FIELD CONTROL OF ASPHALT PAVING MIXTURES

Final Report

SPR Project Number 5284

by

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16. Abstract

The Oregon Department of Transportation (ODOT) controls the quality of its AC paving mixtures by using a statistical pay factor system based on random sampling and testing of aggregate gradation, asphalt content, and compaction density. Concerns about potential toxicity of solvents used for asphalt extraction led to the desire for less hazardous quality control procedures. As a result, ODOT eliminated the use of solvents. Asphalt content is now controlled using a nuclear gage and aggregate gradations are determined from cold feed samples.

The goal of this study was to develop information and evaluate new methods for controlling quality of the AC mixture in the mat. Specifically, this research project evaluated using a gyratory compactor in the field laboratory to determine mix quality. Specimens were prepared from companion mixture samples using both gyratory and kneading compaction. The properties of the mixtures were compared using a variety of standard tests including density, voids, Marshall stability, Hveem stability, etc.

The results of this research study include the following conclusions and recommendations:

Conclusions:

1. The gyratory compactor worked well in the field laboratory. Compared to the kneading compactor, it is relatively inexpensive and simple to operate. The compacted specimens appear to represent the mixture quite well as shown by density and voids.
2. The 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.
3. AC mixtures can be controlled in the field by monitoring stability; however, there is significant variability in the results.
4. The void content measured in gyratory compacted field specimens may be used as a field control parameter.

Recommendations:

1. The gyratory method of compaction should be advanced as a method of field acceptance for asphalt concrete mixtures. This should be delayed until the new SHRP compactor is available.
2. Track the field performance of the four projects evaluated in this study for a period of 2-3 years to see if actual performance correlates with any of the test results evaluated.
3. Develop specifications for controlling asphalt concrete mixtures with a field compaction device used to fabricate specimens to measure air voids and voids in the mineral aggregate (VMA).

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

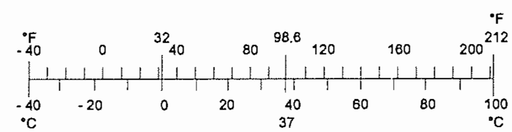
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	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.

Symbol	When You Know	Multiply By	To Find	Symbol
		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	Celcius 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	1.8 + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement

(4-7-94 jbp)

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Field Control of Asphalt Paving Mixtures

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I. INTRODUCTION AND BACKGROUND

The Oregon Department of Transportation (ODOT) controls the quality of its AC paving using a statistical pay factor system, based on random sample testing of mix gradation, asphalt content, and compaction. Until recently, the mix gradation and asphalt content were determined by vacuum extraction of samples taken from the AC mat prior to compaction. The solvent 1,1,1 trichloroethane was used in the vacuum extraction process.

In recent years, there has been growing concern about the toxicity and carcinogenic potential of petroleum based solvents used in the vacuum extraction process. Efforts have been made to reduce employee exposure to chlorinated solvents. Several turpene-based (non-petroleum based) solvents such as Bioact were tested as a substitute for 1,1,1 trichloroethane. These solvents, while less hazardous, did not perform well in the vacuum extraction process and were universally disliked by technicians because of the pungent odor and problems with nausea.

Recently, ODOT eliminated the use of solvents, substituting the asphalt content nuclear gauge for asphalt content determination, and aggregate cold feed testing for mixture gradation control. After several years of testing, the nuclear gauge/cold feed procedure was determined to be an acceptable alternative to the solvent extraction method of quality control.

While the asphalt content nuclear gauge/cold feed gradation method is now used as a substitute for vacuum extraction testing of AC mixtures, the ability to control the quality of the final AC mixture has been reduced. The new methods do not allow ODOT to sample and test the mix in the mat for segregation and/or asphalt migration — two problems which can occur through improper handling of the AC mixture after testing at the plant. These problems can affect the long-term durability and performance of the AC pavement.

The goal of this research project is to test and evaluate new methods of controlling the quality of the final AC mixture in the mat without using vacuum extraction. The objective is to evaluate the feasibility of using a field test such as compaction and void content as a means of controlling pavement quality.

II. MIXTURE DESIGN PERFORMANCE TESTS USED IN THE OREGON PROCEDURE

The ODOT Materials Unit (Salem) standard mixture design procedure for performance-related testing includes several elements as follows:

1. Voids in the mixture following the first compaction (kneading compactor). This value is used as a measure of compaction that is attainable at the time of construction.

2. Hveem stability of the above specimens following first compaction, using FHWA criteria.

3. Voids in the mixture following the second kneading compaction (the specimen is turned over and recompacted). This level of voids is intended to represent the mixture after being subjected to several years of traffic.

4. Hveem stability after the second compaction. This stability must equal or exceed that obtained after the first compaction or the mixture may be prone to rutting.

5. The Index of Retained Strength, IRS, (ratio of water conditioned to dry indirect tensile strength) is used for both dense and open graded mixtures to evaluate stripping potential.

6. The Index of Retained Modulus, IRM_R, (ratio of water conditioned to dry resilient modulus) is used to evaluate potential stripping in dense graded mixtures.

7. Maintaining an adequate ratio of the aggregate passing the No. 200 sieve to asphalt content (p200/asphalt content) helps assure good durability by providing an adequate film thickness.

8. Voids in the Mineral Aggregate, VMA, ODOT uses the FHWA Technical Advisory No. T-5040.27 guidelines to ensure adequate voids and film thickness in the compacted asphalt concrete mixture.

In the laboratory, asphalt concrete mixture samples are prepared according to the ODOT Materials Laboratory Procedures Manual. Specimens for Hveem Stability and Index of

Retained Modulus were prepared according to ODOT test method 302-86 which conforms to AASHTO T-247. ODOT test method 307C-86 (AASHTO T-167) was used to prepare specimens for the Index of Retained Strength test.

Table 2.1 is a summary of ODOT mix design criteria for dense-graded wearing course mixtures. This process is not used in the field due to the amount of time required to run all tests and the infeasability of using the kneading compactor in the field. The field tests used to determine mix acceptance are in-place density using the nuclear density gauge and the asphalt content using the nuclear asphalt content gauge, and gradation from cold feed samples.

Table 2.1. Summary of Mix Design Criteria

ODOT DENSE-GRADED ASPHALT CONCRETE HOT MIX DESIGN CRITERIA

	Heavy Duty[1]	Standard Duty[2]	Light Duty[3]
Asphalt Film Thickness	Sufficient to Sufficient-Thick		
Design Air Voids			
1st Compaction (range)	5.5-6.5%	5.0-6.0%	4.0-5.0%
2nd Compaction (min.)	2.5%	2.0%	1.5%
Hveem Stability			
1st Compaction (min.)	37	35	30
2nd Compaction (min.)	37	35	30
Index of Retained Strength	75	75	75
Index of Retained Modulus	70	70	70
P200/Asphalt Content	0.6-1.2	0.6-1.2	0.6-1.2

[1] Heavy Duty - 20 year design equivalent single axel loads (ESALs) >10,000,000, average daily traffic (ADT) >20,000
[2] Standard Duty - 20 year design ESALs: 1,000,000 - 10,000,000, ADT: 1,500 - 20,000
[3] Light Duty - 20 year design ESALs < 1,000,000, ADT < 1,500

III. A PROTOTYPE FOR A NEW OREGON SYSTEM AND TEST PLAN

This study was aimed at the development of a new system for field control of asphalt concrete mixture quality that includes several elements not yet evaluated. In summary, this system was envisioned as follows:

1. Control of the general asphalt concrete mixture components using samples from the asphalt concrete plant: gradation of aggregates using samples from the cold feed, and asphalt content using the nuclear gauge (this is the present field laboratory procedure).

2. Control moisture in the mixture using a microwave oven for quick drying (this is the present field laboratory procedure). The specimen is heated and weighed, until a constant weight is achieved, using a microwave oven in the field trailer.

3. In the ODOT Materials Laboratory, establish comparison between specimens compacted using the kneading and gyratory compactors. Using the criteria and tolerances currently used for conventional Hveem mix designs, establish similar tolerances for tests that can be conducted in the field laboratory, including those such as voids, Marshall stability and flow, split tensile strength, etc.

4. Use a standard compactor in the field laboratory to fabricate specimens from the field mix on a routine basis for quality control. The key acceptance criteria in the field would be voids in the compacted mixture (rather than, or in addition to, aggregate gradations and asphalt content).

Prior to any laboratory or field work, a plan was established for the project. The original plan is described in the following paragraphs and is somewhat idealistic in that there was considerable uncertainty as to the ability and time available for ODOT to accomplish all the proposed tasks. The actual project was somewhat more limited, yet provided considerable insight to the process of quality control evaluation.

A field control program to ideally manage the quality of mixtures through void control should meet several criteria, including at least the following:

1. The mixture tests should be aimed at achieving end results that are tied to pavement performance such as rutting, cracking, ravelling, or stripping.

2. The contractor should have freedom to adjust or vary proportions to meet the end results required.

3. Test results need to be available quickly in order for the contractor and ODOT (project manager) to effectively control the mixture.

The new prototype procedure for controlling the quality of asphalt concrete paving mixtures in the field incorporates three features, as follows:

1. **Aggregate gradation**. Aggregate samples from each bin and/or blended samples will be taken from the cold feed belt to the asphalt concrete plant. The samples will be tested for water content and gradation. This procedure will be adequate for drum mixers where the aggregate is input on a continuous basis. For batch plants, it may be necessary to sample aggregate from the discharge of the hot bins.

2. **Asphalt content**. The quantity of asphalt in each mixture will be monitored by one or a combination of the following:

   - A sample measured in the field laboratory using a nuclear asphalt content gauge;

   - A record of the asphalt pump meter at the asphalt concrete plant; and

   - By measuring the actual use of asphalt from the contractor's tank at the plant, i.e., "sticking."

   This latter procedure will provide a reasonable average for a period of time (for example a day's production), but does not account for variation throughout the day or migration of asphalt in the mixture.

3. **Compactibility**. The primary feature of the approach to the new system will be an attempt to measure the overall quality of the field mix by measuring its compactibility and void content using a standard compaction energy.

   A key feature of the experiment will be the utilization of a field compaction device. From equipment available, three compaction devices were selected for consideration, as follows:

   1. Gyratory Shear (Texas)
   2. Marshall Hammer
   3. Kneading (bench-mounted Hveem)

The Texas Gyratory Shear compactor was chosen as the test compactor from various sources of information and discussions of the needs of ODOT. Two of these units were purchased from Rainhart Co., Austin, Texas.

Potential advantages of gyratory compaction include:

- Speed - about 15 minutes per specimen.
- Voids can be measured directly without water immersion.
- Compactor is easily bench mounted (no concrete pad required as with the Marshall compactor).
- Easy to operate and calibrate. Other research has shown that gyratory compaction is similar to kneading compaction and is representative of mixtures from the pavement.
- Specimens can be tested in the field laboratory using the appropriate strength test such as Marshall stability, resilient modulus, split tension, or other test.
- Companion field specimens can be transported to the ODOT Materials Laboratory for Hveem stability testing.

Specimen preparation and gyratory compaction for this study followed the Texas method (6).

Discussion of the details of other equipment requirements and procedures such as aggregate and asphalt testing are beyond the scope of this report.

IV. TEST DATA

The field projects evaluated in this study were as follows:

1. S.E. Stark St., S.E. 223rd Ave. - S.E. 242nd Ave. Section (Contract No. C10937), Gresham.

2. Kuebler Blvd./Cordon Rd., S. Commercial St. - N. Santiam Highway Section (Contract No. C10791), Salem.

3. U.S. Route 97, O'Neil Junction - Redmond Couplet Section (Contract No. C10850), near Bend.

4. U.S. Route 30, Rainier - Tide Creek Section (Contract No. C10926), E. of Astoria.

Conventional asphalt concrete mixture designs for the above four projects were conducted at the ODOT Materials Laboratory. The mixture design data is included in Table 4.1. Also, the specific gravity, voids, and Hveem stability have been plotted for these mixtures and are included in Figures 4.1-4.4.

Additional laboratory test data were developed for projects 1 and 2 above. Specimens from the same mixture were compacted with the Cox kneading compactor and the gyratory compactor. Mixture properties for both sets of specimens were determined. The data summarized in Figures 4.5 and 4.6 show a comparison for specific gravity, voids, and Hveem stability. The same type of information was not developed for projects 3 and 4, however.

For projects 3 and 4 above, a mobile trailer with one gyratory compactor and the Marshall testing equipment was set up. This trailer was set up at the job sites in addition to the usual control facility. Thus, testing for these projects was conducted without interfering with normal operations.

The two field projects (3 and 4) were selected to fit the study schedule and also to provide a different set of materials, climates, and contractors. For the two field projects, each sublot of 500 tons of mixture was sampled and tested. Figure 4.7 shows how each 16 kg sample was split into four portions and used as follows:

- Two samples were fabricated in the field laboratory using gyratory compaction. The compacted specimens were then sent to the ODOT Materials Laboratory and tested: one for wet bulk specific gravity and voids; and one for dry measured bulk specific gravity, and voids. The "wet voids" sample was tested for Hveem stability on first compaction. The "dry voids" specimen was tested for Marshall stability and flow.

- One sample was fabricated in the ODOT Materials Laboratory using gyratory compaction and tested for wet measured bulk specific gravity, voids, and Hveem stability on first compaction.

- One sample was fabricated in the ODOT Materials Laboratory using the kneading compactor and tested for wet measured bulk specific gravity, voids, and Hveem stability on first compaction.

The data are presented in four formats as follows:

1. In Figures 4.8-4.16, the voids and stability have been plotted versus the sublot (sample) numbers chronologically. These graphs show the trends as the project progressed. Overlaid on these figures are the ODOT criteria for each variable (see Table 2.1). For voids comparison, criteria from Wisconsin and Virginia DOT are also shown, since these are different from Oregon. For Hveem stability, the Oregon criteria is used, but for Marshall stability and flow, the Wisconsin and Virginia criteria are shown since Oregon does not use Marshall tests.

   The specimens prepared in the field with the gyratory compactor for Hveem testing were tested twice for bulk specific gravity and air voids. Once wet in the field after compaction, and once wet in the lab as part of the Hveem test procedure. On the graphs, these are labeled "Fld Gyr Wet" and "Fld/Lab Wet."

2. In Figures 4.17 and 4.18, data selected from Figures 4.8 through 4.16 are shown as the range and mean for each parameter.

3. In Figures 4.19 and 4.20, field and laboratory data are compared where correlation among several variables might be evaluated.

4. In Tables 4.2-4.5, data are summarized from each field project and include materials and specimens from both field and central laboratories.

Table 4.1. Summary of Mixture Design Data

Property	Asphalt Content, % of Total Weight											
	4.0		4.5		5.0		5.5		6.0		6.5	
	1*	2**	1	2	1	2	1	2	1	2	1	2
SE 223rd - SE 242nd Ave.												
Bulk specific gravity	2.36	2.43	2.37	2.45	2.40	2.47	2.42	2.49	2.44	2.49	-	-
Voids, %	7.8	5.0	6.8	3.6	5.0	2.2	3.7	0.9	2.3	0.3	-	-
Hveem stability, S	37	43	33	42	37	43	33	45	32	37	-	-
S. Commercial St.- N. Santiam Hwy.												
Bulk specific gravity	-	-	2.33	2.37	2.30	2.39	2.32	2.40	2.32	2.41	2.40	2.44
Voids, %	-	-	7.1	5.5	7.3	3.6	6.1	2.9	5.2	1.6	1.9	0.2
Hveem stability, S	-	-	36	45	34	43	38	45	35	41	32	10
Rainier-Tide Creek												
Bulk specific gravity	-	-	2.36	2.43	2.37	2.45	2.40	2.47	2.41	2.47	2.43	2.47
Voids, %	-	-	7.2	4.4	5.9	2.7	4.0	1.2	3.1	0.7	1.5	0.0
Hveem stability, S	-	-	37	46	39	45	32	46	37	41	31	18
O'Neil Jct-Redmond Cplt												
Bulk specific gravity	-	-	2.23	2.30	2.28	2.34	2.29	2.36	2.33	2.40	2.36	2.41
Voids, %	-	-	11.0	8.3	8.7	6.3	7.5	4.7	5.1	2.3	3.2	1.2
Hveem stability, S	-	-	37	44	38	48	40	44	35	47	34	43

* 1st Compaction
** 2nd Compaction

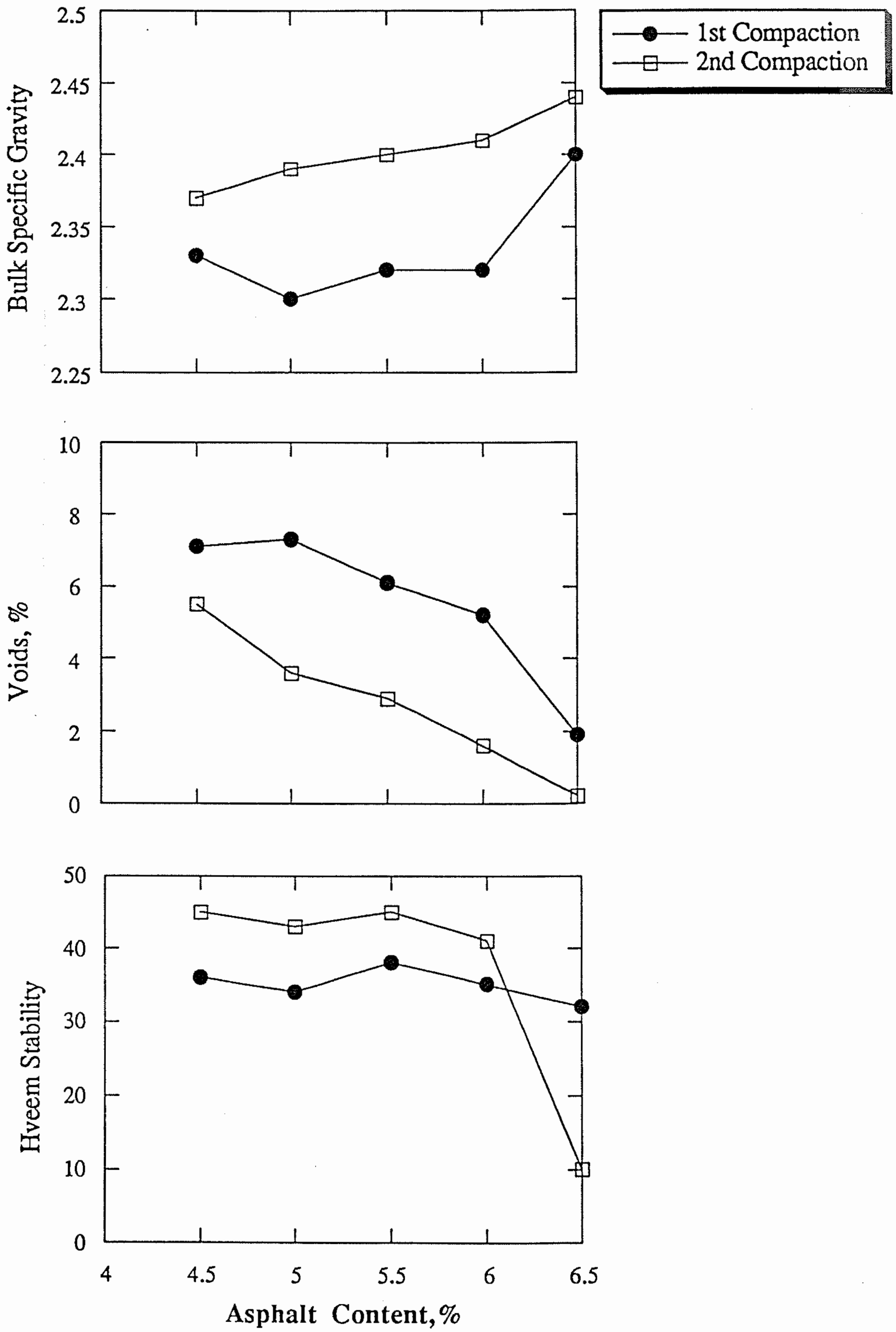


Figure 4.1. Mixture Design for S. Commercial St.-N. Santiam Hwy. project

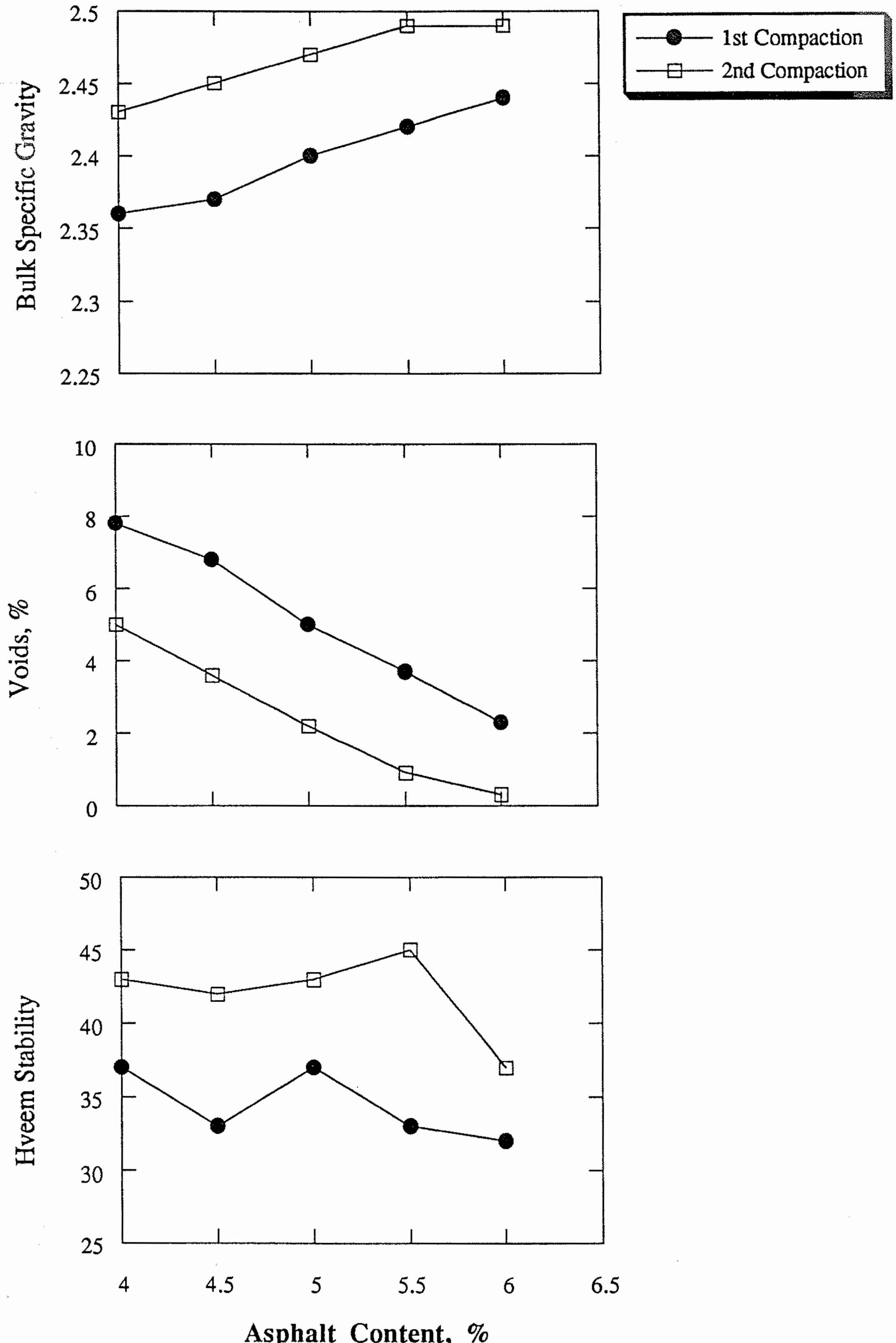


Figure 4.2. Mixture Design for S.E. 223rd-S.E. 242nd Ave. project

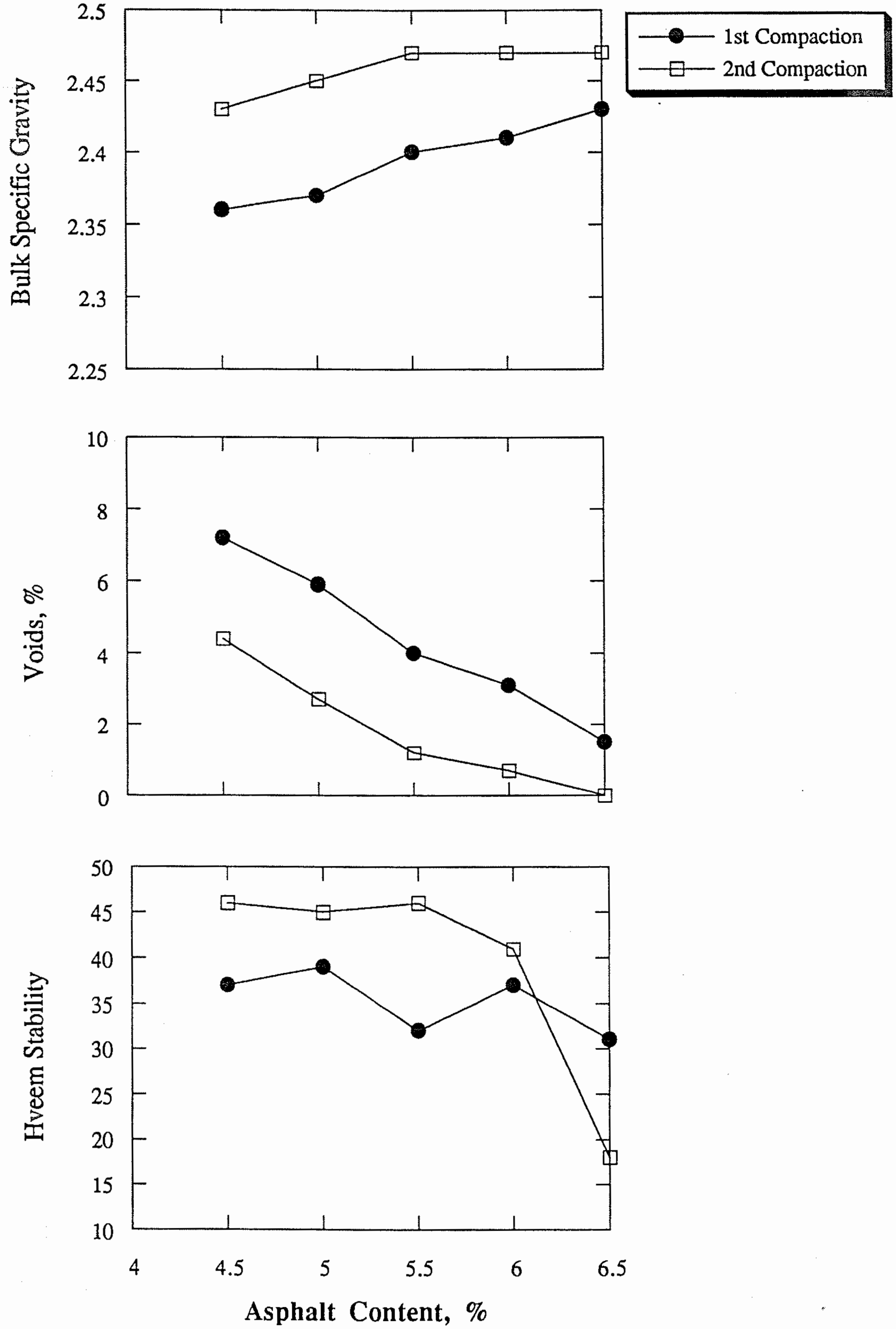


Figure 4.3. Mixture Design for Rainier-Tide Creek project

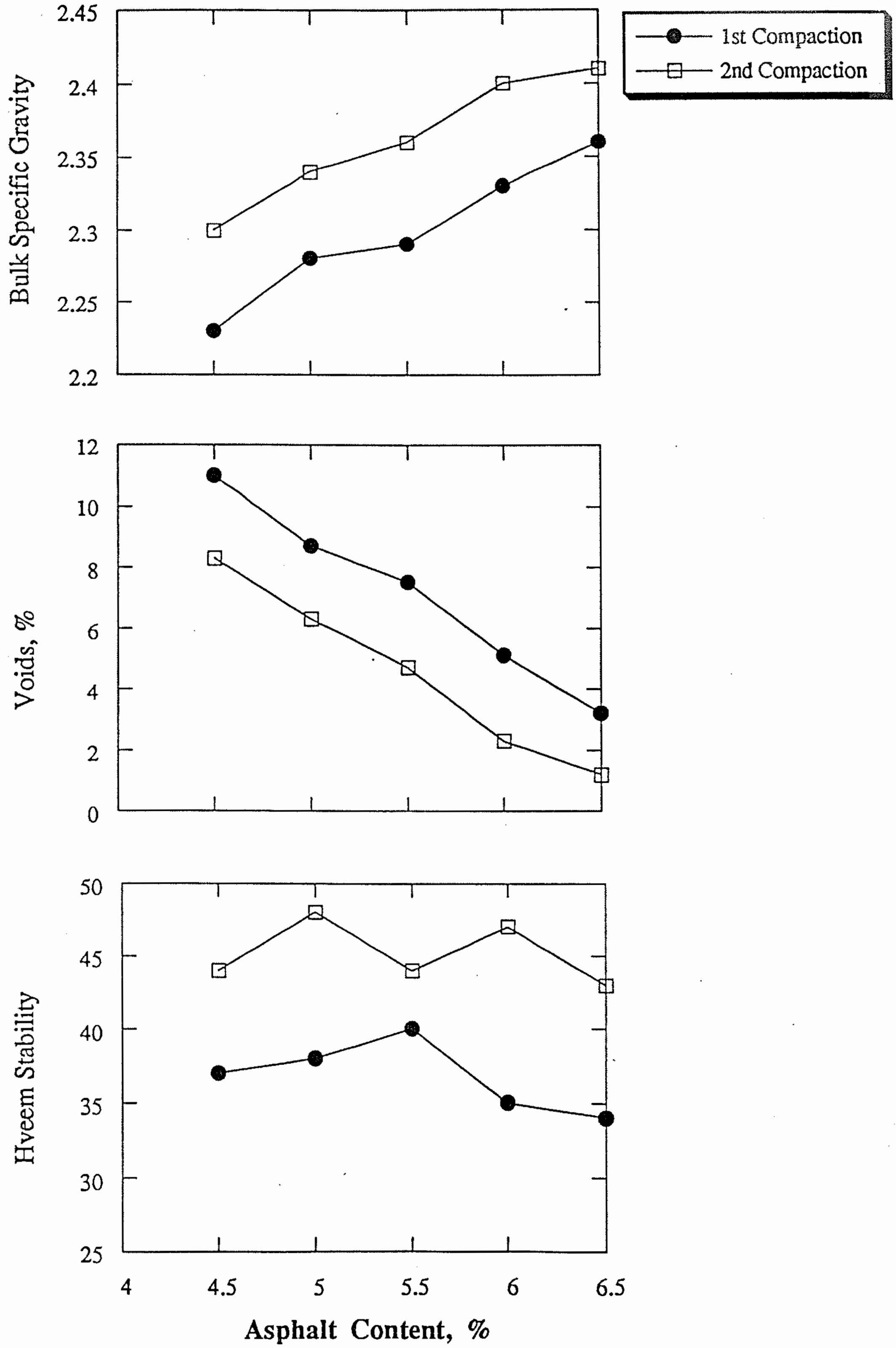


Figure 4.4. Mixture Design for O'Neil Junction-Redmond Couplet project

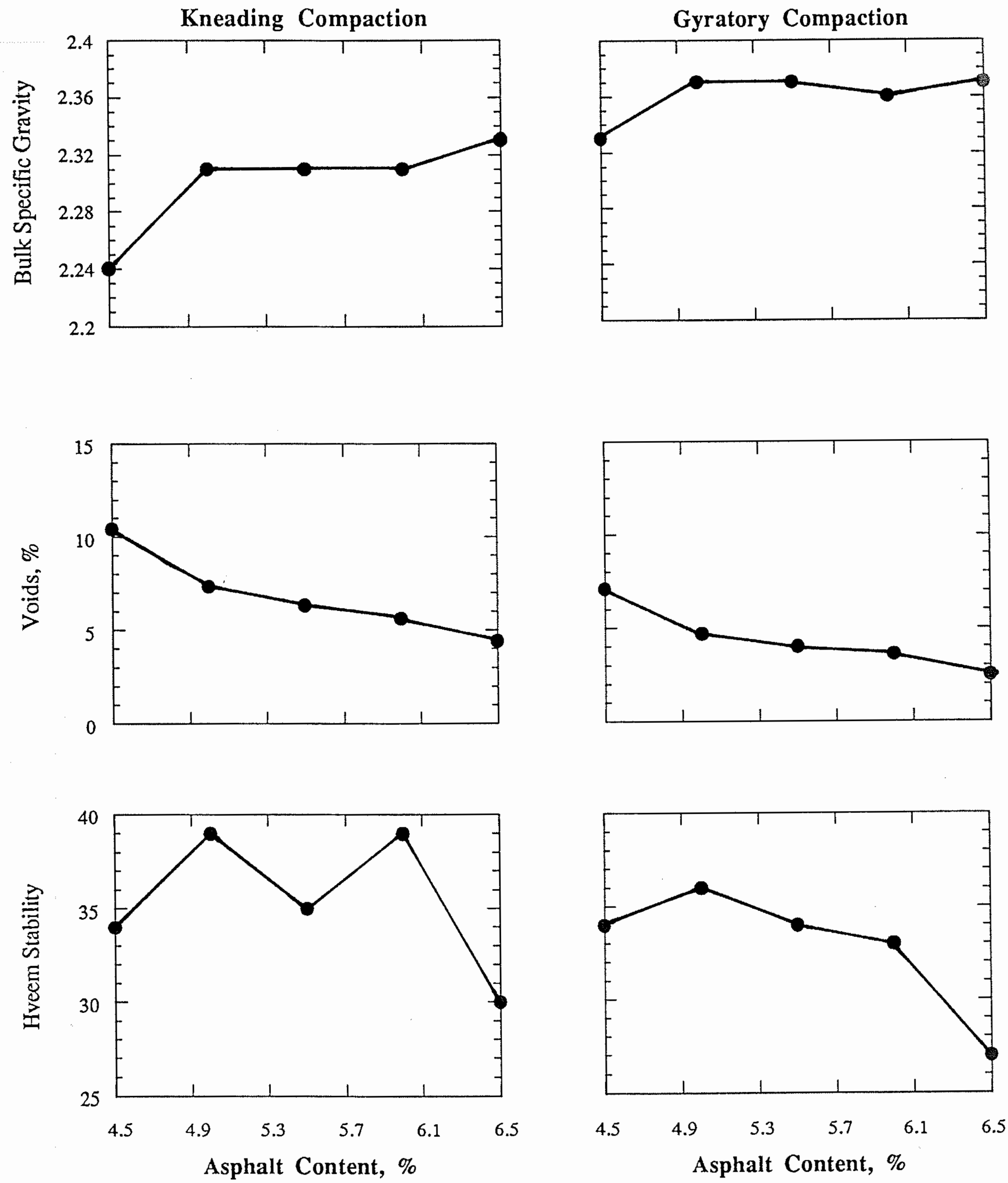


Figure 4.5. Comparison of mixture design data for two compaction methods - S. Commercial St. - N. Santiam Hwy.

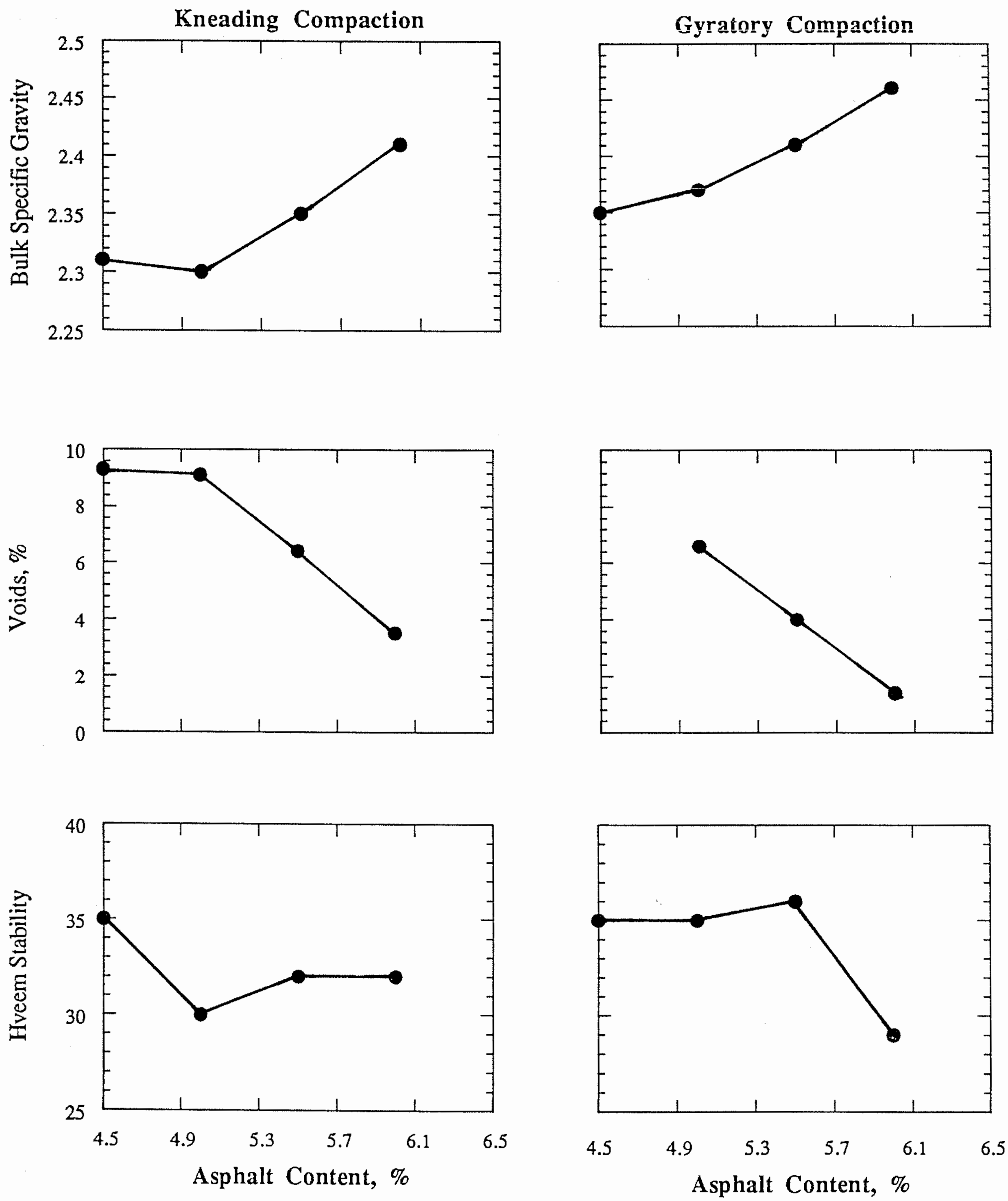


Figure 4.6 Comparison of mixture design data for two compaction methods -
S.E. 223rd - S.E. 242nd

SAMPLE TESTING MATRIX

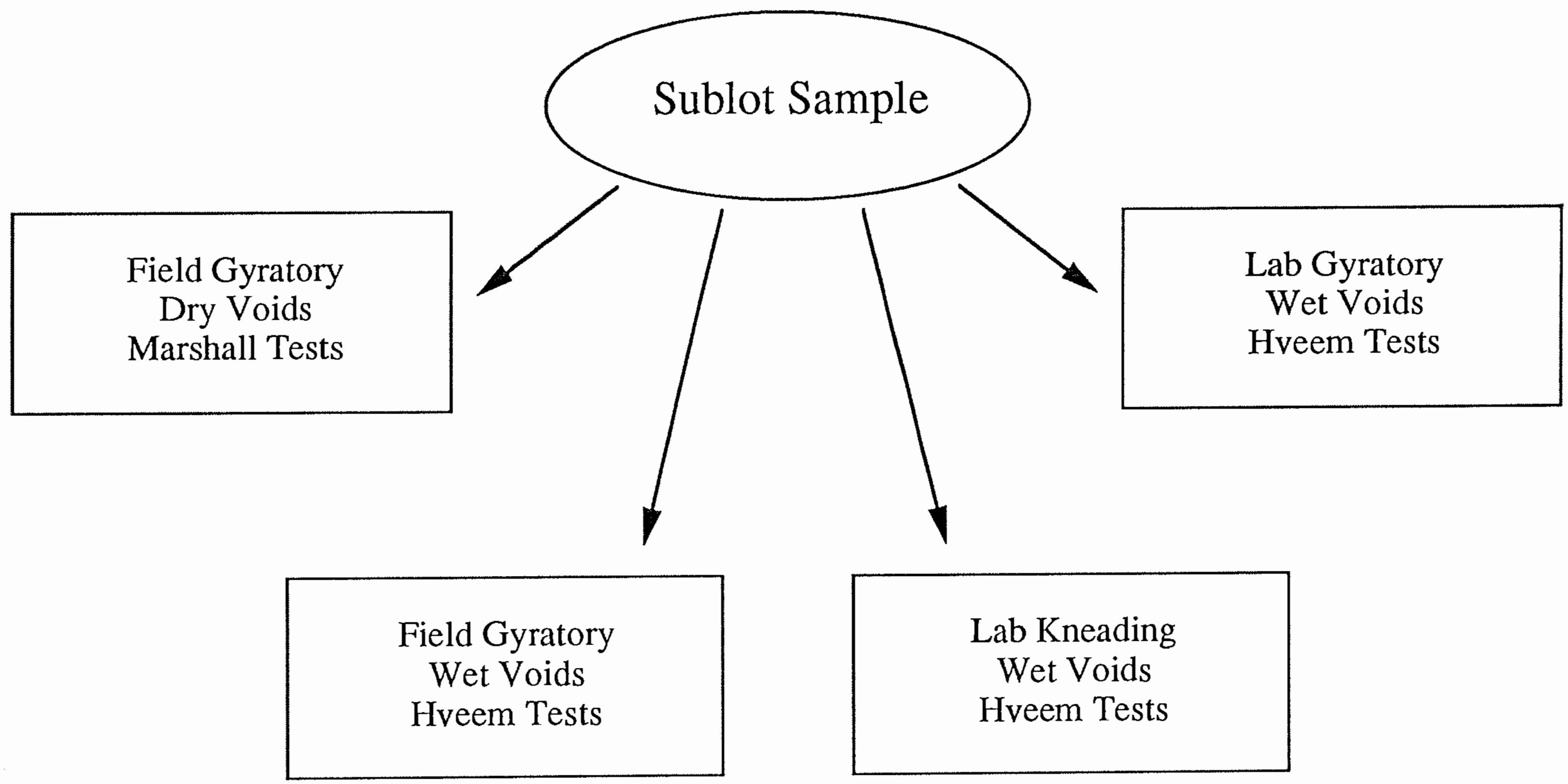


Figure 4.7. Disposition of Four Field Samples of Mixtures for Each Sublot

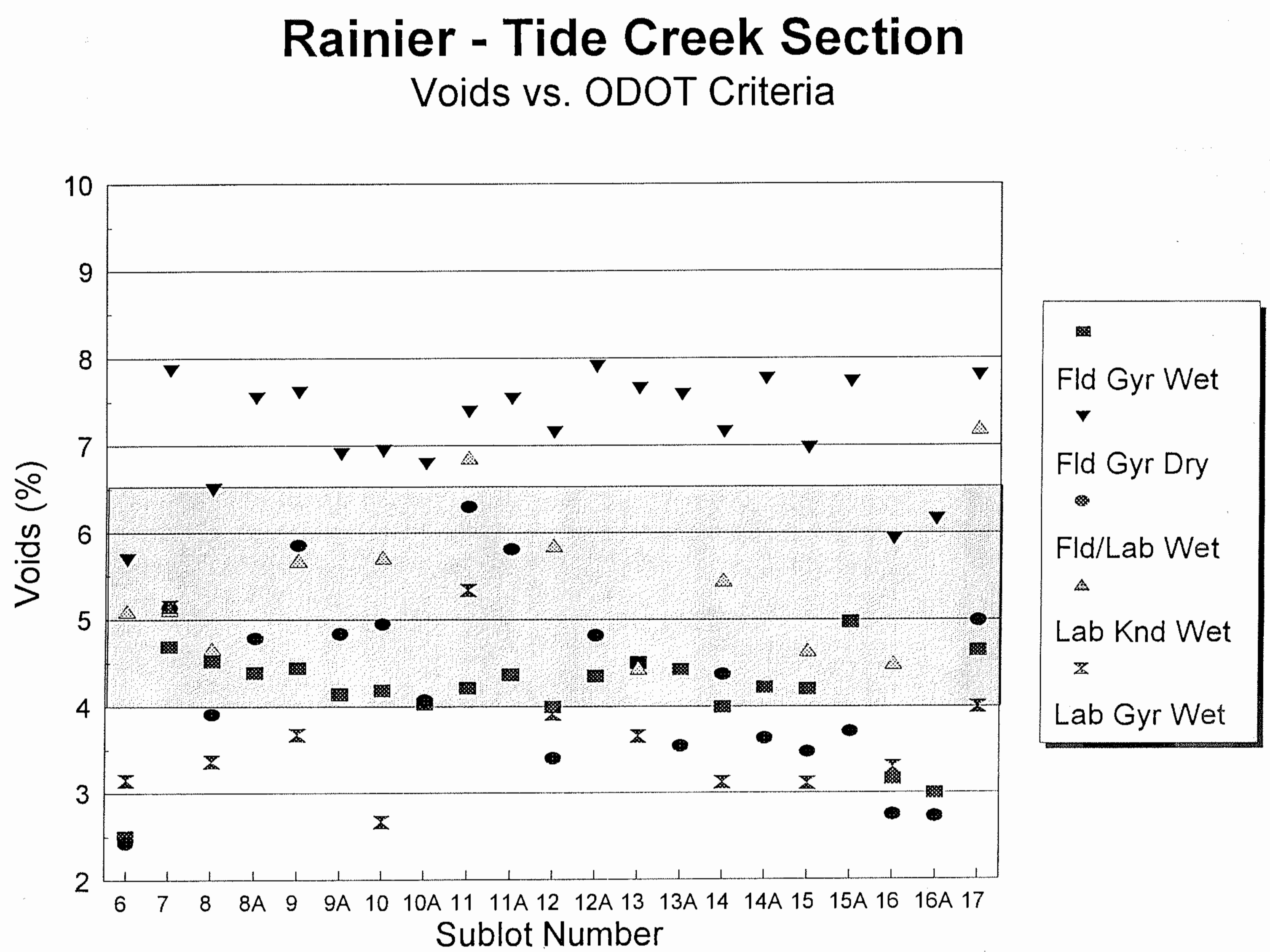


Figure 4.8. Compacted voids compared to ODOT criteria* (based on Lab Knd Wet mix design tests) - Rainier - Tide Creek

* Area shaded in graph

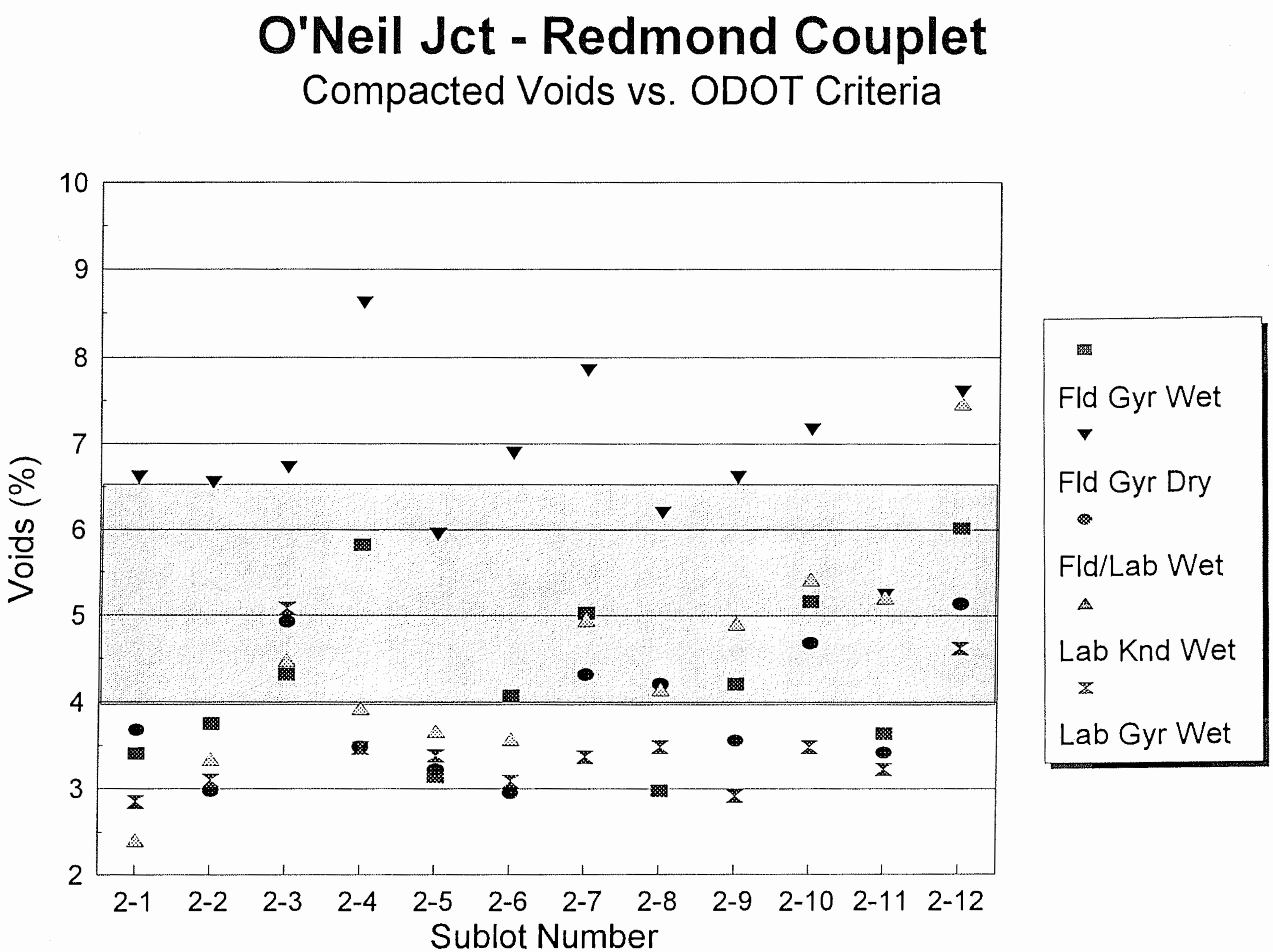


Figure 4.9. Compacted voids compared to ODOT criteria* (based on Lab Knd Wet mix design tests) - O'Neil Junction - Redmond Couplet

* Area shaded in graph

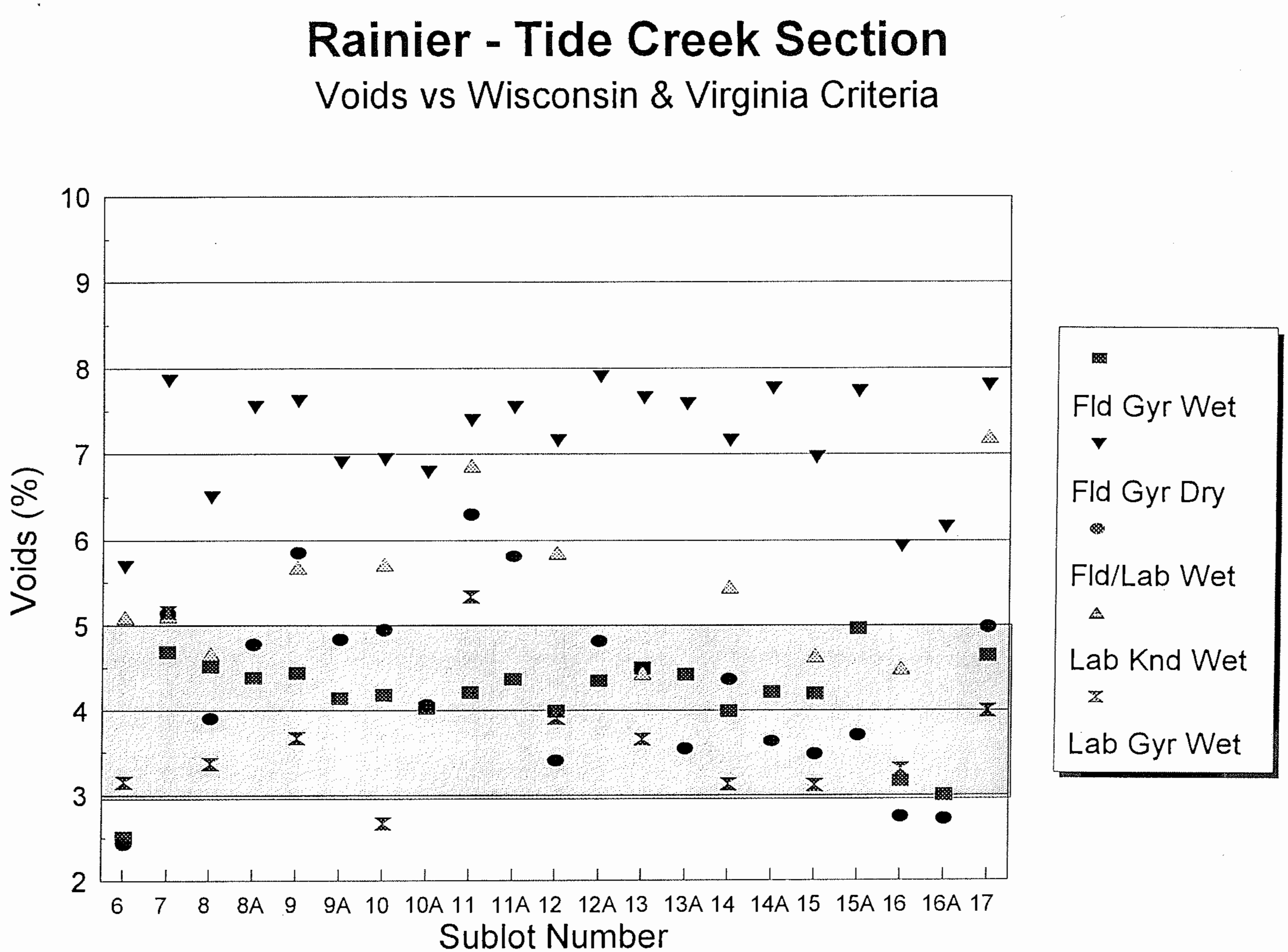


Figure 4.10. Compacted voids compared to Wisconsin and Virginia criteria* - Rainier - Tide Creek

* Area shaded in graph

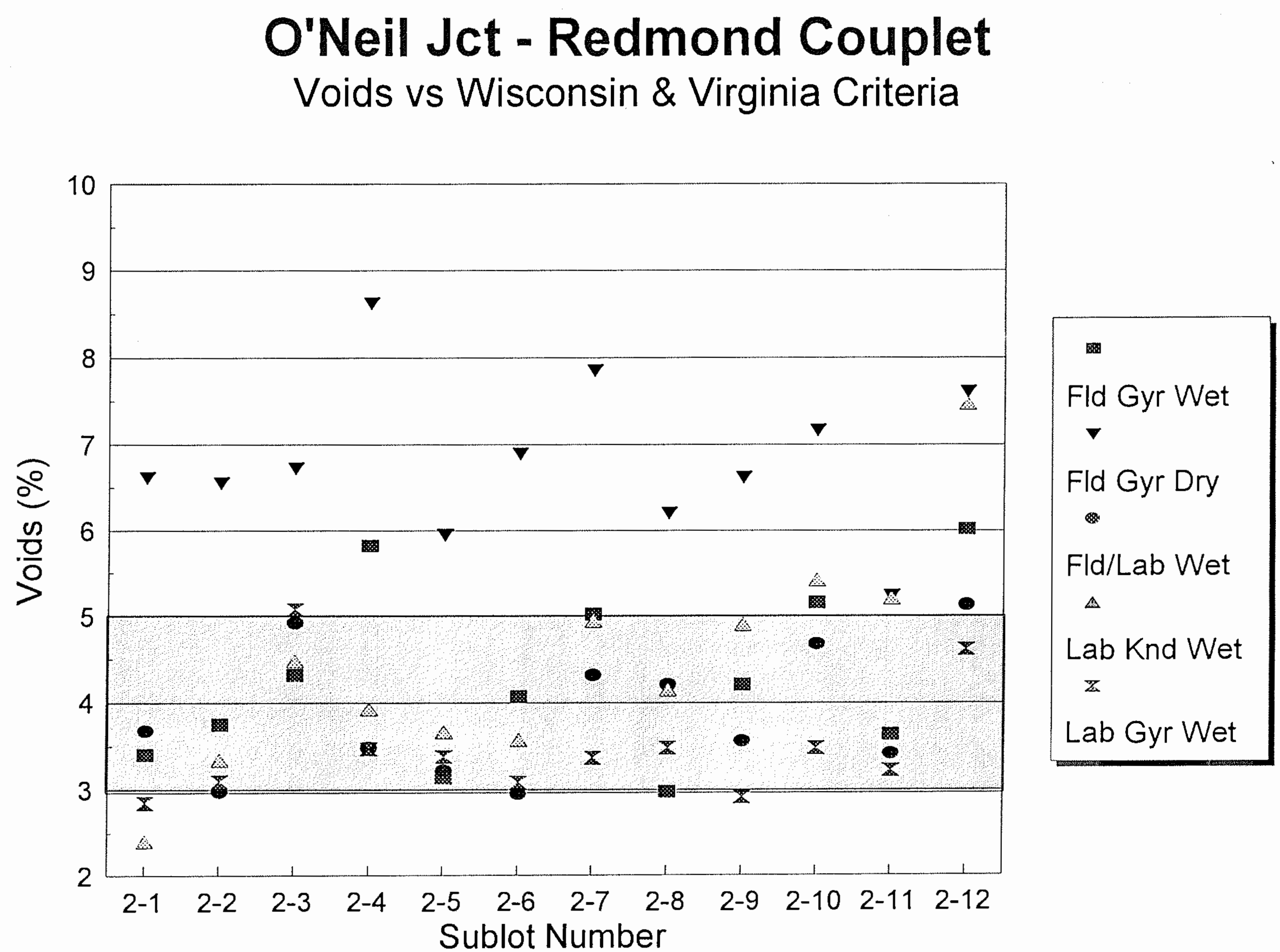


Figure 4.11. Compacted voids compared to Wisconsin and Virginia criteria* - O'Neil Junction - Redmond Couplet

* Area shaded in graph

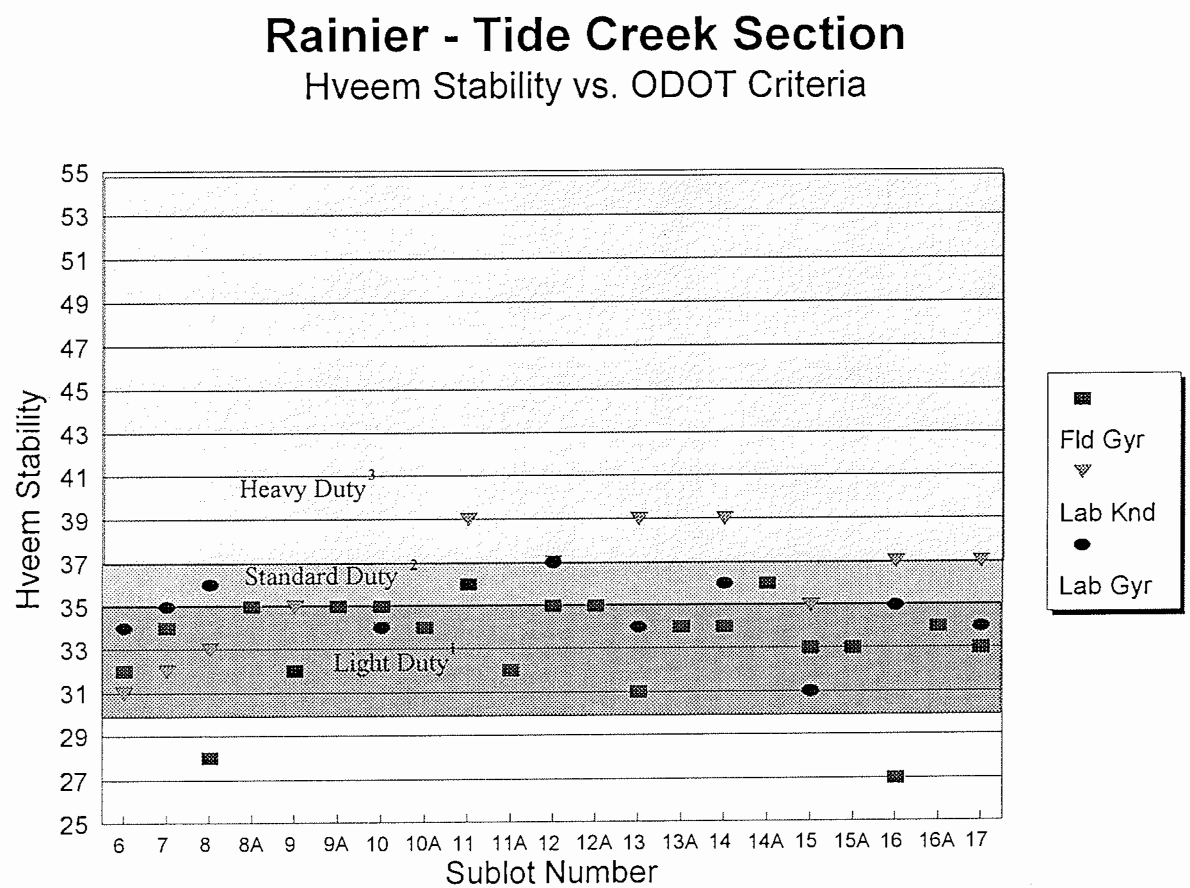


Figure 4.12. Hveem Stability compared to ODOT criteria (based on Lab Knd Wet mix design tests) - Rainier - Tide Creek

1- Light Duty - Heavy Shading (Hveem Stability 30-35)
2- Standard Duty - Medium Shading (Hveem Stability 35-37)
3- Heavy Duty - Light Shading (Hveem Stability > 37)

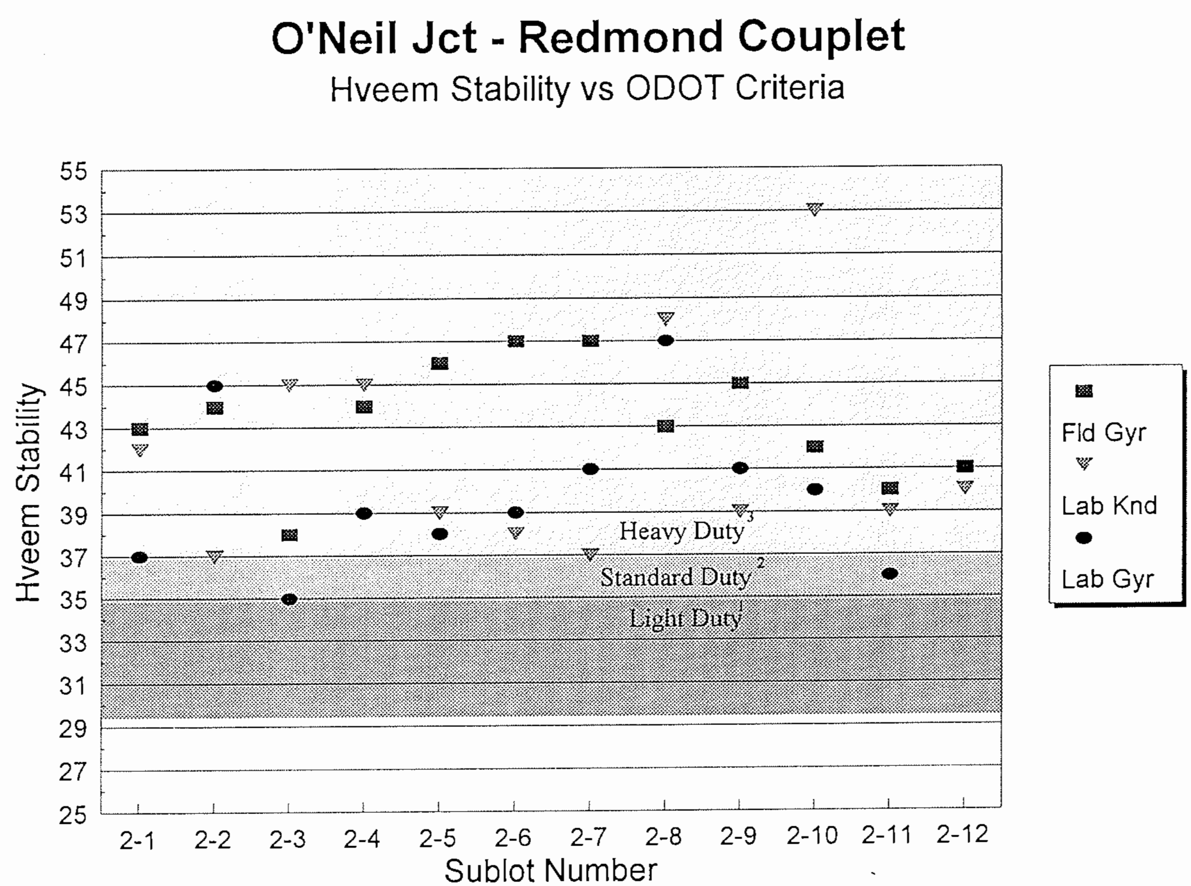


Figure 4.13. Hveem stability compared to ODOT criteria (based on Lab Knd Wet mix design tests) - O'Neil Junction - Redmond Couplet

1- Light Duty - Heavy Shading (Hveem Stability 30-35)
2- Standard Duty - Medium Shading (Hveem Stability 35-37)
3- Heavy Duty - Light Shading (Hveem Stability > 37)

Rainier - Tide Creek Section

Marshall Stab. vs Wis. & Vir. Criteria

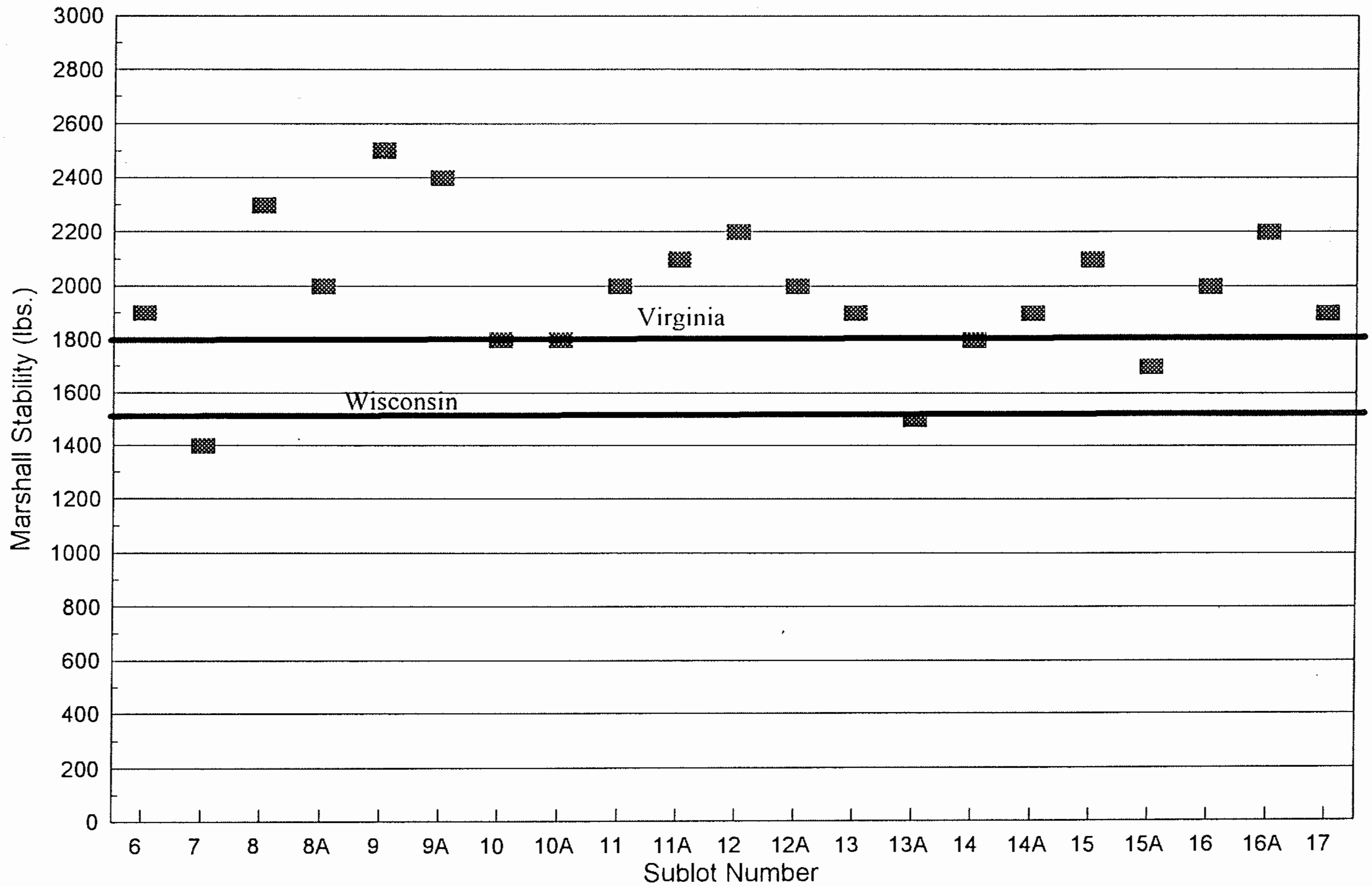


Figure 4.14. Marshall stability compared to Wisconsin and Virginia criteria - Rainier - Tide Creek

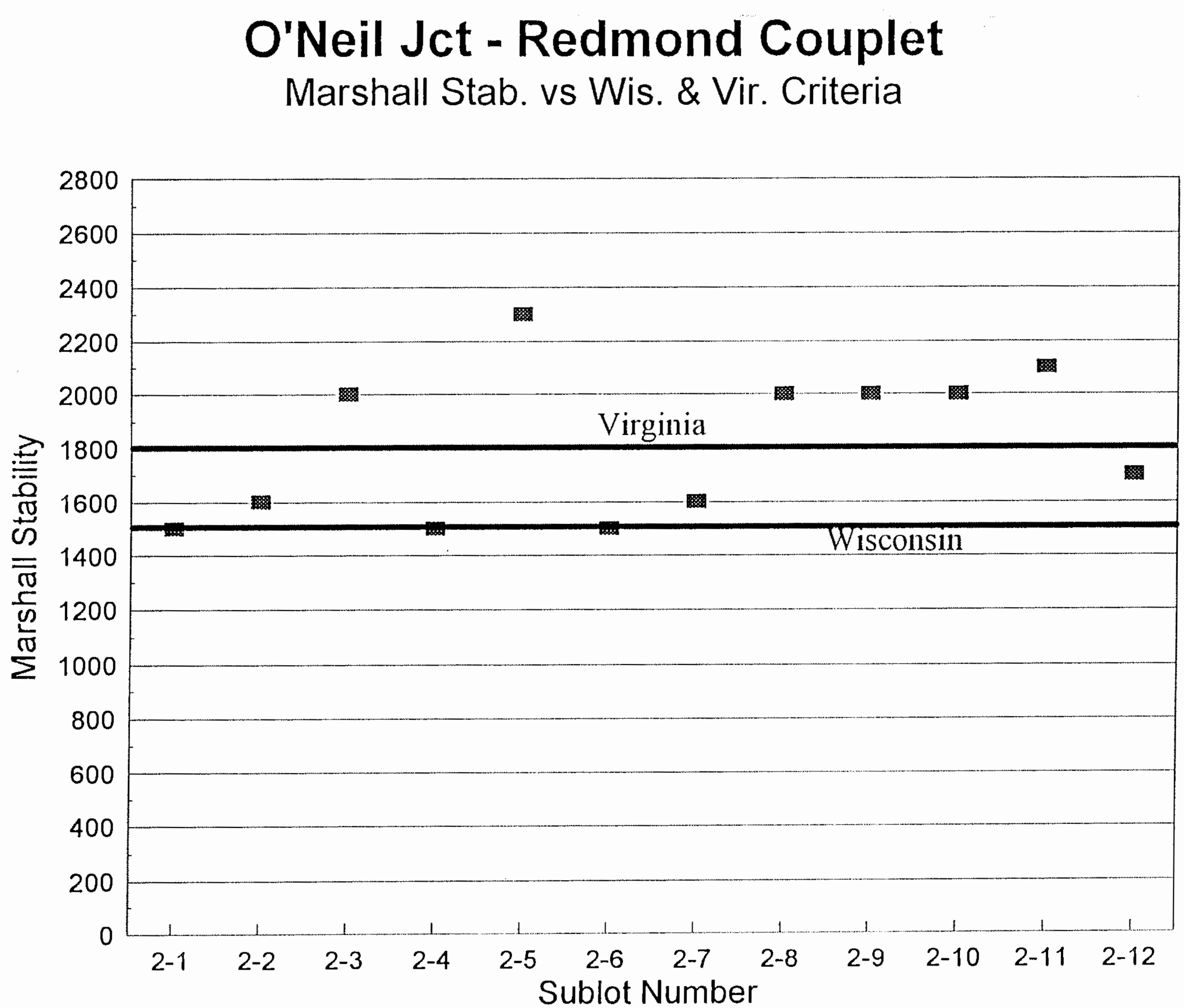


Figure 4.15. Marshall stability compared to Wisconsin and Virginia criteria - O'Neil Junction - Redmond Couplet

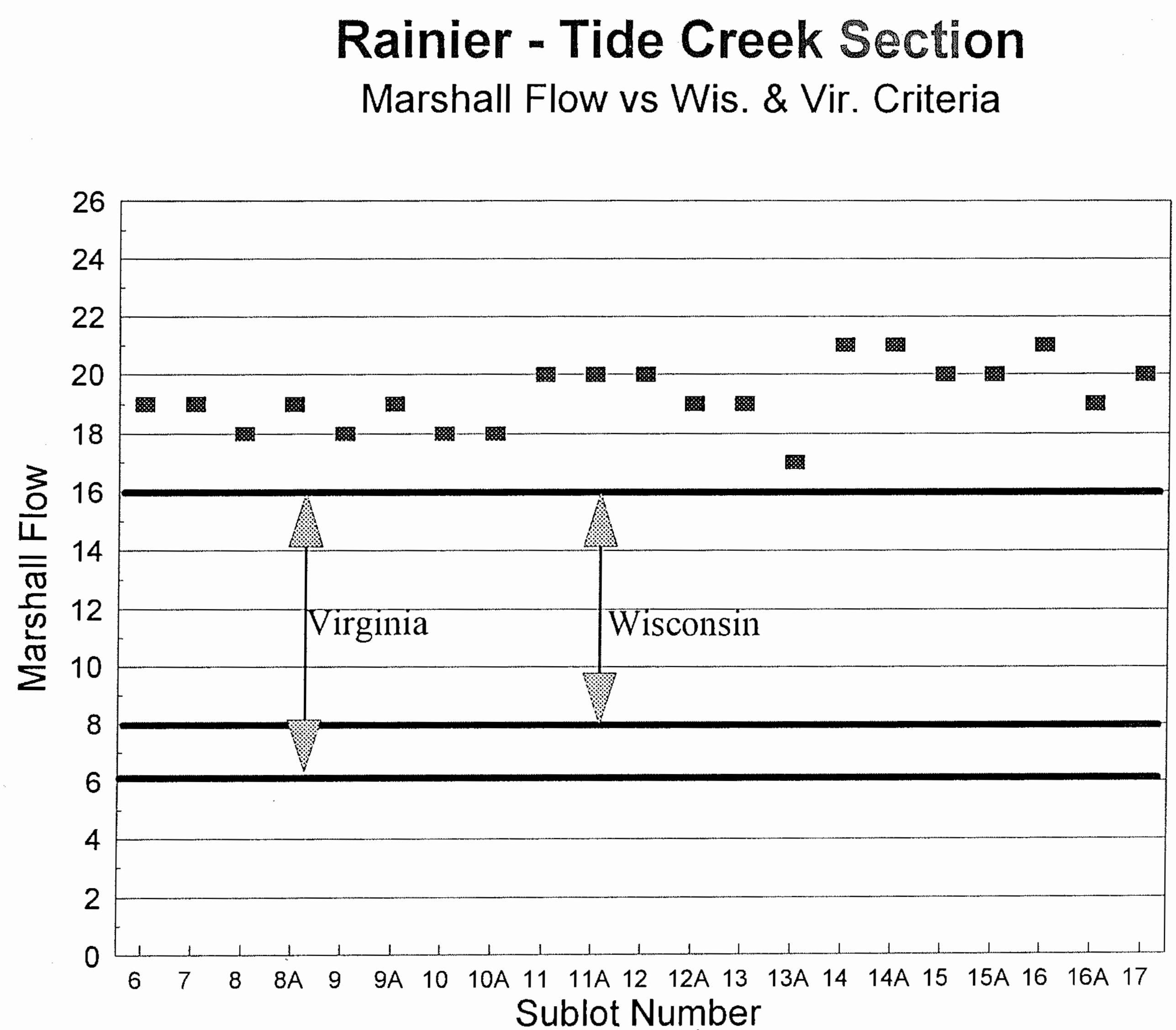
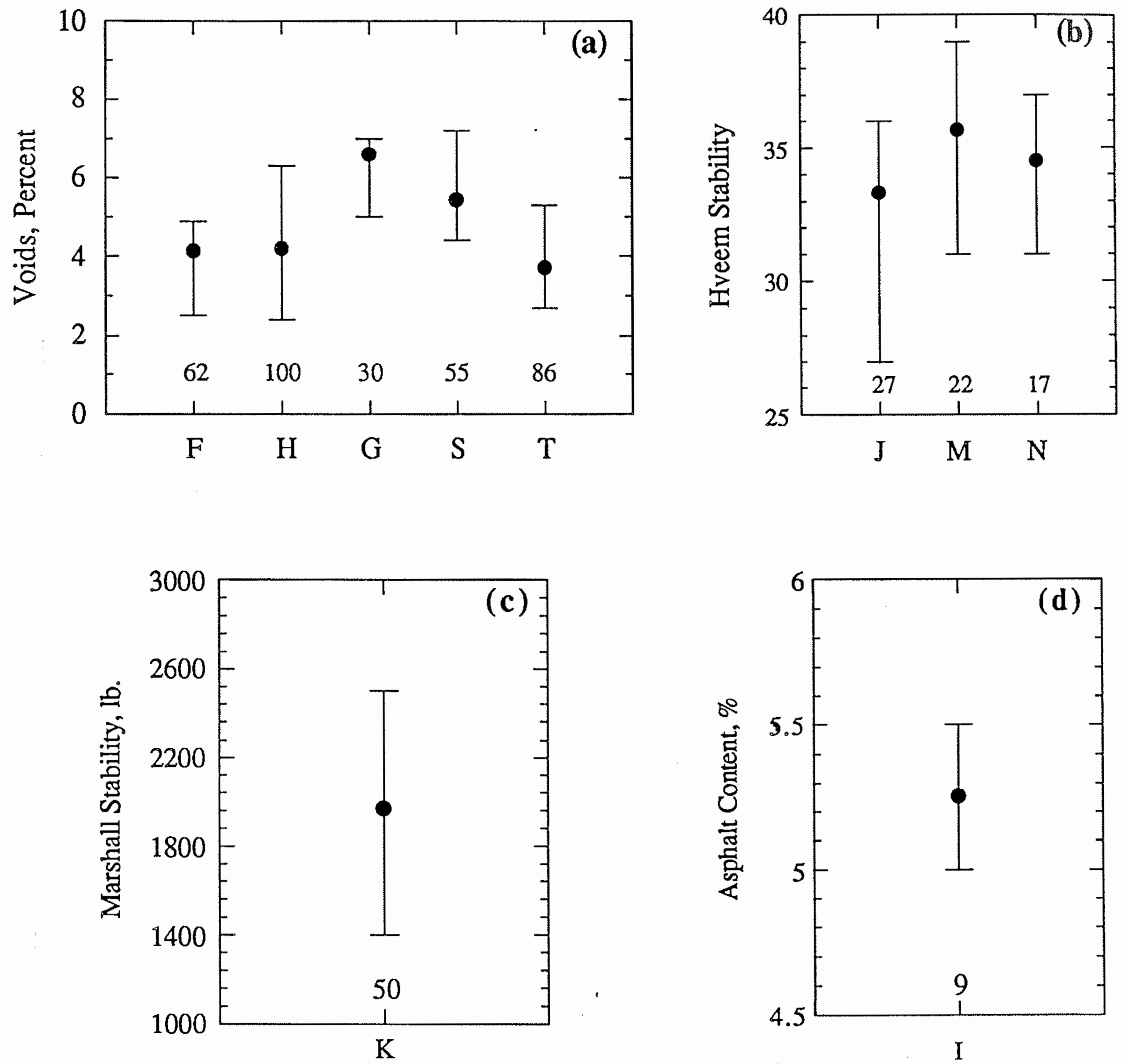


Figure 4.16. Marshall flow compared to Wisconsin and Virginia criteria - Rainier - Tide Creek

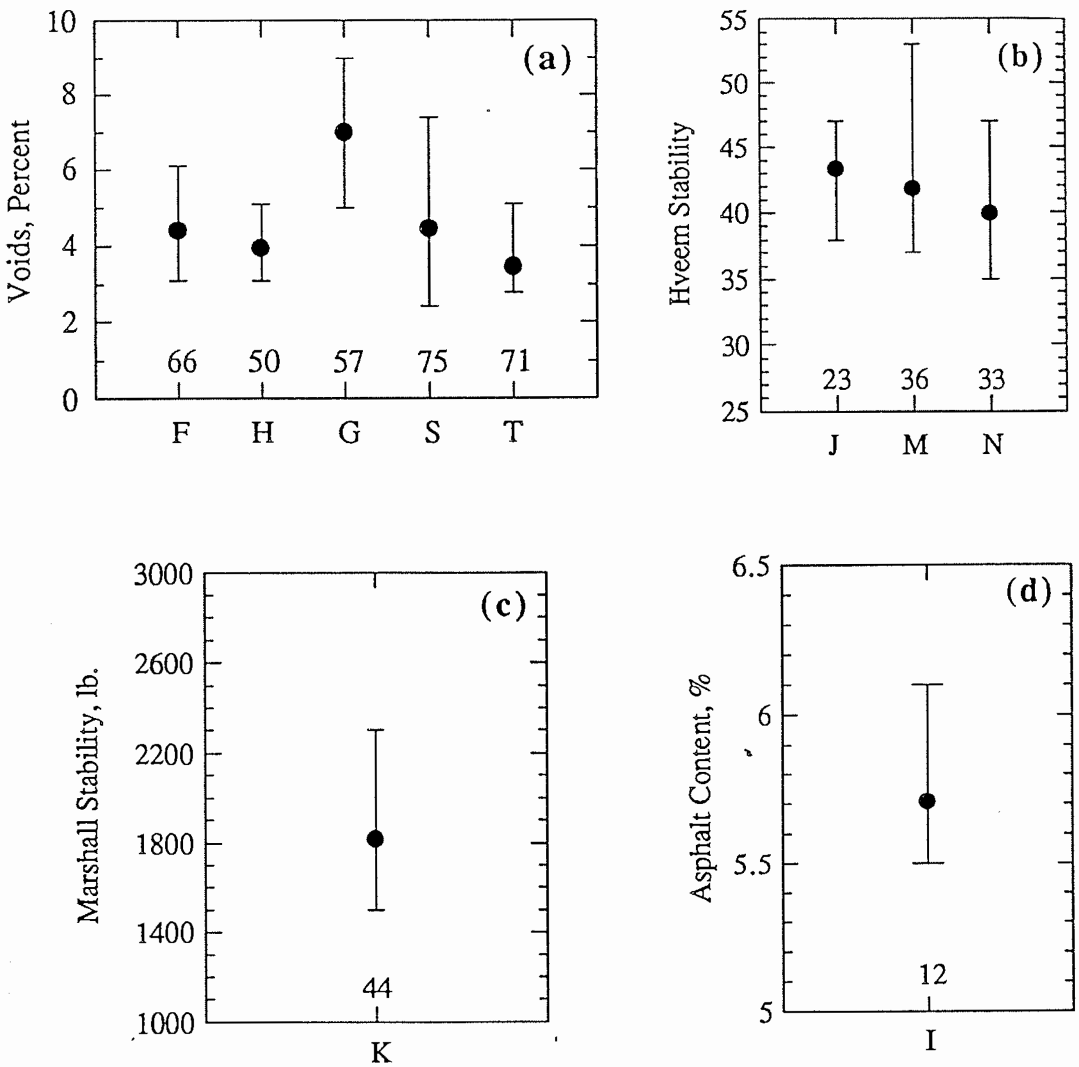


Note: Numbers on each graph are the coefficient of variation, %

Legend

F	Field Wet Measured Voids / Field Gyratory Compacted
G	Field Dry Measured Voids / Field Gyratory Compacted
H	Lab Wet Measured Voids / Field Gyratory Compacted
I	Field Asphalt Content by Nuclear Gage
J	Lab Hveem Stability / Field Gyratory Compacted
K	Field Measured Marshall Stability / Field Gyratory Compacted
M	Lab Hveem Stability / Lab Kneading Compacted
N	Lab Hveem Stability / Lab Gyratory Compacted
S	Lab Wet Measured Voids / Lab Kneading Compacted
T	Lab Wet Measured Voids / Lab Gyratory Compacted

Figure 4.17. Means and range of test parameters - Rainier - Tide Creek



Note: Numbers on each graph are the coefficient of variation, %

Legend

F	Field Wet Measured Voids / Field Gyratory Compacted
G	Field Dry Measured Voids / Field Gyratory Compacted
H	Lab Wet Measured Voids / Field Gyratory Compacted
I	Field Asphalt Content by Nuclear Gage
J	Lab Hveem Stability / Field Gyratory Compacted
K	Field Measured Marshall Stability / Field Compacted
M	Lab Hveem Stability / Lab Kneading Compacted
N	Lab Hveem Stability / Lab Gyratory Compacted
S	Lab Wet Measured Voids / Lab Kneading Compacted
T	Lab Wet Measured Voids / Lab Gyratory Compacted

Figure 4.18. Means and ranges of test parameters - O'Neil Junction - Redmond Couplet

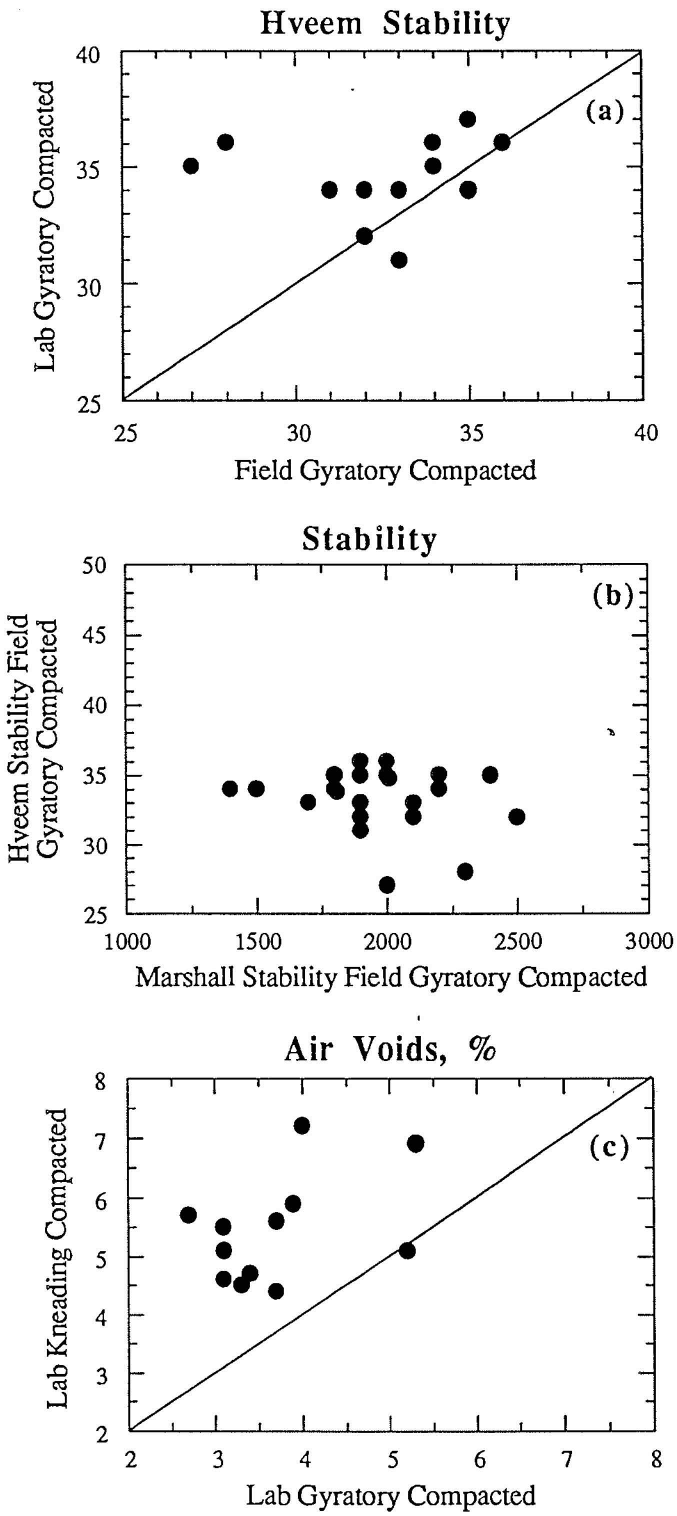


Figure 4.19. Comparison of various laboratory and field test data - Rainier - Tide Creek

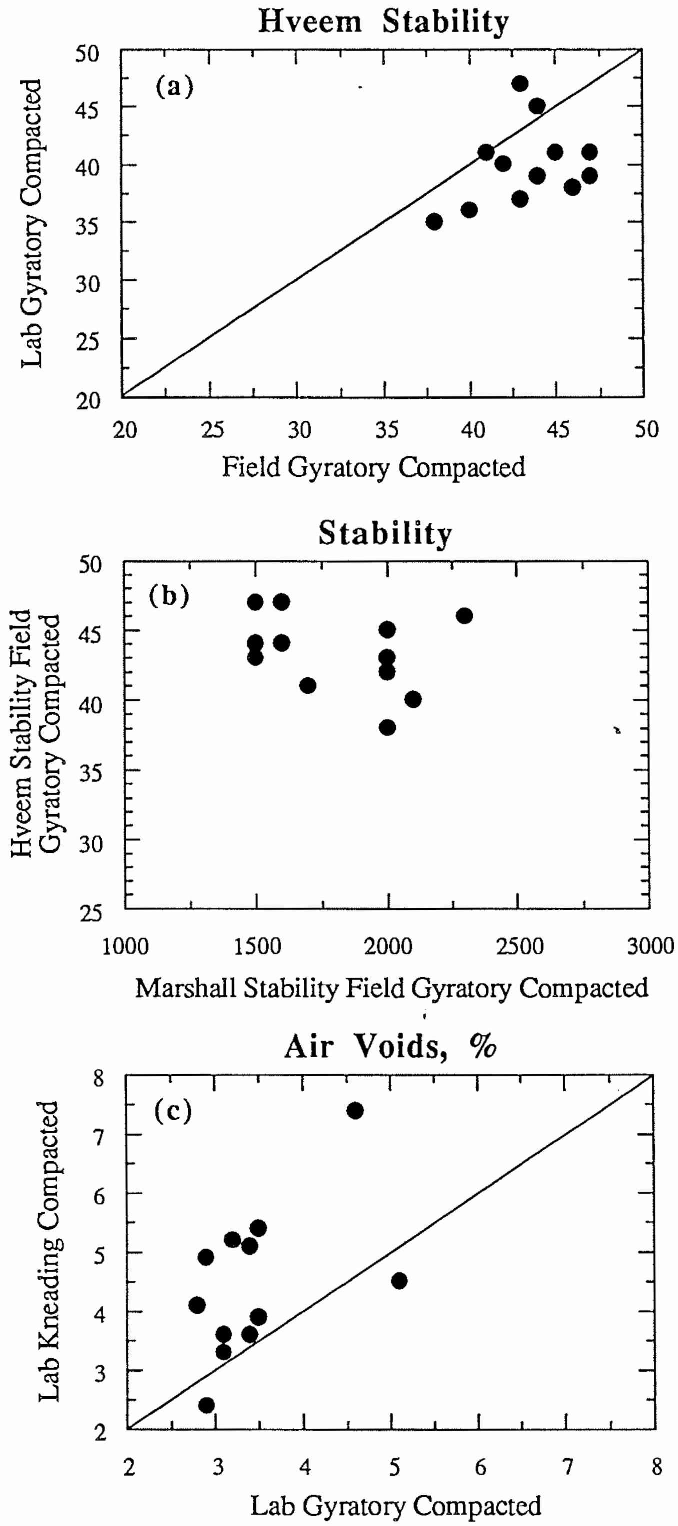


Figure 4.20. Comparison of various laboratory and field test data - O'Neil Junction - Redmond Couplet

Table 4.2. Properties of Mixtures Prepared by Gyratory Compaction in the Field Laboratory Rainier-Tide Creek (Contract No. 10926)

Bulk Specific Gravity			Rice Maximum Specific Gravity		Air Voids, %			Field Nuclear Asphalt Content (%)	Central Laboratory Tests		
Field[a] Wet[c]	Field Dry[d]	Lab[b] Wet	Field	Lab	Field Wet	Field Dry	Lab Wet		Hveem[e] Stability	Marshall[e] Stability (lb.)	Marshall Flow (.01")
2.45	2.45	2.37	2.513	2.511	2.5	5.7	2.4	5.5	32	1900	19
2.40	2.40	2.32	2.518	2.530	4.7	7.9	5.1	5.2	34	1400	19
2.41	2.41	2.36	2.524	2.508	4.5	6.5	3.9	5.2	28	2300	18
2.42	2.41	2.34	2.531	2.531	4.4	7.5	4.4	5.2	35	2000	19
2.41	2.38	2.33	2.522	2.528	4.4	7.6	5.9	5.3	32	2500	18
2.43	2.42	2.36	2.535	2.543	4.2	6.9	4.8	5.3	35	2400	19
2.43	2.42	2.36	2.536	2.546	4.2	6.9	3.8	5.5	35	1800	18
2.43	2.43	2.36	2.532	2.533	4.1	6.8	4.1	5.5	34	1800	18
2.41	2.41	2.33	2.516	2.572	4.2	7.4	6.3	5.0	36	2000	20
2.41	2.40	2.33	2.520	2.548	4.3	7.5	5.8	5.0	32	2100	20
2.43	2.44	2.35	2.531	2.526	4.0	7.2	3.4	5.1	35	2200	20
2.42	2.41	2.33	2.530	2.532	4.3	7.9	4.8	5.1	35	2000	19
2.42	2.42	2.34	2.534	2.534	4.5	7.7	4.5	5.2	31	1900	19
2.42	2.45	2.34	2.532	2.540	4.4	7.6	3.5	5.2	34	1500	17
2.43	2.43	2.35	2.531	2.541	4.0	7.2	4.4	5.2	34	1800	21
2.43	2.44	2.34	2.537	2.532	4.2	7.8	3.6	5.3	36	1900	21
2.42	2.44	2.35	2.526	2.528	4.2	7.0	3.5	5.3	33	2100	20
2.41	2.44	2.34	2.536	2.534	4.9	7.7	3.7	5.3	33	1700	20
2.45	2.44	2.38	2.530	2.509	3.1	5.9	2.8	5.3	27	2000	21
2.46	2.46	2.38	2.536	2.529	3.0	6.2	2.8	5.3	34	2200	19
2.42	2.42	2.34	2.538	2.547	4.6	7.8	5.0	5.3	33	1900	20
2.43	2.45	2.34	2.539	2.548	4.3	7.8	3.8	5.3	35	1900	20

a Field: Tests were conducted in the field laboratory
b Lab: Tests were conducted in the central laboratory
c Wet: By submersing in water
d Dry: Scaled volumetric measurements without submersing in water
e Stability values have been corrected for height

Table 4.3. Properties of Mixtures Prepared in the ODOT Materials Laboratory from Field Samples Rainier-Tide Creek (Contract No. 10926)

Hveem Stability		Bulk Specific Gravity		Rice Maximum Specific Gravity		Air Voids (%)	
Kneading[a]	Gyratory[b]	Kneading	Gyratory	Kneading	Gyratory	Kneading	Gyratory
31	34	2.40	2.43	2.529	2.509	5.1	3.1
32	35	2.39	2.41	2.519	2.541	5.1	5.2
33	36	2.41	2.44	2.528	2.525	4.7	3.4
35	32	2.39	2.44	2.534	2.533	5.6	3.7
34	34	2.39	2.44	2.535	2.507	5.7	2.7
39	36	2.36	2.43	2.534	2.567	6.9	5.3
37	37	2.38	2.43	2.528	2.529	5.9	3.9
39	34	2.41	2.45	2.522	2.543	4.4	3.7
39	36	2.41	2.45	2.549	2.529	5.5	3.1
35	31	2.40	2.46	2.517	2.539	4.6	3.1
37	35	2.42	2.46	2.534	5.544	4.5	3.3
37	34	2.36	2.43	2.543	2.530	7.2	4.0

a Kneading: Compacted using the Cox kneading compactor
b Gyratory: Compacted using the Texas gyratory compactor

Table 4.4. Properties of Mixtures Prepared by Gyratory Compaction in the Field Laboratory O'Neil Jct.-Redmond Couplet (Contract No. 10850)

Bulk Specific Gravity			Rice Maximum Specific Gravity		Air Voids, %			Field Nuclear Asphalt Content (%)	Central Laboratory Tests		
Field[a] Wet[c]	Field Dry[d]	Lab[b] Wet	Field	Lab	Field Wet	Field Dry	Lab Wet		Hveem[e] Stability	Marshall[e] Stability (lb.)	Marshall Flow (.01")
2.41	2.33	2.41	2.495	2.502	3.4	6.6	3.7	5.7	43	1500	21
2.41	2.34	2.41	2.504	2.484	3.8	6.5	3.0	5.5	44	1600	17
2.39	2.33	2.39	2.498	2.514	4.3	6.7	4.9	5.5	38	2000	17
2.36	2.29	2.41	2.506	2.497	5.8	8.6	3.5	5.6	44	1500	18
2.41	2.34	2.43	2.488	2.511	3.1	5.9	3.2	5.5	46	2300	24
2.38	2.31	2.43	2.481	2.504	4.1	6.9	3.0	5.5	47	1500	19
2.36	2.29	2.39	2.485	2.498	5.0	7.8	4.3	6.1	47	1600	20
2.41	2.33	2.39	2.484	2.495	3.0	6.2	4.2	6.1	43	2000	18
2.39	2.33	2.41	2.495	2.499	4.2	6.6	3.6	5.8	45	2000	17
3.37	2.32	2.38	2.499	2.497	5.2	7.2	4.7	5.8	42	2000	20
2.41	2.37	2.43	2.501	2.516	3.6	5.2	3.4	5.8	40	2100	20
2.36	2.32	2.38	2.511	2.509	6.0	7.6	5.1	5.6	41	1700	16

a Field: Tests were conducted in the field laboratory
b Lab: Tests were conducted in the central laboratory
c Wet: By submersing in water
d Dry: Sealed volumetric measurements without submersing in water
e Stability values have been corrected for height

Table 4.5. Properties of Mixtures Prepared in the ODOT Materials Laboratory from Field Samples O'Neil Jct.-Redmond Couplet (Contract No. 10850)

Hveem Stability		Bulk Specific Gravity		Rice Maximum Specific Gravity		Air Voids (%)	
Kneading[a]	Gyratory[b]	Kneading	Gyratory	Kneading	Gyratory	Kneading	Gyratory
42	37	2.39	2.42	2.449	2.491	2.4	2.9
37	45	2.37	2.41	2.452	2.487	3.3	3.1
45	35	2.36	2.39	2.471	2.518	4.5	5.1
45	39	2.37	2.42	2.467	2.507	3.9	3.5
39	38	2.39	2.43	2.481	2.515	3.6	3.4
38	39	2.37	2.42	2.458	2.497	3.6	3.1
37	41	2.38	2.41	2.504	2.494	5.1	3.4
48	47	2.38	2.41	2.483	2.497	4.1	2.8
39	41	2.38	2.43	2.503	2.503	4.9	2.9
53	40	2.37	2.41	2.506	2.497	5.4	3.5
39	36	2.38	2.43	2.511	2.511	5.2	3.2
40	41	2.33	2.39	2.518	2.506	7.4	4.6

a Kneading: Compacted using the Cox kneading compactor
b Gyratory: Compacted using the Texas gyratory compactor

V. ANALYSIS AND DISCUSSION

A. MIXTURE DESIGNS

Early in this research project, mixture designs were selected from four construction projects. Because of the interest in specific gravity, voids, and stability, these data from the designs were summarized in Table 4.1 and plotted in Figures 4.1 through 4.4. The results of both first and second compaction are included. The trends of both density and voids appear to be reasonable for all four projects — the data show a smooth progression in test results from low to high asphalt contents. The Hveem stability, however, is much less predictable, and the stability values after the first compaction are erratic; it would be difficult to draw a smooth curve through these points. Following first compaction, many of the data points fall below the minimum 35 value used for standard designs.

Following the second compaction (Figures 4.1-4.4), the density increased and voids decreased as one might expect. Also, stability is increased and may reflect the expected behavior after several years of traffic. At the high end of the asphalt content range, the stability tends to drop off rapidly, indicating mixture instability as the mixture becomes "over asphalted." For example, the S. Commercial St.-N. Santiam Hwy. (Figure 4.1) and Rainier-Tide Creek (Figure 4.3) mixtures become "critical" or very unstable at 6.5 percent asphalt content.

B. EVALUATION OF COMPACTION METHOD

Although they were not used as field projects, two projects (S. Commercial St.-N. Santiam Hwy. Section and SE 223rd-SE 242nd Ave. Section) were further evaluated in the ODOT Materials Laboratory. These data are shown in Table 4.1 and Figures 4.5 and 4.6. Mixtures were made with a range of asphalt contents similar to the designs discussed above, but two sets of specimens were prepared using both conventional kneading and gyratory compactors.

For both projects, at the compaction levels utilized, gyratory compaction resulted in higher density and lower voids than for kneading compaction. Voids in the gyratory compacted specimens were about two percent lower than those from kneading compaction. D'Angelo (*3*) indicates that using 2-in. rather than 2.5-in. high specimens in the gyratory compactor would result in similar densities and voids. The 2.5-in. high specimens were used for both the kneading and gyratory compacted samples so the Hveem stability could be compared directly without adjustment for height. As with the original mix designs discussed above, the Hveem stability values were erratic, although within the ±8.4 range used by ODOT for laboratory precision. The Hveem stability values were less erratic with gyratory compacted specimens. In Figure 4.5, the Hveem stability values are lower for gyratory compaction, but appear to result in a smoother plot. The gyratory compacted mixture in Figure 4.6 also has smoother stability data, but the average value is higher than for kneading compaction.

In summary, it would appear that density and voids from either compaction method are acceptable, but the compaction energy and/or sample height used needs to be adjusted. The variability of the Hveem stability makes it less suitable for quality control. Gyratory compaction may result in a more predictable curve when the data are plotted and therefore, be more useful.

As noted earlier, it is recommended that data be developed similar to that in Figures 4.5 and 4.6 for a range of mixtures that include not only variable asphalt content, but changes in aggregate gradation and compaction effort as well. This information would be very helpful in assessing the viability of using stability as a performance measure when variation in mixture components occur.

C. FIELD PROJECTS

The data from the two selected field projects have been presented in several ways: as a running series of tests as the data from sublot tests became available (Figures 4.8-4.16), and summarized in the form of means and ranges (Figures 4.17-4.18) or scatter plots (Figures 4.19-4.20).

In Figures 4.8 and 4.9, the mixture voids for the two projects are compared to ODOT criteria. For both sections, Rainier-Tide Creek and O'Neil Junction - Redmond Couplet, most of the field dry measured voids are above the tolerance band, but most of the wet measured voids are within or below the tolerance band. Much of this difference is explained by the nature of testing; in the wet procedure, the surface voids of the specimen are water filled and are not counted in the void total, thus they will always be less than that for dry measured.

In his discussion comparing ODOT criteria and experience to other state highway agencies, George (4) has compared (see Figures 4.10-4.11) the Oregon data to voids criteria used by the states of Wisconsin and Virginia. Again, for both projects, the dry measured voids are well above the 3-5% tolerance range, while the wet measured data are largely within tolerances. The same reasoning for the difference would apply here as for the data in Figures 4.8-4.9.

In Figures 4.12-4.13, the Hveem stability is compared to ODOT design criteria following first compaction. Values from the three compaction procedures show that field mixtures from Rainier-Tide Creek (Figure 4.12) would meet the "light duty" criteria, but only about a third of the tests would meet "standard duty" criteria. For O'Neil-Redmond Couplet

(Figure 4.13), the Hveem stability meet the heavy duty criteria regardless of the compaction method used.

The only Marshall stability data developed were for field gyratory compacted specimens. In Figures 4.14-4.15, these values are compared to Wisconsin (1500 lb.) and Virginia (1800 lb.) design criteria. For both field projects, most of the field test data meet Wisconsin criteria and 50% or more will meet the higher Virginia criteria.

The flow values from the Marshall test for Rainier-Tide Creek (Figure 4.16) indicates that all are well above the criteria used by both Wisconsin (8-16) and Virginia (6-16).

In Figure 4.17(a), one can note that the dry measured voids (code G) are higher than wet measured as discussed earlier. Also, the coefficient of variation (30%) for dry measured air voids is considerably less than other measured values for the Rainier-Tide Creek project. Although the coefficient of variation for O'Neil Junction-Redmond Couplet dry measured air voids in Figure 4.18(a) is higher (57%), it is still at the lower end of all those measured. Therefore, it would appear that dry volumetric measurements may be suitable for field quality control. A further look shows that gyratory compacted specimens that were tested in the ODOT Materials Laboratory have more scatter (see Figure 4.17[a] and 4.18[a]), code T).

The Hveem stability for both projects is not consistent and is considerably lower for Rainier-Tide Creek (Figure 4.17[b]). In addition, there is so much scatter (range) that it is questionable whether Hveem stability should be used in a quality control scheme. This was noted in the discussion of the mixture design data, as well. A similar comment could be made for the Marshall stability data since the range (Figure 4.19, for example) is as much as 1000 lbs. However, state DOTs in the eastern U.S. routinely use Marshall stability to control quality in the field laboratories, even though they experience large scatter.

The asphalt content measured by nuclear gauge is consistent and in a narrow range (see Figures 4.17[d] and 4.18[d], code I). Without additional data and analysis, it appears that the nuclear gauge procedure is an adequate control for field mixtures.

Figures 4.19 and 4.20 provide an opportunity for comparison of air voids and stability. From Figures 4.19(a) and 4.20(a), the correlation of field and laboratory Hveem stability would appear to be reasonable except for two outliers in each project. Additional testing would be required to determine if the differences were due to equipment, operators, or procedures.

In Figures 4.19(b) and 4.20(b), the comparison of Hveem and Marshall stability values is not especially encouraging, but this is not surprising. The two test methods measure the strength properties in different ways and have different modes of failure. Even when the two projects are combined to provide a wider range of stability (see Figure 5.1), the correlation does not seem to be better, indicating that this correlation can not be used. In

Figures 4.19(c) and 4.20(c) the comparison of air voids is presented for kneading and gyratory compacted lab specimens. These figures show that the kneading compacted specimens have a higher value for air voids than do the gyratory specimens. It has been envisioned that voids in the field mixture could be used as a measure of the quality, particularly if correlated with performance. It is not known if stability can be correlated with performance, but it may at least be performance-related. For example, in Figure 5.2, the values for the original design (Hveem stability vs. air voids from Table 4.2) have been plotted for both 1st and 2nd compaction values. Superimposed on the design values in Figure 5.2 are the Hveem stability vs. air voids for both wet and dry measured voids. Although this figure is somewhat cluttered, one can see that the air voids may be a reasonable measure of compliance with the original design for the 1st compaction tests. The wet measured field air voids obviously correlate better with the laboratory design because they were measured using the same method. The dry measured voids are shifted to the right by about 2 percent, which is the typical difference found using volumetric or parafilm methods (*3*). But once the correlation for wet vs dry void measurement is established, this simpler dry method could be used as a field measurement of voids in specimens compacted with a gyratory compactor as a performance/design-related parameter for quality control.

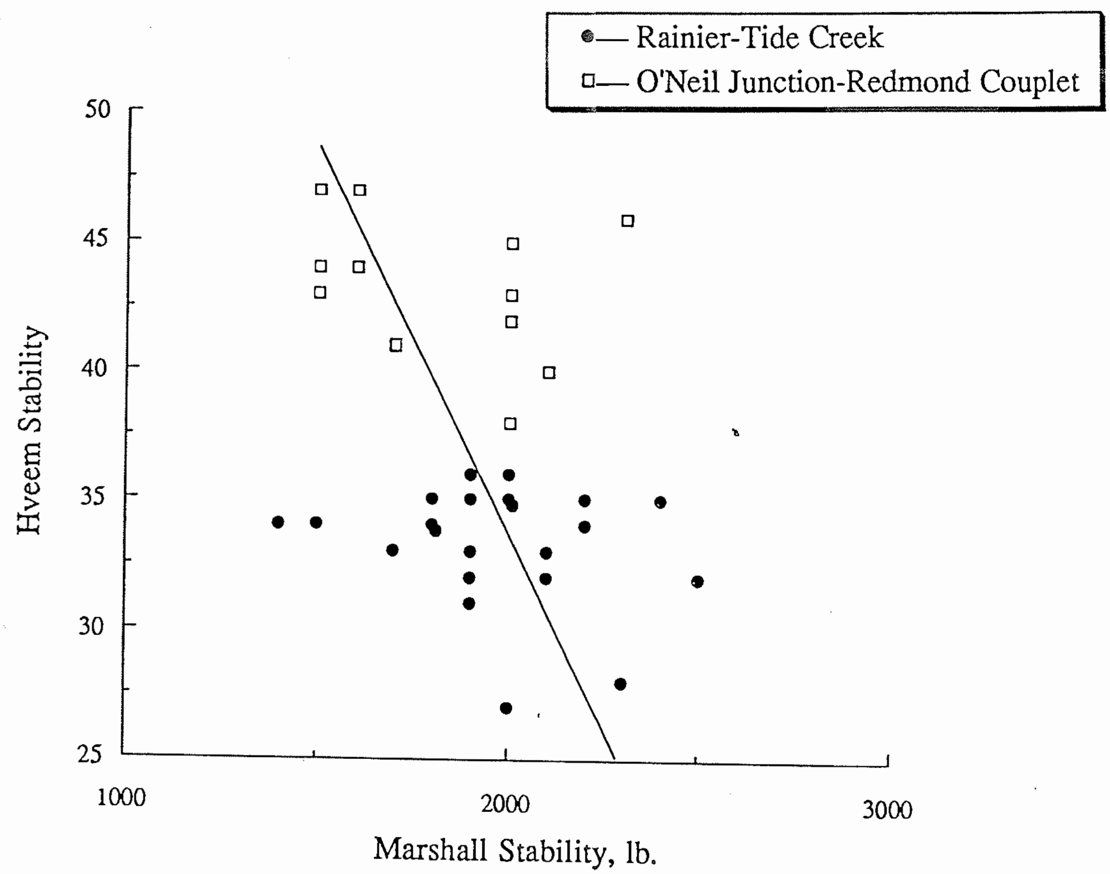


Figure 5.1. Comparison of stability values for both projects combined - Field Gyratory Compacted

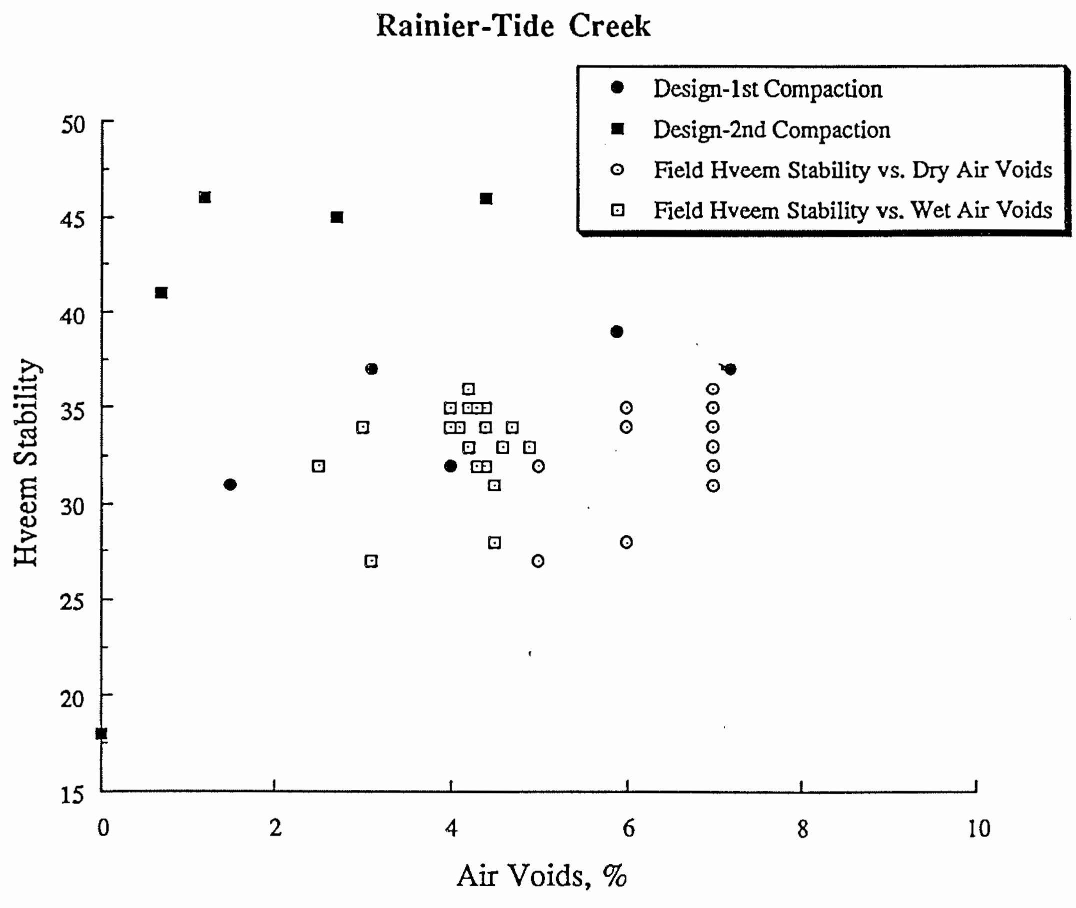


Figure 5.2. Field measured stability and air voids compared to laboratory design

VI. CONCLUSIONS AND RECOMMENDATIONS

This project has been the beginning of the development of a new system for field quality control of asphalt paving mixtures. It was undertaken with the goal of developing information that could be used to substitute for the old system of gradation testing and determination of asphalt content by vacuum extraction using solvents. Evaluation of all of the elements required to develop good relationships were not possible in this single project, but several positive aspects can be identified. The primary feature of this project was to introduce and test a field compactor as a potential method for preparing specimens in the field for testing and evaluation of mixtures as compared to those prepared as part of the mix design.

A. CONCLUSIONS

There is a definite need for a field testing system and accompanying criteria to evaluate how well the field paving mixture is meeting laboratory design.

The following conclusions were apparent:

1. The gyratory compactor worked well in the field laboratory. Compared to the kneading compactor, it is relatively inexpensive and simple to operate. The compacted specimens appear to represent the mixture quite well as shown by density and voids.

2. The void content measured in gyratory compacted field specimens may be used as a field control parameter (other agencies are currently doing this using the Marshall method of compaction).

3. The measured stability values on gyratory compacted specimens are equal or better than those for kneading compacted specimens; the results appear to be more consistent than with kneading or Marshall compacted specimens.

4. AC mixtures can be controlled in the field by monitoring stability; however, there is significant variability in the results.

B. RECOMMENDATIONS

The following are the recommendation from this study:

1. The gyratory method of compaction should be advanced as a method of field acceptance of asphalt concrete mixtures in the same manner as advocated by

the FHWA Demonstration Project No. 74. However, because an improved version of the gyratory compactor is currently being developed by the Strategic Highway Research Program (SHRP) research, it is recommended that partial or full implementation of the field control program be delayed until the new compactor is commercially available and can be evaluated for field applications.

2. Track the field performance of the four projects evaluated in this study for a period of 2-3 years to see if actual performance correlates with any of the test results evaluated.

3. Develop specifications for controlling asphalt concrete mixtures with a field compaction device used to fabricate specimens to measure air voids and voids in the mineral aggregate (VMA).

VII. REFERENCES

1. Asphalt Concrete Plant Certification Study Guide, Fourteenth Edition. Virginia Department of Transportation, Materials Division. 1221 East Broad Street., Richmond VA, 23219. 1988.

2. ASTM Designation D4013-81 (Reapproved 1987), "Standard Practice for Preparation of Test Specimens of Bituminous Mixtures by Means of Gyratory Shear Compactor."

3. D'Angelo, J.A., and T. Ferragut. Field Management of Asphalt Mixes. Federal Highway Administration, Demonstration Project No.74, Summary of Simulation Studies, Oct. 4, 1990.

4. George, A.J. Performance Based Mix Control. Proceedings, Western States Workshop on Field Control of Asphalt Concrete Mixes, Clackamas, OR, Federal Highway Administration and Oregon Department of Transportation, Dec. 4-6, 1990.

5. Terrel, R.L. and S. Al-Swailmi. Water Sensitivity of Asphalt-Aggregate Mixtures—Test Development,Final Report, TM-OSU-A-003A-92-16, Oregon State University, Dec. 1992.

6. Test Method Tex-206-F, State Department of Highways and Public Transportation (Texas), "Method of Compacting Test Specimens of Bituminous Mixtures" (Rev. January 1983).