

# Correlation of Selected Laboratory Compaction Methods with Field Compaction

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It is well established that method of compaction affects the physical properties of compacted asphalt concrete specimens. When evaluating asphalt concrete mixtures in the laboratory, it is desirable to fabricate compacted specimens that closely duplicate the properties of the actual road pavement. The goal was to determine which of four laboratory compaction methods (Exxon rolling wheel, Texas gyratory, rotating base Marshall hammer, and the Elf linear kneading compactor) most nearly simulate field compaction. Field cores were obtained from five different highway pavements. Laboratory specimens were fabricated using materials and mixture designs identical to those used in the pavement cores. Where achievable, they were expected to have the same air-voids range as the pavement cores. Various physical properties of pavement cores as well as the laboratory specimens were measured. The test results were compared and statistically analyzed to determine similarity. From the statistical analysis of the test data, the Texas gyratory compactor simulated pavement cores most often. The Exxon rolling wheel and Elf compactor simulated pavement cores with equal frequency. The rotating base Marshall hammer was similar to the pavement cores least often. From an overall statistical standpoint, however, it cannot be stated with confidence that any one compaction method more closely simulated field compaction than any one of the other three methods tested. The rolling wheel compactor exhibited difficulties in controlling the air voids of the compacted specimens to such an extent that the desired range of air void contents was never attained with this compactor.

Highway researchers and paving engineers recognized many years ago that different compaction techniques produce asphalt concrete specimens with different particle orientations and thus differing physical properties. When evaluating asphalt concrete mixtures in the laboratory, it is desirable to produce test specimens that duplicate, as nearly as possible, the compacted mixture as it exists (or will exist) in an actual pavement layer.

## OBJECTIVE AND SCOPE

The requirement of this research study was to determine which of four compaction devices most closely simulates actual field compaction and to make a recommendation to the Strategic Highway Research Program (SHRP). Detailed studies were conducted to compare the properties of specimens made using the Texas gyratory compactor and the Exxon rolling wheel compactor with pavement cores. An abbreviated study was performed using selected test procedures to evaluate mixtures compacted using the rotating base

Marshall hammer. The Elf linear kneading compactor was evaluated for only two types of mixtures.

Paving mixtures from five different locations and made up of different aggregates and asphalts were used in the study. These materials provided a wide range of engineering properties and test values for the compacted mixtures. The experiment was designed to determine the extent to which the method of laboratory compaction affects certain fundamental and commonly measured properties of asphalt concrete. Statistical analyses of the test results were performed to determine whether significant differences existed between the field cores and the different compaction methods.

This report is an abridged version of the original research report (1) prepared for the National Research Council in partial fulfillment of SHRP project A-005. All of the data are contained in a complete report, compiled in 21 tables and presented graphically in 40 figures.

## RELATED RESEARCH

Several significant studies have been performed that focus on comparing the properties of mixtures compacted with different laboratory compaction devices. These studies include: Vallerga (2), Fields (3), Epps et al. (4), Nunn (5), Huschek (6), Van Grevenynghe (7), Aunan et al. (8), Von Quintus et al. (9), and Sousa et al. (10). The consensus of these studies is that the response of a mixture to loading (mixture property) is affected by the type of laboratory compaction method used to prepare the specimen. Perhaps the most extensive and most relevant studies are the two most recent (9, 10).

In the NCHRP study, *Asphalt-Aggregate Mixture Analysis System*, by Von Quintus et al. (9), the effects of five different laboratory compactors on the selected properties of the compacted mixtures are investigated. Field cores and lab compacted samples were subjected to indirect tensile testing (strength, strain at failure, resilient modulus, and creep) and aggregate particle orientation evaluation. On the basis of the pooled results of mechanical tests performed at three different temperatures, Von Quintus et al. reported the relative similarity between laboratory compaction technique and field compaction (Table 1).

The study by Sousa et al. (10), performed under SHRP contract A-003A at the University of California at Berkeley, evaluated three compaction devices: Texas gyratory, kneading, and rolling wheel. The purpose of the study was to determine the extent to which method of laboratory compaction affects fundamental mixture properties (permanent deformation and fatigue) related to pavement

TABLE 1 Summary of Findings from NHCRP AAMAS Study (9)

<u>Compaction Device</u>	<u>Percent of Cells with Properties,</u>	
	<u>Closest to the</u> <u>Field Cores</u>	<u>Indifferent from</u> <u>the Field Cores</u>
Texas Gyrotory	45	63
Rolling Wheel Compactor*	25	49
Kneading Compactor	23	52
Arizona Vibratory/Kneading	7	41
Standard Marshall Hammer	7	35

\*The rolling wheel compactor was the Mobil Steel Wheel Simulator

performance. Perhaps the most important findings of the study were the following:

1. Samples prepared with the Texas gyratory compactor are expected to be more sensitive to asphalt type (and perhaps to binder content) than samples prepared by the kneading compactor.
2. Samples prepared using the kneading compaction device are more resistant to permanent deformation, primarily because of the development of a more complete interparticle contact "structure," at least for densely graded aggregates; mixtures prepared under kneading compaction are more sensitive to aggregate angularity and surface texture.
3. Specimens prepared using the rolling wheel compactor were ranked between specimens prepared by kneading and gyratory methods in terms of their resistance to permanent deformation. However, they were stiffer under transient (dynamic) loading and more fatigue resistant than either gyratory or kneading specimens.

On the basis of these findings, Sousa et al. (10) stated that the compaction method had a profound impact on fundamental mixture properties and summarized their recommendations by stating that among the methods investigated, the rolling wheel appears to best duplicate field-compacted mixtures.

A criticism of this study is that it is not correlated to field results. Although Sousa et al. performed mixture property tests that have been shown to be related to field performance, the link between laboratory compacted and field compacted mixture properties is absent.

It should be noted that the Von Quintus et al. (9) and Sousa et al. (10) studies are consistent in that both concluded that the kneading compactor produced specimens with the greatest resistance to rutting, as compared with the rolling wheel compactor and the Texas gyratory compactor. Specimens produced by the Texas gyratory compactor were found to have properties most susceptible to rutting. It may be argued that, because the Texas gyratory compactor is the most sensitive to asphalt type and asphalt cement properties, it is an appropriate device for mixture analysis under the SHRP concept, which clearly identified the importance of the ability to discriminate among asphalts with various physical properties.

## DESCRIPTION OF EXPERIMENTAL PROGRAM

### Experiment Design

Five pavement sites were selected from the SHRP SPS-5 and SPS-6 field tests as a foundation for the analysis. Approximately thirty 102-mm (4-in.) diameter cores from each of these pavement sections provided the basis for the evaluation of the laboratory compaction devices. The experiment design is summarized in Table 2.

Aggregate and asphalt identical to that used in the production of these test sections were used to prepare the laboratory compacted specimens using the same mixture design (same proportions of same materials) as in the pavement. Laboratory-fabricated specimens from each compaction device were tested to characterize the material response of each mixture in tensile and compressive shear modes of loading. Test results were compared to corresponding results from field cores and statistically analyzed.

Average air-voids content of the cores among the different sites varied from about 3 to 8 percent; within a given site, they typically had a range of 2 to 5 percent. Laboratory samples for each mixture were compacted to simulate the range of field air voids. This was accomplished by varying the compactive effort. Compaction energy variation was achieved with the Texas gyratory compactor by varying the number of gyrations and the applied pressure. Controlling the compaction energy with the Exxon rolling wheel compactor was more difficult than originally believed; therefore, air-voids content of the resulting specimens was not ideal. Mean air-void contents for the initial set of Exxon compacted samples were too low. A second set of samples was prepared with the hope of achieving a higher air-void content. However, they also had lower air voids than desired.

More work than this study permitted is needed to do a satisfactory comparative evaluation of the Exxon rolling wheel compactor. Compaction energy applied by the Marshall device was varied by simply changing the number of blows of the drop hammer. The Elf compactor can essentially guarantee a particular average air-void content because it compresses a known weight of material into a predetermined volume.

TABLE 2 Compaction Experiment Design

Mixture Type	Compaction Method	Testing Program <sup>1</sup>	
		Test Type	No. Tests
Casa Grande, Az Flagstaff, Az Michigan DOT Alberta, Canada Manitoba, Canada	Field, Tex Gyrotory, <sup>2</sup> Exxon Rolling Wheel	Indirect Tension, 25°C	5
		Resilient Modulus, 0° + 25°C	5
		Marshall Stability	5
		Hveem Stability	5
		Cyclic Creep, 40°C	5
		Direct Compression, 40°C	5
Casa Grande, Az Flagstaff, Az Michigan DOT Alberta, Canada Manitoba, Canada	Marshall Hammer <sup>3</sup>	Indirect Tension, 25°C	5
		Resilient Modulus, 0° + 25°C	5
		Marshall Stability	5
Casa Grande, Az Alberta, Canada	Elf Linear Kneading Compactor	Indirect Tension, 25°C	5
		Resilient Modulus, 0° + 25°C	5
		Marshall Stability	5
		Hveem Stability	5
		Cyclic Creep, 40°C	5
		Direct Compression, 40°C	5

<sup>1</sup> Test results from all laboratory compacted specimens were compared with results from field cores.

<sup>2</sup> The Texas gyratory compactor uses a tilt angle of three degrees, a contact pressure varying from 50 psi to a maximum of 150 psi, and a leveling load of 2500 psi.

<sup>3</sup> Marshall compacted samples were not tested for cyclic creep and direct compression, as only an abbreviated study was performed on Marshall Compaction.

Four commonly used laboratory tests and two specialized tests were used in comparing specimens from the different compaction devices. These tests included indirect tension at 25°C (77°F), resilient modulus at 0°C (32°F) and 25°C, Marshall stability, Hveem stability, and uniaxial repetitive compressive creep followed by compression to failure. These tests may not be ideal for evaluating the effect of compaction method on asphalt concrete, but they were selected because they can be performed on 100-mm (4-in.) core samples from thin pavement layers. The pavement layers sampled were seldom thicker than 64 mm (2.5 in.) and hence were usually not thick enough for tests such as unconfined compressive strength, repeated load triaxial resilient modulus, or compressive creep.

The uniaxial repetitive compressive creep test can be performed on samples that are 76 to 203 mm (3 to 8 in.) in height. A uniaxial compressive load of  $2.76 \times 10^5$  Pascals (40 psi) was applied to the specimen for 60 sec at a temperature of 40°C (104°F), while the deformation in vertical and horizontal directions was measured. After the 60-sec load period, the sample was allowed to relax for 60 sec while creep recovery data was acquired. Each test consisted of eight such cycles followed by compressive load to failure. Indirect tension and resilient modulus tests were used to categorize the fracture and fatigue characteristics of the compacted mixtures.

#### Materials Tested

Pavement cores, aggregates, and asphalt cements from five pavement test sites were obtained and tested (Table 3).

#### Sample Preparation

Immediately before mixing the asphalt and aggregate, both were heated to the mixing temperature specified for the particular compaction method. Then the ingredients were mixed in accordance with the procedures specified for the particular compaction method. Compaction effort was varied to produce specimens with a range of air voids similar to that found in the different pavements.

Mixing and compaction temperatures for the gyratory compactor were 135°C (275°F) and 121°C (250°F), respectively, as required by the standard procedure. Mixing and compaction temperatures for the Marshall method were determined in accordance with ASTM D 1559 and were as follows: Casa Grande, 152°C and 143°C (306°F and 290°F); Flagstaff, 146°C and 138°C (295°F and 280°F); Alberta, 143°C and 132°C (290°F and 270°F); and Manitoba, 143°C and 132°C.

For the Exxon rolling wheel, the mixing process starts with the aggregate at 163°C (325°F) and ends with it at about 144°C (291°F). The Exxon compactor used the equivalent of 10 complete passes at increasing loads up to 714 kg (1,570 lb) on each tire of the dual pneumatic wheel roller. Compaction typically starts when the mix is at about 138°C (280°F) and ends with it at about 105°C (221°F). Approximately 100 kg (220 lb) of mix was used to prepare a single 180-mm (7-in.) thick slab from which 100-mm (4-in.) diameter cores were drilled.

For the Elf compactor, the Casa Grande material was mixed at 149°C (300°F) and compacted at 135°C (275°F), whereas the Alberta material was mixed at 135°C and compacted at 121°C

TABLE 3 Description of Materials Tested

Specimen Identification	Aggregate Type	Asphalt Grade	Content <sup>1</sup>	Admixture	Average Air Void Content of Cores <sup>2</sup> percent	Range of Air-Void Content of Cores <sup>2</sup> , percent
Casa Grande	Gravel, Sand, Crushed Fines	AC-40	4.7	1% Cement	5.6	4.5-7.0
Flagstaff	Crushed Basalt w/ Sand + 1.5% Lime	AC-20	4.6	1.5% Lime	8.8	6.0-12.0
Alberta	Crushed Stone and Sand	150-200 Pen	5.1	None	3.9	2.6-5.6
Manitoba	Crushed Gravel w/ Sand	150-200 Pen High Viscosity	5.9	None	3.8	2.8-5.6
Michigan	Crushed Stone and manuf. sand	AC-10	5.1	None	3.0	1.8-5.5

<sup>1</sup> Asphalt content is given in percent by weight of total mix.

<sup>2</sup> Air void data is for pavement cores received.

(250°F). Approximately 17 kg (38 lb) of mix was used to prepare a 75-mm (3-in.) thick slab from which cores were drilled.

### Field Cores

Cores drilled from the test pavements were shipped to Texas Transportation Institute. All cores were 102 mm (4 in.) in diameter. The layer of interest typically ranged from 25 mm (1 in.) to 152 mm (6 in.) in depth.

### FINDINGS

Pavement cores were drilled within and between the wheel paths in an attempt to obtain samples with low and high air voids. Measurements showed that in many cases there were no significant differences in air voids of cores taken between the wheel paths and those from within the wheel paths. That is likely because these pavements were fairly new and had not been exposed to enough traffic to cause differences in densification.

The Exxon compactor experienced extreme difficulty in producing specimens with the desired air-void content. Because a limited supply of the paving materials was available, the large quantity of material required for repeated operations with the Exxon compactor precluded more than two attempts to obtain the desired level of air voids.

### Statistical Analysis of Standard Tests

The statistical approach used in this portion of the study was to fit linear regression lines using ordinary least squares and comparing the slopes and intercepts of these lines for each laboratory compaction method to field compaction. This was done using a dummy

variable regression model that allowed a separate intercept and slope term for each line for a given site. Hypotheses about the model parameters were tested, to compare each compaction method's terms to the field terms. When necessary, a line with a realistic slope was fitted through the Exxon data to complete the statistical analysis using the available data. Results of the statistical analyses are given in the following subsections. To understand the following statistical discussion, see Figures 1-6.

#### *Resilient Modulus At 25°C (77°F)*

For the Casa Grande mix (Figure 1), gyratory, Elf, and Marshall methods had resilient moduli equivalent to the field. The Exxon method, though decreasing with increasing air voids at the same rate as the field cores, yielded consistently lower modulus values at any given air-void content than did the other methods.

In summary, the Exxon method yielded lower levels of resilient moduli at 25°C (77°F) than the field cores at three of the four sites tested. The gyratory compacted samples were similar to pavement cores at four sites, Marshall compacted samples were similar to the field cores at two sites, and the Elf specimens were similar to the pavement cores at both of the sites tested.

#### *Resilient Modulus At 0°C (32°F)*

For the Flagstaff mixture (Figure 2), there was no difference between any of the laboratory compaction methods and the field cores.

#### *Indirect Tension Tests*

For the Flagstaff mixture (Figure 3), three of the four compaction methods (pavement cores, Marshall, and gyratory) showed a significant decrease in indirect tension (IDT) strength as percent air

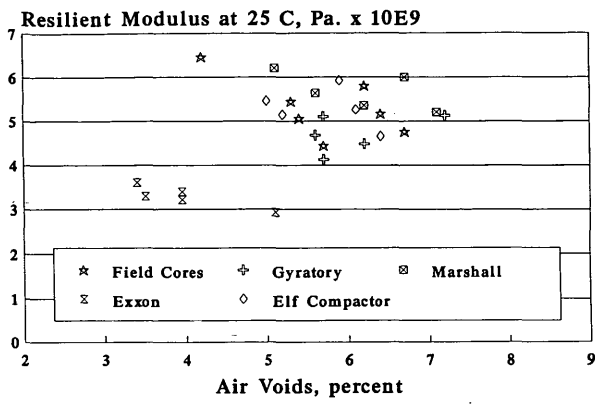


FIGURE 1 Resilient modulus at 25°C for mixture from Casa Grande, Arizona.

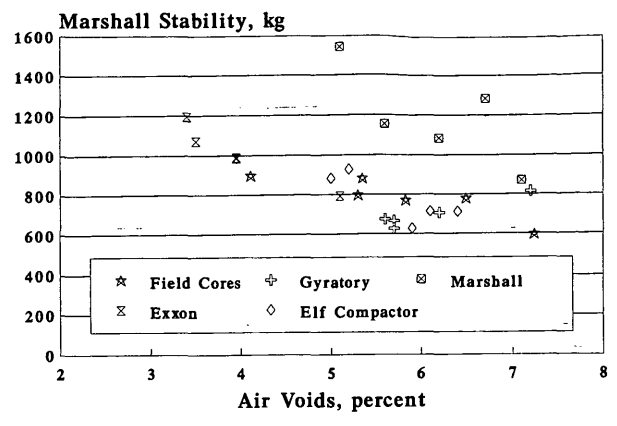


FIGURE 4 Marshall stability at 60°C for mixture from Casa Grande, Arizona.

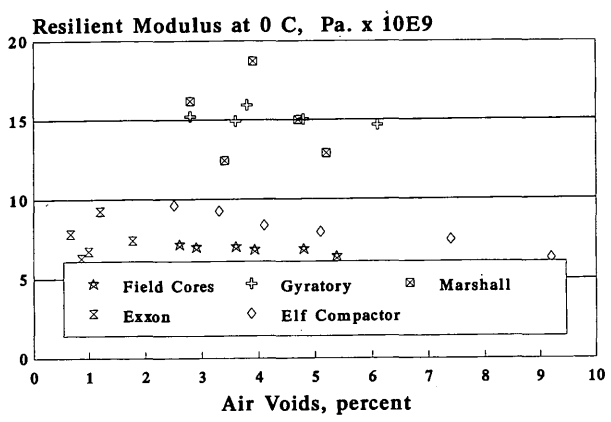


FIGURE 2 Resilient modulus at 0°C for mixture from Alberta, Canada.

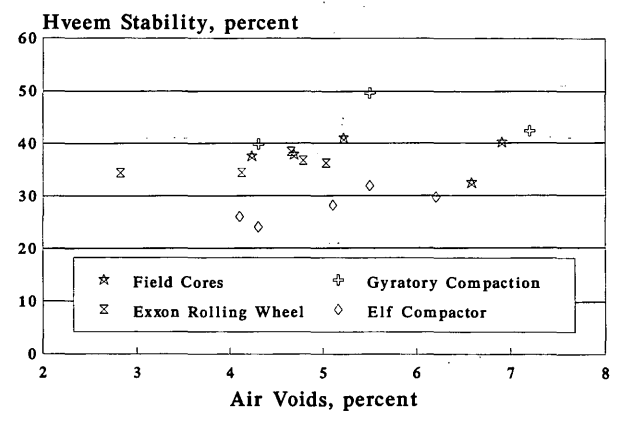


FIGURE 5 Hveem stability at 60°C for mixture from Casa Grande, Arizona.

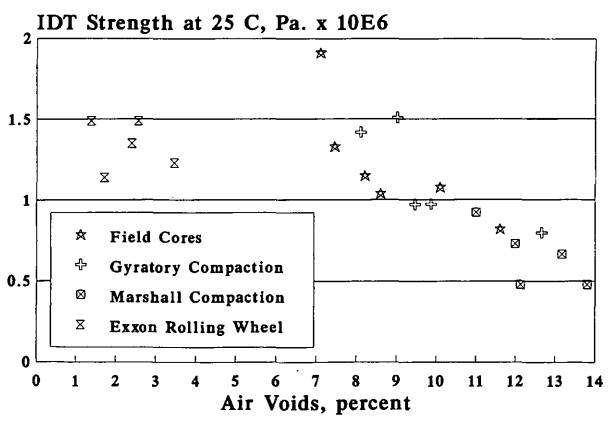


FIGURE 3 Indirect tensile strength at 25°C for mixture from Flagstaff, Arizona.

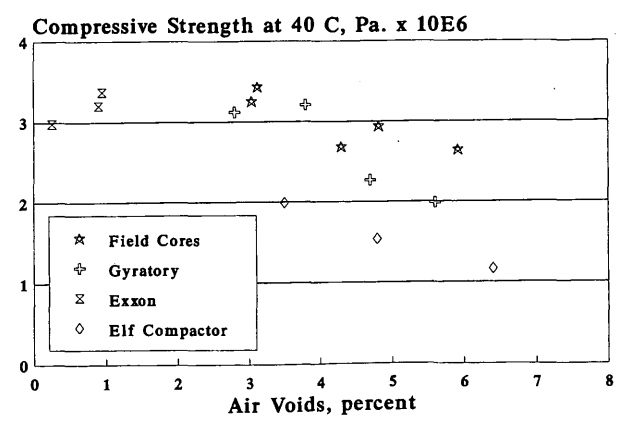


FIGURE 6 Compressive strength at 40°C for mixture from Alberta, Canada.

voids increased and the rate of decrease was equal for the three compaction methods. The Exxon method apparently yielded lower IDT strengths than did the other three methods. Both the Marshall and gyratory methods were equivalent to the field compaction.

In summary, only the Flagstaff site showed a statistically significant decrease in IDT strength as air voids increased and all three compaction methods were equal to the field. Exxon, Marshall, and gyratory methods were equivalent to field at two sites each, and Elf was equivalent to field at the two sites it was tested (Casa Grande and Alberta).

#### *Marshall Stability*

For both the Casa Grande (Figure 4) and Alberta sites, Marshall stability for all four laboratory compaction methods was statistically equivalent to the pavement cores. For the Casa Grande mix, there was no significant relationship between Marshall stability and air voids for any of the compaction methods, and the average stability was equal to the field for all four laboratory compaction methods and at all air-void levels. For Alberta mix, the Marshall stability decreased with increase in air voids and the rate of decrease was the same for all methods.

In summary, the Exxon and Marshall methods were equivalent to the field compaction at three sites, the Elf method was equivalent to the field at both the sites tested, and the gyratory method was equivalent to the field at four of five sites.

#### *Marshall Flow*

All compaction methods produced Marshall flows statistically equivalent to field compaction, except for the Michigan mix, for which Marshall compaction yielded higher values than the other compaction methods.

#### *Hveem Stability*

For the Casa Grande mixtures (Figure 5), none of the compaction methods showed a significant relationship between Hveem and level of air voids and all methods yielded statistically equivalent Hveem stabilities over all air-void levels. Both the Exxon and gyratory methods were equal to the field cores, and the Elf method yielded consistently lower Hveem stability values. (Note: Hveem stability was not measured on Marshall compacted specimens.)

In summary, as with IDT, only the Flagstaff mixture showed a significant decrease in Hveem stability with increasing air voids; this was shown only for the field and gyratory methods. Three of four sites concurred that the Exxon method yielded significantly lower Hveem stability. The gyratory method was equal to the field at four sites, and the Exxon method was equivalent to the field at only one site.

#### **Statistical Analysis of Compressive Creep Tests**

Data from the repetitive compressive creep tests were reduced to vertical stress as well as vertical and horizontal strains. Because some of the specimens failed before the end of the test, the first of eight repetitive load cycles was taken as the basis for comparison.

Dilation ratio, defined as the ratio of horizontal radial strain to vertical strain, and the ultimate compressive strength were determined for each of the samples. The Marshall compactor was not used in this element of work. Compaction method was considered to be the main effect and air-void content was considered the covariate. The two properties, dilation ratio and compressive strength, were the dependent variables. A multifactor analysis of variance, at a confidence level of 95 percent, was performed on each mix separately.

For the Casa Grande mix, analysis of the data indicated that neither air-void content nor compaction method had a statistically significant effect on dilation ratio. Compressive strength was affected significantly both by air voids and by compaction method. With respect to the compressive strength, the Elf compaction was statistically different from the other three methods, which were not different from one another.

The Flagstaff data suggested that neither the air voids nor the compaction method had a significant effect on the dilation ratio. Compaction method had a significant effect on the compressive strength, whereas air voids had no significant effect. All three compaction methods were statistically different from one another.

The Alberta data indicated that air voids had a significant effect on the dilation ratio, whereas the effect of the compaction method was not significant. Compressive strength (Figure 6) was significantly affected both by air voids and compaction method, with the effect of air voids more profound. However, only the Elf compaction method was statistically different from the other three (field, Exxon, and gyratory) methods, which were not different from one another.

For the Manitoba mix, data was used only from field-cores and Exxon compacted specimens (gyratory compacted samples were tested but no meaningful data were obtained). Compaction method showed no significant effect on dilation ratio, whereas the air voids showed a statistically significant effect. Both air voids and compaction method had a significant effect on the compressive strength.

For the Michigan mix, only field cores and gyratory compacted specimens were tested. The dilation ratio was not significantly affected by either air voids or compaction method; although, compaction method had a statistically significant effect on the compressive strength and the air voids did not.

In summary, the statistical analyses showed that for all five test sites (Casa Grande, Flagstaff, Alberta, Manitoba, and Michigan) the compaction methods evaluated (field, Exxon rolling wheel, Texas gyratory, and Elf linear kneading compactor) were not statistically different from each other with respect to their effect on the dilation ratio. Similarly, compressive strength data indicated the compaction methods were not significantly different from each other except for the Flagstaff mix, and that Elf compacted samples exhibited lower compressive strengths than the other methods.

#### **Overall Summary of Statistical Analysis**

Results from the statistical analyses are summarized in Table 4. The results are tabulated according to the source of the paving mixture and method of compaction for each site. For each set of tests performed, the test values as a function of air voids (slope/intercept) for the laboratory compacted specimens were compared statistically to the corresponding test values as a function of air voids for the pavement cores. Results of the comparisons are described in Table 4 by the following statistically significant categories: equivalent to (E), less than (L), higher than (H), or different from (D) the field

TABLE 4 Consolidated Results from Statistical Analysis

Site/ Compaction Method	Resilient Modulus,		IDT Strength	Marshall Stability	Hveem Stability	Compressive Dilation Ratio	Creep Test Compressive Strength
	25°C	0°C					
<u>Casa Grande</u>							
Gyratory	E	H	H	E	E	E	E
Marshall	E	H	E	E	-	-	-
Exxon	L	E	E	E	E	E	E
Elf	E	H	E	E	L	E	L
<u>Flagstaff</u>							
Gyratory	D	E	E	D	E	E	H
Marshall	H	E	E	E	-	-	-
Exxon	L	E	L	E	L	E	D
<u>Alberta</u>							
Gyratory	E	H	D	E	E	E	E
Marshall	E	H	H	E	-	-	-
Exxon	E	E	E	E	L	E	E
Elf	E	E	E	E	L	E	L
<u>Manitoba</u>							
Gyratory	E	E	H	E	H	-	-
Marshall	H	E	H	H	-	-	-
Exxon	L	L	L	E	L	E	E
<u>Michigan</u>							
Gyratory	E	E	E	E	E	E	E
Marshall	H	E	H	H	-	-	-

E = Equivalent to  
 L = Less than  
 H = Higher than  
 D = Different from } the Field Compaction

All four compaction methods were not used to prepare specimens from all five locations.

cores. To clarify the category "different", the following is given: certain values measured on the laboratory specimens had a different relationship (slope) with air voids, and thus some values were higher and some were lower than the corresponding values for the field cores.

The total number of Es determined for each laboratory compaction method from all the five locations was summed and compared with the maximum possible number of Es and was expressed as a percent. Gyratory compaction was equivalent to the field cores 24 times out of a possible 33 times (or 73 percent). Exxon rolling wheel compaction was equivalent to the field cores 18 times out of a possible 28 times (64 percent). Elf linear kneading compaction was equivalent to the field 9 times out of a possible 14 (64 percent). Rotating base Marshall compaction was similar to the field 10 times out of 20 (50 percent). A statistical test of significance (with  $\alpha = 0.05$ ) of these percentages indicated that, although the gyratory compactor is equivalent to field compaction more often than the other methods, the differences between these percentages is not statistically significant.

Other interesting observations can be made from this comparison. The Exxon and Elf compacted specimens were either equal to or less than the field cores in all properties tested. The Marshall method yielded specimens that were higher than the field whenever they were not similar. The gyratory compacted specimens were equal to, higher than, or different from the field cores but never lower.

**STUDY OF AIR VOID STRUCTURE**

One specimen each representing selected mixtures and compaction methods was sent to the Road Directorate of the National Road Laboratory in Denmark, where they used special microscopy and imaging techniques to study the air-void structure (1,11). The objective of the investigation was to analyze and characterize air voids visible in a cut section of the compacted mixtures. The voids in an exposed plane section of a compacted sample were filled with epoxy containing fluorescent dye. Fluorescent image analysis of the

two-dimensional section was used to determine size, shape, and distribution of the air-void intersections as well as to estimate volume percent voids in the specimen.

The image analysis technique provides valuable information that improves the understanding of air-voids distribution in hot-mix asphalt compacted by different methods. Unfortunately, this was a very limited study, and no firm conclusions were made about the various compaction devices.

Generally, the pavement cores and the Exxon rolling wheel compactor exhibited better homogeneity of air-void distribution than the gyratory compactor. The Casa Grande mixture, which contained a relatively hard asphalt (AC-40), was essentially unaffected by compaction method.

## CONCLUSIONS AND RECOMMENDATIONS

The research reported herein was designed primarily to compare specimens compacted using the Exxon rolling wheel compactor and the gyratory compactor with field cores. Additional limited work was performed to compare specimens prepared using the rotating base Marshall compactor and the Elf linear kneading compactor with field cores.

### Conclusions

1. Analyses indicated that the gyratory method most often produced specimens similar to pavement cores (73 percent of the tests performed). Exxon and Elf compactors had the same probability of producing specimens similar to pavement cores (64 percent of the tests performed). The Marshall rotating base compactor had the least probability of producing specimens similar to pavement cores (50 percent of the tests performed). These differences are not statistically significant (at  $\alpha = 0.05$ ).

2. When all the data, as reflected by the mixture properties measured, are considered collectively, the differences between field cores and the specimens produced by the four laboratory compaction methods compared in this study are relatively small. The types of tests selected to evaluate mixture properties were not ideal but were dictated by the small size of many of the field cores.

3. The Exxon rolling wheel compactor exhibited much more difficulty in controlling air voids in the finished specimens than the other compaction methods. The Exxon compactor requires about 100 kg (220 lb) of mix to prepare one set of specimens (one slab) at one air-void level, making it a very labor-intensive and material-intensive operation to prepare samples with various air-void contents. The comparatively low air-void level of the Exxon specimens renders conclusions about similarity or lack of similarity to the pavement specimens questionable.

4. For producing small samples of specific air-void contents, as in this study, the gyratory compactor was much more convenient, faster, and cheaper than the Exxon compactor. This is because much less material is required and no coring is necessary to produce laboratory specimens.

5. Elf compactor easily produces a 17 kg (38 lb) slab with a predictable air-void content. It is convenient and offers a great deal of versatility because the mold can be constructed to almost any plane geometric shape.

6. When compared with the Exxon rolling wheel compactor, the Texas gyratory compactor is more convenient for preparing laboratory specimens for routine mixture design testing of asphalt concrete.

7. On the basis of other studies, air-void distribution of gyratory compacted specimens may be less similar to pavement cores than rolling wheel compacted specimens; however, this difference did not adversely affect the mixture properties measured for this study.

8. Based solely on the findings of this comparative study, the Texas gyratory compactor was recommended to SHRP for use in preparing routine laboratory test specimens.

### Recommendations

1. Additional research is needed to investigate in detail the size and distribution of air voids within hot-mix asphalt specimens compacted by different methods, as compared with field compaction, and to determine the resultant effect on fundamental engineering properties.

2. Testing in this study was limited to dense graded mixtures. Stone mastic or other nonconventional mixtures were not evaluated. Therefore, an evaluation of laboratory compactibility of nonconventional mixtures, including stone mastic and open-graded mixtures, is needed.

### ACKNOWLEDGMENTS

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Elf Asphalt of Terre Haute, Indiana, furnished all test specimens that were prepared using the Elf linear kneading compactor, without cost to the project, and also funded all testing associated with its compactor. The assistance and advice of Michael L. Hines was of significant value to this portion of the work.

Exxon Research and Engineering Company of Linden, New Jersey, furnished all specimens that were prepared using the Exxon rolling wheel compactor, without cost to the project. Nicholas C. Nahas coordinated the work at Exxon and was of particular aid to this study.

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