OTA recommends a minimum QL of 85 percent for production to be acceptable (i.e., *pass*).

SGC for Field Management of Asphalt Mixes

The use of the SGC for field management requires the selection of acceptance parameters and the determination of their associated tolerance limits. During the compaction process in the SGC, specimen height is monitored and recorded. Specimen height data, along with the extruded specimen bulk specific gravity (G_{mb}) and mixture maximum specific gravity (G_{mm}, *Rice*), are used to calculate the percentage of maximum specific gravity (percentage of G_{mm}) during the compaction process. In the SUPERPAVE system, mixture design criteria have been established for three points during the compaction process: initial (N_i), design (N_d), and maximum (N_m) number of gyrations (*1,2*).

In addition to criteria for the percentage of G_{mm}, SUPERPAVE establishes volumetric criteria for voids in mineral aggregate, voids filled with asphalt (VFA), and the fines-to-effective-asphalt (F/A) ratio based on estimated, design traffic level and the location in the pavement cross section. The number of gyrations used for compaction is defined as a function of the average-design, high air temperature at the paving location and the estimated traffic level.

The JMF gradation acceptance parameters are independent of specimen compaction method and therefore do not change. The SUPERPAVE volumetric acceptance parameters recommended by FHWA–OTA are asphalt binder cement (AC) content, voids in total mix at N_d, and voids in mineral aggregate at N_d. The additional volumetric parameters controlled during the SUPERPAVE design process are monitored during production but are not used for quality control. These parameters include voids filled with asphalt, fines to effective asphalt ratio, and the percentage of maximum specific gravity at initial and maximum number of gyrations.

VFA is addressed during production by controlling both V_a and VMA. F/A is addressed during production by controlling both AC content and the percentage passing the 75 μm sieve. The compactability of specimens (percentage of G_{mm} at N_i and N_m) is monitored and, in the future, may be incorporated into the acceptance parameters.

It should be noted that neither Marshall stability and flow nor Hveem stability were determined for the gyratory specimens. Under the SUPERPAVE Design System, stability/strength of a mixture is assessed by the gyratory compaction curves. The use of strength parameters has been replaced in this new system with mix compactability.

FOUR SIMULATION STUDIES

Production Facility

The simulation studies were conducted at four separate plants located in different regions of the United States. All simulations are referenced by study number, actual states and locations remain anonymous. Table 2 lists the plant type and dust collection system used in each simulation study.

Job Mix Formula

The JMF and average production gradation for the four simulation studies were plotted using the SUPERPAVE standard definition for the .45 Power Chart (*1,2,9*). During production, additional sieves were utilized to provide the state with comparison data for its typical sieve stack. These additional sieves are not highlighted on

TABLE 2 Plant Type and Dust Collection System per Study

Study Number	Plant Type	Dust Collection System
# 539	Drum	Wet Scrubber
# 540	Drum	Baghouse
# 641	Drum	Baghouse
# 9409	Drum	Wet Scrubber

the charts, but are reflected in the gradation curves (Figures 2, 3, 4, and 5).

MIXTURE DESIGN METHOD AND COMPACTIVE EFFORT

The original JMFs for the four mixes were based on different design procedures. Table 3 summarizes the different methods used.

PRODUCTION SGC RESULTS

The data indicate that production tolerances for the three control parameters should be ±0.4 percent for asphalt binder content, ±1.1 percent for voids in total mix, and ±0.9 percent for voids in mineral aggregate (Table 4). The tolerances for these studies reflect typical production variability. Based on the asphalt binder content variability, the plants used to produce these mixes exhibit similar variability with those plants used to establish the Marshall tolerances.

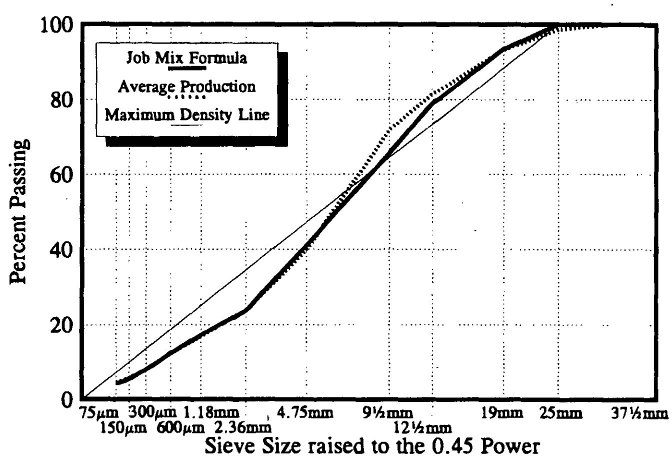

FIGURE 2 Project no. 539 JMF .45 power chart.

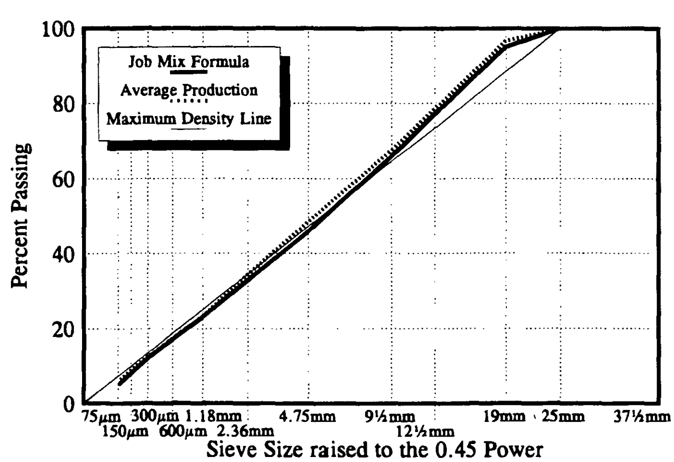

FIGURE 3 Project no. 540 JMF .45 power chart.

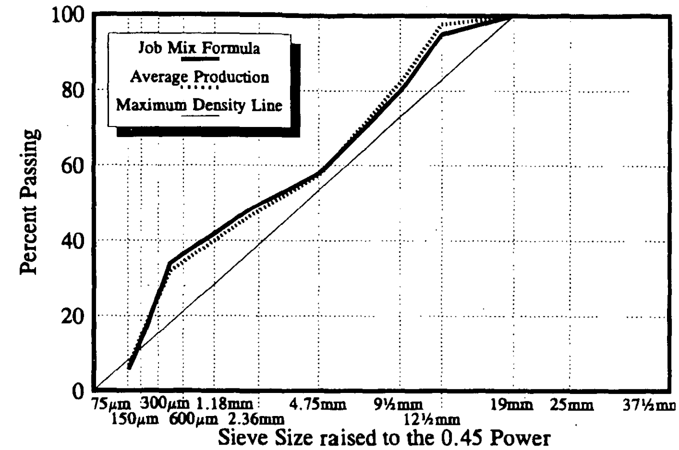

FIGURE 4 Project no. 641 JMF .45 power chart.

The SGC production tolerances determined for V_a and VMA are both lower than the tolerances established for Marshall V_a and VMA (±1.5 percent and ±1.5 percent). This is attributed to the higher compactive effort provided by the SGC at the design number of gyrations. The SGC specimen voids in total mix and voids in mineral aggregate are consistently lower than those specimens compacted using the Marshall compactor for all four studies (Table 5). On average, gyratory specimens have 1.7 percent lower V_a and 1.6 percent lower VMA. It is intuitive that specimens compacted to a lower void level will have less variability and therefore lower production standard deviations.

Under the SUPERPAVE Design System, mixtures are designed to have 4.0 percent voids at the design number of gyrations. Because three of the four mixes studied compacted below 4.0 percent voids at N_d, it is reasonable to assume mixes designed and produced to satisfy the SUPERPAVE criteria will have slightly higher production variability. Therefore, the above tolerance may be too restrictive and should be increased.

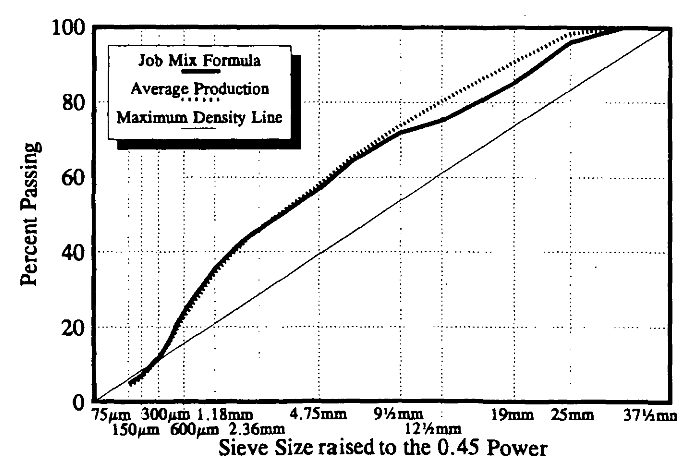

FIGURE 5 Project no. 9409 JMF .45 power chart.

TABLE 3 Summary of Design and Companion Compaction Methods

Study Number	Design Method	Compaction Effort	Companion Compactor	Compaction Effort
# 539	SUPERPAVE Level 1	SGC 150x115mm N_d=100 N_m=158	6" Standard Marshall	112 blows/side
# 540	6" S. Marshall	112 blows/side	SGC	N_d=100 N_m=158
# 641	4" S. Marshall	50 blows/side	SGC	N_d=126 N_m=204
# 9409	4" S. Marshall	75 blows/side	SGC	N_d=113 N_m=181

TABLE 4 Summary of Production Standard Deviations (σ)

Volumetric Parameters	Project Number				Pooled Standard Deviation σ	
	# 539	# 540	# 641	# 9409	σ_{pooled}	2 x σ_{pooled}
AC	0.16	0.23	0.21	0.16	0.189	0.38
V_a @ N_d	0.49	0.53	0.58	0.54	0.542	1.08
VMA @ N_d	0.23	0.48	0.44	0.43	0.423	0.85
n	8	12	14	23		

$$\text{Pooled Standard Deviation}, \sigma_{pooled} = \sqrt{\frac{\Sigma(\sigma^2(n-1))}{\Sigma(n)-N}}$$

Where:
n - number of samples per project
N - number of projects

TABLE 5 Summary of Production Average Volumetrics

Volumetric Property	Project Number				Average Difference
	# 539	# 540	# 541	# 9409	
V_a:					
Marshall	5.2 %	4.8 %	5.3 %	5.5 %	
Gyratory	3.5 %	3.0 %	2.6 %	4.8 %	
Difference	1.7 %	1.8 %	2.7 %	0.7 %	1.7 %
VMA:					
Marshall	17.5 %	15.3 %	12.9 %	15.2 %	
Gyratory	16.0 %	13.7 %	10.4 %	14.6 %	
Difference	1.5 %	1.6 %	2.5 %	0.6 %	1.6 %

TABLE 6 SGC Tolerance Limits

Acceptance Parameter	Tolerance Limits from JMF Targets
Asphalt Binder Cement	± 0.4 %
Voids in Total Mix (V_a) @ N_d	± 1.2 %
Voids in Mineral Aggregate (VMA) @ N_d	± 1.0 %

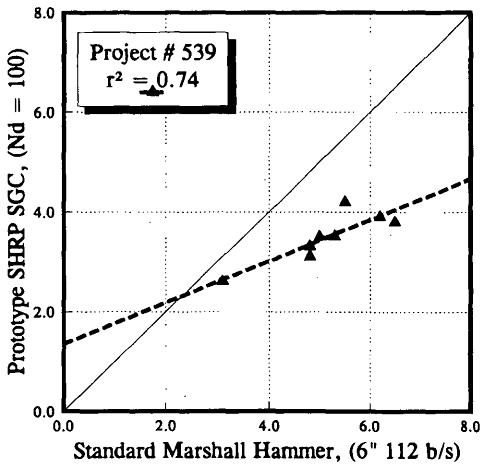

FIGURE 6 Project no. 539—voids in total mix, SGC versus Marshall compactor.

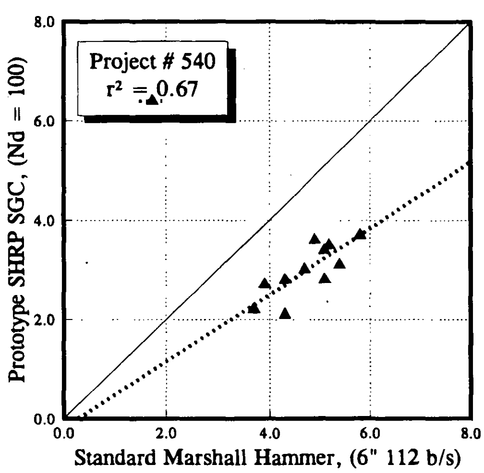

FIGURE 7 Project no. 540—voids in total mix, SGC versus Marshall compactor.

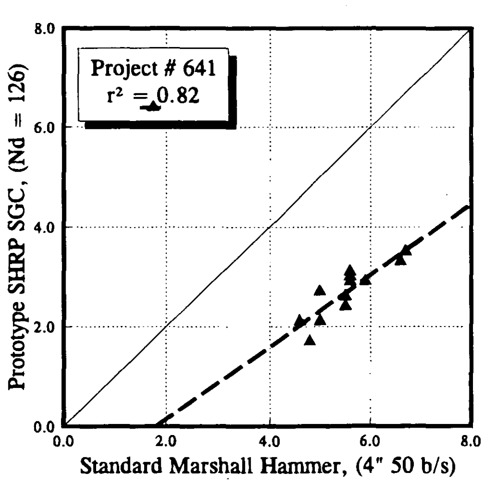

FIGURE 8 Project no. 641—voids in total mix, SGC versus Marshall compactor.

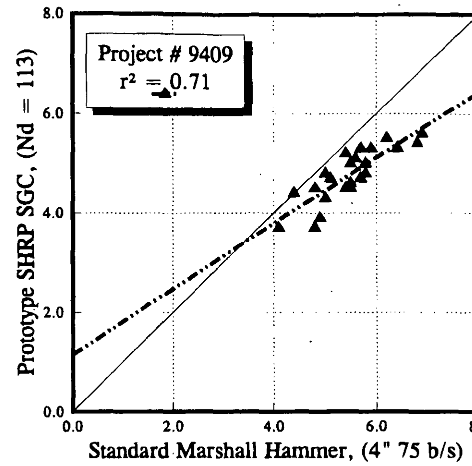

FIGURE 9 Project no. 9409—voids in total mix, SGC versus Marshall compactor.

SURROGATE COMPACTION COMPARISON: SGC VERSUS MARSHALL

Currently, the SGC costs approximately seven times the cost of a standard automatic Marshall compactor. Additionally, only a few SGCs are available for design and field quality control. A "practical" solution for field quality control of mixes designed under the SUPERPAVE Design System is to use the Marshall compactor. However, the data collected during these four simulation studies strongly indicate that there is no constant correlation between the SGC and the Marshall compactor. This is demonstrated graphically by comparing the voids in total mix between companion samples (Figures 6 through 9).

Plotting the voids generated by the SGC versus the voids generated by the Marshall compactor for each sample allows a regression to be developed. The lines plotted in the Figures 6 through 9 represent a best fit of the data. Comparing specimen voids in the SGC at N_d to the Marshall compactor, it is seen that on average the SGC provided a greater compactive effort. More importantly, it is

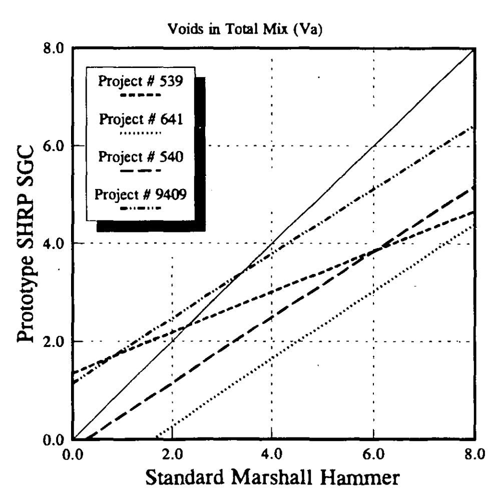

FIGURE 10 Volumetric comparison of compaction methods.

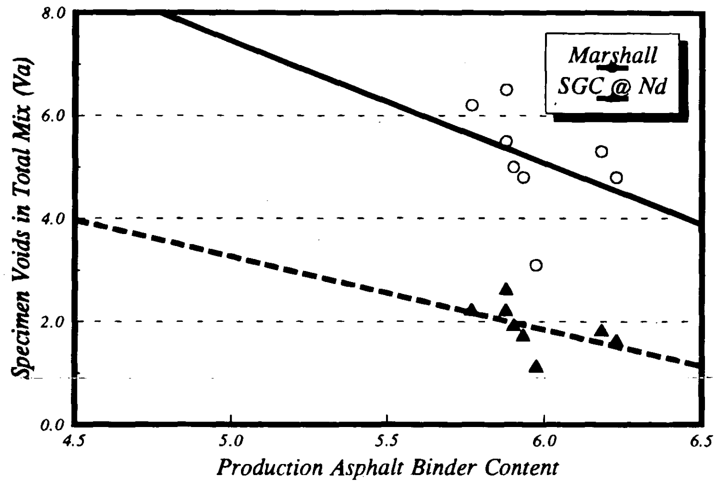

FIGURE 11 Project no. 539—voids in total mix versus production asphalt content.

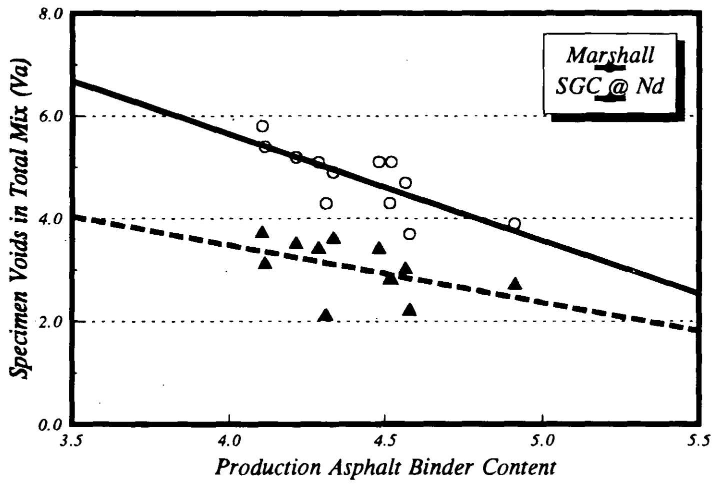

FIGURE 12 Project no. 540—voids in total mix versus production asphalt content.

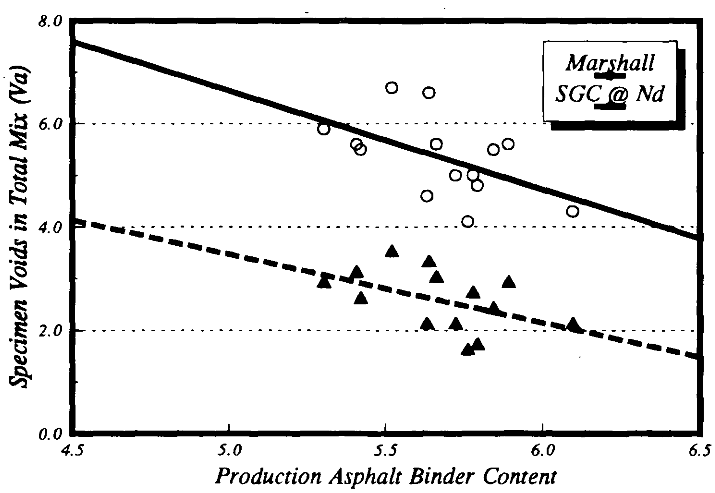

FIGURE 13 Project no. 641—voids in total mix versus production asphalt content.

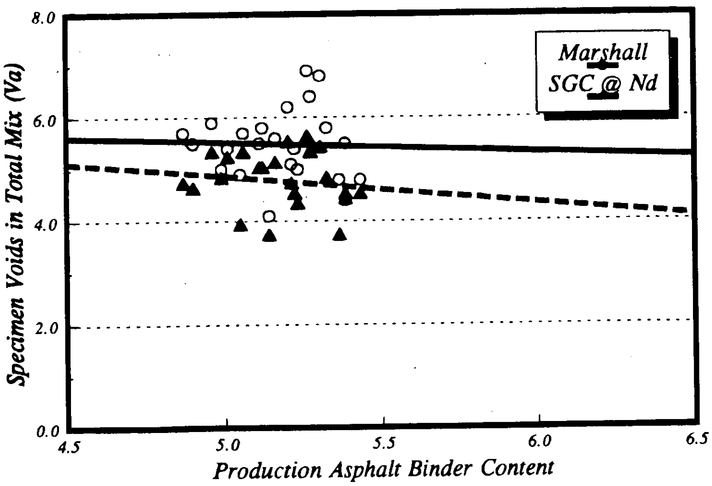

FIGURE 14 Project no. 9409—voids in total mix versus production asphalt content

seen that the difference in compactive effort is not constant among the four mixes studied (Figure 10). Each regression line has a different slope and a different intercept. Therefore, there is no fixed correction factor (fudge factor) that can be established that would allow an engineer to estimate gyratory volumetrics based on Marshall specimens.

Another way to view these data is to plot specimen voids versus asphalt binder content (Figures 11 through 14). The regressions developed from this comparison indicate that not only does the SGC provide a greater compactive effort, but, more importantly, SGC and Marshall specimen volumetrics react differently to changes in asphalt binder content. In study nos. 539 and 641 the relationship between SGC and Marshall voids is relatively parallel; in study no. 540, as asphalt binder content increases, SGC and Marshall voids converge; and in study no. 9409, as asphalt binder content increases, SGC and Marshall voids diverge. These differences in trends indicate that the SGC reacts differently to production variability than the Marshall compactor. Therefore it is impractical to make field adjustments to a SUPERPAVE-designed mix based on Marshall field data.

DISCUSSION AND CONCLUSIONS

The SGC provides an effective means for production mix verification of design volumetric properties and field quality control of asphalt mixes. The effectiveness of this new tool for field management is tied to the selection of pertinent acceptance parameters and the determination of their associated tolerance limits. FHWA–OTA-recommended SGC volumetric acceptance parameters and their associated tolerance limits are asphalt binder content (±0.4 percent), voids in total mix (±1.2 percent), and voids in mineral aggregate (±1.0 percent). These tolerance limits, which are based on the four simulation studies and FHWA–OTA demonstration project experience, will be refined as additional field data are gathered. Each state highway agency must determine appropriate tolerance limits based on local production to account for regional differences.

Using the Marshall compactor as a field surrogate for mixes designed under the SUPERPAVE Design System does not provide effective mix verification. It is evident from the simulation data that aggregate and asphalt compact differently in the Marshall compactor than in the SGC. Surrogate compactors should not be used in the field management of SUPERPAVE mixes.

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