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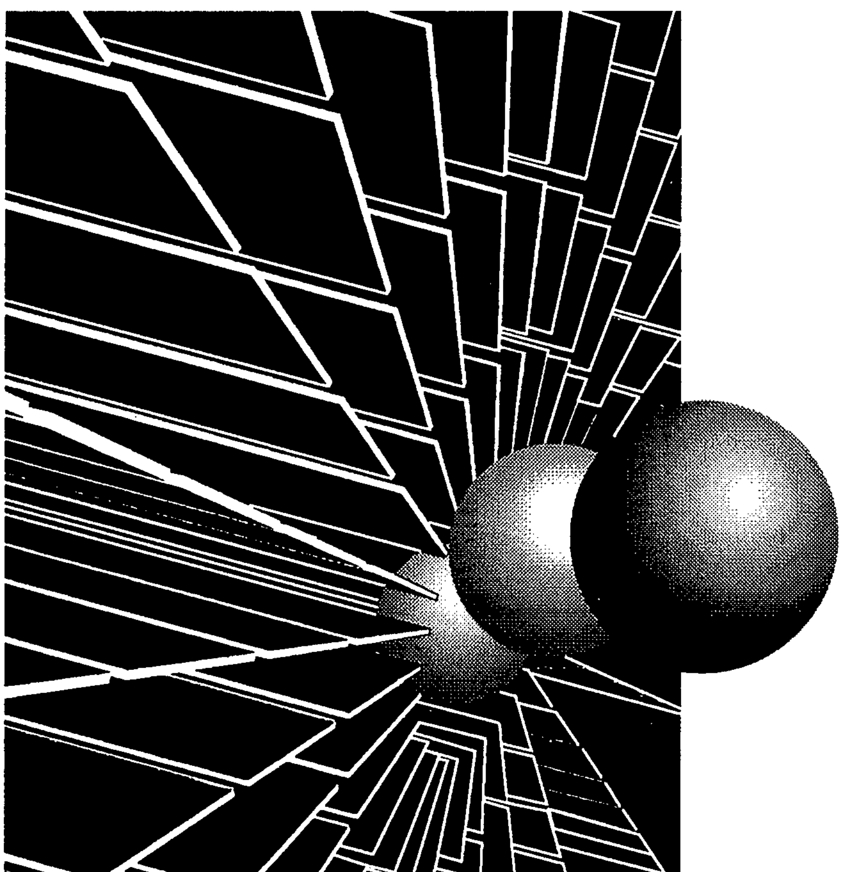
Research, Development and Technology Division

RDT 98-001

Rutting Susceptibility of Bituminous Mixtures by the Georgia Loaded Wheel Tester

Final Report



May, 1998

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15. Supplementary Notes

The investigation was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16. Abstract

The investigation was conducted with using a Georgia Loaded Wheel Tester (LWT) on bituminous mixes which used materials that are native to Missouri. The investigation was used to ascertain the rutting characteristics of bituminous mixes, which Missouri Department of Transportation (MoDOT) uses for high traffic volume routes. Included in these bituminous mixes were the new Superpave mixes. This investigation was also conducted so as to determine if the LWT can be used as a laboratory proof tester of bituminous mixes. This will allow the rejection and redesign of bituminous mixtures which display excessive rutting in the laboratory.

The answer to whether the Georgia Loaded Wheel Tester (LWT) can be used as a laboratory proof tester of bituminous mixes, is yes. Since almost all of the rutting analysis on the mix design properties and combined aggregate properties indicated text book behavior, it can be concluded that this correlation substantiates that the LWT can be used in the laboratory as a proof tester for rutting.

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RDT

Brief

Product Development 96-004 June, 1998

Scrub Seal Treatment

Description:

In 1996, the Missouri Department of Transportation (MoDOT) installed its first scrub seal product. The scrub seal is a process by which an anionic charged polymer modified asphalt agent is applied to an asphalt pavement surface. This asphalt agent rejuvenates the old asphalt surface and is scrubbed into the cracks and voids with a broom before a layer of small aggregate is applied over the asphalt. The aggregate and asphalt is again broomed forcing the mix into the cracks and voids to form a seal. The seal is then rolled with a pneumatic tire roller. Scrub seal is meant to be used as pavement preventive maintenance. Its primary purpose is to fill cracks and seal the asphalt pavement.

Advantages/Disadvantages:

One advantage of scrub seal is the cost. Scrub seal is less expensive per mile than three other processes currently used in Missouri. The other three processes are 1" hot mix overlay, chip seal, and microsurfacing. Other advantages are that it arrests light deterioration, retards progressive failures, and reduces the need for routine maintenance service activities. Field comments concerning the seal are very positive. It's inexpensive, seals the cracks quickly, can be opened to traffic in about 2 hours and basically maintenance free except for some possible crack sealing. Even when the scrub seal becomes removed from the old pavement, it appears the old pavement cracks are still sealed with the scrub seal.

The disadvantage of the scrub seal treatment is that it is limited to pavements in sound condition. This process is not intended to improve the structural condition of the pavement. Therefore, the seal should only be used on stable asphalt pavements that are dry, oxidized and cracked.

Cost:

A cost analysis has been calculated for the scrub seal and compared to 1" hot mix overlay, chip seal and microsurfacing.

- For 1" hot mix overlay, the estimated life is 4 to 10 years. By assuming a 7 year life and a cost of $20,000 per mile, this equates to an annual cost of $2850.
- For chip seal, the estimated life is 4 to 10 years. Assuming a 7 year life and a cost of $19,000 per mile, this equates to an annual cost of $2714.
- For microsurfacing, the estimated life is 4 to 10 years. Assuming a 7 year life and a cost of $24,000 per mile, this equates to an annual cost of $3428.

Research Development and Technology Division

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- For scrub seal, the estimated life is 4 years and a cost of $3000. This equates to an annual cost of $750.

Conclusions:

The condition of an asphalt pavement to become an ideal candidate for the scrub seal is dry, oxidized and cracked. The scrub seal is not intended to fill ruts or to have sufficient thickness to add stability to a pavement. Its prime purpose is to fill the cracks and seal the pavement. Although the scrub seal's purpose is not to improve friction of the pavement, friction values were good following the application. The only exception was the scrub seal in St. Louis where there was a high ADT and the scrub seal has worn extensively. It has been determined that the scrub seal should be limited to areas with an ADT of 7500 or less. At $3000 per mile, this is a good maintenance tool to be used as pavement preventive maintenance. This is a low cost seal and will allow the maintenance division to direct some of their budget toward other needs.

Initial report and specifications will be available August, 1998.

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Please refer to report number 96-004.

FIELD OFFICE INVESTIGATION F.O. 95-06
SPR STUDY NO. SPR 96-03

Rutting Susceptibility of Bituminous Mixtures by the Georgia Loaded Wheel Tester

PREPARED BY
MISSOURI DEPARTMENT OF TRANSPORTATION

Written By: Ronald L. Netemeyer, P.E.

JEFFERSON CITY, MISSOURI
DATE SUBMITTED:
MAY 1, 1998

EXECUTIVE SUMMARY

The objectives of the study were met. The answer to whether the Georgia Loaded Wheel Tester (LWT) can be used as a laboratory proof tester of bituminous mixes, is yes. Since almost all of the rutting analysis on the mix design properties and combined aggregate properties indicated text book behavior, it can be concluded that this correlation substantiates that the LWT can be used in the laboratory as a proof tester for rutting.

In the analysis of rut depth verses asphalt cement characteristics, two asphalt cement characteristics were selected. The specific gravity at 15.6° C was selected because as the specific gravity of an asphalt cement increases there is usually a corresponding increase in viscosity. This in turn means a stiffer asphalt cement, and a stiffer asphalt cement should resist rutting. And, the G*/sin delta was selected because it represents both the viscous and elastic behavior of the asphalt cement. From all of the analysis in this study, the G*/sin delta value proved to be substantial when selecting an asphalt cement to resist rutting. As the G*/sin delta value increased the potential for rutting decreased. This correlates with a research project conducted by the Transportation Research Board. The research study concluded that as G*/sin delta increases, rut depths decrease. ***(1)***

From the analysis of all the Marshall mix designs, dense graded mixes and SMA, the Marshall stability results proved to be a substantial indicator for rutting potential. As the stability of a mix increased, the potential for rutting decreased.

From the analysis of the dense graded Marshall mix designs and the Superpave mix designs, as the percent passing the #50 sieve and #100 sieve material increased, the potential for rutting decreased. This was prevalent in the dense graded Marshall surface mixes, the dense graded Marshall binder mixes, and to the Superpave mixes. With one exception, the correlation was not present in the percent passing the #100 sieve for the Superpave mixes. This correlates with a research project conducted by the Georgia Institute of Technology. The research project concluded that as the percent of material passing the #50 and #100 sieves increase, the rut depth potential decreases. (3*)*

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
A.C.	Asphalt Cement
ESAL	Equivalent Single Axle Load
F.O.	Field Office
GDT-115	Georgia Department of Transportation Test Method 115
G*/Sin Delta	Complex Shear Modulus (G*)/Sin of the Phase Angle (Delta). Asphalt Cement Characteristic of the Viscous and Elastic Behavior
LP	Limestone and Porphyry Asphalt Concrete Mix
LWT	Loaded Wheel Tester
MoDOT	Missouri Department of Transportation
Pb	Percent asphalt cement content by total weight of mix
PG	Performance Graded
SHRP	Strategic Highway Research Program
SMA	Stone Mastic Asphalt
SPR	State Planning and Research
Va	Air voids
VFA	Voids Filled with Asphalt
VMA	Voids in Mineral Aggregate

ABSTRACT

The investigation was conducted with using a Georgia Loaded Wheel Tester (LWT) on bituminous mixes which used materials that are native to Missouri. The investigation was used to ascertain the rutting characteristics of bituminous mixes, which Missouri Department of Transportation (MoDOT) uses for high traffic volume routes. Included in these bituminous mixes were the new Superpave mixes. This investigation was also conducted so as to determine if the LWT can be used as a laboratory proof tester of bituminous mixes. This will allow the rejection and redesign of bituminous mixtures which display excessive rutting in the laboratory.

The answer to whether the Georgia Loaded Wheel Tester (LWT) can be used as a laboratory proof tester of bituminous mixes, is yes. Since almost all of the rutting analysis on the mix design properties and combined aggregate properties indicated text book behavior, it can be concluded that this correlation substantiates that the LWT can be used in the laboratory as a proof tester for rutting.

OBJECTIVE

The objective of this study was to determine if the LWT can be used as a laboratory proof tester of bituminous mixes. If so, this will allow the rejection and re-design of bituminous mixtures which display excessive rutting in the laboratory.

Inclusive to this objective was the analysis of rut depth versus mix design properties, rut depth versus combined aggregate properties, and rut depth verses asphalt cement characteristics. The mix design properties included Voids in Mineral Aggregate (VMA), Air Voids (Va), Voids Filled with Asphalt (VFA), percent asphalt content by total weight of mixture (Pb), stability, and flow values. The combined aggregate properties included the percent of natural sand and the amount of material passing the # 50 and # 100 sieves. The asphalt cement characteristics included the specific gravity at 15.6° C and the G*/sin delta at 64° C.

Inclusive to this objective is an attempt to correlate laboratory rut depth measurements to actual rut depths occurring in the field. This is being attempted by knowing the laboratory rutting characteristics of a particular mix by a regression equation which equates rut depth to loading cycles of the test. Actual rut depths in the field will be recorded on an annual basis for a period of three years. By knowing the date on which the pavement was set into service, and the daily design ESAL's of the project, the field measured rut depths could possibly be correlated to the number of ESAL's and therefore possibly to the laboratory rut depths. Two dense graded surface mixes, two SMA surface mixes, and two Superpave surface mixes will be selected to be monitored for the three year period.

INTRODUCTION

Laboratory rut testing of bituminous mixes continues to gain merit as a means of proof testing mixes for excessive rutting. Several devices, and their corresponding test methods, are available for use as laboratory testers for excessive rutting of bituminous mixes. Some of these devices are the French Pavement Rutting Tester, the Hamburg Wheel-Tracking Device, and the Georgia Loaded Wheel Tester.

The French Pavement Rutting Tester employs a 60° C temperature and 30,000 cycles in its test method. The Hamburg Wheel Tracking Device employs a 50° C temperature and 20,000 cycles in it's test method. It also tests the mixture under water so as to check for the stripping potential of the mix. The Georgia Loaded Wheel Tester employs a 40° C temperature and 8,000 cycles in it's test method. ***(1)***

From cost comparisons of the three devices, the Georgia Loaded Wheel Tester was opted to be the device which MoDOT would purchase and investigate for use as a bituminous mix proof tester for excessive rutting. The following is a brief summary of the investigation procedure. The detailed procedure is within the context of this report.

The 75 blow Marshall mix designs on MoDOT's dense graded mixtures and the 50 blow Marshall mix designs on MoDOT's Stone Matrix Asphalt (SMA) mixtures were compacted by the Georgia Rolling Wheel Compactor and analyzed in the Georgia LWT. MoDOT's Superpave mixes were compacted in the SHRP Gyratory Compactor and analyzed in the Georgia LWT. The Georgia test method GDT-115 was used as the test method, with the following modifications. The dense graded and SMA mixes were not only tested at the prescribed 40° C but also at 60° C. According to SHRP's Superpave pavement temperature model, pavement temperatures are approximately 30° C to 35° C above the air temperature on hot summer days. Therefore the pavement temperatures would be in the ranges of 60° C to 70° C or higher, which are much higher than the prescribed LWT testing. ***(2)***

The Superpave mix designs were subjected to a more severe test. The compacted specimens were first vacuum saturated with water, followed by one freeze thaw cycle, and then a warm water soaking cycle. This was accomplished by following the applicable steps of the AASHTO T-283 test method for conditioning of a sample. These specimens were then tested in the LWT at 60° C and 20,000 cycles. This procedure was set up to analyze both rutting potential and stripping potential of the mix. This was in an attempt to approximate parts of the Hamburg Wheel Tracking Device test method and analysis. The data analysis of the rutting was checked for post compaction consolidation, creep and stripping slopes, and the stripping inflection point.

INVESTIGATION PROCEDURE AND RESULTS

From reviewing past research on the subject matter, a decision was made to conduct a research study on the LWT. A plan was then formulated on how to conduct the research study. The investigation procedure included the testing of dense graded, SMA, and Superpave mixes which MoDOT currently uses for high traffic volume routes.

The Marshall mix design procedure, AASHTO T-245, does not include a two hour aging of the mixture before compaction of the specimens. But since the advent of Superpave mix design, which does employ a two hour aging of the mixture before the compaction of it's specimens, MoDOT incorporated the two hour aging procedure into it's Marshall mix design method. Therefore, the stability results that you will see in this study are higher than what would be expected from a Marshall mix which does not use the two hour aging.

The dense graded mixes were designed by the 75 blow Marshall mix design procedure. These mixes included the MoDOT designated mix types of I-C, I-B, and LP. The I-C mix is a dense graded surface mix with 100% of the aggregate passing the 3/4" sieve. It is allowed a maximum of 15% natural sand and requires 1% hydrated lime as an anti-strip agent. The I-B mix is a dense graded binder course mix with 100% of the aggregate passing the 1" sieve. It is allowed a maximum of 15% natural sand and requires 1% hydrated lime as an anti-strip agent. The LP mix is a dense graded surface mix with 100% of the aggregate passing the 3/4" sieve. LP stands for Limestone and Porphyry (LP), this mix is composed of approximately a 50/50 blend of the two components. This mix does allow natural sand, but specification compliance for the required amount of porphyry will therefore restrict the natural sand to approximately 10%. The LP mix also requires 1% hydrated lime as an anti-strip agent.

Thirty three I-C mixes, thirteen I-B mixes, and seven LP mixes were tested in the research study. These mixes were accumulated from the 1997 construction season and contained aggregates from throughout the state. Analysis of these mixes included the comparison of rut depth versus mix design properties, rut depth versus combined aggregate properties, and rut depth verses asphalt cement characteristics. The mix design properties included Voids in Mineral Aggregate (VMA), Air Voids (Va), Voids Filled with Asphalt (VFA), percent asphalt content by total weight of mixture (Pb), stability and flow values. The combined aggregate properties included the percent of natural sand and the amount of material passing the # 50 and # 100 sieves. The asphalt cement characteristics included the specific gravity at 15.6° C and the G*/sin delta at 64° C.

The SMA mixes were designed by a 50 blow Marshall mix design procedure. The SMA mix is a coarse gap graded mix with high asphalt cement contents and with 100% of the aggregate passing the 3/4" sieve. Nine SMA mixes were tested in the research study. The SMA mixes were predominantly used in the metropolitan areas of St. Louis and Kansas City, therefore the type of aggregates used in these mixes are somewhat restricted by these geographical locations. These mixes were also accumulated from the 1997 construction season. Analysis of these mixes were the same as the dense graded mixes. Except, that the analysis of the combined aggregate properties were excluded because they were not applicable to SMA mixes..

The Superpave mixes were designed by the SHRP Superpave mix design method. These mixes met all of the requirements of the mix design methodology. Approximately fourteen Superpave mixes were tested in the research study. Analysis of these mixes were the same as for the other dense graded mixes.

The 75 blow Marshall mix designs on dense graded mixtures and the 50 blow Marshall mix designs on the SMA mixtures were compacted by the Georgia Rolling Wheel Compactor and analyzed in the Georgia LWT. The Superpave mixes were compacted in the SHRP Gyratory Compactor and analyzed in the Georgia LWT. The Georgia test method GDT-115 was used as the test method, with the following modifications. The dense graded and SMA mixes were not only tested at the prescribed 40° C but also at 60° C. According to SHRP's Superpave pavement temperature model, pavement temperatures are approximately 30° C to 35° C above the air temperature on hot summer days. Therefore the pavement temperatures would be in the ranges of 60° C to 70° C or higher, which are much higher than the prescribed LWT testing. *(2)*

The Superpave mix designs were subjected to a more severe test. The compacted specimens were first vacuum saturated with water, followed by one freeze thaw cycle, and then a warm water soaking cycle. This was accomplished by following the applicable steps of the AASHTO T-283 test method for conditioning of a sample. These specimens were then tested in the LWT at 60° C and 20,000 cycles. This procedure was set up to analyze both rutting potential and stripping potential of the mix. This was in an attempt to approximate parts of the Hamburg Wheel Tracking Device test method and analysis. The data analysis of the rutting was checked for post compaction consolidation, creep and stripping slopes, and the stripping inflection point.

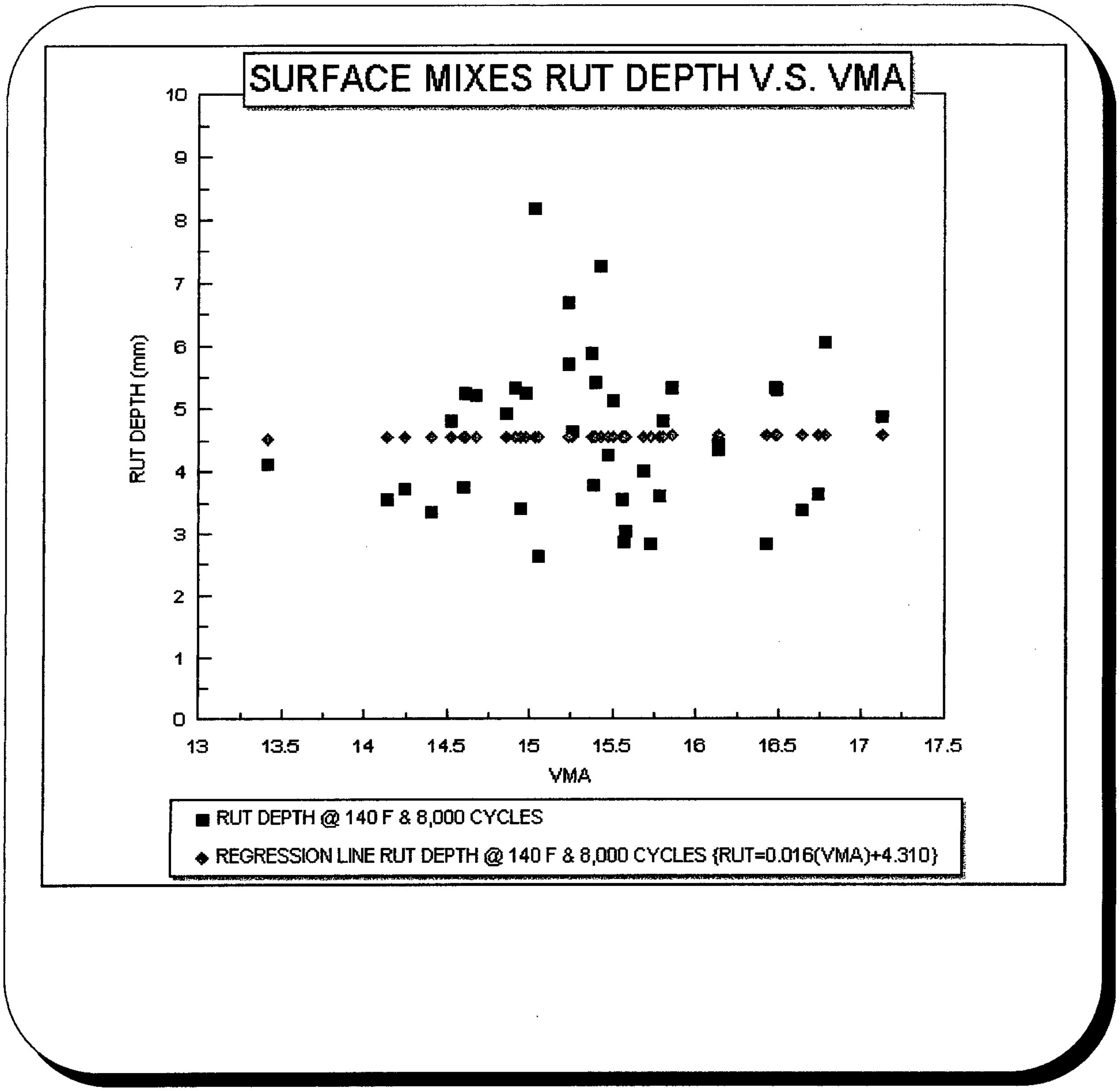
Further analysis, on all of the mixes used in the study, included rut depth versus the number of Loaded Wheel cycles. This was in an attempt to correlate laboratory rut depth and number of loaded wheel cycles to actual rut depth data from the in place mixtures in the field.

On the following pages are graphs and commentary depicting the result of the study. The first set of information will be the results on the testing of the dense graded 75 blow Marshall surface mixes (I-C & LP mixes). Although rut testing was performed at 40° C and 60° C, only the 60° C results will be depicted graphically in the study. Appendix (A) contains a tabulation of all the results for all of the mixes which were used in the study.

1) DENSE GRADED 75 BLOW MARSHALL SURFACE MIX RESULTS

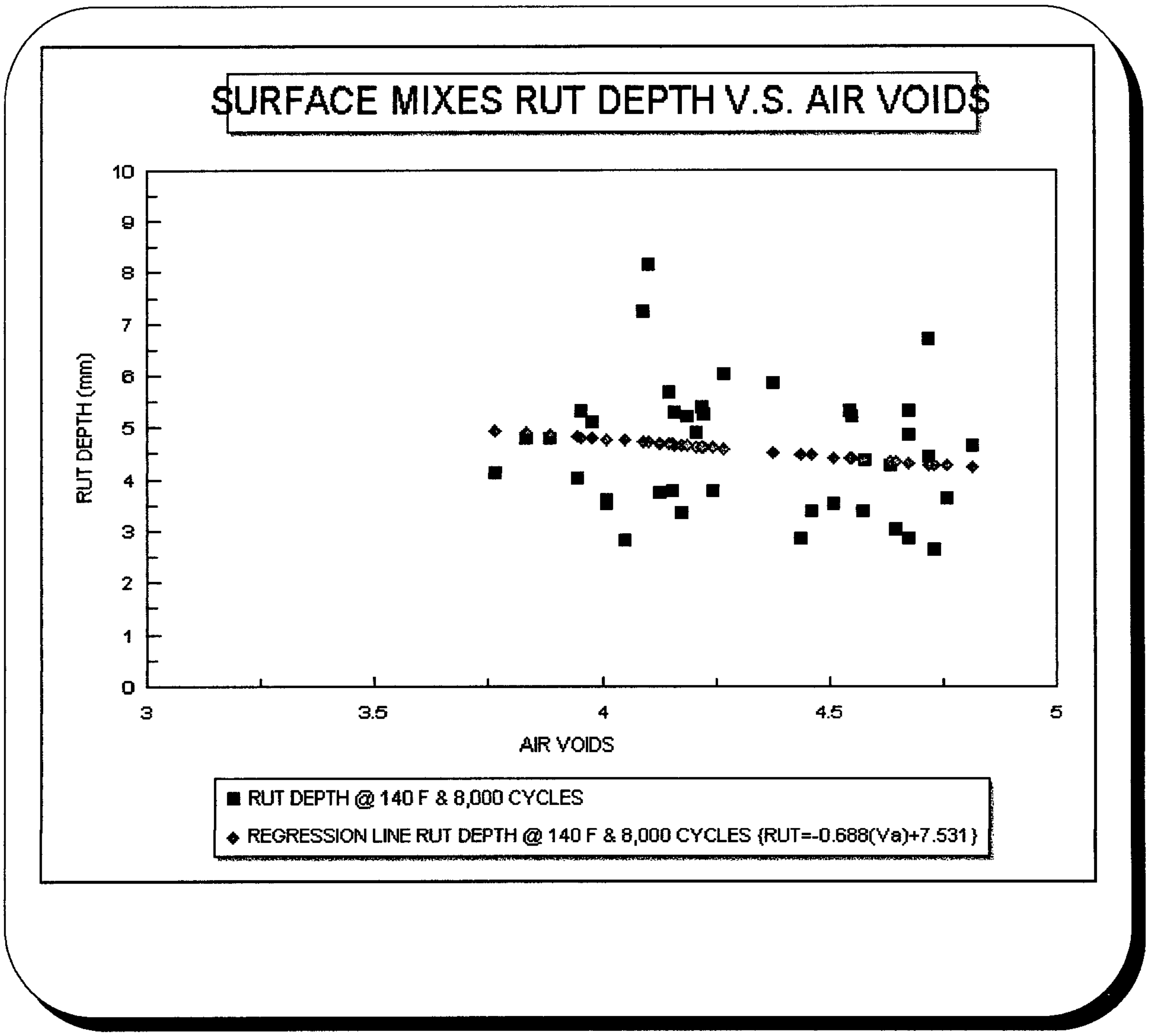
A) RUT DEPTH V.S. MIX DESIGN PROPERTIES

Graph No. 1 - VMA



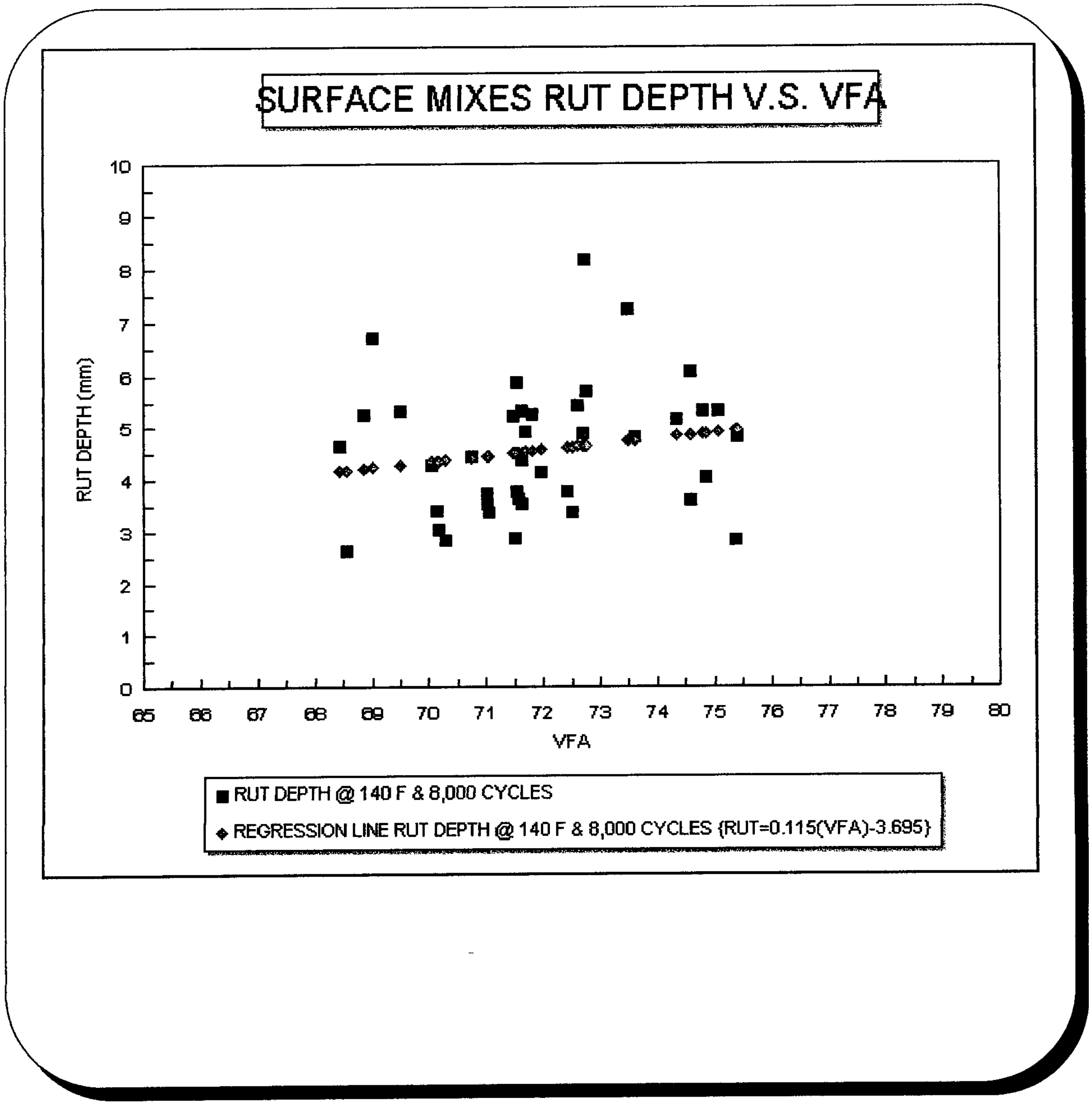
The graph above depicts rut depth versus VMA for dense graded surface mixes which allow up to 15% natural sand. From the regression line, it can be seen that rut depth is all but constant throughout the range of VMA. Rut depth slightly increases with the increase of VMA.

Graph No. 2 - Air Voids



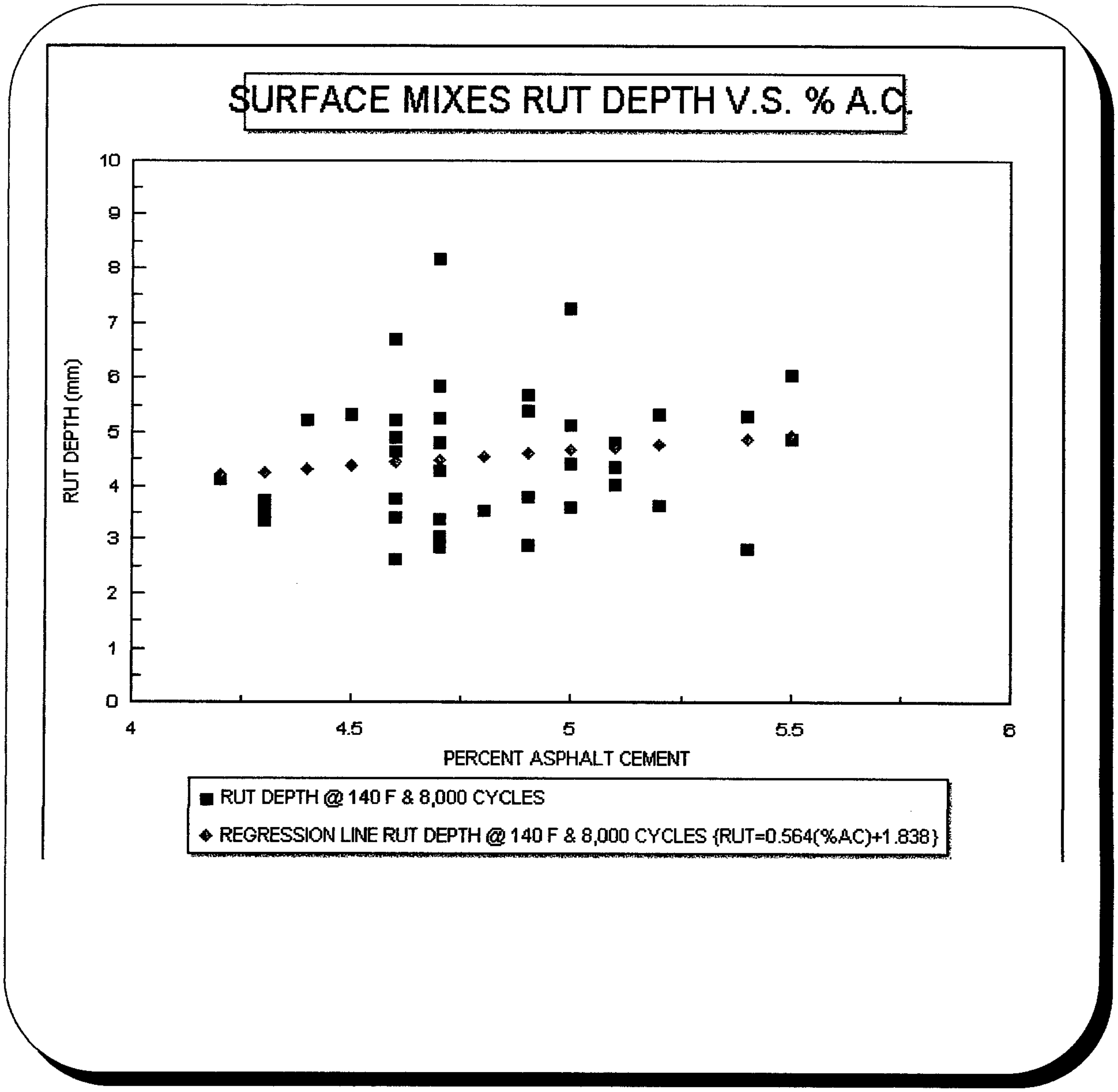
The graph above depicts rut depth versus percent air voids for dense graded surface mixes which allow up to 15% natural sand. From the regression line, it can be seen that as the air voids decrease, the rut depth increases. This correlates with text book behavior.

Graph No. 3 - VFA



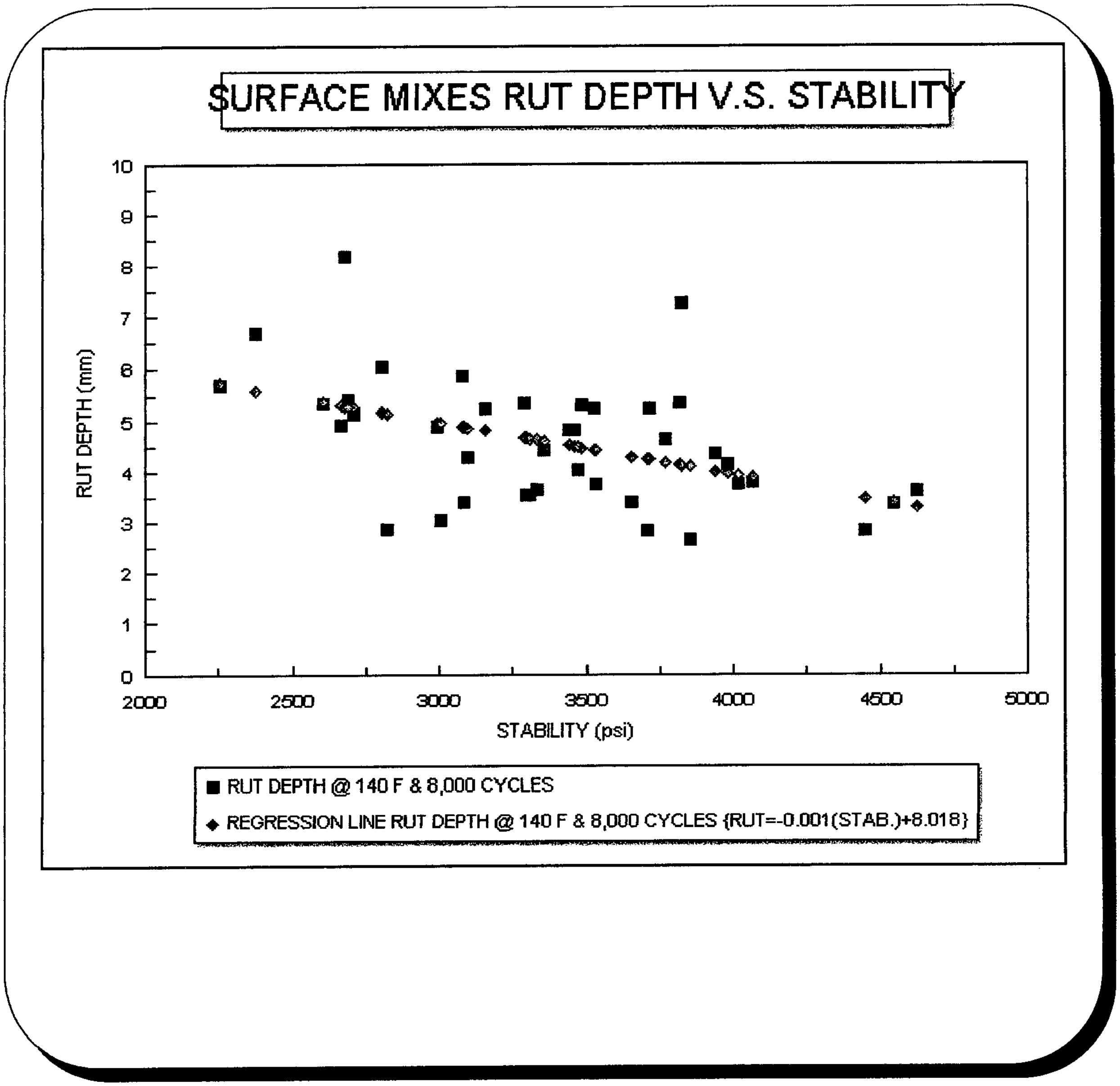
The graph above depicts rut depth versus VFA for dense graded surface mixes which allow up to 15% natural sand. From the regression line, it can be seen that as the VFA increases, the rut depth increases. This correlates with text book behavior.

Graph No. 4 - Percent A.C.



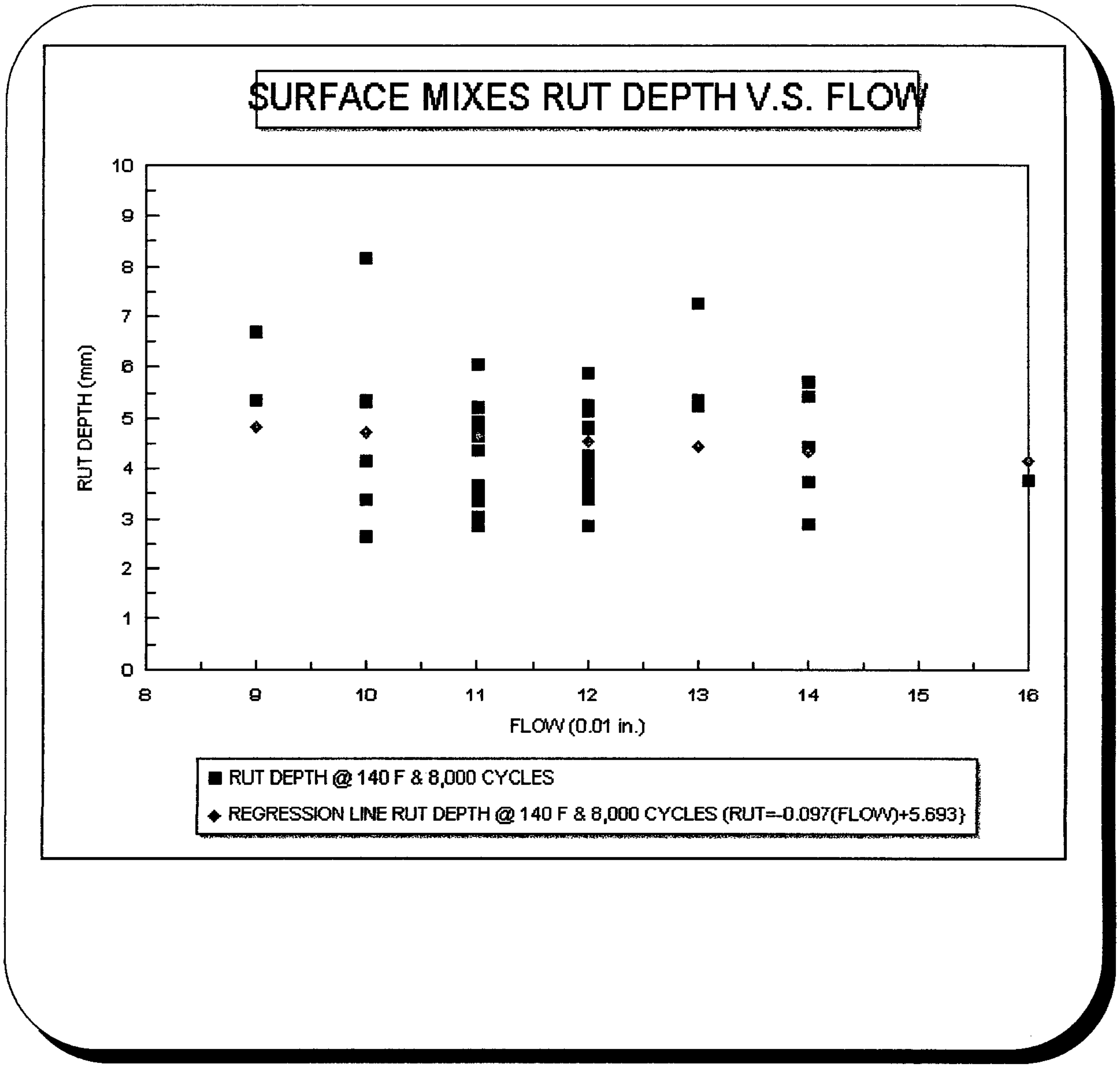
The graph above depicts rut depth versus percent of asphalt cement for dense graded surface mixes which allow up to 15% natural sand. From the regression line, it can be seen that as the percentage of asphalt cement is increased, the rut depth also increases. This correlates with text book behavior.

Graph No. 5 - Stability



The graph above depicts rut depth versus Marshall stability for dense graded surface mixes which allow up to 15% natural sand. From the regression line, it can be seen that as the stability decreases, the rut depth increases. This correlates with text book behavior.

Graph No. 6 - Flow

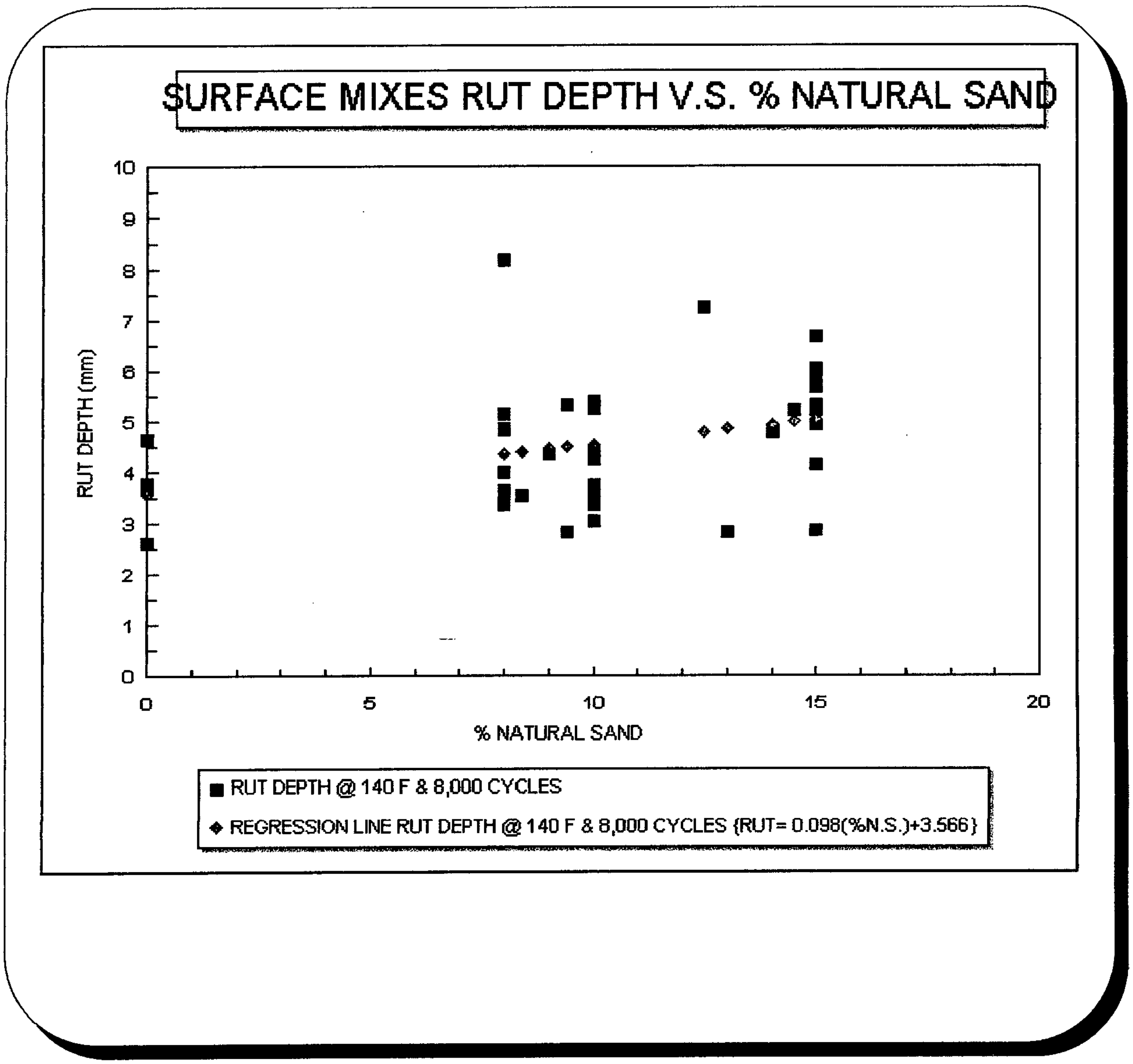


The graph above depicts rut depth versus Marshall flow for dense graded surface mixes which allow up to 15% natural sand. From the regression line, it can be seen that as the flow decreases, the rut depth increases. This does not correlate with text book behavior, it should be just the opposite, as flow decreases rut depth decreases? With the flow and stability results it can be ascertained that the stability results are more meaningful than flow results.

1) DENSE GRADED 75 BLOW MARSHALL SURFACE MIX RESULTS

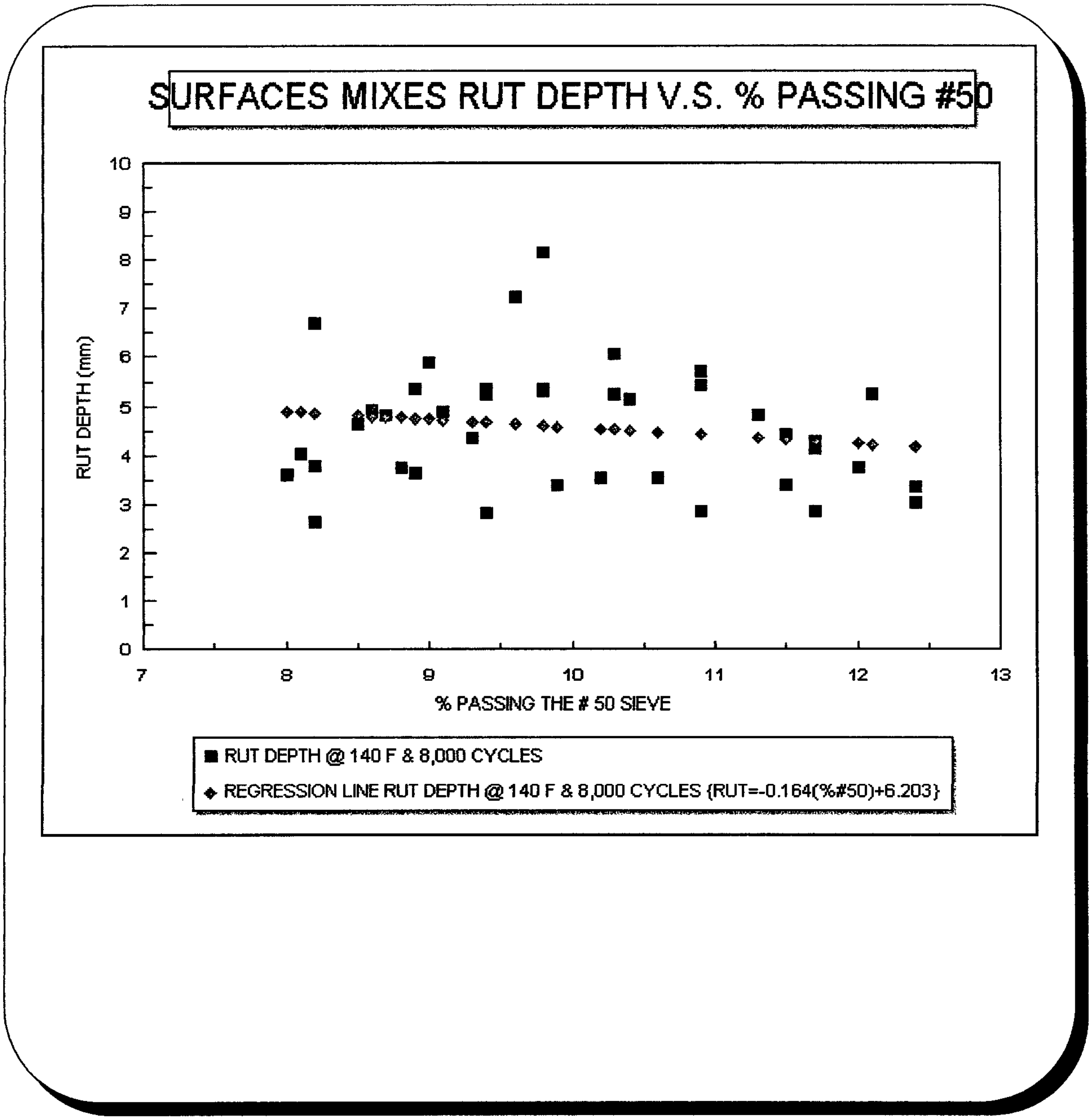
B) RUT DEPTH V.S. COMBINED AGGREGATE PROPERTIES

Graph No. 7 - % Natural Sand



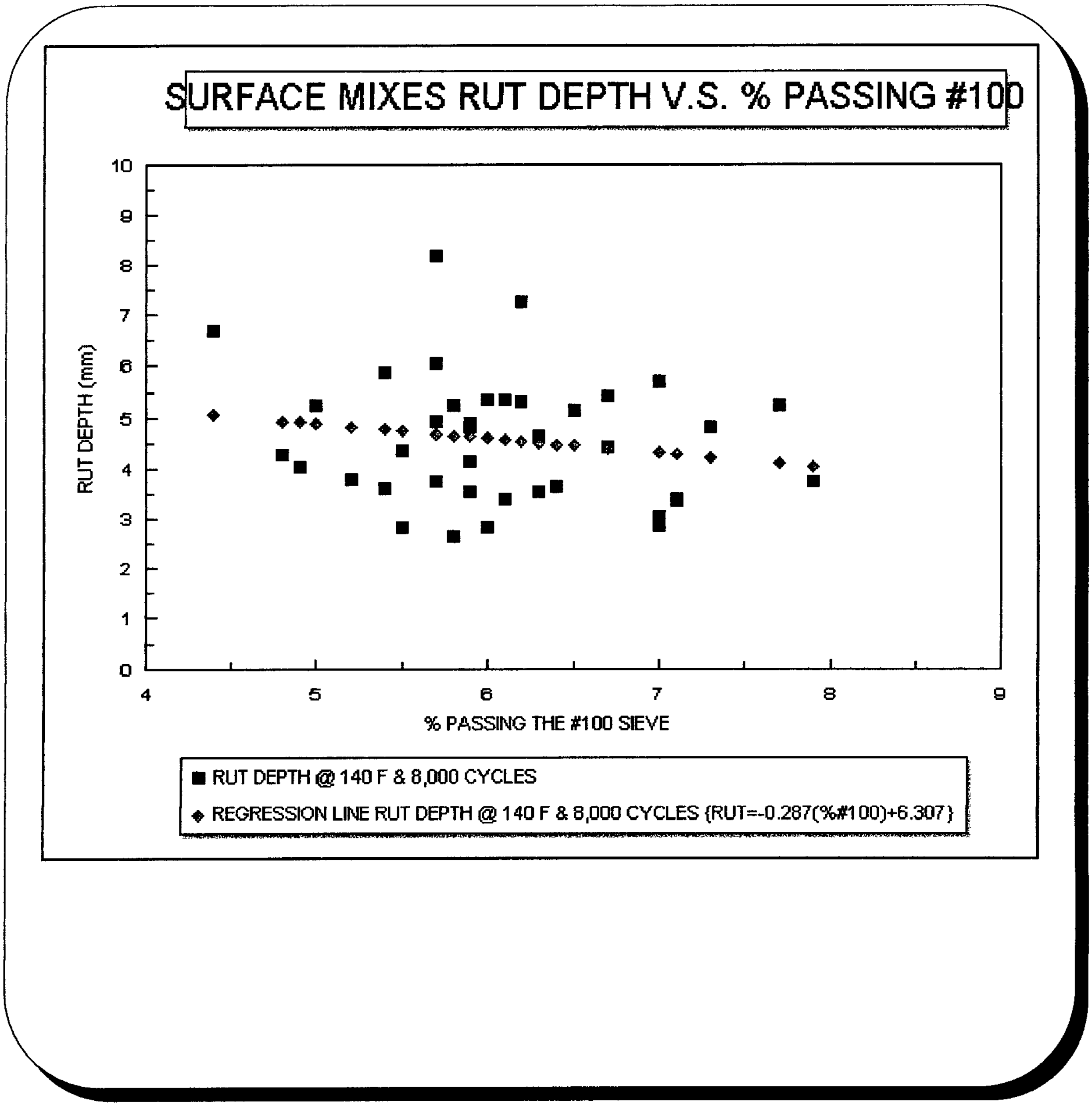
The graph above depicts rut depth versus % natural sand for dense graded surface mixes which allow up to 15% natural sand. From the regression line, it can be seen that as the % natural sand increases, the rut depth increases. This correlates with text book behavior.

Graph No. 8 - % Passing # 50 Sieve



The graph above depicts rut depth versus the percent passing the # 50 sieve for dense graded surface mixes which allow up to 15% natural sand. From the regression line, it can be seen that as the percent passing the # 50 sieve increases, the rut depth decreases. This correlates with a research project conducted by the Georgia Institute of Technology. The research project concluded that as the percent of material passing the #50 and #100 sieves increase, the rut depth potential decreases. (3)

Graph No. 9 - % Passing # 100 Sieve

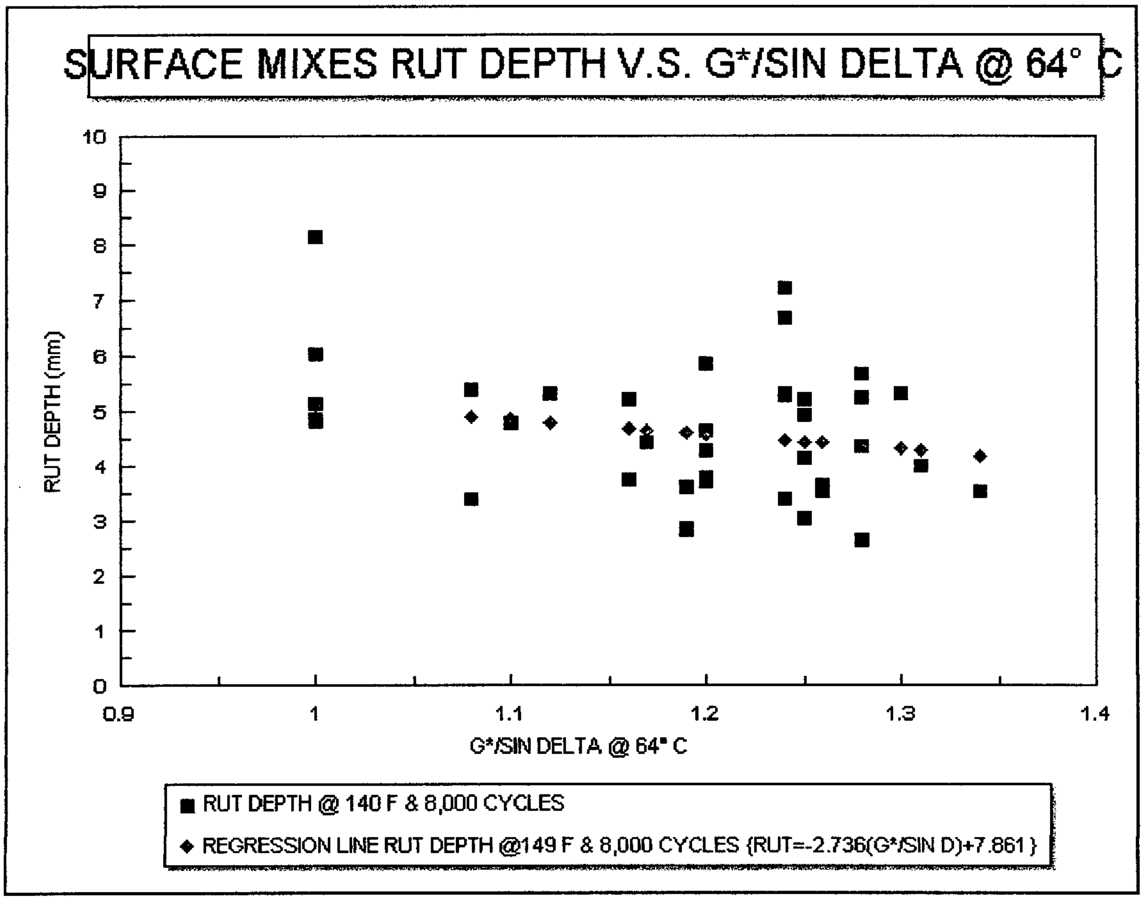


The graph above depicts rut depth versus the percent passing the # 100 sieve for dense graded surface mixes which allow up to 15% natural sand. From the regression line, it can be seen that as the percent passing the # 100 sieve increases, the rut depth decreases. This correlates with a research project conducted by the Georgia Institute of Technology. The research project concluded that as the percent of material passing the #50 and #100 sieves increase, the rut depth potential decreases. (3)

1) DENSE GRADED 75 BLOW MARSHALL SURFACE MIX RESULTS

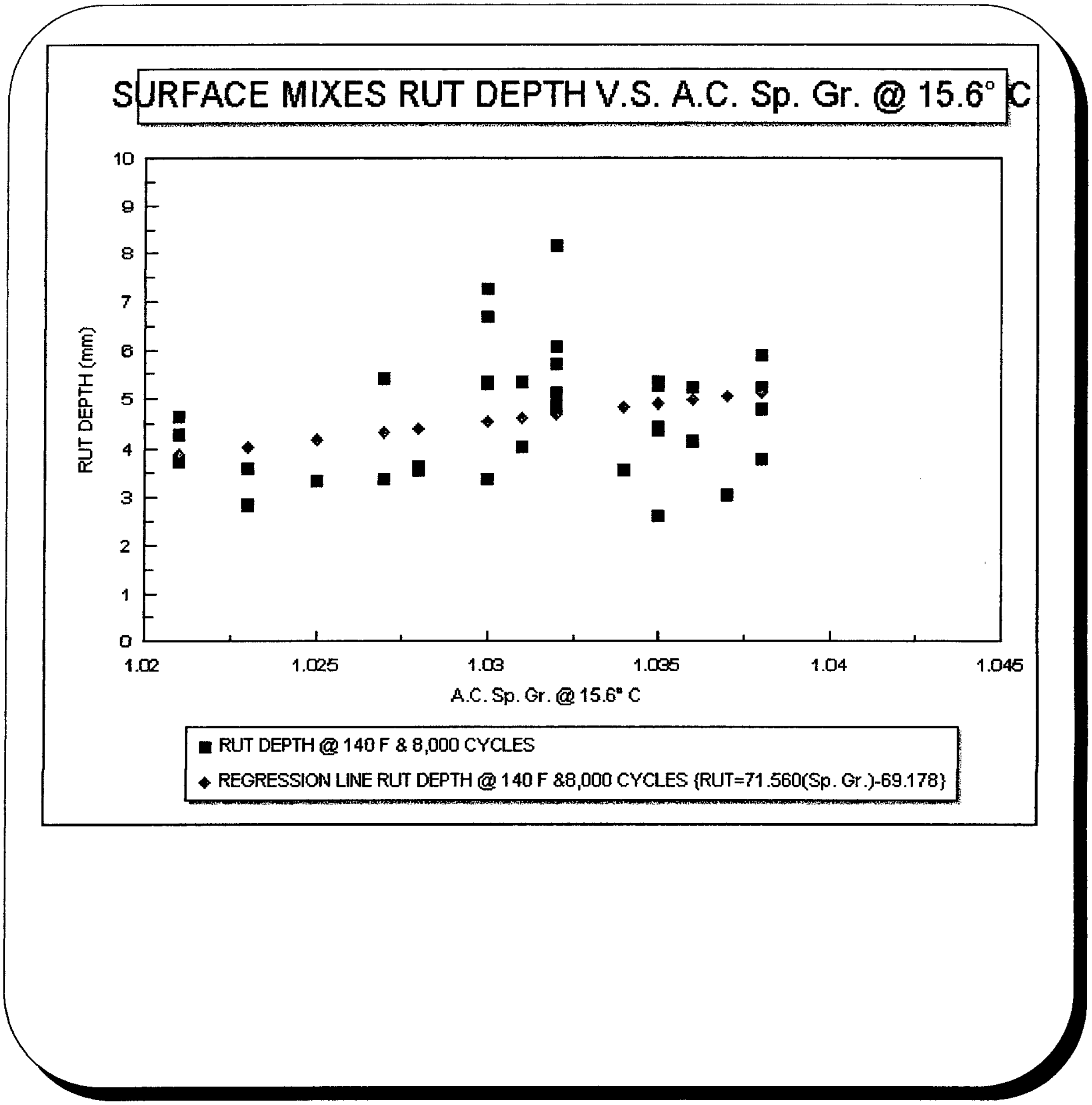
C) RUT DEPTH V.S. ASPHALT CHARACTERISTIC PROPERTIES

Graph No. 10 - G*/SIN DELTA @ 64° C



The graph above depicts rut depth versus the asphalt cement characteristic of G*/sin delta @ 64° C, for dense graded surface mixes which allow up to 15% natural sand. From the regression line, it can be seen that as the G*/sin delta increases, the rut depth decreases. This correlates with a research project conducted by the Transportation Research Board. The research study concluded that as G*/sin delta increases, rut depths decrease. ***(1)***

Graph No. 11 - Specific Gravity @ 15.6° C

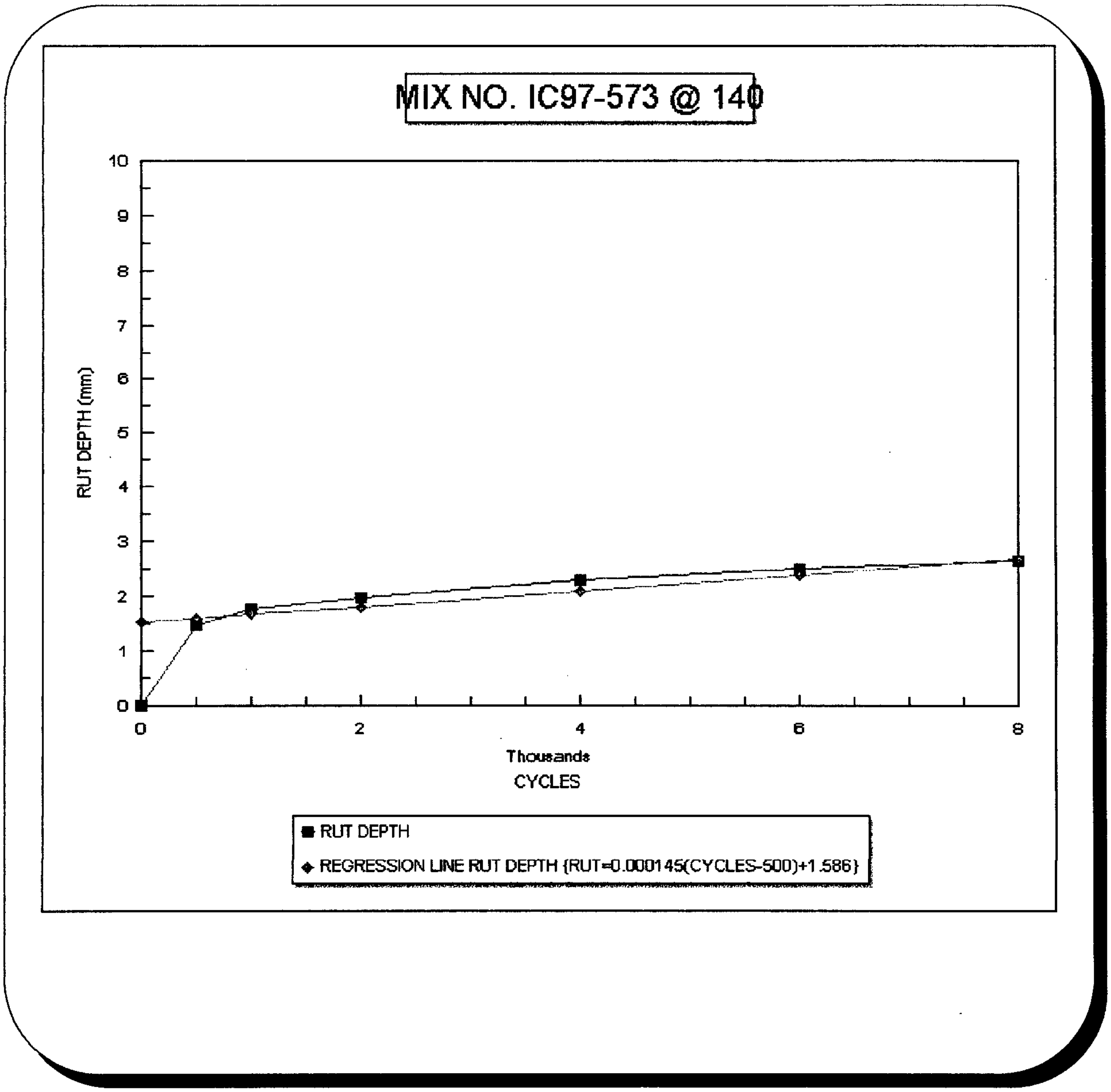


The graph above depicts rut depth versus the asphalt cement characteristic of specific gravity @ 15.6° C for dense graded surface mixes which allow up to 15% natural sand From the regression line, it can be seen that as the specific gravity increases, the rut depth increases. This does not correlate with text book behavior? Usually as the specific gravity of an asphalt cement increases, it also has a corresponding increased viscosity, which in turn means a stiffer asphalt cement. And stiffer asphalt cements should reduce rutting. Therefore, it can be ascertained that the G*/sin delta value has more significance than the specific gravity of an asphalt cement when it comes to selection of an asphalt cement to resist rutting.

1) DENSE GRADED 75 BLOW MARSHALL SURFACE MIX RESULTS

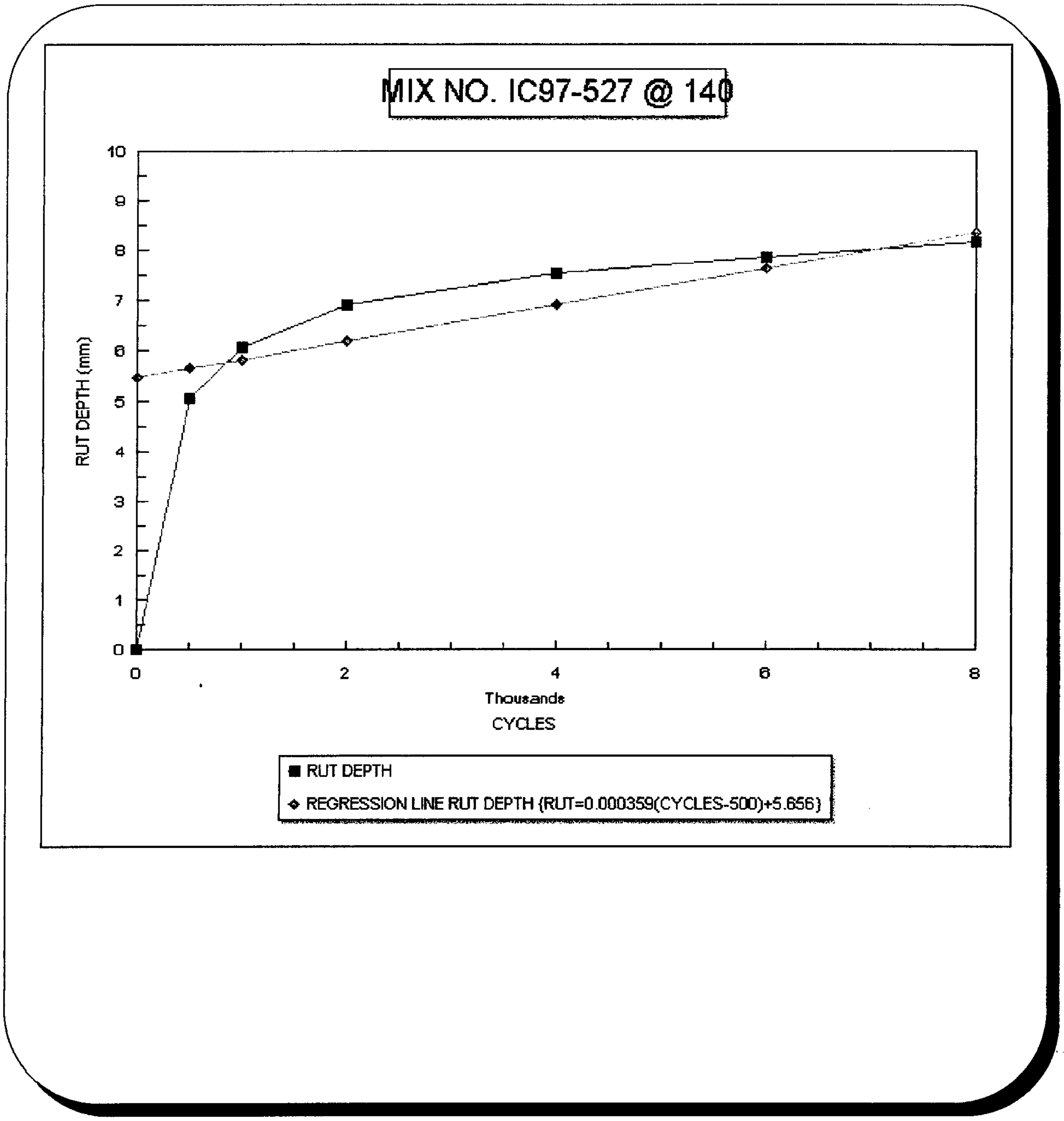
D) RUT DEPTH V.S. TEST CYCLES

Graph No. 12 - Mix No. IC97-573, Lowest Rut Values



The graph above depicts rut depth versus test cycles. This particular mix displayed the lowest rut values and was selected as one of the two mixes for a three year monitoring. The slope of the line from zero to 500 cycles is designated as post compaction consolidation. The slope of the line from 500 to 8,000 cycles is designated as the creep slope. (1) The regression line was calculated only for the creep slope, because it would be expected that approximately 1.5 mm of rutting will be induced into the pavement from post compaction consolidation.

Graph No. 13 - Mix No. IC97-527, Highest Rut Values



The graph above depicts rut depth versus test cycles. This particular mix displayed the highest rut values and was selected as one of the two mixes for a three year monitoring. The slope of the line from zero to 500 cycles is designated as post compaction consolidation. The slope of the line from 500 to 8,000 cycles is designated as the creep slope. (1) The regression line was calculated only for the creep slope, because it would be expected that approximately 5.6 mm of rutting will be induced into the pavement from post compaction consolidation.

1) DENSE GRADED 75 BLOW MARSHALL SURFACE MIX RESULTS

E) SUMMARY OF RESULTS

There is a total of forty dense graded surface mixes, thirty three I-C mixes and seven LP mixes, representing these rut depth results. This is a large sample size and can be considered a complete population. With the exception of Rut Depth V.S. Marshall flow values and Rut Depth V.S. Asphalt Cement Specific Gravity at 15.6° C, the rest of the results indicate text book behavior. Therefore, since the results indicate text book behavior, it can be deduced that the rut tester can be used as a laboratory proof tester of bituminous mixtures.

Several other items of interest can be deduced from the results. In the mix design properties, the Marshall stability values are more significant than Marshall flow values in predicting if a bituminous mixture is prone to rutting. In the combined aggregate properties, a decreased potential for rutting of a bituminous mixture can be achieved by increasing the amount of material, in the combined aggregate gradation, which passes the #50 and #100 sieve. And, when it comes to the selection of an asphalt cement to help resist rutting, the G*/sin delta value is more significant than the Specific Gravity at 15.6° C. The higher the G*/sin delta value the less prone the bituminous mixture will be to rutting.

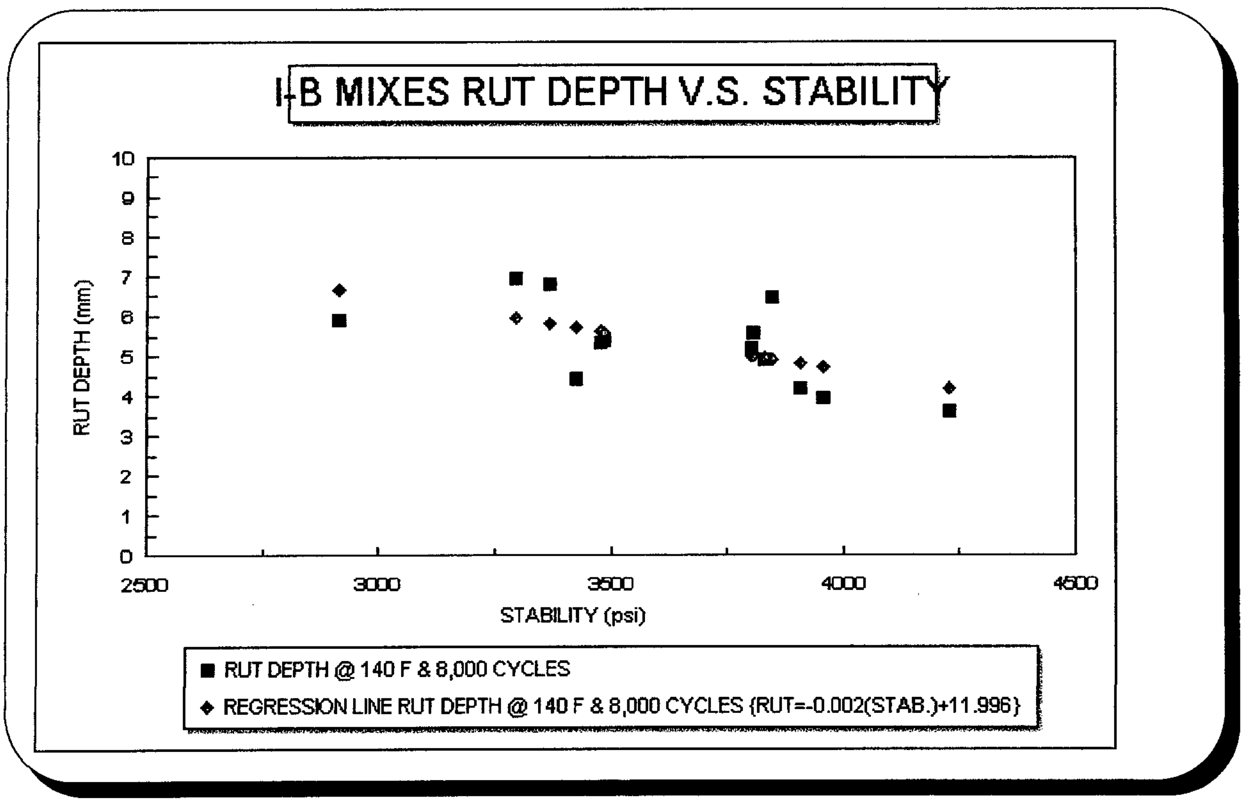
Two I-C mixes were selected to be monitored in the field. These two mixes were selected because of their different rutting characteristics. One mix had the lowest rut depth (2.63 mm) and the other had the highest rut depth (8.16 mm). They are depicted in graphs 11 & 12. It was noted that between zero to 500 cycles the slope of the line is designated as the post compaction consolidation line. Therefore, it can be expected that the laboratory rut depth at 500 cycles should correlate to the amount of rutting in the field which actual wheel loads will induce into the pavement directly after it was opened to traffic.

2) DENSE GRADED 75 BLOW MARSHALL BINDER MIX RESULTS

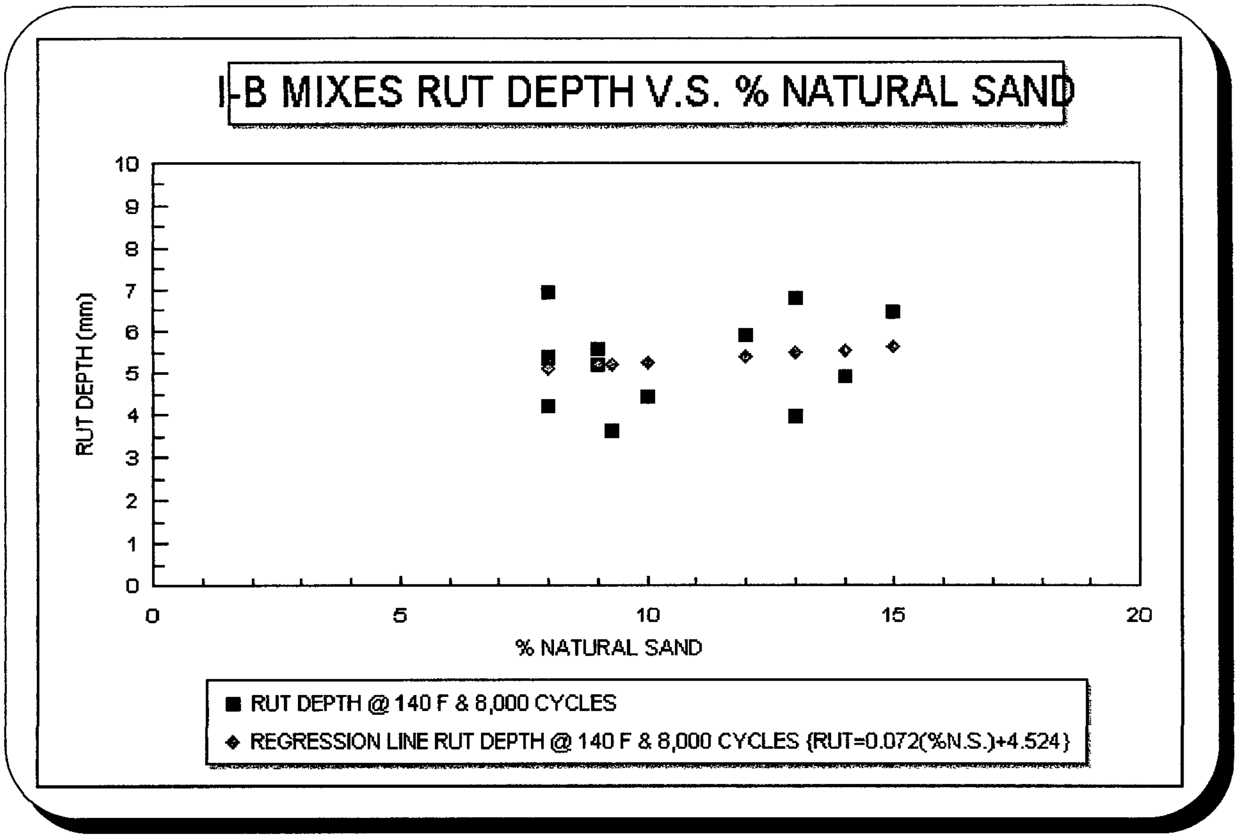
A) SUMMARY OF RESULTS

The results from the thirteen I-B mixes did not yield the same text book behavior as did the results of the forty surface mixes. The reason for this is unknown, one can only speculate that pertinent information could not be yielded from the limited amount of mixes tested. There was only one mix design property, stability, which displayed the same text book behavior as the surface mixes. Here again, as the stability increased the rut depth decreased. There was only one combined aggregate property, percent natural sand, which displayed the same text book behavior as the surface mixes. Here again, as the percent of natural sand in a mix increased, the rut depth increased. And, the asphalt cement characteristic of G*/sin delta again proved to be influential on deterring rutting. The I-B mixes displayed the same behavior as the surface mixes, as the G*/sin delta increased, the rutting decreased. The next three graphs display the results on rut depth versus stability, percent natural sand, and G*/sin delta. All of the remaining graphs for the I-B mix can be found in Appendix (B).

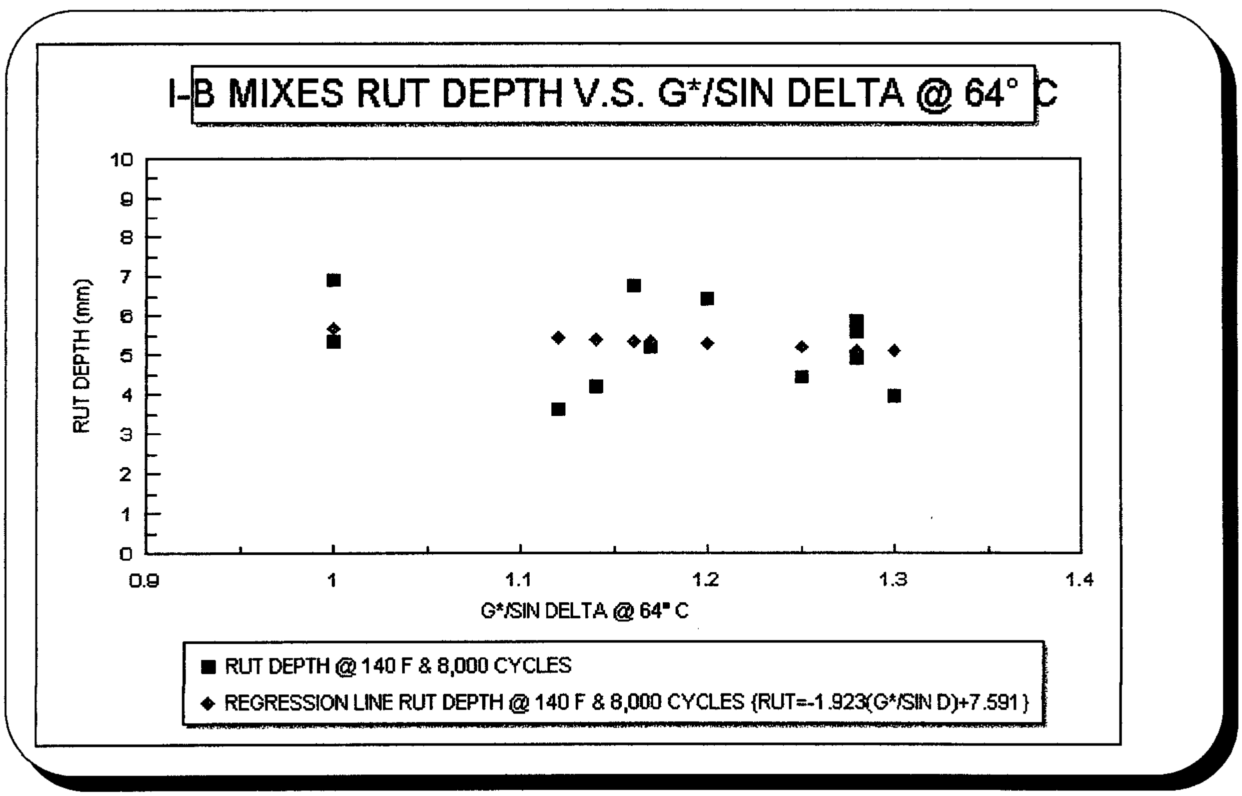
Graph No. 14 - Stability



Graph No. 15 - % Natural Sand



Graph No. 16 - G*/SIN DELTA @ 64 C

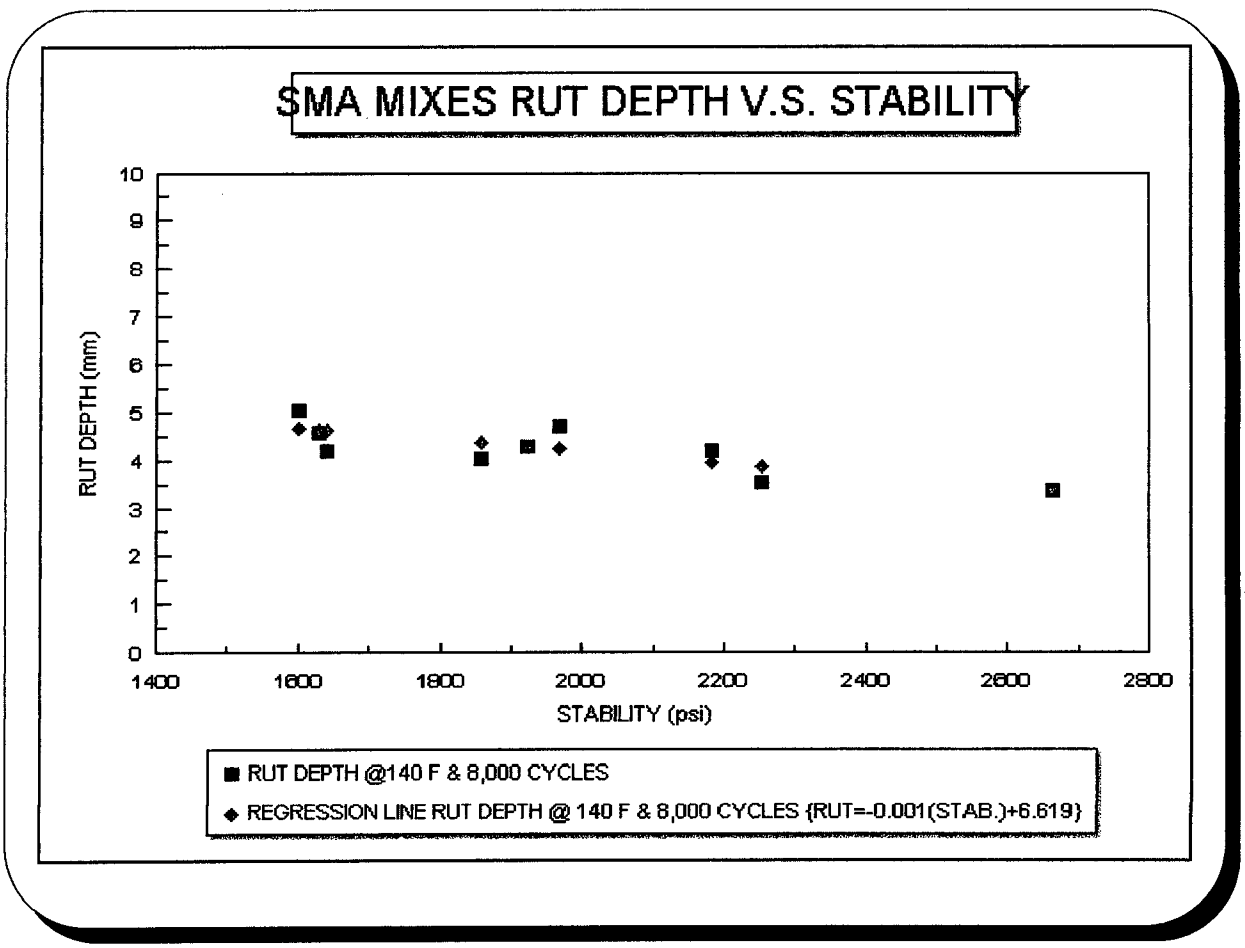


3) SMA 50 BLOW MARSHALL MIX RESULTS

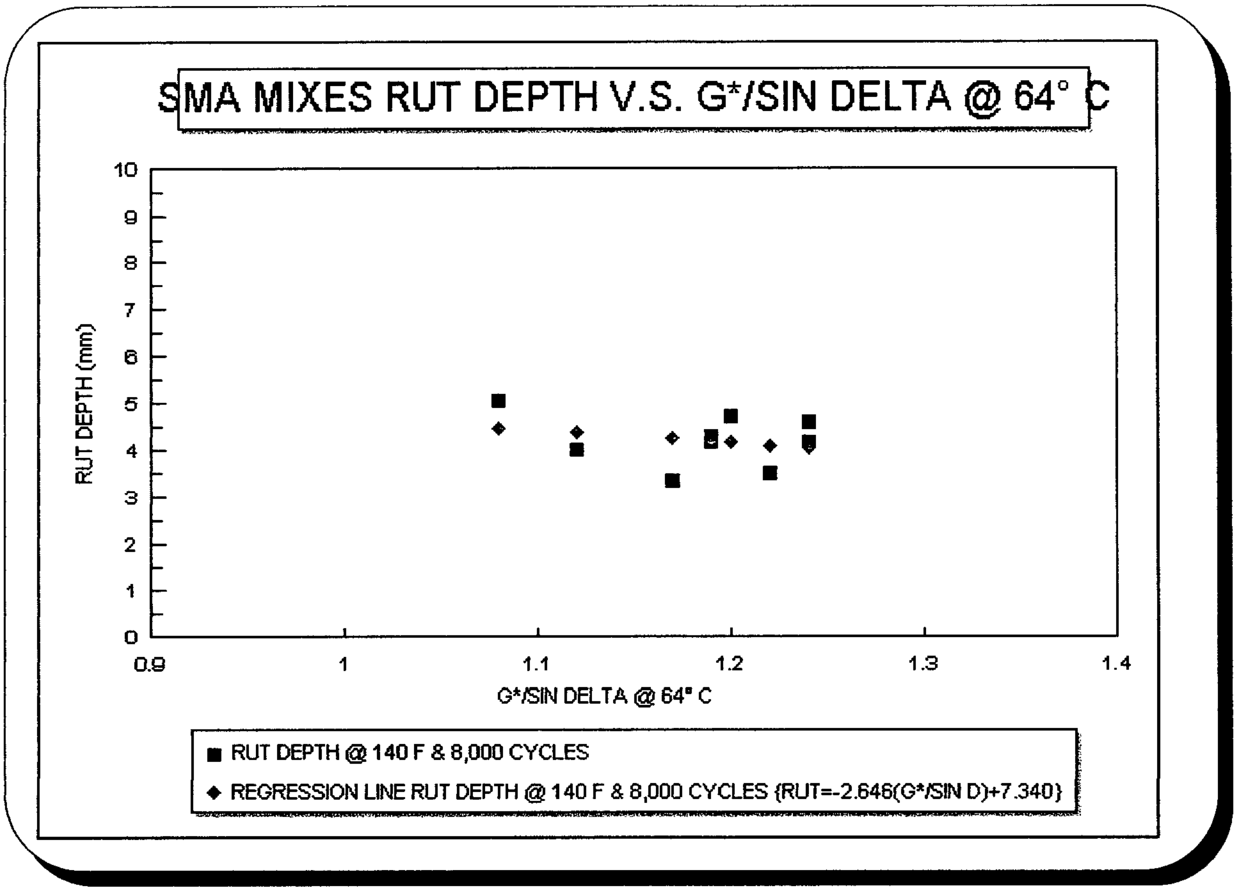
A) SUMMARY OF RESULTS

The results from the nine SMA mixes did not yield the same text book behavior as did the results of the forty surface mixes. One reason for this is the difference in aggregate structure, coarse gap graded for an SMA versus a fine dense graded for the conventional surface mixes. Here again there may be other reasons, one can only speculate that pertinent information could not be yielded from the limited amount of mixes tested. But again as before, the mix design property, stability, displayed the same text book behavior as in the surface mixes and the binder mixes. Here again, as the stability increased the rut depth decreased. And again, the asphalt cement characteristic of G*/sin delta proved to be influential on deterring rutting. The SMA mixes displayed the same behavior as the surface mixes and the binder mixes, as the G*/sin delta increased, the rutting decreased. The next two graphs display the results on rut depth versus stability and rut depth versus G*/sin delta. All of the remaining graphs for the SMA mixes can be found in Appendix (C).

Graph No. 17 - Stability



Graph No. 18 - G*/SIN DELTA @ 64 C

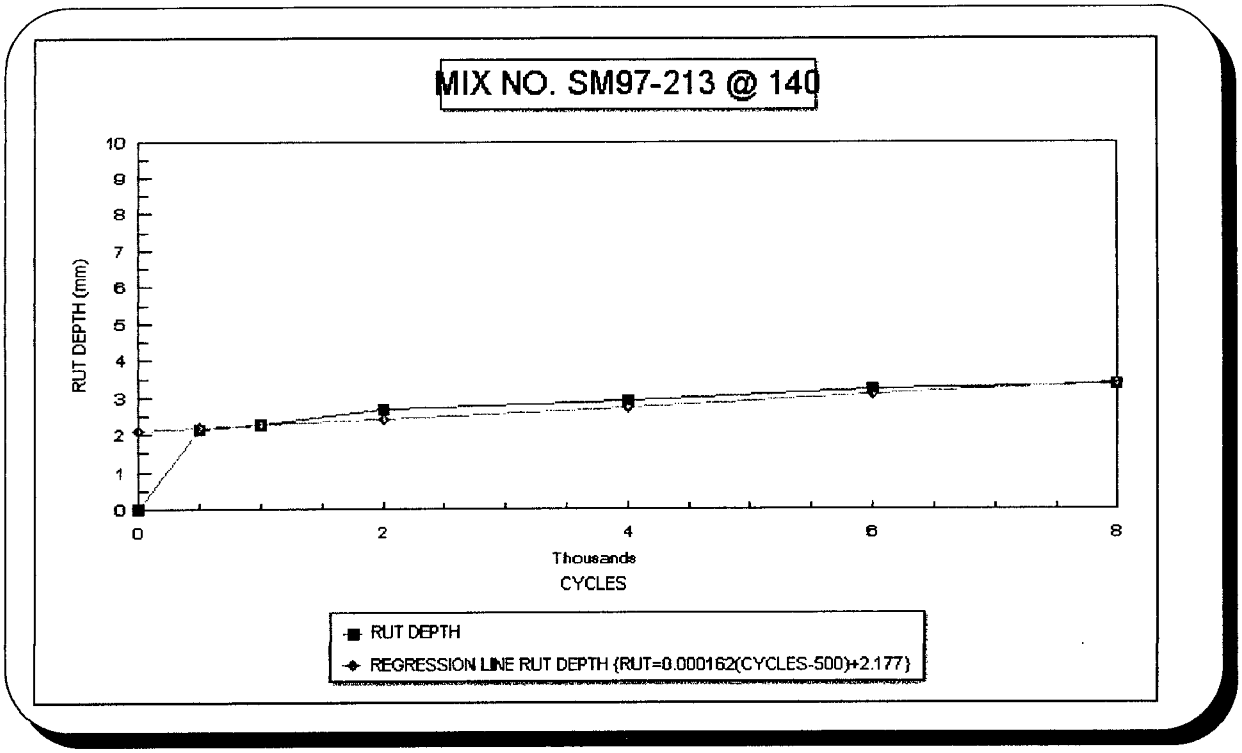


3) SMA 50 BLOW MARSHALL MIX RESULTS

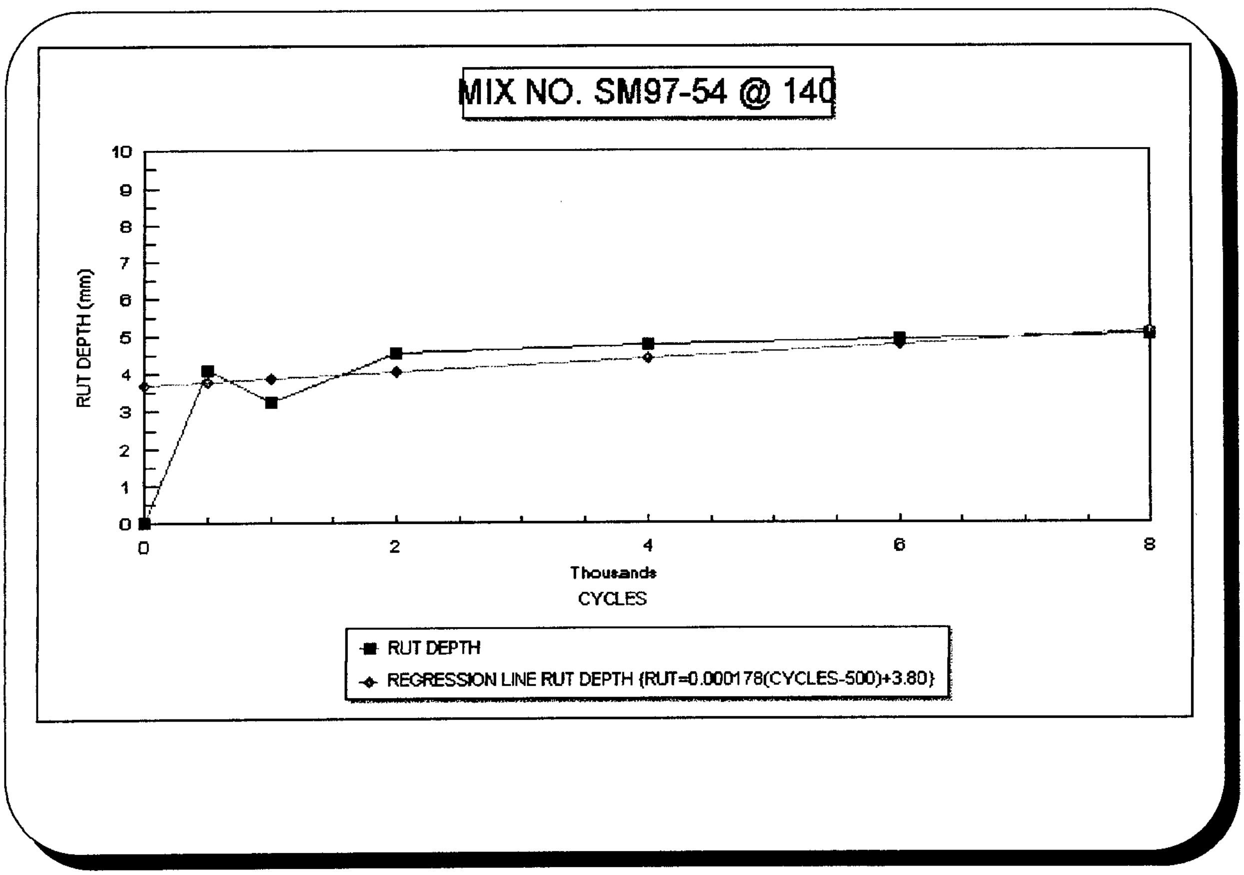
B) RUT TEST V.S. NUMBER OF TEST CYCLES

Two SMA mixes were selected to be monitored in the field. These two mixes were selected because of their different rutting characteristics. One mix had the lowest rut depth (3.36 mm) and the other had the highest rut depth (5.04 mm) of all of the nine mixes tested. Another reason for the selection of these two mixes is that they were both constructed on the same project. As an experiment, both mixes used the same aggregate structure but one mix used a PG64-28 and the other used a PG 76-22 as their asphalt cements. The PG64-28 had a lower G*/sin delta value than the PG76-22. The rutting was the highest in the mix which used the PG64-28 and lowest in the mix which used the PG76-22. The results are depicted in the following graphs 19 & 20. It has been previously noted that between zero to 500 cycles the slope of the line is designated as the post compaction consolidation line. Therefore, it can be expected that the laboratory rut depth at 500 cycles should correlate to the amount of rutting in the field which actual wheel loads will induce into the pavement directly after it was opened to traffic.

Graph No. 19 - Mix No. SM97-213 (PG76-22), Lowest Rut Values



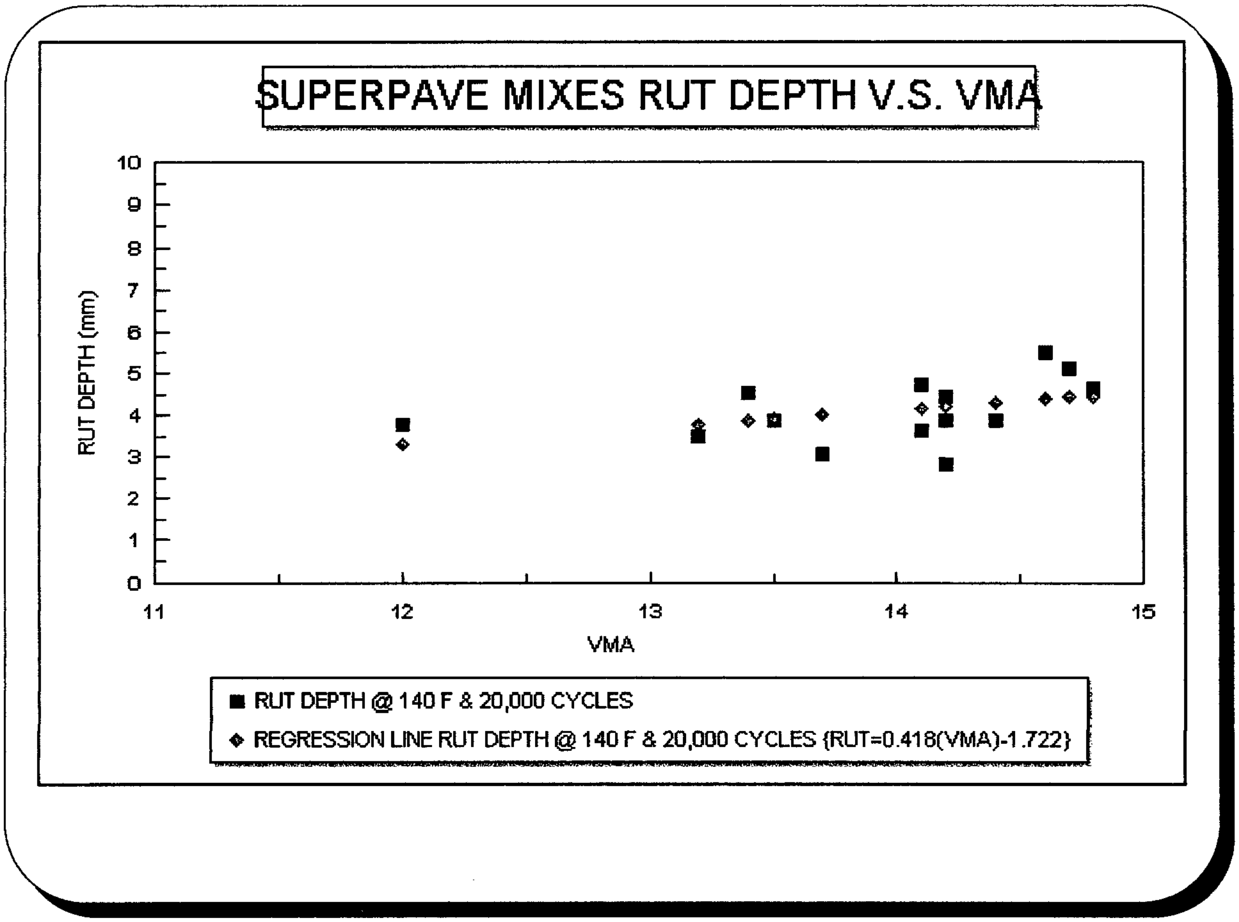
Graph No. 20 - Mix No. SM97-54 (PG64-28), Highest Rut Values



4) SUPERPAVE MIX RESULTS

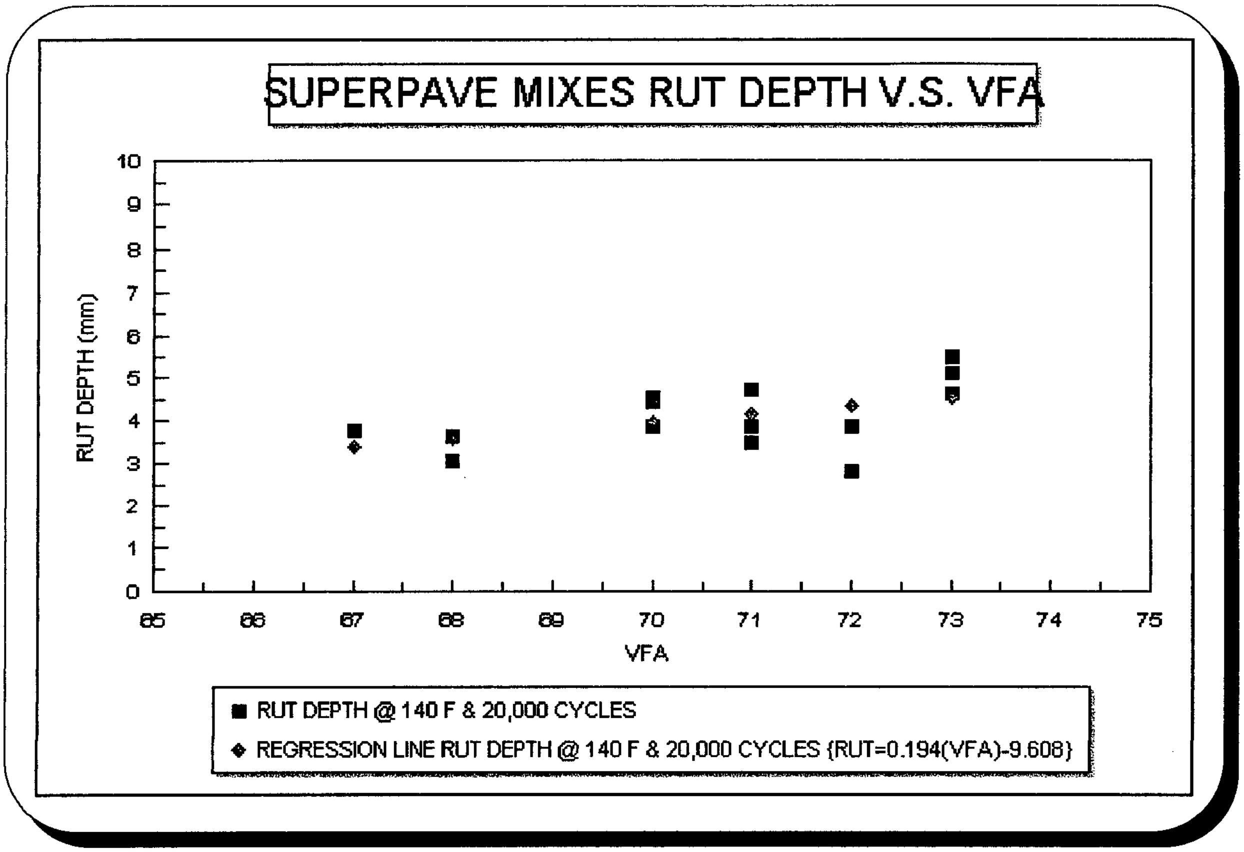
A) RUT DEPTH V.S. MIX DESIGN PROPERTIES

Graph No. 21 - VMA



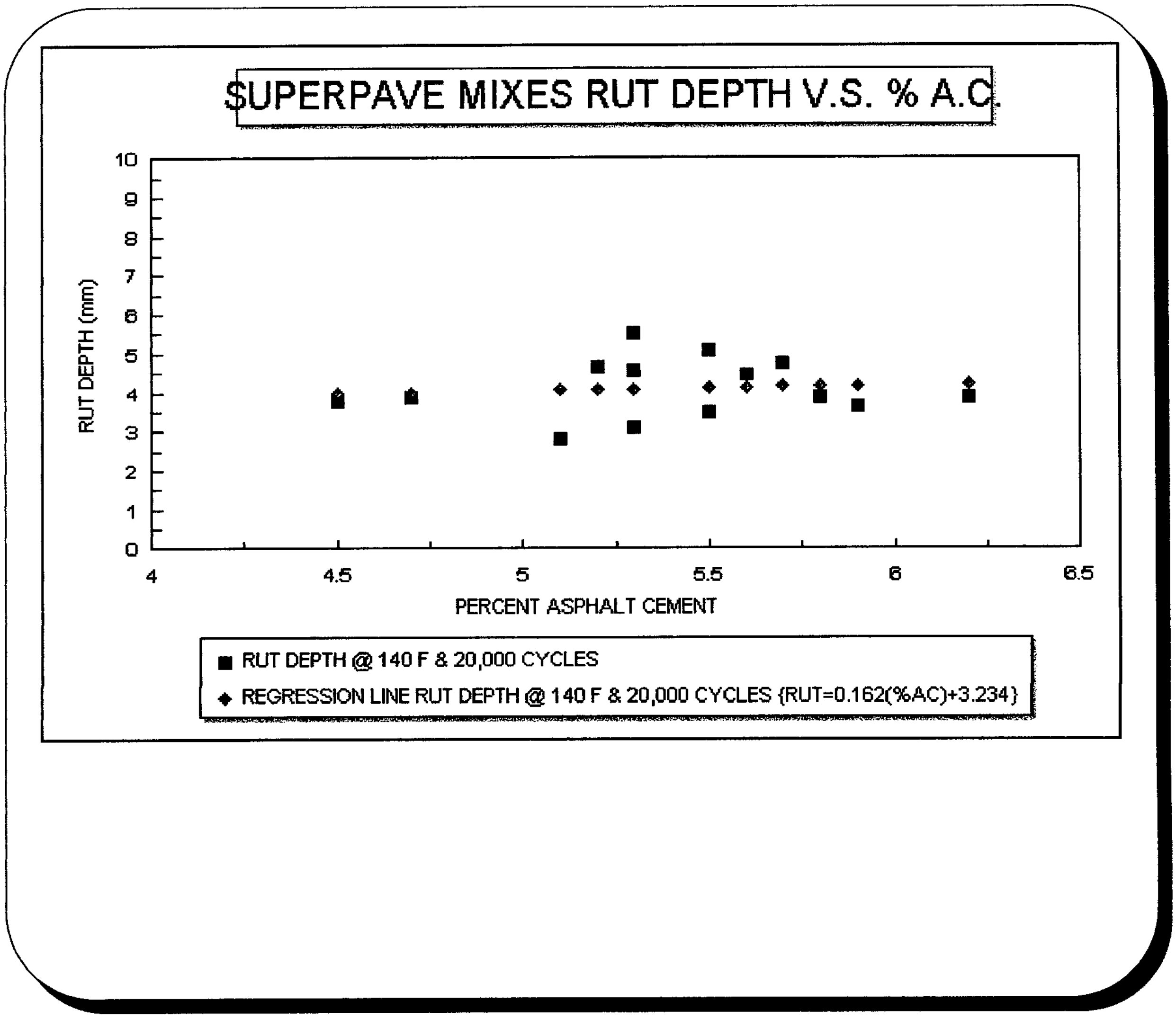
The graph above depicts rut depth versus VMA for Superpave mixes. From the regression line, it can be seen that rut depth is all but constant throughout the range of VMA. Rut depth slightly increases with the increase of VMA.

Graph No. 22 - VFA



The graph above depicts rut depth versus VFA for Superpave mixes. From the regression line, it can be seen that as the VFA increases, the rut depth increases. This correlates with text book behavior.

Graph No. 23 - Percent A.C.

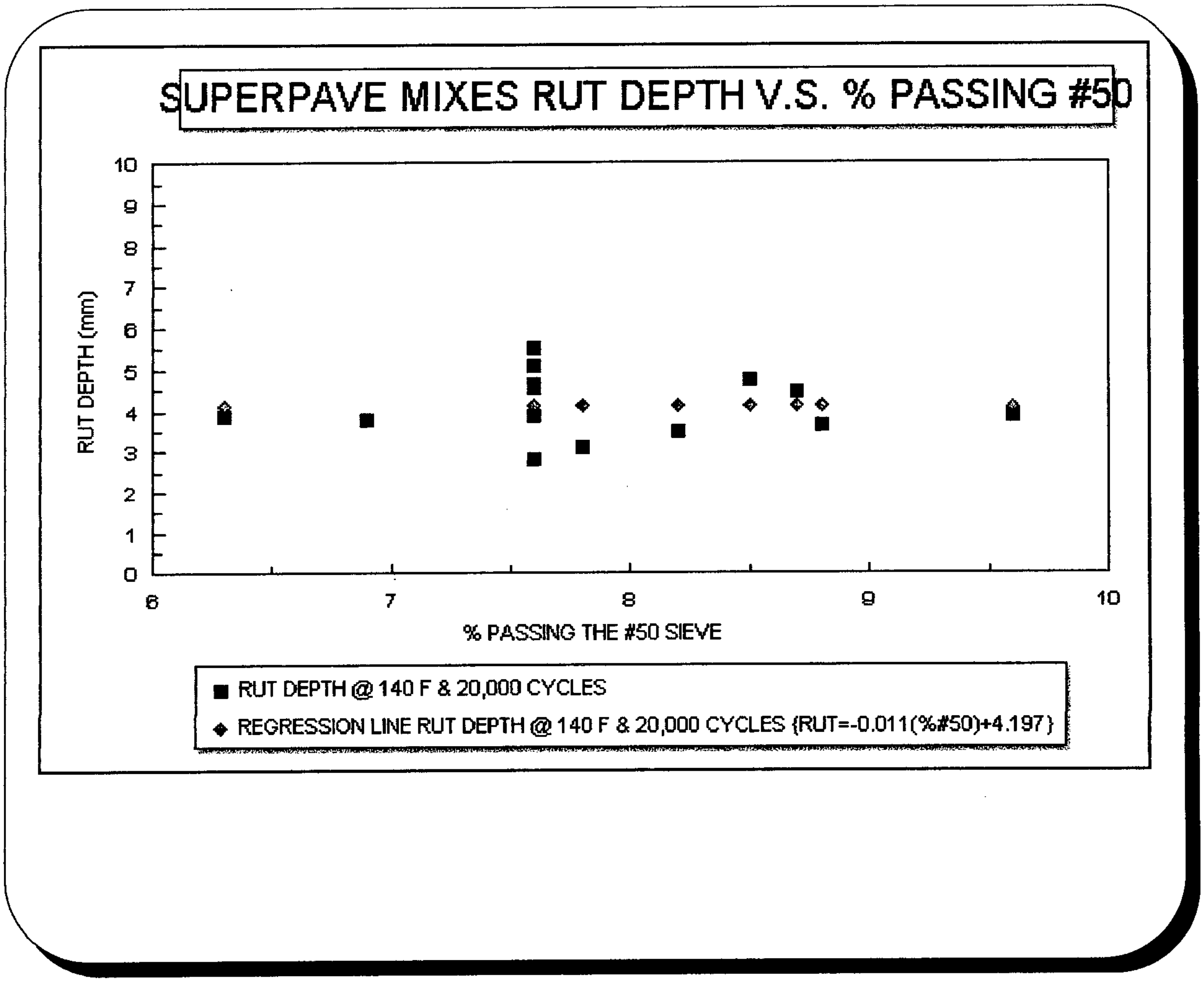


The graph above depicts rut depth versus percent of asphalt cement for Superpave mixes. From the regression line, it can be seen that the rut depth is all but constant through out the range of asphalt cement. Rut depth slightly increases with the increase of percent asphalt cement.

4) SUPERPAVE MIX RESULTS

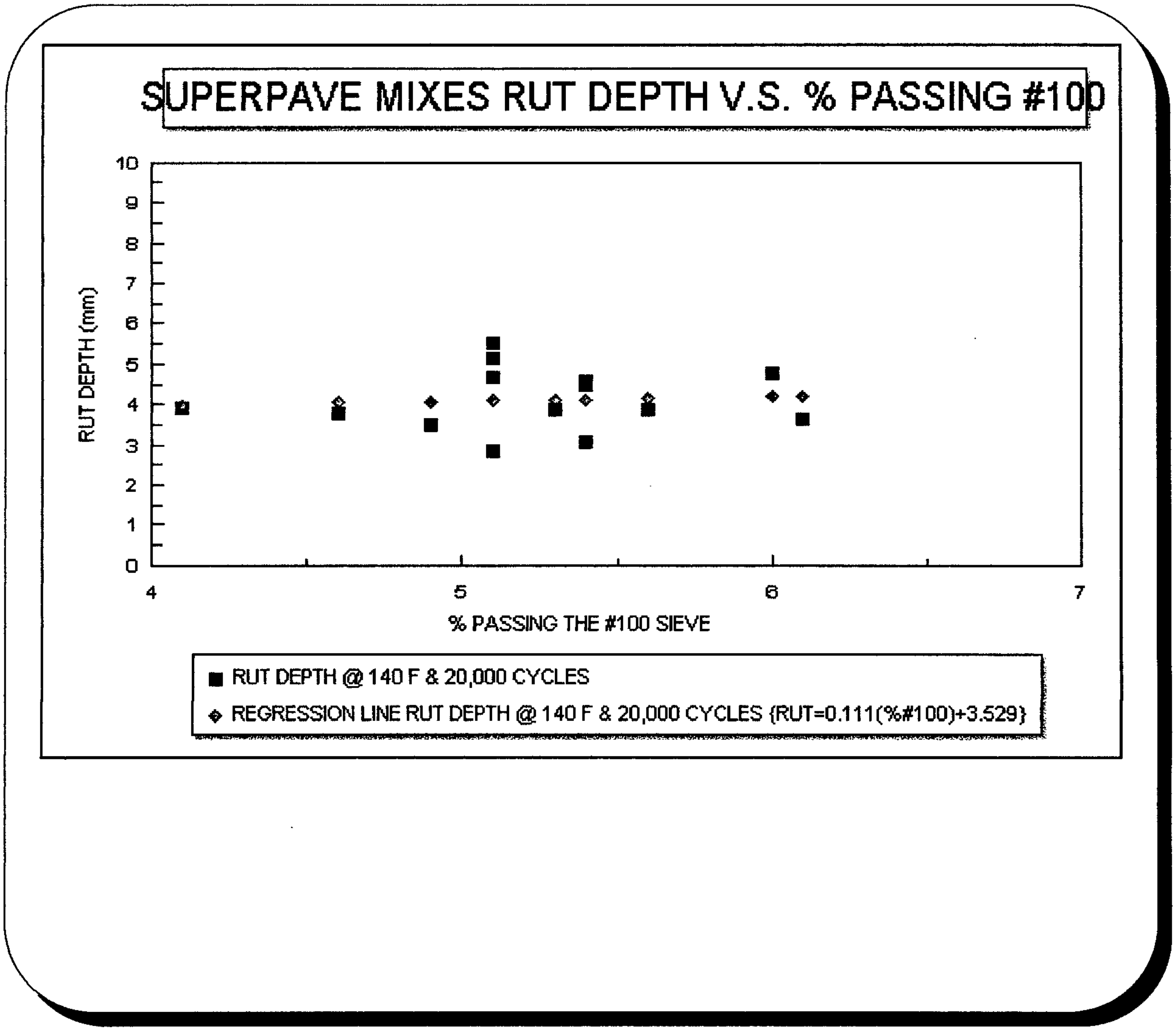
B) RUT DEPTH V.S. COMBINED AGGREGATE PROPERTIES

Graph No. 24 - % Passing #50 Sieve



The graph above depicts rut depth versus the percent passing the # 50 sieve for Superpave mixes. From the regression line, it can be seen that as the percent passing the # 50 sieve increases, the rut depth slightly decreases. This correlates with a research project conducted by the Georgia Institute of Technology. The research project concluded that as the percent of material passing the #50 and #100 sieves increase, the rut depth potential decreases. (3)

Graph No. 25 - % Passing #100 Sieve

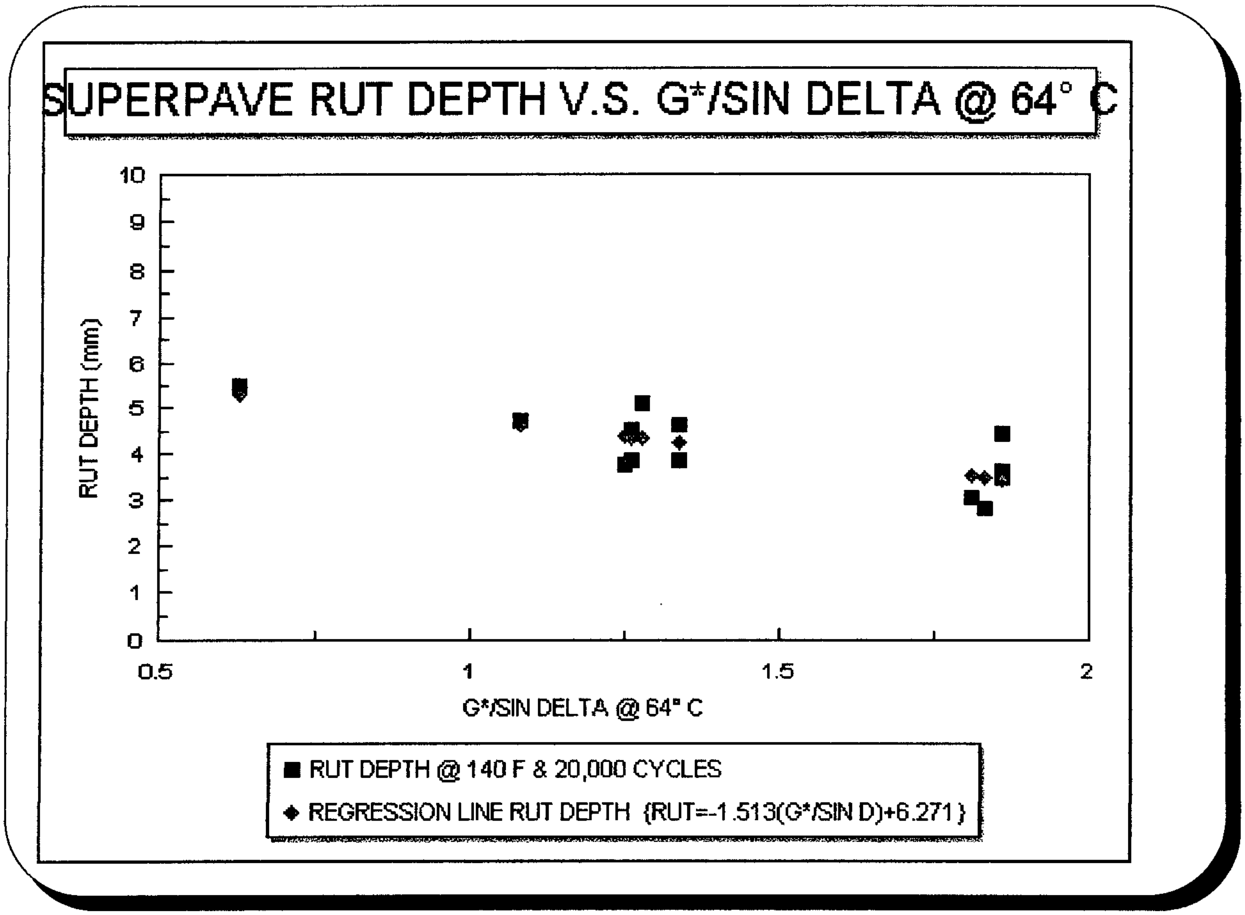


The graph above depicts rut depth versus the percent passing the # 100 sieve for Superpave mixes. From the regression line, it can be seen that as the percent passing the # 100 sieve increases, the rut depth slightly increases. This does not correlate with the results from the 75 blow Marshall dense graded surface mixes. This also does not correlate with a research project conducted by the Georgia Institute of Technology. The research project concluded that as the percent of material passing the #50 and #100 sieves increase, the rut depth potential decreases. (3)

4) SUPERPAVE MIX RESULTS

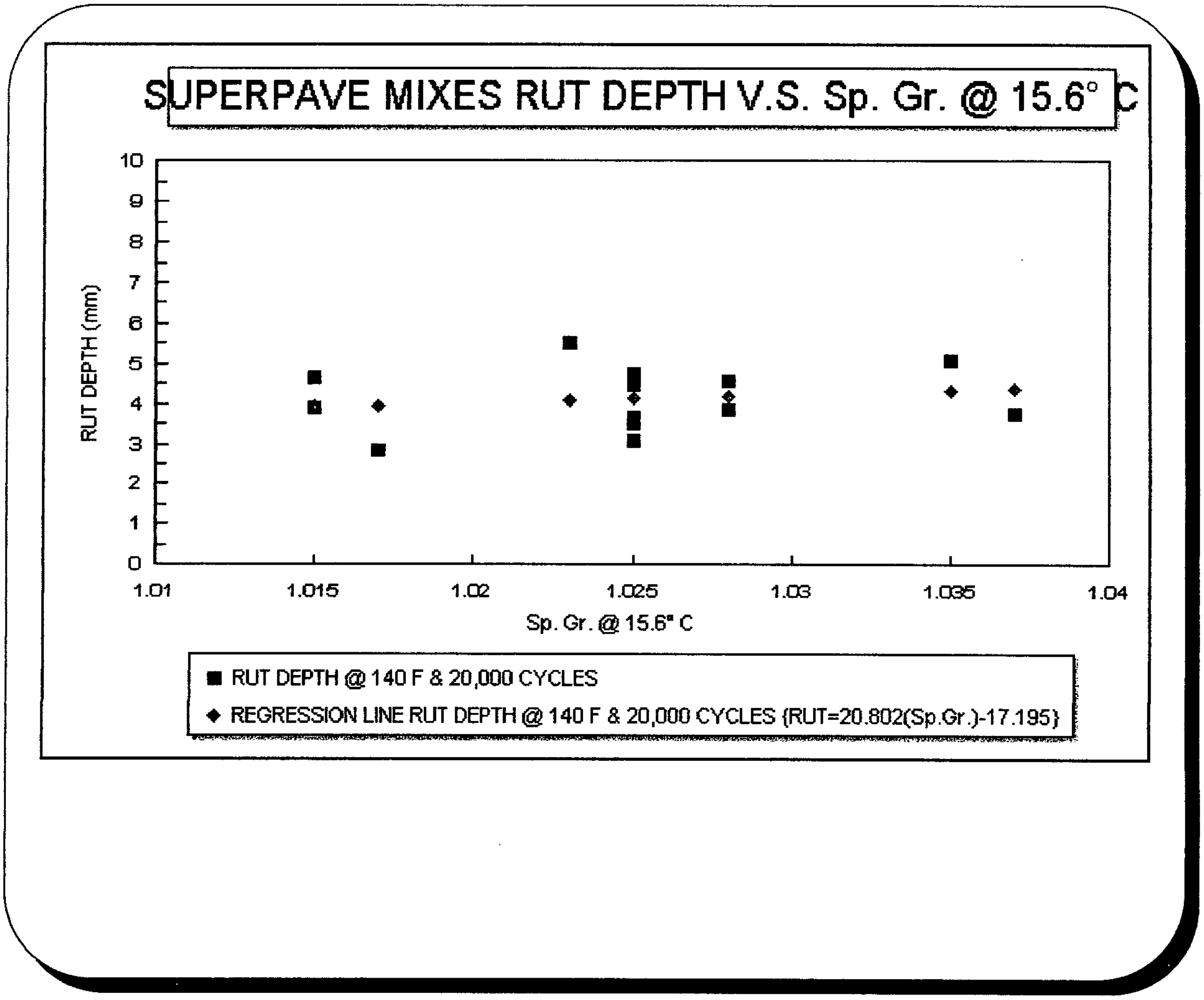
C) RUT DEPTH V.S. ASPHALT CEMENT CHARACTERISTICS

Graph No. 26 - G*/Sin Delta @ 64° C



The graph above depicts rut depth versus the asphalt cement characteristic of G*/sin delta @ 64° C, for Superpave mixes. From the regression line, it can be seen that as the G*/sin delta increases, the rut depth decreases. This correlates with a research project conducted by the Transportation Research Board. The research study concluded that as G*/sin delta increases, rut depths decrease. ***(1)***

Graph No. 27 - Specific Gravity @ 15.6° C

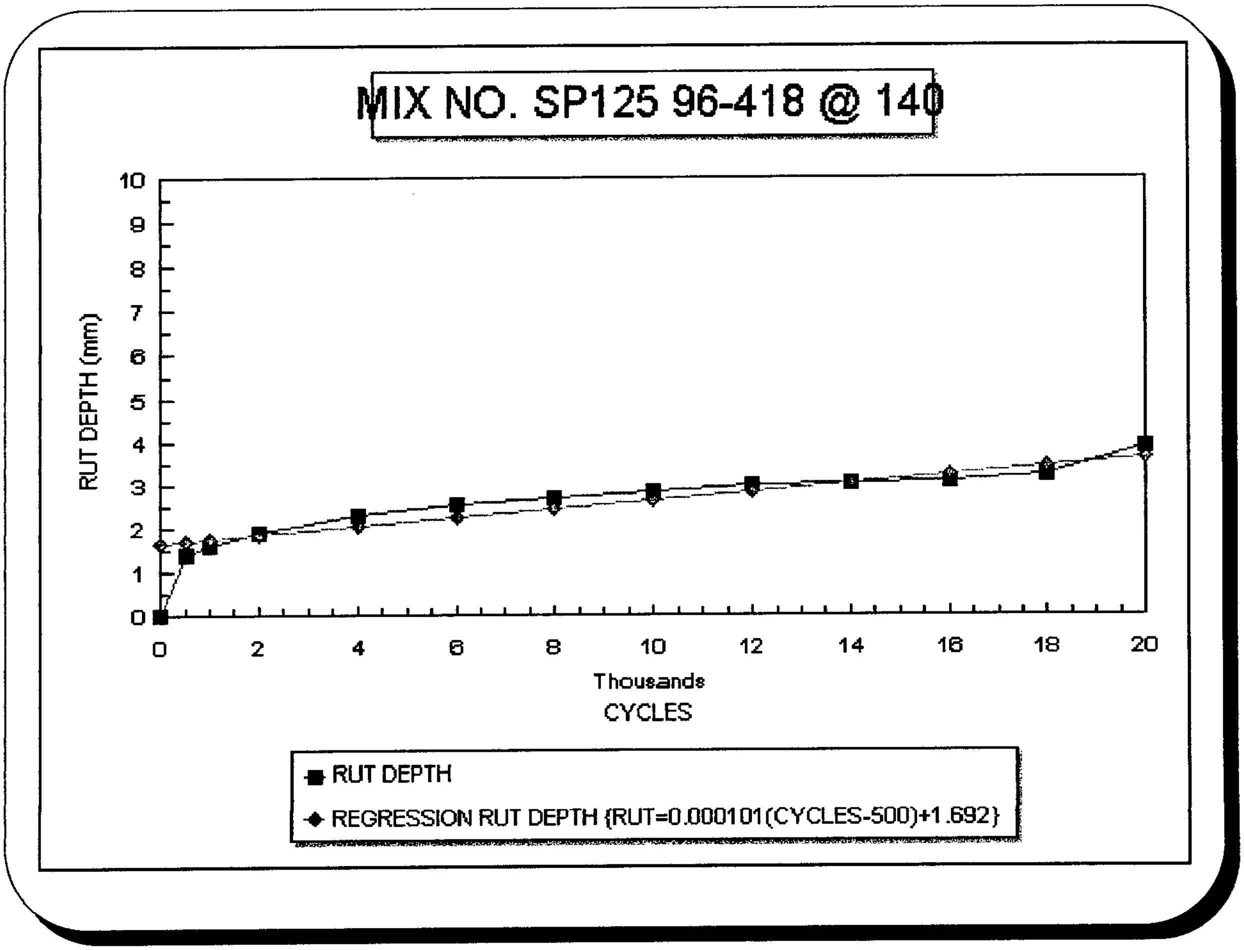


The graph above depicts rut depth versus the asphalt cement characteristic of specific gravity @ 15.6° C for the Superpave mixes. From the regression line, it can be seen that as the specific gravity increases, the rut depth increases. This does not correlate with text book behavior? Usually as the specific gravity of an asphalt cement increases, it also has a corresponding increased viscosity, which in turn means a stiffer asphalt cement. And stiffer asphalt cements should reduce rutting. Therefore, it can be ascertained that the G*/sin delta value has more significance than the specific gravity of an asphalt cement when it comes to selection of an asphalt cement to resist rutting.

4) SUPERPAVE MIX RESULTS

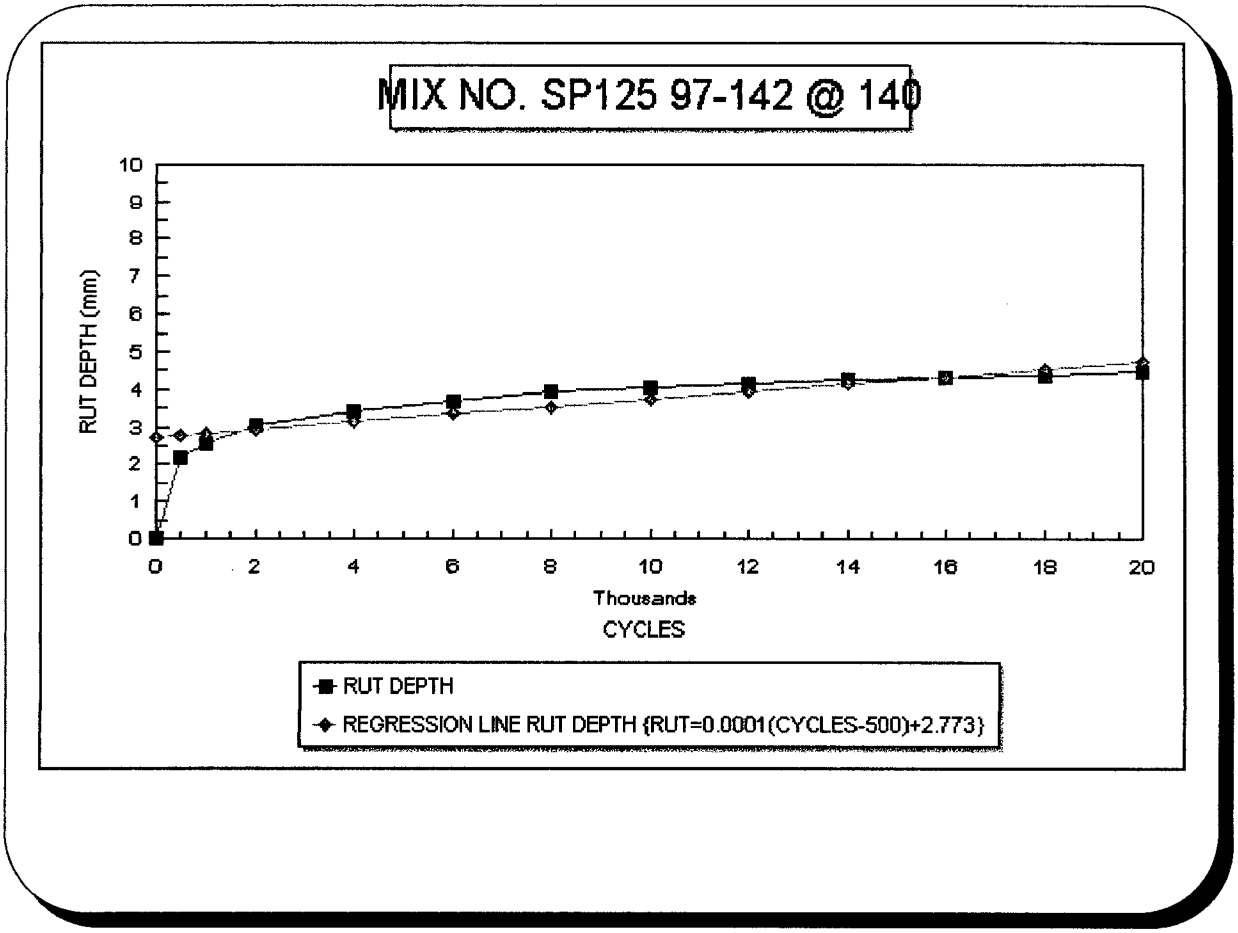
D) RUT DEPTH V.S. NUMBER OF TEST CYCLES

Graph No. 28 - Superpave Mix SP96-418



The graph above depicts rut depth versus test cycles. This particular mix was selected as one of the two mixes for a three year monitoring. It was selected because it contained 25% gravel and was the only Superpave mix in the study which displayed the stripping inflection point at 18,000 cycles. The slope of the line from zero to 500 cycles is designated as post compaction consolidation, the slope of the line from 500 to 18,000 cycles is designated as the creep slope, and the slope of the line from 18,000 to 20,000 cycles is designated as the stripping slope. (1) The regression line was calculated only for the creep slope, because it would be expected that approximately 1.7 mm of rutting will be induced into the pavement from post compaction consolidation.

Graph No. 29 - Superpave Mix SP97-142



The graph above depicts rut depth versus test cycles. This particular mix was selected as one of the two mixes for a three year monitoring. The slope of the line from zero to 500 cycles is designated as post compaction consolidation and, the slope of the line from 500 to 20,000 cycles is designated as the creep slope. (1) The regression line was calculated only for the creep slope, because it would be expected that approximately 2.8 mm of rutting will be induced into the pavement from post compaction consolidation.

4) SUPERPAVE MIX RESULTS

E) SUMMARY OF RESULTS

There is a total of fourteen Superpave mixes representing these rut depth results. The fourteen mixes are composed of nine - 12.5 mm mixes, four - 19.0 mm mixes, and one - 25.0 mm mix. With the exception of Rut Depth V.S. Asphalt Cement Specific Gravity at 15.6° C, the results indicate text book behavior. And again, when it comes to the selection of an asphalt cement to help resist rutting, the G*/sin delta value is more significant than the Specific Gravity at 15.6° C. The higher the G*/sin delta value the less prone the bituminous mixture will be to rutting.

Two Superpave mixes were selected to be monitored in the field. These two mixes were selected because of their different rutting characteristics. One mix contained 25% gravel and was the only mix to display the stripping inflection point and stripping slope. The other mix was selected because it represented a typical Superpave 12.5 mm mix. They are depicted in graphs 28 & 29. It was noted that between zero to 500 cycles the slope of the line is designated as the post compaction consolidation line. Therefore, it can be expected that the laboratory rut depth at 500 cycles should correlate to the amount of rutting in the field which actual wheel loads will induce into the pavement directly after it was opened to traffic.

OVERALL SUMMARY OF RESULTS AND CONCLUSIONS

The objectives of the study were met. The answer to whether the Georgia Loaded Wheel Tester (LWT) can be used as a laboratory proof tester of bituminous mixes, is yes. Since almost all of the rutting analysis on the mix design properties and combined aggregate properties indicated text book behavior, it can be concluded that this correlation substantiates that the LWT can be used in the laboratory as a proof tester for rutting.

There is a total of forty dense graded surface mixes, thirty three I-C mixes and seven LP mixes, that was analyzed in the study. This is a large sample size and can be considered a complete population. With the exception of Rut Depth V.S. Marshall flow values and Rut Depth V.S. Asphalt Cement Specific Gravity at 15.6° C, the rest of the results indicate text book behavior. Several other items of interest can be deduced from the results on the forty dense graded surface mixes. In the mix design properties, the Marshall stability values are more significant than Marshall flow values in predicting if a bituminous mixture is prone to rutting. In the combined aggregate properties, a decreased potential for rutting of a bituminous mixture can be achieved by increasing the amount of material, in the combined aggregate gradation, which passes the #50 and #100 sieve. And, when it comes to the selection of an asphalt cement to help resist rutting, the G*/sin delta value is more significant than the Specific Gravity at 15.6° C. The higher the G*/sin delta value the less prone the bituminous mixture will be to rutting.

The results from the thirteen binder mixes did not yield the same text book behavior as did the results of the forty surface mixes. The reason for this is unknown, one can only speculate that pertinent information could not be yielded from the limited amount of mixes tested. There was only one mix design property, stability, which displayed the same text book behavior as the surface mixes. Here again, as the stability increased the rut depth decreased. There was only one combined aggregate property, percent natural sand, which displayed the same text book behavior as the surface mixes. Here again, as the percent of natural sand in a mix increased, the rut depth increased. And, the asphalt cement characteristic of G*/sin delta again proved to be influential on deterring rutting. The binder mixes displayed the same behavior as the surface mixes, as the G*/sin delta increased, the rutting decreased.

The results from the nine SMA mixes did not yield the same text book behavior as did the results of the forty surface mixes. One reason for this is the difference in aggregate structure, coarse gap graded for an SMA versus a fine dense graded for the conventional surface mixes. Here again there may be other reasons, one can only speculate that pertinent information could not be yielded from the limited amount of mixes tested. But again as before, the mix design property, stability, displayed the same text book behavior as in the surface mixes and the binder mixes. Here again, as the stability increased the rut depth decreased. And again, the asphalt cement characteristic of G*/sin delta proved to be influential on deterring rutting. The SMA mixes displayed the same behavior as the surface mixes and the binder mixes, as the G*/sin delta increased, the rutting decreased.

There is a total of fourteen Superpave mixes representing these rut depth results. The fourteen mixes are composed of nine - 12.5 mm mixes, four - 19.0 mm mixes, and one - 25.0 mm mix. With the exception of Rut Depth V.S. Asphalt Cement Specific Gravity at 15.6° C, the results indicate text book behavior. And again, when it comes to the selection of an asphalt cement to help resist rutting, the G*/sin delta value is more significant than the Specific Gravity at 15.6° C. The higher the G*/sin delta value the less prone the bituminous mixture will be to rutting.

In the analysis of rut depth verses asphalt cement characteristics, two asphalt cement characteristics were selected. The specific gravity at 15.6° C was selected because as the specific gravity of an asphalt cement increases there is usually a corresponding increase in viscosity. This in turn means a stiffer asphalt cement, and a stiffer asphalt cement should resist rutting. And, the G*/sin delta was selected because it represents both the viscous and elastic behavior of the asphalt cement. From all of the analysis in this study, the G*/sin delta value proved to be substantial when selecting an asphalt cement to resist rutting. As the G*/sin delta value increased the potential for rutting decreased. This correlates with a research project conducted by the Transportation Research Board. The research study concluded that as G*/sin delta increases, rut depths decrease. ***(1)***

From the analysis of all the Marshall mix designs, dense graded mixes and SMA, the Marshall stability results proved to be a substantial indicator for rutting potential. As the stability of a mix increased, the potential for rutting decreased.

From the analysis of the dense graded Marshall mix designs and the Superpave mix designs, as the percent passing the #50 sieve and #100 sieve material increased, the potential for rutting decreased. This was prevalent in the dense graded Marshall surface mixes, the dense graded Marshall binder mixes, and to the Superpave mixes. With one exception, the correlation was not present in the percent passing the #100 sieve for the Superpave mixes. This correlates with a research project conducted by the Georgia Institute of Technology. The research project concluded that as the percent of material passing the #50 and #100 sieves increase, the rut depth potential decreases. (3)

REFERENCES

(1) Richard P. Izzo University of Rhode Island & Kevin D Stuart Federal Highway Administration, "Correlation of Superpave G*/Sin Delta with Rutting Susceptibility from Laboratory Mixture Tests", Transportation Research Board 74th Annual Meeting, Paper No. 950917

(2) Haroon I. Shami, James S. Lai, John A. D' Angelo, and Thomas P. Harman, "Development of Temperature-Effect Model for Predicting Rutting of Asphalt Mixtures Using Georgia Loaded Wheel Tester", Transport Research Record 1590

(3) Donald E. Watson, Andrew Johnson, and David Jared Georgia Department of Transportation, "The Superpave Gradation Restricted Zone and Performance Testing with the Georgia Loaded Wheel Tester", Transportation Research Board 76th Annual Meeting, Paper No. 970677

APPENDICES

Appendix (A) - Summary of Results on all Mixes in the Study
Appendix (B) - I-B Mixes Rut Depth V.S. Mix Design Properties, Combined Aggregate Properties, and Asphalt Cement Properties.
Appendix (C) - SMA Mixes Rut Depth V.S. Mix Design Properties and Asphalt Cement Properties.

Appendix (A)
Summary of Results on all Mixes in the Study

75 BLOW MARSHALL DENSE GRADED SURFACE MIXES

MIX NUMBER	Gmm (D)	% A.C.	Gmb	Va	STABILITY	FLOW	VMA	VFA	RUT @ 105° F 8,000 (mm)	RUT @ 140° F 8,000 (mm)	PERCENT NATURAL SAND	G*/SIN DELTA @64° C	PG GRADE	15.6° C ASPH. Sp. Gr.	MIX NUMBER	% PASSING #50	% PASSING #100
IC97-180	2.446	5.1	2.334	4.58	3937	11	16.14	71.6	4.23	4.36	9	1.28	64-28	1.035	IC97-180	9.3	5.5
IC97-184	2.493	5.0	2.393	4.01	4626	12	15.78	74.6	1.85	3.6	8	1.19	64-28	1.023	IC97-184	8	5.4
IC97-185	2.445	5.4	2.346	4.05	4450	12	16.43	75.4	1.87	2.83	9.4	1.19	64-28	1.023	IC97-185	9.4	6
IC97-193	2.478	4.7	2.383	3.83	3440	12	14.52	73.6	3.38	4.8	14	1.10	64-22	1.038	IC97-193	11.3	7.3
IC97-204	2.496	5.1	2.399	3.89	3463	12	15.8	75.4	3.01	4.81	8	1.00	64-22	1.032	IC97-204	8.7	5.9
IC97-209	2.461	5.2	2.346	4.67	3820	10	16.48	71.6	4.37	5.33	15	1.30	64-22	1.035	IC97-209	9.8	6.1
IC97-232	2.461	5.5	2.356	4.27	2804	11	16.78	74.6	3.73	6.04	15	1.00	64-22	1.032	IC97-232	10.3	5.7
IC97-255	2.42	5.0	2.321	4.09	3824	13	15.43	73.5	3.82	7.24	12.5	1.24	64-28	1.030	IC97-255	9.6	6.2
IC97-272	2.453	5.4	2.351	4.16	3483	10	16.49	74.8	4.98	5.3	15	1.24	64-28	1.030	IC97-272	9.8	6.2
IC97-293	2.519	4.3	2.418	4.01	3296	12	14.14	71.6	1.77	3.54	8.4	1.26	64-28	1.028	IC97-293	10.6	6.3
IC97-294	2.56	4.7	2.448	4.37	3080	12	15.37	71.5	5.12	5.86	15	1.20	64-22	1.038	IC97-294	9	5.4
IC97-305	2.48	5.5	2.345	4.67	2993	11	17.13	72.7	2.7	4.87	8	1.00	64-22	1.032	IC97-305	9.1	5.9
IC97-307	2.471	4.2	2.378	3.76	3982	10	13.42	72.0	2.36	4.13	15	1.25	64-28	1.036	IC97-307	11.7	5.9
IC97-342	2.496	4.6	2.391	4.21	2664	11	14.86	71.7	4.32	4.92	15	1.25	64-28	1.032	IC97-342	8.6	5.7
IC97-388	2.451	4.9	2.347	4.24	4063	12	15.38	72.4	2.17	3.78	0	1.20	64-22	1.021	IC97-388	8.2	5.2
IC97-400	2.54	4.3	2.434	4.17	4545	11	14.41	71.0	2.02	3.35	10	1.86	64-28	1.025	IC97-400	12.4	7.1
IC97-403	2.495	4.3	2.392	4.13	4020	14	14.24	71.0	2.42	3.73	0	1.20	64-22	1.021	IC97-403	8.8	5.7
IC97-420	2.485	4.6	2.381	4.19	3526	11	14.68	71.5	5.88	5.22	15	1.16	64-22	1.038	IC97-420	10.3	5.8
IC97-455	2.486	4.7	2.381	4.22	3156	13	14.98	71.8	3.32	5.25	10	1.28	64-28	1.035	IC97-455	9.4	5
IC97-459	2.458	5.1	2.361	3.95	3470	12	15.69	74.8	3.6	4.02	8	1.31	64-22	1.031	IC97-459	8.1	4.9
IC97-460	2.454	5.2	2.357	3.95	3293	13	15.86	75.1	3.05	5.33	9.4	1.12	64-22	1.031	IC97-460	9.4	6
IC97-461	2.484	4.4	2.371	4.55	3714	12	14.61	68.9	3.47	5.23	14.5	1.25	64-28	1.036	IC97-461	12.1	7.7
IC97-502	2.479	4.6	2.362	4.72	2375	9	15.23	69.0	3.44	6.69	15	1.24	64-28	1.030	IC97-502	8.2	4.4
IC97-504	2.506	4.8	2.393	4.51	3311	11	15.56	71.0	3.36	3.54	10	1.34	64-22	1.034	IC97-504	10.2	5.9
IC97-517	2.546	4.7	2.427	4.67	3708	11	15.73	70.3	2.16	2.84	13	1.19	64-28	1.023	IC97-517	11.7	5.5
IC97-527	2.512	4.7	2.409	4.10	2680	10	15.03	72.7	3.84	8.16	8	1.00	64-22	1.032	IC97-527	9.8	5.7
IC97-537	2.479	5.2	2.361	4.76	3334	11	16.74	71.6	2.67	3.64	8	1.26	64-28	1.028	IC97-537	8.9	6.4
IC97-539	2.467	4.6	2.357	4.46	3084	10	14.94	70.2	1.88	3.39	10	1.24	64-28	1.030	IC97-539	9.9	6.1
IC97-564	2.451	4.6	2.333	4.81	3767	11	15.26	68.5	3.12	4.64	0	1.20	64-22	1.021	IC97-564	8.5	6.3
IC97-565	2.482	4.7	2.367	4.63	3097	12	15.47	70.0	1.87	4.27	10	1.20	64-22	1.021	IC97-565	11.7	4.8
IC97-573	2.452	4.6	2.336	4.73	3852	10	15.05	68.6	2.07	2.63	0	1.28	64-28	1.035	IC97-573	8.2	5.8
IC97-575	2.539	4.7	2.421	4.65	3008	11	15.58	70.2	3.2	3.04	10	1.25	64-22	1.037	IC97-575	12.4	7
IC97-584	2.486	4.5	2.373	4.55	2606	9	14.91	69.5	3.09	5.33	10	1.24	64-28	1.030	IC97-584	8.9	6.1
LS97-198	2.776	4.7	2.649	4.57	3652	12	16.64	72.5	2.54	3.38	8	1.08	64-28	1.027	LS97-198	11.5	7.1
LP97-21	2.458	5	2.342	4.72	3358	14	16.14	70.8	1.8	4.43	10	1.17	64-22	1.035	LP97-21	11.5	6.7
LP97-36	2.463	5	2.365	3.98	2708	12	15.5	74.3	2.06	5.13	8	1.00	64-22	1.032	LP97-36	10.4	6.5
LP97-82	2.48	4.6	2.377	4.15	3535	16	14.6	71.6	3.14	3.76	10	1.16	64-22	1.038	LP97-82	12	7.9
LP97-115	2.457	4.9	2.348	4.44	2823	14	15.57	71.5	2.91	2.87	15	1.19	64-28	1.023	LP97-115	10.9	7
LP97-154	2.466	4.9	2.362	4.22	2691	14	15.4	72.6	4.01	5.41	10	1.08	64-28	1.027	LP97-154	10.9	6.7
LP97-220	2.459	4.9	2.357	4.15	2251	14	15.23	72.8	4.31	5.69	15	1.28	64-22	1.032	LP97-220	10.9	7
AVERAGE	2.487	4.8	2.379	4.3	3387	11.7	15.4	72.0	3.12	4.56	10.1	1.21		1.030		10.0	6.1
STD. DEV.	0.056	0.3	0.053	0.3	573	1.5	0.8	1.9	1.02	1.24	4.3	0.14		0.005		1.3	0.8

75 BLOW MARSHALL DENSE GRADED BINDER MIXES

MIX NUMBER	Gmm (D)	% A.C.	Gmb	Va	STABILITY	FLOW	VMA	VFA	RUT @ 105° F 8,000 (mm)	RUT @ 140° F 8,000 (mm)	PERCENT NATURAL SAND	G*/SIN DELTA @64° C	PG GRADE	15.6° C ASPH. Sp. Gr.	MIX NUMBER	% PASSING #60	% PASSING #100
IB97-101	2.488	4.5	2.391	3.90	3803	13	14.23	72.6	3.74	5.2	9	1.17	64-22	1.035	IB97-101	9.6	5.8
IB97-164	2.475	4.5	2.368	4.32	4229	11	14.61	70.4	2.75	3.65	9.3	1.12	64-22	1.031	IB97-164	9.5	5.9
IB97-198	2.507	4.7	2.402	4.19	3477	14	15.03	72.1	4.07	5.33	8	1.42	64-22	1.037	IB97-198	7.3	4.9
IB97-233	2.46	4.7	2.367	3.78	3906	12	14.45	73.8	3.02	4.21	8	1.14	64-22	1.037	IB97-233	8.1	4.8
IB97-235	2.442	4.2	2.343	4.05	3955	13	13.59	70.2	3.89	3.95	13	1.30	64-22	1.035	IB97-235	8.9	5.7
IB97-279	2.572	4.1	2.476	3.73	3847	11	13.55	72.5	5.42	6.45	15	1.20	64-22	1.038	IB97-279	8.3	4.8
IB97-352	2.499	4.1	2.395	4.16	3806	11	13.72	69.7	2.54	5.57	9	1.28	64-22	1.032	IB97-352	9.9	6
IB97-387	2.526	4.3	2.421	4.16	3294	12	14.25	70.8	3.47	6.93	8	1.00	64-22	1.032	IB97-387	8.9	5
IB97-389	2.513	4.1	2.417	3.82	2912	11	13.48	71.7	3.59	5.88	12	1.28	64-22	1.032	IB97-389	7.9	5.3
IB97-423	2.546	4.1	2.448	3.85	3423	10	13.59	71.7	1.78	4.43	10	1.25	64-22	1.037	IB97-423	11.7	6.6
IB97-429	2.472	4	2.36	4.53	3831	12	13.71	67.0	2.89	4.92	14	1.28	64-22	1.032	IB97-429	10.1	4.6
IB97-469	2.493	4.2	2.383	4.41	3369	12	14.08	68.7	2.44	6.8	13	1.16	64-22	1.038	IB97-469	11.5	7.4
IB97-536	2.508	4.5	2.395	4.51	3487	12	14.95	69.9	3.8	5.36	8	1.00	64-22	1.032	IB97-536	7.5	5.2
AVERAGE	2.500	4.3	2.397	4.11	3641	11.8	14.10	70.8	3.34	5.28	10.5	1.20		1.034		9.2	5.5
STD. DEV.	0.035	0.2	0.037	0.28	350	1.1	0.54	1.8	0.92	1.05	2.6	0.12		0.003		1.4	0.8

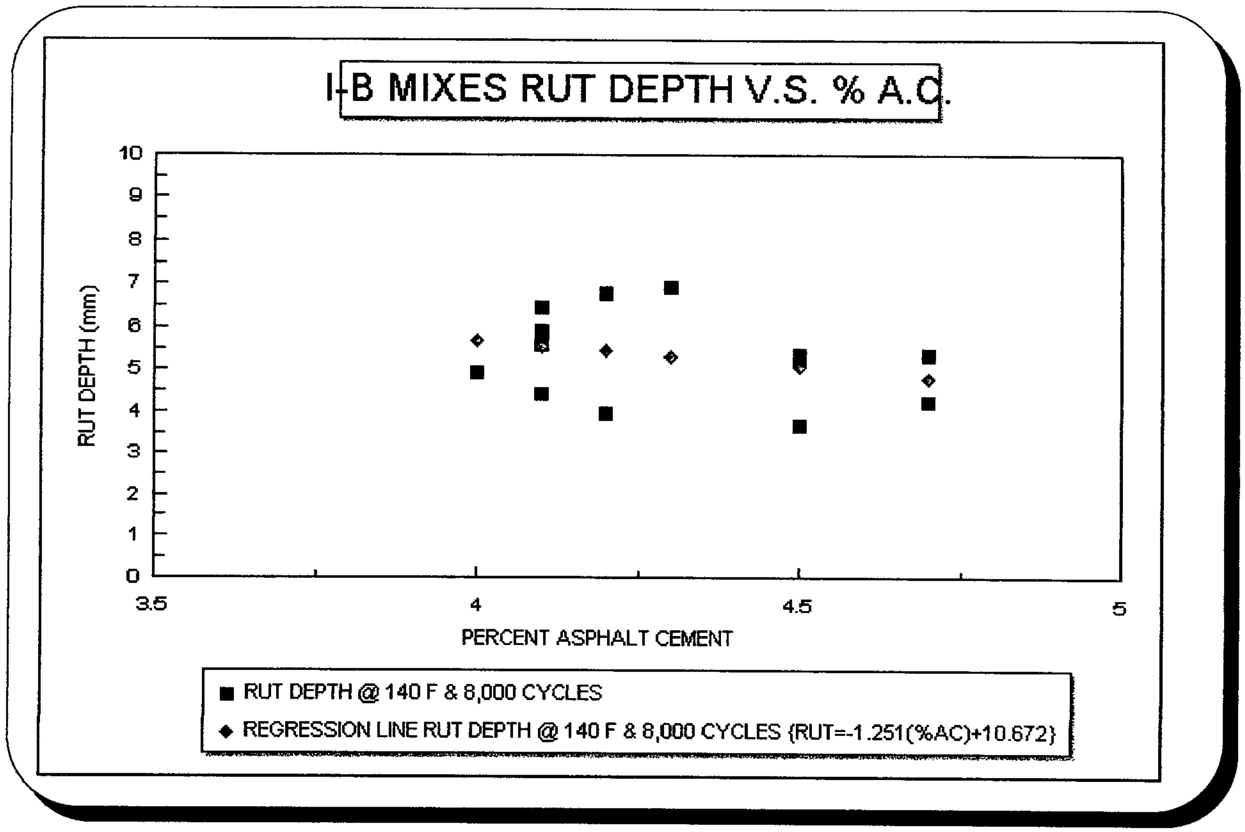
50 BLOW MARSHALL SMA MIXES

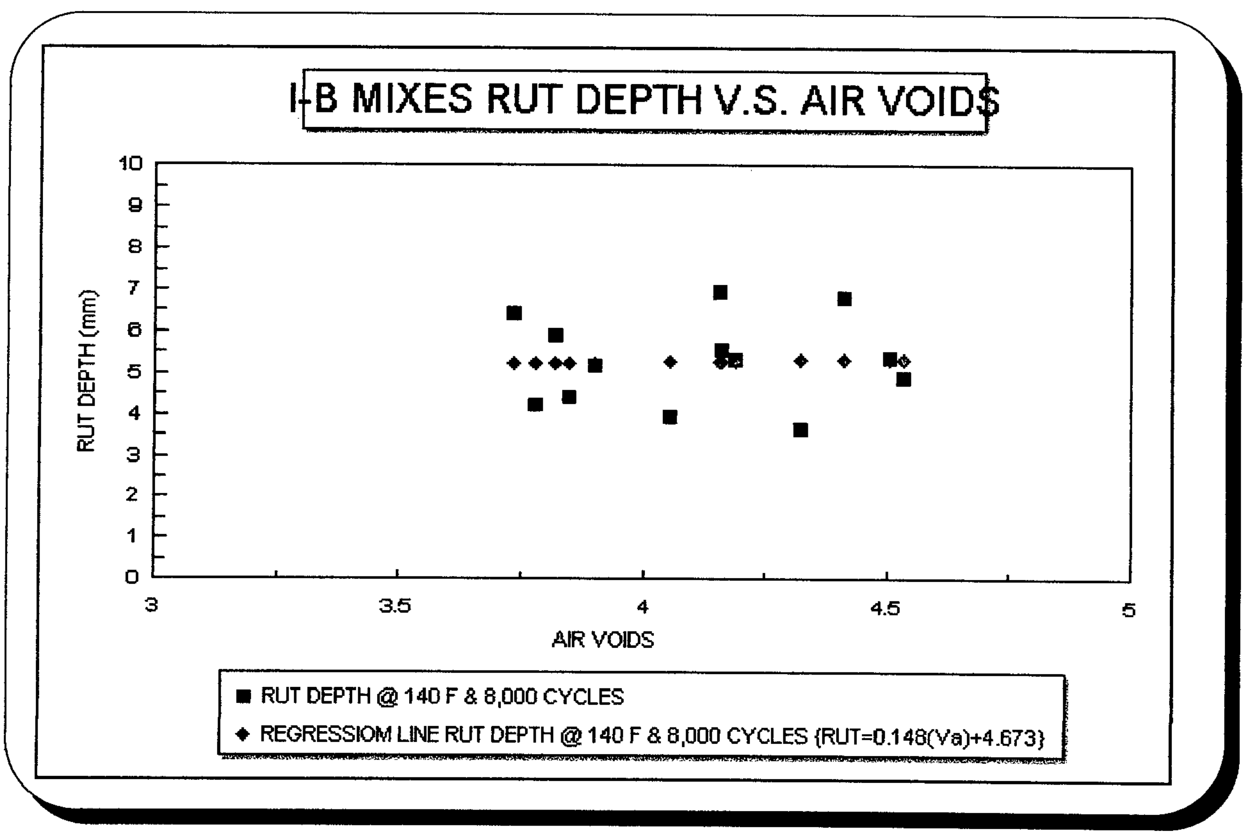
MIX NUMBER	Gmm (D)	% A.C.	Gmb	Va	STABILITY	FLOW	VMA	VFA	RUT @ 105° F 8,000 (mm)	RUT @ 140° F 8,000 (mm)	PERCENT NATURAL SAND	G*/SIN DELTA @64° C	PG GRADE	15.6° C ASPH. Sp. Gr.	MIX NUMBER
SM97-54	2.416	6	2.312	4.30	1601	19	17.87	75.9	4.02	5.04	0	1.08	64-28	1.027	SM97-54
SM97-71	2.378	6.5	2.279	4.16	2182	19	17.5	76.2	2.87	4.18	0	1.19	64-28	1.023	SM97-71
SM97-78	2.378	6.5	2.276	4.29	1857	24	18.68	77.0	4.64	4.03	0	1.12	64-22	1.031	SM97-78
SM97-94	2.695	6	2.585	4.08	2253	19	18.94	78.4	2.99	3.51	0	1.22	64-28	1.042	SM97-94
SM97-106	2.69	6.1	2.579	4.13	1967	13	19.27	78.6	3.74	4.7	0	1.20	64-22	1.038	SM97-106
SM97-109	2.431	6.6	2.321	4.52	1641	21	19.83	74.9	2.84	4.18	0	1.24	64-28	1.030	SM97-109
SM97-141	2.418	6	2.312	4.38	1923	15	17.94	75.6	3.61	4.3	0	1.19	64-28	1.023	SM97-141
SM97-213	2.416	6.1	2.309	4.43	2664	17	18	75.4	2.29	3.36	0	1.17	76-22	1.035	SM97-213
SM97-222	2.685	6	2.573	4.17	1630	12	18.15	77.0	1.98	4.58	0	1.24	64-28	1.030	SM97-222
AVERAGE	2.501	6.2	2.394	4.27	1969	17.7	18.46	76.6	3.22	4.21	0.00	1.18		1.031	
STD. DEV.	0.143	0.3	0.140	0.15	350	3.8	0.76	1.3	0.85	0.54	0.00	0.05		0.006	

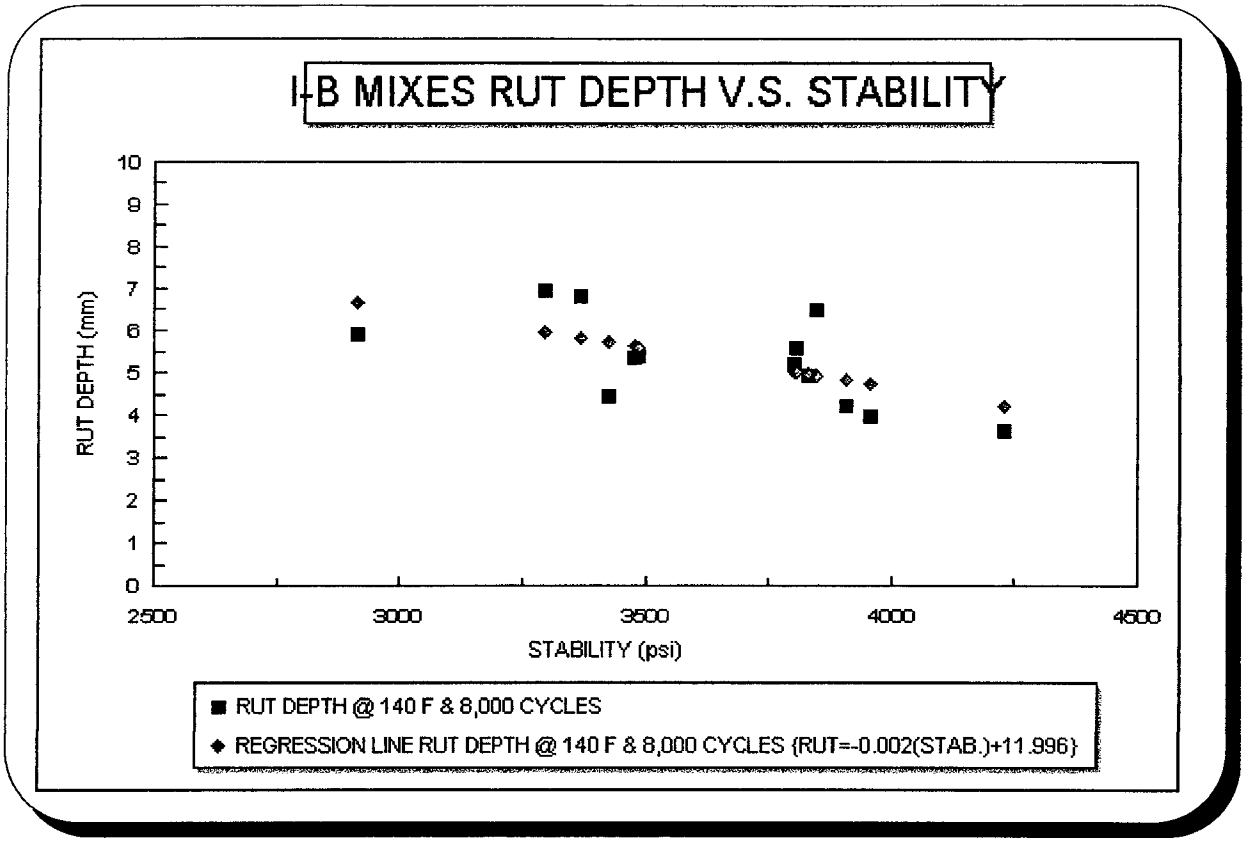
SUPERPAVE MIXES, 12.5 mm, 19.0 mm, & 25.0 mm

MIX NUMBER	% A.C.	VFA	RUT @ 140° F 20,000 (mm)	G*/SIN DELTA @64° C	MIX NUMBER	% PASSING #50	% PASSING #100
SP125					**SP125**		
96-418	6.2	72	3.88	1.34	96-418	9.6	5.6
96-421	5.5	73	5.11	1.28	96-421	7.6	5.1
96-422	5.2	73	4.65	1.34	96-422	7.6	5.1
96-423	5.3	73	5.5	0.63	96-423	7.6	5.1
96-424	5.1	72	2.84	1.83	96-424	7.6	5.1
LP 96-547	5.7	71	4.74	1.08	LP 96-547	8.5	6
97-81	5.9	68	3.65	1.86	97-81	8.8	6.1
97-88	5.8	71	3.86	1.26	97-88	7.6	5.3
97-142	5.6	70	4.47	1.86	97-142	8.7	5.4
SP190					**SP190**		
96-420	4.7	70	3.9	1.34	96-420	6.3	4.1
97-57	5.3	68	3.09	1.81	97-57	7.8	5.4
97-85	5.3	70	4.56	1.26	97-85	7.6	5.4
97-106	5.5	71	3.51	1.86	97-106	8.2	4.9
SP250					**SP250**		
97-12	4.5	67	3.77	1.25	97-12	6.9	4.6

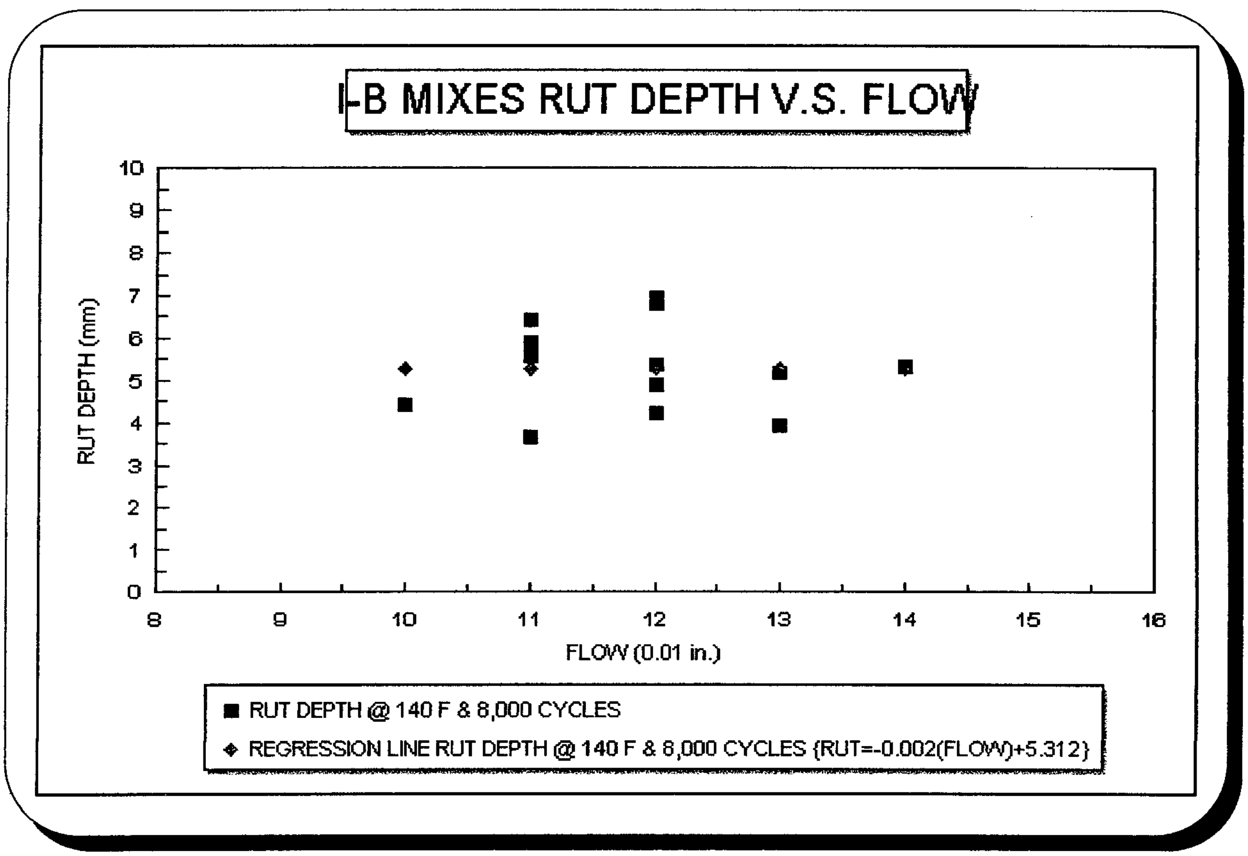
Appendix (B)
I-B Mixes Rut Depth V.S. Mix Design Properties, Combined Aggregate Properties, and Asphalt Cement Properties.


I-B MIXES RUT DEPTH V.S. % A.C.
RUT DEPTH (mm)
PERCENT ASPHALT CEMENT
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=-1.251(%AC)+10.672}

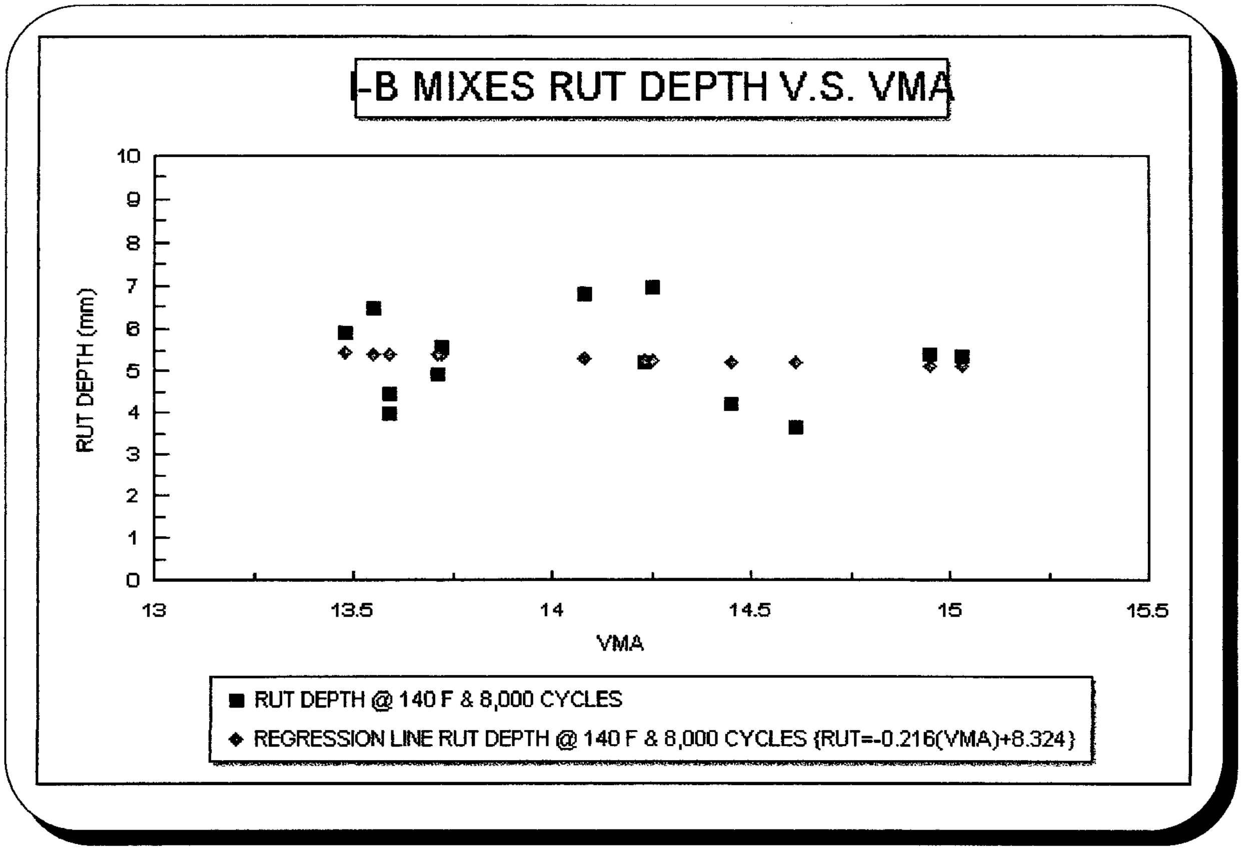

I-B MIXES RUT DEPTH V.S. AIR VOIDS
RUT DEPTH (mm)
AIR VOIDS
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSIOM LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=0.148(Va)+4.673}

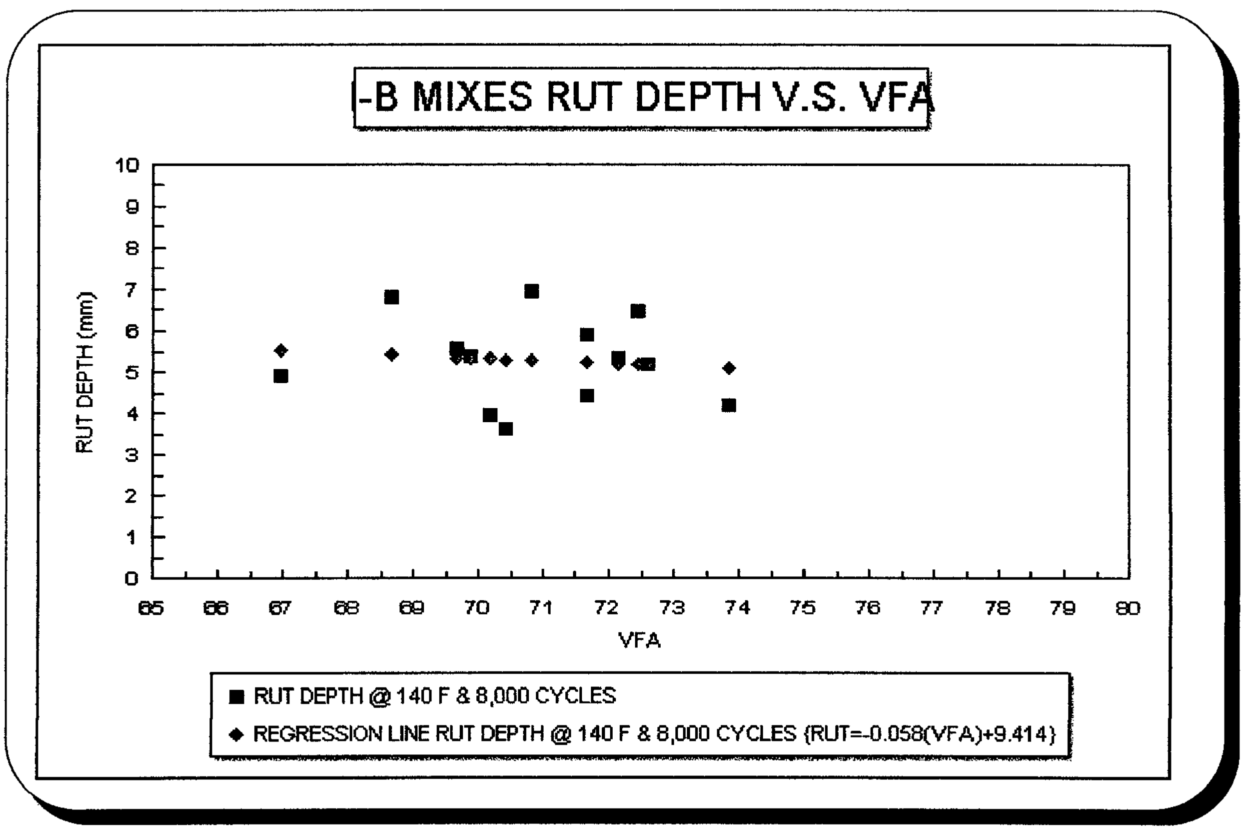


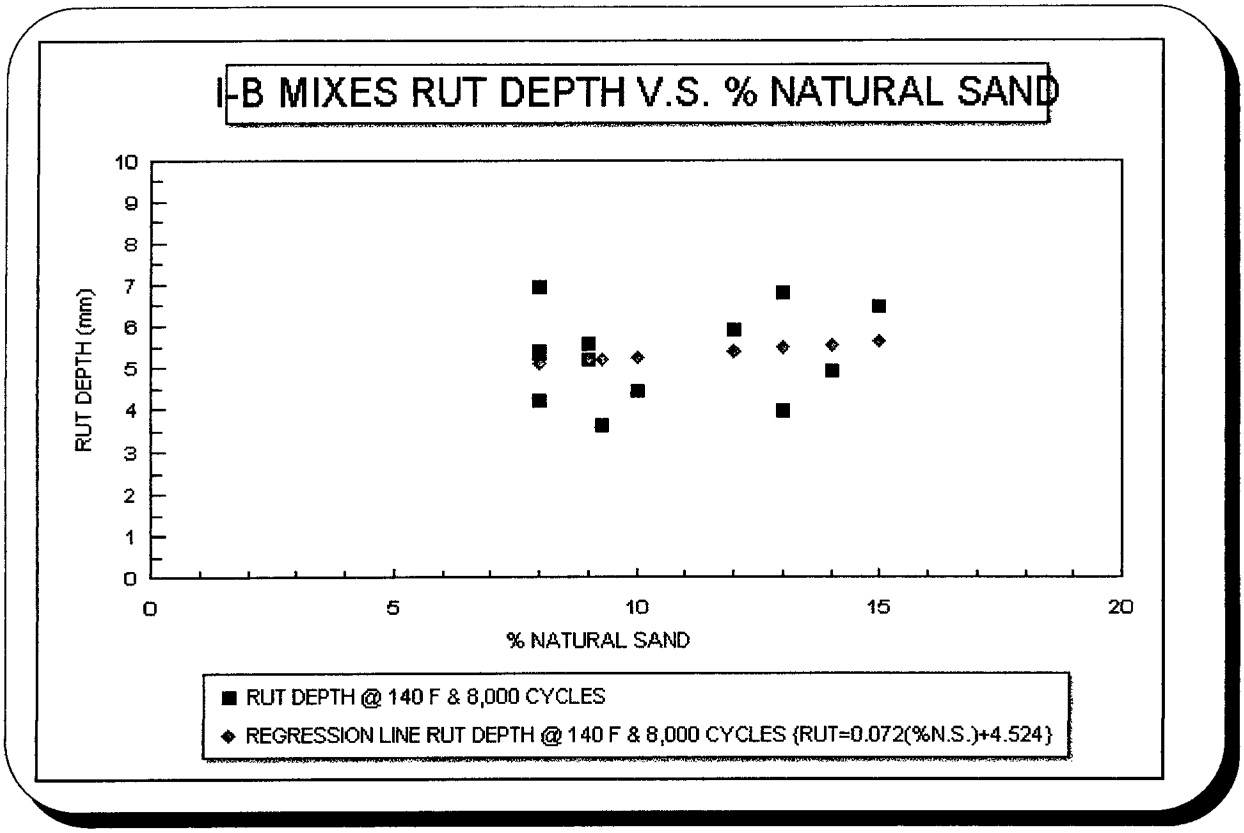
I-B MIXES RUT DEPTH V.S. STABILITY
RUT DEPTH (mm)
STABILITY (psi)
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=-0.002(STAB.)+11.996}

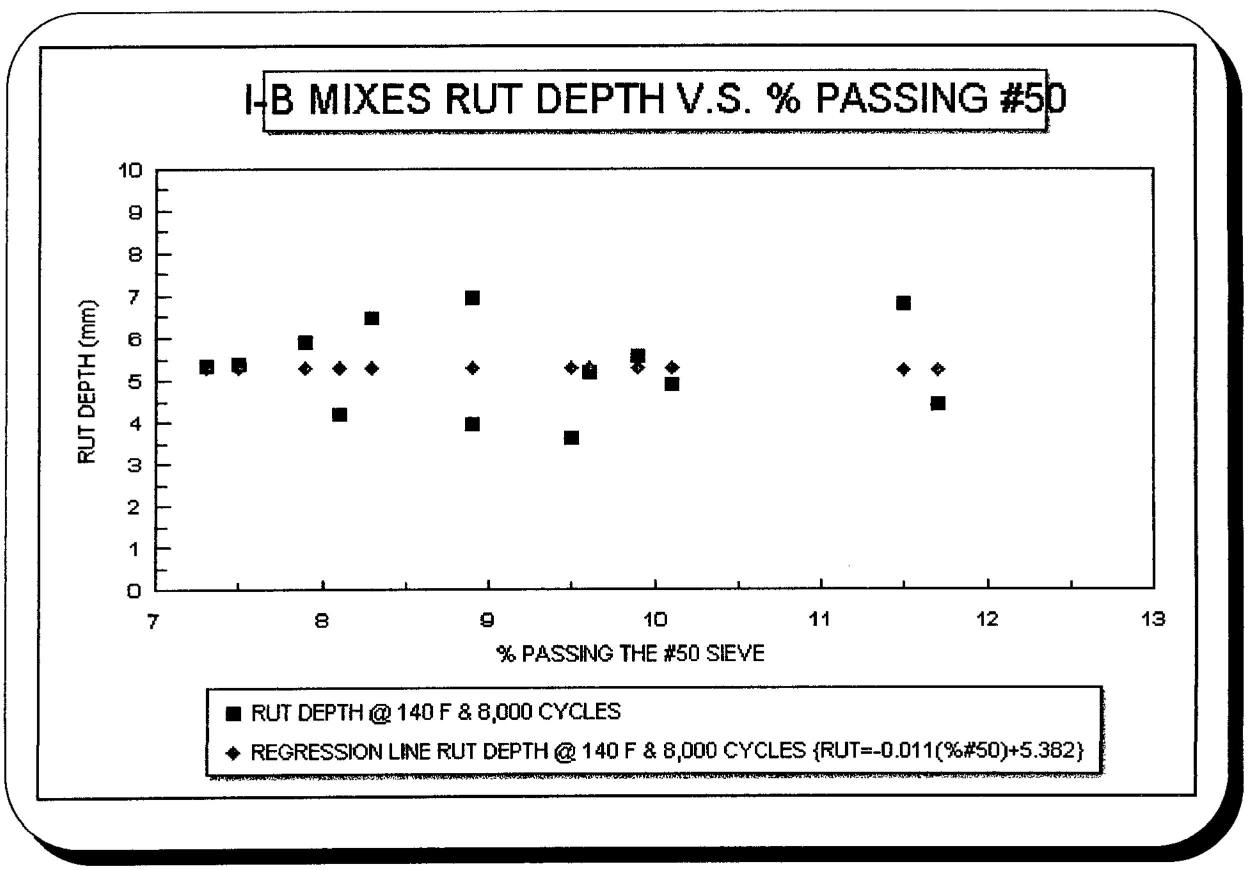


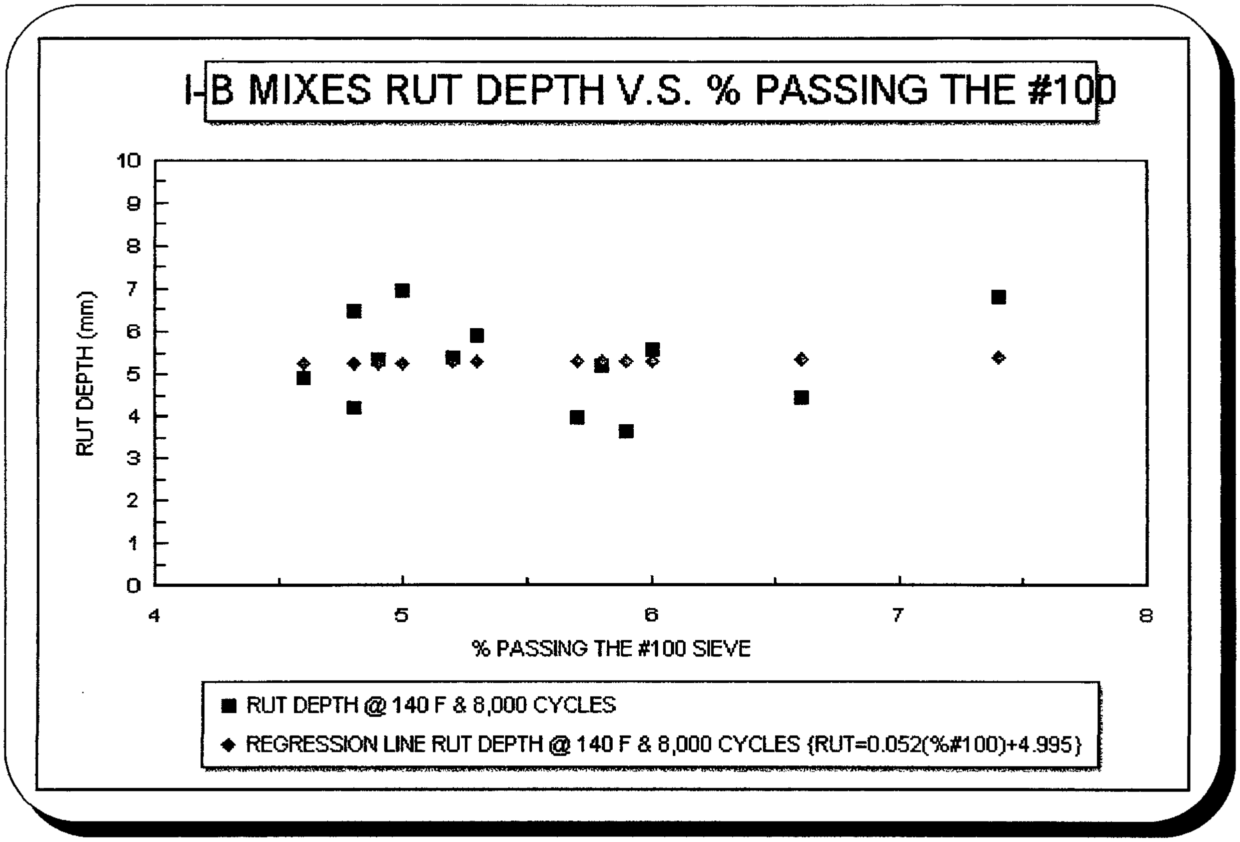
I-B MIXES RUT DEPTH V.S. FLOW
RUT DEPTH (mm)
FLOW (0.01 in.)
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=-0.002(FLOW)+5.312}

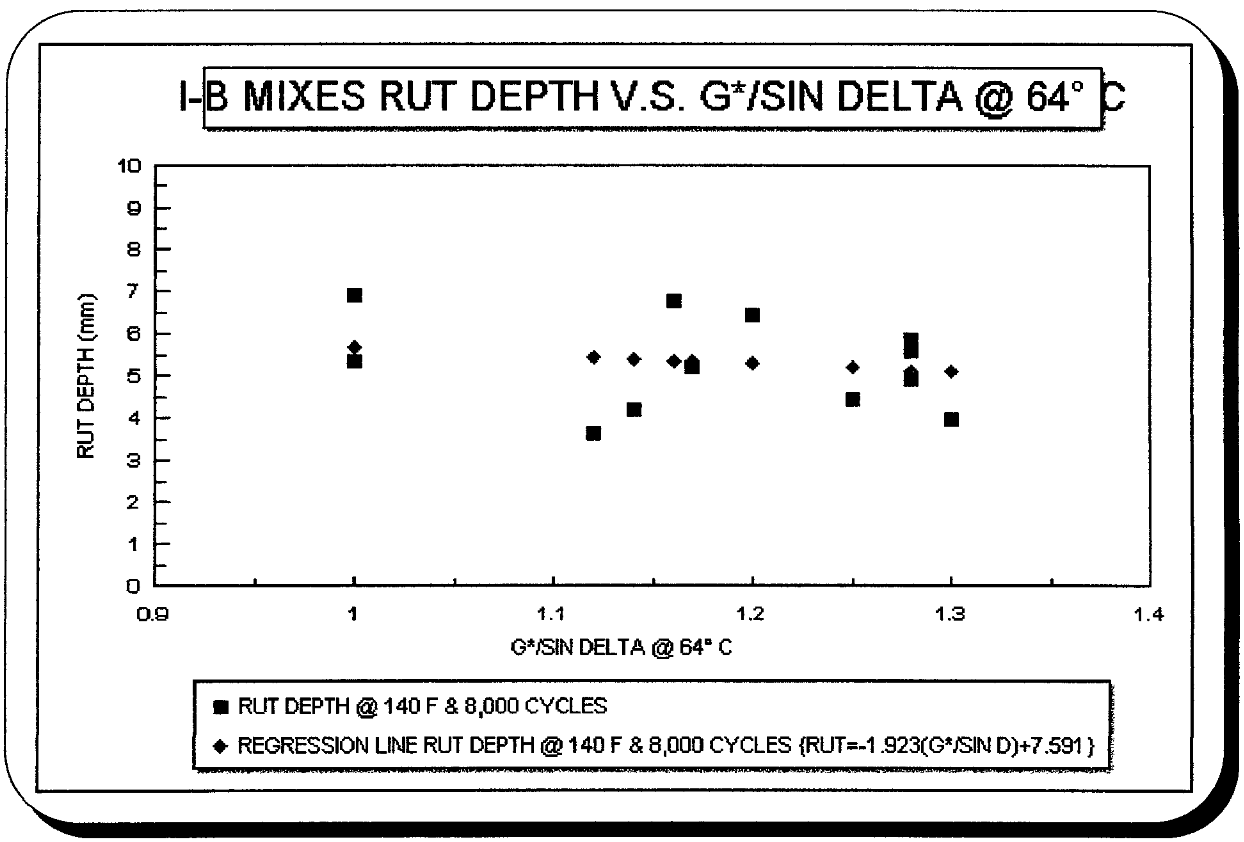

I-B MIXES RUT DEPTH V.S. VMA
RUT DEPTH (mm)
0
1
2
3
4
5
6
7
8
9
10
13
13.5
14
14.5
15
15.5
VMA
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=-0.216(VMA)+8.324}

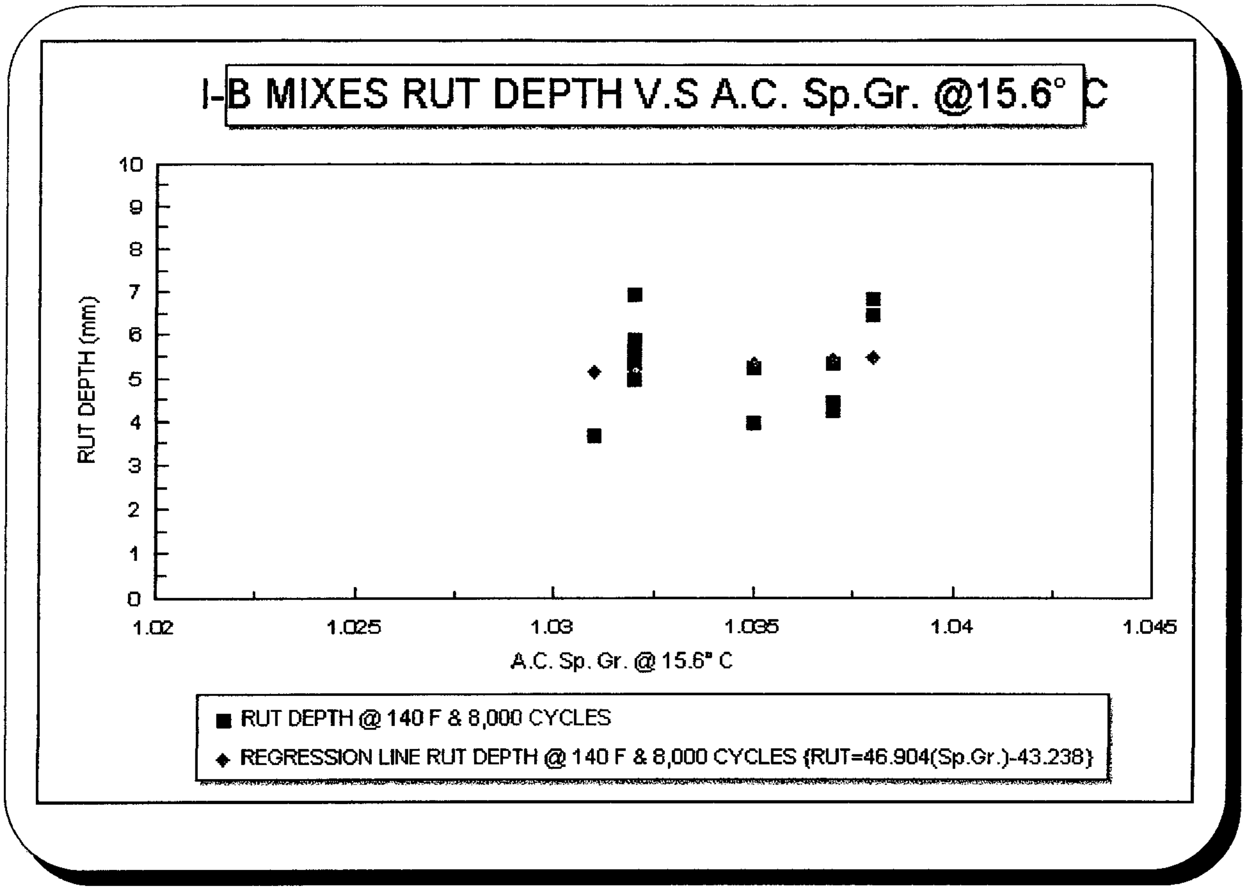

I-B MIXES RUT DEPTH V.S. VFA
RUT DEPTH (mm)
0
1
2
3
4
5
6
7
8
9
10
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
VFA
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=-0.058(VFA)+9.414}


I-B MIXES RUT DEPTH V.S. % NATURAL SAND
RUT DEPTH (mm)
% NATURAL SAND
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=0.072(%N.S.)+4.524}

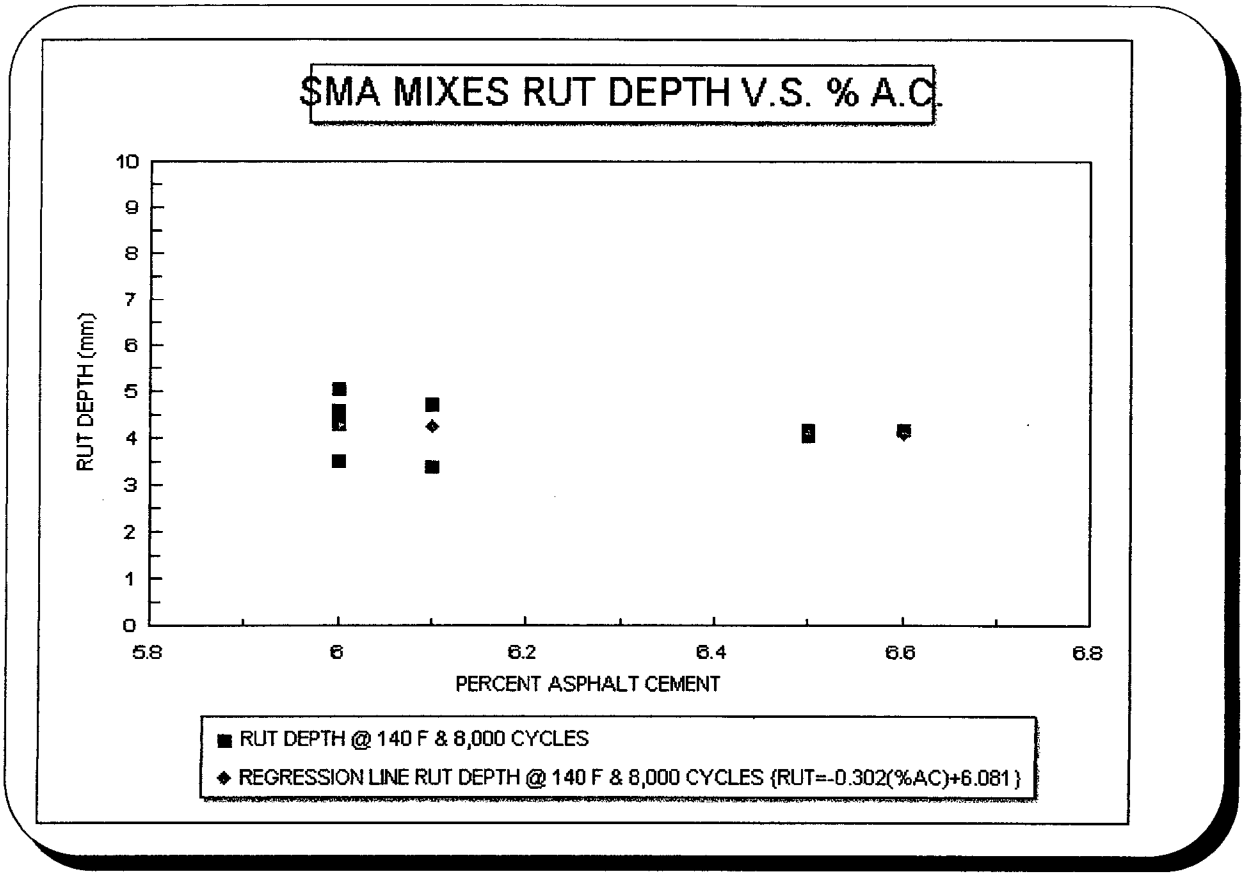

I-B MIXES RUT DEPTH V.S. % PASSING #50
RUT DEPTH (mm)
% PASSING THE #50 SIEVE
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=-0.011(%#50)+5.382}

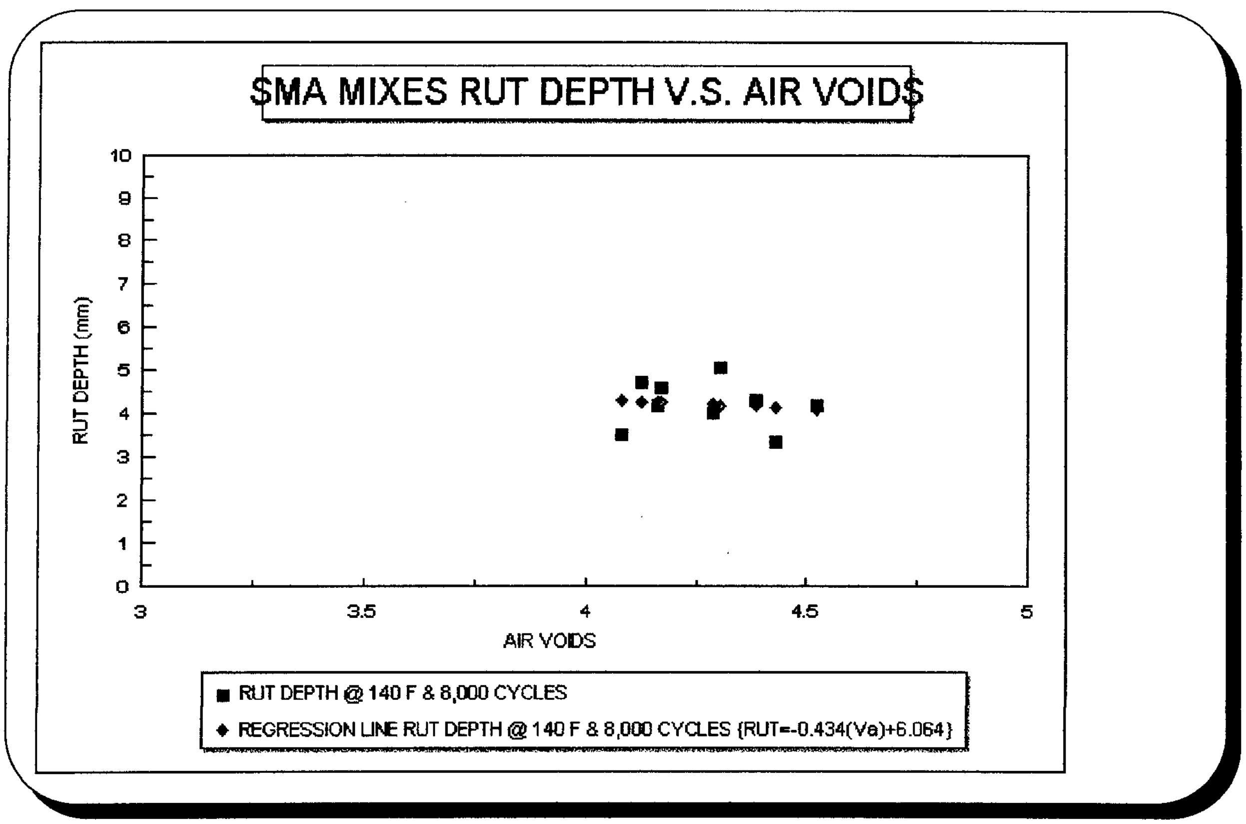

I-B MIXES RUT DEPTH V.S. % PASSING THE #100
RUT DEPTH (mm)
% PASSING THE #100 SIEVE
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=0.052(%#100)+4.995}

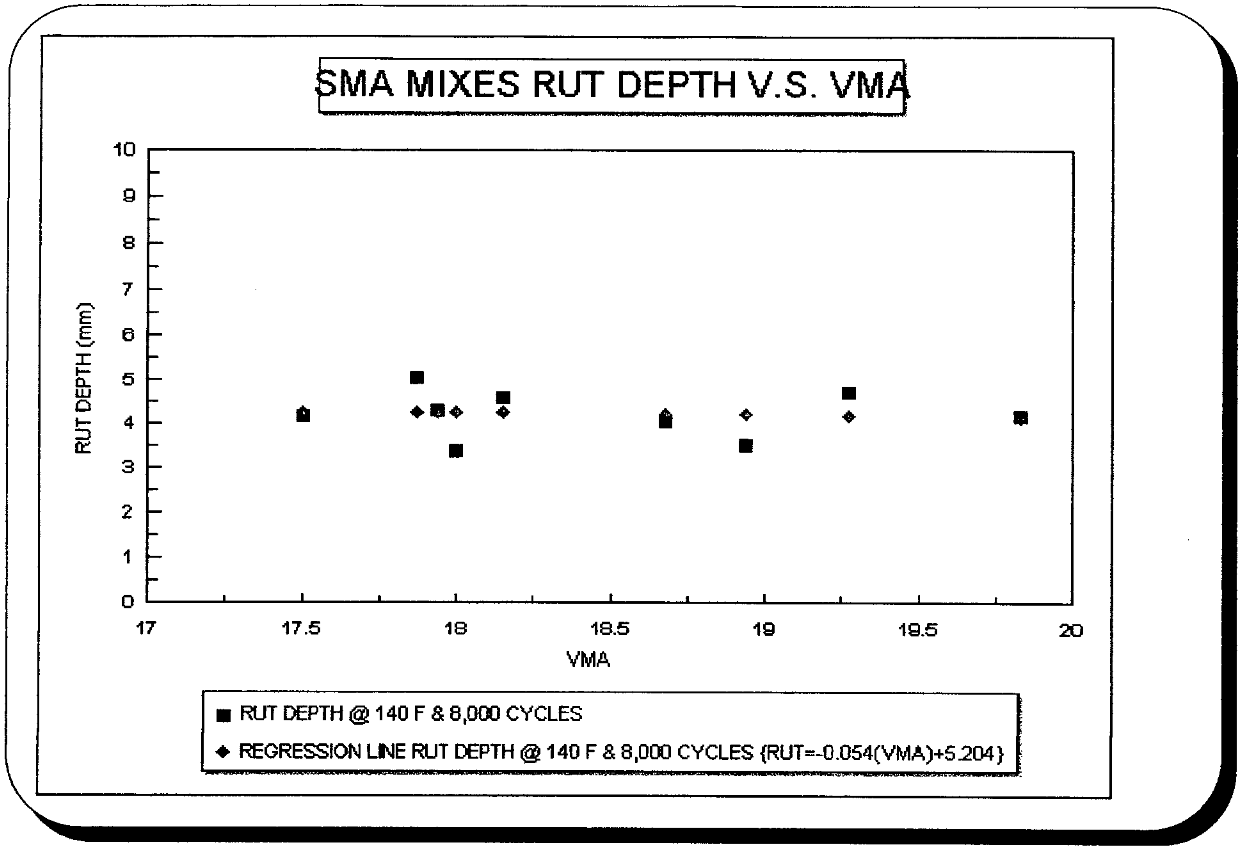

I-B MIXES RUT DEPTH V.S. G*/SIN DELTA @ 64° C
RUT DEPTH (mm)
G*/SIN DELTA @ 64° C
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=-1.923(G*/SIN D)+7.591}

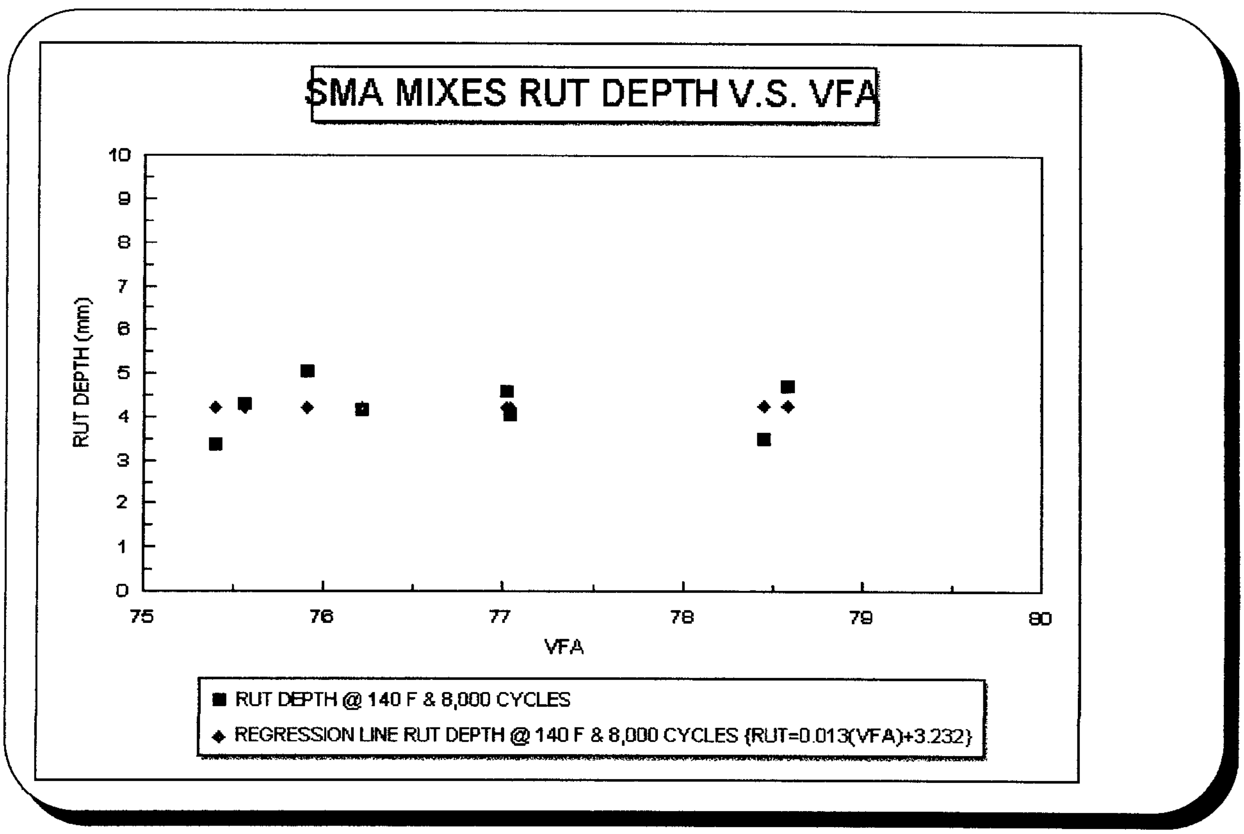

I-B MIXES RUT DEPTH V.S A.C. Sp.Gr. @15.6° C
RUT DEPTH (mm)
10
9
8
7
6
5
4
3
2
1
0
1.02
1.025
1.03
1.035
1.04
1.045
A.C. Sp. Gr. @ 15.6° C
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=46.904(Sp.Gr.)-43.238}

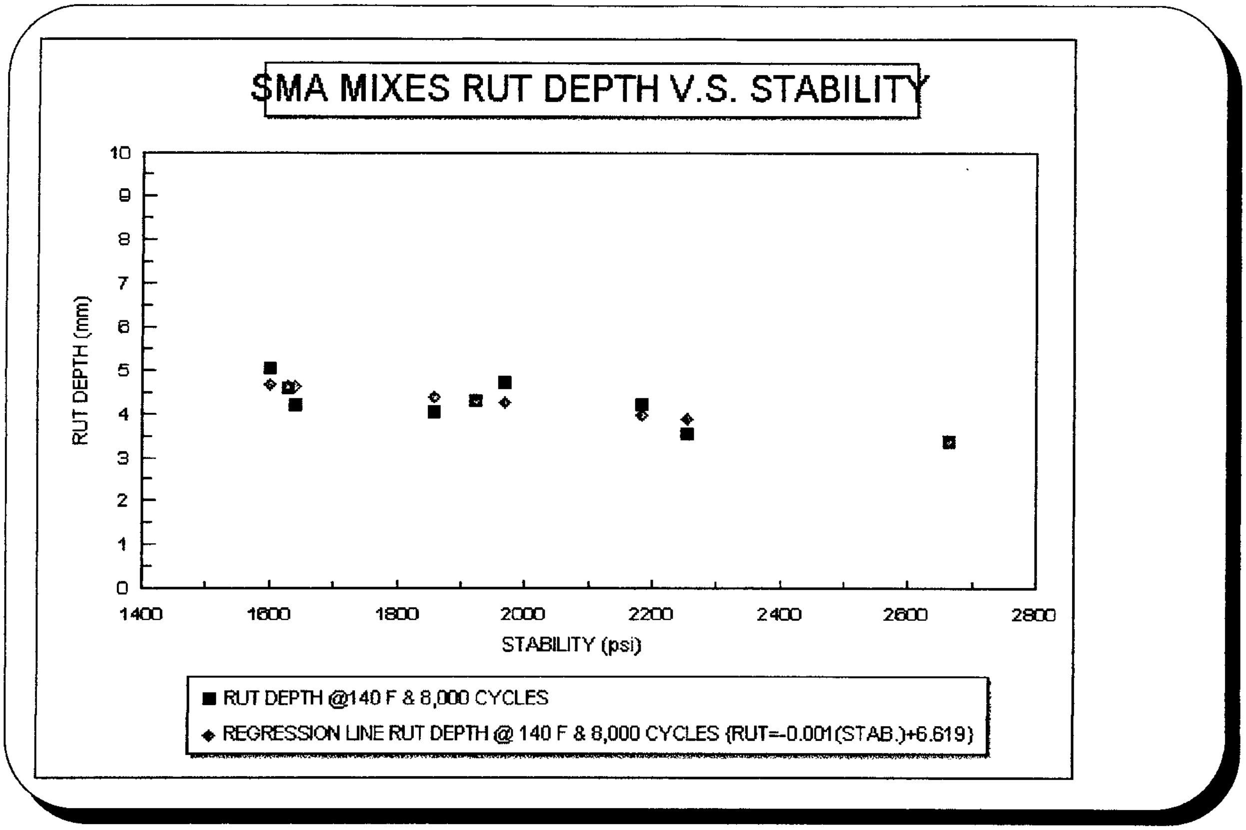
Appendix (C)
SMA Mixes Rut Depth V.S. Mix Design Properties and Asphalt Cement Properties.

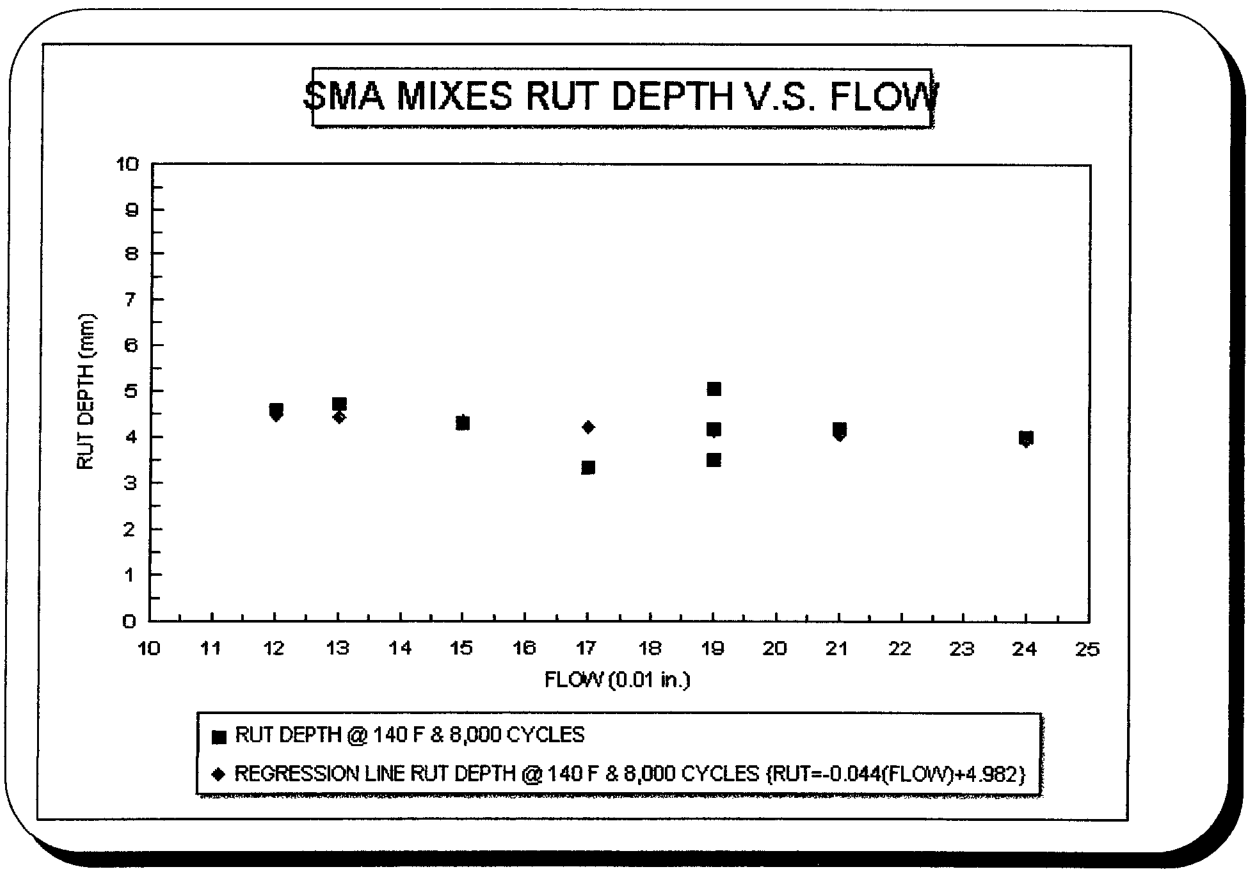

SMA MIXES RUT DEPTH V.S. % A.C.
RUT DEPTH (mm)
PERCENT ASPHALT CEMENT
0
1
2
3
4
5
6
7
8
9
10
5.8
6
6.2
6.4
6.6
6.8
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=-0.302(%AC)+6.081}

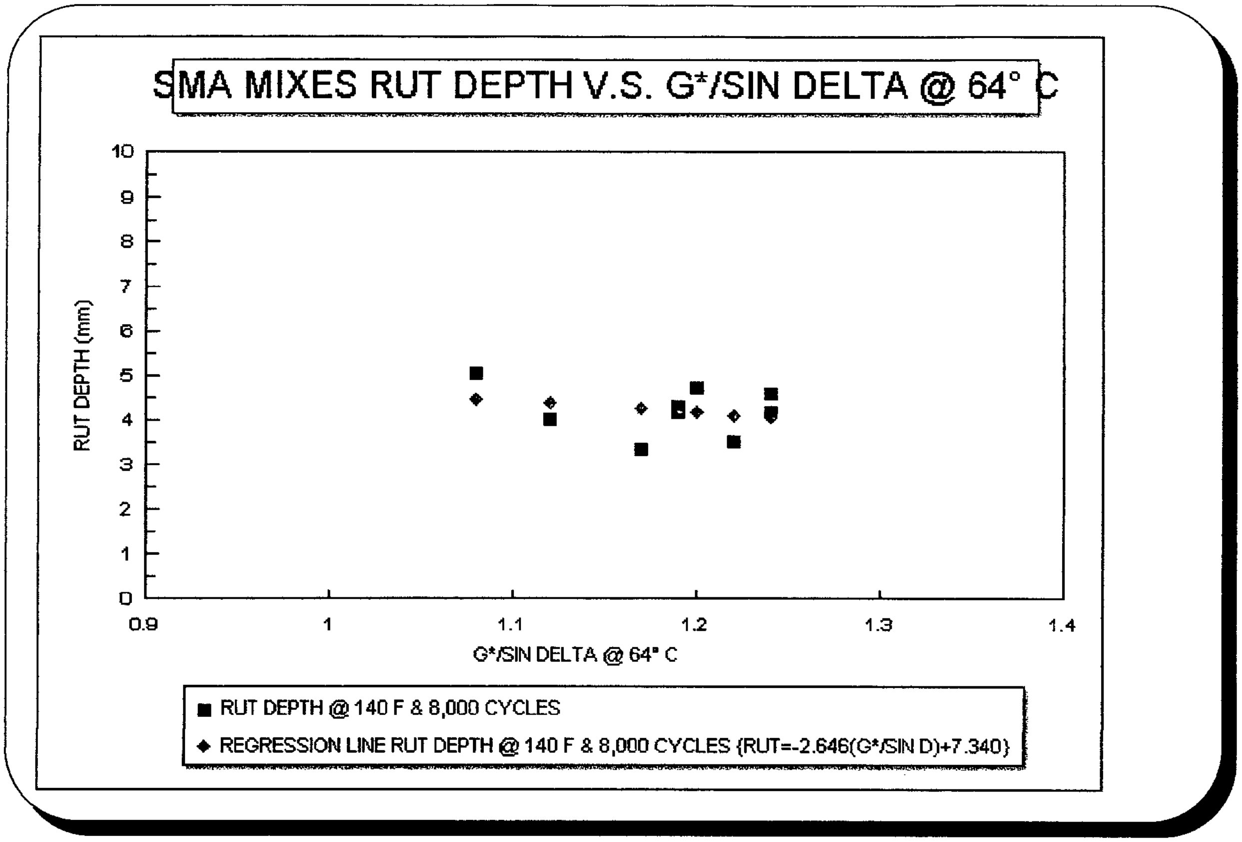

SMA MIXES RUT DEPTH V.S. AIR VOIDS
RUT DEPTH (mm)
AIR VOIDS
0
1
2
3
4
5
6
7
8
9
10
3
3.5
4
4.5
5
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=-0.434(Va)+6.064}

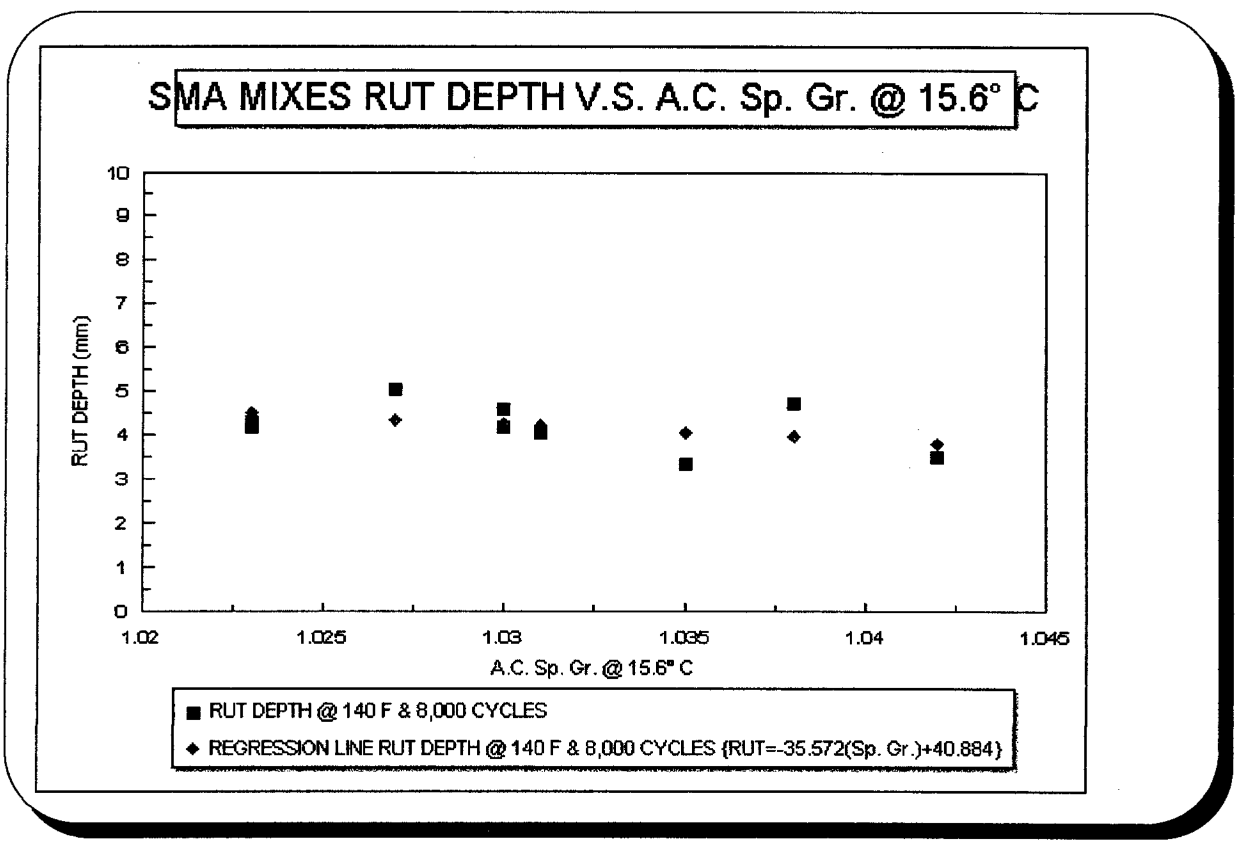

SMA MIXES RUT DEPTH V.S. VMA
RUT DEPTH (mm)
10
9
8
7
6
5
4
3
2
1
0
17
17.5
18
18.5
19
19.5
20
VMA
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=-0.054(VMA)+5.204}


SMA MIXES RUT DEPTH V.S. VFA
RUT DEPTH (mm)
10
9
8
7
6
5
4
3
2
1
0
75
76
77
78
79
80
VFA
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=0.013(VFA)+3.232}


SMA MIXES RUT DEPTH V.S. STABILITY
RUT DEPTH (mm)
10
9
8
7
6
5
4
3
2
1
0
1400
1600
1800
2000
2200
2400
2600
2800
STABILITY (psi)
RUT DEPTH @140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=-0.001(STAB.)+6.619}


SMA MIXES RUT DEPTH V.S. FLOW
RUT DEPTH (mm)
10
9
8
7
6
5
4
3
2
1
0
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
FLOW (0.01 in.)
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=-0.044(FLOW)+4.982}


SMA MIXES RUT DEPTH V.S. G*/SIN DELTA @ 64° C
RUT DEPTH (mm)
10
9
8
7
6
5
4
3
2
1
0
0.9
1
1.1
1.2
1.3
1.4
G*/SIN DELTA @ 64° C
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=-2.646(G*/SIN D)+7.340}


SMA MIXES RUT DEPTH V.S. A.C. Sp. Gr. @ 15.6° C
RUT DEPTH (mm)
10
9
8
7
6
5
4
3
2
1
0
1.02
1.025
1.03
1.035
1.04
1.045
A.C. Sp. Gr. @ 15.6° C
RUT DEPTH @ 140 F & 8,000 CYCLES
REGRESSION LINE RUT DEPTH @ 140 F & 8,000 CYCLES {RUT=-35.572(Sp. Gr.)+40.884}