Technical Report Documentation Page

1. Report No.
FHWA/VA -91-R16

2. Government Accession No.

3. Recipient s Catalog No.

4. Title and Subtitle
Final Report - Design of Heavy Duty Mixes

5. Report Date
April 1991

6. Performing Organization Code

7. Author(s)
G. W. Maupin, Jr.

8. Performing Organization Report No.
VTRC

9. Performing Organization Name and Address
Virginia Transportation Research Council
Box 3817, University Station
Charlottesville, Virginia 22903-0817

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
HPR 2675

12. Sponsoring Agency Name and Address
Virginia Department of Transportation
1221 E. Broad Street
Richmond, Virginia 23219

13. Type of Report and Period Covered
Final
April 1985 - Sept. 1990

14. Sponsoring Agency Code

15. Supplementary Notes
In cooperation with the U. S. Department of Transportation, Federal Highway Administration

16. Abstract

Permanent deformation of asphalt concrete, which is frequently manifested by excessive pavement rutting, has become a problem in much of the United States. Virginia began to experience rutting problems on highways with heavy traffic in the early 1980s. The purpose of this study was to evaluate several promising test procedures that could be used to test asphalt mixes for susceptibility to rutting. Several mixes representing a range of rutting potential were tested with five test methods: resilient modulus test, indirect tensile test, compaction resistance test, compression creep test, and a test using the gyratory testing machine.

The compaction resistance test did not point up differences in the tendencies of mixes to rut. The resilient modulus test, the indirect tensile test, and the compression creep test were capable of distinguishing between mixes with wide difference in rutting, but these tests failed to differentiate between the performance of mixes with questionable rutting resistance. The use of the gyratory testing machine ranked mixes prepared in the laboratory correctly and pointed up deficiencies in some field mixes that had been designed according to the 75-blow Marshall design but had demonstrated poor field performance.

The report recommends that the gyratory testing machine be further evaluated as a design tool for heavy duty asphalt mixes to supplement the Marshall design.

17. Key Words
Rutting, gyratory testing machine, resilient modulus, indirect tensile test, compaction resistance, compression creep, mix design

18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Clasif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages

22. Price

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

1565

# FINAL REPORT

# DESIGN OF HEAVY DUTY MIXES

**G. W. Maupin, Jr.**
**Research Scientist**

Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

April 1991
VTRC 91-R16

# BITUMINOUS RESEARCH ADVISORY COMMITTEE

W. L. HAYDEN, Chairman, Richmond District Engineer - Construction, VDOT

C. S. HUGHES, Executive Secretary, Senior Research Scientist, VTRC

J. D. BARKLEY, II, Halifax Resident Engineer, VDOT

A. D. BARNHART, Salem District Materials Engineer, VDOT

M. K. BRITTLE, Abingdon Resident Engineer, VDOT

W. B. COBURN, Staunton District Engineer—Construction, VDOT

G. W. F. CURTIS, Fredericksburg District Materials Engineer, VDOT

B. J. DAVIS, Area Engineer - Culpeper, Federal Highway Administration

C. E. ECHOLS, Professor of Civil Engineering, University of Virginia

R. L. FINK, Asst. Maintenance Engineer, VDOT

D. H. GRIGGS, JR., Lynchburg District Materials Engineer, VDOT

R. D. HORAN, Asst. Materials Division Administrator, VDOT

J. T. LOVE, Transportation Engineering Program Supervisor, VDOT

J. G. G. MCGEE, Asst. Construction Engineer, VDOT

D. E. OGLE, Northern Va. District Engineer—Construction, VDOT

R. D. WALKER, Professor of Civil Engineering, Virginia Polytechnic Institute and State University

# ABSTRACT

Permanent deformation of asphalt concrete, which is frequently manifested by excessive pavement rutting, has become a problem in much of the United States. Virginia began to experience rutting problems on highways with heavy traffic in the early 1980s. The purpose of this study was to evaluate several promising test procedures that could be used to test asphalt mixes for susceptibility to rutting. Several mixes representing a range of rutting potential were tested with five test methods: resilient modulus test, indirect tensile test, compaction resistance test, compression creep test, and a test using the gyratory testing machine.

The compaction resistance test did not point up differences in the tendencies of mixes to rut. The resilient modulus test, the indirect tensile test, and the compression creep test were capable of distinguishing between mixes with wide difference in rutting, but these tests failed to differentiate between the performance of mixes with questionable rutting resistance. The use of the gyratory testing machine ranked mixes prepared in the laboratory correctly and pointed up deficiencies in some field mixes that had been designed according to the 75-blow Marshall design but had demonstrated poor field performance.

The report recommends that the gyratory testing machine be further evaluated as a design tool for heavy duty asphalt mixes to supplement the Marshall design.

# FINAL REPORT

# DESIGN OF HEAVY DUTY MIXES

**G. W. Maupin, Jr.**
**Research Scientist**

## INTRODUCTION

Permanent deformation of heavily traveled asphalt highways is usually manifested by channelized depressions in the wheel paths, known as ruts. Minor ruts that develop because of consolidation of asphalt by traffic often occur and are not of great concern; however, major ruts that result from permanent deformation have become a greater problem during the last decade. The two major problems that can be caused by rutting are that (1) a safety hazard may be created and (2) pavement deterioration may accelerate as cracking develops along the middle and sides of the wheel paths.[1]

Although rutting has been a problem for many years, it has become more severe recently, probably because of increased traffic loads and tire pressures. The problem became so severe in the western United States that representatives of the U.S. Department of Transportation met in 1983 to discuss it. After several meetings, the group issued a report with recommendations to help alleviate the rutting problem.[2]

Rutting is not confined to highways in the western states. The National Cooperative Highway Research Program (NCHRP) funded a study entitled *Asphalt Aggregate Mixture Analysis System (AAMAS)*, which was initiated at the request of the Virginia Department of Transportation (VDOT) and the Federal Highway Administration (FHWA). Rutting was one of its prime concerns. Virginia began to experience severe problems on highways with heavy truck traffic in the early 1980s. Changes were made in the Marshall design that alleviated rutting, but other problems with durability, such as cracking and raveling, may have worsened. An ideal design method should optimize the mix design with respect to all of the failure modes, just as the AAMAS will attempt to do.

This project was planned in order to identify a test method that could be used to test mix designs for rutting resistance. Such a test would supplement the Marshall design, which has been used in Virginia for many years. A great deal of Marshall design information related to pavement durability has been gathered in Virginia.

## PURPOSE AND SCOPE

The purpose of this investigation was to evaluate several procedures used to test asphalt mixes for susceptibility to rutting. Several mixes with an intended range of susceptibilities were tested using five test methods.

## TEST PROCEDURES

The procedures selected for predicting rutting were the resilient modulus test, the indirect tensile strength test, the compaction resistance test, the compression creep test, and the indirect tensile creep test. The results of these tests have directly or indirectly been linked to deformation of asphalt concrete. The resilient modulus, which was measured in the indirect tension mode with a Schmidt device at a fast loading rate, approximated the stiffness of asphalt concrete under traffic. The indirect tensile strength, which was obtained under a moderate loading rate, yielded the ultimate strength of the asphalt concrete. Compaction resistance determined the rate at which density increased during compaction. Creep tests determined the elastic and permanent deformation that occurred under a constant load. The Schmidt device, which was used to measure resilient modulus, was the only equipment available to perform indirect tensile creep tests; however, after trial tests, this procedure was eliminated from the study because it was impossible to obtain accurate deformation measurements during the test since the clamping mechanism for the deformation measuring units restricted specimen deformation at the high test temperature (104°F).

After testing had begun, the U.S. Corps of Engineers gyratory testing machine (GTM) came to the research forefront as a possible tool for asphalt mix design. The NCHRP study on AAMAS revealed that engineering properties of specimens made with the GTM closely duplicated the properties of the compacted pavement. Not only can the GTM be used to compact mixes with properties similar to those of the pavement, it can also be used to measure stresses during compaction. Since both the stresses measured during the compaction process with the GTM and stresses that cause rutting failure are shear stresses, the GTM was a logical choice. The GTM was purchased and evaluated as a possible design tool.

### Resilient Modulus Test

Using the Schmidt device, the resilient modulus test was performed at 104°F according to ASTM D4123. The Schmidt device does not measure vertical deformation; therefore, Poisson's ratio was assumed to be 0.35 for the calculation of the resilient modulus.

$$M_R = P(\nu + 0.273)/t\Delta$$

where:

$M_R$ = resilient modulus (psi)
$P$ = applied load (lb)
$\nu$ = Poisson's ratio (assume 0.35)
$t$ = thickness of specimen (in)
$\Delta$ = horizontal deformation (in).

## Indirect Tensile Strength Test

The indirect tensile strength test has the potential of identifying tender mixes, i.e., mixes in which there is excessive deformation soon after placement;[3] therefore, the indirect tensile strength was investigated as a possible design parameter.

The tests were performed at a temperature of 104°F and a load deformation rate of 2 in/min. The tensile strength was computed by

$$S_T = \frac{2P_u}{\pi t d}$$

where:

$P_u$ = ultimate applied load required to fail the specimen (lbf)
$t$ = thickness of specimen (in)
$d$ = diameter of specimen (in).

## Compaction Resistance Test

Bissada[4] found that the resistance of a mix to compaction was related to its stiffness, which suggests that compaction resistance may also be related to rutting. The compaction resistance can be obtained with Marshall design equipment, which is readily available; therefore, this method was promising from a practical viewpoint.

Compaction curves were developed for each mix by plotting air voids versus the number of blows that were applied with a Marshall hammer (see Figure 1). Mixes with a flat slope (Mix A) tend to resist deformation more than mixes with a steep slope (Mix B). It is expected that mixes with a flat slope would be compacted close to the maximum achievable density during construction. With such mixes, a minimum amount of consolidation would occur under traffic.

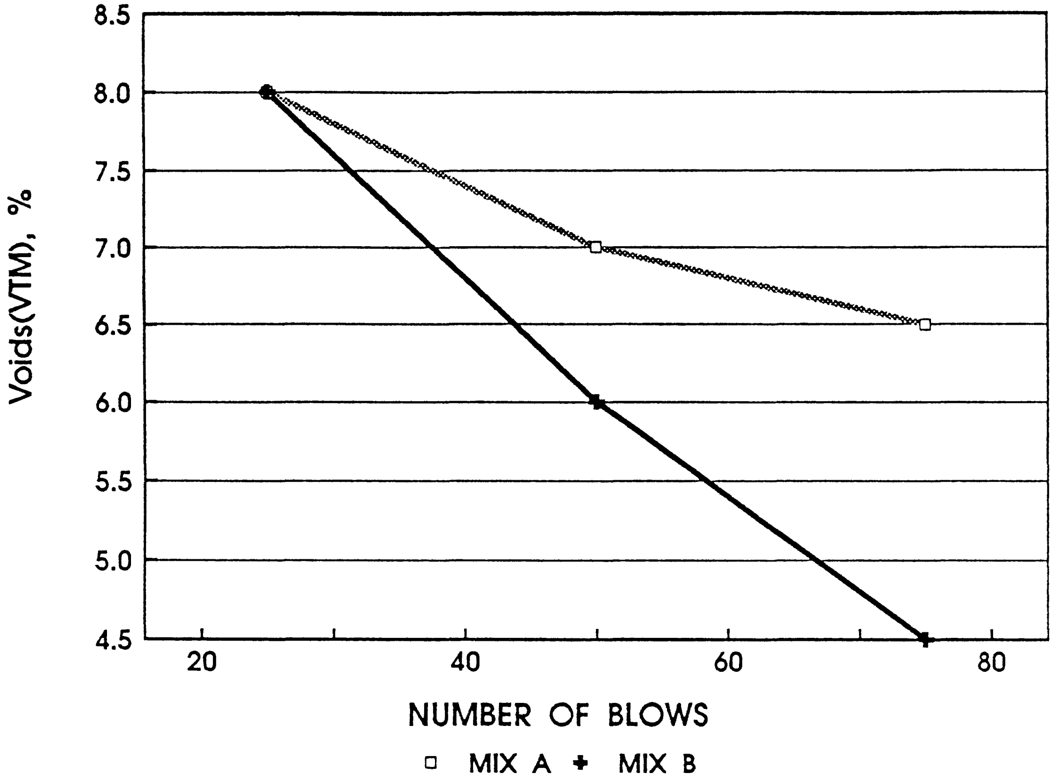

Figure 1. Examples of compaction resistance curves.

## Compression Creep Test

Compression creep tests were conducted on specimens with a diameter of 2.5 in by 4 in (the same as used in the Shell creep test procedure[5]) at 104°F using an axial loading of 30 psi for 60 min. The specimen was preloaded for 2 min, unloaded, and allowed to relax for 5 min before the test load was applied. The deformation, which was measured with two dial gages placed on opposite sides of the top loading plate, was recorded at sufficient intervals to yield a strain-time curve (Figure 2). After 60 min of loading, the load was released, and the deformation recovery was recorded for an additional 60 min.

The properties that were analyzed were stiffness modulus and unrecovered axial strain. The stiffness modulus was computed by the following formula using a loading pressure of 30 psi and a total strain at the 60-min load interval:

$$E = \sigma/\epsilon$$

where:

$E$ = stiffness modulus (psi)

$\sigma$ = 30 lb/in$^2$ applied axial pressure
$\varepsilon$ = strain at 60 min.

The tests were conducted on specimens that were prepared on the GTM. The specimens were 3 in tall, and 0.25 in was sawed from each end by a diamond blade saw, resulting in a 2.5-in specimen. An attempt was made to grind each end to produce a smooth surface and minimize friction during the test, but this practice was discontinued because it required too much time. Instead, a thin layer of polyindurate joint compound was applied to each sawed surface and sanded to give a smooth surface. Before the specimen was placed in the testing device, the surface of each end was coated with a thin coat of silicone grease that had been mixed with graphite flakes.

## Gyratory Testing Machine

The GTM was used to test the mixes according to ASTM D3387.[6] The GTM applies a vertical pressure and gyrating action, which produces shear stress and shear strain in the cylindrical specimen as it compacts. The oil-filled mode of operation used in this study yielded strength properties as well as compaction and strain information.

An initial gyratory angle of 1 degree and a vertical pressure of 120 psi, which is supposed to simulate heavy traffic, was used on all mixes. Also, vertical pressure

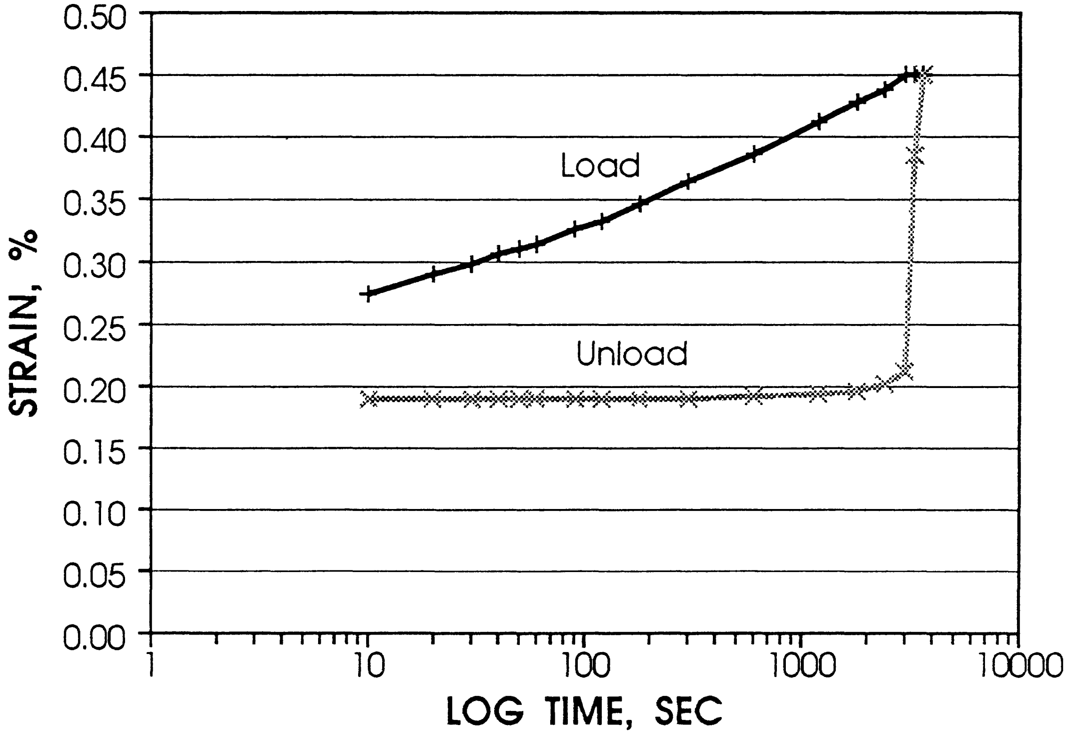

Figure 2. Typical creep test.

of 90 psi, which is supposed to simulate moderate traffic, was also used on some mixes sampled during construction (field mixes). The specimens were compacted until the rate of compaction (change in height) decreased to 0.010 in per 50 revolutions, which is approximately 1 pcf per 100 revolutions. This cutoff point was suggested by the supplier of the equipment, John McCrae, as the compaction level that approximates pavement density after it has had traffic on it. The three properties used to characterize the mixes were final voids (VTM), shear strength, and the gyratory stability index (GSI). The GSI is a ratio of the maximum gyratory angle and the minimum gyratory angle; it is one of the indicators of the stability of a mix. Values have been suggested by McCrae to gage whether mixes will behave satisfactorily under traffic. The VTM should be greater than 3 percent, the shear strength should be greater than 38.2 lb/in$^2$ at 120 psi vertical pressure and 28.6 psi at 90 psi, and the GSI should be less than 1.10.

## MATERIALS AND MIX DESIGNS

At the outset, three mixes were used in this study (an S-5, an I-2, and an S-5 modified). The S-5 mix had rutted on a heavily traveled highway, the I-2 was designed in the laboratory in an attempt to produce a mix more stable than the other two, and the S-5 modified mix was tender under the roller during a paving job. The S-5 modified mix was redesigned during the study in an attempt to improve its compaction properties. As testing progressed, it became evident that the three mixes did not represent as wide a range of performance as desired and that all of the mixes were probably unstable to some degree. When the study began, VDOT was using the 50-blow Marshall design for mixes placed on all highways irrespective of traffic level, but as the study progressed and experience was gained, it was realized that the 75-blow Marshall design should be used for all highways subject to severe traffic conditions. Therefore, it was necessary to select additional mixes and redesign some of them using a 75-blow compactive effort in order to include mixes that would be resistant to rutting. It was expected that mixes designed using 50 blows, which resulted in a relatively high asphalt content, would be more susceptible to rutting than mixes designed with 75 blows with a lower asphalt content.

Because of the large number of mixes tested, the study was divided into phase I, which included the initial mixes, and phase II, which included three mixes designed using a 50-blow and a 75-blow compactive effort. The mixes tested are listed in Table 1.

Table 1

MIXES

| Mix Type | Contractor |
|---|---|
| Phase I | |
| S-5 | APAC-Va., Inc., Chesterfield, Va. |
| I-2 | APAC-Va., Inc., Chesterfield, Va. |
| S-5 modified | APAC-Va., Inc., South Boston, Va. |
| S-5 modified (redesigned) | APAC-Va., Inc., South Boston, Va. |
| Phase II | |
| S-5[a] | APAC-Va., Inc., Chesterfield, Va. |
| I-2[b] | APAC-Va., Inc., Chesterfield, Va. |
| S-10 | S. L. Williamson Co., Inc., Charlottesville, Va. |

[a] Same mix as used in phase I.

[b] Different mix than used in phase I.

A summary of the mixes tested and their expected performance is given in Table 2.

Table 2

EXPECTED PERFORMANCE OF MIXES

| Mix Type | Design (blows) | Asphalt Content (%) | Performance |
|---|---|---|---|
| Phase I | | | |
| S-5 | 50 | 5.6 | Poor |
| I-2 | 50 | 4.95 | Poor |
| S-5 modified | 75 | 5.3 | Marginal |
| S-5 modified (redesigned) | 75 | 5.3 | Good |
| Phase II | | | |
| S-5L[a] | 75 | 5.1 | Good |
| S-5H[b] | 50 | 5.6 | Poor |
| I-2L | 75 | 5.2 | Good |
| I-2H | 50 | 5.6 | Poor |
| S-10L | 75 | 4.7 | Good |
| S-10H | 50 | 5.0 | Poor |

[a] Low asphalt content.

[b] High asphalt content.

Several mixes that had a history of performance problems were also sampled. These mixes were tested with the GTM to try to determine whether the GTM provided useful information on problem mixes that the ordinary Marshall design did not provide.

# RESULTS

## Phase I

### VTM at Testing

In phase I, the mixes were tested at 7 percent VTM to simulate pavement voids after construction; however, it might have been more appropriate to test them at a void level representative of the pavement after several years of traffic. Although resilient modulus tests and indirect tensile tests were conducted on specimens compacted at 25, 50, and 75 blows in phase II, the resilient modulus and tensile strength were compared at interpolated or extrapolated values corresponding to 7 percent VTM.

### Resilient Modulus

The values for resilient modulus are shown in Figure 3. The mixes were ranked S-5, I-2, and S-5 modified, from weakest to strongest, respectively. The S-5 mix was known to be unstable because of poor field performance in the past. I-2 mixes would normally be more stable, which was verified by the relative modulus values. However, the S-5 modified mix, which was observed to be unstable during field compaction, had the highest modulus. This instability during compaction was not predicted by low modulus values. The absence of a low modulus for an unstable mix indicates that resilient modulus may not be a good predictor of instability.

### Indirect Tensile Strength

The trend of the indirect tensile strength values shown in Figure 4 is similar to that for the resilient modulus, i.e., the S-5 mix was the lowest and the S-5 modified mix was the highest. The range of values is very narrow; therefore, the indirect tensile strength does not appear to be sufficiently sensitive to predict how these mixes would behave.

### Compaction Resistance

The compaction curves that were developed for 25, 50, and 75 blows are shown in Figure 5. The rates of compaction (slopes) are approximately equal for the three mixes. The author suspected that a mix which is susceptible to deformation would tend to have a steeper slope, but the data did not support the supposition. This test predicts that these mixes will behave similarly in the field. The S-5 mix, which had been observed to be more unstable, behaved the same as the other two mixes in this test procedure. This indicates that the use of this procedure may be misleading.

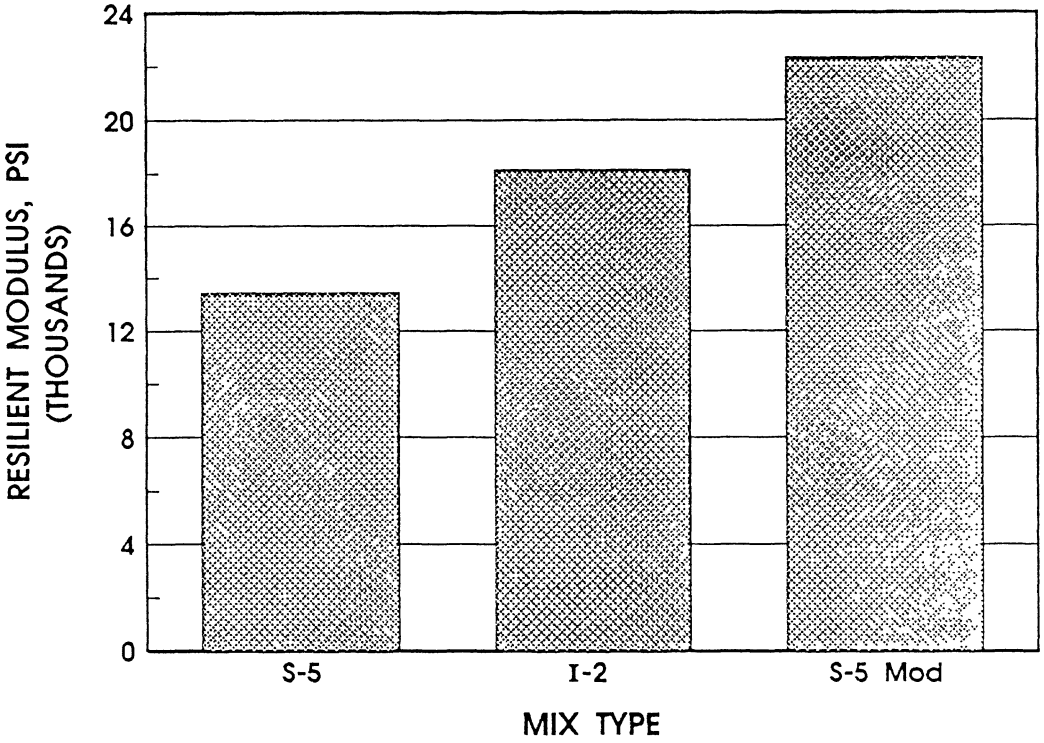

Figure 3. Resilient modulus—phase I.

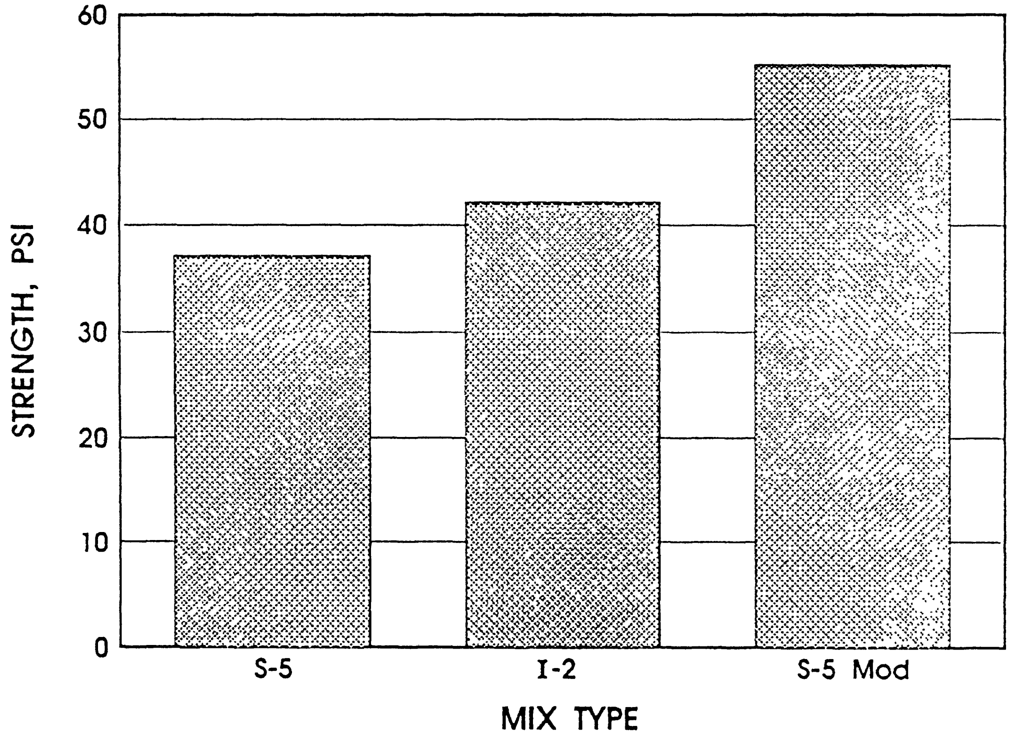

Figure 4. Indirect tensile strength—phase I.

1578

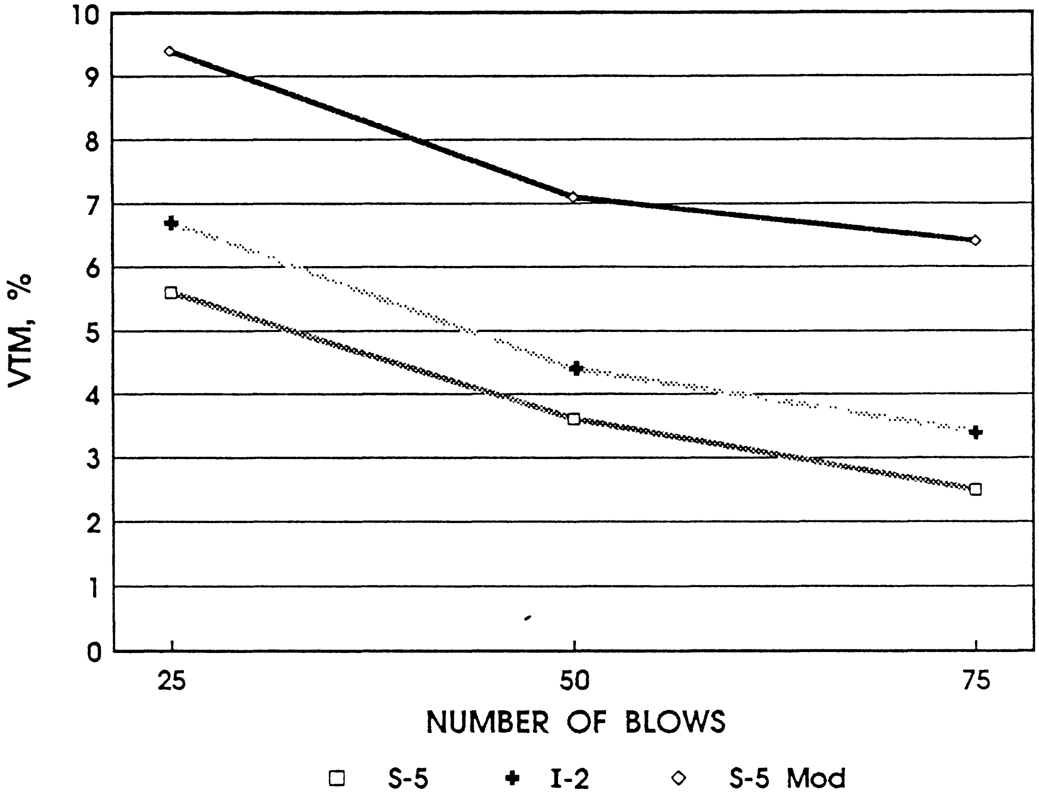

Figure 5. VTM v. compactive effort—phase I.

## Compression Creep

Since the mixes did not demonstrate significant differences according to the tests that were discussed previously, and since the mixes should have been designed using 75 blows instead of 50 blows, creep tests were not performed. It was decided that the mixes should be redesigned or additional mixes should be selected to make sure that there was a wide range of mix behavior from good to poor. Thus, creep tests were performed only on the mixes in phase II of the study.

## GTM

VTM, shear strength, and GSI results are presented in Figures 6, 7, and 8, respectively. The VTM of the S-5 and I-2 mixes are below the minimum level of 3 percent and would be considered unsatisfactory for pavement under heavy traffic. Similarly, the shear strength of these same mixes is less than the allowable 38.2 psi, and the GSI is greater than the allowable 1.1. High values of GSI probably indicate that these mixes contained too much asphalt cement.

Two S-5 modified mixes were tested: one that had shown some tenderness during construction and the same mix after it had been altered in the field by changing the asphalt source and gradation to cure the tenderness problem. The VTM, shear strength, and GSI of the problem mix were 3.4 percent, 36 psi, and 0.98, respectively. The shear strength is below the allowable limit; therefore, this

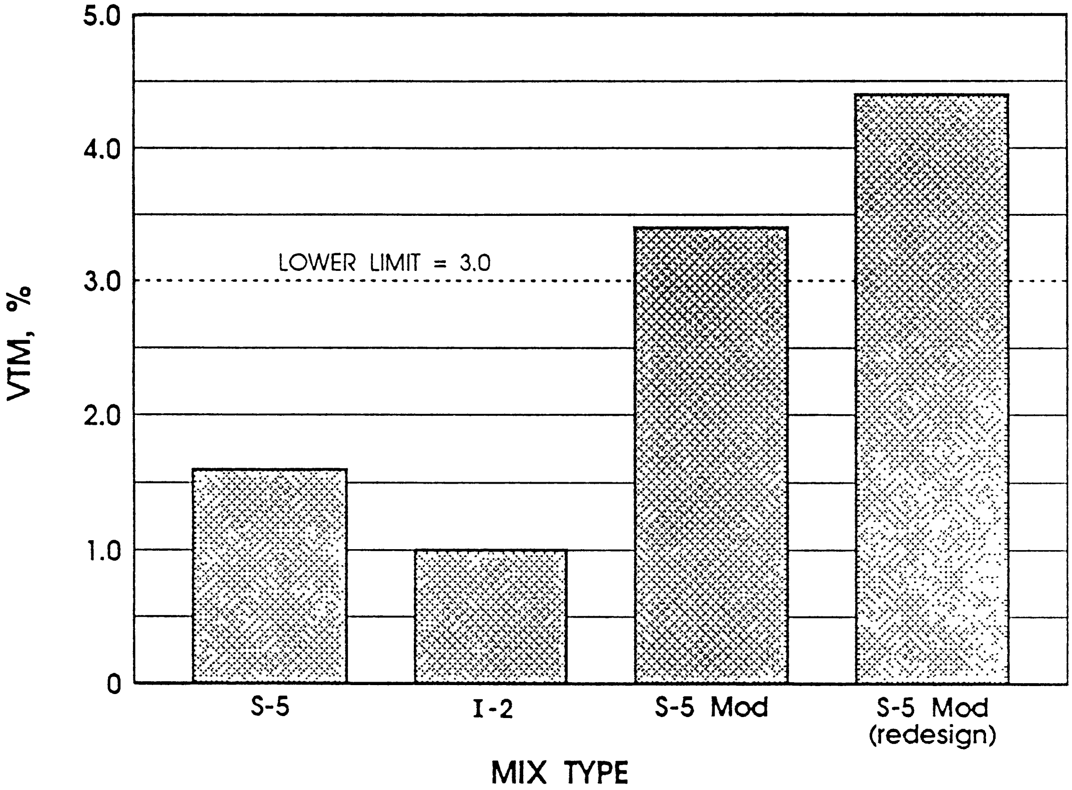

Figure 6. Predicted pavement VTM by GTM—phase I.

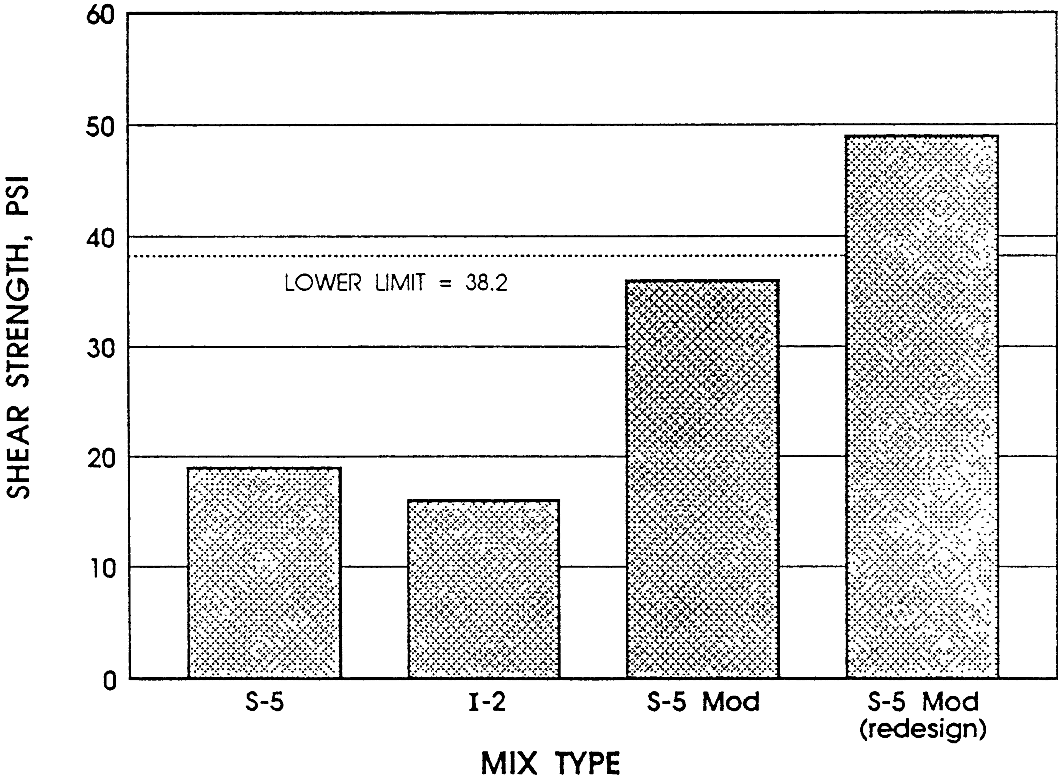

Figure 7. GTM shear strength—phase I.

1580

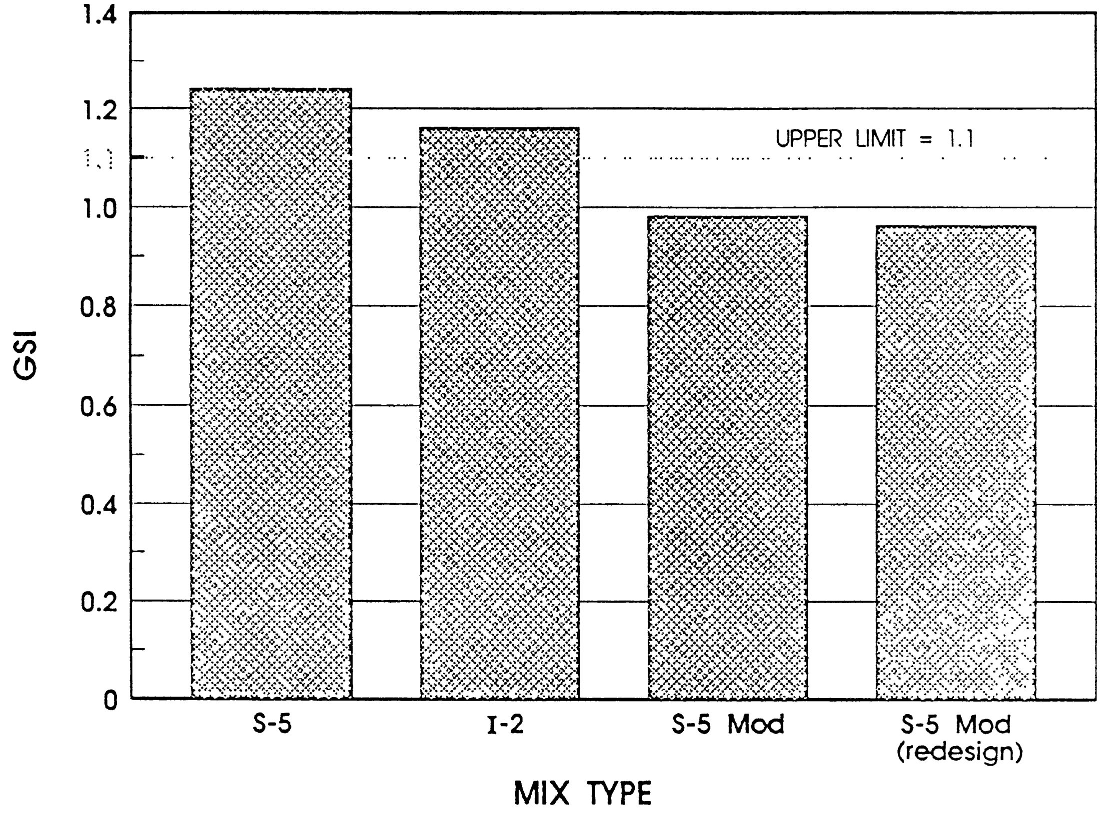

Figure 8. GTM stability index—phase I.

mix would have been considered unsatisfactory if it had been designed with the GTM. After the mix was altered, the VTM, shear strength, and GSI were 4.4 percent, 49 psi, and 0.96, respectively. It was evident that the changes that were made brought the shear strength to an acceptable level. Although the Marshall design method had not indicated that the original S-5 modified mix was a problem, the GTM did. The GTM also demonstrated a marked improvement in shear strength after changes in the mix design were made.

The GTM was effective in identifying a defective mix design when the conventional Marshall design did not. It indicated deficient shear strength in a mix that had been tender under the roller, which is a mix problem that has been difficult to predict with the Marshall design method.

## Field Mixes

The GTM was used to test five mixes obtained from the field that were reportedly problem mixes or had been problems in the past. The mixes had been submitted by VDOT field personnel, and evidently the Marshall method failed to indicate problems with mix instability ranging from tenderness during construction to rutting under traffic. Tables 3 and 4 list the test results for these mixes. A, B, and D had a VTM that was less than the recommended minimum of 3 percent, and mix A was also low in strength and high in GSI for the 120 psi pressure. Although field personnel were somewhat suspicious of mixes C and E, which had had problems, the GTM predicted that the deficiencies of these mixes had apparently been corrected. Therefore, it appears that the GTM may have indicated deficiencies of some mixes that appeared to be satisfactory according to conventional Marshall design tests.

Table 3

RESULTS OF FIELD MIXES TESTED IN GTM

| Mix | Vertical Pressure (psi) | Shear Strength (psi) | GSI | VTM (%) |
|---|---|---|---|---|
| A | 120 | 27 | 1.20 | 2.5 |
| | 90 | 26 | 1.05 | 4.4 |
| B | 120 | 43 | 1.08 | 1.8 |
| | 90 | 41 | 0.98 | 3.5 |
| C | 120 | 48 | 1.00 | 3.4 |
| | 90 | 32 | 0.98 | 4.5 |
| D | 120 | 43 | 1.00 | 2.2 |
| | 90 | 36 | .96 | 2.8 |
| E | 120 | 47 | 0.97 | 3.7 |
| | 90 | 32 | 0.99 | 4.3 |

Table 4

GTM CRITERIA THAT FIELD MIXES FAILED

| Mix | Compaction Pressure | Shear Strength ($S_G$) | GSI | VTM |
|---|---|---|---|---|
| A | 120 | • | • | • |
| | 90 | • | | |
| B | 120 | | | • |
| | 90 | | | |
| C | 120 | | | |
| | 90 | | | |
| D | 120 | | | • |
| | 90 | | | • |
| E | 120 | | | |
| | 90 | | | |

## Phase II

Rather than test the mixes at 7 percent VTM as was done in phase I, compaction was accomplished at 25, 50, and 75 blows, and these specimens were used for the compaction resistance, resilient modulus, and indirect tensile tests. VTM curves were developed (see Figures 9 and 10), and the interpolated and extrapolated values of resilient modulus and indirect tensile strength were selected at a 7 percent VTM. It was felt that this approach would be preferable to trying to

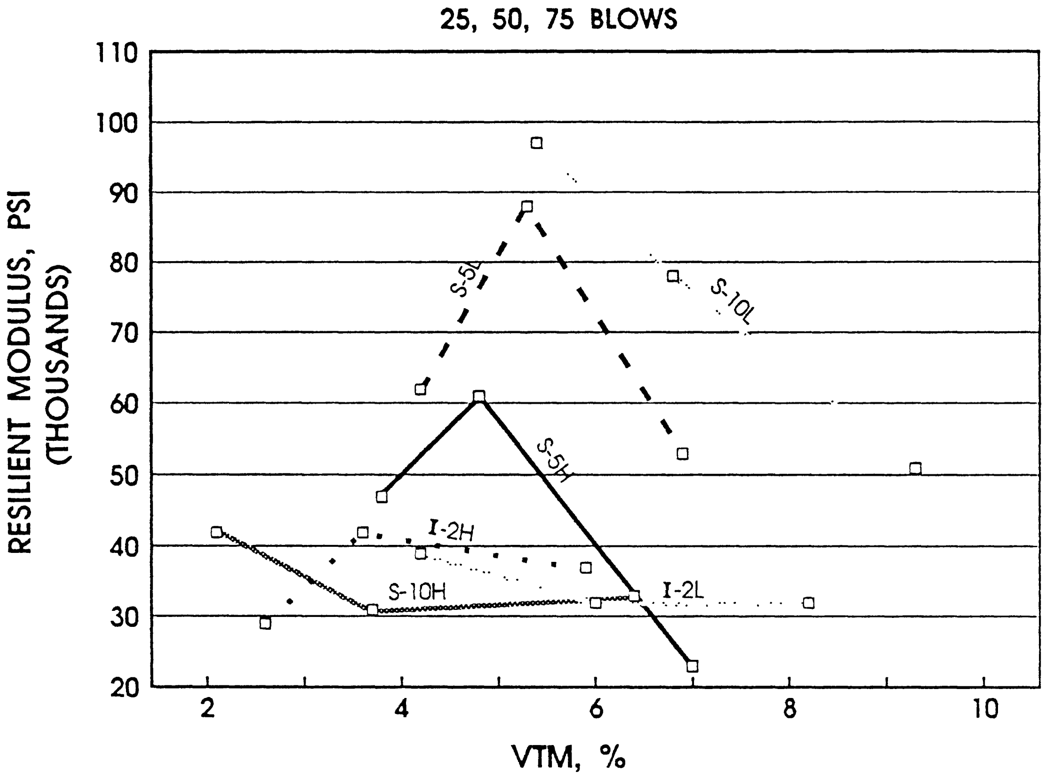

Figure 9. Resilient modulus at three compaction levels—phase I.

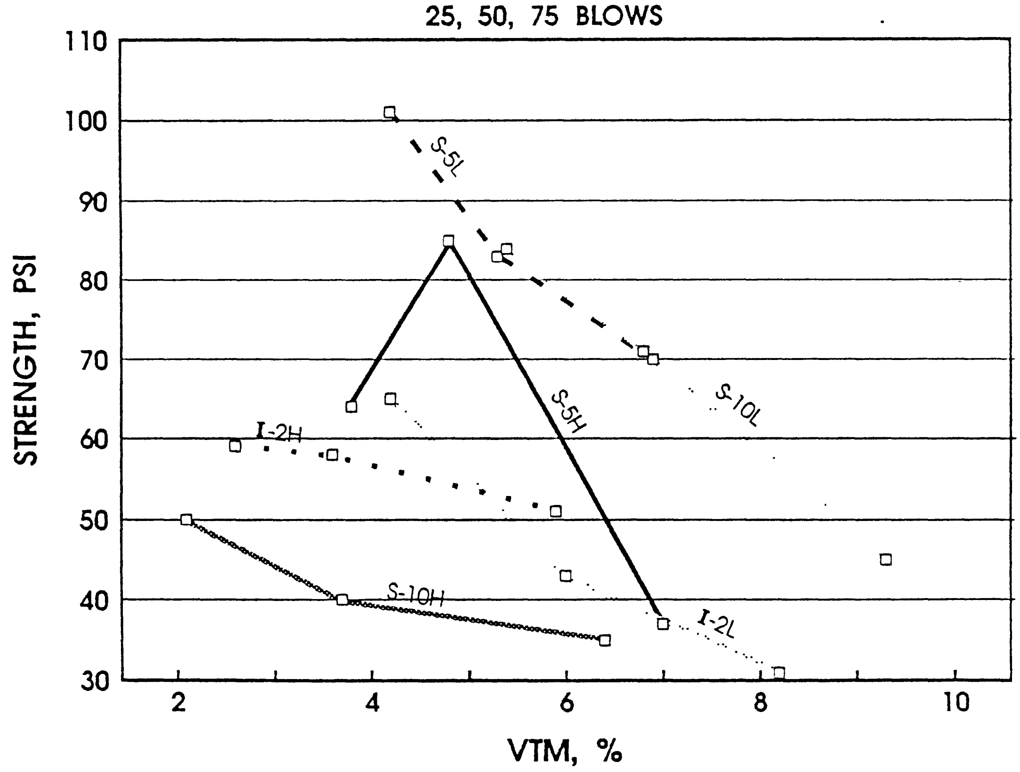

Figure 10. Indirect tensile strength at three compaction levels—phase I.

produce 7 percent VTM in the specimens since it would tend to average the results of several sets of specimens rather than use only one set of specimens.

### Resilient Modulus

The interpolated values of resilient modulus are shown in Figure 11 in ascending order. As expected, the mixes with a low asphalt content generally had a higher modulus than the mixes with a high asphalt content. Asphalt content did not seem to affect the modulus of the I-2 mix, which is also evident from Figure 9. The modulus of the strongest mix, the S-10L with the low asphalt content, was approximately triple the modulus of the weakest mix, i.e., the S-5H with the high asphalt content. Except for the two mixes with extremely high and low moduli, the test procedure did not differentiate the expected performance.

### Indirect Tensile Test

The trend of the results is similar to that in phase I where the indirect tensile test results mirrored the resilient modulus test results. The mixes with a low asphalt content generally had a higher tensile strength than the mixes with a high asphalt content (see Figure 12). The S-5L and S-10L mixes with a low asphalt content are significantly stronger than the other mixes. As observed with the resilient modulus tests, the I-2 mix was not sensitive to a change in asphalt content. This procedure did not point up the performance differences expected between the I-2 mixes with high and low asphalt contents.

### Compaction Resistance

Similar to the results of phase I, the slopes of the compaction curves shown in Figure 13 do not differ a great deal; therefore, the procedure does not appear to be useful. It was anticipated that the mixes with a high asphalt content would demonstrate steeper slopes than the mixes with a low asphalt content.

### Compression Creep

The properties that were measured were total strain and stiffness modulus at 60 min and the unrecovered strain after a 60-min relaxation. The moduli are shown in Figure 14. Although the trend of the moduli was similar to that observed with the resilient modulus and indirect tensile tests, the S-10L mix with the low asphalt content was the only mix that was significantly different from the other mixes. The behavior of the mixes would be predicted to be similar with the exception of the S-10L mix, which would possibly be more resistant to permanent deformation under traffic.

One might expect the unrecovered strain to be more indicative of the potential permanent pavement deformation than moduli values because each time a pavement is loaded, it undergoes some strain that will never be recovered, just as occurs in the test specimens. The unrecovered creep strain between the mixes with

1584

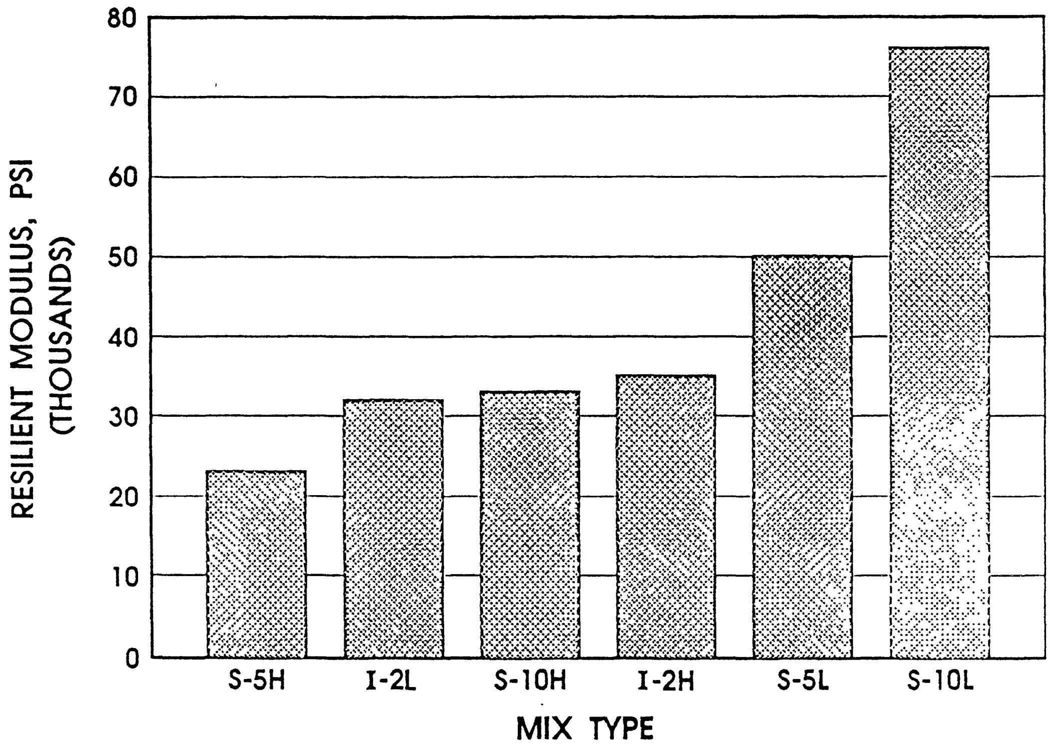

Figure 11. Resilient modulus—phase II.

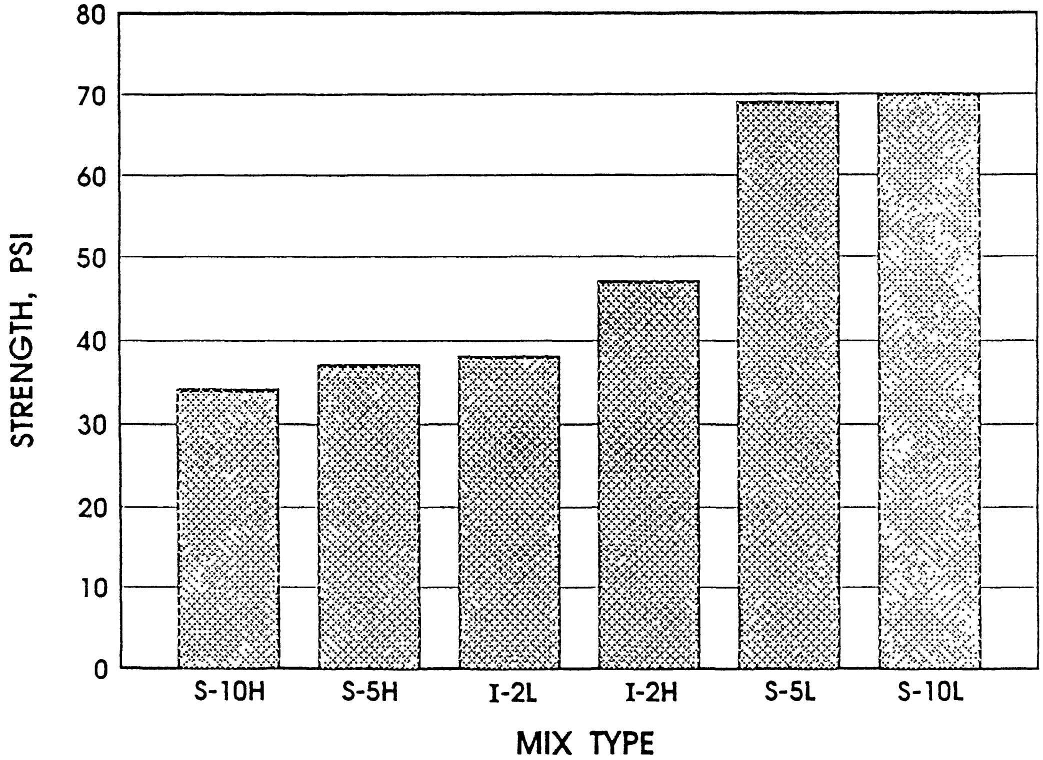

Figure 12. Indirect tensile strength—phase II.

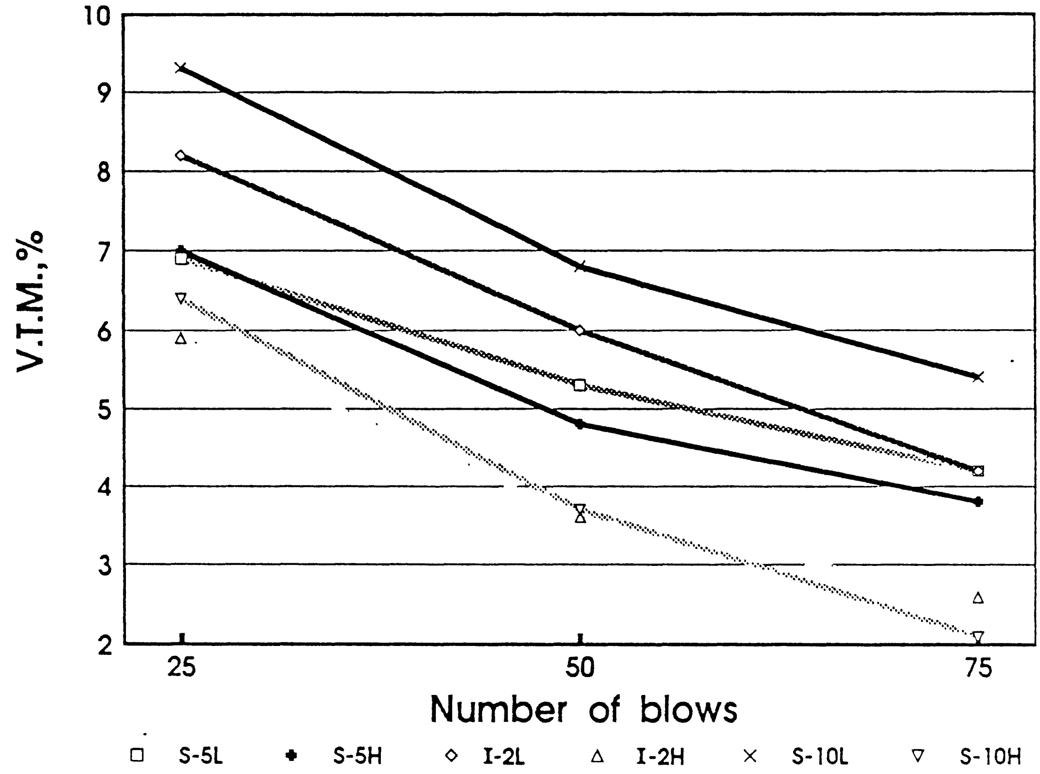

Figure 13. VTM v. compactive effort—phase II.

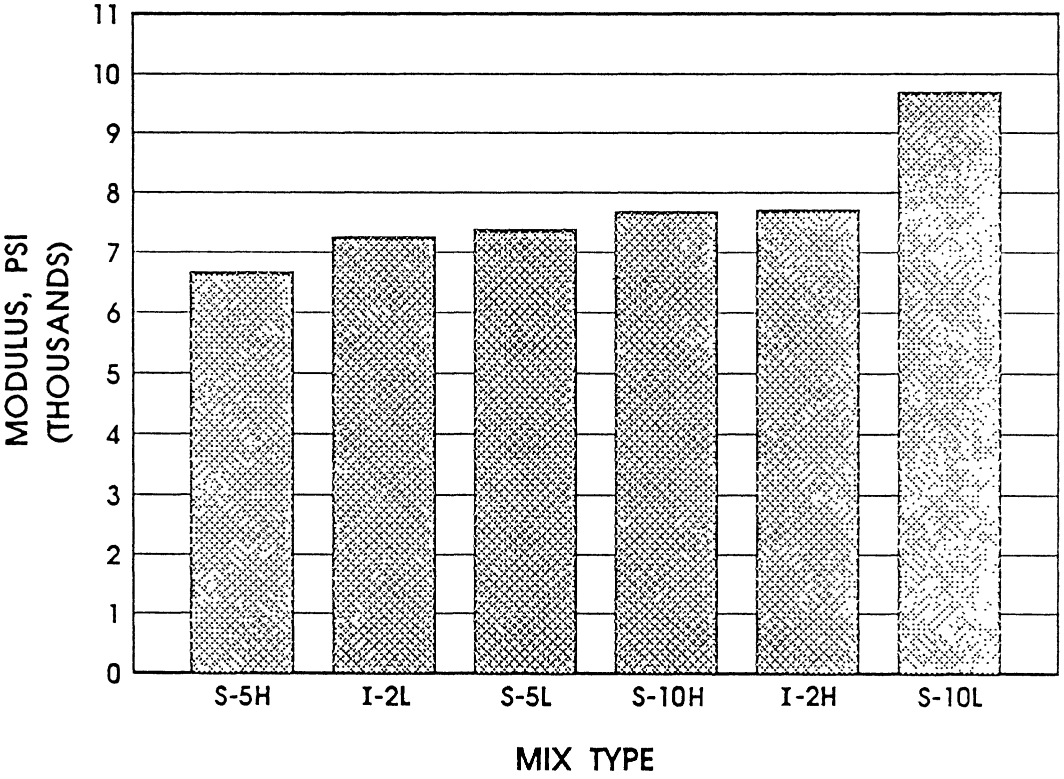

Figure 14. Creep modulus.

extremely high and low strain (Figure 15) shows a trend similar to that observed in the other test results, but there is also a difference in the strain of the intermediate mixes. The unrecovered strain for mixes I-2L and S-10H were reversed from the results that were expected; therefore, there was doubt about the validity of the performance prediction using this test method.

## GTM

VTM, shear strength, and GSI are shown in Figures 16, 17, and 18, respectively. The VTM of the all mixes with a low asphalt content were satisfactory, i.e., the VTM was above or very close to the minimum limit of 3 percent. The VTM of the S-5H and I-2H mixes with a high asphalt content was much less than the recommended minimum; however, the VTM of the S-10H mix with high asphalt content was only slightly below the minimum. The S-10 mix was also not very sensitive to asphalt content according to some of the test results that were reported in previous sections. (This is an advantage for this gradation.) Similarly, the shear strength was less than the minimum of 38 psi for the mixes with a high asphalt content. Again, the strength of the S-10H mix with a high asphalt content is only slightly below the minimum. The GSI was satisfactory for all of the mixes. It was believed that the S-5H and I-2H mixes with a high asphalt content had too much asphalt; therefore, these results are somewhat surprising. It is possible that the GSI is sensitive only to large changes in asphalt content; therefore, differences of approximately 0.5 percent, as existed between the low and high levels for these mixes, was not detected. Thus, the GSI may not be a good indicator of unstable mixes. The GTM was able to differentiate the expected performance of the six mixes by using the voids and shear strength criteria.

## DISCUSSION

The compaction resistance tests did not differentiate between the potential performance of any of the mixes in phase I or phase II of the study; therefore, this test would not be useful as a design tool for rutting resistance.

Resilient modulus and indirect tensile tests ranked the mixes that were tested in phase I (S-5, I-2, and S-5 modified) in an order of weak to strong (see Table 5). In a similar fashion, the GTM rated the S-5 and I-2 mixes as unsatisfactory. The GTM also rated the shear strength of the S-5 modified mix as being low, which may explain why it had behaved in a tender manner during construction in the field. The resilient modulus and indirect tensile results were nearly parallel with the GTM results, yet the GTM gave additional information about the S-5 modified mix.

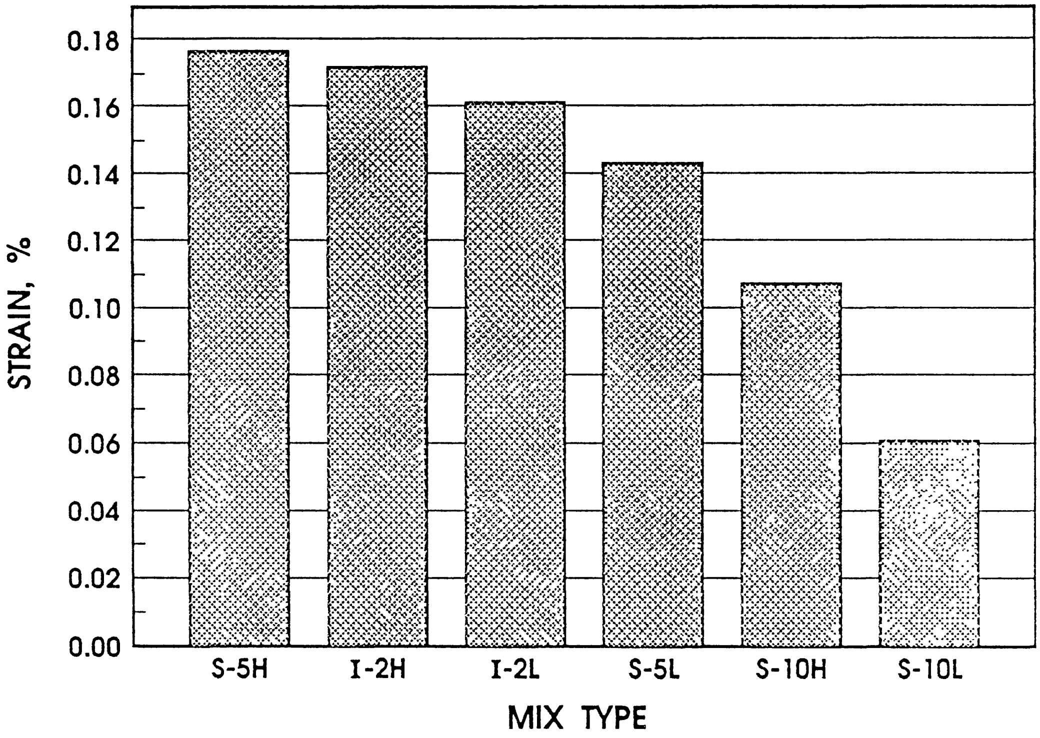

Figure 15. Unrecovered creep strain.

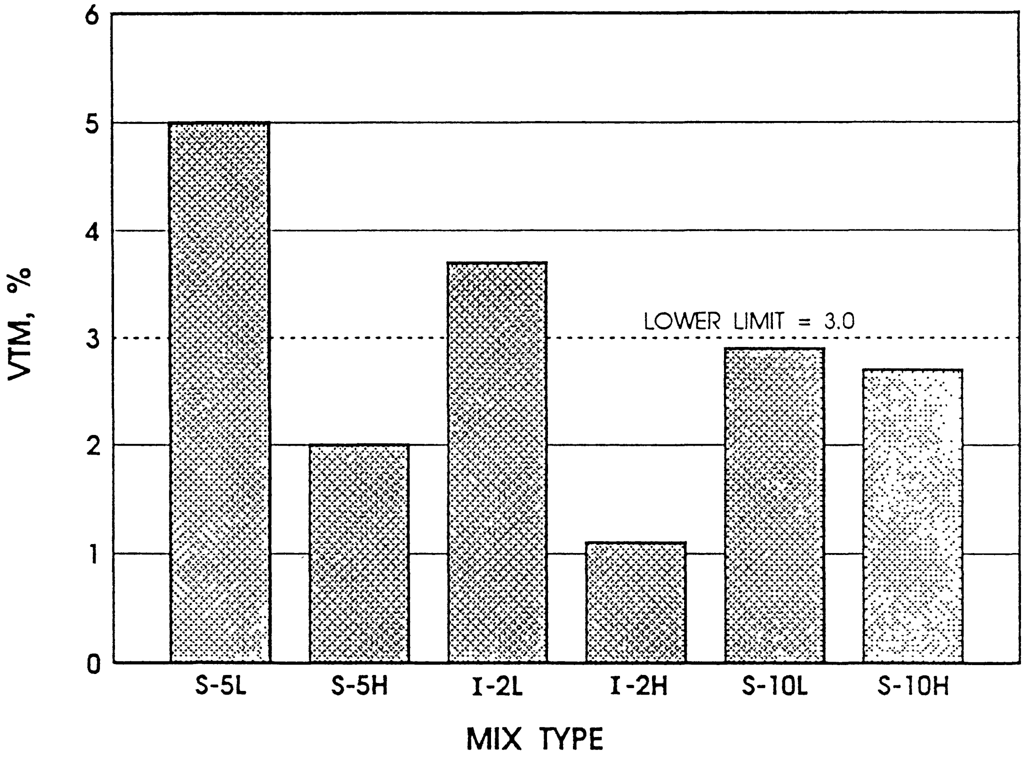

Figure 16. Predicted pavement VTM by GTM—phase II.

1588

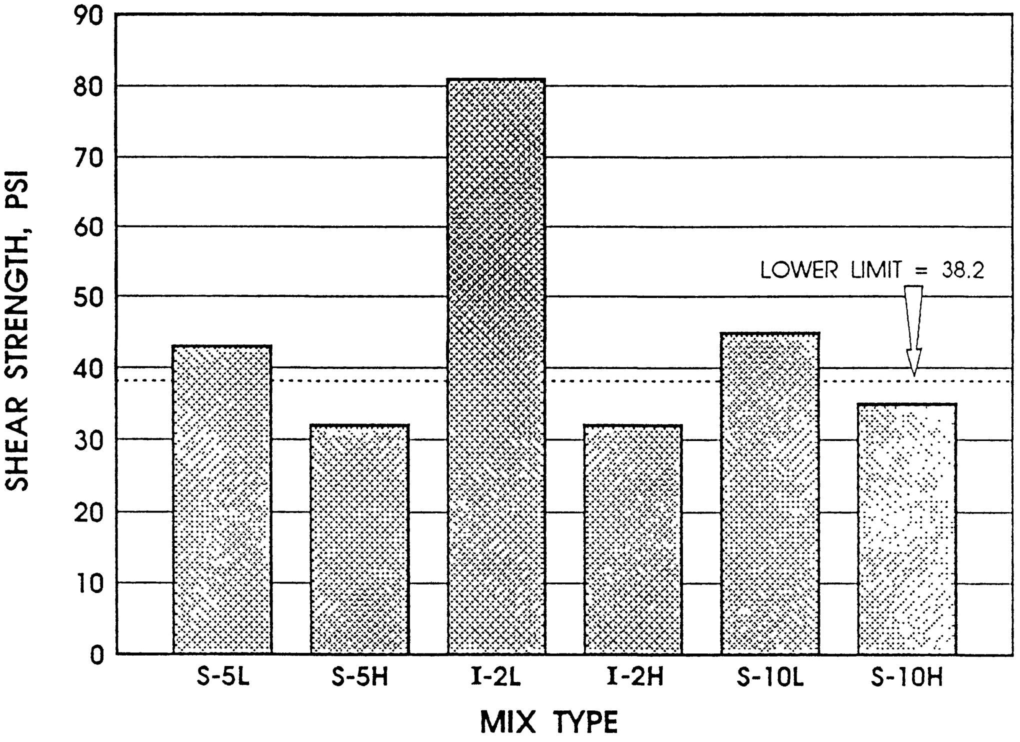

Figure 17. GTM shear strength—phase II.

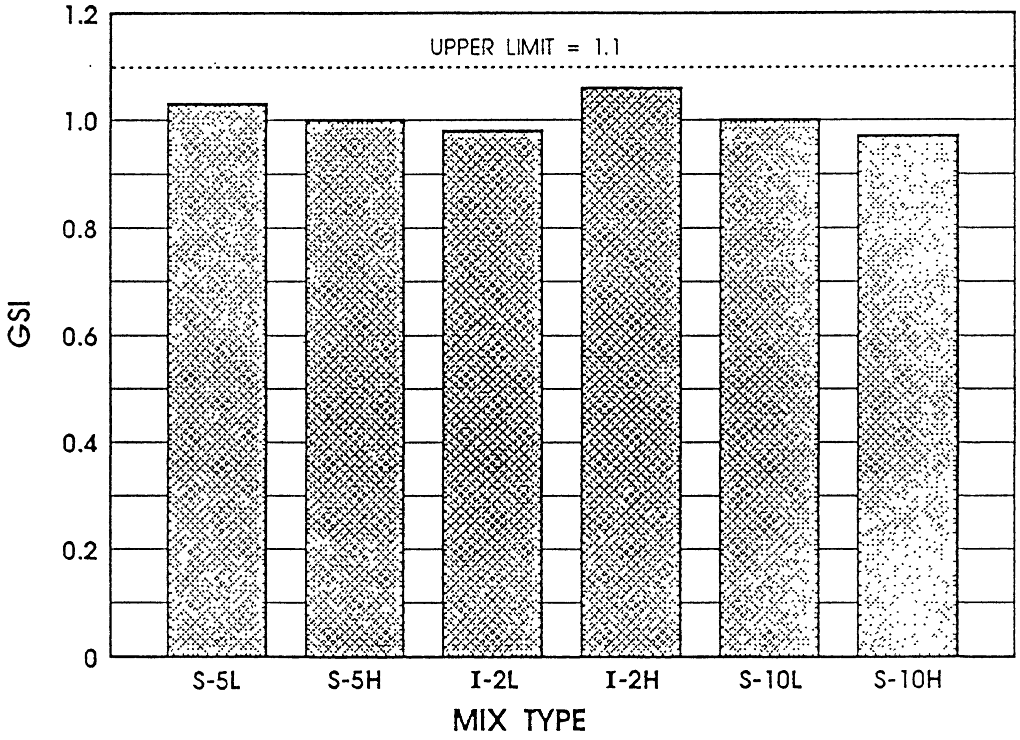

Figure 18. GTM stability index—phase II.

## Table 5

## RANK OF MIXES IN PHASE I

| | Weak or Unsatisfactory | | | Strong or Satisfactory | |
|---|---|---|---|---|---|
| Expected ranking | S-5 | I-2 | S-5 Mod. | S-5 Mod. (Redesign) | |
| Res. Mod. | S-5 | I-2 | | S-5 Mod. | |
| Ind. Ten. Test | S-5 | I-2 | | S-5 Mod. | |
| GTM | | | | | |
| VTM (>3%) | S-5 | I-2 | | S-5 Mod. | S-5 Mod. (Redesign) |
| Shear Str. (>38.2) | S-5 | I-2 | S-5 Mod. | | S-5 Mod. (Redesign) |
| GSI (<1.1) | S-5 | I-2 | | S-5 Mod. | S-5 Mod. (Redesign) |

*Note*: The S-5 modified mix that was redesigned was tested only with the GTM.

The rankings of the mixes tested in phase II are shown in Table 6. The relative extreme high and low rankings are very similar for the various tests, for instance, the S-5H mix with a high asphalt content is the most unsatisfactory and the S-10L with a low asphalt content is the most satisfactory. Resilient modulus, indirect tensile strength, and creep modulus tests do not differentiate between the remaining mixes; however, these mixes can be differentiated using unrecovered strain.

The GTM ratings for phase II tend to group the mixes with a high asphalt content as unsatisfactory and the mixes with a low asphalt content as satisfactory, which is logical.

It is possible that the test procedures would have differentiated between the mixes more closely if the tests had been conducted at VTMs that simulated the VTM of a typical pavement after considerable traffic rather than at VTMs of pavements after construction. For instance, according to Figure 13, the S-10H and I-2H mixes with a high asphalt content had VTM less than 3 percent at 75 blows (simulating VTM after traffic), which would likely have resulted in unstable mixes (i.e., low strength and moduli). Since the indirect tensile strength and resilient modulus were measured on specimens compacted at 75 blows, the rankings were also compared at low VTM for these tests. When the mixes are ranked using the strength and moduli obtained on 75-blow specimens (see Figures 19 and 20), the rankings are very similar to those obtained with the GTM (see Table 8).

Generally, mixes designed with the 75-blow Marshall do not rut, although some have shown a propensity to deteriorate in other ways, such as raveling. Therefore, the mixes in this study with a low asphalt content (75-blow design) probably will not rut in the field. The GTM predicts the behavior as one expects it to occur; however, the predictions of the other test procedures are not so clear, particularly for the mixes that may be in the "gray area." It would be difficult to use resilient modulus or indirect tensile strength to design or check mixes because of a lack of definitive cutoff values and the impossibility of differentiating between many mixes. The GTM has advantages: the possibility of better predicting the density in the field after traffic, the possibility of determining shear strength during the

1590

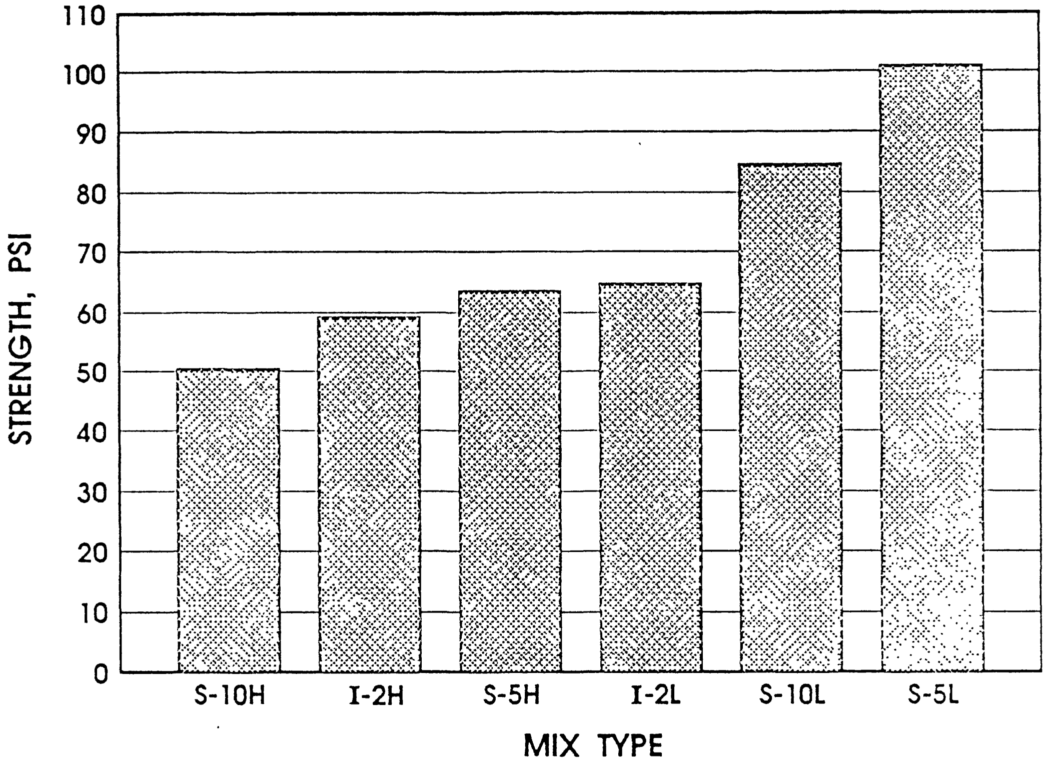

Figure 19. Indirect tensile strength (75-blow specimens)—phase II.

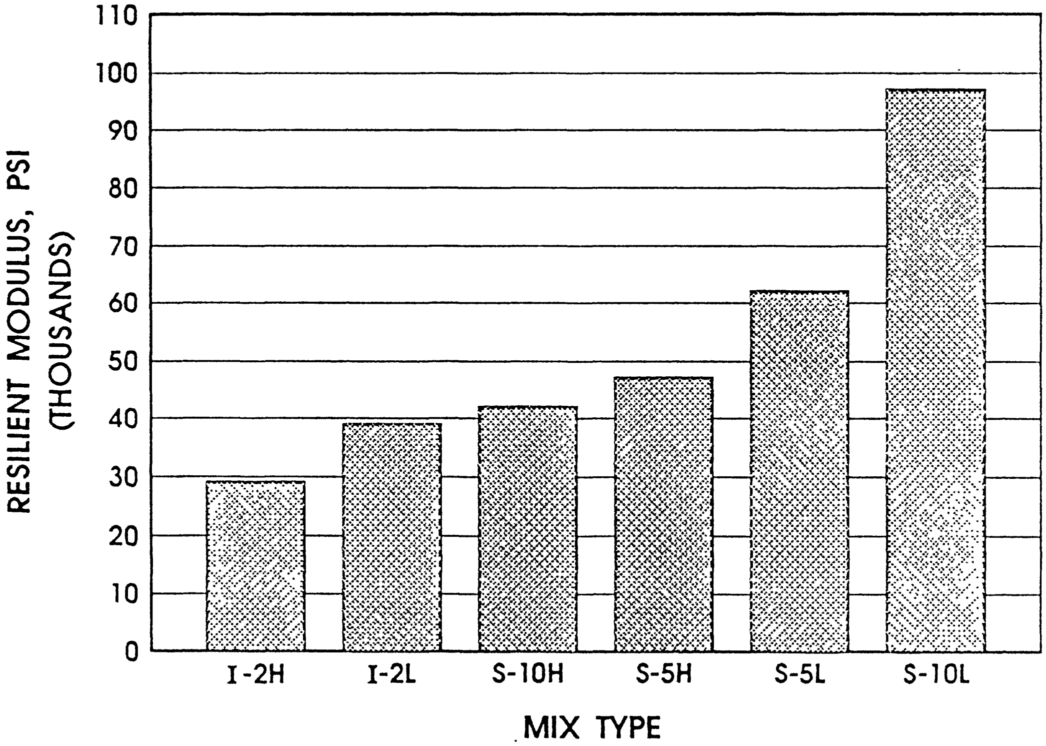

Figure 20. Resilient modulus (75-blow specimens)—phase II.

compaction process, and the possibility of testing (with certain models of the machine) mixes with large aggregates. It is expected that the GTM will be recommended as the compaction device in the final procedure emanating from the NCHRP AAMAS study; therefore, it will be used by other agencies. Its biggest disadvantage is its high cost.

Table 6

RANKINGS OF MIXES IN PHASE II

| Test | Weak or Unsatisfactory | | | Strong or Satisfactory | | |
|---|---|---|---|---|---|---|
| Expected ranking | S-5H | I-2H | S-10H | S-5L | I-2L | S-10L |
| Res. Mod. (7% VTM) | S-5H | I-2L | S-10H | I-2H | S-5L | S-10L |
| Ind. Ten. Test (7% VTM) | S-10H | S-5H | I-2L | I-2H | S-5L | S-10L |
| Res. Mod. (75-blow) | I-2H | I-2L | S-10H | S-5H | S-5L | S-10L |
| Ind. Ten. Test (75-blow) | S-10H | I-2H | S-5H | I-2L | S-10L | S-5L |
| Compression creep | | | | | | |
| Modulus | S-5H | I-2L | S-5L | S-10H | I-2H | S-10L |
| Unrecovered strain | S-5H | I-2H | I-2L | S-5L | S-10H | S-10L |
| GTM[a] | | | | | | |
| VTM (>3%) | S-5H | I-2H | S-10H | S-5L | I-2L | S-10L[b] |
| Shear Str. (>38.2) | S-5H | I-2H | S-10H | S-5L | I-2L | S-10L |
| GSI (<1.1) | | | | S-5L | I-2L | S-10L |
| | | | | S-5H | I-2H | S-10H |

[a] Rankings are not in any particular order.

[b] Slightly less than suggested minimum value of 3%.

## CONCLUSIONS

1. Four tests—resilient modulus, indirect tensile strength, compression creep, and GTM—yielded similar rankings for mixes that were at the extremities of rutting resistance.
2. Three tests—resilient modulus, indirect tensile strength, and compression creep (modulus)—did not differentiate between the performance of intermediate mixes.
3. The GTM ranked mixes with a high or a low asphalt content correctly and indicated deficiencies in field mixes with poor performance.
4. Tentative design criteria are available for use with the GTM.

## RECOMMENDATION

The GTM should be pursued as a design tool for heavy duty pavement design. Projects to refine the test procedure are currently being conducted in a state study[7] and nationwide. It is anticipated that the use of GTM would supplement the basic mix design method (Marshall); it will not be required for every mix design.

## REFERENCES

1. Meyer, F. R. P.; Haas, R. C. G.; and Hignell, E. T. *The prediction of rut depths in asphalt pavements.*

2. *Asphalt pavement rutting: Western states.* May 1984. Western Association of State Highway and Transportation Officials.

3. Button, Joe W., and Epps, Jon A. 1985. Identifying tender asphalt mixtures in the laboratory. *Transportation Research Record 1034.*

4. Bissada, Amir F. 1983. Compactibility of asphalt paving mixtures and relation to permanent deformation. *Transportation Research Record 911.*

5. *Shell pavement design manual: Asphalt pavements and overlays for road traffic.* 1978. London: Shell International Petroleum Company Limited.

6. American Society for Testing and Materials. 1988. *Road and paving materials: Traveled surface characteristics* (Vol. 04.03). Philadelphia.

7. Maupin, G. W., Jr. 1990. *Work plan: Gyratory testing machine—Lab density vs. pavement density.* VTRC Report No. 90-WP24. Charlottesville: Virginia Transportation Research Council.

# APPENDIX A

## Sources and Proportions of Materials

## S-5

| | |
|---|---|
| 45% No. 78s | APAC-Va., Inc., Chesterfield, Va. |
| 35% No. 10s | APAC-Va., Inc., Chesterfield, Va. |
| 20% sand | Lonestar Industries (Puddledock), Petersburg, Va. |
| AC-20 | Exxon, Richmond, Va. |

## I-2 (PHASE I)

| | |
|---|---|
| 75% I-2 blend | APAC-Va., Inc., Chesterfield, Va. |
| 5% No. 68s | APAC-Va., Inc., Chesterfield, Va. |
| 20% sand | Lonestar Industries (Puddledock), Petersburg, Va. |
| AC-20 | Exxon, Richmond, Va. |

## S-5 MODIFIED

| | |
|---|---|
| 10% RAP | Same as above |
| 55% No. 8s | Same as above |
| 20% No. 10s | Same as above |
| 15% sand | Staunton River |
| AC-30 | Elf Asphalt, Chesapeake, Va. |

## S-5 MODIFIED (REDESIGN)

| | |
|---|---|
| 10% RAP | APAC-Va., South Boston, Va. |
| 50% No. 8s | Vulcan Materials, South Boston, Va. |
| 23% No. 10s | Vulcan Materials, South Boston, Va. |
| 17% sand | McCarty Sand, Staunton and Dan Rivers |
| AC-30 | Exxon, Richmond, Va. |

## I-2 (PHASE II)

| | |
|---|---|
| 60% I-2 blend | APAC-Va., Inc., Chesterfield, Va. |
| 25% No. 68s | APAC-Va., Inc., Chesterfield, Va. |
| 15% sand | Massopanox Sand & Gravel, Fredericksburg, Va. |
| AC-20 | Exxon, Richmond, Va. |

## S-10

| | |
|---|---|
| 50% No. 68s | Luck Stone Corporation, Charlottesville, Va. |
| 3% No. 8s | Luck Stone Corporation, Charlottesville, Va. |
| 22% No. 10s | Luck Stone Corporation, Charlottesville, Va. |
| Grade B sand | Massopanox Sand & Gravel, Fredericksburg, Va. |
| AC-20 | Exxon, Richmond, Va. |

# APPENDIX B

## Mix Designs

| Sieve | S-5 (I & II) | I-2 (I) | S-5 Modified (I) | S-5 Modified (I) Redesign | I-2 (II) | S-10 (II) |
|---|---|---|---|---|---|---|
| 1 in | | 100 | | | 100 | 100 |
| 3/4 in | | | | | | |
| 1/2 in | 100 | | 100 | 100 | | |
| 3/8 in | | 73 | | | 66 | 70 |
| No. 4 | 61 | 55 | 58 | 55 | 46 | 50 |
| No. 30 | 28 | | 19 | 21 | 17 | 19 |
| No. 50 | | 16 | | | | |
| No. 200 | 4.3 | 5 | 5 | 5 | 4.5 | 4.5 |