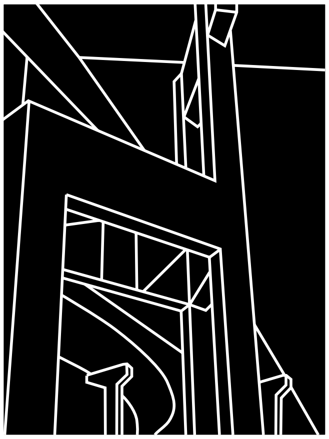
RESEARCH REPORT 1250-3

EVALUATION OF SUPERPAVE GYRATORY COMPACTORS

Mansour Solaimanian, Yetkin Yildirim, Robert B. McGennis, and
Thomas W. Kennedy



CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

JANUARY 1999

Technical Report Documentation Page

1. Report No. FHWA/TX-99/1250-3	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle EVALUATION OF SUPERPAVE GYRATORY COMPACTORS		5. Report Date January 1999 6. Performing Organization Code
7. Author(s) Mansour Solaimanian, Yetkin Yildirim, Robert B. McGennis, and Thomas W. Kennedy		8. Performing Organization Report No. 1250-3
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 3208 Red River, Suite 200 Austin, TX 78705-2650		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 0-1250
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Section/Construction Division P.O. Box 5080 Austin, TX 78763-5080		13. Type of Report and Period Covered Research Report (9/98 — 1/99) 14. Sponsoring Agency Code

15. Supplementary Notes

Project conducted in cooperation with the Federal Highway Administration.

16. Abstract

This is the third report from the South Central Superpave Center (SCSC). It presents the results, findings, conclusions, and recommendations based on a comprehensive 12-month laboratory study of gyratory compactors conducted at the center.

17. Key Words Superpave, asphalt pavements, gyratory compactors		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.	
19. Security Classif. (of report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 84	22. Price

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

EVALUATION OF SUPERPAVE GYRATORY COMPACTORS

by

Mansour Solaimanian
Yetkin Yildirim
Robert B. McGennis
Thomas W. Kennedy

Research Report Number 1250-3

Research Project 0-1250
South Central Superpave Center

Conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

by the

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

January 1999

PREFACE

This is the third report from the South Central Superpave Center (SCSC). It presents the results, findings, conclusions, and recommendations based on a comprehensive 12-month laboratory study conducted at the center.

IMPLEMENTATION STATEMENT

Following the positive response generated by the original Superpave gyratory compactors (SGCs), it soon became clear that the SGC would become the laboratory compactor of choice. Consequently, since 1995 several additional manufacturers have developed SGCs to meet the growing demand for such devices. While these units generally meet the broad requirements of the original FHWA SGC specification, their basic designs differed somewhat. Accordingly, potential users of the new SGCs were prompted to ask, "Will I get the same test results from a new SGC that I would get from the original compactors?"

To ensure a systematic means for answering this question, the FHWA developed a standard protocol for the evaluation of SGCs. This protocol was reviewed by the FHWA Superpave Mixtures Expert Task Group (ETG), with changes made based on this review. This procedure, designated AASHTO PP 35-98, was used in this research study to evaluate the newly introduced gyratory compactors.

The results of this study can assist state agencies in their efforts to procure new compactors for their facilities.

ACKNOWLEDGMENTS

The success of this project was made possible only through the cooperation and the assistance of a number of dedicated people. Special thanks are extended to University of Texas researchers Mr. Eugene Betts, Mr. Weng Tam, and Mr. Jau-Yang Wu, all of whom were involved in carrying out the required laboratory tests. The authors also thank TxDOT project director Mr. Maghsoud Tahmoressi (MAT), who, along with other personnel from TxDOT's Materials Section, Construction Division, greatly assisted in this project (we are particularly grateful for permission to use one of the agency's Pine compactors).

Special thanks are extended to the various compactor manufacturers for providing the SCSC with compactors for evaluation. The support of the Center for Transportation Research is also greatly appreciated.

Finally, we acknowledge and appreciate the financial support of Texas Department of Transportation and the Federal Highway Administration.

DISCLAIMERS

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

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

NOT INTENDED FOR CONSTRUCTION,
BIDDING, OR PERMIT PURPOSES

Thomas W. Kennedy, P.E. (Texas No. 29596)
Research Supervisor

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Mix design is the first stage in developing a high quality hot mix asphalt (HMA) mixture. One of the most important stages in the mix design procedure is the laboratory compaction of specimens. In addressing this issue, the Strategic Highway Research Program (SHRP) introduced the Superpave gyratory compactor (SGC). Since then, several manufacturers have developed SGCs to meet the growing demand for such devices. To ensure that these compactors provide consistent test results, the FHWA developed a standard protocol for the evaluation of SGCs (1). This protocol is designated AASHTO PP 35-98, "Standard Practice for Evaluation of Superpave Gyratory Compactors."

Among a series of significant activities that the South Central Superpave Center (SCSC) has been pursuing since its inception was the evaluation of the new gyratory compactors. In this regard, evaluations of six new gyratory compactors were undertaken utilizing AASHTO's PP 35 procedure (2). The compactors used for this purpose included Rainhart, Test Quip, Troxler Model No. 4141, Pine Model AFG1A, original Interlaken (ITC), and updated Interlaken. These compactors were compared with either Pine Model AFGC125X or Troxler Model No. 4140 SGC, which were used as reference compactors. In addition, the project included comparing two Pine compactors of the same model (AFGC125XS) with one another (3); one belonged to the Superpave Center and the other to the TxDOT Materials Section, Construction Division.

Based on the experimental work conducted as part of this study, AASHTO PP 35 proved to be an effective procedure for determining the suitability of new SGCs. This procedure provides a uniform approach toward estimating the veracity of new SGCs. The procedure in AASHTO PP 35 was followed during the evaluation of the compactors. As required in the AASHTO PP 35 protocol, a value of 0.010 for the difference in G_{mb} (bulk specific gravity) was used to discriminate between acceptable and unacceptable results. A total of 384 specimens were prepared for all the compactors to fulfill the comparison (forty-eight specimens for each compactor) (4). Twelve comparisons were made for each candidate compactor and the reference compactor.

All the candidate compactors compared favorably with an existing SGC. Except in one case, the results were comparable eleven or twelve out of twelve times. It was found that all eight compactors would provide the same results within the given tolerance range throughout mix design and plant quality control.

In this experiment, extreme care was taken to ensure that variability in data was restricted to variability induced by the compactors themselves. Users of these or any other laboratory compaction devices should be aware that consistency of results is considerably influenced by many other factors. Operator proficiency, oven size and quality, compactor operating condition, adherence to standard test procedures, and, of course, material variability are among the many factors that can influence the comparability of test results.

Prospective purchasers of SGCs should require that a manufacturer demonstrate that its new device has been rigorously evaluated according to the protocol and shown to

be comparable. Such data constitute a baseline frame of reference from which other features may be used to make a purchasing decision. These features include cost, availability, operating features, field lab suitability, user friendliness, data acquisition, and management. Should an agency or organization prefer a particular model because of one of these or other factors, it can develop a purchasing specification accordingly.

CHAPTER 1. INTRODUCTION

The Strategic Highway Research Program (SHRP) has provided the asphalt industry with a completely new way to specify and design asphalt materials. This new system has been termed *Superpave.* And within the Superpave system, the volumetric mix design procedure is based on the use of a Superpave gyratory compactor (SGC) *(5).* AASHTO PP 35, "Standard Practice for Evaluation of Superpave Gyratory Compactors," is the evaluation procedure used to determine if a supplier has indeed manufactured a functional SGC.

BACKGROUND

At the conclusion of the SHRP study, the Federal Highway Administration's (FHWA's) Office of Technology Applications developed a specification for the pooled-fund purchase of Superpave gyratory compactors. The specification was largely based on the recommendations of SHRP researchers and on early FHWA experience with prototype units. In 1994, the FHWA evaluated the first models delivered by two manufacturers — Pine Instrument Company and Troxler Electronic Laboratories, Inc. — to meet this specification.

The FHWA's first evaluation consisted primarily in comparing SGC test results obtained from the Pine, Troxler, and a modified Texas gyratory unit. The modified Texas unit was the prototype device that was used by SHRP (and considered to be the comparison standard). This evaluation showed that the Pine and Troxler compactors yielded results similar to those of the modified Texas device. Overall, the FHWA judged the compactors to be in conformity with the specification and thus suitable for the pooled-fund purchase. Thirty units of the Pine and Troxler compactors were then procured as part of the pooled-fund purchase. In 1995, these units were distributed to state DOT laboratories and to FHWA facilities; each of the five Superpave regional centers also received units. Since then, a considerable number of the compactors have been purchased by state DOTs, industry, academia, and others (3).

Both Pine and Troxler compactors have been upgraded in numerous ways. The most significant change to both compactors has been an upgrade in parts to allow the compaction angle to be more closely held at the desired value, 1.25°. A ruggedness experiment was conducted on the Superpave gyratory compaction procedure (AASHTO TP4). This experiment showed that the bulk specific gravity (G_{mb}) of test specimens produced using the procedure was not unduly sensitive to tolerable operator variation. The FHWA undertook a study comparing the results of the two compactors using plant-produced mixes. This study showed that the Pine and Troxler compactors were providing very similar test results. In general, the compactors were subjected to considerable scrutiny by the asphalt materials engineering community. The consensus appears to be overwhelmingly in favor of their use as a mix design tool.

Because of this positive experience, it soon became clear that the SGC would become the laboratory compactor of choice. Consequently, since 1995 several additional manufacturers have developed SGCs to meet the growing demand for such devices. While these units generally meet the broad requirements of the original FHWA SGC specification, their basic designs differ somewhat. Therefore, potential users of the new SGCs must ask the question, “Will I get the same test results from a new SGC that I would get from the original SGCs?”

To ensure a systematic means for answering this question, the FHWA developed a standard protocol for the evaluation of SGCs. This protocol was reviewed by the FHWA Superpave Mixtures Expert Task Group (ETG), with changes made based on this review. This procedure is designated AASHTO PP 35-98.

PURPOSE OF THIS REPORT

This report describes the results of eight compactor comparison experiments using the AASHTO PP 35 protocol. The experiments were conducted at the South Central Superpave Center (SCSC) at The University of Texas at Austin, where the project team evaluated the following SGCs: the original and updated Interlaken (ITC), Test Quip, Rainhart, Pine Instruments Model AFG1A, and Troxler Electronics Model 4141. Also in this project, two original compactors of the same model from Pine Instruments (Model AFGC125X) were compared using the AASHTO PP 35 protocol. The objective of this effort was to determine how the results from different compactors compared. The study also sought to evaluate the effectiveness of AASHTO PP 35.

Chapter 2 provides background information regarding the SGC and includes the protocol for the evaluation of SGC (AASHTO PP 35). In addition, it provides information about volumetric comparison, the preparation of evaluation mixtures, and results reporting. The experimental program used in this study is explained in Chapter 3. In this program, four different mixtures were prepared as required by AASHTO PP 35, with the four mixes designed according to AASHTO PP 28. The results of this experimental program are described in Chapter 4. Finally, Chapter 5 provides conclusions and recommendations.

CHAPTER 2. GYRATORY COMPACTOR AND EVALUATION PROTOCOL

SUPERPAVE GYRATORY COMPACTOR

The Superpave gyratory compactor (SGC) is used to produce compacted specimens for volumetric analysis and determination of mechanical properties. The equipment is capable of providing data to indicate the trend of density variation throughout the compaction procedure. Large aggregates can be accommodated, and compactability can be evaluated so that potential tender mix behavior and similar compaction problems can be identified. Finally, the equipment is portable and can be used in plant mix facilities as part of quality control operations. A number of different gyratory compactors have been manufactured and introduced into the market. Figure 2.1 shows a Pine Model AFGC125X.

Figure 2.1. Pine Superpave Gyratory Compactor, Model AFGC125X

The Texas gyratory compactor, which was used as the basis for the SGC, was modified by lowering its angle and speed of gyration, and by adding real-time specimen height recording capabilities.

The SGC consists of the following components:

- Frame, rotating base, and motor
- Loading ram and pressure control
- Height measuring and recording system
- Mold and base plate

A loading system applies a load to the loading ram, which imparts a 600 KPa compaction pressure to the specimen. A pressure gauge measures the ram loading to maintain constant pressure during compaction. The SGC mold is cylindrical wall (inside diameter of 150 mm) with a base plate at the bottom to provide confinement during compaction. The SGC base rotates at a constant speed of 30 revolutions per minute during compaction, while the mold is positioned at a compaction angle of 1.25°. Figure 2.2 shows the mold configuration during the compaction process (5).

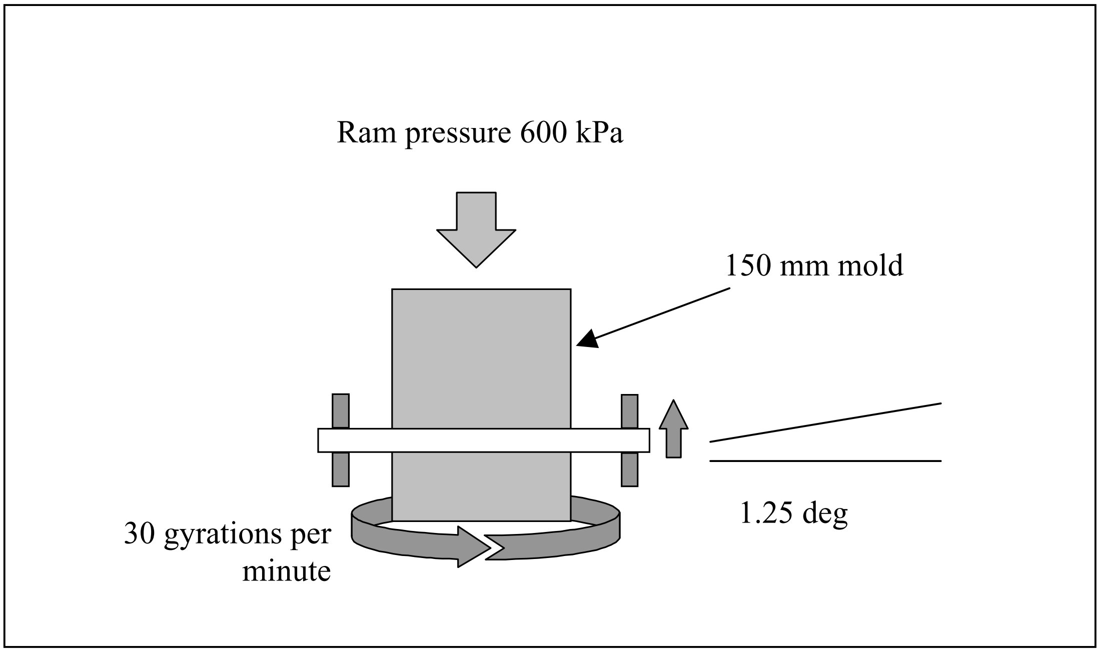


Figure 2.2. SGC mold configuration

Specimen height measurement is an important function of the SGC. By knowing the mass of the material placed in the mold and the specimen height, an estimate of specimen density can be made at any time throughout the compaction process. Specimen density is computed by dividing the mass by the volume of the specimen. Height is measured by recording the position of the ram throughout the test. By this method, a compaction characteristic is developed as the specimen is compacted.

Figure 2.3 shows a densification plot of an asphalt mixture with increasing number of gyrations. Three gyration levels specified by the Superpave volumetric mixture design procedure are of interest:

- Design number of gyrations (N_{design})
- Initial number of gyrations ($N_{initial}$)
- Maximum number of gyrations ($N_{maximum}$)

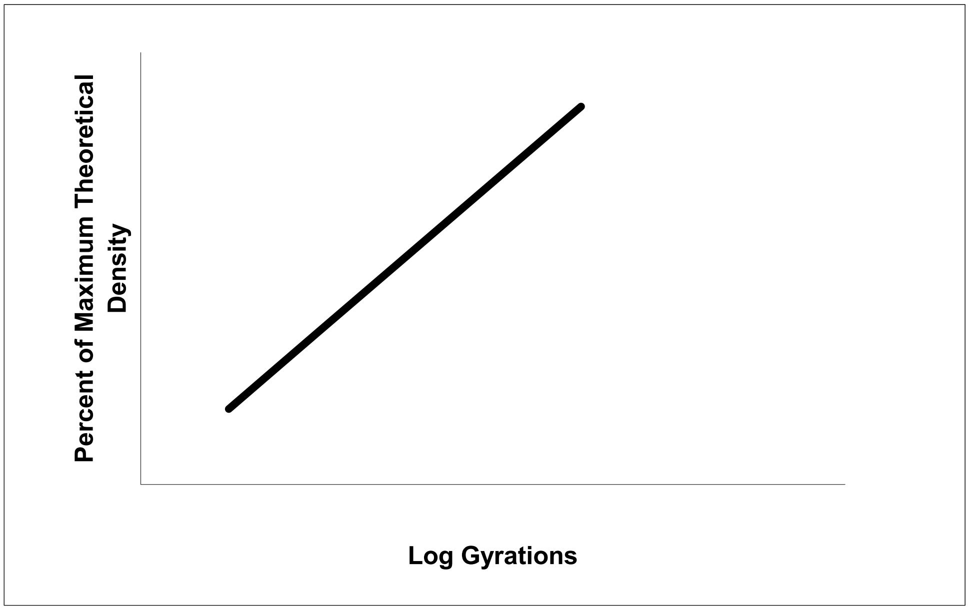


Figure 2.3. Mixture compaction characteristics from the SGC

In Superpave, asphalt mixtures are designed at a specified level of compactive effort, identified by N_{design}. As a function of the traffic level, N_{design} is used to vary the compactive effort of the design mixture. Traffic is represented by the design equivalent single axle loads (ESALs). Currently, N_{design} ranges from 68 to 172. However, recent research suggests that the range and the number of gyrations may need to be modified depending on traffic (6).

The test specimens are compacted to the maximum level using $N_{maximum}$ gyrations. At $N_{maximum}$, the density is not allowed to exceed 98 percent of maximum theoretical density. Specifying this maximum density requirement at $N_{maximum}$ prevents the design of a mixture that is susceptible to excessive compaction under the design traffic. Such a mix is prone to excessive rutting. $N_{maximum}$ is calculated using N_{design} in the following relationship:

$$\text{Log } N_{maximum} = 1.10 \text{ Log } (N_{design})$$

The compactability of the mixture is estimated at $N_{initial}$. The density is not to exceed 89 percent of G_{mm} at $N_{initial}$. Specifying this maximum density requirement at $N_{initial}$ prevents the design of a mixture that has a weak aggregate structure and low internal friction, which are sometimes indicators of a tender mix. $N_{initial}$ is calculated using N_{design} through the following relationship:

$$\text{Log } N_{initial} = 0.45 \text{ Log } (N_{design})$$

Currently, the values of $N_{maximum}$ range from 104 to 288 and the values of $N_{initial}$ range from 7 to 10.

Protocol for Evaluation of Superpave Gyratory Compactors

The purpose of the AASHTO PP 35 protocol is to evaluate the suitability of the SGC with respect to its ability to produce similar volumetric properties in compacted specimens at various compaction levels.

A cylindrical compacted specimen is created in the SGC from loose, hot mix asphalt through a gyratory effort. The components inducing the gyratory effort are angle of gyration, consolidation pressure, and speed of gyration. The SGC compaction procedure is described in AASHTO TP 4, "Method for Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the SHRP Gyratory Compactor."

Two SGCs were purchased and evaluated by the Federal Highway Administration (FHWA) in a pooled-fund purchase for the state highway agencies: One SGC unit was produced by the Pine Instruments Company (Model AFGCl25X), while the other SGC unit was produced by the Troxler Electronic Laboratories (Model No. 4140).

Evaluated units must conform to the equipment requirements in AASHTO TP 4. AASHTO PP 35 is intended to provide a uniform process for verifying that the candidate SGC meets the operational requirements outlined in AASHTO TP 4 and that the candidate SGC can provide compaction results comparable to the two models of SGC evaluated in the FHWA pooled-fund purchase. These units function as referee testers.

Evaluation of a Candidate Gyratory Compactor

A candidate gyratory compactor must be fabricated in compliance with the operating characteristics defined in AASHTO TP4. The candidate gyratory compactor will be evaluated through a volumetric comparison with a previously evaluated SGC. AASHTO PP 35 recommends that the volumetric comparison experiment be performed by an evaluation laboratory located at one of the following Superpave regional centers (SRCs):

- Northeast SRC: Penn State University, State College, Pennsylvania
- Southeast SRC: Auburn University, Auburn, Alabama
- North-Central SRC: Purdue University, West Lafayette, Indiana
- South Central SRC: The University of Texas at Austin, Austin, Texas
- West Coast SRC: University of Nevada at Reno, Reno, Nevada
- SHRP Research Originating Laboratory: Asphalt Institute, Lexington, Kentucky

Volumetric Comparison

Comparisons must employ a minimum of four evaluation mixtures, with each satisfying the Superpave volumetric requirements. A single operator must be used throughout the evaluation. Prior to compaction, the operator shall perform, on all compactors included in the evaluation, the manufacturer's calibration procedures to verify that the angle of gyration, compaction pressure, speed of gyration, and height measurement conform to

AASHTO TP 4. A summary of the calibration results, including date and time, must be provided in the final report.

Adequate amounts of each evaluation mixture shall be prepared to yield six gyratory specimens per mix per compactor and G_{mm} specimens. Evaluation mixture samples must be compacted in the candidate and referee compactor according to AASHTO TP 4. Six gyratory specimens per evaluation mixture shall be compacted for each compactor.

Specimens are compacted to the maximum number of gyrations ($N_{maximum}$). Specimen height is recorded at each gyration and is needed to conduct the analysis. After compaction the specimens are extruded and their bulk specific gravity (G_{mb}) is determined according to AASHTO T 166. Bulk specific gravity at N_{design} and $N_{initial}$ are calculated for each specimen using the height data.

The average of the bulk specific gravities at $N_{initial}$, N_{design}, and $N_{maximum}$ of each set of six specimens is determined. No individual specimen's bulk specific gravity at $N_{maximum}$ may deviate from the average of all six specimens in the group by more than 0.020. If the bulk specific gravity of any one specimen is not within 0.020 of its group average, the group must be discarded. A notation of this must be made in the final report. A new batch of mixture, to produce six specimens for each of the subjected compactors, must be prepared and the above procedure must be repeated. If the deviation of any specimen of this new set again exceeds the group average for either compactor, another set will not be prepared. At the discretion of the evaluation laboratory and the manufacturer, a decision will be made whether to continue testing on that mixture. A note to this effect will be made in the final report.

The standard deviations of G_{mb} for the candidate and referee compactor at $N_{initial}$, N_{design} and $N_{maximum}$ must be reported and must be comparable. If candidate compactor results are repeatedly greater, it must be discussed in the final report.

The difference in average G_{mb} values between the candidate compactor and the referee compactor at $N_{initial}$, N_{design}, and $N_{maximum}$ must be less than 0.010 to be considered comparable.

Evaluation Mixtures

Evaluation mixtures must be designed according to AASHTO PP 28 and MP 2. Two of the evaluation mixtures must have 19 mm nominal maximum size blends, referred to as 19 mm mixtures. One of the 19 mm mixtures must be on the coarse side of the Superpave restricted zone (coarse 19 mm mixture). The coarse 19 mm mixture must be designed for a traffic level greater than 10 million ESALs at an N_{design} of 109. The other 19 mm mixture must be on the fine side of the restricted zone (fine 19 mm mixture). The fine 19 mm mixture must be designed for a traffic level greater than 1 million ESALs at an N_{design} of 86.

A 12.5 mm and a 25.0 mm nominal maximum size mixtures are also required. Each of these mixes must be designed for properties commensurate with a traffic loading of greater than 10 million ESALs at an N_{design} of 109.

Peer Review

The evaluation of the candidate SGC must be reviewed by a minimum of one of the other evaluation laboratories. All reviewer comments must be included in the final evaluation report.

Reporting

A final report must include a summary of evaluation findings; G_{mb} values for SGCs at $N_{initial}$, N_{design}, and $N_{maximum}$; a summary of the evaluation mixture designs; a summary of the calibrations performed on each unit; and all comments from the reviewers. Copies of the final report must be provided to the manufacturer, to all evaluation laboratories, and to the FHWA.

The evaluation is valid only for the model tested. If the manufacturer elects to modify the unit, a new evaluation is necessary. If these tests are performed on a prototype candidate compactor, they must be repeated on an actual production model.

CHAPTER 3. EXPERIMENTAL PROGRAM

This project included comparison tests for eight Superpave gyratory compactors (SGCs) using AASHTO PP 35. For each evaluation the same experimental features were used.

A full-factorial design was utilized for evaluation and comparison of compactors. Four different asphalt mixtures were used, and for each mixture, six replicates were prepared. For each compactor comparison experiment, a total of forty-eight specimens (4 mixes x 2 compactors x 6 replicates) were prepared, with a total of 384 specimens (48 specimens x 8 compactors) produced. Specimens were individually batched and stored in plastic bags prior to use. As required by AASHTO PP 35, the four mixes were designed according to AASHTO PP28-95, *Standard Practice for Superpave Volumetric Design for HMA,* and met all the Superpave requirements. The mixes were:

- Mix 1 — 12.5 mm coarse
- Mix 2 — 19 mm coarse
- Mix 3 — 19 mm fine
- Mix 4 — 25 mm coarse

Coarse mixes have gradations below the Superpave restricted zone, while the fine mixes have gradations above the restricted zone. The design asphalt content was selected at 4-percent air voids at the selected number of design gyrations using the Pine Model AFGC 125X compactor. This compactor unit was operated by the South Central Superpave Center. The Pine compactor was employed for this purpose because two of the mixes had previously been designed using that device for roadway projects in Texas (4).

MATERIALS

Asphalt Binder

A PG 64-22 was used for this project. The source of the binder was Neste Trifinery Petroleum Services of Corpus Christi, Texas. A complete suite of Superpave binder tests was conducted to verify that the binder met all the requirements of a PG 64-22.

Rolling Thin Film Oven

The Rolling Thin Film Oven (RTFO) test simulates the aging that occurs in asphalt plants during manufacturing of hot mix asphalt (7). Thus, while a series of tests were performed on the unaged binder, some of the binder was aged using the RTFO in order to continue checking this asphalt against the specification. Tests were conducted on the RTFO-aged binders using a dynamic shear rheometer.

Pressure Aging Vessel

The pressure aging vessel (PAV) creates a long-term aged binder. It is intended to simulate the aging that occurs in the actual pavement after several years of service. In PAV, the binder is aged under a pressure of 2070 KPa and at 100 °C for 20 hours. For this study, tests were conducted on the PAV-aged binder using a dynamic shear rheometer to determine the stiffness of the asphalt after long-term aging.

Rotational Viscometer

The rotational viscosity test (ASTM D 4402) was used to characterize the viscosity of the asphalt at high construction temperatures (7). High-temperature viscosity is measured to ensure that the asphalt is fluid enough for pumping, mixing, and compaction. Mixing and compaction temperatures used in this project were 135 ºC and 150 ºC, respectively.

Dynamic Shear Rheometer

The Dynamic Shear Rheometer (DSR) test (AASHTO TP 5) is used to characterize binder stiffness and visco-elastic properties (7). It measures the complex shear modulus (G*) and the phase angle (δ) when loaded in an oscillatory shear mode. In the Superpave system, binder stiffness is designated by the stiffness parameter $G^*/\sin\delta$. Binder properties are generally measured in three states: the unaged binder, the RTFO-aged binder, and the RTFO-PAV-aged binder at the required temperatures shown in Appendix C.

$G^*/\sin\delta$ values for the binder used in this research project were 1.15 KPa for the original binder and 2.46 KPa for the RTFO aged asphalt binder at 64 °C. The $G^*/\sin\delta$ value for PAV aged binder was 2.51 MPa at 25 °C.

Bending Beam Rheometer

The Bending Beam Rheometer (BBR) is used to characterize the low-temperature stiffness and relaxation properties of binders (7). For this test, only the PAV-aged binders were used. Creep stiffness (S) and logarithmic creep rate *(m)* were the two important properties determined with this test. Specification requirements are shown in Appendix C.

The creep stiffness value for the binder used in this study was 138 MPa, and the *m* value was 0.32, both reported at -12 °C.

AGGREGATE TESTING REQUIREMENTS

Gradation

Aggregate gradations were selected according to Superpave gradation requirements. Gradation control is based on four control sieves and the restricted zone. The four control sieves are the maximum sieve, the nominal maximum sieve, the 2.36 mm sieve and the 75 micron sieve. The restricted zone is an area on either side of the maximum density line. For different nominal sizes, the restricted zone starts and ends at different sieve sizes.

Specific Gravity of Aggregates

The specific gravity of an aggregate is, by definition, the ratio of the mass of a unit of volume of the material to the mass of an equal volume of water at 25 ºC. The procedure for determining specific gravity of coarse and fine aggregates is outlined in AASHTO T 85 and AASHTO T 84, respectively. The combined bulk specific gravity of aggregate blend is computed by:

$$G_{sb} = \frac{P_1 + P_2 + ... + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + ... + \frac{P_n}{G_n}}$$

where

G_{sb} = combined bulk specific gravity of the aggregate blend

$G_1, G_2, \ldots G_n$ = specific gravity values for fractions 1, 2, …, n

$P_1, P_2, \ldots P_n$ = mass percentages of fractions 1, 2, …, n

Aggregate Properties

Aggregate requirements in Superpave involve consensus and source properties. Consensus aggregate requirements are critical and need to be achieved in all cases to arrive at a well-performing hot mix asphalt. Consensus aggregate requirements are applied to coarse aggregate angularity, fine aggregate angularity, flat and elongated particles, and clay content. Source aggregate requirements are intended to be established by local agencies based on their experience with local materials. Source properties include toughness, soundness, and percentage of deleterious materials (5).

Consensus Aggregate Requirements

Coarse Aggregate Angularity:

This property ensures a high degree of aggregate internal friction and rutting resistance. It is defined as the mass percentage of aggregates larger than 4.75 mm with one or more fractured faces. A fractured face is defined as any mechanically induced fractured surface that is larger than 25 percent of the largest projected face (5).

Fine Aggregate Angularity:

This property ensures a high degree of fine aggregate internal friction and rutting resistance. It is defined as the volume percentage of air voids present in loosely compacted aggregates smaller than 2.36 mm. Higher void contents imply more angular fine aggregate. The air void content is computed by:

$$\text{Void Content} = \frac{V - \dfrac{M}{G_{sb}}}{V} \text{ x } 100$$

where

V = volume of test cylinder (100 cm^3)

M = mass of loosely compacted sample

G_{sb} = bulk specific gravity of fine aggregate

Flat and Elongated Particles:

Flat and elongated particles are considered to be those particles that have a maximum to minimum dimension of greater than a specified ratio. Superpave uses a maximum to minimum dimension of 5 to 1 as a discriminating value. Elongated particles are undesirable because they have a tendency to degrade by breaking during handling, manufacturing, and construction. These particles are presented as the percentage by mass of coarse aggregate (5).

Clay Content:

Clay content is the percentage of clay or silty material contained in the aggregate fraction that is finer than a 4.75 mm sieve.

Source Properties

Soundness:

Soundness is the percent loss of materials from an aggregate blend during the sodium or magnesium sulfate soundness test. This test estimates the resistance of aggregate to weathering while in service.

Toughness:

Toughness is the percentage loss of material from an aggregate blend when tested using the Los Angeles abrasion apparatus. This test estimates the resistance of coarse aggregate to mechanical degradation during handling, construction, and in service.

Deleterious Materials:

Deleterious materials are defined as the mass percentage of contaminants, such as shale, mica, and coal, in the blended aggregate.

VOLUMETRIC TEST REQUIREMENTS

Compacted specimens were required to be mixed and compacted under equiviscous temperature conditions corresponding to 0.170 Pa•sec and 0.280 Pa•sec, respectively. Bulk samples of plant produced HMA mixture were compacted in the SGC and analyzed according to the procedure specified in the Superpave mix design manual.

Volumetric mixture properties were determined in accordance with AASHTO MP 2, "Superpave Volumetric Mix Design." These mixture properties were determined as part of this experiment.

The maximum theoretical specific gravity (G_{mm}) was obtained from a loose mix sample. The bulk specific gravity of the compacted specimen (G_{mb}) was obtained from the compacted specimens at $N_{maximum}$. Properties at N_{design} were determined using the procedures described in the Superpave mix design manual. By knowing the G_{mb} at $N_{maximum}$, the specimen height at $N_{maximum}$, and the specimen height at N_{design}, it is possible to compute G_{mb} and any other mix property at N_{design}.

Table 3.1. Superpave mixture design tests on HMA

Test Name	**Standard Protocol**	**No. of Tests**	**No. of Replicate Samples per Test**
Gyratory Compaction at design asphalt content at $N_{maximum.}$	AASHTO M 002	1	6
Gyratory Compaction at 7% Air Voids	AASHTO M 002	1	6
Bulk Specific Gravity	AASHTO T 166	1	6
Maximum Specific Gravity	AASHTO T 209	1	2
Moisture Susceptibility	AASHTO T 283	1	6
Volume Percent of Air Voids	AASHTO PP 19	1	6
Percent Voids in Mineral Aggregate	AASHTO PP 19	1	6
Percent Voids Filled with Asphalt	AASHTO PP 19	1	6

Another Superpave mixture requirement is dust proportion. This is computed by:

$$DP = \frac{P_{.075}}{P_{be}}$$

where

DP = dust proportion
$P_{.075}$ = percent by mass of total aggregate passing 0.075 mm sieve
P_{be} = percent effective asphalt content by mass of total mix

ASPHALT MIXTURES

For this project, all four Superpave mixes were designed and produced at the South Central Superpave Center. Appendix A contains mix gradation and volumetric properties.

Mix 1 (12.5 mm coarse) serves as the laboratory standard mix for the South Central Superpave Center. It is used for routine experimental purposes and training activities. A very similar mix was used to overlay a section of Business IH-35 in New Braunfels, Texas. It is composed of 90 percent crushed limestone and 10 percent natural sand. The design asphalt binder content is 5.7 percent.

Mix 2 (19 mm coarse) was designed and used for an overlay of US 79 near Taylor, Texas. It is composed of 30 percent sandstone coarse aggregate and 70 percent crushed limestone. The design asphalt binder content is 4.8 percent.

Mix 3 (19 mm fine) is composed of the same materials as Mix 2 with different blend percentages to achieve a gradation above the Superpave restricted zone. The design asphalt binder content is 5.1 percent.

Mix 4 (25 mm coarse) is composed entirely of crushed limestone from the same source as Mix 1. An additional coarse aggregate from the same supplier was obtained to achieve the 25 mm maximum size. The design asphalt binder content is 4.3 percent.

MIXING AND COMPACTION

Specimens were required to be mixed and compacted under equiviscous temperature conditions corresponding to 0.170 ± 0.02 Pa•sec and 0.280 ± 0.03 Pa•sec, respectively**.** (Appendix E shows a temperature-viscosity chart for the project binders.) The materials were mixed at a temperature of 150 ºC. After mechanically mixing, the loose specimens were spread in a pan to a thickness of about 21 to 22 kg per square meter and aged in a forced draft oven at 135 ºC for 4 hours. To simplify the experiment and reduce variability, the compaction temperature was selected to be the same as the aging temperature, 135 ºC.

As required by AASHTO PP 35, a single operator was used throughout the experiment for the compaction process. Working closely with the compaction operator, a different operator was used for mixing. A mixing and compaction cycle of 15 minutes was used; that is, there was a constant 15-minute interval between mixing of specimens and, likewise, a constant interval of 15 minutes between compaction of specimens. A short-term aging period of 4 hours was used. Each day twelve specimens were produced. The experiments were conducted over a period of 4 days.

Oven temperatures were verified prior to the experiments and daily throughout the mixing and compaction process. A calibrated thermocouple with digital readout was employed. The determination of bulk specific gravity (G_{mb}) was accomplished according to AASHTO T 166, Method A. The calibration of the balance used for this activity was verified before and after the experiments.

EQUIPMENT CHECKS AND CALIBRATION

Prior to the experiments, the compactors were thoroughly checked on-site by the manufacturer to ensure they were in proper working order. The proper methods of verification of calibration were meticulously reviewed and understood.

In an effort to explain testing variation to the greatest extent possible, the verification of calibration items was accomplished before the experiments commenced and before each day's compaction activities for both compactors. The calibration items were compaction angle, compaction pressure, height measurement, and rotational speed. The information regarding the daily calibration checks is presented in Appendix F.

EXPERIMENTAL DESIGN

A randomized test sequence was used as described in AAHTO PP 35. This ensured that systematic or unnoticed errors in the experiment would be randomly distributed among all the data. Three response variables were collected and analyzed for each specimen:

- G_{mb} at $N_{initial}$
- G_{mb} at N_{design}
- G_{mb} at $N_{maximum}$

The G_{mb} at $N_{maximum}$ was a measured value. The other response variables were computed by the following equation:

$$G_{mb} \text{ at x gyrations} = (h_{max} / h_x) \text{ X } G_{mb} \text{ at } N_{maximum}$$

where

h_{max} = specimen height at $N_{maximum}$

h_x = specimen height at x gyrations

Comparisons were conducted according to AASHTO PP 35. For a given mix, the average and standard deviations in G_{mb} for each compactor were computed. The protocol states that any candidate compactor having an average G_{mb} that differs 0.010 or more from the referee SGC will not be considered comparable. And while AASHTO PP 35 also requires that the variation in G_{mb} be analyzed, the evaluation is more qualitative. According to the protocol, the standard deviations are observed and should be comparable.

CHAPTER 4. EXPERIMENTAL RESULTS

STATISTICAL ANALYSIS OF DATA

The experiment proceeded in accordance with the initial plan. The compactors also remained within calibration.

The G_{mb} values at $N_{initial}$, N_{design}, and $N_{maximum}$, for all experiments are shown in Appendix F. In this chapter, only the summary tables of average G_{mb} values and standard deviation values are included. The comparison was made according to the following specification:

> *Null Hypothesis*: For a given mix, the G_{mb} of a candidate compactor is the same as the G_{mb} of a referee compactor.
>
> *Alternate Hypothesis*: For a given mix, the G_{mb} of a candidate compactor is not the same as the G_{mb} of a referee compactor.
>
> *Criteria*: Reject null hypothesis and accept alternate hypothesis if
> $| G_{mb} \text{ (evaluated) - } G_{mb} \text{ (candidate)}| \geq 0.010$.

The referee compactor used in seven out of the eight comparisons was the Pine Model AFGC125X. In one comparison, the Troxler Model No. 4140 was used as the referee compactor.

RAINHART VERSUS PINE

Tables 4.1 through 4.3 show the average G_{mb} values, the standard deviation of G_{mb} values, and the difference in G_{mb} values for Rainhart and Pine SGCs.

Table 4.1. Average G_{mb} values for Rainhart and Pine SGCs

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Mix	Rainhart	Pine	Rainhart	Pine	Rainhart	Pine
1	2.029	2.031	2.303	2.302	2.341	2.341
2	2.061	2.061	2.360	2.358	2.396	2.394
3	2.166	2.168	2.384	2.386	2.402	2.405
4	2.034	2.042	2.324	2.324	2.362	2.361

Table 4.2. Standard deviation of G_{mb} values for Rainhart and Pine SGCs

Mix	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$		Mix
	Rainhart	Pine	Rainhart	Pine	Rainhart	Pine	Average
1	0.008	0.012	0.006	0.009	0.006	0.008	0.008
2	0.006	0.009	0.004	0.007	0.004	0.005	0.006
3	0.015	0.008	0.004	0.005	0.003	0.005	0.007
4	0.011	0.012	0.012	0.010	0.010	0.008	0.011
Average	0.010	0.010	0.007	0.008	0.006	0.007	0.008

Table 4.3. Difference in G_{mb} between Pine and Rainhart Compactors

Mix	G_{mb} at $N_{initial}$	G_{mb} at N_{design}	G_{mb} at $N_{maximum}$
1	0.002	-0.001	0.000
2	0.000	-0.002	-0.002
3	0.002	0.002	0.003
4	0.008	0.000	-0.001
Average	0.003	0.001	0.002

As it can be seen from Table 4.3, all of the comparisons of G_{mb} meet the AASHTO PP 35 test for comparability. The average G_{mb} differences in the Pine and Rainhart compactors are 0.003, 0.001, and 0.002 at $N_{initial}$, N_{design}, and $N_{maximum}$, respectively. In other words, all twelve comparisons have differences in G_{mb} values that are less than 0.010. It appears that the two compactors exhibit almost identical standard deviations (Table 4.3).

TEST QUIP VERSUS PINE

Tables 4.4 and 4.5 show the average G_{mb} values and the standard deviation of G_{mb} values for Test Quip and Pine SGCs.

Table 4.4. Average G_{mb} values for Test Quip and Pine SGCs

Mix	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
	Test Quip	Pine	Test Quip	Pine	Test Quip	Pine
1	2.029	2.039	2.297	2.304	2.338	2.342
2	2.064	2.072	2.361	2.362	2.398	2.399
3	2.182	2.182	2.392	2.391	2.404	2.407
4	2.050	2.057	2.317	2.315	2.357	2.353

Table 4.5. Standard deviation of G_{mb} values for Test Quip and Pine SGCs

Mix	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$		Mix Average
	Test Quip	Pine	Test Quip	Pine	Test Quip	Pine	
1	0.010	0.006	0.005	0.003	0.005	0.003	0.006
2	0.007	0.003	0.009	0.006	0.006	0.005	0.006
3	0.015	0.005	0.011	0.005	0.010	0.005	0.008
4	0.013	0.005	0.012	0.007	0.010	0.007	0.009
Average	0.011	0.005	0.009	0.005	0.008	0.005	0.007

According to Table 4.5, there are differences in the standard deviations of the compactors. The Test Quip compactor produced G_{mb} values that were about twice as variable in comparison with those of the Pine compactor. The Pine standard deviation values were consistently 0.005. On the other hand, the Test Quip standard deviation values ranged from 0.008 to 0.011. No definite cause can be assigned to this variability. However, a possible explanation is the proficiency of the operator: The operator conducting the compaction had considerable experience with the Pine compactor and relatively less experience with the Test Quip compactor.

In Table 4.6, the differences in G_{mb} values are shown. The numbers represent the difference in Pine and Test Quip G_{mb} values. The shaded cell indicates the difference that equals or exceeds the discriminating value of 0.010.

Table 4.6. Difference in G_{mb} between Test Quip and Pine compactors

Mix	G_{mb} at $N_{initial}$	G_{mb} at N_{design}	G_{mb} at $N_{maximum}$
1	0.010	0.007	0.004
2	0.007	0.001	0.001
3	0.000	-0.001	0.003
4	0.007	-0.001	-0.004
Average	0.006	0.003	0.003

Once again, the results in Table 4.6 indicate that AASHTO PP 35 criteria for comparability are satisfied. The average differences in the Test Quip and Pine compactors are 0.006, 0.003, and 0.003 at $N_{initial}$, N_{design}, and $N_{maximum}$, respectively. Overall, eleven out of twelve (92 percent) total comparisons have differences in G_{mb} that are less than 0.010. At $N_{initial}$, the comparison for Mix 1 showed a difference in G_{mb} greater than 0.010. It can be concluded that the trend for the Test Quip compactor is to exhibit a G_{mb} slightly smaller than that of the Pine compactor.

TROXLER MODEL NO. 4141 VERSUS TROXLER MODEL NO. 4140

In this experiment, the Troxler SGC Model No. 4141 was evaluated by comparing it with the Troxler SGC Model No. 4140. These two devices were referred to as “new Troxler” and “old Troxler.” The average G_{mb} values, the standard deviations, and the differences in G_{mb} values are shown in Tables 4.7 through 4.9, respectively.

Table 4.7. Average G_{mb} values for Troxler and Pine SGCs

Mix	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
	New Troxler	Old Troxler	New Troxler	Old Troxler	New Troxler	Old Troxler
1	2.022	2.027	2.281	2.282	2.322	2.320
2	2.070	2.075	2.360	2.364	2.399	2.399
3	2.168	2.171	2.385	2.384	2.405	2.402
4	2.047	2.043	2.319	2.312	2.359	2.351

Table 4.8. Standard deviation of G_{mb} values for Troxler and Pine SGCs

Mix	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$		Mix Average
	New Troxler	Old Troxler	New Troxler	Old Troxler	New Troxler	Old Troxler	
1	0.009	0.006	0.010	0.005	0.010	0.005	0.007
2	0.006	0.007	0.007	0.007	0.005	0.005	0.006
3	0.011	0.009	0.006	0.005	0.005	0.004	0.007
4	0.005	0.010	0.008	0.006	0.008	0.006	0.007
Average	0.008	0.008	0.008	0.006	0.007	0.005	0.007

Table 4.9. Difference in G_{mb} between old and new Troxler compactors

Mix	G_{mb} at $N_{initial}$	G_{mb} at N_{design}	G_{mb} at $N_{maximum}$
1	0.005	0.001	-0.002
2	0.005	0.004	0.000
3	0.003	-0.001	-0.002
4	-0.004	-0.007	-0.008
Average	0.004	0.003	0.003

From Table 4.9, it is obvious that all the comparisons of G_{mb} meet the AASHTO PP 35 test for comparability. The average differences in G_{mb} values are 0.004, 0.003, and 0.003 at $N_{initial}$, N_{design}, and $N_{maximum}$, respectively. In other words, all twelve comparisons show differences in G_{mb} of less than 0.010. The new Troxler compactor exhibits a slightly higher

G_{mb} at $N_{maximum}$ than the old Troxler compactor. The standard deviation values in Table 4.8 indicate that there is not a significant difference in the variability of results.

PINE MODEL AFG1A VERSUS PINE MODEL AFGC125

In this experiment, the Pine SGC Model AFG1A was evaluated using Pine SGC Model AFGC125X. These two devices were called “new Pine” and “old Pine” models, respectively. Table 4.10 provides the average G_{mb} values while Table 4.11 gives the standard deviation values for New Pine and Old Pine SGCs.

Table 4.10. Average G_{mb} values for Pine versus Pine

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Mix	New Pine	Old Pine	New Pine	Old Pine	New Pine	Old Pine
1	2.036	2.035	2.305	2.304	2.342	2.342
2	2.059	2.062	2.355	2.351	2.390	2.385
3	2.165	2.175	2.387	2.389	2.401	2.404
4	2.043	2.051	2.324	2.330	2.359	2.366

Table 4.11. Standard deviation of G_{mb} values for Pine versus Pine

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$		Mix
Mix	New Pine	Old Pine	New Pine	Old Pine	New Pine	Old Pine	Average
1	0.005	0.004	0.005	0.004	0.005	0.002	0.004
2	0.008	0.008	0.010	0.011	0.009	0.007	0.009
3	0.016	0.005	0.006	0.004	0.004	0.004	0.007
4	0.009	0.006	0.012	0.006	0.012	0.005	0.008
Average	0.010	0.006	0.008	0.006	0.007	0.005	0.007

The differences in G_{mb} values for old Pine and new Pine are presented in Table 4.12. The shaded cell indicates the difference that equals or exceeds the discriminating value of 0.010.

Table 4.12. Difference in G_{mb} between new and old Pine Compactors

Mix	G_{mb} at $N_{initial}$	G_{mb} at N_{design}	G_{mb} at $N_{maximum}$
1	-0.001	-0.002	0.000
2	0.003	-0.003	-0.005
3	0.010	0.003	0.003
4	0.008	0.006	0.007
Average	0.006	0.004	0.004

From Table 4.12, it is obvious that the G_{mb} values satisfy the AASHTO PP 35 test for comparability. The average differences in the New and Old Pine compactors are 0.006, 0.004, and 0.004 at $N_{initial}$, N_{design}, and $N_{maximum}$, respectively. Overall, eleven out of twelve (92 percent) comparisons have difference in G_{mb} that are less than 0.010. Only in one case, for Mix 3, is there a difference in G_{mb} equal to 0.010 at $N_{initial}$. The trend for the new Pine compactor is to exhibit a G_{mb} slightly smaller than that of the old Pine compactor, as verified by the positive numbers in Table 4.12.

The standard deviation values in Table 4.11 demonstrate that there is a slight difference between compactors. The new Pine compactor produced G_{mb} values that were slightly more variable when compared to the old Pine compactor. The old Pine standard deviation values were very consistent at about 0.006. The new Pine standard deviation values ranged from 0.005 to 0.010. There is no obvious explanation for this variability.

INTERLAKEN VERSUS PINE

Table 4.13 summarizes the average G_{mb} values, while Table 4.14 contains the standard deviation of G_{mb} values for Interlaken (ITC) and Pine SGCs. The differences in G_{mb} values (Pine G_{mb} minus ITC G_{mb}) are presented. The shaded cells in Table 4.15 indicate differences that equal or exceed the discriminating value of 0.010.

Table 4.13. Average G_{mb} values for Interlaken and Pine SGCs

Mix	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
	ITC	Pine	ITC	Pine	ITC	Pine
1	2.039	2.038	2.303	2.313	2.344	2.352
2	2.078	2.084	2.360	2.365	2.396	2.405
3	2.195	2.197	2.408	2.406	2.420	2.418
4	2.059	2.061	2.324	2.338	2.361	2.373

Table 4.14. Standard deviation of G_{mb} values for Interlaken and Pine SGCs

Mix	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$		Mix Average
	ITC	Pine	ITC	Pine	ITC	Pine	
1	0.009	0.010	0.005	0.010	0.006	0.010	0.008
2	0.010	0.003	0.012	0.002	0.011	0.002	0.007
3	0.012	0.007	0.009	0.003	0.007	0.003	0.007
4	0.014	0.007	0.009	0.009	0.010	0.008	0.010
Average	0.011	0.007	0.009	0.006	0.008	0.006	0.008

Table 4.15. Difference in G_{mb} between Interlaken and Pine SGCs

Mix	G_{mb} at $N_{initial}$	G_{mb} at N_{design}	G_{mb} at $N_{maximum}$
1	-0.001	0.010	0.008
2	0.005	0.004	0.009
3	0.002	-0.002	-0.001
4	0.002	0.014	0.012
Average	0.003	0.008	0.008

From Table 4.16, it is evident that the majority of comparisons of G_{mb} values meet the AASHTO PP 35 test for comparability. The average differences in the ITC and Pine compactors are 0.003, 0.008, and 0.008 at $N_{initial}$, N_{design}, and $N_{maximum}$, respectively. Overall, nine out of twelve (75 percent) total comparisons have differences in G_{mb} that are less than 0.010. The comparisons for Mix 4 showed differences in G_{mb} greater than 0.010. The trend for the ITC compactor is to exhibit a G_{mb} smaller than that of the Pine compactors. This is evidenced by the mostly positive values in Table 4.15.

Based on the standard deviation values presented in Table 4.14, it does not appear that there are differences between compactors. The ITC compactor produced less variable results than the Pine compactor for Mix 1, but more variable results for Mixes 2, 3, and 4. Overall, the standard deviations of G_{mb} were similar and within the range of 0.006 to 0.011.

UPDATED INTERLAKEN VERSUS PINE

Table 4.16 contains the average G_{mb} values and Table 4.17 shows the standard deviation of G_{mb} values for updated Interlaken (Up ITC) and Pine SGCs.

Table 4.16. Average G_{mb} Values for updated Interlaken and Pine

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Mix	Up ITC	Pine	Up ITC	Pine	Up ITC	Pine
1	2.031	2.029	2.301	2.297	2.340	2.336
2	2.073	2.068	2.355	2.358	2.392	2.393
3	2.168	2.164	2.381	2.381	2.401	2.402
4	2.039	2.043	2.317	2.321	2.356	2.357

Table 4.17. Standard deviation of G_{mb} values for updated Interlaken and Pine

Mix	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$		Mix Average
	Up ITC	Pine	Up ITC	Pine	Up ITC	Pine	
1	0.010	0.003	0.007	0.003	0.006	0.003	0.005
2	0.007	0.008	0.004	0.010	0.005	0.006	0.007
3	0.004	0.007	0.005	0.005	0.004	0.004	0.005
4	0.007	0.015	0.007	0.013	0.007	0.011	0.010
Average	0.007	0.008	0.006	0.008	0.006	0.006	0.007

Table 4.18. Difference in G_{mb} between Pine and updated ITC Compactors

Mix	G_{mb} at $N_{initial}$	G_{mb} at N_{design}	G_{mb} at $N_{maximum}$
1	-0.002	-0.004	-0.004
2	-0.005	0.003	0.001
3	-0.004	0.000	0.001
4	0.004	0.004	0.001
Average	0.004	0.003	0.002

Table 4.18 shows the differences in G_{mb} values. The numbers are Pine G_{mb} minus ITC G_{mb}. From this table, it can be seen that all the comparisons of G_{mb} meet the AASHTO PP 35 test for comparability. The average differences in the Pine and updated ITC compactors are 0.004, 0.003, and 0.002 at $N_{initial}$, N_{design}, and $N_{maximum}$, respectively. In other words, all of the comparisons have differences in G_{mb} that are less than 0.010. It appears that the two compactors exhibit almost identical standard deviations (Table 4.17). The Pine compactor exhibited a relatively high standard deviation for Mix 4, a consequence of a relatively low value for just one of the specimens. However, even this low value remained within the individual specimen tolerance of 0.020 as required in AASHTO PP 35.

PINE MODEL AFGC125X VERSUS PINE MODEL AFGC125X

In this experiment, two Pine SGC AFGC125X models were compared using AASHTO PP 35. In this experiment, the two SGCs are simply referred to as “TX Pine” and “UT Pine.” TX Pine is located at TxDOT’s material laboratory, while UT Pine is located at the South Central Superpave Center at The University of Texas at Austin.

The average G_{mb} values, the corresponding standard deviations, and the differences in G_{mb} values are presented in Tables 4.19 through 4.21, respectively.

Table 4.19. Average G_{mb} values for UT Pine and TX Pine SGCs

Mix	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
	TX Pine	UT Pine	TX Pine	UT Pine	TX Pine	UT Pine
1	2.029	2.032	2.298	2.294	2.336	2.332
2	2.069	2.066	2.358	2.358	2.397	2.395
3	2.171	2.172	2.386	2.385	2.406	2.404
4	2.033	2.038	2.318	2.317	2.357	2.357

Table 4.20. Standard deviation of G_{mb} values for UT Pine and TX Pine SGCs

Mix	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$		Mix Average
	TX Pine	UT Pine	TX Pine	UT Pine	TX Pine	UT Pine	
1	0.003	0.018	0.005	0.004	0.007	0.003	0.007
2	0.010	0.006	0.010	0.007	0.007	0.007	0.008
3	0.011	0.011	0.007	0.008	0.006	0.005	0.008
4	0.012	0.020	0.010	0.008	0.010	0.007	0.011
Average	0.009	0.014	0.008	0.007	0.008	0.006	0.008

Table 4.21. Difference in G_{mb} between TX Pine and UT Pine SGCs

Mix	G_{mb} at $N_{initial}$	G_{mb} at N_{design}	G_{mb} at $N_{maximum}$
1	0.002	0.004	0.004
2	0.003	0.001	0.001
3	0.001	0.001	0.002
4	0.005	0.002	0.000
Average	0.003	0.002	0.002

Based on the comparisons of G_{mb} values, the AASHTO PP 35 test for comparability is satisfied. The average differences in the UT Pine and TX Pine compactors are 0.003, 0.002, and 0.002 at $N_{initial}$, N_{design}, and $N_{maximum}$, respectively. In other words, all of the comparisons have differences in G_{mb} that are less than 0.010. The two compactors exhibit almost identical standard deviations (Table 4.20).

PINE MODEL AFGC125X VERSUS TROXLER MODEL NO. 4140

In this experiment, a Pine SGC Model AFGC125X was compared with a Troxler Model No. 4140 using AASHTO PP 35. Table 4.22 summarizes the average G_{mb} values and Table 4.23 contains the standard deviation of G_{mb} values for the Pine and Troxler SGCs.

Table 4.22. Average G_{mb} values for Pine and Troxler SGCs

Mix	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
	Pine	Troxler	Pine	Troxler	Pine	Troxler
1	2.030	2.021	2.298	2.272	2.336	2.318
2	2.070	2.071	2.358	2.350	2.397	2.391
3	2.171	2.167	2.386	2.381	2.406	2.403
4	2.033	2.047	2.318	2.319	2.357	2.352

Table 4.23. Standard deviation of G_{mb} values for Pine and Troxler SGCs

Mix	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$		Mix Average
	Pine	Troxler	Pine	Troxler	Pine	Troxler	
1	0.003	0.004	0.004	0.004	0.004	0.004	0.004
2	0.006	0.010	0.007	0.011	0.007	0.010	0.008
3	0.019	0.010	0.010	0.005	0.008	0.005	0.009
4	0.006	0.010	0.005	0.006	0.004	0.006	0.006
Average	0.009	0.008	0.007	0.007	0.006	0.006	0.007

Table 4.24. Difference in G_{mb} values for Pine and Troxler SGCs

Mix	G_{mb} at $N_{initial}$	G_{mb} at N_{design}	G_{mb} at $N_{maximum}$
1	0.009	0.026	0.028
2	-0.001	0.008	0.006
3	0.004	0.005	0.003
4	-0.015	-0.001	0.005
Average	0.007	0.010	0.011

Table 4.24 shows the differences in G_{mb} values. The numbers are Pine minus Troxler G_{mb}. The average differences of G_{mb} values for the Pine and Troxler compactors are 0.007, 0.010, and 0.011 at $N_{initial}$, N_{design}, and $N_{maximum}$, respectively. In this comparison, the Pine and Troxler compactors are comparable at nine out of twelve times (75 percent). Again, it appears that the two compactors exhibit almost identical standard deviations (Table 4.23).

COMPARISON OF COMPACTORS USING T-TEST

The comparison between compactors was repeated using a heteroscedastic t-test, which is a method of comparing two sample means assuming unequal sample variances. The following specification was used:

- *Null Hypothesis*: For a given mix, the G_{mb} of a candidate compactor is the same as the G_{mb} of an evaluated compactor.
- *Alternate Hypothesis*: For a given mix, the G_{mb} of a candidate compactor is not the same as the G_{mb} of an evaluated compactor.
- *Criteria:* Reject null hypothesis and accept alternate hypothesis if $t > t_{crit}$ using $\alpha=0.05$.

Results of these comparisons are given in Tables 4.25 and 4.26.

Table 4.25. Summary of compactor comparisons using t-test

	Rainhart versus Pine			Test Quip versus Pine			New Troxler versus Old Troxler		
	$N_{initial}$	N_{design}	N_{max}	$N_{initial}$	N_{design}	N_{max}	$N_{initial}$	N_{design}	N_{max}
Mix 1	Y	Y	Y	N	N	N	Y	Y	Y
Mix 2	Y	Y	Y	N	Y	Y	Y	Y	Y
Mix 3	Y	Y	Y	Y	Y	Y	Y	Y	Y
Mix 4	Y	Y	Y	Y	Y	Y	Y	Y	Y

Table 4.26. Summary of compactor comparisons using t-test

	New Pine versus Pine			ITC versus Pine			Updated ITC versus Pine			Pine versus Pine		
	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}
Mix 1	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y
Mix 2	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Mix 3	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Mix 4	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

The shaded cells in Tables 4.25 and 4.26 represent those comparisons where the AASHTO PP 35 did not agree with the t-test comparison. Overall, both comparison methods agree very closely. Using the discriminating value of 0.010 for G_{mb} produced results very close to those obtained from the t-test.

COMPARISON OF MIXES PRODUCED AT DIFFERENT TIMES

Most of the compactors were compared with the Pine compactor. For each comparison a new set of specimens was prepared. During a period of 1 year, seven sets of twenty-four specimens were compacted with the same Pine compactor and by the same operator.

The comparison between mixes was performed using the analysis of variance (ANOVA) test. This analysis is performed to test the hypothesis that the means of two or more samples are equal (drawn from populations with the same mean). The following specification was used:

- *Null Hypothesis*: For a given mix, the variances of G_{mb} values of the all sets are the same.
- *Alternate Hypothesis*: For a given mix, the variances of G_{mb} values of the all sets are not the same.
- *Criteria:* Reject null hypothesis and accept alternate hypothesis if $F > F_{crit}$ using $\alpha=0.05$.

Results of this comparison are given in Table 4.27. The critical value for F is 2.371 at the α level of 0.05. In Table 4.27 "N" means "reject null hypothesis" and "Y" means "do not reject the null hypothesis."

Table 4.27. Summary of results for the ANOVA test for the Pine compactor

	F values			P values			Result		
	$N_{initial}$	N_{design}	N_{max}	$N_{initial}$	N_{design}	N_{max}	$N_{initial}$	N_{design}	N_{max}
Mix 1	1.176	6.280	6.821	0.341	0.0002	$7x10^{-5}$	Y	N	N
Mix 2	6.968	1.685	6.763	$6x10^{-5}$	0.154	$8x10^{-5}$	N	Y	N
Mix 3	11.696	12.885	7.837	$4x10^{-7}$	$1x10^{-7}$	$2x10^{-5}$	N	N	N
Mix 4	4.227	4.893	4.236	0.003	0.001	0.003	N	N	N

Null hypotheses were rejected ten out of twelve times. Overall, the mixes were different, with such differences explained by the fact that during the 1-year period, the material produced in the quarry might have changed. The hardness of the rocks in the quarry may be different at different locations.

CONFIDENCE INTERVALS BASED ON TXDOT SPECIFICATIONS

In this research, four different mixes were produced and ninety-six specimens were prepared for each mix. The G_{mb} values were calculated at $N_{initial}$, N_{design}, and $N_{maximum}$. The averages of G_{mb} values and the standard deviation of G_{mb} values for each mix at $N_{initial}$, N_{design}, and $N_{maximum}$ are presented in Table 4.28 and Table 4.29, respectively.

TxDOT's "Special Specification for Superpave Hot Mix Asphaltic Concrete Pavement" recommends that the operating range for control of laboratory density during production should have an optimum density of 96.0 percent at N_{design}, plus or minus 1.0 percent (8). In this specification it states: "Laboratory density is a mixture design and process control parameter. If the laboratory density of the mixture produced has a value outside the range specified, the Contractor shall investigate the cause and take corrective action. If three consecutive test results fall outside the specified range, production shall cease unless test results or other information indicate, to the satisfaction of the Engineer, that the next mixture to be produced will be within the specified range.”

Table 4.28. Average G_{mb} values

Mix	G_{mb} at $N_{initial}$	G_{mb} at N_{design}	G_{mb} at $N_{maximum}$
1	2.031	2.297	2.336
2	2.069	2.358	2.395
3	2.174	2.388	2.405
4	2.045	2.321	2.359

Table 4.29. Standard deviation of G_{mb} values

Mix	G_{mb} at $N_{initial}$	G_{mb} at N_{design}	G_{mb} at $N_{maximum}$
1	0.005	0.010	0.009
2	0.007	0.004	0.005
3	0.010	0.008	0.006
4	0.009	0.006	0.005

This 1.0 percent tolerance range for air void content can be converted to the tolerance range for G_{mb} values using the average G_{mb} values of Table 4.28 and the maximum theoretical specific gravity. Tolerance ranges for G_{mb} values are given in Table 4.30.

Table 4.30. Tolerance ranges for G_{mb} at N_{design}

Mix	G_{mm}	G_{mb} at N_{design}	Air Voids %	Tolerance Range for Air Voids, %	Tolerance Range for G_{mb} at N_{design}
1	2.398	2.297	4.2	3.2 – 5.2	2.273 – 2.321
2	2.432	2.358	3.0	2.0 – 4.0	2.334 – 2.382
3	2.428	2.388	1.6	0.6 – 2.6	2.364 – 2.412
4	2.427	2.321	4.4	3.4 – 5.4	2.297 – 2.345

A total of 384 specimens were prepared (4 mixes x 96). The number of specimens is sufficiently large to assume a normal distribution for G_{mb} values. Because the standard deviation values were known, the confidence level for mixes could be calculated. The confidence level provides the probability that the measurements of one specimen’s G_{mb} is correct within the given tolerance range. Using the standard deviation values of Table 4.29, the confidence level for the tolerance ranges was calculated as shown in Table 4.31.

Table 4.31. Confidence levels for mixes

Mix	Tolerance Range for G_{mb} at N_{design}	Confidence Level, %
1	2.273 – 2.321	98.4
2	2.334 – 2.382	99.9
3	2.364 – 2.412	99.8
4	2.297 – 2.345	99.9

It can be observed that SGCs would give very similar results. Overall, Table 4.31 gives information about all eight SGCs. From the table, it can be seen that the system composed of those eight compactors will provide the same results within the given tolerance range throughout mix design and plant quality control.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Based on the experimental work conducted as part of this study, AASHTO PP 35 is an effective procedure for determining the suitability of new Superpave gyratory compactors (SGCs). It is a very straightforward experiment that yields meaningful results. This procedure provides a uniform approach to estimate the veracity of new SGCs. During the design and production of an asphalt mix, several different SGCs may be employed. The SGC used in the mix design stage may differ from that used in the plant for quality control. Accordingly, the SGC used for the plant quality acceptance may differ from that used for independent quality assurance testing. As a result it can be claimed that the uniformity between SGCs is an important matter.

Table 5.1. Comparison of results for compactors

Compactor	Comparison Result
New Rainhart	12 out of 12 times
New Troxler	12 out of 12 times
Updated ITC	12 out of 12 times
Test Quip	11 out of 12 times
New Pine	11 out of 12 times
ITC	9 out of 12 times

The procedure in AASHTO PP 35 was followed during the evaluation of the compactors. Using the discriminating value of 0.010 for G_{mb} as required in the AASHTO PP 35 protocol, the compactors were evaluated in terms of G_{mb} at the three levels of gyrations of interest. The results are given in Table 5.1.

Even with the discriminating value of 0.010, the FHWA Expert Task Group (ETG) protocol does not state the extent to which two compactors need to be "comparable" to be judged substantially the same. In making this judgment, one method is to compare the Pine and Troxler compactors. Thus, a compactor comparison experiment was conducted between those two compactors. The Pine and Troxler compactors were comparable nine out of twelve times. However, the Rainhart, Troxler, updated ITC, Test Quip, and the new Pine compactors compared with the old Pine compactor eleven or twelve times.

TxDOT's "Special Specification for Superpave Hot Mix Asphaltic Concrete Pavement" recommends that the operating range for control of laboratory density during production should be an optimum density of 96.0 percent at the N_{design}, plus or minus 1.0 percent. This 1.0 percent tolerance range for air void content was converted to the tolerance range for G_{mb} values using the average G_{mb} values of Table 4.28 and the maximum theoretical specific gravity values. It was found that all compactors would provide the same results within the given tolerance range throughout mix design and plant quality control.

RECOMMENDATIONS

In this experiment, extreme care was taken to ensure that variability in data was restricted as much as possible to variability induced by the compactors themselves. Users of these or any other laboratory compaction devices should be aware that comparability of results is considerably influenced by many other factors. Operator proficiency, oven size and quality, compactor operating condition, adherence to standard test procedures, and, of course, material variability are among the many factors that can influence the comparability of test results.

Prospective purchasers of SGCs should require that a manufacturer show that its new device has been rigorously evaluated according to the protocol and shown to be comparable. Such data constitute a baseline frame of reference from which other features may be used to make a purchasing decision. These features include cost, availability, operating features, field lab suitability, user friendliness, data acquisition, and management. If an agency or organization should prefer a particular model because of these or other factors, they can develop a purchasing specification accordingly.

REFERENCES

1. “Standard Practice for Evaluation of Superpave Gyratory Compactors,” American Association of State Highway and Transportation Officials, Designation PP 35-98, Washington, D.C., 1998.

2. McGennis, R. B., “Evaluation of Superpave Gyratory Compactors,” Internal Documents, South Central Superpave Center (SCSC), The University of Texas at Austin, September 1997 – June 1998.

3. Yildirim, Y., “Compactor Comparison Test between Two Pine Superpave Gyratory Compactors,” Internal Documents, SCSC, The University of Texas at Austin, January 1998.

4. Yildirim, Y., “Comparison of Superpave Gyratory Compactors According to AASHTO PP 35,” master’s thesis, The University of Texas at Austin, December 1998.

5. McGennis, R. B., R. M. Anderson, T. W. Kennedy, and M. Solaimanian, “Background of Superpave Asphalt Mixture Design and Analysis,” Federal Highway Administration (FHWA), FHWA-SA-95-003, Washington, D.C., February 1995.

6. “Superpave for the Generalist Engineer and Project Staff Participant Manual,” FHWA, FHWA HI 97-031, July 1997.

7. McGennis, R B., T. S. Shuler, and H. U. Bahia, “Background of Superpave Asphalt Binder Test Methods,” Federal Highway Administration, FHWA-SA-94-069, July 1994.

8. “Special Specification for Superpave Hot Mix Asphaltic Concrete Pavement,” Texas Department of Transportation, 1995.

APPENDIX A

AGGREGATE GRADATIONS

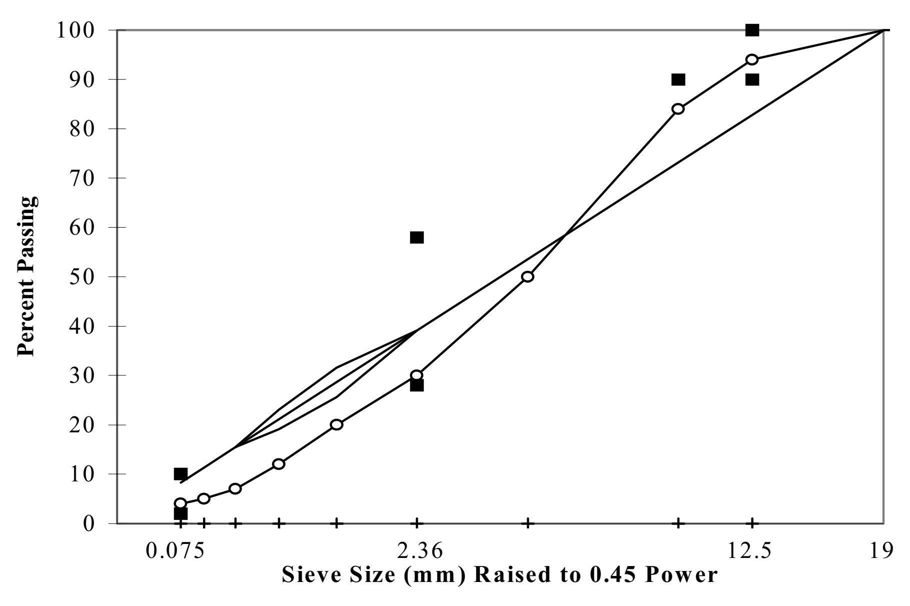


Figure A.1. Gradation of Mix 1 (12.5 mm coarse)

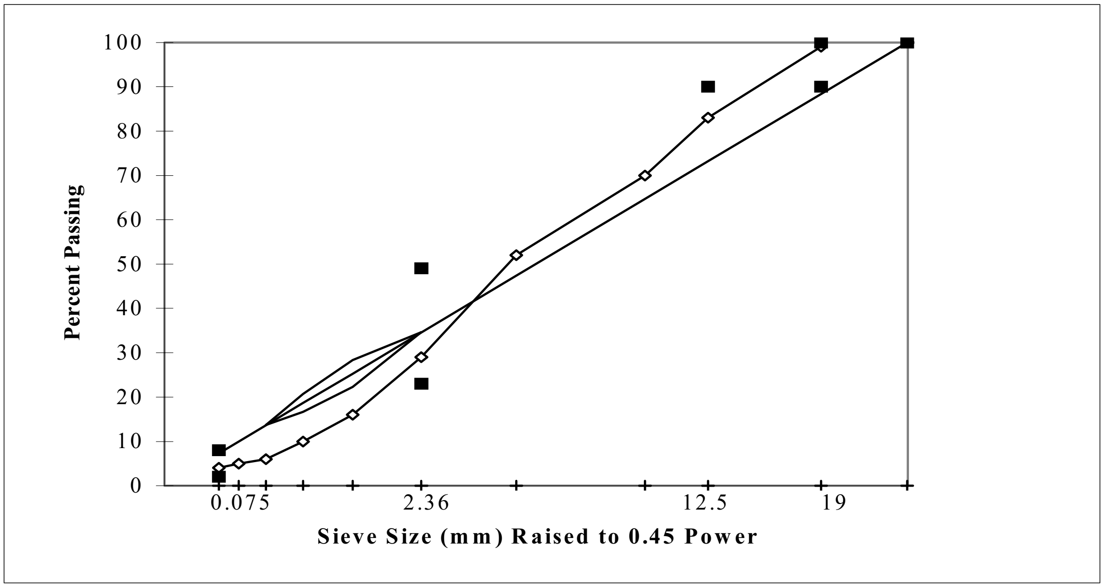


Figure A.2. Gradation of Mix 2 (19 mm coarse)

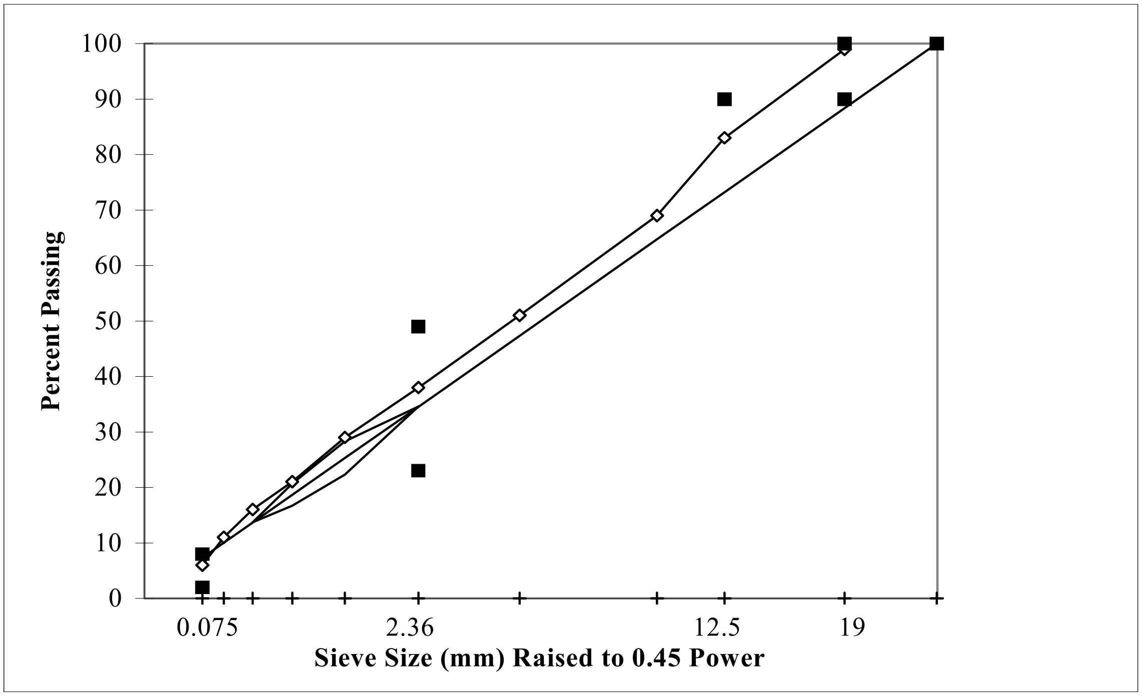


Figure A.3. Gradation of Mix 3 (19 mm fine)

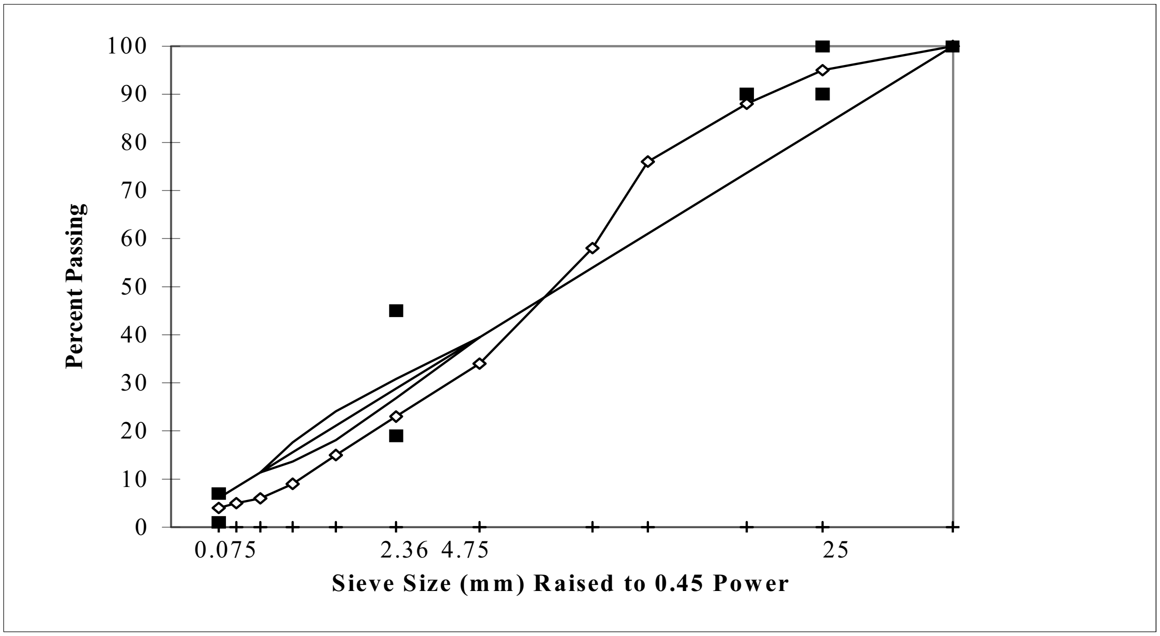


Figure A.4. Gradation of Mix 4 (25 mm coarse)

APPENDIX B

MIX PROPERTIES

Table B.1. Properties of the Mixes

	Mixes			
Parameter	1	2	3	4
Binder Content, %	5.7	4.8	5.1	4.1
Air Void Content, %	4.0	4.0	4.0	4.0
VMA, %	15.0	13.5	14.1	13.2
VFA, %	73.2	70.5	71.6	69.7
%G_{mm} at N_{ini}	84.6	84.0	86.9	84.4
%G_{mm} at N_{design}	96.0	96.0	96.0	96.0
%G_{mm} at N_{max}	97.6	97.6	97.1	97.4
Compaction Slope	10.0	10.6	9.1	11.6
Dust Proportion	0.6	1.0	1.2	0.8

Mixes 1, 2, and 4: N_{ini} = 8, N_{des} = 109, N_{max} = 174
Mix 3: N_{ini} = 7, N_{des} = 86, N_{max} = 134

APPENDIX C

SUPERPAVE BINDER SPECIFICATION

Performance Grade	PG 52							PG 58					PG 64					PG 70			
	-10	-16	-22	-28	-34	-40	-46	-16	-22	-28	-34	-40	-16	-22	-28	-34	-40	-10	-16	-22	-28
Average 7-day Maximum Pavement Design Temperature, °C [a]	<52							<58					<64					<70			
Minimum Pavement Design Temperature, °C [a]	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	>-22	>-28	>-34	>-40	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28
Original Binder																					
Flash Point Temp, T48: Minimum °C	230																				
Viscosity, ASTM D 4402 [b]: Maximum, 3 Pa·s (3000 cP), Test Temp, °C	135																				
Dynamic Shear, TP5 [c]: G*/sin δ, Minimum, 1.00 KPa Test Temperature at 10 rad/s, °C	52							58					64				70				
Rolling Thin Film Oven (T240)																					
Mass Loss, Maximum, %	1.00																				
Dynamic Shear, TP5: G*/sin δ, Minimum, 2.20 KPa Test Temp at 10 rad/sec, °C	52							58					64				70				
Pressure Aging Vessel Residue (PP1)																					
PAV Aging Temperature, °C[d]	90							100					100				100 (110)				
Dynamic Shear, TP5: G*sin δ, Maximum, 5000 KPa Test Temp at 10 rad/sec, °C	25	22	19	16	13	10	7	25	22	19	16	13	28	25	22	19	16	34	31	28	25
Physical Hardening [e]	Report																				
Creep Stiffness, TP1 [f]: S, Maximum, 300 MPa m value, Minimum, 0.300 Test Temp, at 60 sec, °C	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	-6	-12	-18	-24	-30	0	-6	-12	-18
Direct Tension, TP3 [f]: Failure Strain, Minimum, 1.0% Test Temp at 1.0 mm/min, °C	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	-6	-12	-18	-24	-30	0	-6	-12	-18

Notes:

a. Pavement temperatures can be estimated from air temperatures using an algorithm contained in theSuperpave software program or may be provided by the specifying agency or by following the procedures outlined in PPX.

b. This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

c. For quality control of unmodified asphalt cement production, measurement of the viscosity of the original asphalt cement may be substituted for dynamic shear measurements of G*/sin δ at test temperatures where the asphalt is a Newtonian fluid. Any suitable standard means of viscosity measurement may be used, including capillary or rotational viscometer (AASHTO T 201 or T 202).

d. The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures: 90°C, 100 °C, or 110 °C. The PAV aging temperature is 100 °C for PG 58- and above, except in desert climates, where it is 110 °C.

e. Physical Hardening - TP 1 is performed on a set of asphalt beams according to Section 13.1, except the conditioning time is extended to 24 hrs ± 10 minutes at 10 °C above the minimum performance temperature. The 24-hour stiffness and m-value are reported for information purposes only.

f. If the creep stiffness is below 300 MPa, the direct tension test is not required. If the creep stiffness is between 300 and 600MPa the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The m value requirement must be satisfied in both cases.

APPENDIX D

DETAILED DATA ON COMPARISON OF COMPACTORS

RAINHART VERSUS PINE

Table D.1. Bulk specific gravity data for Mix 1 (12.5 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	Rainhart	Pine	Rainhart	Pine	Rainhart	Pine
1	2.031	2.021	2.307	2.294	2.346	2.333
2	2.016	2.042	2.294	2.311	2.332	2.350
3	2.021	2.024	2.300	2.297	2.338	2.338
4	2.038	2.043	2.299	2.308	2.335	2.345
5	2.033	2.038	2.310	2.310	2.347	2.349
6	2.034	2.017	2.308	2.290	2.345	2.330
Avg	2.029	2.031	2.303	2.302	2.341	2.341
SD	0.008	0.012	0.006	0.009	0.006	0.008

Table D.2. Bulk specific gravity data for Mix 2 (19 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	Rainhart	Pine	Rainhart	Pine	Rainhart	Pine
1	2.067	2.064	2.361	2.361	2.397	2.397
2	2.056	2.071	2.355	2.356	2.393	2.394
3	2.066	2.051	2.366	2.350	2.400	2.388
4	2.054	2.055	2.355	2.358	2.390	2.394
5	2.068	2.054	2.362	2.353	2.397	2.391
6	2.057	2.070	2.360	2.369	2.396	2.401
Avg	2.061	2.061	2.360	2.358	2.396	2.394
SD	0.006	0.009	0.004	0.007	0.004	0.005

Table D.3. Bulk specific gravity data for Mix 3 (19 mm fine)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	Rainhart	Pine	Rainhart	Pine	Rainhart	Pine
1	2.162	2.167	2.388	2.382	2.407	2.400
2	2.174	2.176	2.386	2.393	2.403	2.412
3	2.177	2.173	2.385	2.386	2.401	2.404
4	2.174	2.154	2.383	2.379	2.399	2.399
5	2.137	2.171	2.378	2.386	2.401	2.402
6	2.171	2.164	2.385	2.389	2.403	2.410
Avg	2.166	2.168	2.384	2.386	2.402	2.405
SD	0.015	0.008	0.004	0.005	0.003	0.005

Table D.4. Bulk specific gravity data for Mix 4 (25 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	Rainhart	Pine	Rainhart	Pine	Rainhart	Pine
1	2.018	2.044	2.307	2.318	2.348	2.358
2	2.043	2.039	2.327	2.326	2.364	2.364
3	2.023	2.043	2.313	2.320	2.352	2.358
4	2.040	2.029	2.330	2.319	2.366	2.357
5	2.041	2.064	2.337	2.343	2.372	2.377
6	2.037	2.032	2.333	2.316	2.371	2.354
Avg	2.034	2.042	2.324	2.324	2.362	2.361
SD	0.011	0.012	0.012	0.010	0.010	0.008

TESTQUIP VERSUS PINE

Table D.5. Bulk specific gravity data for Mix 1 (12.5 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	Test Quip	Pine	Test Quip	Pine	Test Quip	Pine
1	2.046	2.051	2.302	2.307	2.339	2.344
2	2.027	2.040	2.298	2.308	2.341	2.345
3	2.034	2.041	2.305	2.306	2.344	2.345
4	2.027	2.036	2.301	2.303	2.340	2.342
5	2.022	2.034	2.292	2.300	2.333	2.339
6	2.019	2.034	2.291	2.300	2.332	2.337
Avg	2.029	2.039	2.297	2.304	2.338	2.342
SD	0.010	0.006	0.005	0.003	0.005	0.003

Table D.6. Bulk specific gravity data for Mix 2 (19 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	Test Quip	Pine	Test Quip	Pine	Test Quip	Pine
1	2.062	2.073	2.354	2.361	2.395	2.398
2	2.055	2.071	2.355	2.365	2.391	2.404
3	2.064	2.071	2.358	2.357	2.395	2.394
4	2.066	2.070	2.363	2.359	2.400	2.398
5	2.076	2.076	2.378	2.373	2.409	2.404
6	2.061	2.068	2.356	2.355	2.395	2.394
Avg	2.064	2.072	2.361	2.362	2.398	2.399
SD	0.007	0.003	0.009	0.006	0.006	0.005

Table D.7. Bulk specific gravity data for Mix 3 (19 mm fine)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	Test Quip	Pine	Test Quip	Pine	Test Quip	Pine
1	2.164	2.178	2.377	2.382	2.391	2.398
2	2.199	2.189	2.398	2.392	2.411	2.406
3	2.176	2.179	2.388	2.394	2.403	2.411
4	2.173	2.183	2.384	2.391	2.398	2.408
5	2.164	2.187	2.386	2.394	2.403	2.409
6	2.196	2.178	2.402	2.393	2.417	2.410
Avg	2.182	2.182	2.392	2.391	2.404	2.407
SD	0.015	0.005	0.011	0.005	0.010	0.005

Table D.8. Bulk specific gravity data for Mix 4 (25 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	Test Quip	Pine	Test Quip	Pine	Test Quip	Pine
1	2.066	2.054	2.330	2.318	2.369	2.356
2	2.053	2.054	2.326	2.315	2.362	2.353
3	2.048	2.057	2.313	2.304	2.355	2.339
4	2.061	2.055	2.325	2.312	2.363	2.350
5	2.032	2.054	2.306	2.319	2.346	2.357
6	2.037	2.067	2.300	2.324	2.345	2.360
Avg	2.050	2.057	2.317	2.315	2.357	2.353
SD	0.013	0.005	0.012	0.007	0.010	0.007

TROXLER VERSUS PINE

Table D.9. Bulk specific gravity data for Mix 1 (12.5 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	New Troxler	Old Troxler	New Troxler	Old Troxler	New Troxler	Old Troxler
1	2.021	2.026	2.283	2.280	2.325	2.318
2	2.033	2.020	2.291	2.280	2.331	2.318
3	2.031	2.027	2.293	2.282	2.334	2.318
4	2.012	2.034	2.268	2.284	2.308	2.322
5	2.018	2.019	2.277	2.277	2.317	2.315
6	2.014	2.033	2.276	2.292	2.316	2.329
Avg	2.022	2.027	2.281	2.282	2.322	2.320
Std. Dev.	0.009	0.006	0.010	0.005	0.010	0.005

Table D.10. Bulk specific gravity data for Mix 2 (19 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	New Troxler	Old Troxler	New Troxler	Old Troxler	New Troxler	Old Troxler
1	2.073	2.073	2.359	2.359	2.398	2.396
2	2.076	2.062	2.366	2.353	2.405	2.391
3	2.071	2.076	2.365	2.368	2.404	2.401
4	2.060	2.083	2.351	2.371	2.393	2.406
5	2.075	2.075	2.366	2.366	2.401	2.401
6	2.064	2.078	2.354	2.364	2.392	2.396
Avg	2.070	2.075	2.360	2.364	2.399	2.399
SD	0.006	0.007	0.007	0.007	0.005	0.005

Table D.11. Bulk specific gravity data for Mix 3 (19 mm fine)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	New Troxler	Old Troxler	New Troxler	Old Troxler	New Troxler	Old Troxler
1	2.158	2.163	2.377	2.380	2.402	2.398
2	2.154	2.169	2.379	2.382	2.400	2.402
3	2.166	2.167	2.384	2.384	2.405	2.402
4	2.185	2.188	2.392	2.392	2.409	2.409
5	2.175	2.175	2.384	2.385	2.400	2.403
6	2.170	2.166	2.392	2.380	2.411	2.400
Avg	2.168	2.171	2.385	2.384	2.405	2.402
SD	0.011	0.009	0.006	0.005	0.005	0.004

Table D.12. Bulk specific gravity data for Mix 4 (25 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	New Troxler	Old Troxler	New Troxler	Old Troxler	New Troxler	Old Troxler
1	2.051	2.049	2.312	2.312	2.354	2.352
2	2.046	2.046	2.317	2.306	2.357	2.343
3	2.045	2.055	2.312	2.322	2.352	2.360
4	2.054	2.035	2.333	2.308	2.373	2.347
5	2.039	2.043	2.313	2.316	2.353	2.354
6	2.048	2.028	2.326	2.309	2.366	2.350
Avg	2.047	2.043	2.319	2.312	2.359	2.351
SD	0.005	0.010	0.008	0.006	0.008	0.006

PINE MODEL AFG1A VERSUS PINE

Table D.13. Bulk specific gravity data for Mix 1 (12.5 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	New Pine	Old Pine	New Pine	Old Pine	New Pine	Old Pine
1	2.027	2.028	2.297	2.297	2.334	2.338
2	2.039	2.037	2.308	2.305	2.345	2.342
3	2.034	2.037	2.302	2.306	2.339	2.343
4	2.035	2.037	2.304	2.307	2.341	2.344
5	2.038	2.038	2.305	2.304	2.344	2.343
6	2.042	2.035	2.311	2.302	2.348	2.339
Avg	2.036	2.035	2.305	2.304	2.342	2.342
SD	0.005	0.004	0.005	0.004	0.005	0.002

Table D.14. Bulk specific gravity data for Mix 2 (19 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	New Pine	Old Pine	New Pine	Old Pine	New Pine	Old Pine
1	2.054	2.057	2.349	2.342	2.385	2.378
2	2.060	2.054	2.351	2.342	2.387	2.378
3	2.066	2.071	2.361	2.356	2.397	2.390
4	2.060	2.068	2.363	2.359	2.397	2.392
5	2.045	2.051	2.339	2.342	2.377	2.380
6	2.069	2.068	2.366	2.367	2.399	2.394
Avg	2.059	2.062	2.355	2.351	2.390	2.385
SD	0.008	0.008	0.010	0.011	0.009	0.007

Table D.15. Bulk specific gravity data for Mix 3 (19 mm fine)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	New Pine	Old Pine	New Pine	Old Pine	New Pine	Old Pine
1	2.180	2.184	2.390	2.396	2.404	2.408
2	2.163	2.171	2.384	2.389	2.400	2.406
3	2.140	2.172	2.376	2.388	2.394	2.402
4	2.175	2.174	2.390	2.383	2.404	2.397
5	2.169	2.174	2.390	2.391	2.402	2.408
6	2.168	2.176	2.391	2.390	2.403	2.402
Avg	2.165	2.175	2.387	2.389	2.401	2.404
SD	0.016	0.005	0.006	0.004	0.004	0.004

Table D.16. Bulk specific gravity data for Mix 4 (25 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	New Pine	Old Pine	New Pine	Old Pine	New Pine	Old Pine
1	2.031	2.057	2.304	2.337	2.339	2.371
2	2.054	2.048	2.339	2.335	2.371	2.369
3	2.047	2.062	2.328	2.334	2.360	2.370
4	2.036	2.046	2.321	2.321	2.357	2.359
5	2.038	2.047	2.319	2.330	2.357	2.366
6	2.052	2.048	2.334	2.327	2.370	2.363
Avg	2.043	2.051	2.324	2.330	2.359	2.366
SD	0.009	0.006	0.012	0.006	0.012	0.005

INTERLAKEN VERSUS PINE

Table D.17. Bulk specific gravity data for Mix 1 (12.5 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	ITC	Pine	ITC	Pine	ITC	Pine
1	2.030	2.048	2.298	2.319	2.335	2.359
2	2.047	2.042	2.304	2.319	2.345	2.358
3	2.026	2.020	2.297	2.293	2.351	2.332
4	2.046	2.041	2.310	2.314	2.349	2.353
5	2.043	2.036	2.300	2.317	2.341	2.356
6	2.041	2.041	2.303	2.316	2.344	2.355
Avg	2.039	2.038	2.303	2.313	2.344	2.352
SD	0.009	0.010	0.005	0.010	0.006	0.010

Table D.18. Bulk specific gravity data for Mix 2 (19 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	ITC	Pine	ITC	Pine	ITC	Pine
1	2.085	2.088	2.364	2.365	2.399	2.405
2	2.082	2.083	2.371	2.366	2.406	2.406
3	2.075	2.082	2.368	2.364	2.403	2.404
4	2.083	2.087	2.356	2.367	2.390	2.407
5	2.060	2.081	2.339	2.368	2.377	2.408
6	2.085	2.081	2.364	2.361	2.401	2.401
Avg	2.078	2.084	2.360	2.365	2.396	2.405
SD	0.010	0.003	0.012	0.002	0.011	0.002

Table D.19. Bulk specific gravity data for Mix 3 (19 mm fine)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	ITC	Pine	ITC	Pine	ITC	Pine
1	2.209	2.187	2.410	2.401	2.423	2.413
2	2.203	2.196	2.411	2.404	2.426	2.417
3	2.183	2.197	2.395	2.407	2.410	2.420
4	2.182	2.194	2.399	2.405	2.414	2.418
5	note 1	2.207	Note 1	2.410	note 1	2.420
6	2.200	2.201	2.417	2.409	2.425	2.422
Avg	2.195	2.197	2.408	2.406	2.420	2.418
SD	0.012	0.007	0.009	0.003	0.007	0.003

1 Software malfunction, no data for this specimen

Table D.20. Bulk specific gravity data for Mix 4 (25 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	Up ITC	Pine	Up ITC	Pine	Up ITC	Pine
1	2.034	2.062	2.308	2.344	2.344	2.379
2	2.068	2.068	2.326	2.342	2.362	2.377
3	2.074	2.069	2.334	2.350	2.370	2.383
4	2.065	2.063	2.324	2.338	2.360	2.374
5	2.055	2.054	2.320	2.327	2.358	2.363
6	2.061	2.051	2.334	2.329	2.370	2.363
Avg	2.059	2.061	2.324	2.338	2.361	2.373
SD	0.014	0.007	0.009	0.009	0.010	0.008

UPDATED INTERLAKEN VERSUS PINE

Table D.21. Bulk specific gravity data for Mix 1 (12.5 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	Up ITC	Pine	Up ITC	Pine	Up ITC	Pine
1	2.014	2.029	2.292	2.300	2.332	2.339
2	2.035	2.033	2.303	2.300	2.342	2.339
3	2.028	2.030	2.297	2.298	2.336	2.337
4	2.031	2.026	2.299	2.297	2.338	2.336
5	2.036	2.029	2.301	2.297	2.340	2.336
6	2.044	2.026	2.314	2.292	2.351	2.331
Avg	2.031	2.029	2.301	2.297	2.340	2.336
SD	0.010	0.003	0.007	0.003	0.006	0.003

Table D.22. Bulk specific gravity data for Mix 2 (19 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	Up ITC	Pine	Up ITC	Pine	Up ITC	Pine
1	2.063	2.070	2.354	2.357	2.392	2.393
2	2.078	2.068	2.353	2.356	2.391	2.394
3	2.079	2.058	2.359	2.347	2.395	2.385
4	2.065	2.066	2.350	2.354	2.388	2.390
5	2.074	2.065	2.351	2.356	2.387	2.394
6	2.077	2.083	2.361	2.376	2.400	2.403
Avg	2.073	2.068	2.355	2.358	2.392	2.393
SD	0.007	0.008	0.004	0.010	0.005	0.006

Table D.23. Bulk specific gravity data for Mix 3 (19 mm fine)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	Up ITC	Pine	Up ITC	Pine	Up ITC	Pine
1	2.168	2.166	2.391	2.381	2.407	2.402
2	2.171	2.174	2.384	2.388	2.405	2.407
3	2.173	2.167	2.380	2.385	2.398	2.405
4	2.162	2.156	2.379	2.376	2.399	2.396
5	2.165	2.155	2.377	2.375	2.400	2.397
6	2.168	2.168	2.377	2.383	2.397	2.403
Avg	2.168	2.164	2.381	2.381	2.401	2.402
SD	0.004	0.007	0.005	0.005	0.004	0.004

Table D.24. Bulk specific gravity data for Mix 4 (25 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	Up ITC	Pine	Up ITC	Pine	Up ITC	Pine
1	2.041	2.047	2.323	2.321	2.361	2.357
2	2.040	2.049	2.321	2.317	2.359	2.353
3	2.033	2.044	2.306	2.335	2.343	2.371
4	2.030	2.015	2.313	2.299	2.353	2.338
5	2.051	2.040	2.325	2.323	2.363	2.359
6	2.036	2.060	2.315	2.332	2.355	2.366
Avg	2.039	2.043	2.317	2.321	2.356	2.357
SD	0.007	0.015	0.007	0.013	0.007	0.011

PINE VERSUS PINE

Table D.25. Bulk specific gravity data for Mix 1 (12.5 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	TX Pine	UT Pine	TX Pine	UT Pine	TX Pine	UT Pine
1	2.024	2.032	2.296	2.300	2.335	2.337
2	2.030	2.018	2.303	2.290	2.342	2.328
3	2.033	2.021	2.304	2.294	2.343	2.333
4	2.032	2.027	2.299	2.293	2.338	2.330
5	2.029	2.025	2.295	2.295	2.332	2.334
6	2.028	2.068	2.289	2.291	2.324	2.329
Avg	2.029	2.032	2.298	2.294	2.336	2.332
SD	0.003	0.018	0.005	0.004	0.007	0.003

Table D.26. Bulk specific gravity data for Mix 2 (19 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		Gmb at $N_{maximum}$	
Spec	TX Pine	UT Pine	TX Pine	UT Pine	TX Pine	UT Pine
1	2.070	2.072	2.360	2.365	2.396	2.401
2	2.072	2.069	2.369	2.361	2.406	2.400
3	2.078	2.067	2.365	2.362	2.400	2.400
4	2.075	2.060	2.357	2.352	2.398	2.390
5	2.051	2.057	2.341	2.347	2.387	2.385
6	2.066	2.068	2.358	2.361	2.392	2.395
Avg	2.069	2.066	2.358	2.358	2.397	2.395
SD	0.010	0.006	0.010	0.007	0.007	0.007

Table D.27. Bulk specific gravity data for Mix 3 (19 mm fine)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	TX Pine	UT Pine	TX Pine	UT Pine	TX Pine	UT Pine
1	2.176	2.193	2.390	2.401	2.409	2.413
2	2.190	2.168	2.398	2.382	2.417	2.405
3	2.170	2.169	2.383	2.384	2.403	2.402
4	2.160	2.168	2.381	2.381	2.401	2.399
5	2.165	2.169	2.381	2.382	2.401	2.403
6	2.164	2.163	2.384	2.379	2.402	2.402
Avg	2.171	2.172	2.386	2.385	2.406	2.404
SD	0.011	0.011	0.007	0.008	0.006	0.005

Table D.28. Bulk specific gravity data for Mix 4 (25 mm coarse)

	G_{mb} at $N_{initial}$		G_{mb} at N_{design}		G_{mb} at $N_{maximum}$	
Spec	TX Pine	UT Pine	TX Pine	UT Pine	TX Pine	UT Pine
1	2.050	2.040	2.325	2.322	2.363	2.362
2	2.044	2.044	2.330	2.320	2.368	2.358
3	2.029	2.018	2.317	2.312	2.357	2.353
4	2.033	2.044	2.323	2.329	2.361	2.367
5	2.027	2.013	2.313	2.309	2.350	2.352
6	2.016	2.068	2.302	2.309	2.341	2.348
Avg	2.033	2.038	2.318	2.317	2.357	2.357
SD	0.012	0.020	0.010	0.008	0.010	0.007

APPENDIX E

CHART FOR MIXING AND COMPACTION TEMPERATURES

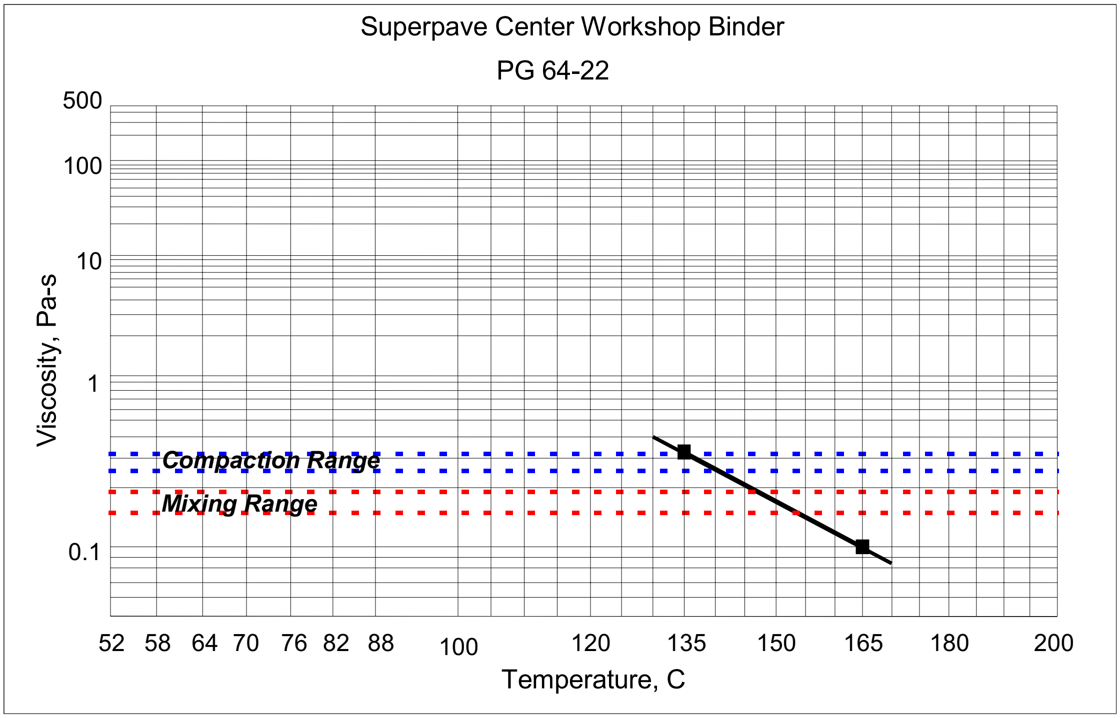


Figure E.1. Calculation of mixing and compaction temperature

APPENDIX F

CALIBRATION VERIFICATION FOR COMPACTORS

Table F.1. Summary of calibration verification for Pine and Rainhart SGCs

Pine Compactor				
Date	Height, mm (152.40)	Pressure, KPa (77.1 and 323.4)	Speed, rpm (30)	Angle, degree (1.23 - 1.27)
3/26	152.35	78.5, 323.1	30	1.23
3/27	152.37	78.9, 321.9	30	1.23
3/30	152.37	78.8, 326.8	30	1.23
3/31	152.37	78.0, 326.1	30	1.23

Rainhart Compactor				
Date	Height, mm (152.40)	Pressure, KPa (582 - 618)	Speed, rpm (30)	Angle, degree (1.23 - 1.27)
3/26	152.41	604	30	1.25
3/27	152.48	610	30	1.24
3/30	152.50	600	30	1.26
3/31	152.46	599	30	1.24

Table F.2. Summary of calibration verification for Pine and Test Quip SGCs

Pine Compactor				
Date	Height, mm (152.4)	Pressure, KPa (76.3-77.1 and 320.1-326.6)[a]	Speed, rpm (30)	Angle, degree (1.23 - 1.25)
10/13	152.42	77.8 - 325.1	30	1.25
10/14	152.38	77.8 - 321.2	30	1.23
10/15	152.39	77.8 - 324.9	30	1.25
10/16	152.39	78.1 - 325.0	30	1.23
10/17	152.39	78.1 - 324.4	30	1.24

[a] Numbers are dial gauge readings.

Test Quip Compactor				
Date	Height (ok)	Pressure, KPa (600)	Speed, rpm (30)	Angle, degree (1.23 - 1.25)
10/13	check ok	601	30	1.24
10/14	check ok	601	30	1.24
10/15	check ok	601	30	1.25
10/16	check ok	601	30	1.25
10/17	check ok	601	30	1.24

Table F.3. Summary of calibration verification for old Troxler and new Troxler SGCs

Old Troxler Compactor				
Date	Height, mm (114.4)	Pressure, KPa (582 - 618)	Speed, rpm (30)	Angle, degree (1.23 - 1.27)
3/4	114.39	594	30	1.26
3/5	114.40	595	30	1.26
3/6	114.40	594	30	1.26
3/9	114.40	593	30	1.25
3/10	113.97	602	30	1.25
3/11	114.40	592	30	1.25
3/12	114.38	593	30	1.26
3/13	114.39	596	30	1.26

New Troxler Compactor				
Date	Height, mm (114.03)	Pressure, KPa (582 - 618)	Speed, rpm (30)	Angle, degree (1.23 - 1.27)
3/4	114.02	601	30	1.25
3/5	114.00	600	30	1.25
3/6	113.97	599	30	1.25
3/9	114.03	598	30	1.25
3/10	113.97	602	30	1.25
3/11	113.91	597	30	1.25
3/12	113.99	603	30	1.25
3/13	113.96	607	30	1.25

Table F.4. Summary of calibration verification for Pine and Interlaken SGCs

Pine Compactor				
Date	Height, mm (152.4)	Pressure, KPa (76.3-77.1 and 320.1-326.6)[a]	Speed, rpm (30)	Angle, degree (1.23 - 1.25)
10/13	152.42	77.8 - 325.1	30	1.25
10/14	152.38	77.8 - 321.2	30	1.23
10/15	152.39	77.8 - 324.9	30	1.25
10/16	152.39	78.1 - 325.0	30	1.23
10/17	152.39	78.1 - 324.4	30	1.24

[a] Numbers are dial gauge readings.

ITC Compactor				
Date	Height (ok)	Pressure, KPa (600)	Speed, rpm (30)	Angle, degree (1.23 - 1.25)
10/13	check ok	601	30	1.24
10/14	check ok	601	30	1.24
10/15	check ok	601	30	1.25
10/16	check ok	601	30	1.25
10/17	check ok	601	30	1.24

Table F.5. Summary of calibration verification for updated Interlaken and Pine SGCs

Pine Compactor				
Date	Height, mm (152.40)	Pressure, KPa (77.1 & 323.4)	Speed, rpm (30)	Angle, degree (1.23 - 1.27)
6/8	152.38	78.7, 326.3	30	1.23
6/9	152.40	78.9, 326.8	30	1.24
6/15	152.38	78.0, 326.0	30	1.26
6/16	152.38	77.8, 325.8	30	1.23

ITC Compactor				
Date	Height (100, 200)	Pressure, KPa (600)	Speed, rpm (30)	Angle, degree (1.23 - 1.27)
6/8	100.0, 200.0	603	30	1.25
6/9	100.0, 200.2	601	30	1.24
6/15	100.0, 200.0	604	30	1.25
6/16	100.0, 200.0	603	30	1.25

Table F.6. Summary of calibration verification for old Pine and new Pine SGCs

Old Pine Compactor				
Date	Height, mm (152.4)	Pressure, KPa (76.3-77.1 and 320.1-326.6)[a]	Speed, rpm (30)	Angle, degree (1.23 - 1.27)
11/20	152.38	77.7 - 324.6	30	1.24
11/21	152.37	77.8 - 324.2	30	1.25
11/22	152.37	77.6 - 325.0	30	1.25
11/23	152.38	77.8 - 324.8	30	1.26
[a] Numbers are dial gauge readings.				

New Pine Compactor				
Date	Height 152.4, mm	Pressure, KPa (108.1-114.8 and 228.4-242.5)[a]	Speed, rpm (30)	Angle, degree (1.23 - 1.27)
11/20	152.36	111.3 - 235.2	30	1.25
11/21	152.36	111.2 - 235.6	30	1.25
11/22	152.41	111.1 - 234.9	30	1.25
11/23	152.41	111.2 - 236.0	30	1.25
[a] Numbers are dial gauge readings.				

Table F.7. Summary of calibration verification for UT Pine and TX Pine SGCs

UT Pine Compactor				
Date	Height, mm (152.4)	Pressure, KPa (76.3-77.1 and 320.1-326.6)[a]	Speed, rpm (30)	Angle, degree (1.23 - 1.27)
2/4	152.38		30	1.265
2/5	152.37	76.1 – 323.8	30	1.27
2/6	152.37	76.1 – 323.1	30	1.27
2/7	152.38	76.0 – 323.1	30	1.26
[a] Numbers are dial gauge readings.				

TX Pine Compactor				
Date	Height (ok)	Pressure, KPa (76.3-77.1 and 320.1-326.6)[a]	Speed, rpm (30)	Angle, degree (1.23 – 1.27)
2/4	152.36		30	1.245
2/5	152.36	78.8 – 326.0	30	1.23
2/6	152.41	78.1 – 323.4	30	1.24
2/7	152.41	78.5 – 326.0	30	1.24
[a] Numbers are dial gauge readings.				