AHTD TRC TRANSPORTATION RESEARCH COMMITTEE

TRC9801

LWT and RCM Based SHRP Mix Design Procedure / Evaluation of the Asphalt Pavement Analyzer

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Final Report

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LWT AND RCM BASED SHRP MIX DESIGN PROCEDURE / EVALUATION OF THE ASPHALT PAVEMENT ANALYZER

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16. Abstract

The Asphalt Pavement Analyzer (APA) is a type of loaded wheel pavement tester with capabilities to evaluate pavement performance criteria, such as rutting and stripping potential. The objective of this study was to develop a procedure for proof-testing SHRP Superpave mix designs utilizing the APA. Precision and accuracy of the APA was verified initially. 281 mix designs were evaluated for rutting potential; in addition 47 mix designs were evaluated for stripping potential and 12 mix designs were included for lab/field correlation.

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INTRODUCTION

The design of Hot Mix Asphalt (HMA) pavements has evolved significantly in the last ten years. Pavements previously designed using the conventional Marshall method are now being designed using Strategic Highway Research Program (SHRP) Superpave design criteria.

Along with advances that assist in the design phase, there are devices available to predict performance. Loaded Wheel Testing (LWT) provides insight into how the HMA pavement will perform under traffic. LWT subjects the HMA to a wheel load under repetitive loading conditions and measures the permanent deformation under the wheel path, thereby providing data to predict rutting susceptibility. Examples of LWT's are the French Pavement Rutting Tester, the Hamburg Wheel-Tracking Device, and the Georgia Loaded Wheel Tester.

This study focused on one type LWT: the Asphalt Pavement Analyzer (APA) which is a follow-on of the Georgia Loaded Wheel Tester.

Problem Statement

The Arkansas State Highway and Transportation Department is currently implementing SHRP hot mix asphalt design procedures by incorporating a number of SHRP designs in high traffic overlays. Part of the SHRP design procedure is the testing of mix designs with equipment that will indicate how well a design will work under actual traffic. Georgia Tech University in conjunction with the Georgia Department of Transportation developed a Loaded Wheel Tester (LWT) for proof testing of mix designs. The LWT tests for rutting potential and allows for varying test temperatures (25° C - 65° C, 77° F - 149° F) and loading (wheel loads to 250 lbs. and contact pressure to 120 psi).

Project Objective

The objective of this research was to develop a procedure for proof-testing SHRP mix designs utilizing the Loaded Wheel Tester (LWT). The LWT allows specimens to be tested using variable temperatures and variable amounts of wheel pressure or loading. The research will determine testing parameters that should be used with the different SHRP design levels and establish acceptable performance levels that should be required for SHRP mix design to obtain desired field performance.
(Another objective of this project was to also investigate a Rolling Compaction Machine as part of the research; this portion of the study was abandoned due to the cost of the Rolling Compaction Machine.)

Scope of Project

Instead of testing a limited number of mixes with varying aggregate gradations and asphalt cement contents, this study chose to test as many current Superpave mix designs as feasible within the limits of the project.

Numerous Superpave projects have been let to contract since 1997, the year the Department first began use of Superpave mix designs. Most of these mixes were designed by a Department approved Contractor or an independent testing laboratory. Blended dry aggregate samples are provided with each design submittal in order to verify the results. In an effort to build a database for this study, additional samples were requested for APA testing.

Four 75mm Superpave Gyratory Compactor (SGC) samples were prepared for each mix design to be tested in the APA (samples were compacted to 7% air voids). Of the four samples, two samples were tested dry for rutting and two samples were intended to be tested wet for stripping. The bulk specific gravity (Gmb) of each sample was determined in addition to the maximum theoretical specific gravity (Gmm) of the mix in order to determine percent air voids.

REVIEW OF LITERATURE

Loaded Wheel Testing has been a topic in recent years with many agencies publishing reports dealing with this subject and the various aspects of this type of performance testing.

The Georgia Department of Transportation (GDOT) is no exception. GDOT started loaded wheel testing research in 1985 by contacting Georgia Tech to assist in the development of a machine that would meet their needs.

Research Project No. 8503 "Development of a Simplified Test Method to Predict Rutting Characteristics of Asphalt Mixes" followed. The objective of this research was to evaluate this early LWT's capability in predicting rutting tendencies of asphalt mixes. Three variables were thought to be significant in potential rut development: tire pressure, testing temperature, and load.

This testing differed from other LWT devices with the addition of a linear tube to simulate tire contact. The tube was made of high-pressure rubber capable of maintaining pressures up to 120 psi and was placed on the surface of an HMA specimen and inflated to the desired pressure. A concave wheel, attached to a reciprocating arm, would travel forward and back along the inflated hose to apply the desired load. Temperature was controlled by installing the LWT in a thermostatically controlled room.

This research project demonstrated loaded wheel testing could be successfully used in evaluating the rutting potential of HMA samples.

GDOT followed with more research involving the loaded wheel tester. Research Project No. 8609, "Evaluation of Rutting Characteristics of Asphalt Mixes Using the Loaded Wheel Tester," and Research Project No. 8706, "Evaluation of the Effect of Gradation of Aggregate on Rutting Characteristics of Asphalt Mixes," evaluated how aggregate characteristics in HMA such as gradation requirements, angularity, and surface texture reduced rutting potential. Research Project No. 8717, "Development of a Laboratory Rutting Resistance Testing Method for Asphalt Mixes," modified the testing apparatus and sample preparation, and for the first time, developed a standard testing procedure.

Based on this extensive research, GDOT implemented GDT-115 "Method of Test for Determining Rutting Susceptibility Using the Loaded Wheel Tester" for interstate projects and other state routes in 1989. Developmental work and further testing at this time indicated a need to increase the test temperature from 95° F to 120° F when testing mixtures modified with polymer.

The Federal Highway Administration (FHWA) became involved in LWT testing due to an interest in developing an economical proof tester for HMA mixes. To obtain a thorough, unbiased assessment of the apparatus, FHWA provided funding for round robin testing that included six states to evaluate the LWT. This round of testing found LWT results to be comparable to actual field performance.

Another series of round robin tests followed which included eleven states. Phase I of this study evaluated the applicability of the LWT only, while Phase II evaluated the applicability of the rolling wheel compactor with the loaded wheel tester.

The LWT evolved into a computer-automated apparatus utilizing LVDT (linear variable displacement transducer) to measure rutting. Transportation Research Board (TRB) Committee A2D05 sponsored the development of the next generation Loaded Wheel Tester constructed by ASTEC Industries. One significant modification involved utilizing asphalt specimens prepared with a Superpave Gyratory Compactor (SGC) in lieu of beam samples which require a separate compaction device.

PROJECT TESTING PROGRAM

Verification of Accuracy and Precision

Before a database of Superpave mix design rutting characteristics was started, this study began by testing twenty "like" samples to verify or establish the accuracy of the Asphalt Pavement Analyzer.

Samples were prepared with a locally available syenite aggregate from Granite Mountain Quarries. The aggregate "cold feed" percentages were:

¾" minus - 40%
½" minus - 50%
Screenings - 10%

The job mix formula for all twenty samples was taken to the –200 sieve to insure precision. All other properties were also identical, including asphalt content (5.5%), and asphalt cement binder (Ergon PG64-22).

Results indicated the APA's accuracy to be + or – 1 mm for "like" samples; proving the APA to be sufficiently accurate to proceed with the research.

Dry /Rutting Testing

As mentioned previously in this report, additional material was requested for APA testing for every Superpave mix design to be verified. Superpave Gyratory Compactor (SGC) samples were prepared for each mix design to be tested in the APA. A database was created that included rutting information for all current Superpave mix designs. Superpave mix designs included 9.5, 12.5, 25, and 37.5mm mixes with PG 64-

22, PG 70-22 and PG 76-22 asphalt cements at varying Nmax gyration levels. Initial testing parameters were:

Testing temperature - 60°C (140°F)
Test cycles – 8,000
Hose pressure - 100psi
Wheel load – 100lbs

These parameters were determined by the TRC-9801 subcommittee after contacting other agencies (Georgia DOT, Virginia DOT, NCAT, APAC, and the University of Arkansas) concerning their specifications, requirements, and experience.

APA testing under this study was interrupted for six months due to an agreement between the Arkansas State Highway Department and the University of Arkansas Department of Civil Engineering. This agreement allowed Dr. Kevin Hall to correlate APA testing with testing done in a related study, TRC 9804 "ERSA Wheel Track Testing for Rutting and Stripping" (ERSA is an acronym for **E**valuator of **R**utting and **S**tripping in **A**sphalt). The APA was shipped via truckline to Fayetteville.

Correlation testing concluded, the APA was returned, and calibration of the unit followed. Testing resumed, but the subcommittee suggested the test temperature be changed from 60°C(140°F) to 64°C (147°F). This decision was based on a draft ASTM Standard Test Method for "Determining Rutting Susceptibility Using the Asphalt Pavement Analyzer". The test procedure required the test temperature to be set to the high temperature of the standard Superpave binder Performance Grade. The majority of other agencies within the APA Users Group had adopted this test temperature also.

Another variation in testing procedure was adopted at this time. This involved taking polymer modified HMA mixes (PG 70-22, PG 76-22) to 16,000 cycles instead of 8,000 cycles. This would provide information related to any additional or significant rutting that might occur after 8,000 cycles. Testing parameters for the remainder of the project are listed below:

Testing temperature - 64°C (147°F)
Test cycles – 8,000 (PG 64-22)
– 16,000 (PG 70-22, PG 76-22)
Hose pressure - 100psi
Wheel load – 100lbs

This study evaluated 281 Superpave mix designs from 51 different asphalt plants over a 20 month time period for rutting susceptibility.

Wet /Stripping Testing

Arkansas, like many other states with similar climates, can experience pavement damage, not only from rutting, but from stripping (moisture damage) as well. This occurs when water is trapped within the pavement layers and pressure is allowed to build due to increased temperatures. Factor in the traffic load, and a "churning" process is underway that will eventually result in uncoated aggregate, which can lead to any number of failures.

The workplan for this study included wet/stripping testing as part of this project. The APA not only is equipped to perform wet testing , but includes a recommended procedure for this method of testing.

The suggested procedure for performing a wet/stripping test is more time consuming than the companion dry/rutting test. Two procedures are offered for moisture conditioning of the test specimens, depending on climate. One procedure, for warmer climates, involves vacuum saturation followed by immersion of the specimens into 64°C water for 24 hours. The other procedure , for colder climates, also involves vacuum saturation, but a freeze cycle (-18°C, 0°F) of 16 hours is included, before immersion of the samples as in the warmer climate procedure. To achieve vacuum saturation, specimens are placed in the vacuum container then immersed in distilled water at room temperature. A vacuum of 250 mm Hg partial pressure is then applied for 5-10 minutes to attain a level of saturation between 55% and 80%.

The procedure for warmer climates was chosen for this study. Following the recommended procedure, the samples are then transferred to the APA, and again immersed in 64°C water for testing.

To most efficiently test a large number of mix designs, a number of dry/rutting tests were performed before the wet/stripping procedure was begun (two additional samples were prepared for each mix design for wet/stripping testing).

Due to time constraints, the subcommittee chose to perform the wet/stripping test on approximately 40 mix designs previously tested in the dry/rutting test mode.
The 20 best performing mix designs, or least rutted, would be subjected to the wet/stripping test as would the 20 worst performing mix designs, or most rutted.

Lab/Field Correlation

The workplan for this project also specified laboratory/field correlation. Initially, laboratory compacted specimens for each mix design were tested for rutting potential in the APA. As a result, a large database of rutting results was available from which to select projects for laboratory/field correlation.

An attempt was made to select projects that represented various and typical types of aggregates and asphalt cement grades utilized in HMA pavements in Arkansas. Both overlay and new construction projects with different levels of traffic (Nmax) were selected for this task.

Laboratory specimens were compacted to 75mm (~3") with the Superpave Gyratory Compactor (SGC). 75mm is the suggested specimen height for a proper fit in the APA testing molds. Many of the pavement cores collected were less than 75mm in height. For these cores to properly fit the APA molds, plaster was used to "build up" the cores from the bottom, thereby insuring consistent heights from core to core.

A clear understanding of lab sample and pavement core conditions may be necessary to better interpret laboratory/field correlation results. Lab samples are compacted with the Superpave Gyratory Compactor (SGC) in a controlled environment. Rutting, or permanent deformation, is inflicted by 8,000 cycles in the APA. Pavement core (field) samples are compacted by steel-wheeled rollers (static and vibratory) and pneumatic-tired rollers. Pavement (mat) temperature is required to be within a specified range during compaction. Weather conditions influence these operations on every project. Some amount of rutting or permanent deformation begins when the new pavement is opened to traffic. As a result, when pavement cores were sampled, some degree of permanent deformation already existed. This condition, though minimal in most cases, did preexist before APA testing occurred.

RESULTS OF TESTING

Dry/Rutting Test Results

Of 281 Superpave mix designs tested for rutting susceptibility in the APA:

0 / 281 rutted > 15.0 mm (0.6")
7 / 281 rutted > 12.5 mm (0.5")
90 / 281 rutted > 6.2 mm (0.25")
245 / 281 rutted > 2.5 mm (0.1")

To be more specific, properties of these mixes such as: type asphalt cement binder (PG grade), type mix, and Nmax are considered also.

In Figure 1, the average rut depth in mm is shown for different grades of asphalt cement binder. Nine different asphalt cement producers were included in this study. PG 64-22 and PG 67-22 are unmodified asphalt cement binders. PG 70-22, depending on the manufacturer, may be polymer modified. PG 76-22 and PG 82-22 are polymer modified; Superpave mixes with PG 76-22 typically are designed at the 205 Nmax gyration level. PG 67-22 and PG 82-22 were not used on a regular basis; limited use of these products were for research purposes.

Figure 2 plots Nmax and type mix versus rut depth. Superpave asphalt mixtures are designed at a specific level of compactive effort, a function of the design number of gyrations, or Ndesign (Ndes). Ndes is a function of climate and traffic level. Nmax is a certain percentage of compactive effort above Ndes resulting in no more than 98% density. Type mix is better described as: base (37.5mm), binder (25mm), and surface courses (12.5mm & 9.5mm).

Four predominant aggregate types are used in HMA in Arkansas: limestone, sandstone, syenite, and gravel. Figure 3 shows rutting results for each of these aggregates used with different PG grades of asphalt binder.

VFA (voids filled with asphalt), a volumetric property, is plotted in Figure 4.

Figure 5 depicts rut data at 4.0% and 4.5% air void levels for PG64-22 and PG70-22. Prior to October 1999, the 4.0% air void level was used for selection of asphalt binder content. In an effort to "dry up" Superpave mixes designed with PG64-22 or PG70-22, asphalt binder content was later selected at the 4.5% air void level.

On 3/30/00, the Arkansas State Highway and Transportation Department revised Supplemental Specification for Asphalt Concrete Hot Mix Base, Binder, and Surface Courses (SS-400-1), to include Asphalt Pavement Analyzer testing (see Figure 6). Meeting this requirement would allow the contractor's combined aggregate gradation to pass through the restricted zone. Figures 7, 8, and 9 display rutting results of HMA producers (asphalt plants) working in Arkansas. Figures 10, 11, 12, and 13 compare rutting data by Highway District in Arkansas.

Wet/Stripping Test Results

47 mix designs previously tested in the dry/rutting test mode were selected for wet/stripping testing in the APA. 27 of the best performing mix designs, or least rutted, and 20 of the worst performing mix designs, or most rutted, were tested in this manner.

17/27 of the best performing mix designs were polymer modified. Of these 27 mix designs, no visible stripping was evident after wet testing. The criteria for wet testing appears more severe than for dry testing; as a result wet rut depth could be expected to be greater than dry rut depth for the same mix design. Figures 14 & 15 do not indicate such a pattern.

0/20 of the worst performing mix designs were polymer modified. Stripping, was evident in 13/20 of these mixes. However, Figures 16 & 17 also fail to show a consistent pattern in wet/dry rutting comparison.

Lab/Field Correlation Test Results

As previously noted, the intention for this portion of the study was to select both overlay and new construction projects with a varied range of aggregates, asphalt cement binders, and traffic levels. 12 Superpave projects were selected and investigated. Figure 18 illustrates the following: the 5 mixes which rutted the least in the lab-compacted category had more rutting when companion field-compacted samples were tested. Conversely, the 3 mixes which rutted the most in the lab-compacted category had less rutting when companion field-compacted samples were tested. Another mix (150-99), showed lab-compacted ruts of 8.4 mm while field-compacted samples were in excess of 12 mm. 2 mixes had virtually the same results for lab and field-compacted samples.

Another aspect of this testing involved taking actual rut depths of each in-service pavement. APA testing, like other loaded wheel testing, is accelerated, or meant to predict pavement deformation for an extended period of traffic and weather conditions. Therefore, in most cases, the actual rut depth of the in-service pavement will be different from the APA rut depths; but this additional information is useful in completing the lab/field correlation. For instance, the pavements which exhibited the largest actual rut depths *would have failed* at the mix design level (APA testing) *if the* revised (see Fig. 6) Supplemental Specification for Asphalt Concrete Hot Mix Base, Binder, and Surface Courses (SS-400-1), applied to all mix designs.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the analysis of the results from this study, the following conclusions can be drawn:

1. Results are positive for dry/rutting testing. Based on findings that included results from dry/rutting testing of 281 HMA mix designs, the Asphalt Pavement Analyzer (APA) can identify rutting susceptible mixes.

2. Results were inconclusive for wet/stripping testing. No reliable pattern was evident when analyzing wet/stripping test results; therefore this study cannot recommend the Asphalt Pavement Analyzer (APA) to be an accurate indicator of stripping susceptible mixes.

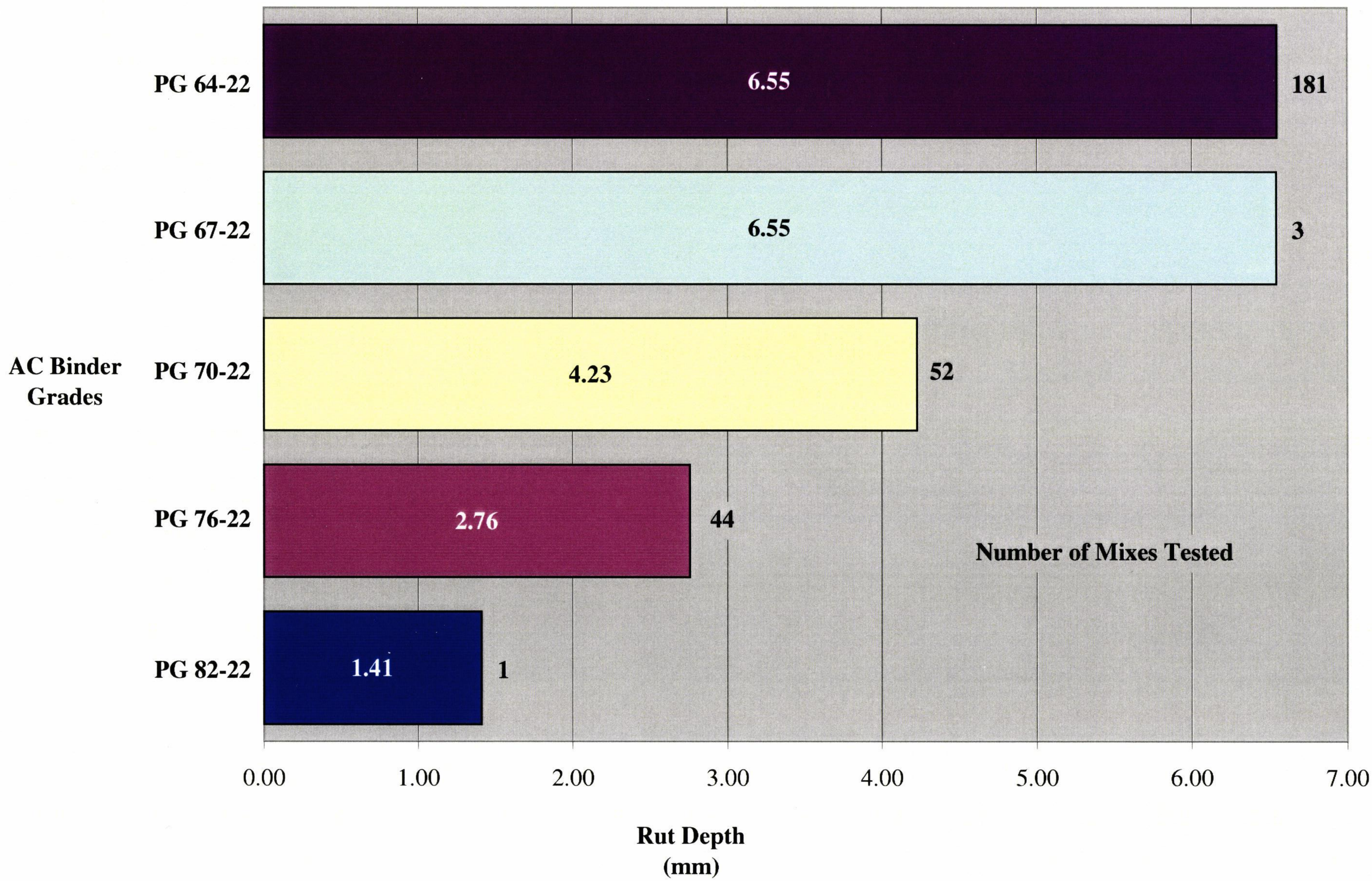
3. The lab/field correlation was a necessary portion of this study to determine how results differed between lab-compacted and field-compacted samples when dry/rutting tested in the APA. Although a definite pattern was not established, this testing did provide information concerning results from the two sources of samples. For instance, the pavements which exhibited the largest actual rut depths had relatively high rut results for the corresponding mix design.

Recommendations

1. Based on extensive Asphalt Pavement Analyzer (APA) dry/rutting testing of 281 HMA mix designs over a 20 month period, this study can recommend implementing a maximum rut depth specification based on APA testing. A "tiered" specification based on Nmax of the mix design, similar to the revised (see Fig. 6) Supplemental Specification for Asphalt Concrete Hot Mix Base, Binder, and Surface Courses (SS-400-1), would be necessary.

Fi[illegible] 1

APA Testing:
AC Binder Grades vs. Rut Depth



Fi 2

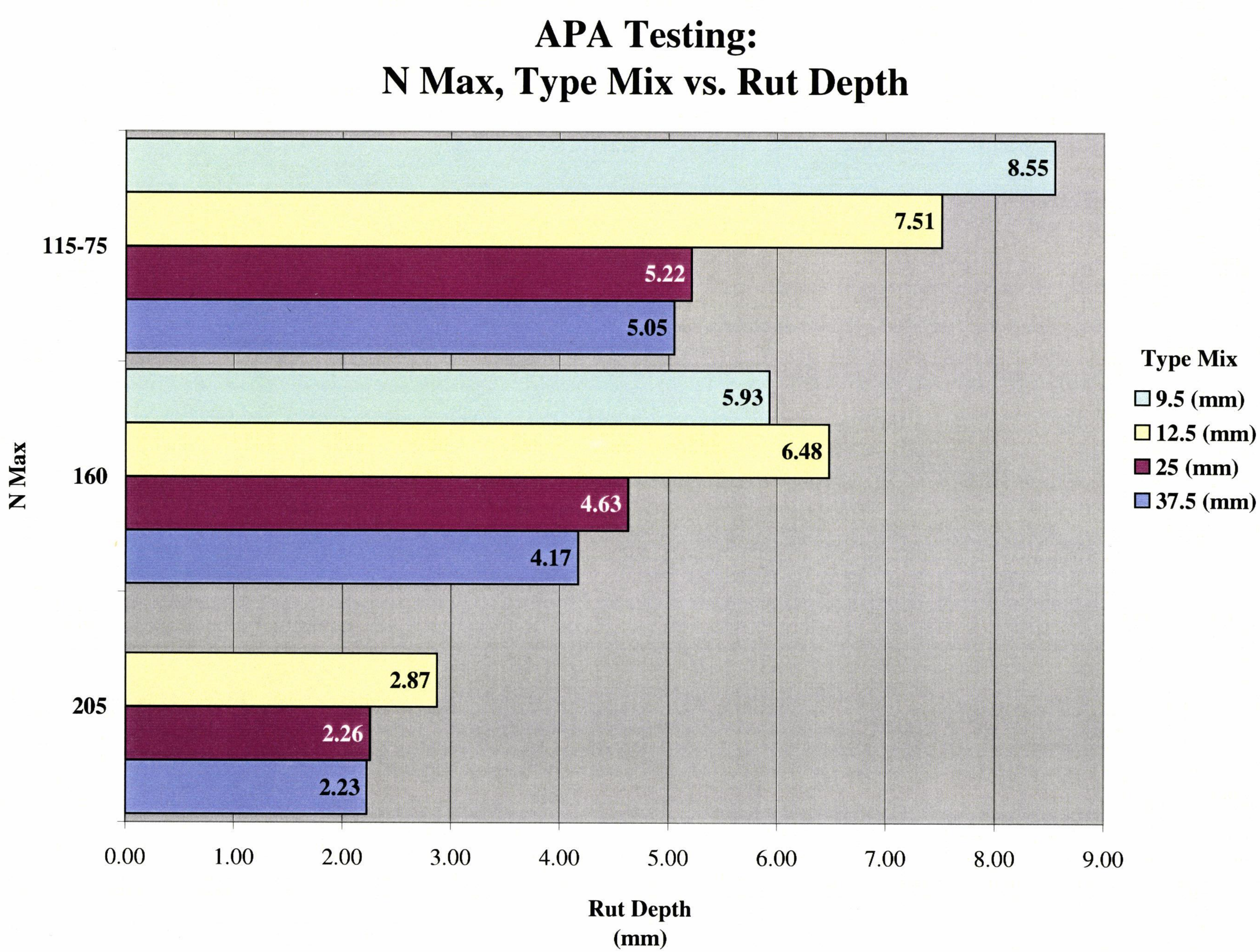
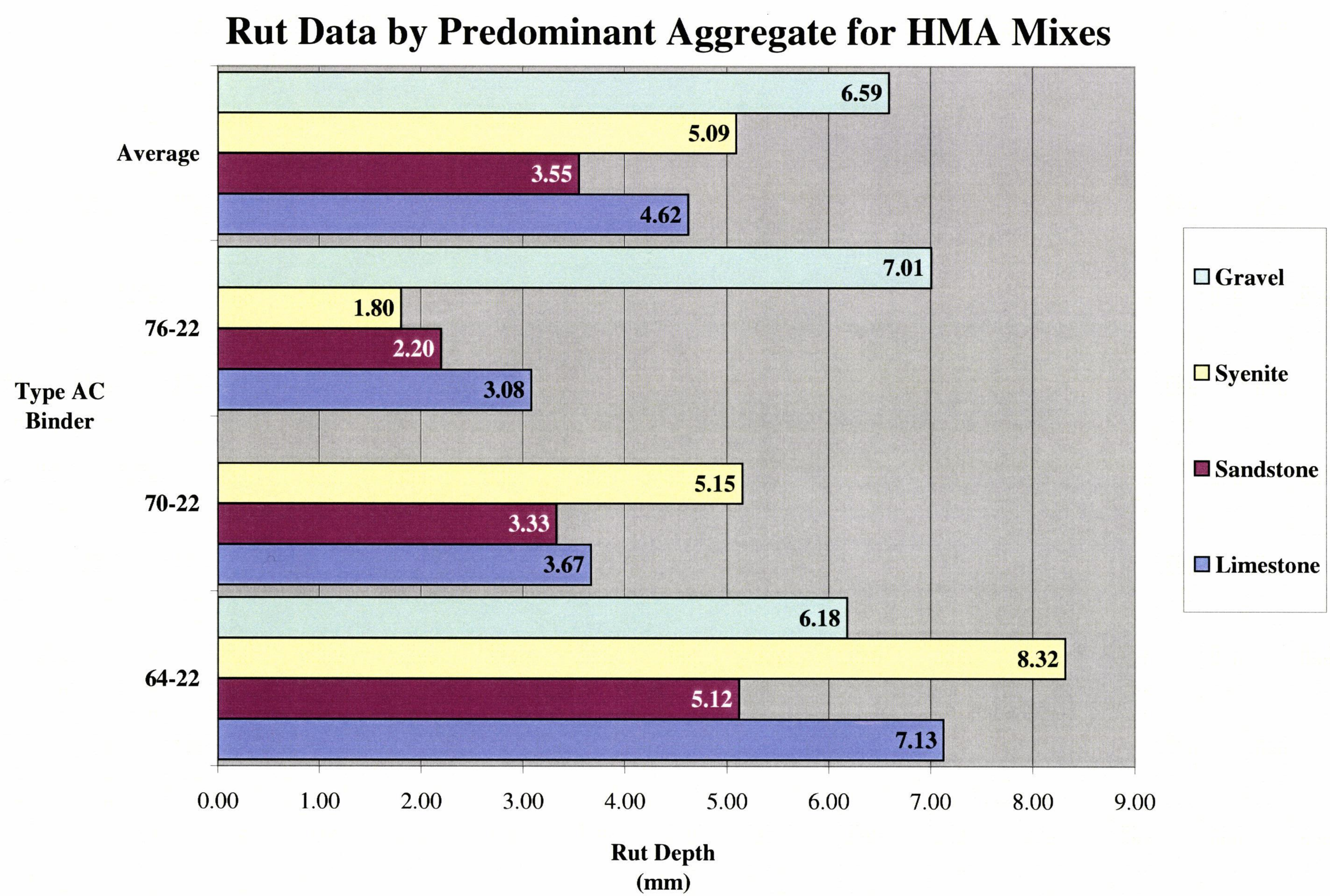

APA Testing:
N Max, Type Mix vs. Rut Depth
N Max
115-75
160
205
8.55
7.51
5.22
5.05
5.93
6.48
4.63
4.17
2.87
2.26
2.23
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
Rut Depth
(mm)
Type Mix
9.5 (mm)
12.5 (mm)
25 (mm)
37.5 (mm)

Fig 3



Rut Data by Predominant Aggregate for HMA Mixes
Type AC Binder
Average
76-22
70-22
64-22
6.59
5.09
3.55
4.62
7.01
1.80
2.20
3.08
5.15
3.33
3.67
6.18
8.32
5.12
7.13
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
Rut Depth (mm)
Gravel
Syenite
Sandstone
Limestone

Fi[illegible] 4

Voids Filled with Asphalt (VFA) Rut Data

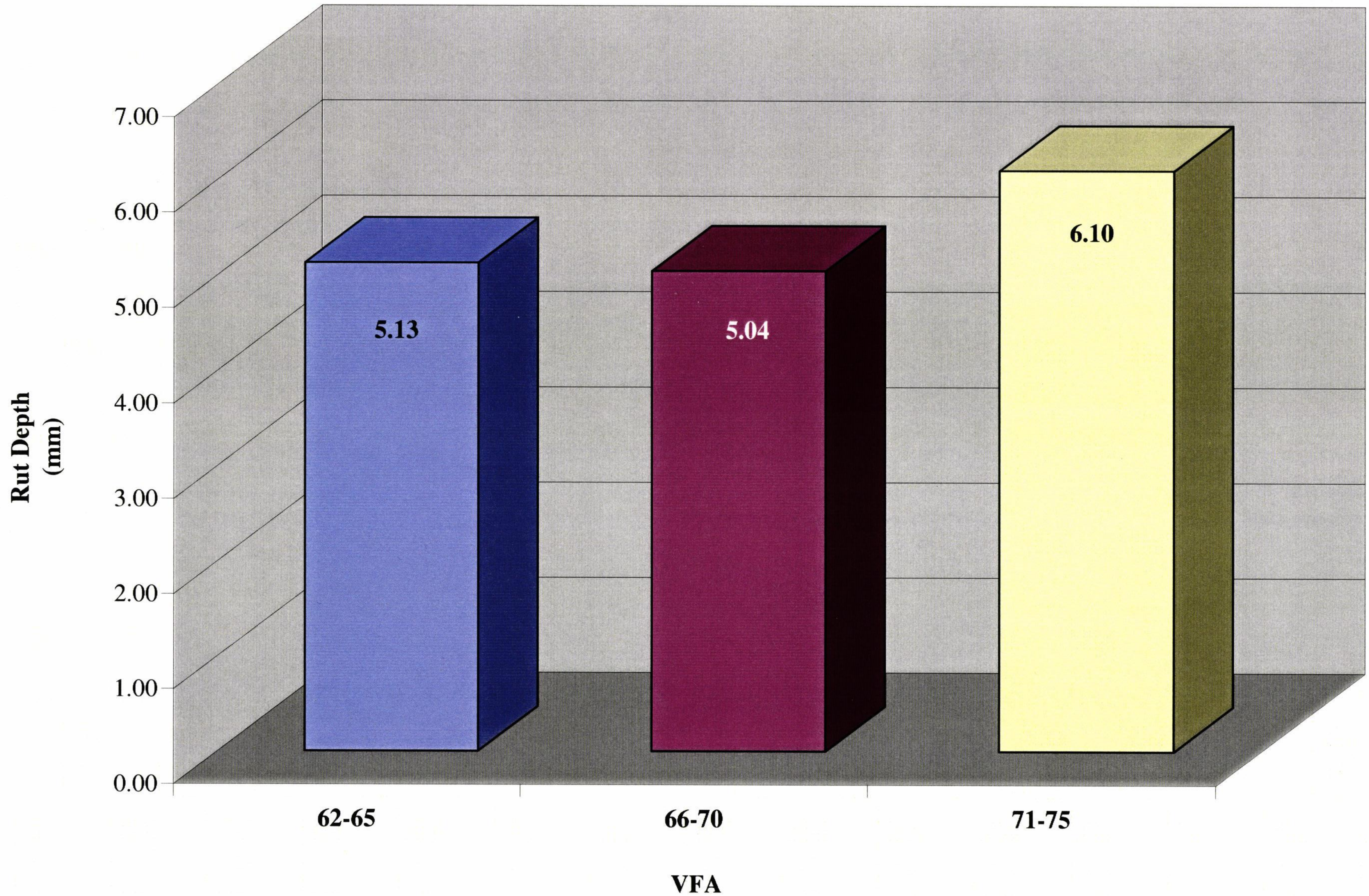


Fig 5

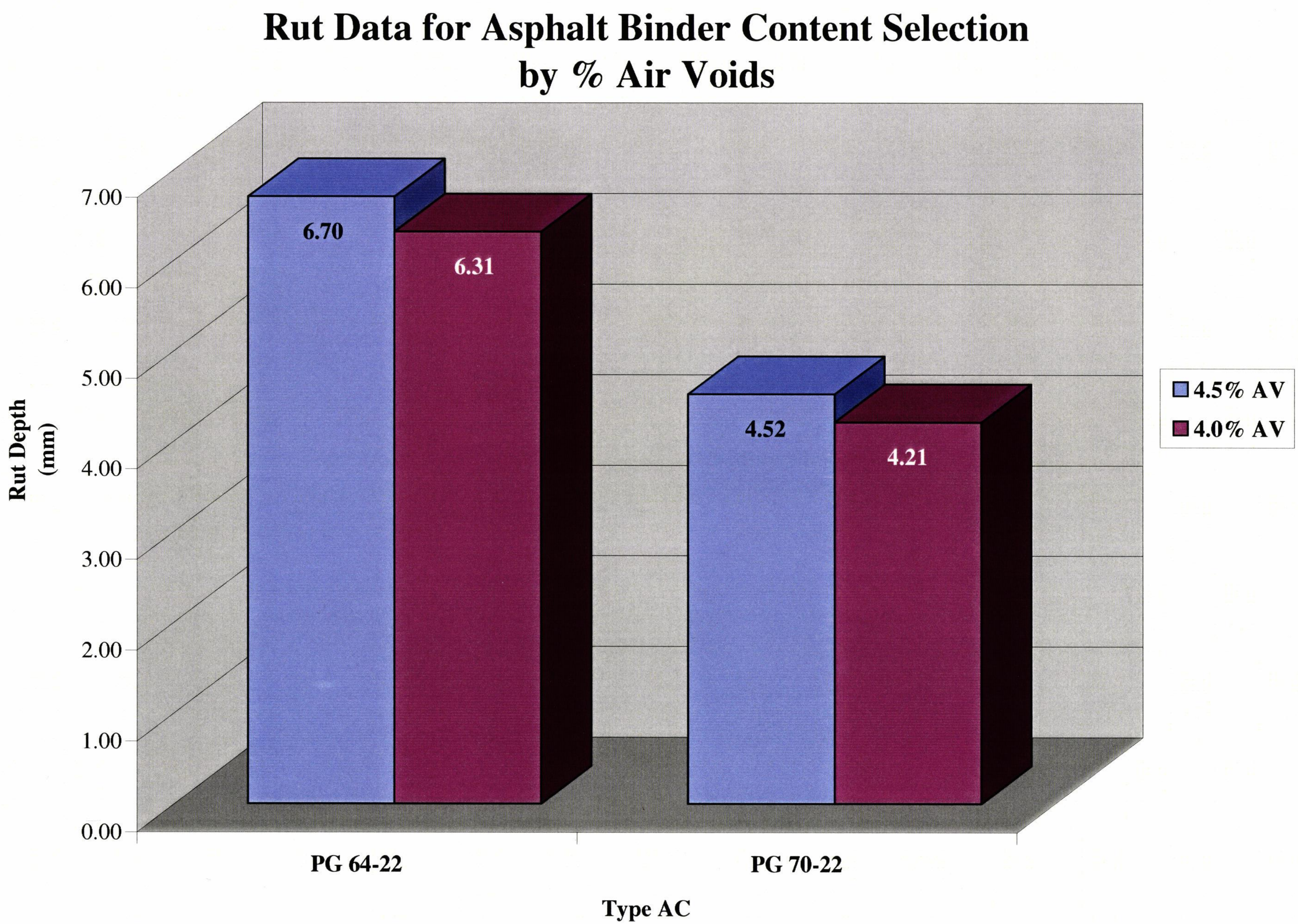

Rut Data for Asphalt Binder Content Selection
by % Air Voids
Rut Depth
(mm)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
6.70
6.31
4.52
4.21
4.5% AV
4.0% AV
PG 64-22
PG 70-22
Type AC

Figure 6

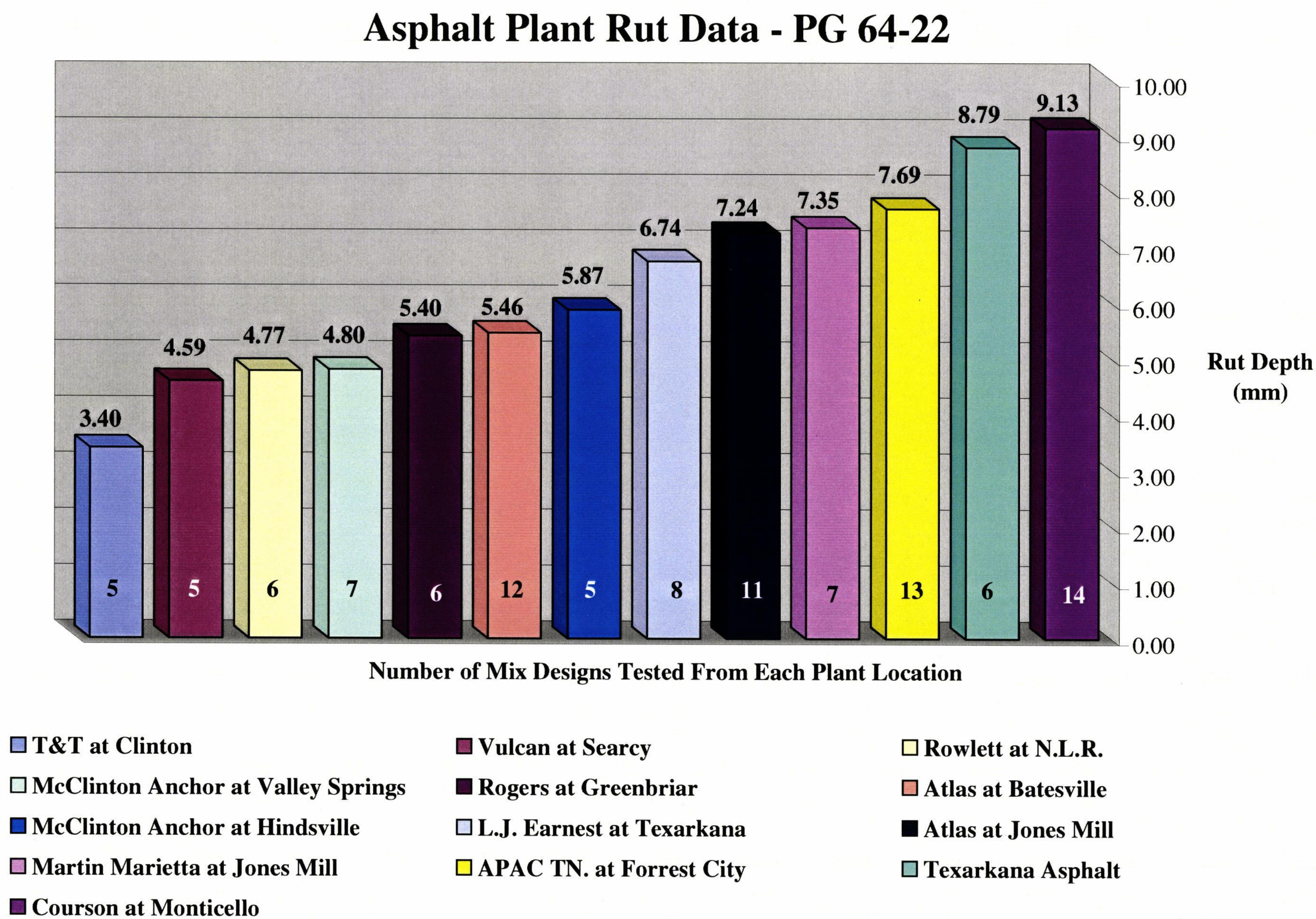
Supplemental Specification SS-400-1

Job Mix Through Restricted Zone Asphalt Pavement Analyzer

(8,000 cycles, 100 lbs. Load, 100 psi, 64°C)

Design Gyration	Max. Rut
75 & 115	8 mm
160	5 mm
205	3 mm

Fi 7



Asphalt Plant Rut Data - PG 64-22
3.40
4.59
4.77
4.80
5.40
5.46
5.87
6.74
7.24
7.35
7.69
8.79
9.13
5
5
6
7
6
12
5
8
11
7
13
6
14
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Rut Depth (mm)
Number of Mix Designs Tested From Each Plant Location
T&T at Clinton
Vulcan at Searcy
Rowlett at N.L.R.
McClinton Anchor at Valley Springs
Rogers at Greenbriar
Atlas at Batesville
McClinton Anchor at Hindsville
L.J. Earnest at Texarkana
Atlas at Jones Mill
Martin Marietta at Jones Mill
APAC TN. at Forrest City
Texarkana Asphalt
Courson at Monticello

Fi 8

Asphalt Plant Rut Data - PG 70-22

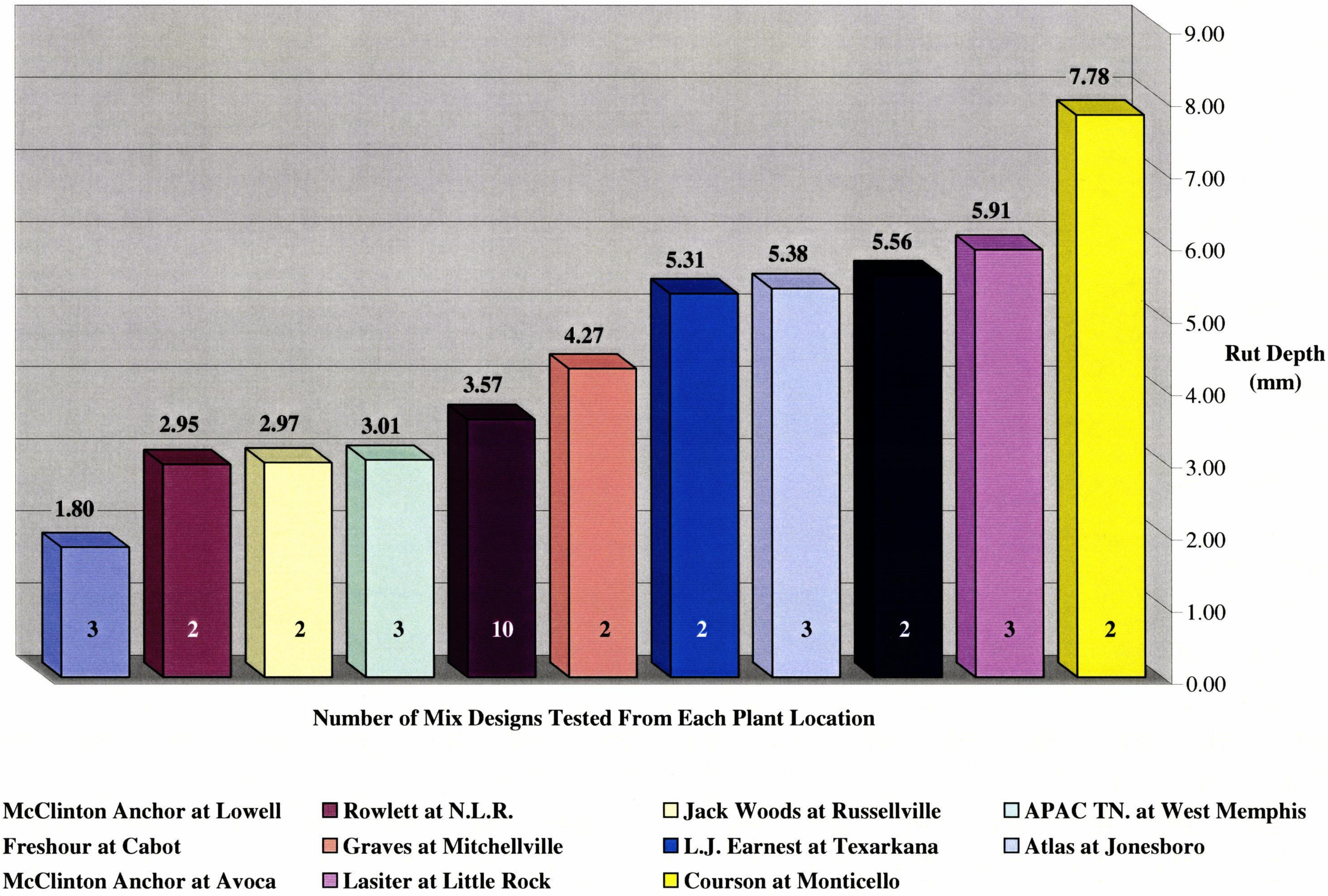


Figure 9

Asphalt Plant Rut Data - PG 76-22

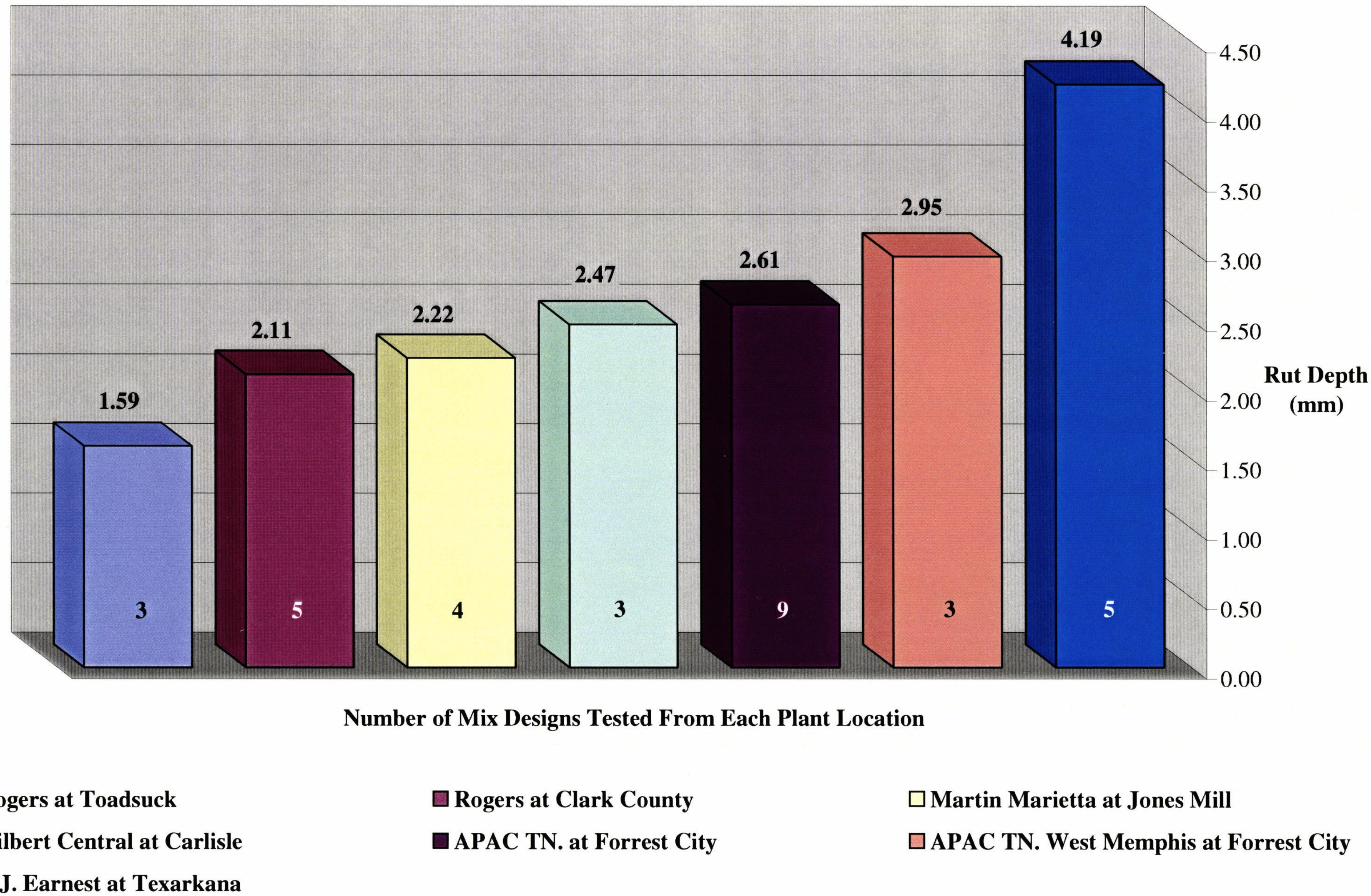


Fig 10

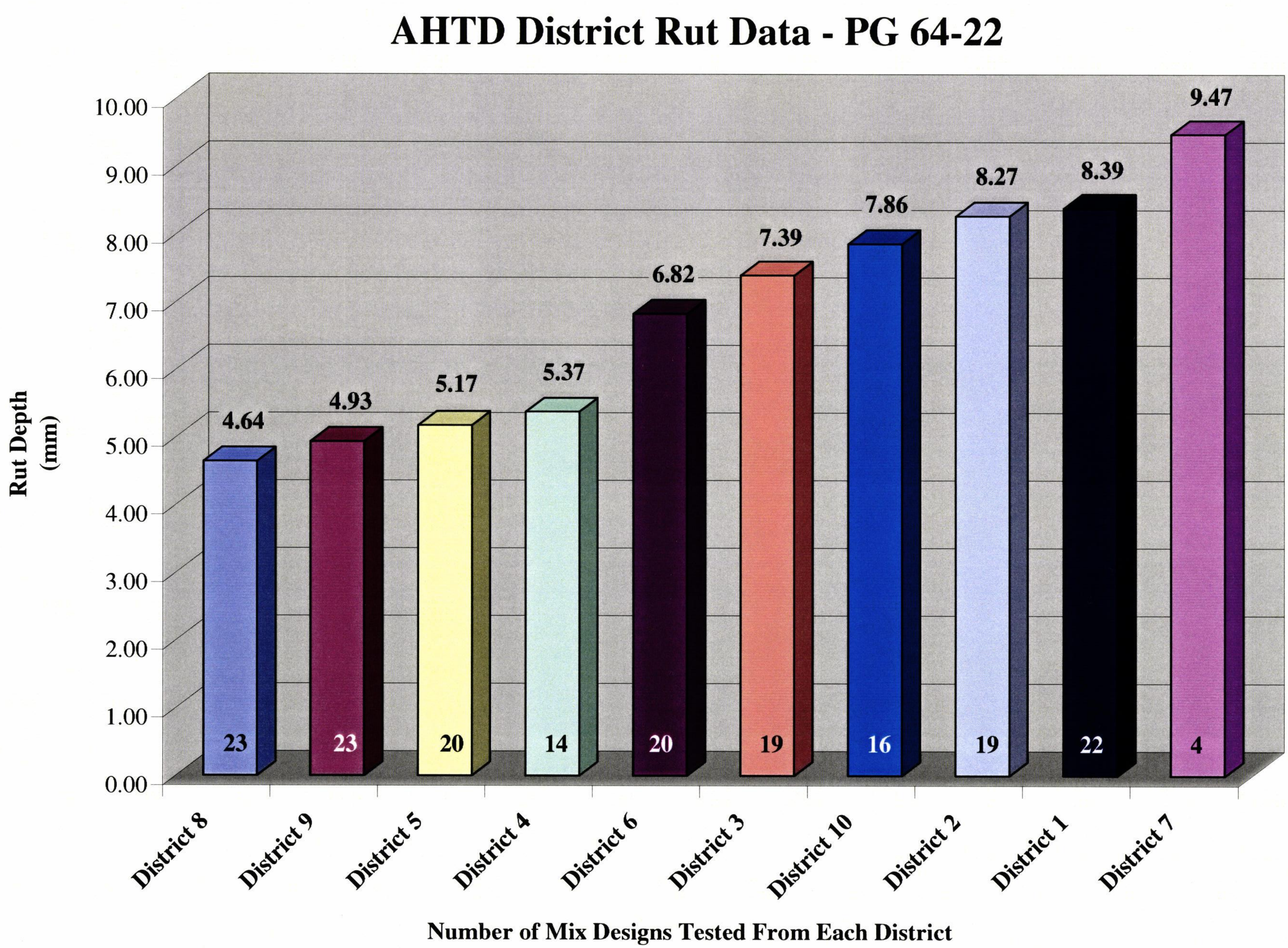

AHTD District Rut Data - PG 64-22
Rut Depth (mm)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4.64
4.93
5.17
5.37
6.82
7.39
7.86
8.27
8.39
9.47
23
23
20
14
20
19
16
19
22
4
District 8
District 9
District 5
District 4
District 6
District 3
District 10
District 2
District 1
District 7
Number of Mix Designs Tested From Each District

Fig 11

AHTD District Rut Data - PG 70-22

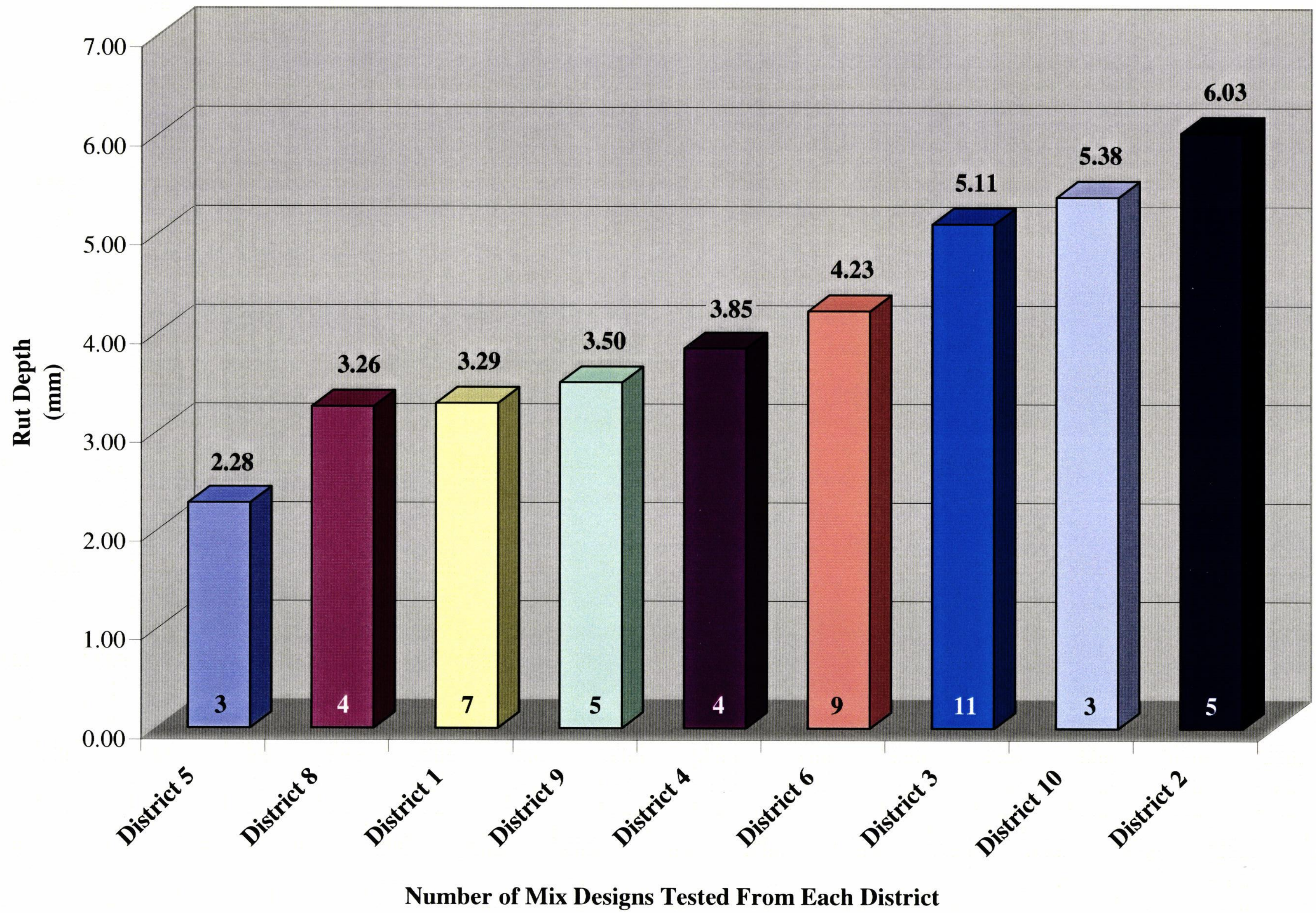


Fig 12

AHTD District Rut Data - PG 76-22

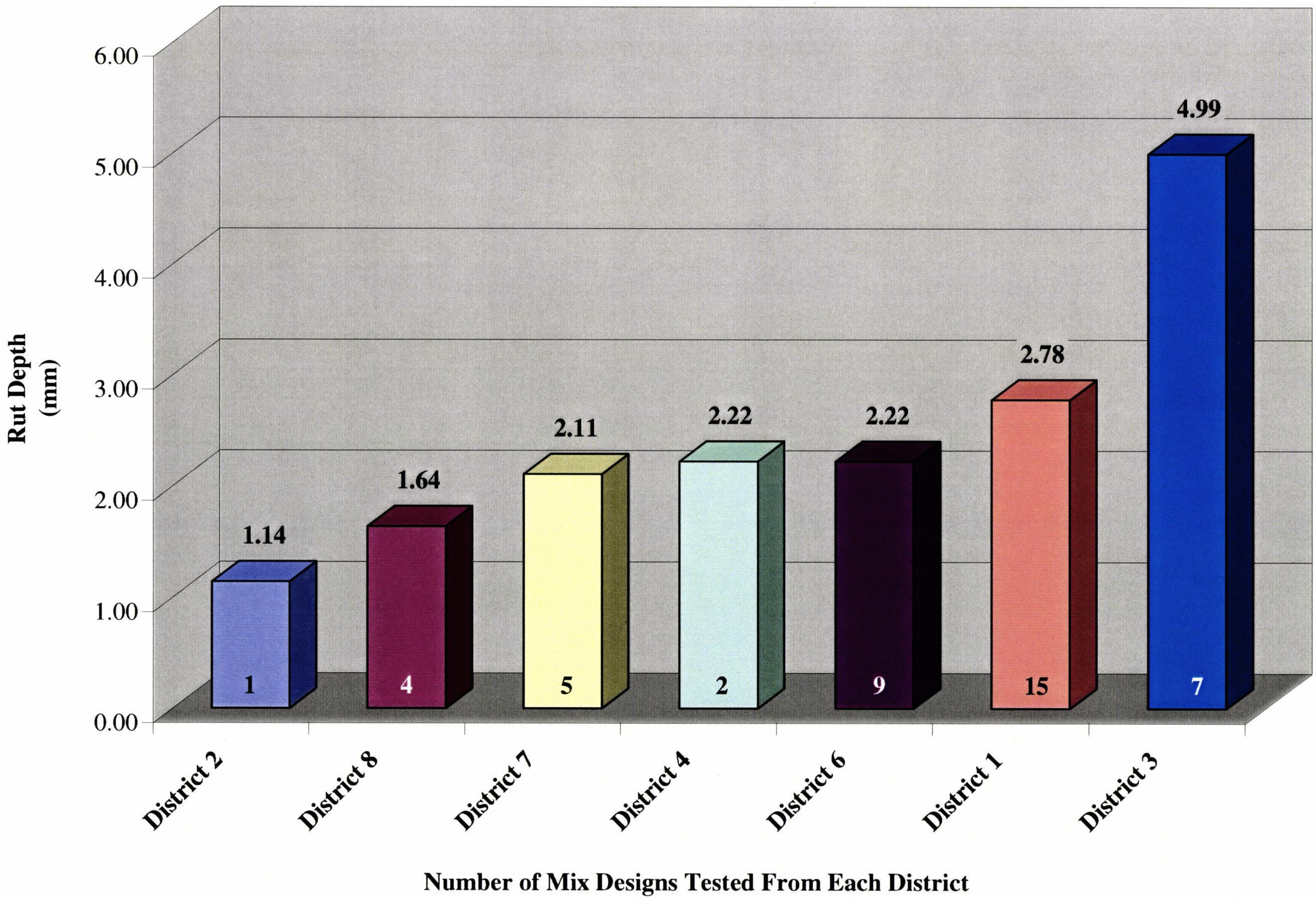
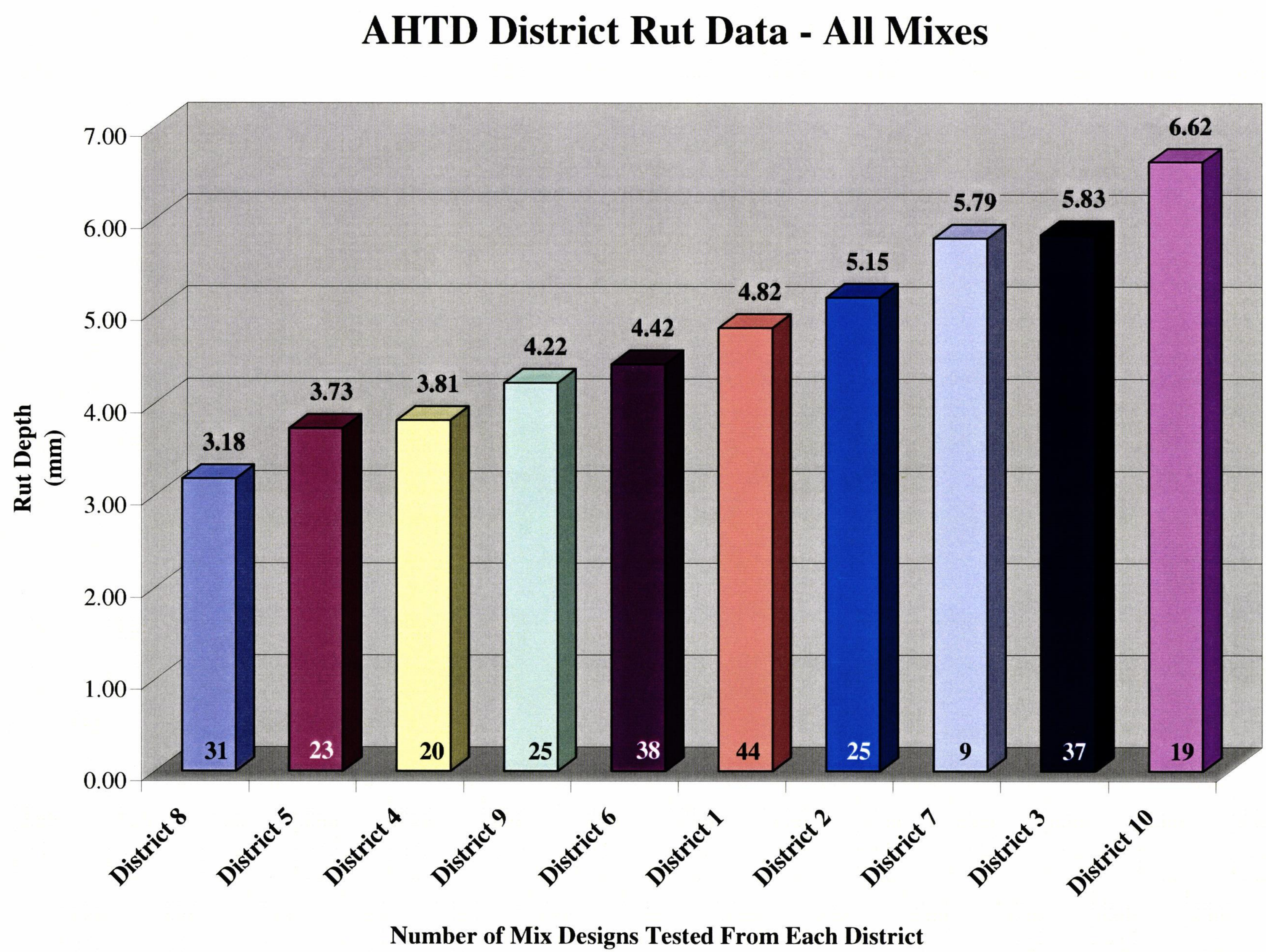
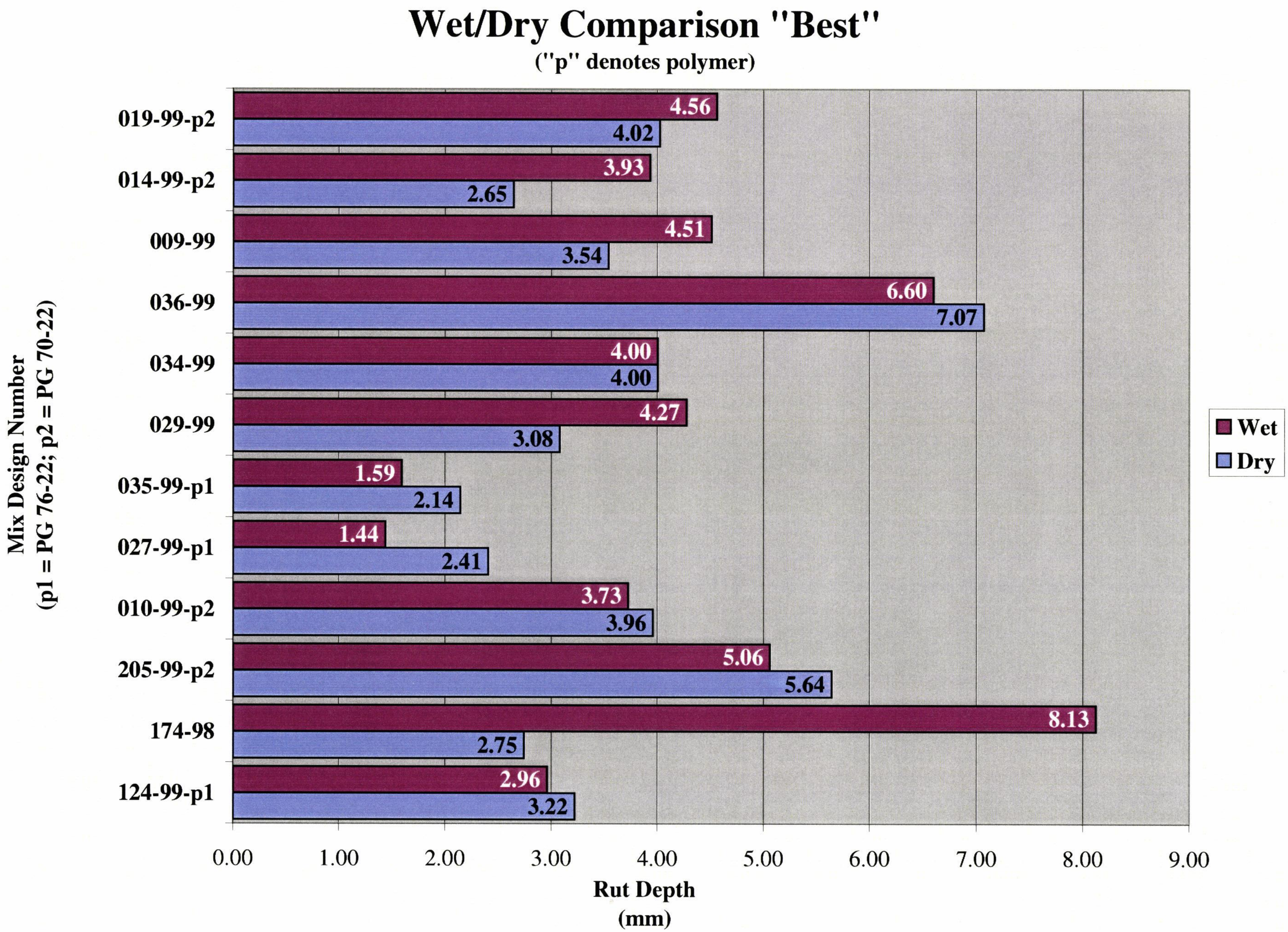


Fig. 13


AHTD District Rut Data - All Mixes
Rut Depth (mm)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
3.18
3.73
3.81
4.22
4.42
4.82
5.15
5.79
5.83
6.62
31
23
20
25
38
44
25
9
37
19
District 8
District 5
District 4
District 9
District 6
District 1
District 2
District 7
District 3
District 10
Number of Mix Designs Tested From Each District

Fi 14

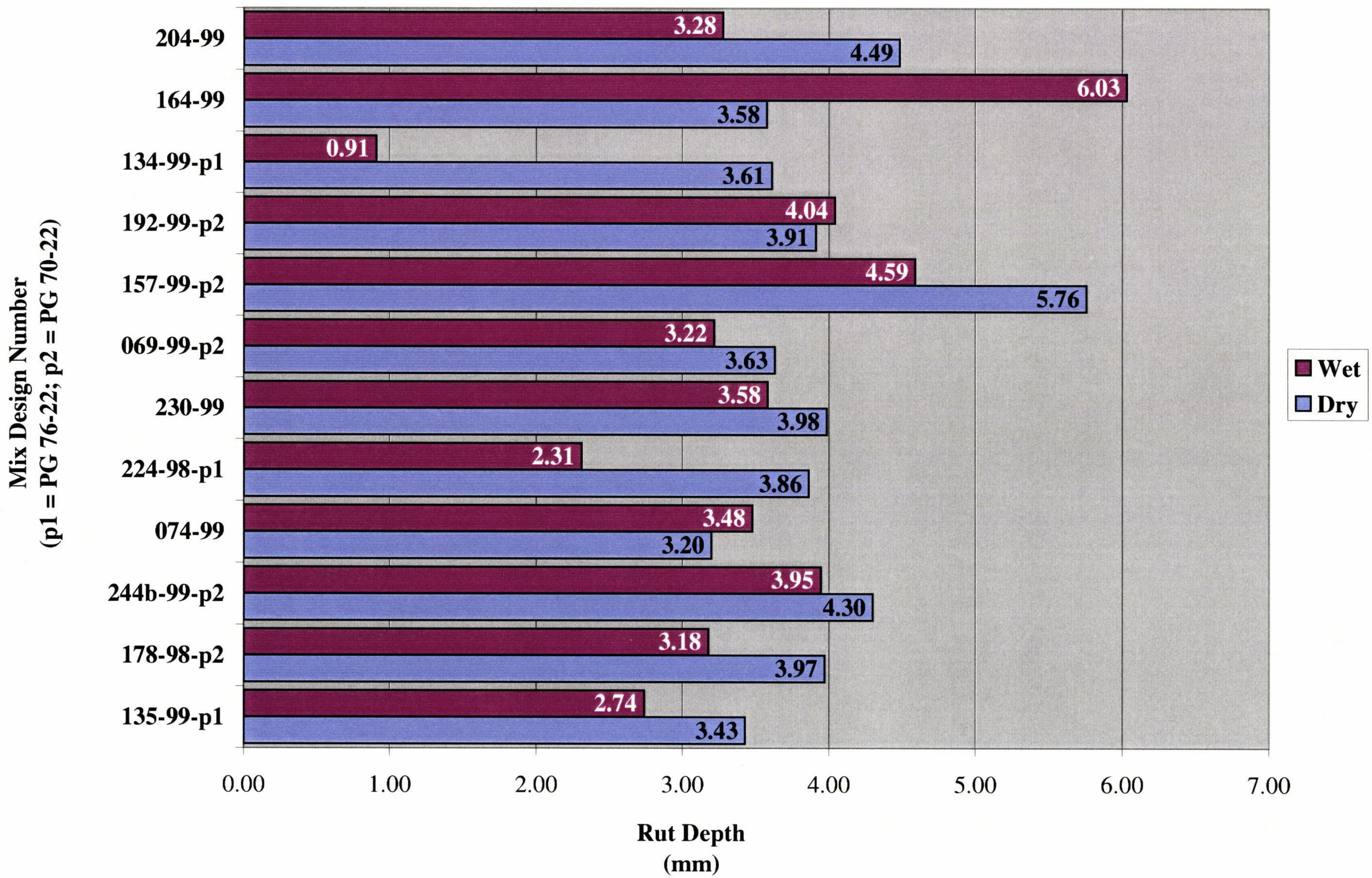


Wet/Dry Comparison "Best"
("p" denotes polymer)
019-99-p2
014-99-p2
009-99
036-99
034-99
029-99
035-99-p1
027-99-p1
010-99-p2
205-99-p2
174-98
124-99-p1
4.56
4.02
3.93
2.65
4.51
3.54
6.60
7.07
4.00
4.00
4.27
3.08
1.59
2.14
1.44
2.41
3.73
3.96
5.06
5.64
8.13
2.75
2.96
3.22
Mix Design Number
(p1 = PG 76-22; p2 = PG 70-22)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
Rut Depth
(mm)
Wet
Dry

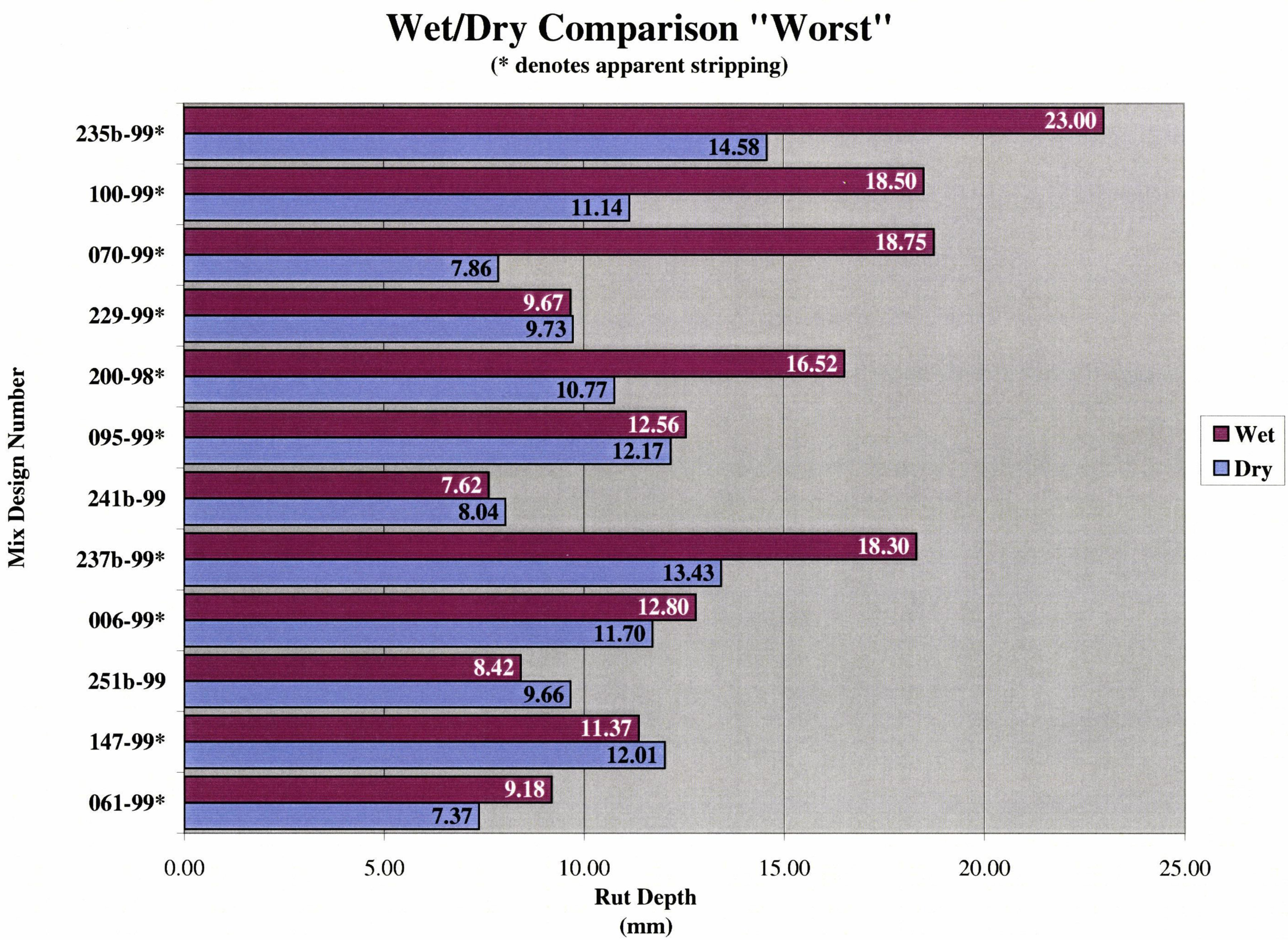
Fi[illegible] 15

Wet/Dry Comparison "Best"

("p" denotes polymer)



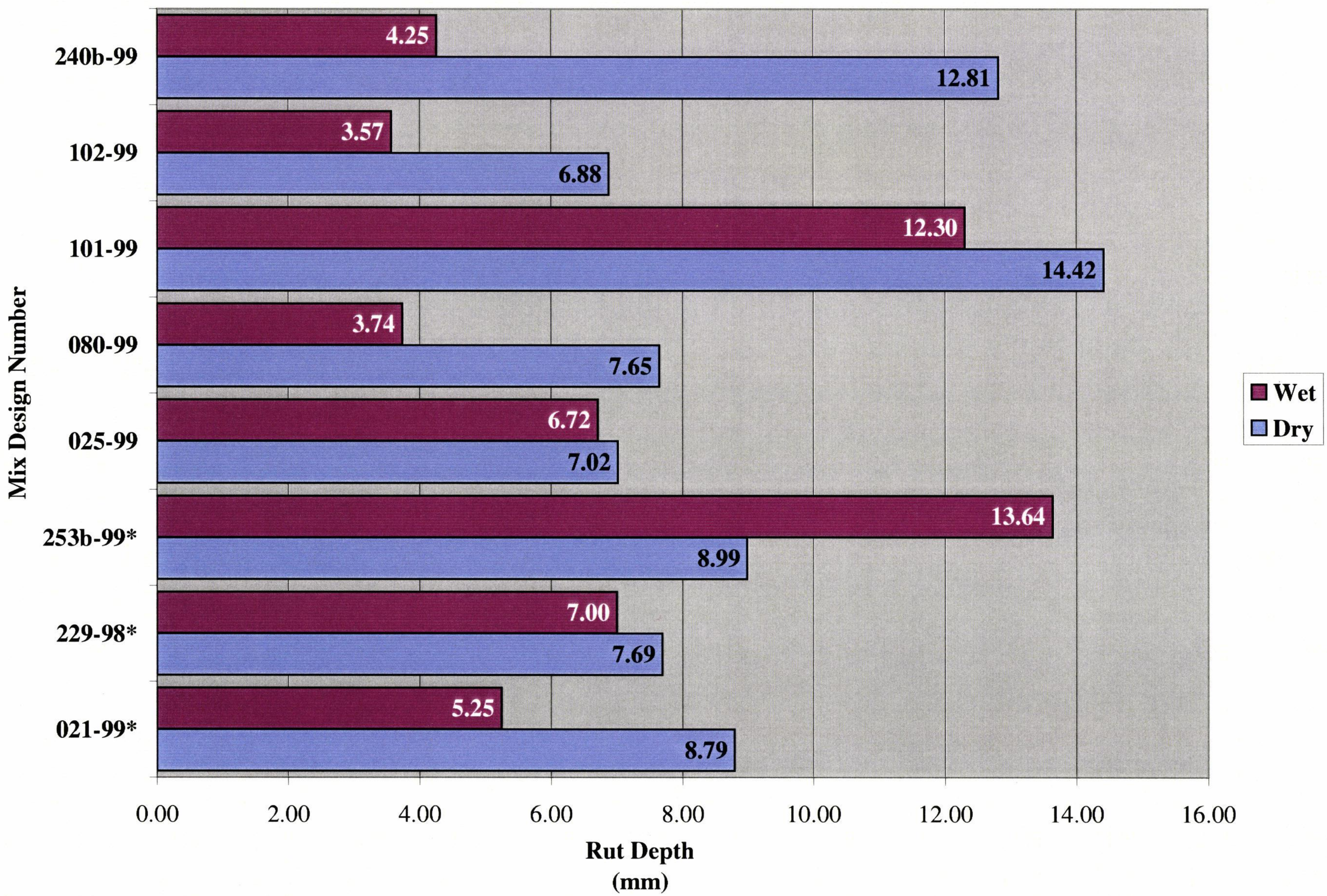
Fi 16


Wet/Dry Comparison "Worst"
(* denotes apparent stripping)
235b-99*
100-99*
070-99*
229-99*
200-98*
095-99*
241b-99
237b-99*
006-99*
251b-99
147-99*
061-99*
23.00
14.58
18.50
11.14
18.75
7.86
9.67
9.73
16.52
10.77
12.56
12.17
7.62
8.04
18.30
13.43
12.80
11.70
8.42
9.66
11.37
12.01
9.18
7.37
0.00
5.00
10.00
15.00
20.00
25.00
Rut Depth
(mm)
Mix Design Number
Wet
Dry

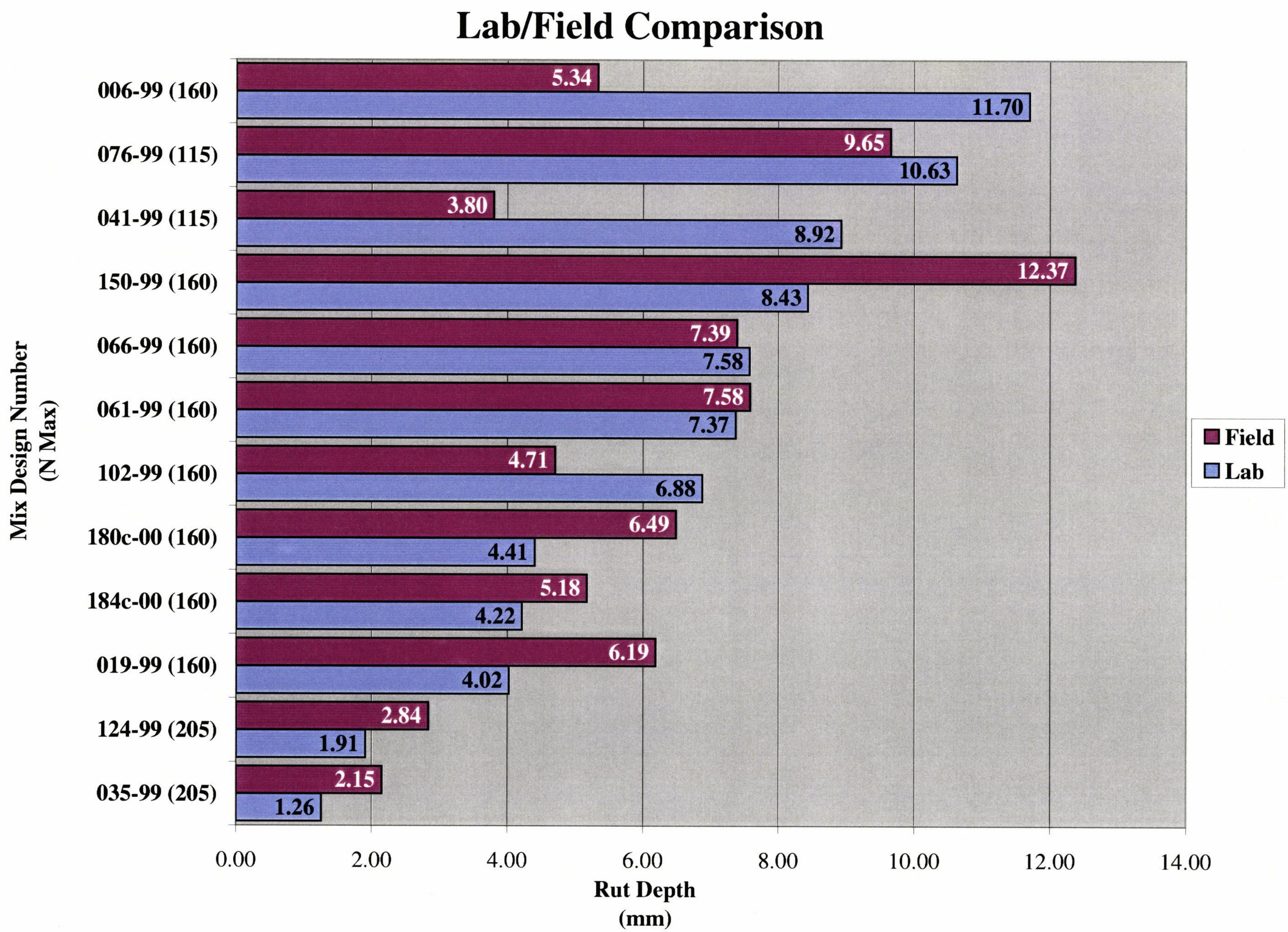
Fi 17

Wet/Dry Comparison "Worst"

(* denotes apparent stripping)



Fi 18


Lab/Field Comparison
Mix Design Number
(N Max)
006-99 (160)
076-99 (115)
041-99 (115)
150-99 (160)
066-99 (160)
061-99 (160)
102-99 (160)
180c-00 (160)
184c-00 (160)
019-99 (160)
124-99 (205)
035-99 (205)
5.34
11.70
9.65
10.63
3.80
8.92
12.37
8.43
7.39
7.58
7.58
7.37
4.71
6.88
6.49
4.41
5.18
4.22
6.19
4.02
2.84
1.91
2.15
1.26
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
Rut Depth
(mm)
Field
Lab