FIELD EVALUATION OF A PORTABLE GYRATORY COMPACTOR

Final Report

SPR 375

by

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16. Abstract

Application of quality management concepts to asphalt paving evolved because recipe specifications frequently proved inadequate for ensuring pavement performance. Quality management of asphalt concrete is founded on the premise that the producer controls the end-quality of the product, including the in-place void content on which pavement performance is highly dependent. In its quality management program the Oregon Department of Transportation (ODOT) originally used the Marshall hammer, since neither the Hveem (kneading) nor Superpave prototype compactor was suitable for field quality control/assurance (QC/QA). Post-SHRP research led to the development of truly portable gyratory compactors, ie, those of 70 kg to 140 kg mass. Although selecting and proportioning materials as well as compaction are integral parts of the Superpave technology, there is some apprehension given the fact that no strength test is required at low traffic levels.

Given ODOT's long and successful use of the Hveem method of mix design, the primary objective of this research was to assess the effectiveness of a portable gyratory compactor for field quality control purposes. A secondary objective was to determine the quality of Superpave mixes as measured by Hveem stability. To achieve these objectives plant-produced material was sampled during construction and compacted with both portable and prototype gyratory compactors. Shortly after construction, cores were extracted. All samples (gyratory compacted and field cores) were subsequently tested in the Hveem stabilometer.

The following conclusions are noteworthy: Overall, the operational characteristics of the portable gyratory, including calibration and maintenance, were satisfactory. There was essentially no difference between the portable and prototype gyratory compactors as measured by air void content of 150 mm samples. In no case was the difference in air void content greater than 0.5 percent. Comparison of 100 mm and 150 mm samples compacted in the prototype gyratory was instructive in that the latter were consistently lower in air void content, typically by 0.5 to 1.5 percent. The air void content of plant mix samples compacted to N_{design} gyrations was consistently lower than that of the field cores, generally by at least 2 percent. The range in air void content of plant mix samples compacted to N_{design} gyrations was 3.0 to 8.8 percent, whereas the range in air void content of the field cores was 6.8 to 9.1 percent. The data indicate that there is virtually no difference in air void content between 100 mm and 150 mm field cores. Field cores generally had lower stabilities than did gyratory- or kneading-compacted samples. However, there was virtually no difference in the stability of lab compacted samples, regardless of gyratory type or specimen diameter. None of the field cores, regardless of project, met ODOT's minimum Hveem stability criterion of 35.

The data gathered in this research indicate that there is virtually no difference between the prototype (Pine) and portable (Test Quip) gyratory compactors as measured by air void content and Hveem stability. Accordingly, it is recommended that ODOT consider the use of the portable gyratory for QC/QA purposes, assuming that the more fundamental issues of Superpave mix design are resolved. Since Hveem stability of field cores did not meet ODOT's minimum criterion of 35, early and continuous monitoring of the field performance is imperative. As part of the performance monitoring, it is recommended that wheel-path air void content be periodically measured to confirm/refute the N_{design} concept.

17. Key Words		18. Distribution Statement	
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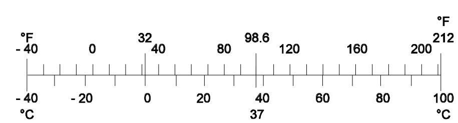
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
In	Inches	25.4	Millimeters	Mm
Ft	Feet	0.305	Meters	M
Yd	Yards	0.914	Meters	M
Mi	Miles	1.61	Kilometers	Km
		AREA		
in^2	Square inches	645.2	Millimeters	mm^2
ft^2	Square feet	0.093	meters squared	M^2
yd^2	Square yards	0.836	meters squared	M^2
Ac	Acres	0.405	Hectares	Ha
mi^2	Square miles	2.59	Kilometers	Km^2
		VOLUME		
fl oz	Fluid ounces	29.57	Milliliters	ML
Gal	Gallons	3.785	Liters	L
ft^3	Cubic feet	0.028	meters cubed	m^3
yd^3	Cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
Oz	Ounces	28.35	Grams	G
Lb	Pounds	0.454	Kilograms	Kg
T	Short tons (2000 lb)	0.907	Megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	Millimeters	0.039	inches	in
m	Meters	3.28	feet	ft
m	Meters	1.09	yards	yd
km	Kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
ha	Hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
mL	Milliliters	0.034	fluid ounces	fl oz
L	Liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	Grams	0.035	ounces	oz
kg	Kilograms	2.205	pounds	lb
Mg	Megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8C + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement

(4-7-94 jbp)

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DISCLAIMER

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1.0 INTRODUCTION

Application of quality management concepts to asphalt paving evolved because recipe specifications frequently proved inadequate for ensuring pavement performance. Quality management of asphalt concrete is founded on the premise that the producer controls the end-quality of the product, including the in-place void content on which pavement performance is highly dependent. Traditional compaction devices (Marshall or Hveem) have proved cumbersome, expensive and/or ineffective for field control of air voids. Since ODOT's primary objective is to produce a quality product, a system/procedure is necessary which allows the contractor to measure void properties during production and adjust the job mix formula (JMF) as needed. Though based on experimental work with dense graded mixes, the Superpave concepts and technology can be readily extended, with some modifications, to the heavy-duty and standard wearing course mixes routinely used by ODOT, perhaps even open-graded friction courses.

1.1 BACKGROUND

An important aspect of the Superpave technology is the method of laboratory compaction. Though not new in concept, gyratory compaction is likely to be the industry standard as evidenced by an article in *Asphalt Contractor* (*Bukowski 1995*). Forty-seven states have acquired the Superpave gyratory. In its quality management program Oregon DOT uses the Marshall Hammer for field control for a variety of reasons: the Hveem compactor (kneading) was not suitable for field operations and the Superpave gyratory compactor was not available at the time this research began. However, ODOT's earlier work on field control of asphalt concrete mixes using the Texas gyratory compactor was encouraging. It concluded that "… measured stability values on gyratory compacted specimens are equal to or better than those for kneading compacted specimens; the results appear to be more consistent than with kneading or Marshall compacted specimens" (*Terrel, et al. 1994*). Other studies suggest that the Superpave gyratory compactor may be a useful tool for field management (*Harmon, et al. 1995*; *Anderson, et al. 1995*).

As originally configured, the mass of Superpave gyratory compactors was approximately 360 to 540 kg, not ideally suited for field quality control. In research sponsored by the Transportation Research Board, NCHRP 9-7, *Field Procedures and Equipment to Implement SHRP Asphalt Specifications*, indicated that the Finnish gyratory compactor produced specimens comparable to the Superpave gyratory compactors (i.e., those manufactured by Pine and Troxler). The Finnish compactor mass and cost are considerably less, approximately 90 to 140 kg, and $15,000, respectively. All three compactors (Pine, Troxler and Finnish) have proved successful for field quality control on a number of FHWA-funded projects, including SPS-9 and WesTrack (*Accelerated Field Test of Performance Related Specifications for Hot Mix Asphalt Construction*). Furthermore, Pine Instruments, Industrial Process Controls (IPC), an Australian Firm, and Test Quip exhibited portable gyratory compactors at the January 1997 meeting of the

Transportation Research Board. The mass of the IPC and Test Quip compactors is about 70 to 140 kg. Also, both manufacturers indicated that the retail price is likely to be $15,000 - $20,000. Portability and cost of the gyratory compactor are, understandably, key concerns. Perhaps more important, however, is the suitability of the Superpave technology to the wide variety of mix types used as alternatives to the standard dense-graded mixes. Research conducted under the auspices of the National Cooperative Highway Research Program, in NCHRP Project 9-9, *Refinement of Superpave Gyratory Compaction Procedure*, addressed this issue.

Although selecting and proportioning materials as well as compaction are integral parts of the Superpave technology, there is some apprehension given the fact that no strength test is required at low traffic levels. Already, numerous state DOTs have indicated that some sort of "proof testing" will be used to supplement the Superpave volumetric design. Elsewhere, some state DOTs have purchased (or plan to purchase) a scaled down version of the Superpave Shear Tester (SST) for mechanical testing and performance prediction as a function of material properties, time/traffic, environment and pavement geometry. Finally, field performance data from WesTrack indicate that some Superpave mixes are not performing as anticipated, suggesting that volumetric mix design should be supplemented with mechanical testing in some cases. Given ODOT's long and successful use with Hveem mix design, Hveem stability was used in this research as a relative measure of the strength of Superpave mixes.

1.2 OBJECTIVES

The success of the quality management initiative is related not only to field voids management, but also to mix design and performance testing, all of which now include some elements of the Superpave technology. Embracing the new technology, Oregon DOT has already developed an implementation strategy and schedule for the binder component of the Superpave system. Similarly, since 1996 it has started to evaluate Hveem mix designs used on construction projects with the Superpave technology. To fully realize the benefits of the Superpave technology it is imperative that it be implemented as a system. Accordingly, this work was intended to extend that already completed on the binder evaluation. The primary objective of this research was to assess the effectiveness of a portable gyratory compactor for field quality control purposes. A secondary objective was to determine the quality of Superpave mixes as measured by Hveem stability.

The objectives may be formulated in terms of the following hypothesis: gyratory compaction is an effective tool for field quality control/quality assurance (QC/QA) purposes. To test this hypothesis, the experiment outlined in Figure 1.1 was proposed. More details of the experiment are shown in Figures 1.2 and 1.3. Due to budget constraints, however, only the evaluation of plant-produced material shown in Figure 1.2 was undertaken; i.e., the research did not include construction of "control" sections based on Hveem mix design, as originally envisioned.

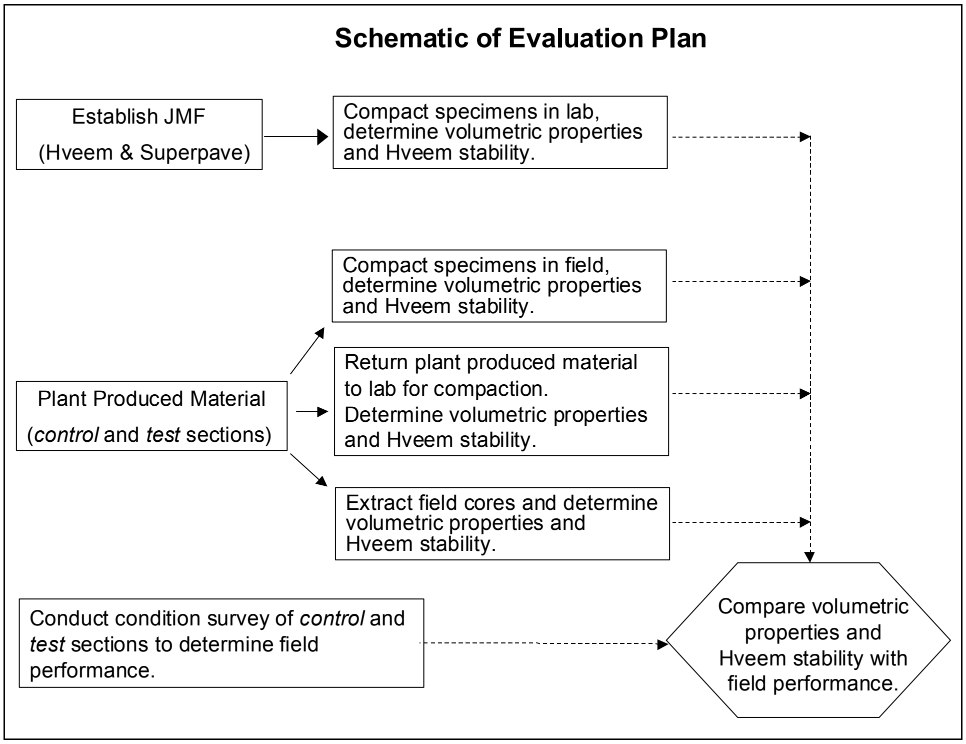

Figure 1.1: Overview of experiment design

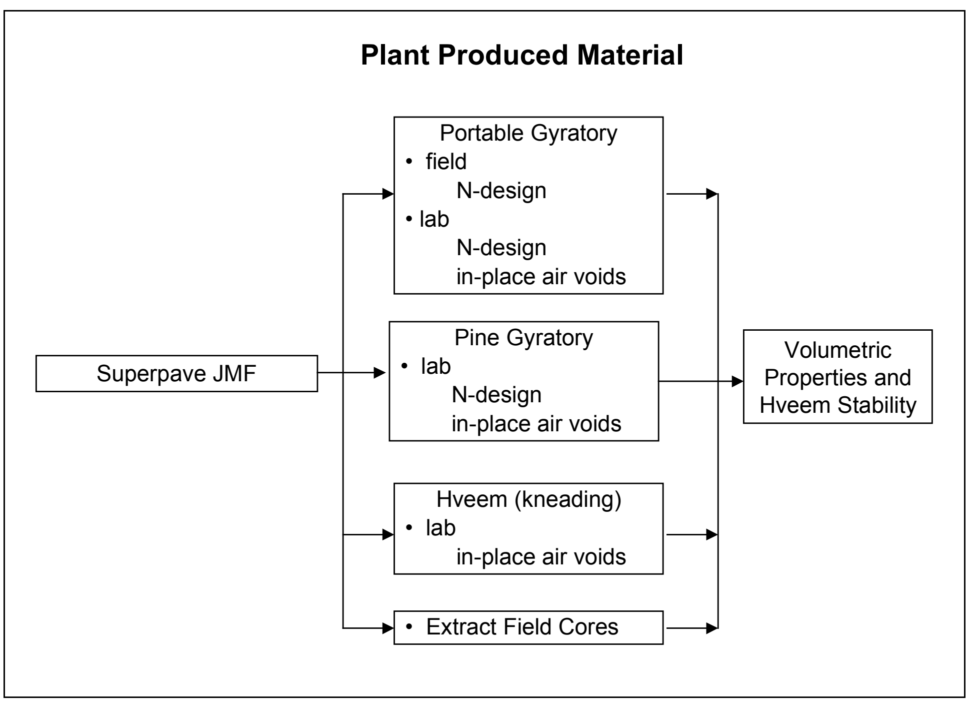

Figure 1.2: Assessment of plant produced HMAC

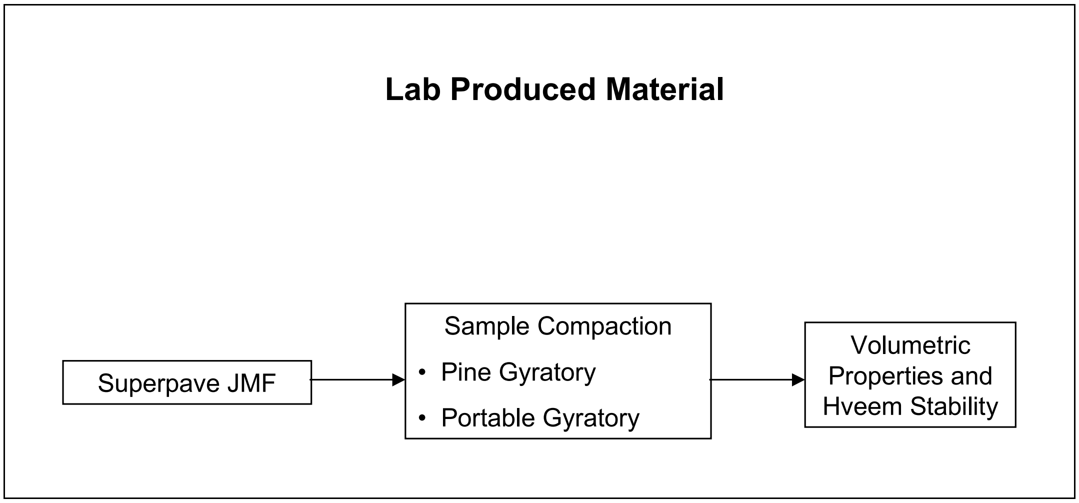

Figure 1.3: Assessment of laboratory produced HMAC

1.3 MIX DESIGN OVERVIEW

1.3.1 Superpave

The Superpave mix design method represents a system for specifying asphalt concrete component materials, mix design and analysis, and pavement performance prediction. The goal of mix design is to determine the optimum proportion of materials to achieve the most economical HMAC (hot mix asphalt concrete) that will give long-lasting pavement characteristics when placed in the field. As originally configured, Superpave mix design and analysis was to be performed at one of three increasingly rigorous levels, with each providing more definitive information as to the mix's likely performance. Level 1 represented an improved process for material selection and volumetric proportioning. Levels 2 and 3 used the volumetric mix design as a starting process and included a battery of tests to predict performance in terms of fatigue and low temperature cracking as well as permanent deformation. The research conducted herein addressed what was originally referred to as Superpave Level 1 mix design. Procedural details of Superpave mix design, including materials selection and proportioning, are concisely described by the Asphalt Institute (*Asphalt Institute 1996*).

Gyratory compaction, an integral part of Superpave mix design, is also a potential tool for quality control/quality assurance (QC/QA) as measured by as-constructed air void content. Specifically, SHRP researchers hypothesized that compaction to N_{design} gyrations should yield specimens with air void contents of approximately 4 percent.

SHRP researchers identified three levels of particular concern during gyratory compaction:

- $N_{initial}$ - initial number of gyrations,
- N_{design} - design number of gyrations, and

- $N_{maximum}$ - maximum number of gyrations.

$N_{initial}$ reflects the hot mix asphalt concrete (HMAC) behavior during breakdown rolling; N_{design} reflects the mix at the design traffic, i.e., design ESALs; and $N_{maximum}$ reflects a mix that has sustained significantly more traffic than anticipated.

1.3.2 Hveem

Widely used by state DOTs on the West Coast, the Hveem method of mix design includes a non-destructive test that provides an empirical measure of the HMAC's strength or stability, computed as shown in Equation 1-1. As noted previously, Hveem stability testing was conducted to provide a relative measure of the strength of the Superpave mixes. All Hveem stabilometer values were "corrected" to the effective specimen height of 64 mm as outlined by the Asphalt Institute (*Asphalt Institute 1993*).

$$S = \frac{22.2}{\frac{P_h \cdot D}{P_v - P_h} + 0.222} \qquad \textbf{(1-1)}$$

where

S = stabilometer value

D = specimen displacement

P_v = vertical pressure

P_h = horizontal pressure

2.0 EXPERIMENTAL DESIGN

2.1 FIELD PROJECTS

In this research, materials from four ODOT projects were considered. The "Gardiner Project" was located on U.S. 101 (Hwy 9) northbound between mileposts 205.60 and 204.90 approximately 8 km north of the coastal town of Gardiner. The "OR 58/US 97 Project" was located near U.S. 97 on Oregon Hwy 58 eastbound between mileposts 64.00 and 65.70. The "Corvallis Project" was located on northbound Oregon Hwy 99W (Hwy 1W) between mileposts 84.00 and 84.40. The "Hermiston Project" was located on southbound Oregon Hwy 395 (Hwy 54) between mileposts 5.55 and 5.61. All projects were constructed between July and September of 1998.

For comparison purposes, both ODOT and OSU staff conducted Superpave mix designs. However, production mix for all projects was based on the job mix formula (JMF) established by the ODOT Materials Laboratory. Since these mix design data are not a critical component of this study they are not included herein.

2.2 SAMPLING AND TESTING

In addition to the raw materials used for mix design, HMAC was sampled during construction for subsequent compaction. Hot mix for all four projects was produced with a drum mixer. HMAC from the Corvallis and OR 58/US 97 projects was sampled from the conveyor belt immediately after it was discharged from the drum and stored in 5-gallon buckets. Because of timing and/or equipment limitations, HMAC from the Gardiner and Hermiston projects was sampled from the haul trucks. For all projects, sampling at the plant was completed within one day's production.

Plant-produced HMAC was compacted with three devices: a portable gyratory, the Test Quip BGC-1; a full-size, standard lab model manufactured by Pine Instruments; and the standard Hveem kneading compactor. Compaction in the field was accomplished with the portable gyratory. Lab compaction was accomplished with the portable and standard gyratories as well as with the standard kneading device. Field cores were extracted (between the wheel path) within 24 hours of placement, returned to the lab and trimmed to a thickness of approximately 50 mm. Also, field cores of 150 mm diameter were cored to 100 mm diameter for testing in the Hveem stabilometer. Close coordination between plant sampling and paving operations ensured that HMAC used for lab compaction was representative of HMAC from which field cores were extracted. Shown in Figure 2.1 are the materials evaluated for each project. It was envisioned that 53 specimens from each project would be tested: 14 portable gyratory; 12 standard gyratory; 3 standard kneading; and 24 field cores.

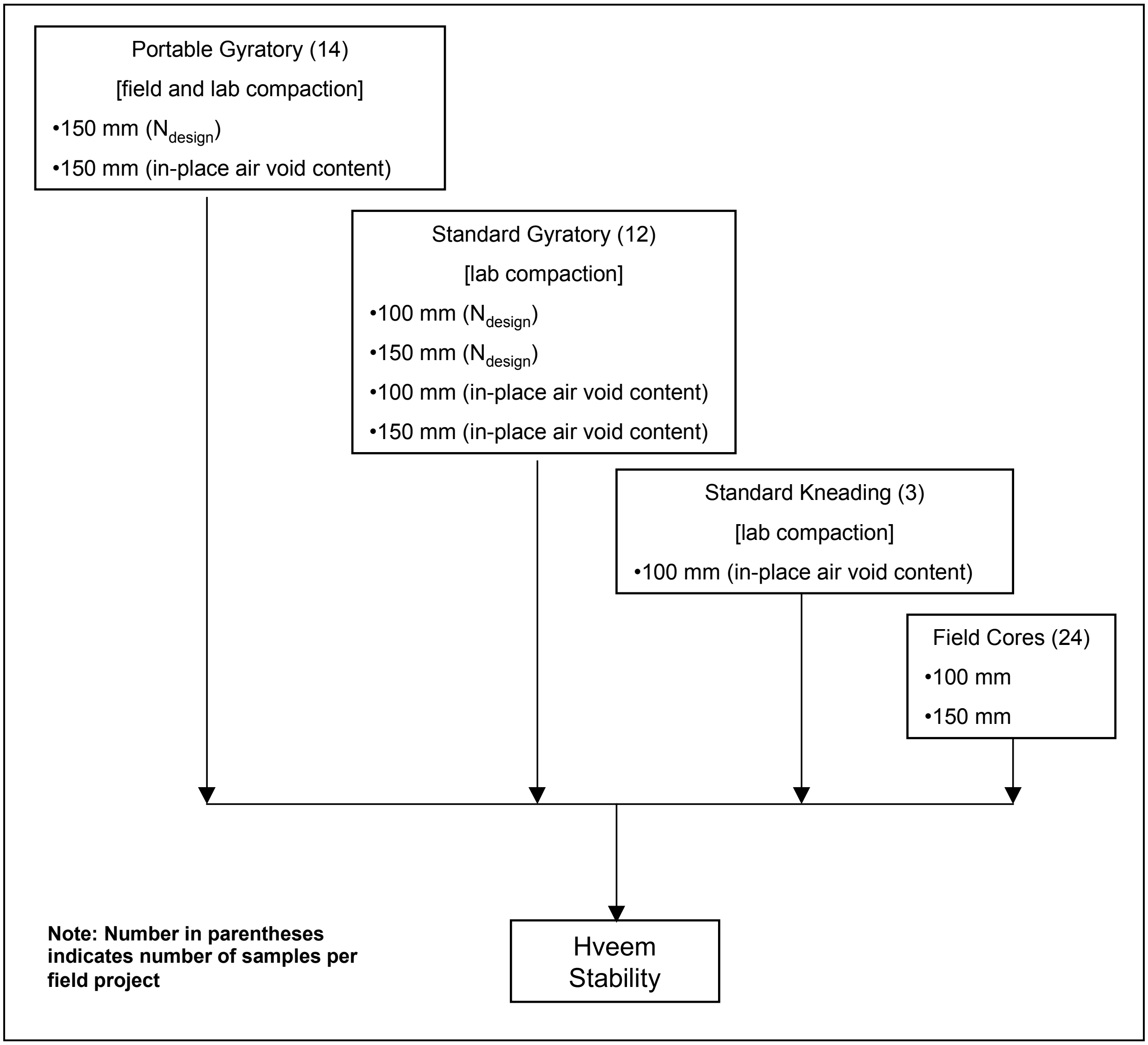

Figure 2.1: Evaluation of Plant-Produced HMAC

3.0 PROPERTIES OF PLANT-PRODUCED HMAC

3.1 GARDINER PROJECT

3.1.1 Air Void Content

The air void content of all plant-produced HMAC samples is shown in Table 3.1. Gyratory compaction summaries for N_{design} and “in-place or as-constructed air void content” are shown in Figures 3.1 and 3.2, respectively. Note that the compaction summaries are expressed in two formats: percent of theoretical maximum specific gravity (% G_{mm}) and percent air voids. The number of gyrations required to achieve the “as-constructed air void content” was 19 and 22 for the 150-mm and 100-mm samples, respectively. With the kneading compactor the number of tamps required to achieve the “as-constructed air void content” was 35.

3.1.2 Hveem Stability

Individual sample and average Hveem stability numbers are shown in Table 3.2. Average Hveem stabilities for samples compacted to N_{design} gyrations and as-constructed air void contents are shown in Figures 3.3a and 3.3b, respectively.

Table 3.1: Air Void Content of Gardiner Samples (Average Asphalt Content = 5.6%)

Field Cores

Sample	Percent Air Voids	Average Percent Air Voids	
4GARD01	4.3	6.9	100 mm
4GARD04	6.9		
4GARD07	6.7		
4GARD08	7.2		
4GARD09	7.5		
4GARD10	8.5		
4GARD11	7.3		
6GARD01	4.7	6.8	150 mm
6GARD02	6.8		
6GARD03	8.5		
6GARD04	7.7		
6GARD05	5.0		
6GARD06	7.3		
6GARD07	5.3		
6GARD08	6.3		
6GARD09	6.8		
6GARD10	8.6		
6GARD11	6.5		
6GARD12	7.8		

Plant Mix Compacted in Lab
Samples Compacted to In-Place Air Voids

Sample	Percent Air Voids	Average Percent Air Voids	
G351	6.9	7.1	100 mm Kneading Compactor
G352	7.5		
G353	6.9		
LVGPN5	6.4	6.4	100 mm Pine Gyratory Compactor
LVGPN6	6.4		
LVGPN7	6.4		
LVGBG151	6.1	6.4	150 mm Test Quip Gyratory
LVGBG152	6.5		
LVGBG153	6.7		
LVGPN152	6.2	6.1	150 mm Pine Gyratory
LVGPN153	6.0		
LVGPN155	6.1		

Plant Mix Compacted on Site
Samples Compacted to N_{design} Gyrations

Sample	Percent Air voids	Average Percent Air Voids	
GBG152	5.7	4.9	150 mm Test Quip Gyratory Compactor
GBG154	5.2		
GBG155	5.4		
GBG156	5.7		
GBG157	4.2		
GBG158	4.6		
GBG159	4.7		
GBG1510	4.2		

Plant Mix Compacted in Lab
Samples Compacted to N_{design} Gyrations

Sample	Percent Air Voids	Average Percent Air Voids	
LGPN01	3.8	3.9	100 mm Pine Gyratory Compactor
LGPN02	4.1		
LGPN03	3.9		
LGBG151	2.6	3.0	150 mm Test Quip Gyratory
LGBG152	3.4		
LGBG153	3.0		
LGPN151	2.9	2.9	150 mm Pine Gyratory
LGPN152	3.1		
LGPN153	2.7		

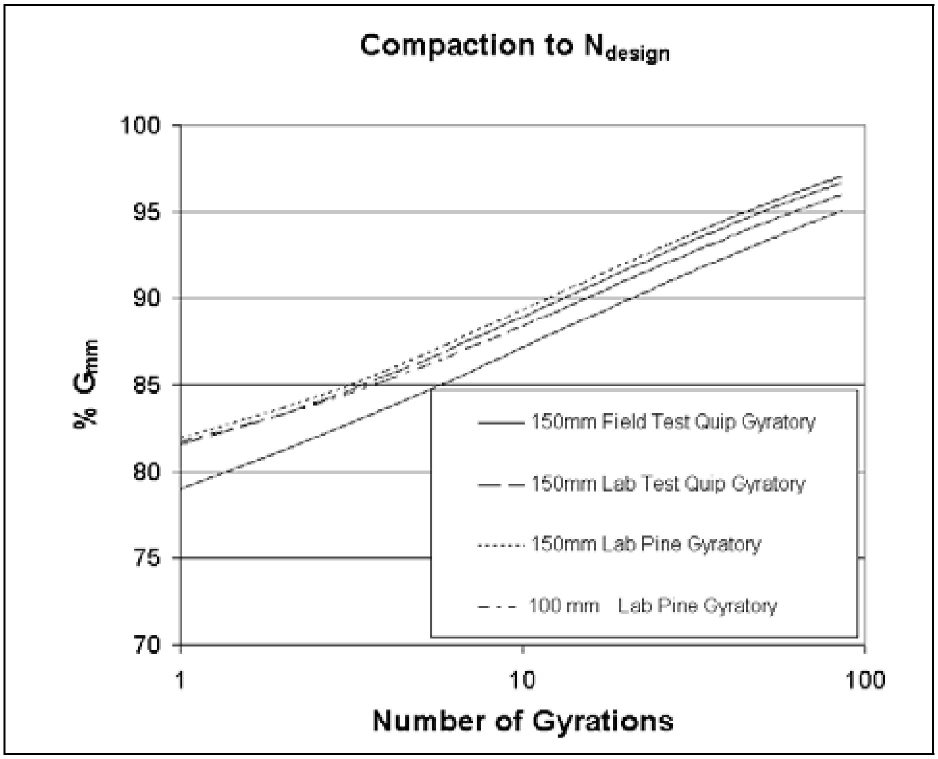

Figure 3.1a: Percent G_{mm} vs gyrations for Gardiner samples (N_{design} gyrations)

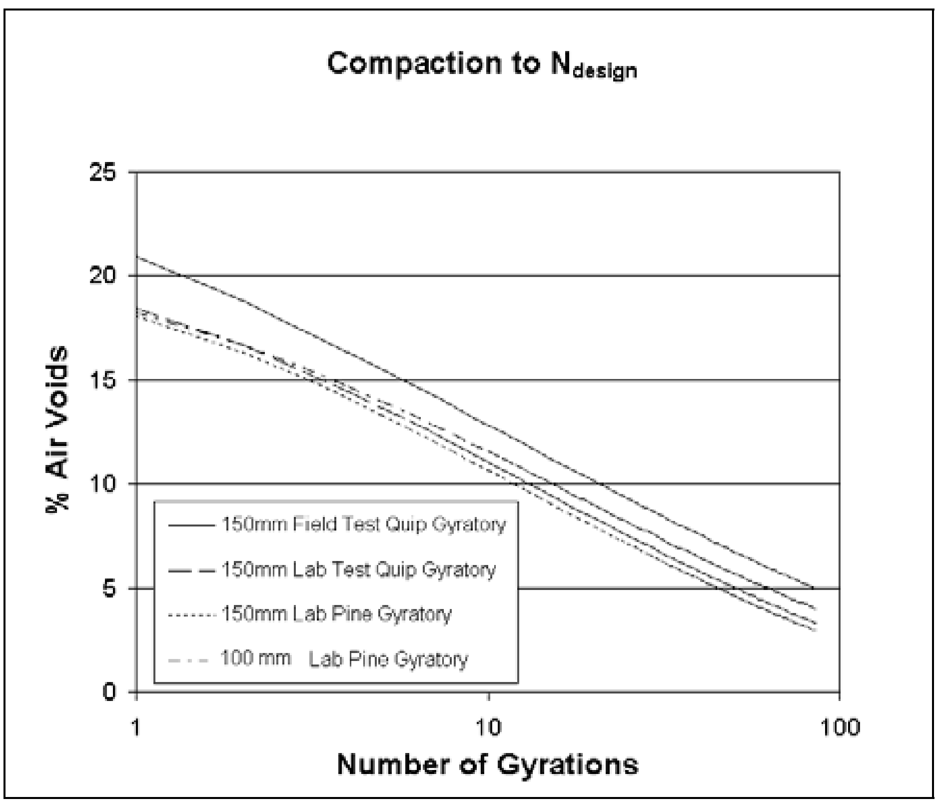

Figure 3.1b: Percent air voids vs gyrations for Gardiner samples (N_{design} gyrations)

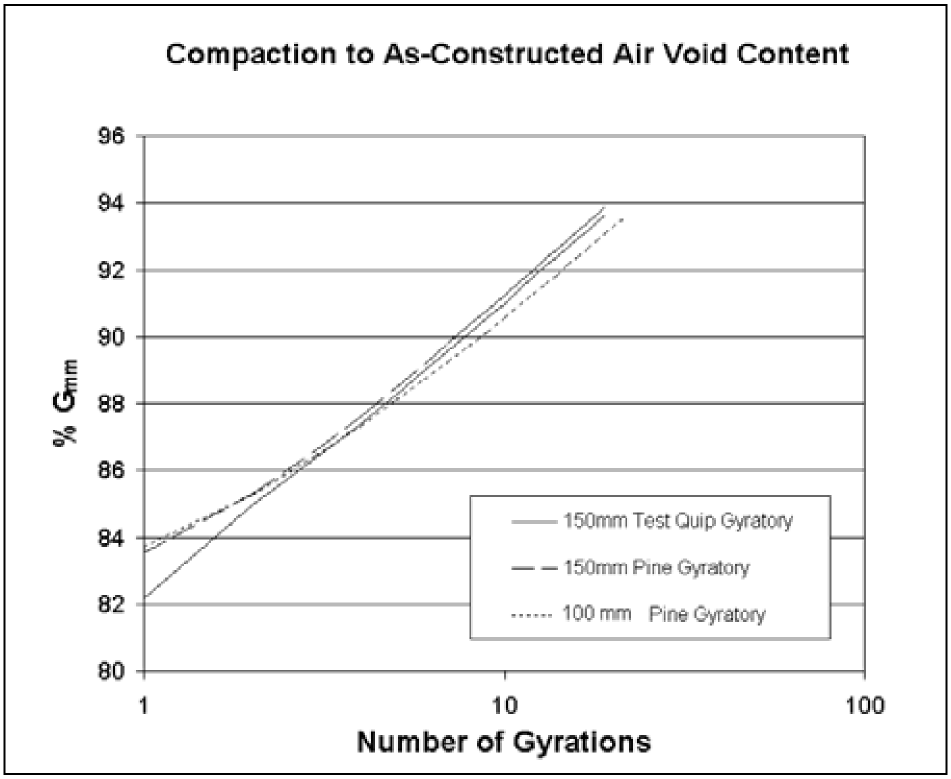

Figure 3.2a: Percent G_{mm} vs gyrations for Gardiner samples (as-constructed air void content)

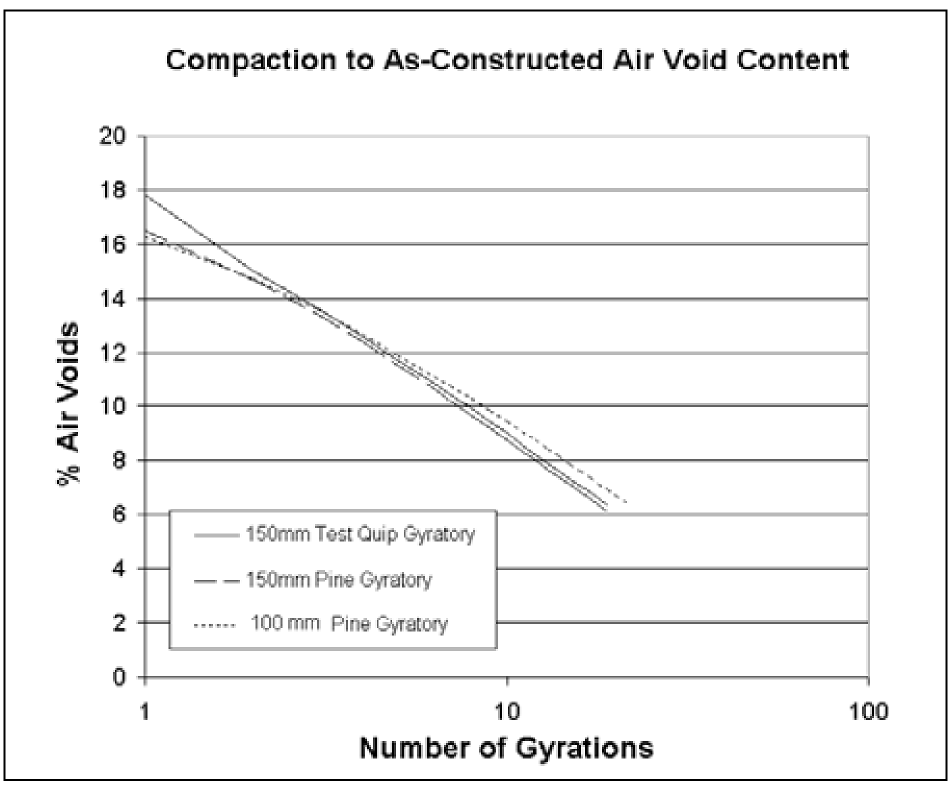

Figure 3.2b: Percent air voids vs gyrations for Gardiner samples (as-constructed air void content)

Table 3.2: Hveem Stability of Gardiner Samples

Samples Compacted to In-Place Air Voids

Sample	Corrected Stability Number	Average Corrected Stability Number		
4GARD01	25	22	100 mm Core Samples	Field Cores
4GARD04	23			
4GARD07	23			
4GARD08	19			
4GARD09	23			
4GARD10	19			
4GARD11	21			
G351	21	25	100 mm Kneading Compactor	Plant Mix Compacted in Lab
G352	32			
G353	22			
LVGPN5	32	29	100 mm Pine Gyratory Compactor	
LVGPN6	31			
LVGPN7	24			
LVGBG151	30	26	150 mm Test Quip Gyratory Compactor	
LVGBG152	20			
LVGBG153	25			
LVGBG154	29			
LVGPN152	25	26	150 mm Pine Gyratory Compactor	
LVGPN153	26			
LVGPN155	26			

Samples Compacted to N_{design} Gyrations

Sample	Corrected Stability Number	Average Corrected Stability Number		
GBG152	29	30	150 mm Test Quip Gyratory Compactor	Plant Mix Compacted on Site
GBG154	34			
GBG155	29			
GBG156	32			
GBG157	29			
GBG158	31			
GBG159	28			
GBG1510	27			
LGPN01	28	33	100 mm Pine Gyratory Compactor	Plant Mix Compacted in Lab
LGPN02	33			
LGPN03	38			
LGBG151	33	32	150 mm Test Quip Gyratory	
LGBG152	28			
LGBG153	35			
LGPN151	31	32	150 mm Pine Gyratory Compactor	
LGPN152	31			
LGPN153	32			

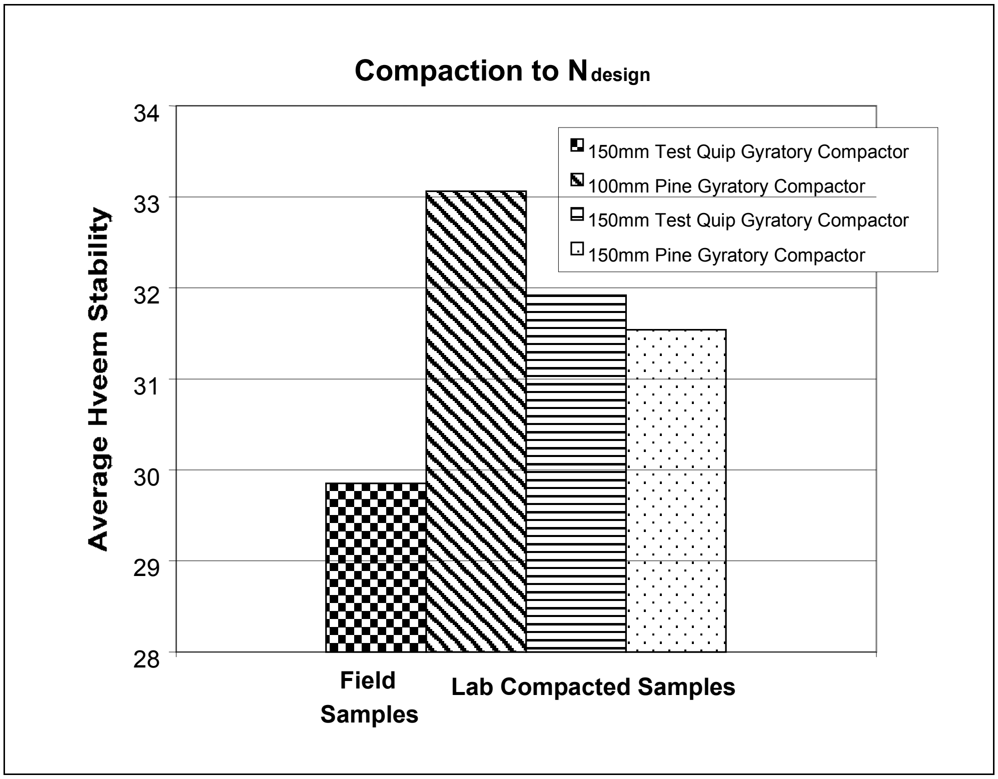

Figure 3.3a: Hveem stability of Gardiner samples (N_{design} gyrations)

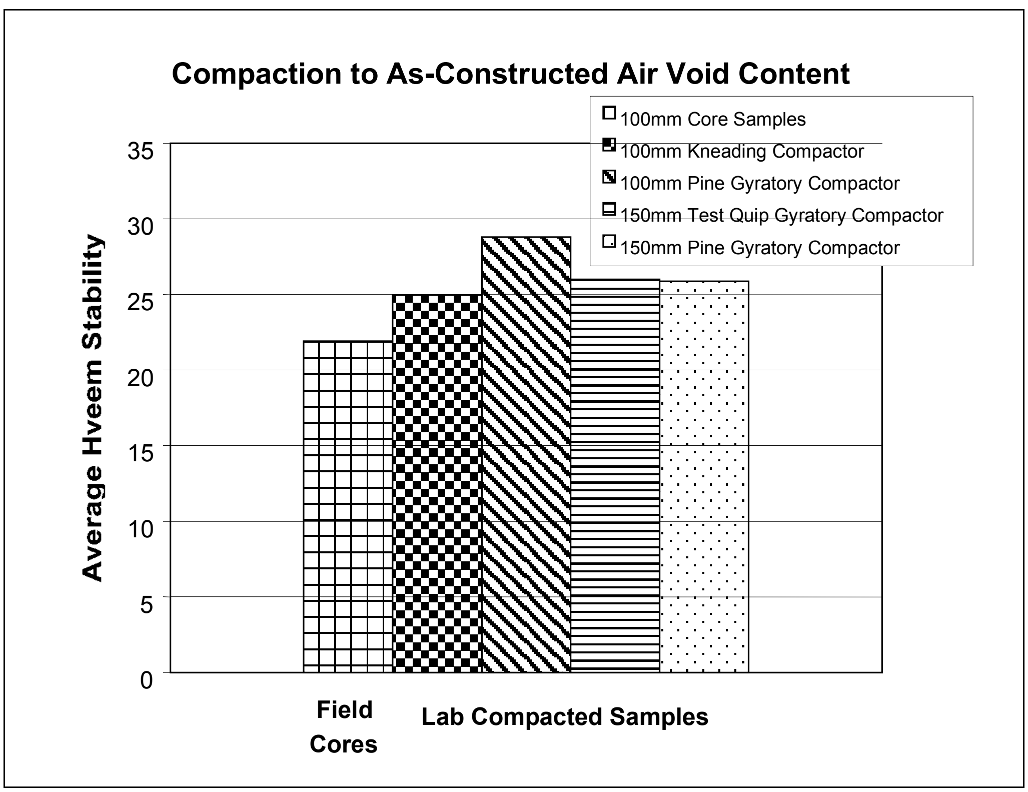

Figure 3.3b: Hveem stability of Gardiner samples (as-constructed air void content)

3.2 OR 58/U.S. 97 PROJECT

3.2.1 Air Void Content

The air void content of all plant-produced HMAC samples is shown in Table 3.3. Gyratory compaction summaries for N_{design} and as-constructed air void content are shown in Figures 3.4 and 3.5, respectively. The number of gyrations required to achieve the as-constructed air void content was 23 and 32 for the 150-mm and 100-mm samples, respectively. With the kneading compactor the number of tamps required to achieve the as-constructed air void content was 35.

3.2.2 Hveem Stability

Individual sample and average Hveem stability numbers are shown in Table 3.4. Average Hveem stabilities for samples compacted to N_{design} gyrations and as-constructed air void contents are shown in Figures 3.6a and 3.6b, respectively.

Table 3.3: Air Void Content of OR 58/U.S. 97 Samples (Average Asphalt Content = 6.0%)

Field Cores

Sample	Percent Air Voids	Average Percent Air Voids	
4US9701	9.2	7.2	100 mm
4US9702	6.0		
4US9703	8.2		
4US9704	7.2		
4US9705	6.1		
4US9706	8.7		
4US9707	7.4		
4US9708	7.1		
4US9709	6.0		
4US9710	7.0		
4US9711	7.5		
4US9712	5.5		
6US9701	8.6	7.3	150 mm
6US9703	9.1		
6US9704	7.0		
6US9705	6.1		
6US9706	8.4		
6US9707	7.5		
6US9708	6.8		
6US9709	6.1		
6US9710	7.3		
6US9711	7.0		
6US9712	6.2		

Plant Mix Compacted in Lab
Samples Compacted to In-Place Air Voids

Sample	Percent Air Voids	Average Percent Air Voids	
97351	7.6	7.8	100 mm Kneading Compactor
97352	8.0		
97353	7.9		
LV97PN01	7.3	7.5	100 mm Pine Gyratory Compactor
LV97PN02	7.3		
LV97PN03	7.8		
LVBG97151	6.9	7.2	150 mm Test Quip Gyratory
LVBG97152	7.2		
LVBG97153	7.5		
LV97PN151	7.3	7.3	150 mm Pine Gyratory
LV97PN152	7.4		
LV97PN153	7.2		

Plant Mix Compacted on Site
Samples Compacted to N_{design} Gyrations

Sample	Percent Air Voids	Average Percent Air Voids	
97BG151	3.2	2.9	150 mm Test Quip Gyratory Compactor
97BG152	3.7		
97BG153	2.4		
97BG154	3.0		
97BG155	2.5		
97BG156	2.6		
97BG157	3.1		
97BG158	2.5		

Plant Mix Compacted in Lab
Samples Compacted to N_{design} Gyrations

Sample	Percent Air Voids	Average Percent Air Voids	
4L97PN01	3.7	4.5	100 mm Pine Gyratory Compactor
4L97PN02	4.9		
4L97PN03	4.9		
LBG97151	2.1	2.2	150 mm Test Quip Gyrator
LBG97152	2.3		
LBG97153	2.1		
L97PN151	2.9	2.7	150 mm Pine Gyratory
L97PN152	2.9		
L97PN153	2.2		

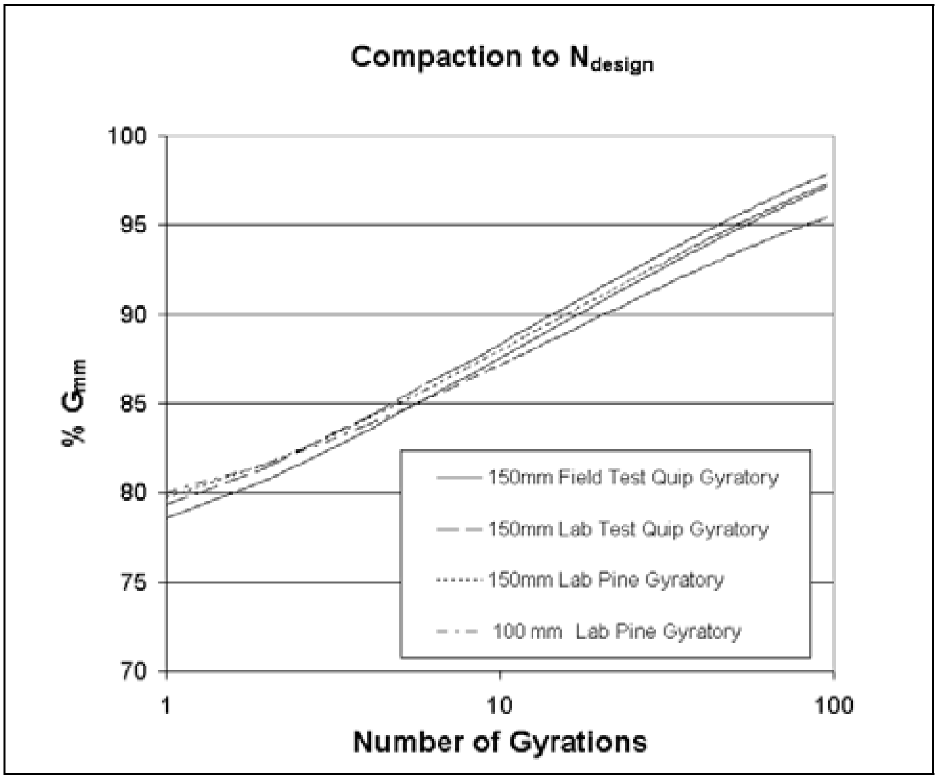

Figure 3.4a: Percent G_{mm} vs gyrations for OR 58/U.S. 97 samples (N_{design} gyrations)

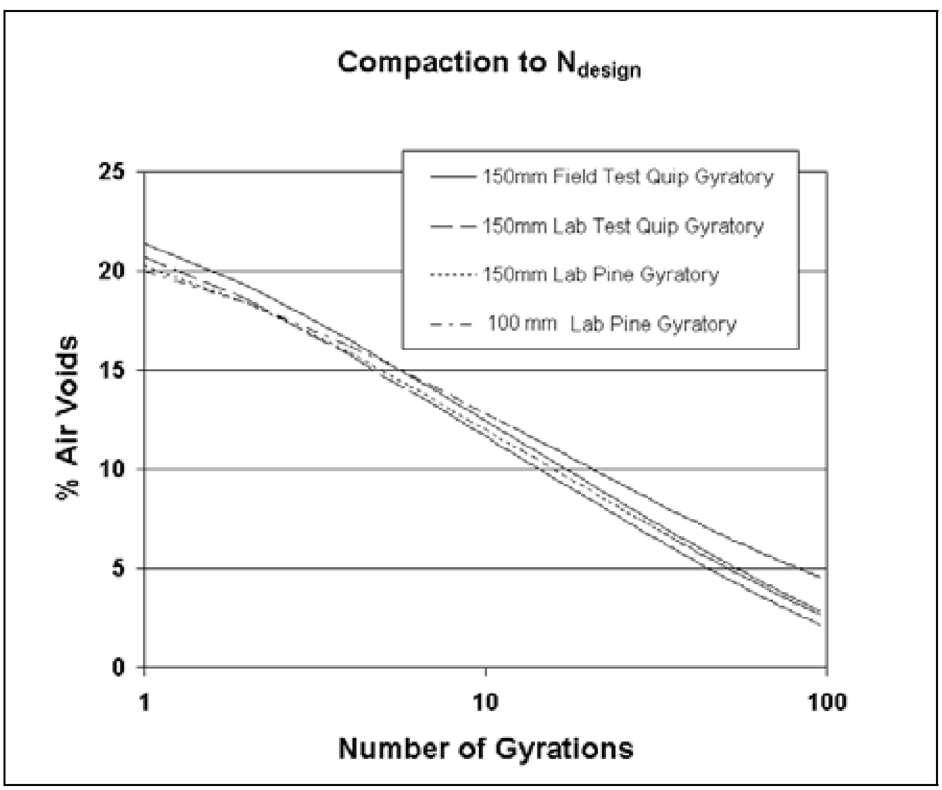

Figure 3.4b: Percent air voids vs gyrations for OR 58/U.S. 97 samples (N_{design} gyrations)

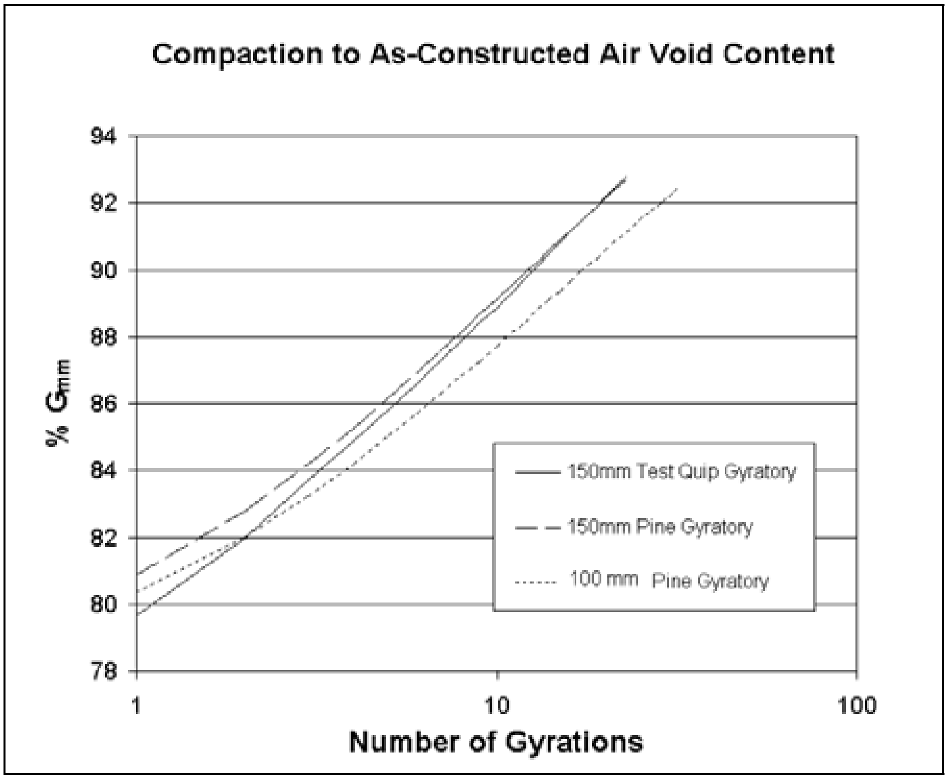

Figure 3.5a: Percent G_{mm} vs gyrations for OR 58/U.S. 97 samples (as-constructed air void content)

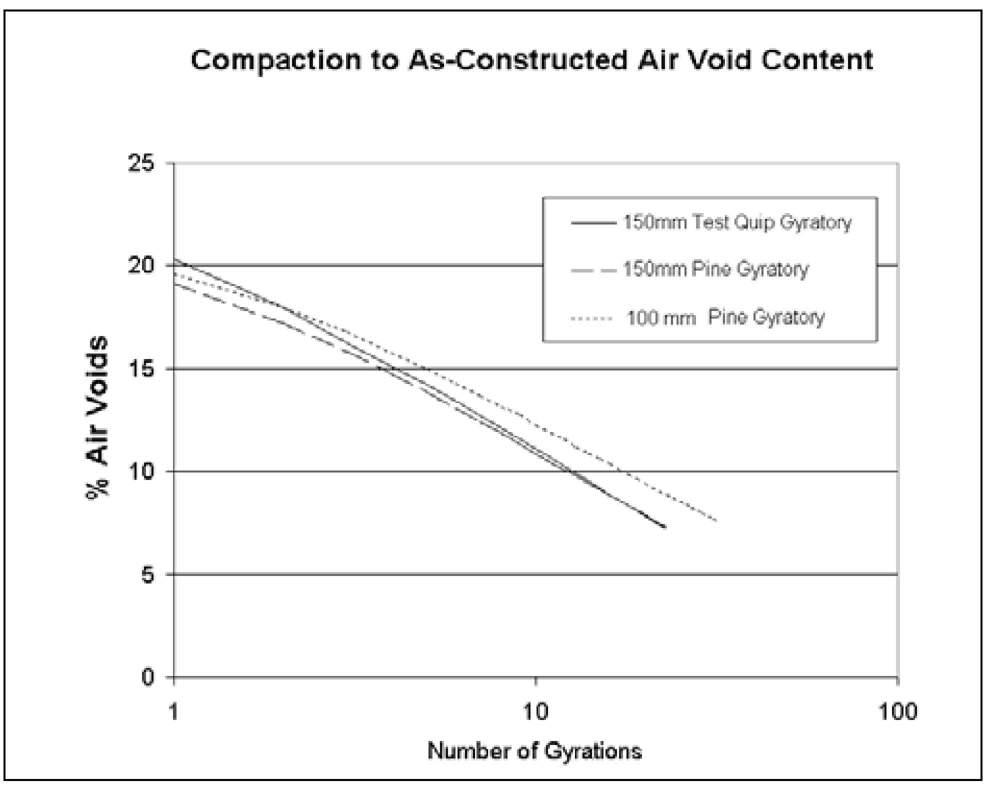

Figure 3.5b: Percent air voids vs gyrations for OR 58/U.S. 97 samples (as-constructed air void content)

Table 3.4: Hveem Stability of OR 58/U.S. 97 Samples

Samples Compacted to In-Place Air Voids				
Sample	**Corrected Stability Number**	**Average Corrected Stability Number**		
4US9701	18	28	100 mm Core Samples	Field Cores
4US9702	28			
4US9703	28			
4US9704	30			
4US9705	33			
4US9706	22			
4US9707	31			
4US9708	31			
4US9709	27			
4US9710	27			
4US9711	27			
4US9712	31			
6US9701	22	25	150 mm Core Samples	
6US9703	22			
6US9704	29			
6US9705	27			
6US9706	23			
6US9707	22			
6US9708	25			
6US9709	22			
6US9710	27			
6US9711	32			
6US9712	26			
97351	25	28	100 mm Kneading Compactor	Plant Mix Compacted in Lab
97352	28			
97353	30			
LV97PN01	25	29	100 mm Pine Gyratory Compactor	
LV97PN02	34			
LV97PN03	28			
LVBG97151	20	20	150 mm Test Quip Gyratory	
LVBG97152	19			
LVBG97153	21			
LV97PN151	25	29	150 mm Pine Gyratory Compactor	
LV97PN152	31			
LV97PN153	30			

Table 3.4 (Continued): Hveem Stability of OR 58/U.S. 97 Samples

Samples Compacted to N_{design} Gyrations				
Sample	**Corrected Stability Number**	**Average Corrected Stability Number**		
97BG151	37	37	150 mm Test Quip Gyratory Compactor	Plant Mix Compacted on Site
97BG152	33			
97BG153	34			
97BG154	37			
97BG155	37			
97BG156	37			
97BG157	42			
97BG158	39			
4L97PN01	41	40	100 mm Pine Gyratory Compactor	Plant Mix Compacted in Lab
4L97PN02	40			
4L97PN03	40			
L97PN151	39	40	150 mm Test Quip Gyratory	
L97PN152	42			
L97PN153	39			
LBG97151	44	42	150 mm Pine Gyratory Compactor	
LBG97152	39			
LBG97153	44			

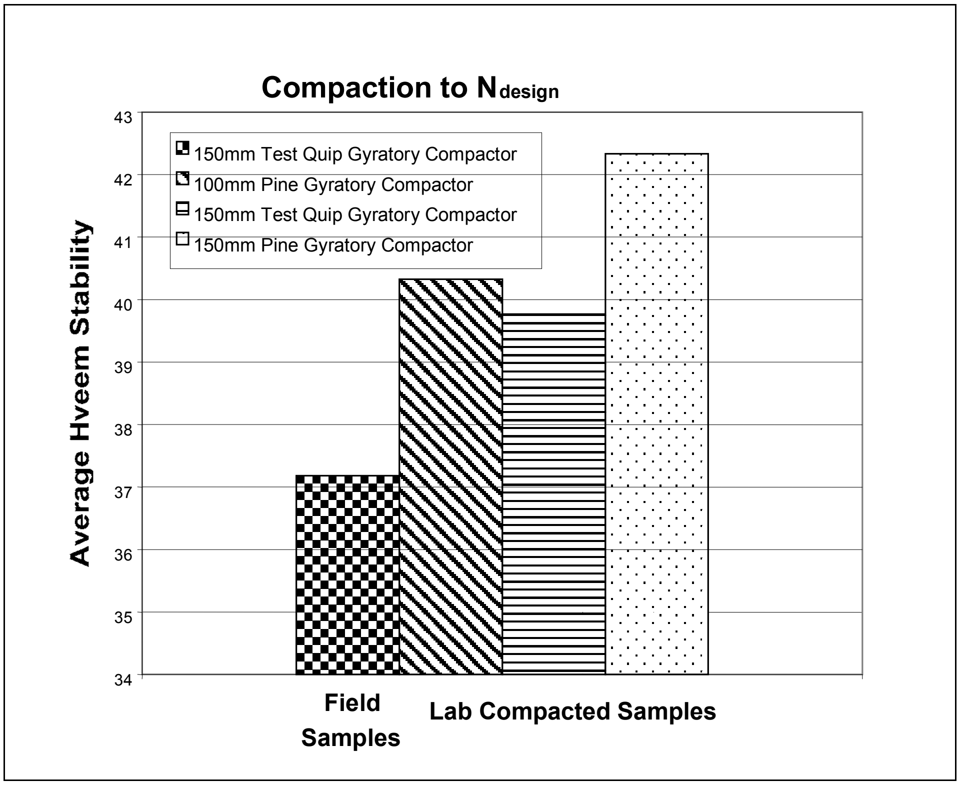

Figure 3.6a: Hveem stability of OR 58/U.S. 97 samples (N_{design} gyrations)

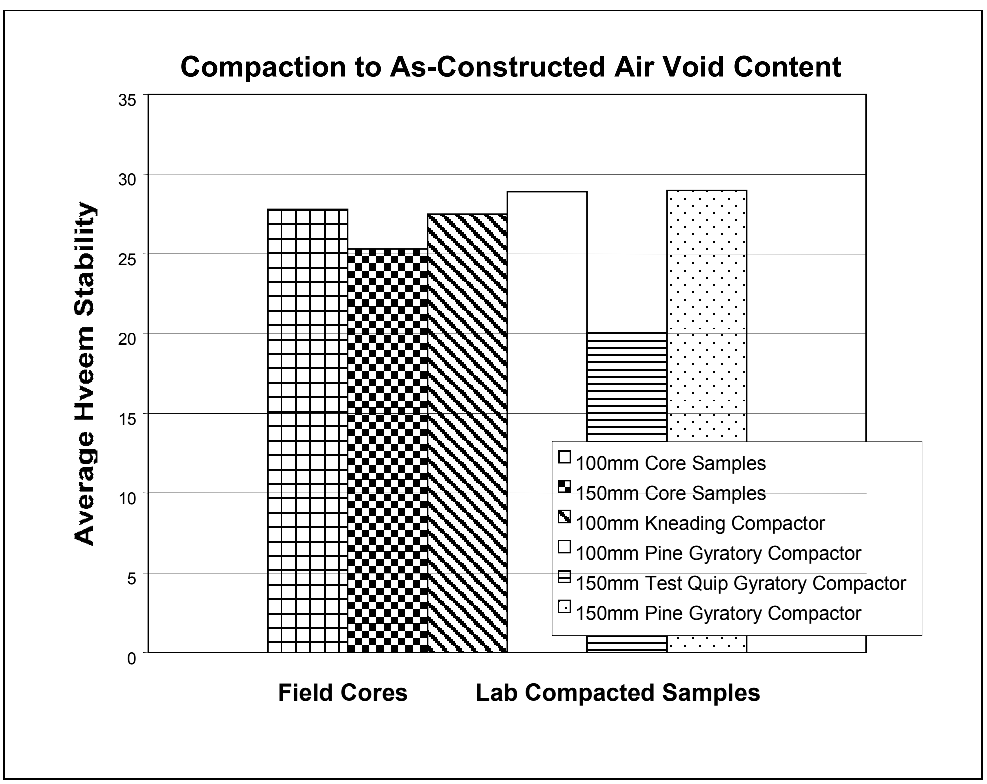

Figure 3.6b: Hveem stability of OR 58/U.S. 97 samples (as-constructed air void content)

3.3 CORVALLIS PROJECT

3.3.1 Air Void Content

The air void content of all plant-produced HMAC samples is shown in Table 3.5. Gyratory compaction summaries for N_{design} and "in-place or as-constructed air void content" are shown in Figures 3.7 and 3.8, respectively. The number of gyrations required to achieve the "as-constructed air void content" was 49 and 55 for the 150-mm and 100-mm samples, respectively. With the kneading compactor the number of tamps required to achieve the "as-constructed air void content" was 110.

3.3.2 Hveem Stability

Individual sample and average Hveem stability numbers are shown in Table 3.6. Average Hveem stabilities for samples compacted to N_{design} gyrations and as-constructed air void contents are shown in Figures 3.9a and 3.9b, respectively.

Table 3.5: Air Void Content of Corvallis Samples (Average Asphalt Content = 5.6%)

Field Cores

Sample	Percent Air Voids	Average Percent Air Voids	
4C01	8.2	7.7	100 mm
4C02	7.2		
4C03	7.3		
4C04	8.5		
4C05	7.9		
4C06	7.9		
4C07	6.4		
4C08	7.0		
4C10	8.0		
4C11	8.0		
4C12	8.1		
6C01	8.4	8.0	150 mm
6C02	7.0		
6C03	7.7		
6C04	9.1		
6C05	8.4		
6C06	7.9		
6C07	7.2		
6C08	8.1		
6C10	8.0		
6C11	8.2		
6C12	8.3		

Plant Mix Compacted in Lab
Samples Compacted to In-Place Air Voids

Sample	Percent Air Voids	Average Percent Air Voids	
C110	9.3	8.3	100 mm Kneading Compactor
C1103	8.4		
C1104	8.0		
C1105	7.6		
LVCPN01	8.2	8.2	100 mm Pine Gyratory Compactor
LVCPN02	8.3		
LVCPN03	8.0		
LVCBG151	7.6	7.7	150 mm Test Quip Gyratory
LVCBG152	7.9		
LVCBG153	7.7		
LVCPN151	7.7	7.9	150 mm Pine Gyratory
LVCPN152	8.0		
LVCPN153	8.0		

Plant Mix Compacted on Site
Samples Compacted to N_{design} Gyrations

Sample	Percent Air Voids	Average Percent Air Voids	
CBG151	6.9	6.7	150 mm Test Quip Gyratory Compactor
CBG152	6.9		
CBG153	6.9		
CBG154	6.9		
CBG155	6.6		
CBG156	6.6		
CBG157	6.2		
CBG158	6.6		

Plant Mix Compacted in Lab
Samples Compacted to N_{design} Gyrations

Sample	Percent Air Voids	Average Percent Air Voids	
LCPN01	7.3	7.3	100 mm Pine Gyratory Compactor
LCPN02	7.5		
LCPN03	7.2		
LCBG151	6.0	5.8	150 mm Test Quip Gyratory
LCBG152	5.5		
LCBG153	5.8		
LCPN151	5.5	5.7	150 mm Pine Gyratory
LCPN152	5.9		
LCPN153	5.7		

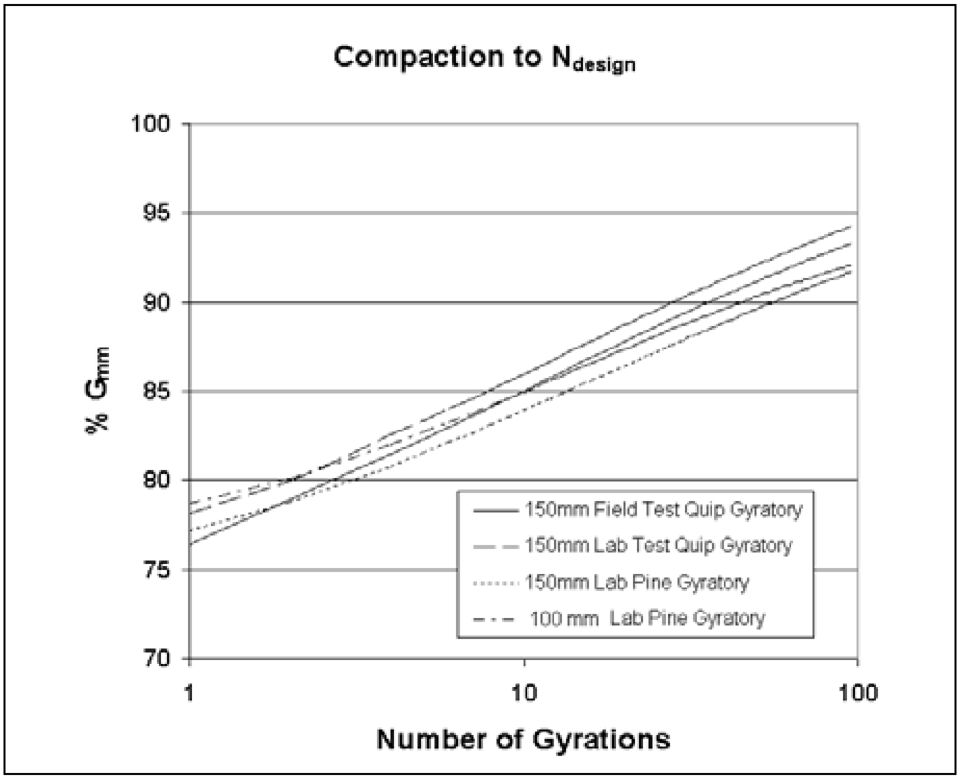

Figure 3.7a: Percent G_{mm} vs gyrations for Corvallis samples (N_{design} gyrations)

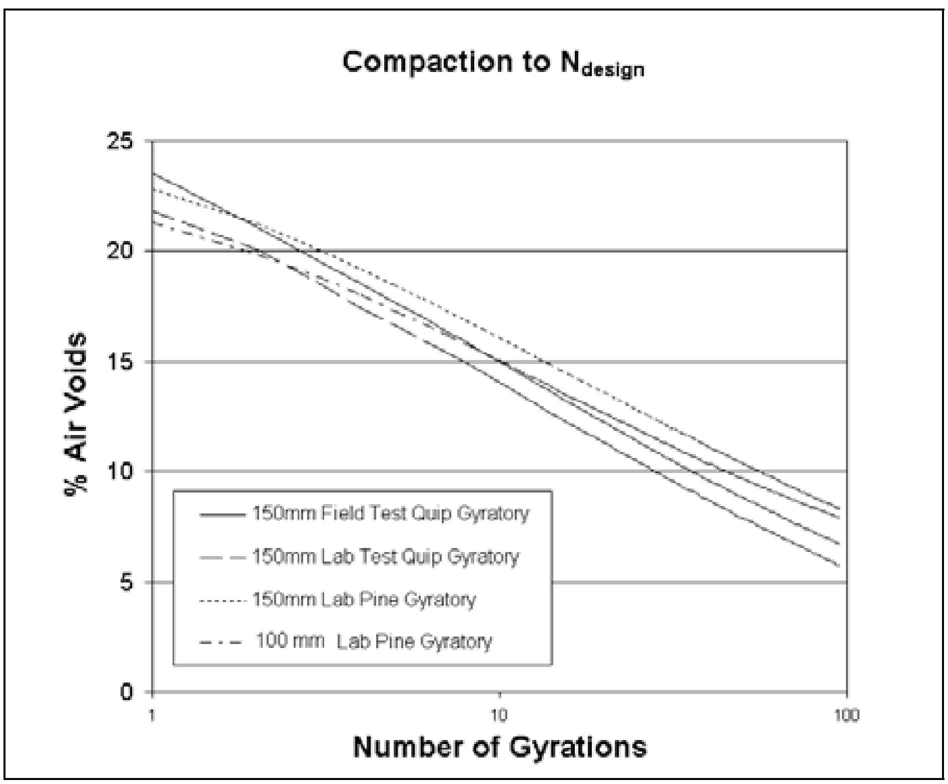

Figure 3.7b: Percent air voids vs gyrations for Corvallis samples (N_{design} gyrations)

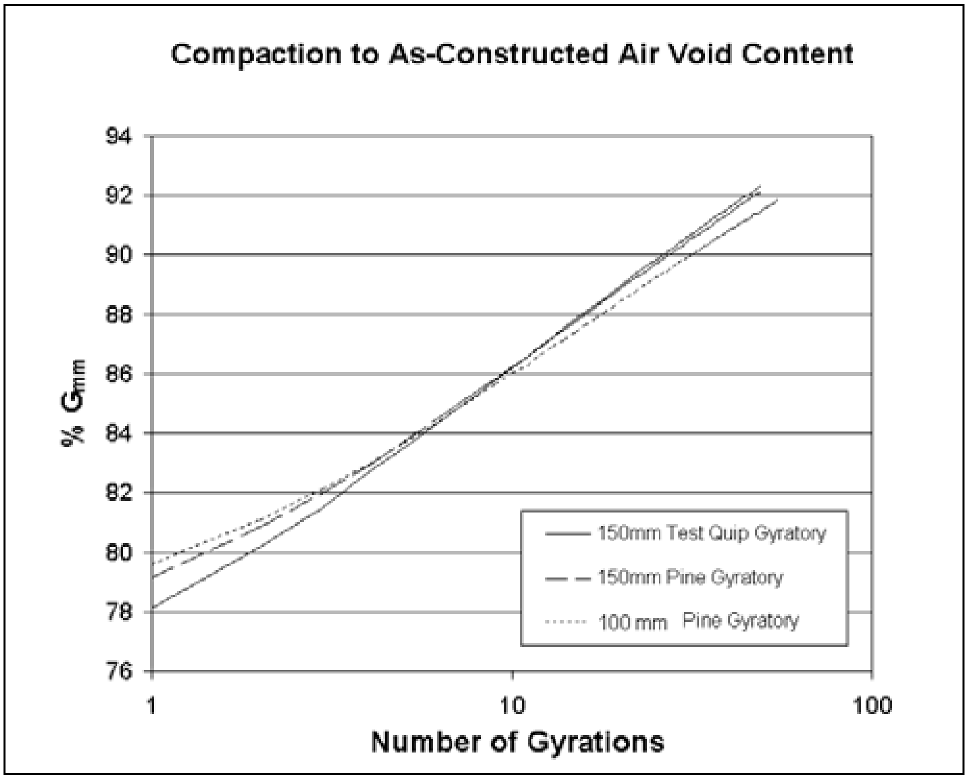

Figure 3.8a: Percent G_{mm} vs gyrations for Corvallis samples (as-constructed air void content)

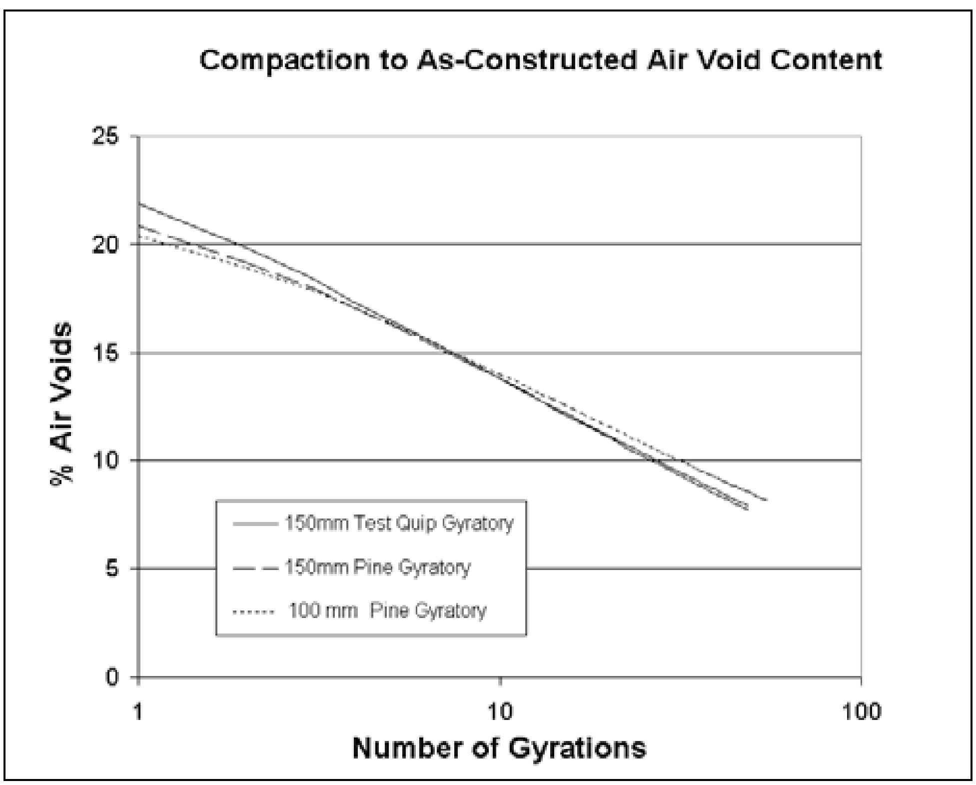

Figure 3.8b: Percent air voids vs gyrations for Corvallis samples (as-constructed air void content)

Table 3.6: Hveem Stability of Corvallis Samples

Samples Compacted to In-Place Air Voids				
Sample	Corrected Stability Number	Average Corrected Stability Number		
4C01	25	27	100 mm Core Samples	Field Cores
4C02	32			
4C03	26			
4C04	26			
4C05	26			
4C06	33			
4C07	29			
4C08	25			
4C09	23			
4C10	25			
4C11	23			
4C12	26			
6C01	29	25	150 mm Core Samples	
6C02	27			
6C03	29			
6C04	28			
6C05	25			
6C06	24			
6C07	28			
6C08	25			
6C09	20			
6C10	25			
6C11	23			
6C12	23			
C110	30	31	100 mm Kneading Compactor	Plant Mix Compacted in Lab
C1103	30			
C1104	32			
C1105	31			
LVCPN01	33	32	100 mm Pine Gyratory Compactor	
LVCPN02	32			
LVCPN03	33			
LVCBG151	30	33	150 mm Test Quip Gyratory	
LVCBG152	34			
LVCBG153	34			
LVCPN151	33	33	150 mm Pine Gyratory Compactor	
LVCPN152	32			
LVCPN153	33			

Table 3.6 (Continued): Hveem Stability of Corvallis Samples

Samples Compacted to N_{design} Gyrations				
Sample	Corrected Stability Number	Average Corrected Stability Number		
CBG151	29	32	150 mm Test Quip Gyratory Compactor	Plant Mix Compacted on Site
CBG152	31			
CBG153	30			
CBG154	30			
CBG155	30			
CBG156	33			
CBG157	36			
CBG158	35			
LCPN01	35	35	100 mm Pine Gyratory Compactor	Plant Mix Compacted in Lab
LCPN02	36			
LCPN03	35			
LCBG151	38	36	150 mm Test Quip Gyratory	
LCBG152	35			
LCBG153	34			
LCPN151	34	36	150 mm Pine Gyratory Compactor	
LCPN152	36			
LCPN153	36			

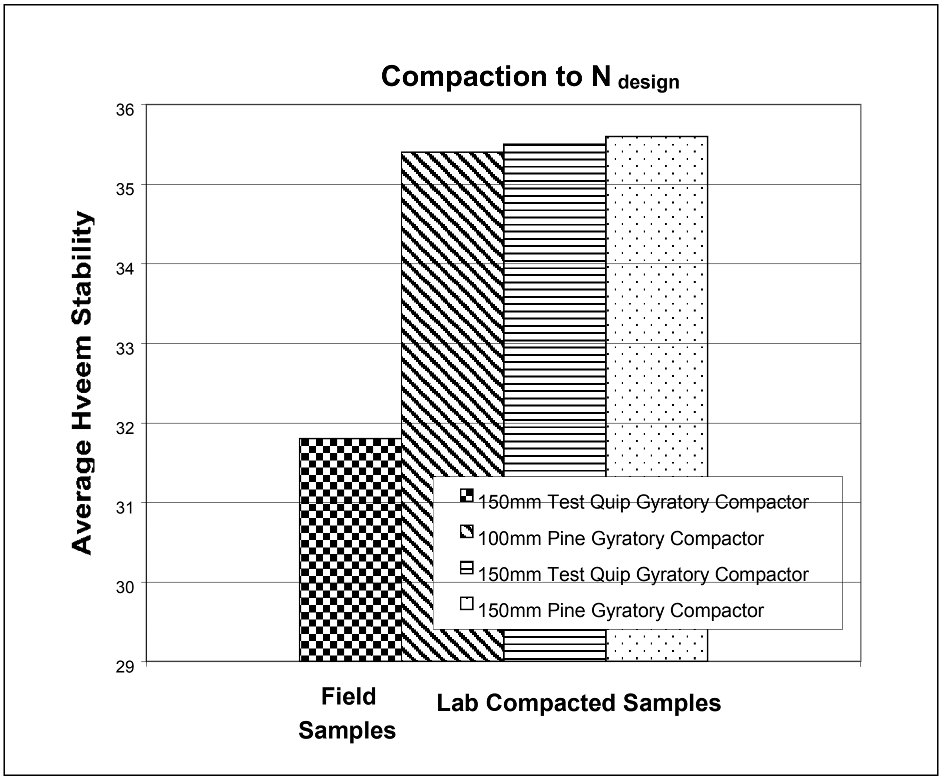

Figure 3.9a: Hveem stability of Corvallis samples (N_{design} gyrations)

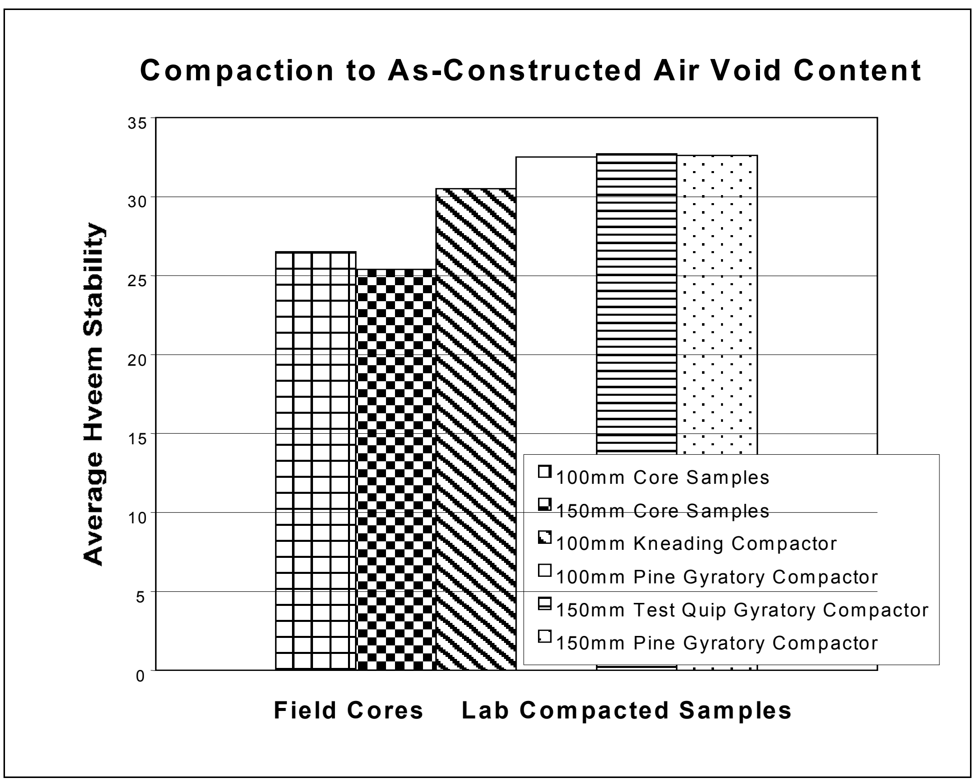

Figure 3.9b: Hveem stability of Corvallis samples (as-constructed air void content)

3.4 HERMISTON PROJECT

3.4.1 Air Void Content

The air void content of all plant-produced HMAC samples is shown in Table 3.7. Gyratory compaction summaries for N_{design} and "in-place or as-constructed air void content" are shown in Figures 3.10 and 3.11, respectively. The number of gyrations required to achieve the "as-constructed air void content" was 96 and 100 for the 150-mm and 100-mm samples, respectively. With the kneading compactor the number of tamps required to achieve the "as-constructed air void content" was 100.

3.4.2 Hveem Stability

Individual sample and average Hveem stability numbers are shown in Table 3.8. Average Hveem stabilities for samples compacted to N_{design} gyrations and as-constructed air void contents are shown in Figures 3.12a and 3.12b, respectively.

Table 3.7: Air Void Content of Hermiston Samples (Average Asphalt Content = 5.5%)

Field Cores

Sample	Percent Air Voids	Average Percent Air Voids	
4H01	10.3	9.2	100 mm
4H02	10.1		
4H03	9.3		
4H04	9.6		
4H05	9.8		
4H06	8.1		
4H07	9.4		
4H08	9.5		
4H09	9.8		
4H10	9.0		
4H11	8.3		
4H12	7.5		
6H01	10.4	9.1	150 mm
6H02	8.8		
6H03	8.6		
6H04	9.2		
6H05	8.7		
6H06	9.0		
6H07	9.6		
6H08	9.3		
6H09	9.8		
6H10	8.4		
6H11	9.0		
6H12	7.9		

Plant Mix Compacted in Lab
Samples Compacted to In-Place Air Voids

Sample	Percent Air Voids	Average Percent Air Voids	
H1001	9.1	9.3	100 mm Kneading Compactor
H1002	9.1		
H1004	9.7		
LVPNH01	9.4	9.6	100 mm Pine Gyratory Compactor
LVPNH02	9.6		
LVPNH03	9.7		
LVBGH151	9.1	9.0	150 mm Test Quip Gyratory
LVBGH152	9.0		
LVBGH153	9.0		
LVHPN154	8.8	8.9	150 mm Pine Gyratory
LVHPN155	9.3		
LVHPN156	8.5		

Plant Mix Compacted on Site
Samples Compacted to N_{design} Gyrations

Sample	Percent Air Voids	Average Percent Air Voids	
HBG152	7.9	8.2	150 mm Test Quip Gyrator Compactor
HBG153	7.5		
HBG154	7.9		
HBG155	7.6		
HBG156	8.5		
HBG157	8.8		
HBG158	8.9		

Plant Mix Compacted in Lab
Samples Compacted to N_{design} Gyrations

Sample	Percent Air Voids	Average Percent Air Voids	
LPNH01	9.4	9.7	100 mm Pine Gyratory Compactor
LPNH02	9.6		
LPNH03	10.0		
LBGH151	9.1	8.9	150 mm Test Quip Gyratory
LBGH152	8.7		
LBGH153	8.9		
LPNH151	9.9	9.2	150 mm Pine Gyratory
LPNH152	9.1		
LPNH153	8.7		

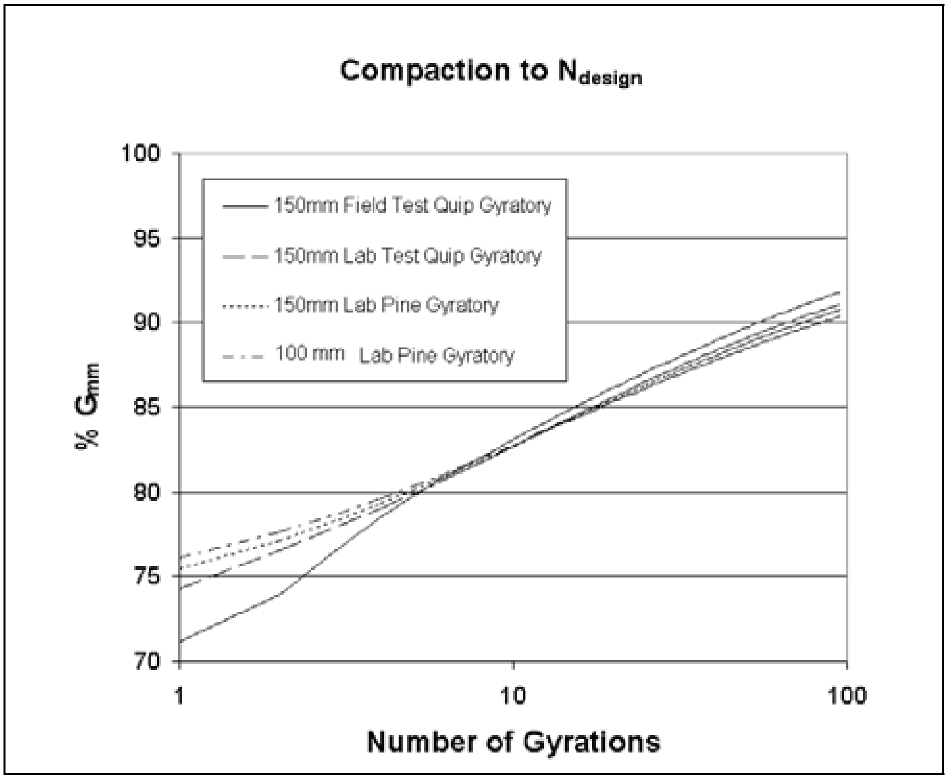

Figure 3.10a: Percent G_{mm} vs gyrations for Hermiston stamples (N_{design} gyrations)

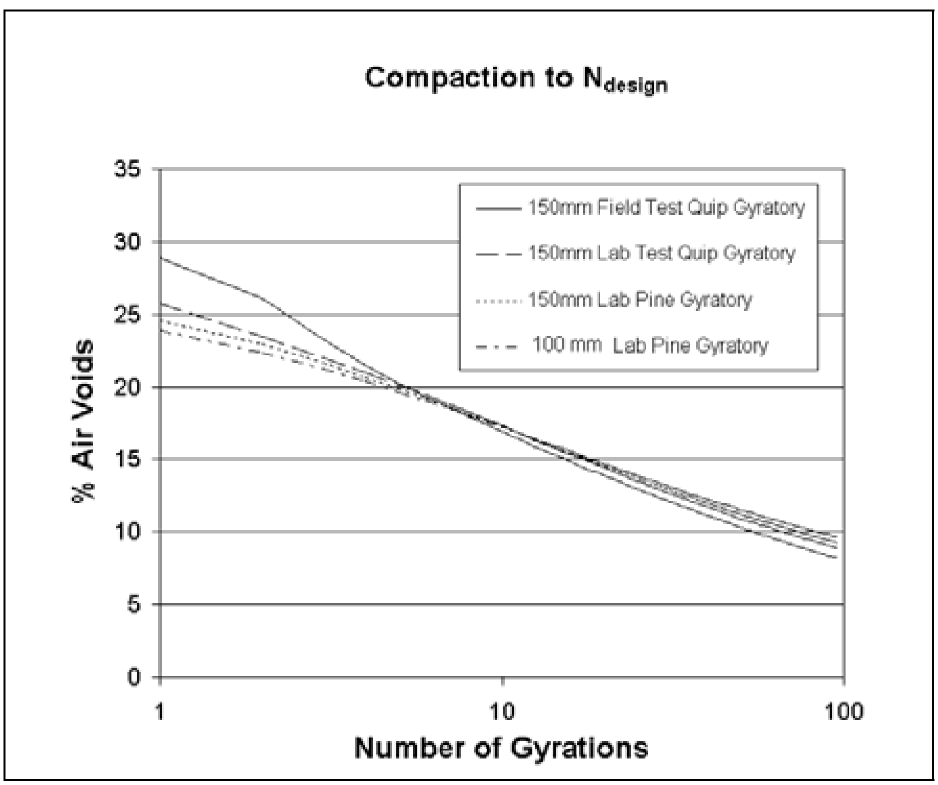

Figure 3.10b: Percent air voids vs gyrations for Hermiston samples (N_{design} gyrations)

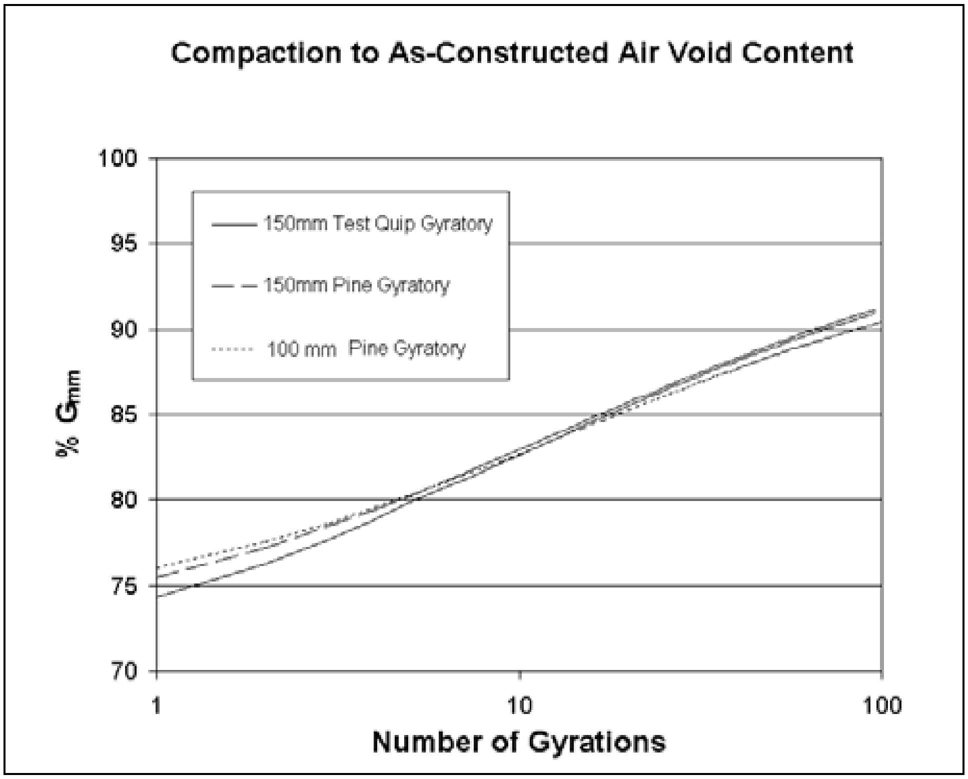

Figure 3.11a: Percent G_{mm} vs gyrations for Hermiston samples (as-constructed air void content)

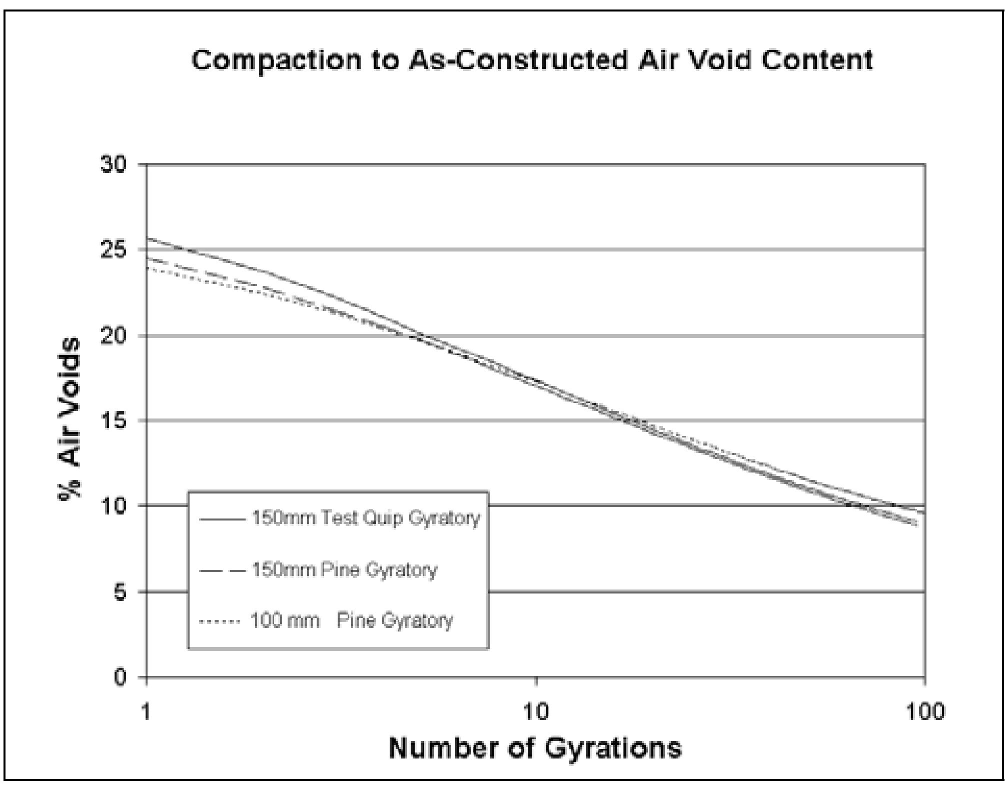

Figure 3.11b: Percent air voids vs gyrations for Hermiston samples (as-constructed air void content)

Table 3.8: Hveem Stability of Hermiston Samples

Samples Compacted to In-Place Air Voids				
Sample	**Corrected Stability Number**	**Average Corrected Stability Number**		
4H01	25	26	100 mm Core Samples	Field Cores
4H02	28			
4H03	23			
4H04	25			
4H05	25			
4H06	28			
4H07	26			
4H08	27			
4H09	20			
4H10	27			
4H11	26			
4H12	31			
6H01	25	26	150 mm Core Samples	
6H02	24			
6H03	23			
6H04	27			
6H05	24			
6H06	28			
6H07	25			
6H08	29			
6H09	24			
6H10	30			
6H11	26			
6H12	29			
H1001	22	25	100 mm Kneading Compactor	Plant Mix Compacted in Lab
H1002	28			
H1004	26			
LVH01	27	27	100 mm Pine Gyratory Compactor	
LVH02	27			
LVH03	25			
LVBGH151	28	27	150 mm Test Quip Gyratory	
LVBGH152	27			
LVBGH153	26			
LVHPN154	31	29	150 mm Pine Gyratory Compactor	
LVHPN155	28			
LVHPN156	28			

Table 3.8 (Continued): Hveem Stability of Hermiston Samples

Samples Compacted to N_{design} Gyrations				
Sample	**Corrected Stability Number**	**Average Corrected Stability Number**		
HBG151	29	28	150 mm Test Quip Gyratory Compactor	Plant Mix Compacted on Site
HBG152	29			
HBG153	26			
HBG154	29			
HBG155	30			
HBG156	25			
HBG157	28			
HBG158	26			
LH01	27	31	100 mm Pine Gyratory Compactor	Plant Mix Compacted in Lab
LH02	34			
LH03	30			
LBGH151	30	31	150 mm Test Quip Gyratory	
LBGH152	31			
LBGH153	32			
LPNH151	24	27	150 mm Pine Gyratory Compactor	
LPNH152	29			
LPNH153	29			

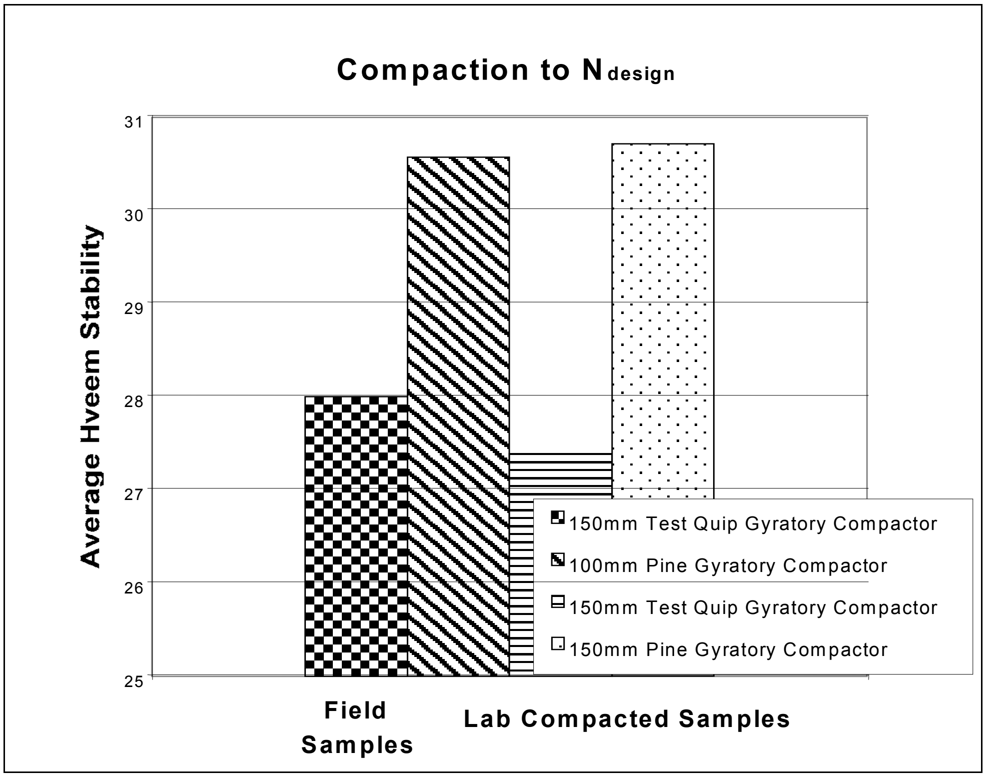

Figure 3.12a: Hveem stability of Hermiston samples (N_{design} gyrations)

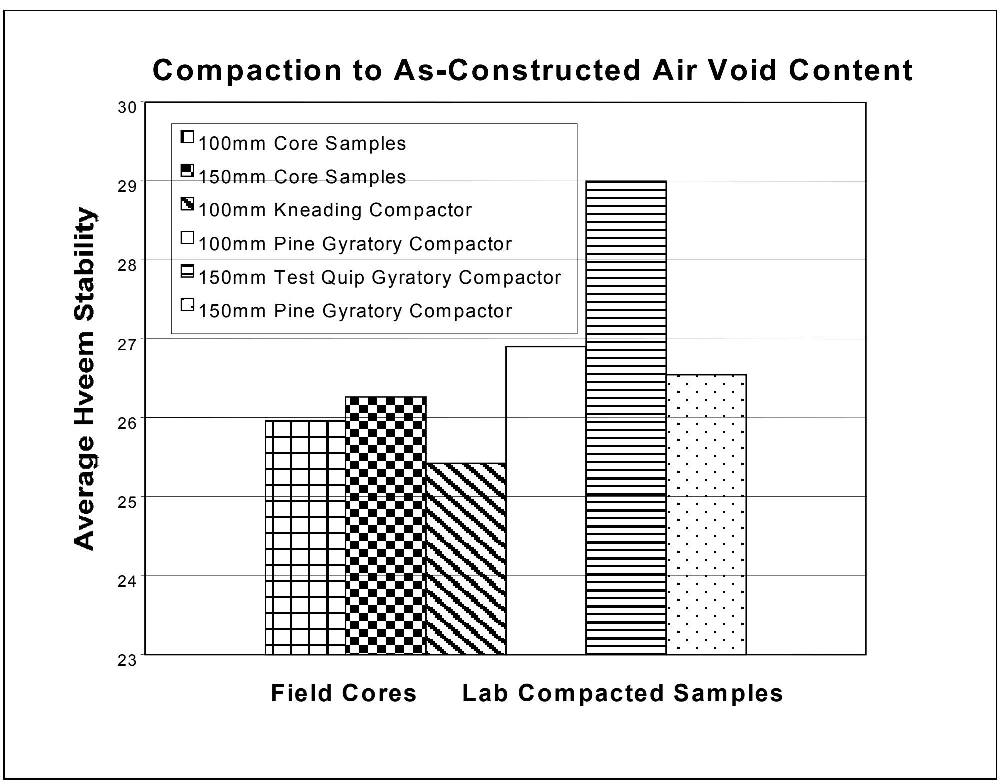

Figure 3.12b: Hveem stability of Hermiston samples (as-constructed air void content)

4.0 ANALYSIS AND DISCUSSION

To determine the effectiveness of a portable gyratory compactor for field quality control, plant-produced HMAC was compacted and tested as shown in Figure 4.1. Since air void content is the most commonly used criterion for HMAC "acceptance," and Hveem stability is widely used as an indicator of quality, a summary of these data is shown in Table 4.1 for ready reference. Note that the air void content data in Table 4.2 and Hveem stability data in Table 4.3 reflect the mean values across sample size.

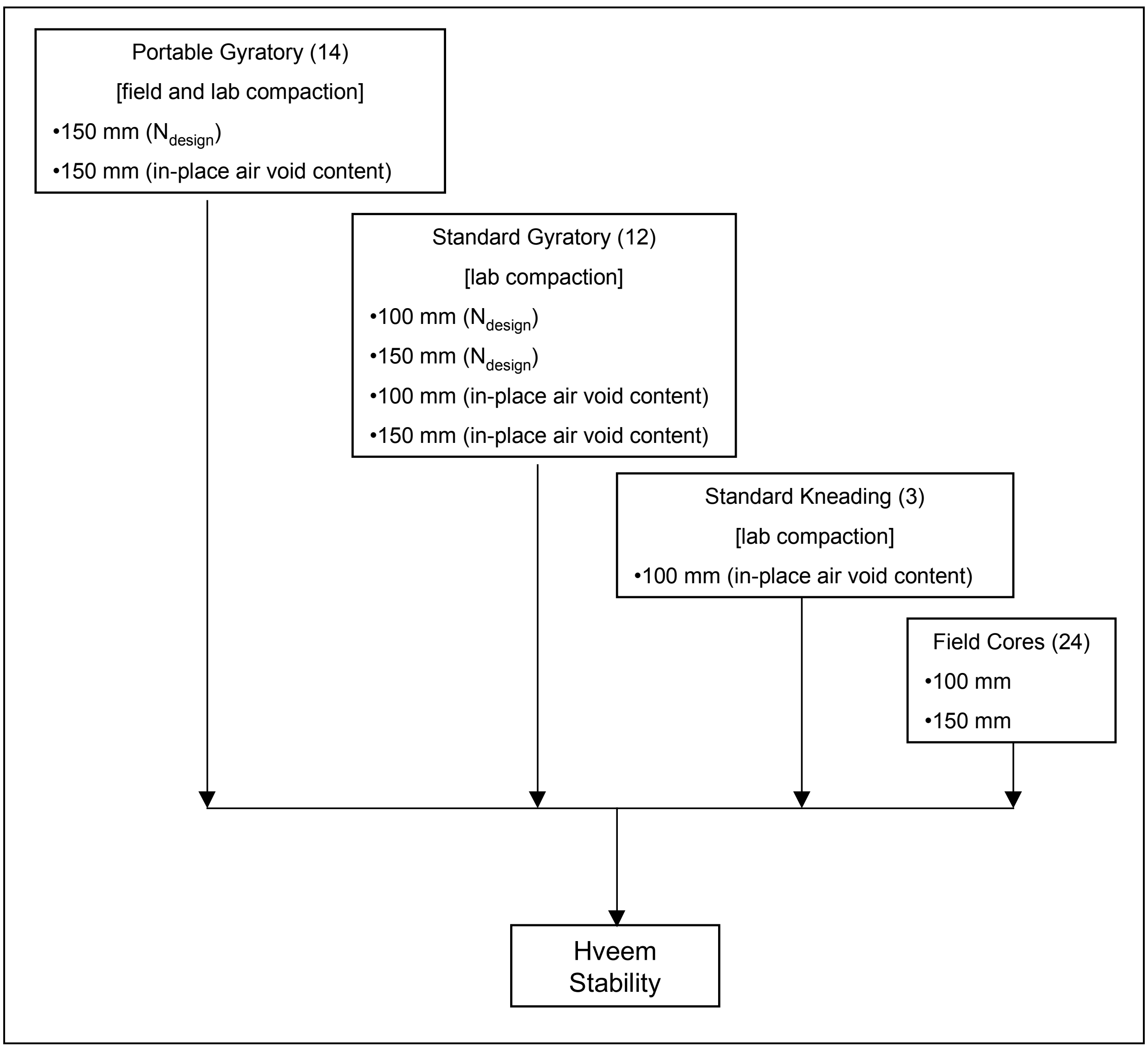

Figure 4.1: Evaluation of Plant-Produced HMAC

Table 4.1: Summary of Air Void Content and Hveem Stability

AIR VOID CONTENT (PERCENT)

	Field Cores		Compaction to As-Constructed Air Void Content				Compaction to N_{design}			
							Lab			Field
			Kneading	Standard Gyratory		Portable Gyratory	Standard Gyratory		Portable Gyratory	
Project	100 mm	150 mm	100 mm	100 mm	150 mm	150 mm	100 mm	150 mm	150 mm	150 mm
Gardiner	6.9	6.8	7.1	6.4	6.1	6.4	3.9	2.9	3.0	4.9
US97/OR58	7.2	7.3	7.8	7.5	7.3	7.2	4.5	2.7	2.2	2.9
Corvallis	7.7	8.0	8.3	8.2	7.9	7.7	7.3	5.7	5.8	6.7
Hermiston	9.2	9.1	9.3	9.6	8.9	9.0	9.7	9.2	8.9	8.2
Mean	7.8	7.8	8.1	7.9	7.6	7.6	6.4	5.1	5.0	5.7

HVEEM STABILITY

	Field Cores		Compaction to As-Constructed Air Void Content				Compaction to N_{design}			
							Lab			Field
			Kneading	Standard Gyratory		Portable Gyratory	Standard Gyratory		Portable Gyratory	
Project	100 mm	150 mm	100 mm	100 mm	150 mm	150 mm	100 mm	150 mm	150 mm	150 mm
Gardiner	22		25	29	26	26	33	32	32	30
US97/OR58	28	25	28	29	29	20	40	42	40	37
Corvallis	27	25	31	32	33	33	35	36	36	32
Hermiston	26	26	25	27	29	27	31	27	31	28
Mean	26	25	27	29	29	27	35	34	35	32

Table 4.2: Average Percent Air Voids

Project	Field Cores	Samples Compacted to In-Place Air Void Content	Samples Compacted to N_{design}
Gardiner	6.8	6.5	4.1
OR 58/U.S. 97	7.2	7.5	3.0
Corvallis	7.9	8.0	6.5
Hermiston	9.1	9.2	8.8

4.1 AIR VOID CONTENT

Table 4.2 and Figures 4.2 to 4.6 include comparisons of air void content among various samples. As shown in Figure 4.2, there is virtually no difference between the 100 mm and 150 mm diameter field cores. Since air void content appears to be independent of core diameter, there may be both logistical and economic benefits: less effort for handling; less storage space needed; and reduced drilling costs. However, the benefit of performance testing, which is likely to require 150 mm diameter cores, may offset the logistical and economic benefits previously noted.

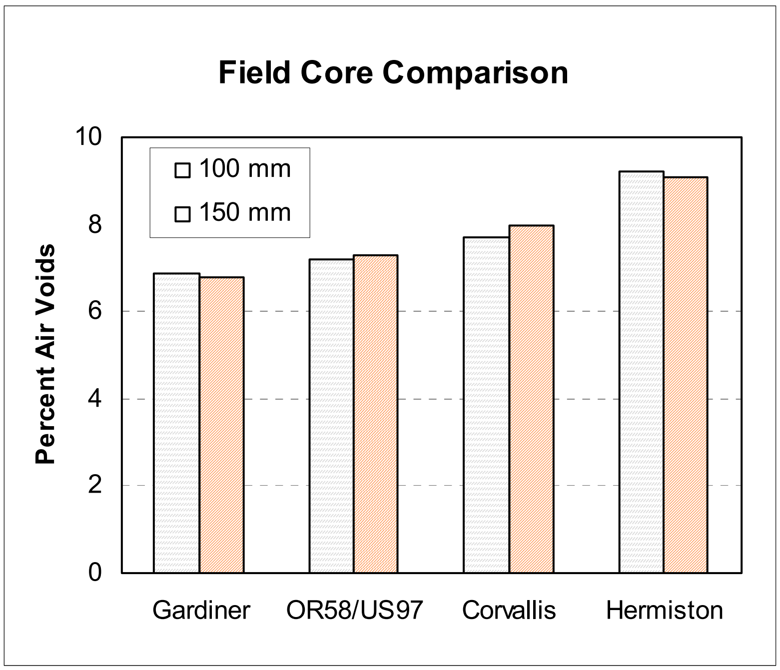

Figure 4.2: Air void content of field cores

There was, as expected, a difference in air void content between field cores and samples compacted to N_{design} gyrations, as shown in Figure 4.3. Generally, the as-constructed air void content was higher than that of samples compacted to N_{design} gyrations. The range in as-constructed air void content was 6.8 to 9.1 percent, whereas the range in air void content for samples compacted to N_{design} was 3.0 to 8.8 percent. The as-constructed air void content was typically about 2 percent higher than the N_{design} air void content. It was only for the Hermiston project that the as-constructed and N_{design} air void contents were approximately equal – 9.1 and 8.8 percent, respectively.

Recalling that SHRP researchers hypothesized that N_{design} gyrations should yield an equilibrium or ultimate air void content, i.e., after the pavement had sustained the design traffic, one might have expected an even greater difference between the as-constructed air void content and that of the field cores. To confirm or refute the hypothesis that lab compaction to N_{design} gyrations is equivalent to the equilibrium air void content of the pavement will require periodic monitoring of the field projects. The air void content of field cores taken subsequently, i.e., at various traffic (or time) intervals, might help to better define the relationship between N_{design} and air void content. With data from only four projects and at only one time interval (pre-traffic) the conclusions were, however, encouraging. Other factors that might account for the difference in air void content include the following: changes in asphalt content; compaction temperature and compaction methodology, i.e., the kneading and/or vibratory action of the paving operation versus that of the lab gyratory.

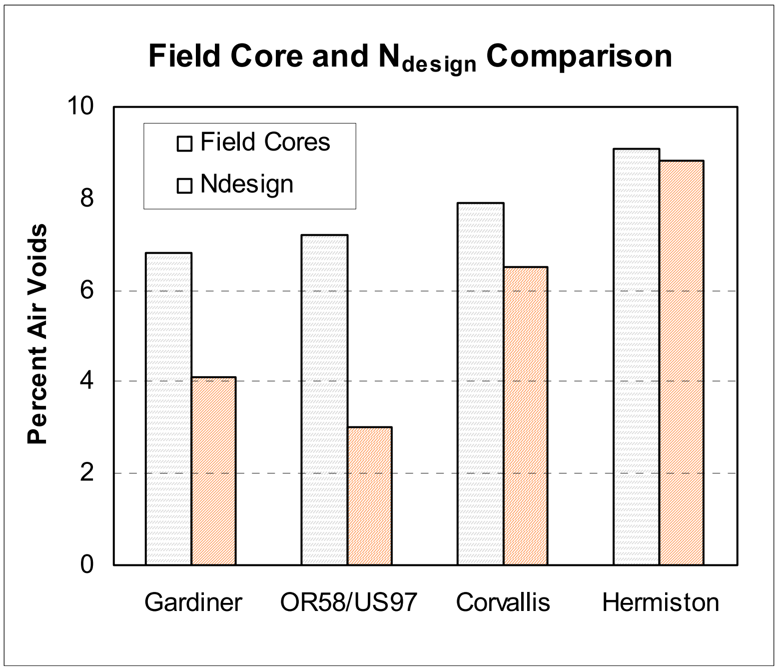

Figure 4.3: Air void content of field cores and specimens compacted to N_{design} gyrations

Shown in Figures 4.4 and 4.5 are comparisons of air void content across sample size and gyratory compactor. Figure 4.4 shows a comparison of 100 mm and 150 mm Pine gyratory compacted samples. Note that the 150 mm samples are consistently lower in air void content than the 100 mm samples, typically by 0.5 to 1.5 percent. These data may be important if ODOT were to consider using 100 mm diameter samples for field QC/QA purposes.

A key concern in this research was the compatibility of the original Superpave gyratory compactors (e.g., Pine, Troxler) with the more portable Test Quip gyratory. Although the portable gyratory used in this study was a prototype, one would conclude from the data shown in Figure 4.5 that there was essentially no difference in compactors as measured by air void content. In no case was the difference in air void content for the two compactors – standard and portable – greater than 0.5 percent. This bodes well for the use of a portable gyratory compactor for field QC/QA purposes.

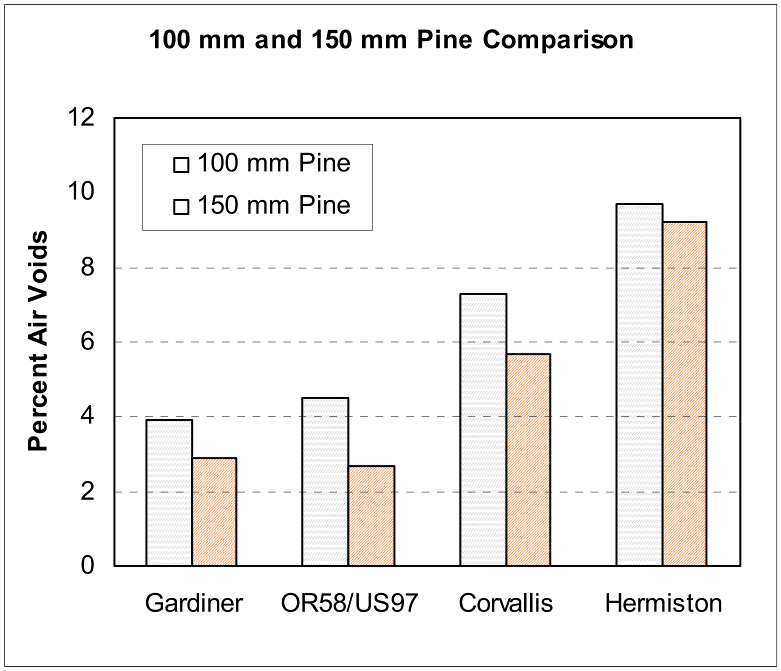

Figure 4.4: Air void content of gyratory compacted specimens (100 mm vs. 150 mm)

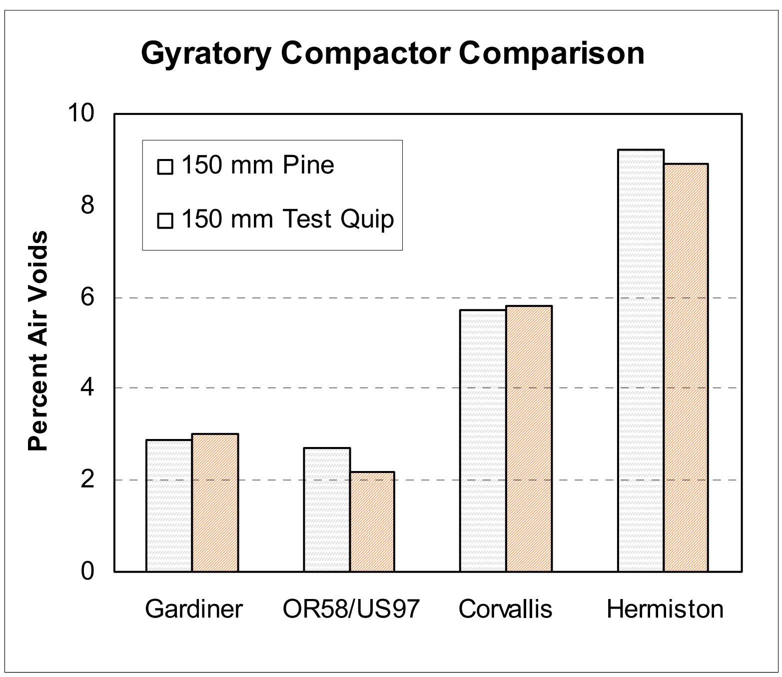

Figure 4.5: Air void content of gyratory compacted specimens (Pine vs. Test Quip)

Figure 4.6 shows a comparison of field and lab compacted samples. With only one exception, the field compacted specimens had higher air void contents. These results are somewhat counter-intuitive. One would have expected the lab compacted samples, because of binder hardening associated with limited oxidation occurring during storage and re-heating, to be somewhat more difficult to compact yielding slightly higher air void contents. The only possible explanation for these differences is a difference in compaction temperature.

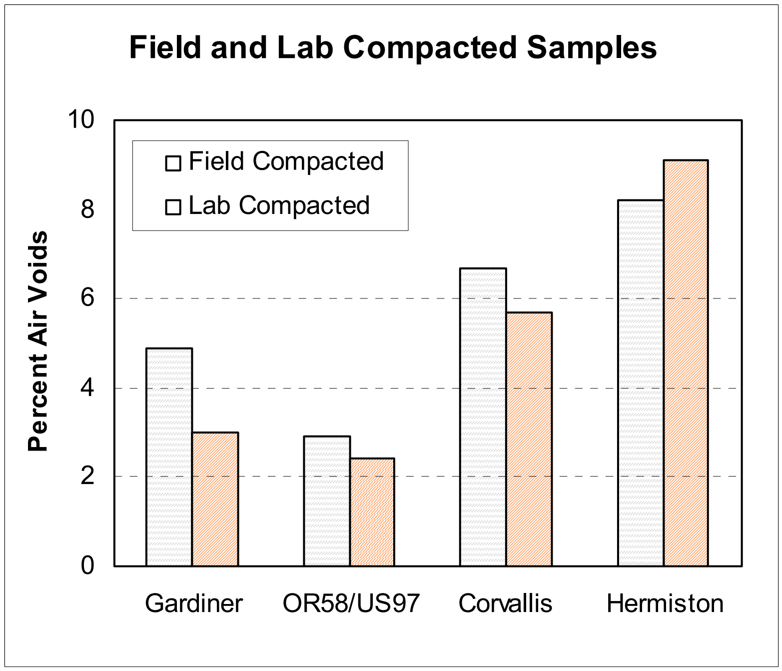

Figure 4.6: Air void content of field and lab compacted samples

4.2 HVEEM STABILITY

In part, Hveem stability is a function of air void content, as shown in Figure 4.7. Although the explained variation (R^2) appears to be somewhat project dependent, ranging from 0.11 to 0.71, one can reasonably conclude that Hveem stability is generally inversely related to air void content.

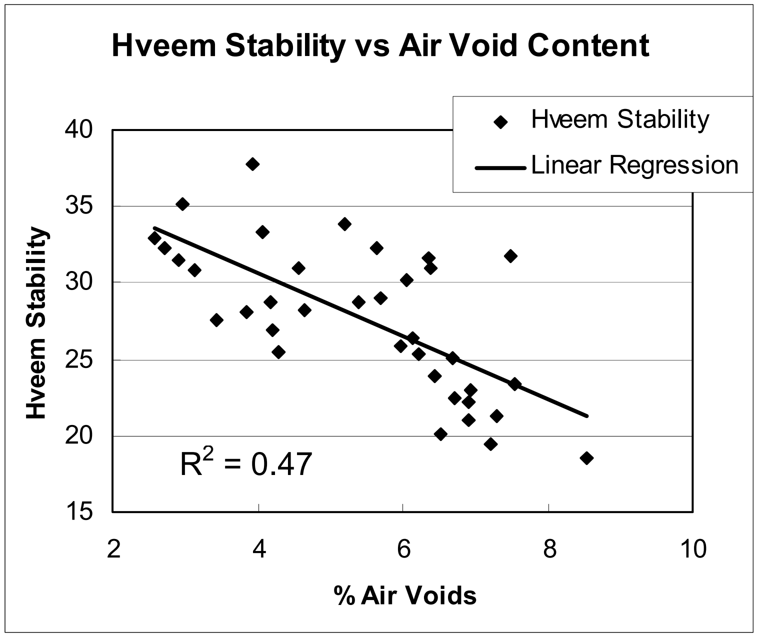

Figure 4.7a: Regression of Hveem stability vs air void content (Gardiner)

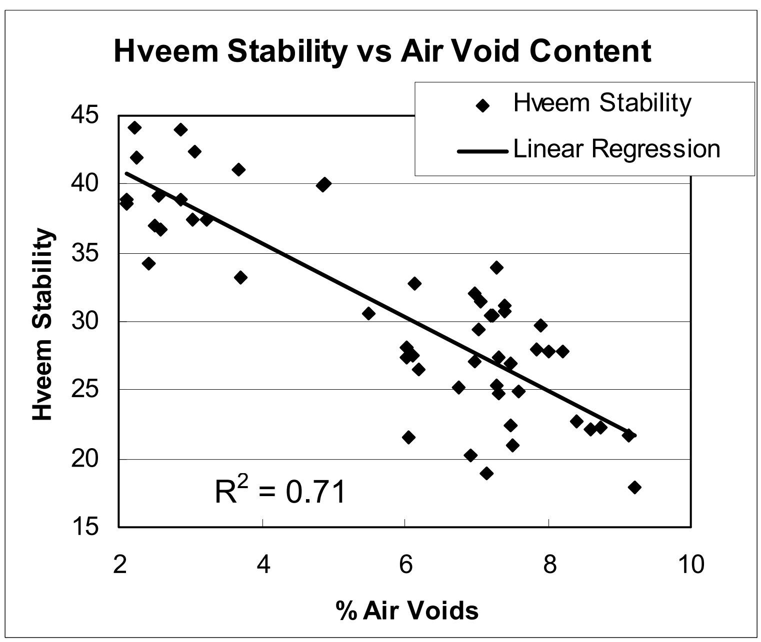

Figure 4.7b: Regression of Hveem stability vs air void content (OR 58/U.S. 97)

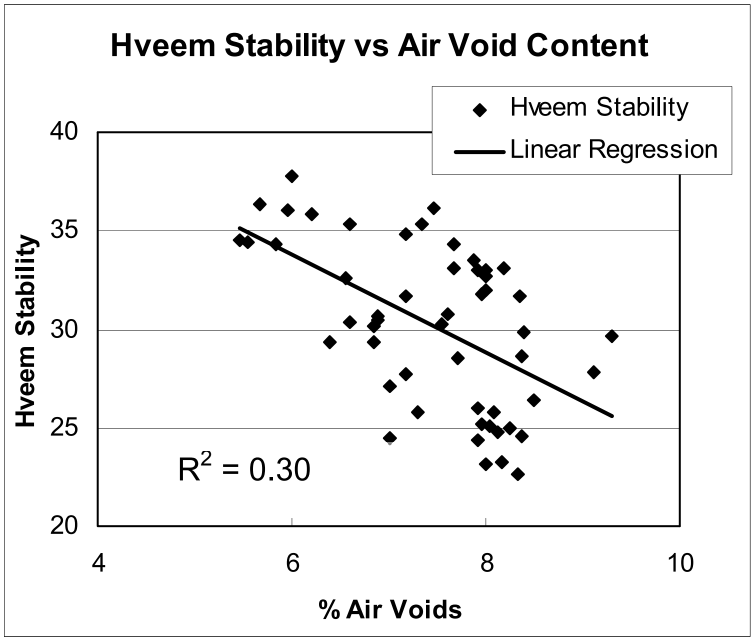

Figure 4.7c: Regression of Hveem stability vs air void content (Corvallis)

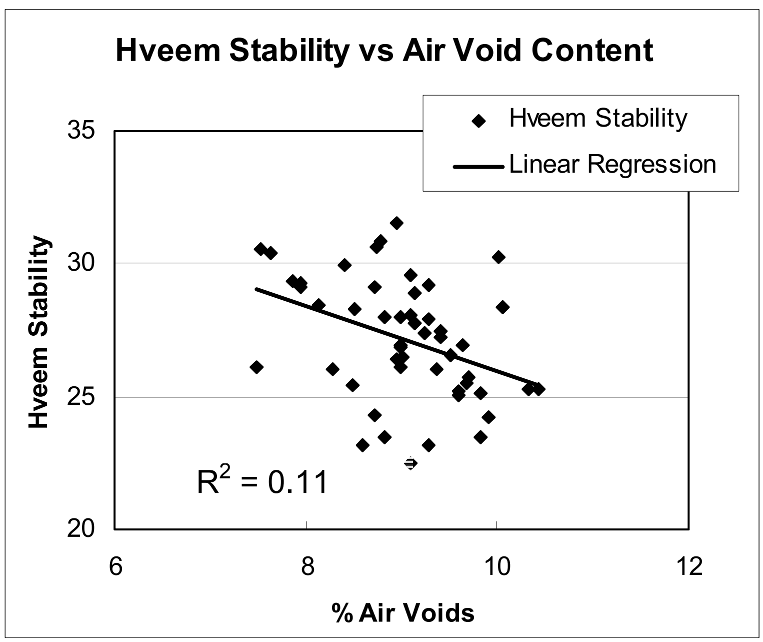

Figure 4.7d: Regression of Hveem stability vs air void content (Hermiston)

Table 4.3 and Figures 4.8 and 4.9 include comparisons of Hveem stability among various samples. The data in Table 4.3 indicate that the field cores generally had lower stabilities than the samples compacted to the as-constructed air void content or to N_{design} gyrations. From Figure 4.8 one observes that the gyratory compacted specimens yielded slightly higher stability numbers than did the field cores. There appears to be only one exception, that of the 150 mm Test Quip samples from the OR 58/US 97 project. Also, the kneading compacted specimens tended to yield slightly higher stability numbers than did the field cores. Finally, there were but minor differences in stability between 100 mm specimens and 150 mm specimens from which 100 mm specimens were cored.

Shown in Figure 4.9 is a comparison of Hveem stability for samples compacted to N_{design}. Note that there were samples compacted in the field during construction and in the lab at a later date. Generally, the samples compacted in the field (150 mm Test Quip gyratory) had lower stability numbers than did the samples compacted in the lab. Data from the Hermiston project was the only exception. The consistent difference in stability, though small (3 to 5), was between field and lab compacted samples. There was very little difference in the stability of lab compacted samples, regardless of gyratory type or specimen diameter. The slight difference in stability between field and lab compacted samples may be attributed to the fact that lab compacted samples have aged somewhat during storage and re-heating making the binder a bit stiffer and, in turn, increasing the stiffness of the mix.

Table 4.3: Average Hveem Stability

Project	Field Cores	Samples Compacted		150 mm Test Quip to N_{design}	150 mm Pine to N_{design}
		To In-Place Air Voids	To N_{design}		
Gardiner	22	26	31	32	32
OR 58/U.S. 97	27	26	39	40	42
Corvallis	26	32	34	36	36
Hermiston	26	27	29	31	27

It is noteworthy that none of the field cores, regardless of field project, met ODOT's minimum Hveem stability criterion of 35. Possible reasons for low stability include a low percentage of fractured aggregate faces, binder content that exceeds "optimum," and segregation. Although the aggregate met the Superpave criterion for percent fractured faces, it was near the lower limit. Unfortunately, the aggregate consensus criteria included in the Superpave methodology were not validated with any strength or performance tests. Inadequate fractured faces of aggregate would obviously limit internal friction and thus yield a low Hveem stability. Though these data are anecdotal at best, it appears that the Superpave mix design tended to yield a design binder content slightly higher than ODOT's traditional Hveem methodology, and hence, a lower stability. Mix segregation, perhaps due to the sampling technique, might also have contributed to the low stability.

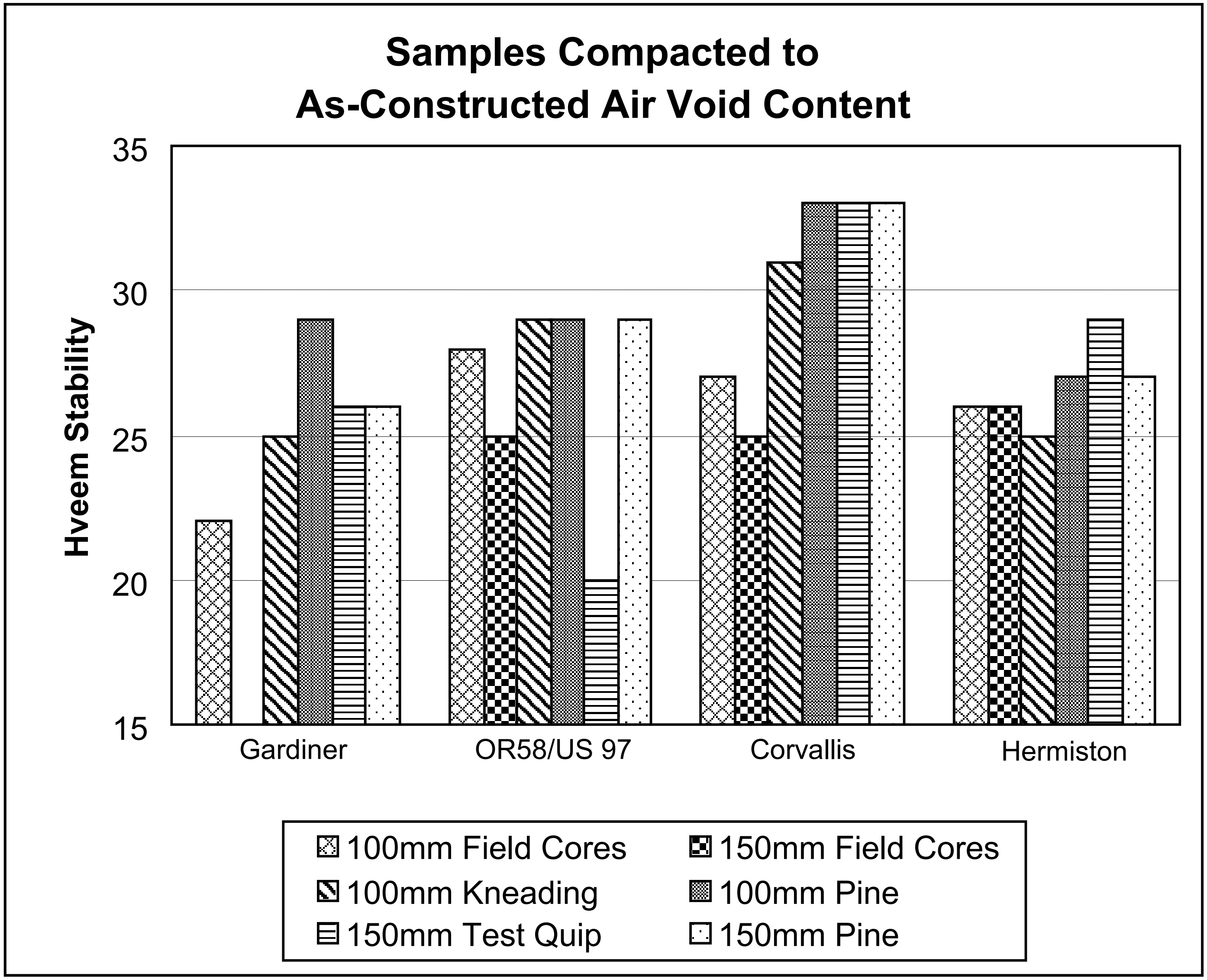

Figure 4.8: Hveem stability of specimens compacted to as-constructed air void content

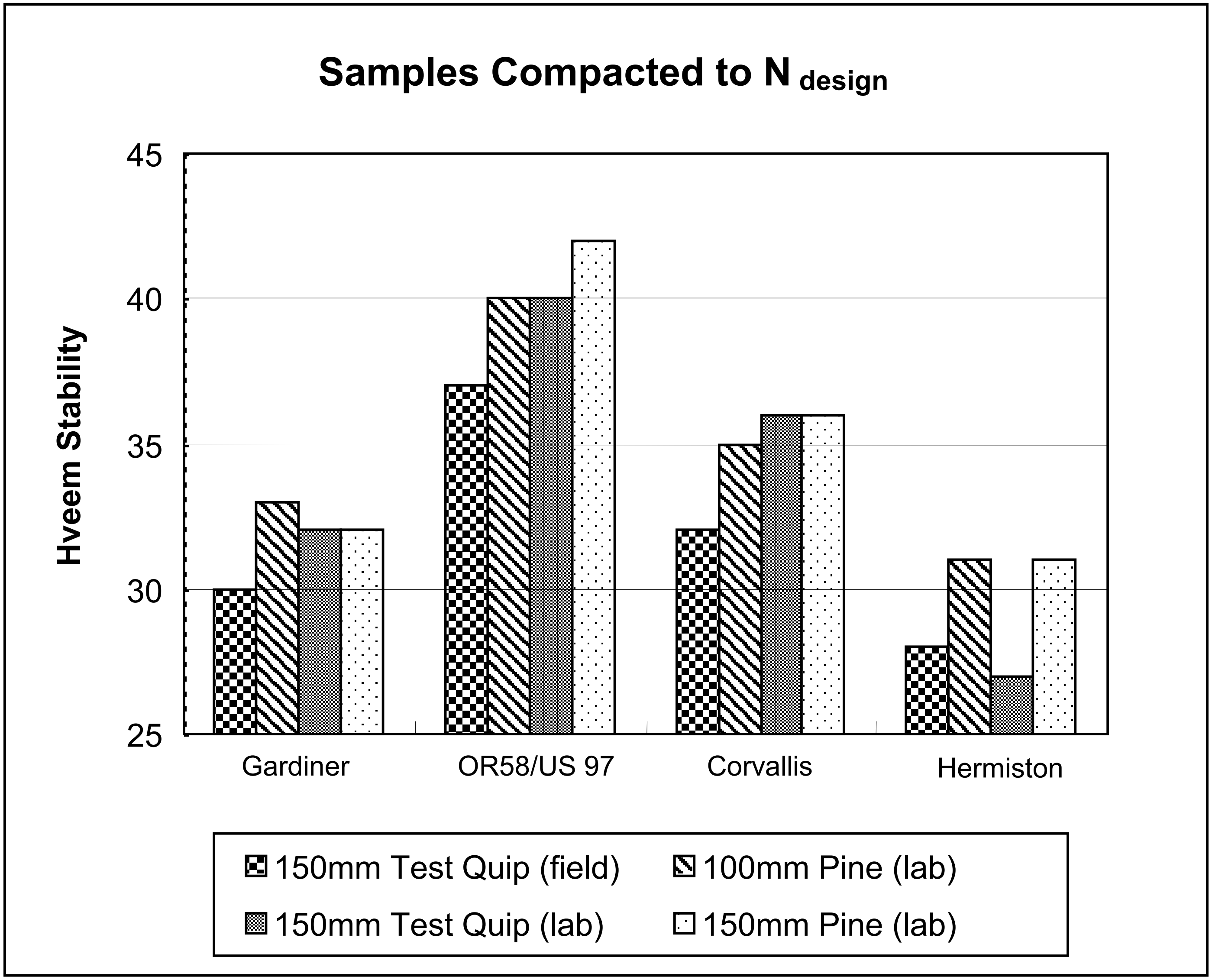

Figure 4.9: Hveem stability of specimens compacted to N_{design} gyrations

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Application of quality management concepts to asphalt paving evolved because recipe specifications frequently proved inadequate for ensuring pavement performance. Quality management of asphalt concrete is founded on the premise that the producer controls the end-quality of the product, including the in-place void content on which pavement performance is highly dependent.

In its quality management program Oregon DOT initially used the Marshall hammer for field control for a variety of reasons: the Hveem compactor (kneading) was not suitable for field operations and the Superpave gyratory compactor was not available at the time this research began. However, ODOT's earlier work on field control of asphalt concrete mixes using the Texas gyratory compactor was encouraging. The gyratory compactor, an integral part of the Superpave system, is also a potential tool for quality control/assurance (QC/QA) as measured by as-constructed air void content. However, as originally configured the mass of the prototype Superpave gyratory compactors was approximately 360 kg to 540 kg, not ideally suited for field operations. Post-SHRP research led to the development of truly portable gyratory compactors, ie, those of 70 kg to 140 kg mass.

Like the conventional Hveem method of mix design, selecting and proportioning materials as well as laboratory compaction are integral parts of the Superpave technology. There is, however, some concern as no strength test is required at low traffic levels. Numerous state DOTs have indicated that some sort of "proof testing" will be used to supplement the Superpave mix design. Given ODOT's long use of and success with Hveem mix design, Hveem stability was used in this research as a relative measure of the strength of Superpave mixes.

In view of the preceding, the primary objective of this research was to assess the effectiveness of a portable gyratory compactor for field quality control purposes. A secondary objective was to determine the quality of Superpave mixes as measured by Hveem stability. To that end the following conclusions are noteworthy:

- With regard to the operational characteristics of the Test Quip gyratory, its mass of approximately 140 kg requires at least two people to maneuver or lift it. An opening at the top of the hydraulic fluid reservoir allows the fluid to spill when the machine is tilted, making loading and transport somewhat tentative. Calibration, however, is straightforward, simple and completely automated. Similarly, charging the mold, compaction, and sample extrusion are accomplished with relative ease but are a bit more time consuming than with the prototype gyratory, i.e., Pine or Troxler. Using a torque wrench was found to be helpful when securing the gyratory head to the loading frame. Finally, maintenance of the device was quite easy.

- There was essentially no difference between the portable and prototype gyratory compactors as measured by air void content of 150 mm samples. In no case was the difference in air void content greater than 0.5 percent.

- Comparison of 100 mm and 150 mm samples compacted in the prototype gyratory was instructive in that the latter were consistently lower in air void content, typically by 0.5 to 1.5 percent. This certainly must be considered should ODOT opt to use 100 mm samples for mix design and/or QC/QA purposes.

- The air void content of plant mix samples compacted to N_{design} gyrations was consistently lower than that of the field cores, generally by at least 2 percent. The range in air void content of plant mix samples compacted to N_{design} gyrations was 3.0 to 8.8 percent, whereas the range in air void content of the field cores was 6.8 to 9.1 percent. It is the range in air void content – 3.0 to 8.8 percent – that is of primary concern as it indicates an unexpected degree of variability in the process. The most likely sources of this variability are project-specific materials and/or construction operations. Post-SHRP research has led to a dramatic consolidation of the N_{design} compaction matrix (*Brown, et al. 1998*). Instead of the original 28 N_{design} alternatives there are now only 4. Still, this revision to the compaction matrix is not believed to be a contributing factor to the variability previously noted. The original N_{design} gyrations for the ODOT projects were 86 (Gardiner) and 96 (OR 58/US 97, Corvallis and Hermiston). In the revised compaction matrix N_{design} gyrations for all ODOT projects is 100. To confirm or refute the SHRP researchers' hypothesis – that N_{design} represents the air void content of the pavement at the design traffic level – requires periodic measurement of wheel-path air void content. An assumption made in the mix design phase – that the correction factor for the computation of bulk specific gravity (G_{mb}) is linear – might be a contributing factor to the difference between the as-measured and N_{design} air void contents. Recall that in mix design specimens are compacted to $N_{maximum}$ gyrations. At $N_{maximum}$ the height of the compacted specimen is used to compute a bulk specific gravity, an *estimated* G_{mb}. This *estimated* G_{mb} is used with the *measured* G_{mb} to determine a correction factor that is used with the height of the specimen to compute the bulk specific gravity at each gyration. This issue was recently addressed in research funded by the National Cooperative Highway Research Program. During mix design specimens are now compacted to N_{design} rather than $N_{maximum}$ and bulk specific gravity is measured rather than estimated (*Brown, et al. 1998*).

- On a more positive note, the data indicate that there is virtually no difference in air void content between 100 mm and 150 mm field cores.

- Although the explained variation (R^2) appears to be somewhat project dependent, ranging from 0.11 to 0.71, one can reasonably conclude that Hveem stability is generally inversely related to air void content.

- Field cores generally have lower stabilities than do gyratory- or kneading-compacted samples.

- There is very little difference in the stability of lab compacted samples, regardless of gyratory type or specimen diameter.

- There was a consistent but small difference in stability (3 to 5 percent) between field and lab compacted samples. The slight difference is attributed to the fact that lab compacted samples have aged somewhat during storage, and re-heating makes the binder a bit more viscous and, in turn, increases the stiffness of the mix.

- None of the field cores, regardless of project, met ODOT's minimum Hveem stability criterion of 35. Possible reasons for low stability include the following: a low percentage of fractured aggregate faces; binder content that exceeds optimum; and segregation. Although the aggregate met the Superpave criterion for percent fractured faces, it was near the lower limit. Recall, however, the aggregate consensus criteria included in the Superpave methodology were not validated with any strength or performance tests. Inadequate fractured faces of aggregate would obviously limit internal friction and thus yield a low Hveem stability. Though these data are anecdotal at best, it appears that the Superpave mix design tends to yield a design binder content slightly higher than ODOT's traditional Hveem methodology, and hence, a lower stability. Given the unusually low Hveem stability numbers associated with these Superpave mix designs, careful monitoring of the field performance is imperative.

5.2 RECOMMENDATIONS

The data gathered in this research indicate that there is virtually no difference between the prototype (Pine) and portable (Test Quip) gyratory compactors as measured by air void content and Hveem stability. Accordingly, it is recommended that ODOT consider the use of the portable gyratory for QC/QA purposes, assuming that the more fundamental issues of Superpave mix design are resolved.

Since Hveem stability of field cores did not meet ODOT's minimum criterion of 35, early and continuous monitoring of the field performance is imperative. As part of the performance monitoring, it is recommended that wheel-path air void content be periodically measured to confirm/refute the N_{design} concept.

6.0 REFERENCES

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